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Oral session abstract

Searches for New Physics at SND@LHC

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Abstract:

We discuss a potential of the SND@LHC (a newly approved experiment at the CERN) to search for new feebly interacting particles (FIPs) that may be produced at the LHC.

Keywords:

FIPs

Study of Eco-Friendly Gas Mixtures for Phenolic RPCs

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Abstract:

Over the past few decades, tetrafluoroethane (TFE, R134a Freon)-based gases have been widely used in the operation of phenolic resistive plate chambers (RPCs) in many high-energy experiments. However, TFE has high global warming potential (GWP) and therefore a search for new eco-friendly gases to replace traditional TFE-based ones is now unavoidable. In this research, we present cosmic-ray test results of phenolic RPCs for CMS and SHiP (Search for Hidden Particles) experiments using 1.6- and 1.4-mm-thick RPC electrodes containing mixtures of various gases including 1,3,3,3-Tetrafluoropropene (HFO1234ze), CO₂, iC₄H₁₀ and SF₆, we compare the performance data gathered with these new gas mixtures with that with traditional TFE-based gas in CMS and ATLAS RPCs. Here is a summary of the results from this study:

1. Compared to TFE, HFO1234ze acts as a stronger quencher and increases the HV_{WP} by more than 60% when the TFE component of the detector's gas is simply replaced by HFO1234ze. However, the proper addition of CO₂ to the HFO1234ze-based gas can stop this increase in working-point high voltage (HV_{WP}) for phenolic RPCs below 11 kV.
2. For the SHiP SND RPCs intended to be operated at ground level, we propose the use of a larger-ratio of iC₄H₁₀ (10%) in the HFO1234ze-based gas compared to that in the traditional TFE-based gas (4.5%), this is to provide further suppression of detector noise and delayed avalanche hits. The advantage of using thinner electrodes is the possibility of using single-gap RPCs without CO₂, this reduces the delayed hit problem with HFO1234ze-based gas. The use of 40% CO₂ or less in HFO1234ze-based gas will give us reliable tracking performance from the SHiP SNDs.
3. The expected HV_{WP} of existing CMS RPCs constructed with 2-mm-thick electrodes is 11.7 kV when operated with HFO1234ze-based gas with an addition of 60% CO₂. Therefore, adding or even higher than 60% CO₂ to the HFO1234ze-based gas is obviously inevitable for proper operation of the CMS RPC system in future. For new CMS double-gap improved RPCs composed of 1.4-mm-thick electrodes, the measured HV_{WP} is 8.1 kV when operated with the HFO1234ze-based gas with 60% CO₂.

Keywords:

Tetrafluoropropene, Eco-friendly gas, Resistive Plate Chambers, Compact Muon Solenoid experiments, Search for Hidden Particles

Status of the SND@LHC Experiment

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Abstract:

The SND@LHC (Scattering and Neutrino Detector at the LHC) is a newly approved experiment (the 9th CERN LHC experiment) whose goal is to directly detect collider neutrinos at TeV energies for the first time and search for feebly interacting particles (FIPs) in an unexplored domain. Unlike the four big LHC experiments, the SND@LHC sits in a tangent line from the interaction point (IP) and therefore it can detect "forward moving particles" which will cover the high pseudo-rapidity region ($7.2 < \eta < 8.7$). The SND@LHC detector will be installed in TI18 tunnel, 480m away from ATLAS IP and positioned slightly off the beam axis on the opposite side of FASER. In order to identify neutrino interactions of the three flavours and search for FIPs via their scatterings on the target, the ECC (Emulsion Cloud Chamber) will be used together with electronic detectors. The ECC which is composed of nuclear emulsion films interleaved with tungsten plates can play the roles of both target and precision tracker. It displays the tracks of the particles produced from the neutrinos and FIPs scatterings, while the electronic tracking devices provide time stamps for these tracks. The tracking devices also measure the energy of the particles together with the downstream muon detector. It is expected to begin taking data when the LHC Run 3 starts up in 2022. In this talk, we will introduce the current status of the experiment and also the possible future plan of FPF (Forward Physics Facility) at the LHC.

Keywords:

LHC, SND, Neutrino, Feebly interacting particles

Beam induced gamma background at JSNS²

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Abstract:

The JSNS² experiment aims to search for sterile neutrinos with Δm^2 near 1eV^2 . A 3 GeV J-PARC proton beam incident on a mercury target produces an intense muon antineutrinos from muon decay at rest which oscillates to electron antineutrinos. The JSNS² detector is located at a 24 m baseline from the target. The detector has a fiducial volume of 17 tons filled with gadolinium-loaded liquid scintillator (GdLS), that efficiently can detect electron antineutrinos via the inverse beta decay followed by gammas from the captured neutron on Gd. The external gamma events induced by the proton beam are one of the sources of accidental backgrounds and one of the main backgrounds in sterile neutrino search. In this talk, we report preliminary results on beam related gamma background from data taken in June 2020 and January 2021.

Keywords:

JSNS2, Beam background

Status of JSNS² Experiment.

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Abstract:

The JSNS² (J-PARC Sterile Neutrino Search at the J-PARC Spallation Neutron Source) experiment will search for neutrino oscillations over a short 24 m baseline with $\Delta m^2 \sim 1 \text{ eV}^2$ at the J-PARC Materials and Life Science Experimental Facility. The JSNS² detector is filled with 17 tons of gadolinium-loaded liquid scintillator (LS) with an additional 31 tons of unloaded LS in the intermediate gamma-catcher and outer veto. A 3 GeV 1 MW proton beam incident on a mercury target at the MLF at J-PARC produces an intense neutrino flux from muon decay at rest (μ -DAR). The experiment will search for muon antineutrino to electron antineutrino oscillations detected via the inverse beta decay reaction, which is then tagged by the distinctive gammas from neutron capture on gadolinium. The JSNS² experiment is expected to provide the ultimate test of the LSND anomaly by replicating nearly identical conditions with a much better S/N ratio. In June 2021, JSNS² successfully finished the first long-term operation by half-year of the data. In parallel, we are preparing the JSNS²-II experiment, the second phase of the JSNS² experiment, with a second detector that has 35 tons of fiducial weight and a 48 m baseline. The second phase will improve the sensitivity of the search for sterile neutrino, especially in the low Δm^2 region. In this talk, we will summarize the detector operation and subsystems including the scintillator filling and extraction procedure, data acquisition system, preliminary data analysis status, and the prospect of the JSNS²-II experiment.

Keywords:

JSNS², Neutrino, Sterile Neutrino

Search of new physics by EWP by Belle and Belle II

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Abstract:

As it is well known, Flavor changing neutral current (FCNC) is highly sensitive to new physics effects such as 2HDM, super symmetry and so on. The decay of B meson via FCNC would thus provide many interesting measurements. One of the most important role of Belle (I and II) experiments is to search the new physics effects by measuring the FCNC; $b \rightarrow s(d)$ transitions via electroweak penguin process (EWP). For example, search of lepton flavor non-universality by $B \rightarrow K^{(*)} \ell \ell$ events is very important as LHCb recently reported the series of anomaly for this process. Interestingly, many new physics models to explain the lepton flavor non-universality no longer guarantee lepton flavor conservation. Hence search of lepton flavor violation process such as $B \rightarrow K \tau \mu$ is also studying by Belle. On the other hand, Belle II is the upgraded experiment, which is expected to achieve 40 times greater luminosity than Belle. So far Belle II collected more than 200/fb data, and plan to collect same size data as BaBar experiment in 2021. Using those data, Belle II recently measured very interesting processes, $B \rightarrow K \nu \nu$, $B \rightarrow K^* \gamma$ and so on. In 2021, it is also expected to measure $b \rightarrow d$ transition process ($B \rightarrow \rho \gamma$). In this presentation, the speaker will provide the recent measurement results of those EWP processes and future plans of Belle and Belle II experiments.

Keywords:

EWP, B physics, Belle, Belle II, LFUV

Search for sub-millicharged particles at J-PARC (SUBMET)

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Abstract:

Recently, SUB-Millicharge Experiment (SUBMET) sensitive to millicharged particles produced at the 30 GeV proton fixed-target collisions at J-PARC was proposed. The detector is based on long scintillators that allow the particles with a small electric charge to produce photons by ionization energy loss. With the number of protons on target of 5×10^{21} , the experiment is sensitive to particles with electric charge $6 \times 10^{-5} e$ for mass less than $0.2 \text{ GeV}/c^2$ and $1.0 \times 10^{-3} e$ for mass less than $1.6 \text{ GeV}/c^2$. The status and plan for SUBMET will be discussed in this talk.

Keywords:

millicharged particles, J-PARC, scintillator, PMT, proton fixed-target collisions

The measurement of forward-backward asymmetry in Drell-Yan with a single b-jet events at LHC

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Abstract:

The precision measurement of the electroweak mixing angle is valuable for the standard model test. The most precise measurements of the mixing angle was conducted by LEP experiment and SLD experiment, and their results still have 3 sigma discrepancies. Especially, the results from LEP used forward-backward asymmetry(AFB) in a single Z boson events decaying into the pairs of b quark. This AFB measurement from the Zbb vertex also can be achieved at Large Hadron Collider(LHC) via Drell-Yan(DY) with a single b-jet events. Large background from ttbar events, and DY events with the pairs of b-jet or misidentified b-jet can be avoided by the suitable way, and also efficient discriminating b and bbar jets can be achieved by the novel method.

Keywords:

AFB, CMS, Mixing angle, Drell-Yan, b-jet

Lattice studies of $Sp(2N)$ gauge theory with fermions in the antisymmetric representation

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Abstract:

We perform lattice studies of $Sp(2N)$ gauge theories with fermions in the antisymmetric representation. We particularly focus on the theory with three Dirac flavors and $N=2$, because it is relevant to partial top quark compositeness in a certain model of composite Higgs. For the numerical simulations we adopt the standard Wilson gauge action and Wilson-Dirac fermions discretized in the four-dimensional Euclidean space. We present the results of mass spectra and decay constants of spin 0 and 1 (flavored) mesons in both dynamical and quenched setups. We also discuss the finite size effects and the fermion mass dependence of the measured quantities.

Keywords:

composite Higgs, partial top quark compositeness, lattice gauge theory

The effects of magnetic fields on magnetic dipole moments

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Abstract:

We calculate the effect of magnetic fields on the magnetic dipole moment of leptons up to the quadratic order in the magnetic field. We find that the effect is too small for the current experiment but might be important in the future experiment of anomalous magnetic moment of muons. We also discuss the general field-dependent form factors and the Ward-Takahashi identity under the external magnetic fields.

Keywords:

Evidence of the fine-structure constant in H_0 -tension

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Abstract:

Modern precision measurements on Hubble expansion $H(z)$ introduce two integral constraints on background models derived from early and late-time cosmology, based on Planck observations of the BAO and, respectively, H_0 , here normalized to Λ CDM. For $H(z)$ coupled to $\Lambda = (1-q)H^2$ of zero wave-number modes of cosmological spacetime with deceleration parameter $q(z)$, we infer a coupling constant $g < 1$ for H_0 in tension with Λ CDM. Results from the Local Distance Ladder give $g \simeq 1 - \xi \alpha$ with $\xi = 0.46 \pm 0.1$. This result appears natural upon identifying H_0 -tension with breaking of T-duality in the Friedmann scale factor $a(t)$ to the same order.

Keywords:

dark energy, cosmological parameters

Cosmology of Linear Higgs-Sigma Models

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Abstract:

Higgs inflation has drawn attention due to the minimal possibility of the Standard Model Higgs playing the role of the inflation field. However, it comes with an associated problem of unitarity violation, due to the large non-minimal coupling with gravity.

In this work, we consider general higher curvature terms beyond Einstein gravity and recast them into a class of models dubbed sigma models. These models can be regarded as UV completions of Higgs inflation and are subject to perturbativity constraints.

We find that successful inflation is possible for R^2 , and for $R^{(p+1)}$ with $-1 < p < 0$, the tracker behavior for dark energy is realized. We also discuss the sigma-Higgs interaction implications for inflation, vacuum stability and the reheating process.

Keywords:

Cosmology, Higgs Inflation, UV completion

Inflation and Supersymmetry Breaking in Higgs-R2 Supergravity

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Abstract:

It is known that the Higgs inflation suffers from unitarity problem due to a large non-minimal coupling of Higgs field to Ricci scalar. Recently, it has been clear that introducing a Ricci square term (R² term) in the Higgs inflation can solve this problem, and provide its UV completion. This model known as Higgs-R² inflation perfectly agrees with the CMB observation of the Planck result.

In this talk, we discuss a supersymmetric embedding of the Higgs-R² inflation, which is desired from a naturalness consideration. We investigate several conditions for the original successful inflation to be kept after supersymmetrization, and also discuss supersymmetry breaking and its phenomenological consequence.

Keywords:

Inflation, Supergravity, Supersymmetry breaking

Single production of vector-like quarks: the effects of large width, interference and NLO corrections

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Abstract:

We provide a comprehensive discussion, together with a complete setup for simulations, relevant for the production of a single vector-like quark at hadron colliders. Our predictions include finite width effects, signal-background interference effects and next-to-leading order QCD corrections. We explicitly apply the framework to study the single production of a vector-like quark T with charge $2/3$, but the same procedure can be used to analyse the single production of vector-like quarks with charge $-4/3$, $-1/3$, $2/3$ and $5/3$, when the vector-like quark interacts with the Standard Model quarks and electroweak bosons. Moreover, this procedure can be straightforwardly extended to include additional interactions with exotic particles. We provide quantitative results for representative benchmark scenarios characterised by the T mass and width, and we determine the role of the interference terms for a range of masses and widths of phenomenological significance. We additionally describe in detail, both analytically and numerically, a striking feature in the invariant mass distribution appearing only in the $T \rightarrow t\bar{h}$ channel.

Keywords:

BSM, vector-like quarks, large width, NLO corrections, LHC

Exploring new possibilities to discover a light pseudo-scalar at LHCb

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Abstract:

We study the possibility of observing a light pseudo-scalar a at LHCb. We target the mass region $1 \lesssim m_a \lesssim 60$ GeV and various decay channels, some of which have never been considered before: muon pairs, tau pairs, D meson pairs, and di-photon. We interpret the results in the context of models of 4D Composite Higgs and Partial Compositeness in particular.

Keywords:

BSM, light scalar, composite Higgs, LHCb

Contact interactions and top-philic scalar dark matter

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Abstract:

We investigate the phenomenology of a scalar top-philic dark matter candidate when adding a dimension-five contact interaction term, as motivated by possible underlying extensions of the Standard Model such as composite Higgs models. We show that the presence of contact interactions can have a major impact on the dark matter relic density as well as on its direct and indirect detection prospects, while the collider phenomenology of the model is unaffected. This underlines the complementarity of collider and cosmological constraints on dark matter models.

Keywords:

BSM, dark matter, LHC phenomenology, phenomenological models, top portal

Luminosity estimation via van der Meer Scan in ALICE

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Abstract:

As a baseline of normalization for many physics analyses, the cross-section and the luminosity of hadronic collisions are indispensable pieces of information that must be measured accurately. The observable used to determine the luminosity in ALICE is the visible cross-section (σ_{vis}), which is measured by using information from the LHC instrumentation and the ALICE detector collected during the van der Meer scan. In this talk, we present a review of the ALICE luminosity determination analysis and the recent results for Run 2 of the LHC, especially for pp collisions at $\sqrt{s} = 13$ TeV and for Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

Keywords:

ALICE Collaboration, Luminosity, van der Meer scan

Performance of a prototype Active target TPC

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Abstract:

An active Target Time Projection Chamber (AT-TPC) is designed to measure nuclear reactions at a low energy rare isotope collision experiments at Rare isotope Accelerator complex for ON-line experiment (RAON). The active target means that drift gas in AT-TPC is used for target as well, and for this reason, the active volume can be extended to the entire volume of the TPC including the collisional vertex. We are planning a new experiment using the AT-TPC as the main component to measure a scattering of alpha particles and heavy ions, in particular, associated with the formation of alpha cluster resonance. We developed the prototype AT-TPC with Gas Electron Multipliers (GEM). The prototype AT-TPC has a drift volume of $10 \times 10 \times 15 \text{ cm}^3$, and the 256 read-out pads are used for data acquisition. In this presentation, we present the progress of R&D for the prototype AT-TPC. The assembly of hardware, construction of a DAQ system, the performance of AT-TPC are reported in detail.

Keywords:

TPC, RAON, LAMPS, AT-TPC

Active Target TPC for Multiple Nuclear Experiments

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Abstract:

In recent decades, our understandings of the nuclear reactions and the nuclear properties have been enhanced due to the help of developments in rare isotope beams. Because the RI beam intensities are very limited in many facilities, a development of the new detector plays an important role in the experimental studies. Active Target for Multiple nuclear astrophysics eXperiments (AToM-X) at the Center for Exotic Nuclear Studies (CENS) is under development which enables the high resolution measurement in the particle track, energy, and position with the high detection efficiency. Details of the development status of AToM-X will be discussed in this presentation.

Keywords:

Active target TPC, Nuclear Astrophysics, Nuclear Reaction

Status report of the production of the Beam Drift Chamber (BDC) for the LAMPS experiment

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Abstract:

The Large Acceptance Multi-Purpose Spectrometer (LAMPS) detector, which is assembled for the analysis of the dynamics between nucleons inside neutron-rich nuclei produced by Rare Isotope Accelerator complex for ON-line experiments (RAON), is being manufactured to complete the assembly at the end of this year.

In this presentation, we will report the status of the construction of the Beam Drift Chamber (BDC), which is the drift chamber to measure the beam profile to the LAMPS detectors.

Keywords:

RAON, LAMPS, BDC, Beam Drift Chamber, Drift chamber

Improvement for Prototype Beam Drift Chamber (BDC) of the LAMPS Experiment

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Abstract:

The Large Acceptance Multi-Purpose Spectrometer (LAMPS) experiment has the purpose to study the dynamics between nucleons inside neutron-rich nuclei. The LAMPS will use a rare isotope beam from the Rare Isotope Accelerator complex for ON-line experiments (RAON).

Beam Drift Chamber (BDC), which is one of the gaseous detectors, will be installed in the front of the beamline to determine the beam trajectories of injected rare isotopes for the LAMPS.

In this presentation, we will show the improvement of the prototype BDC on the various sides, checked with cosmic muon or radioactive sources.

Keywords:

drift chamber, LAMPS, RAON, gas detector, wire chamber

Development of LAMPS TOF Arrays with MPPC Readout

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Abstract:

We have developed time-of-flight (TOF) arrays of plastic scintillators for triggering and timing measurements in RI beam experiments with LAMPS at RAON. The TOF arrays comprise a barrel TOF (BTOF) detector and a forward TOF (FTOF) detector in the LAMPS solenoid magnet. Each BTOF EJ-230 scintillator is 1500 mm long with a cross-section of 90 x 10 mm², tapered on both ends to 45 x 10 mm², and is read out by 5 MPPCs (S13360-6050PE) at both ends. The taper has a length of 150 mm on both sides. On the other hand, each FTOF EJ-232 scintillator is trapezoidal with a dimension of 500 x (90, 24) x 5 mm³. Scintillation light is read out by 3 MPPCs (S14160-4050HS) on a narrow side and 8 MPPCs on a long side.

The timing properties of the scintillators were measured using cosmic rays. In addition, we studied the TOF detector performance in terms of plastic scintillator materials, taper shapes, MPPC types, and signal amplification circuits.

The intrinsic time resolutions of the scintillators are estimated to be 150 ps, which is adequate for reliable separation among light particles hitting TOF arrays. However, the readout circuit gain drops to half near the MHz region.

Keywords:

RAON, LAMPS, MPPC, gain drop

A conceptual design study for the rebuncher at SCL3-KoBRA beamline

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Abstract:

KoBRA (Korea Broad acceptance Recoil spectrometer and Apparatus) is a low energy nuclear physics facility at RAON (Rare isotope Accelerator complex for ON-line experiments). Stable ion beams with energies up to 40 MeV/u will be delivered to KoBRA from the SCL3 (Superconducting Linear accelerator 3) of RAON. Secondary RI beams are produced by bombarding stable ion beams from SCL3 to the target at KoBRA. For improvement of particle identification of the secondary RI beams, a short longitudinal bunch length is required at the entrance of KoBRA. Since the pulsed beam is debunched due to the long distance between the end of the SCL3 and the entrance of KoBRA, an additional re-bunching system (RF-cavity) is necessary so as to decrease the bunch length. In this talk, the conceptual design study for the re-buncher will be presented with a brief overview of KoBRA beamline.

Keywords:

KoBRA, RAON, Rebuncher

Development of detector system SNACK for transfer reaction measurements at KoBRA

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Abstract:

KoBRA (Korea Broad acceptance Recoil spectrometer and Apparatus) [1] is a low energy nuclear physics facility at RAON (Rare isotope Accelerator complex for ON-line experiments) [2]. In its early phase of operation, KoBRA will produce RI beams with energies of 5 to 10 MeV/u from stable ion beams (10 ~ 40 MeV/u) delivered from the superconducting linear accelerator SLC3 of RAON. With these RI beams, astrophysically important thermonuclear reaction rates can be studied in transfer reaction experiments. Therefore, RISP (Rare Isotope Science Project) has developed the detector system SNACK (Silicon detector array for Nuclear Astrophysics study at KoBRA), suitable for measuring the energies and scattering angles of the light ejectiles from the transfer reactions. Excitation energy levels in the heavy recoils from the transfer reactions can be reconstructed by using SNACK together with the beam trajectories obtained from upstream PPAC (Parallel Plate Avalanche Counter) detectors. The background events from fusion evaporation can be suppressed by using a downstream ionization chamber. In this talk, details of the detector system development will be presented.

[1] K. Tshoo *et al.*, Nucl. Instrum. Methods Phys. Res. B **376** (2013) 188.

[2] D. Jeon *et al.*, J. Korean Phys. Soc. **65** (2014) 1010.

Keywords:

KoBRA, Silicon detector array, Transfer reaction

Development of a new silicon telescope array for reaction studies in inverse kinematics, STARK

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Abstract:

Measuring the energy and momentum of charged particles from nucleon transfer or scattering is essential for reconstructing the desired reactions. A new Silicon Telescope Array for Reaction studies in inverse Kinematics (STARK) has been developed at Center for Exotic Nuclear Studies (CENS) for this purpose. STARK is a barrel type silicon telescope array. The array consists of 40 double-sided silicon strip detectors with resistive strips in junction side, 12 thin single-sided silicon strip detectors and 4 additional quadrant detectors. The angular resolution of charged particles from reactions at the center of expected target position is estimated to be better than 1 degree in backward region, which is comparable to or better than other existing silicon telescopes such as SHARC in TRIUMF and ORRUBA . STARK is designed to be a complete and independent array and can be utilized in many nuclear experiment facilities including KoBRA beamline at RAON. The concept of STARK and its overall development status including estimated performance will be presented.

Keywords:

Silicon Telescope, Nuclear Structure, Nuclear Reaction, Nuclear Astrophysics Experiments

Coherent electrical control of single-atom electron and nuclear spin qubits in silicon

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Abstract:

Single-atom electron and nuclear spin qubits in silicon are among the most coherent quantum systems in the solid state [1]. Their embedding within a technologically-relevant, CMOS-compatible physical platform, makes them a prominent candidate for scalable quantum processors [2]. Until recently, the quantum control of such spins has been achieved using ordinary magnetic resonance. However, there are potential advantages in being able to control spins by electrical means, since electric fields can be highly localized at the nanoscale, and are easier to screen. I will present two breakthrough results in the electrical control of spins at the nanoscale. First, the discovery of nuclear electric resonance (NER) in a single ¹²³Sb nuclear spin [3]. NER was obtained through the local modulation of the nuclear quadrupole interaction, mediated by a distortion of the atomic bonds. Second, the coherent control of an electron-nuclear flip-flop qubit, encoded in a single ³¹P donor atom. The electrical drive is mediated by a local modulation of the hyperfine interaction [4]. Taken together, these results provide a method to achieve complete electrical control over the Hilbert space of a single-atom spin qubit in silicon.

[1] J.T. Muhonen et al., *Nature Nanotech.* **9**, 986 (2014)

[2] A. Morello et al. *Adv. Quant. Tech.* **3**, 2000005 (2020)

[3] S. Asaad et al., *Nature* **579**, 205 (2020)

[4] G. Tosi et al., *Nature Comm.* **8**:450 (2017)

Keywords:

Spin qubits, electric resonance, silicon quantum computing

Coherent Quantum Control of Superconducting Qubits

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Abstract:

Today's quantum information technology widely uses the superconducting qubits as key elements, especially in quantum computers. In this talk, we will look into the Josephson junction based superconducting circuits in detail, and will analyze some of the key factors that affects the quantum coherence of the circuit. Also the key requirements and techniques for better coherent control of the qubits will be discussed.

Keywords:

Superconducting qubit, Quantum computer, Josephson junction

Lock-in detection based Quantum diamond magnetometry

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Abstract:

The nitrogen vacancy (NV) center in diamond is widely used as a quantum magnetometer due to the high magnetic field sensitivity with nano-scale spatial resolution at room temperature. The magnetic field sensitivity can be further enhanced by adopting ensembles of NV centers at the cost of the spatial resolution. The improved field sensitivity contributes to identifying magnetic field distributions in various spatial resolutions, from sub-micrometer to millimeter, across condensed matter physics, biology, and IC failure analysis. Here, we demonstrate lock-in detection based ensemble NV magnetometers, a widefield microscope and a multiplexed magnetometer. The volume normalized magnetic field sensitivity of the microscope is $72 \text{ nT} \cdot \mu\text{m}^{1.5} / \text{Hz}^{0.5}$. The sensitivity was achieved by adopting lock-in detection, exciting three hyperfine peaks between the NV center and ^{14}N nucleus simultaneously, and a dual-resonance modulation with opposite phase. We have further improved the field sensitivity down to $40 \text{ pT/Hz}^{0.5}$ at milli-meter scale spatial resolution. Additionally, the multiplexed magnetometer can perform simultaneous sensing of magnetic field and temperature at the sensitivity of $40 \text{ pT/Hz}^{0.5}$ and $14 \text{ mK/Hz}^{0.5}$, respectively.

Keywords:

Diamond Nitrogen Vacancy, quantum sensor, magnetometer

Readout and coherent control of spin-qubits using shallow NV-sensors

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Abstract:

Controlling single atoms and molecules not only offers the epitome of miniaturization of electronic devices, but also the realization of operational quantum bits (qubits). Although various forefront quantum architectures already exploit single atoms as qubits, upscaling them fails due to the extremely low temperatures and associated energy costs required for their use. In contrast, surface-supported individual atoms, molecules, and engineered atomic/molecular-structures with specific and robust quantum properties (spin states) have the potential to function as qubits with coveted scalability and high-temperature operations [1-4]. However, the desired non-invasive readout and quantum control of their spin states with simultaneous access to individual qubits, still remain elusive. In this talk, I will introduce the use of the nitrogen vacancy centers (NV) in diamond as the least invasive and yet highly sensitive quantum sensor, for coherent control of isolated atomic spin qubits that are encapsulated within C₆₀ fullerene cage [5]. The C₆₀ fullerene cage offers a robust packaging for the atomic spin qubits, while allowing in-situ positioning at the nanoscale [6]. We demonstrate electron paramagnetic resonance on such an encapsulated spin (i.e., ¹⁴N@C₆₀) using a single near-surface NV-sensor in diamond at 4.7 K [7]. By exploiting the strong magnetic dipolar interaction between the NV-sensor and the endofullerene electronic spin, we demonstrate radio-frequency pulse-controlled Rabi oscillations and measure spin-echos from individual ¹⁴N@C₆₀ spins [5]. This work opens up incredibly exciting possibilities to work with surface-based quantum architectures where the NV-sensors can be utilized as a highly sensitive non-invasive nanoscale quantum sensor over a wide-operational range of temperatures.

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Keywords:

nitrogen vacancy centers (NV) in diamond, atomic spin qubits, quantum sensor

Observation of the back-donation π -bonding states near Fermi level with ARPES

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Abstract:

In molecular orbital theory, the chemisorption of CO molecules onto metals is described as a combination of π - and σ -bonding interactions, in which the electronic properties of the metal play a critical role. Using state-of-art angle-resolved photoemission spectroscopy (ARPES), we report the direct observation of frontier orbitals of metal substrate back-donation states near the Fermi level as CO molecules are adsorbed on Pt(111) and Pt-Sn/Pt(111) 2×2 surfaces. Spectral features near the Fermi level show that enhanced participation of π -bonding (xz and yz orbitals) in chemical bonding. Our results provide important insight into how the delocalized electronic band structure of metals interacts with localized surface molecular orbitals.

Keywords:

Pt-Ni Alloys, Electronic Structure, ARPES

Metallic columbite SnO₂ thin films deposited on sapphire(0001) substrates using radio-frequency powder sputtering

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Abstract:

We report the metallic electrical characteristics of epitaxial SnO₂ thin films grown on sapphire(0001) substrates by radio-frequency powder sputtering. Phase competition between the columbite and rutile phases was observed. Initially, the orthorhombic columbite phase (C-SnO₂) was dominant, and as film thickness increased, the tetragonal rutile phase (T-SnO₂) began to appear. Synchrotron X-ray diffraction measurements were performed to determine the phase and epitaxial relationship between the C-SnO₂ thin film and the sapphire(0001) substrate. Electrical properties were determined using a 4-point probe and Hall effect measurements. The SnO₂ thin films are highly conductive with a resistivity of 1×10^{-2} Ohm·cm at 25 °C and exhibit metallic characteristics in electrical resistivity in the range of 25-500 °C.

Keywords:

SnO₂ thin films, Metallic characteristics, Epitaxy, Electrical conductivity, Orthorhombic columbite phase

TR-XANES study of diamond under extreme conditions

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Abstract:

Measurement of X-ray absorption spectra is of interest in many different fields of science. X-ray spectra related to the K-shell of light elements, and the L- and M-shells of transition metals are closely related to the electronic structure and various properties of materials in different phases. Herein I present the development of a soft XR-XANES beamline using laser plasma source and its application. Broadband soft X-ray emission from various plasmas (Bi, Ta, W) irradiated with high power laser pulses. The spectrum covers from 250 to 1000 eV. In the sample chamber, another femtosecond laser pulse isochorically heats diamond to create warm dense conditions. Laser and x-ray pulses were both spatially and temporally overlapped on the target. Transmitted x-rays were dispersed with a grating spectrometer and a spectrum near carbon K-edge was detected. XANES of carbon K-edge region show band structures around Fermi level, which indicating π^* and σ^* anti-bonding features. The TR-XANES show significant modification of band structure and we obtain data on the DOS of highly transient and exotic state of matter. Evolutions of both resonances, the increase of π^* and the decrease of σ^* resonances, indicate the changes in coordination number and strength of interaction between atoms. Both resonances have two different time scales which may be related to the time scales of energy relaxation and expansion of super-heated solid. Detailed analysis of the spectra and the associated changes in electronic properties of warm dense carbon will be presented.

Keywords:

TR-XANES, WDM, diamond

Computational understanding of semiconductors for photovoltaic applications

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Abstract:

Global warming has accelerated the research of solar cells as a sustainable energy source. Solar cells are semiconductor devices that absorb photons and convert them into electron and hole carriers. The working principle seems quite simple, but its efficiency is affected by many physical parameters. The absorber layer should have an ideal band gap as the solar conversion efficiency is fundamentally limited by the band gap. The absorption coefficient is also an essential parameter for designing solar cells. For optimal device performance, the photogenerated carriers also should not be recombined until those are extracted through the contacts. These physical properties can be calculated with reasonable accuracy by using first-principles calculation methods [1,2]. As many solar cells are made of the polycrystalline absorber layer, extended defects such as grain boundaries are also important to investigate [3-6]. In this presentation, we discuss our recent works on materials for photovoltaic applications in terms of generation and recombination.

- [1] Point defect engineering in thin-film solar cells, J.-S. Park, et al., *Nat. Rev. Mater.* 3, 194 (2018).
- [2] Electronic Structure and Optical Properties of α -CH₃NH₃PbBr₃ Perovskite Single Crystal, J.-S. Park, et al., *J. Phys. Chem. Lett.* 6, 4304 (2015).
- [3] Stabilization and self-passivation of symmetrical grain boundaries by mirror symmetry breaking, J.-S. Park, *Phys. Rev. Mater.* 3, 014602 (2019).
- [4] Accumulation of Deep Traps at Grain Boundaries in Halide Perovskites, J.-S. Park, et al., *ACS Energy Lett.* 4, 1321 (2019).
- [5] Hexagonal Stacking Faults Act as Hole-Blocking Layers in Lead Halide Perovskites, J.-S. Park, et al., *ACS Energy Lett.* 5, 2231 (2020).
- [6] Modelling Grain Boundaries in Polycrystalline Halide Perovskite Solar cells, J.-S. Park and A. Walsh, *Annu. Rev. Condens. Matter Phys.* 12, 95 (2021).

Keywords:

solar cell, first-principles, density functional theory, grain boundary, dielectric function

Ferroelectricity-driven Berry curvature in two-dimensional systems

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Abstract:

The concept of Berry curvature (BC) is becoming important due to its unique behaviors in various topology- and transport-related phenomena. In symmetry-broken crystalline solids, BC is established from the quantum geometry hidden in the electronic structure. For example, the monopole component of the BC is created by the time-reversal symmetry breaking, and the BC dipole arises from a lack of inversion symmetry, thereby giving rise to the anomalous Hall and nonlinear Hall effects, respectively. In this talk, we will show in-plane and out-of-plane electric polarizations can develop intriguing BC structures in two dimensions. The in-plane ferroelectricity in a van der Waals monolayer of SnTe offers charge- and spin-controllable photocurrents by manipulating the photon handedness and the ferroelectric polarization. The fundamental origin of the ferroelectrically driven (out-of-plane) BC is closely related to an orbital angular momentum texture, referred to as the orbital Rashba effect. We also suggest a more generalized Berry curvature formula for a two-dimensional system, enabling the estimation of the in-plane components of BC which is closely related to the vertical transport response. From first-principles calculations, a large in-plane BC can appear even in an atomic-thick GdAg₂ monolayer, and a hexagonal BiAg₂ monolayer can host a large BC dipole known to vanish in the conventional BC.

Keywords:

Berry curvature, first-principles calculation, density functional theory, two-dimensional materials

First-Principles Computational Studies on Correlated Magnetic Chalcogenides Under Pressure

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Abstract:

Layered transition metal trichalcogenides, $MP\{S,Se\}_3$ ($M=Mn,Fe,Co,Ni$), has been actively studied recently because of possible two-dimensional magnetism and potential applications for resistivity switching devices. Compared to layered oxide compounds, stronger hybridization between transition metal d -orbital and chalcogen p -orbitals in these layered chalcogenides can yield bigger response of electronic and magnetic properties with respect to external stimuli such as pressure. Here we present our recent computational study of $MP\{S,Se\}_3$ with $M = Mn, Fe, and Ni$ under external pressure, employing ab-initio dynamical mean-field theory (DMFT) combined with density functional theory (DFT). All three compounds show insulator-to-metal transitions but with different structural and electronic responses. Nature of pressure-driven insulator-metal transitions, which depends on the orbital occupations and structural changes, is discussed in combinations with recent experimental observations.

Keywords:

Layered chalcogenides, pressure, Insulator-to-metal transition, dynamical mean-field theory, density functional theory

Octahedral rotation-driven ferroelectricity in CaTiO_3 by interfacial coupling

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Abstract:

In perovskite oxides, the octahedral rotation pattern is one of the important parameters that can be tuned to alter the phase of the matter. In particular ferroelectricity in perovskite oxides is intimately related to the octahedral rotation pattern, in which ferroelectricity can either be enhanced or suppressed depending on the octahedral rotation pattern. This leads to questions that which types of metastable octahedral rotation patterns would be compatible with the stable polarization and if so, how to stabilize the metastable rotation pattern. In this talk, we investigate the relation between octahedral rotation patterns and polar instability in CaTiO_3 using first-principles density functional theory. The unstable polar modes in the octahedral rotation patterns prevalent in perovskite oxides are systematically investigated. We find that the $a^-a^-a^-$ and $a^+a^+c^-$ types of Glazer rotation patterns have polar instability with sizable polarization. Moreover, by atomic-scaling imaging and second harmonic generation measurements, we experimentally show the thin-film CaTiO_3 film that grown on (111)- LaAlO_3 substrate can stabilize the metastable $a^-a^-a^-$ rotation pattern, which induces polar distortion at room temperature. The control of the metastable octahedral rotational pattern and the associated formation of polarization provides new ways to control a phase of matter and to design new functional materials utilizing interfacial coupling.

Keywords:

first-principles calculations, ferroelectricity, perovskite oxides, oxide heterostructures, octahedral rotations

Strain-Engineering of Topological Phases in Pyrochlore Iridates

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Abstract:

Pyrochlore iridates are the first candidate that a Weyl semimetal is predicted to exist. However, because of the insulating behavior and high-symmetry of their ground state, the smoking-gun evidence for a Weyl semimetal is absent so far. In order to overcome such difficulties, we applied the epitaxial strain on pyrochlore iridate thin films near the quantum critical point. Previously, on fully strained $\text{Nd}_2\text{Ir}_2\text{O}_7$ thin films, an unconventional magnetotransport and a spontaneous Hall Effect were observed, but it is due to the strain-induced cluster magnetic multipoles instead of a Weyl semimetal. On the other hand, in our recent work, on partially strained $\text{Pr}_2\text{Ir}_2\text{O}_7$ thin films, a planar Hall Effect was observed in addition to the anomalous Hall Effect and magnetotransport. Comparing the dependence of planar Hall conductivity on temperature with a renormalization group analysis, we show that a correlated Weyl semimetal appears. As a result, our work highlights the interplay of strain, magnetism, and topology in strongly correlated systems.

Keywords:

Pyrochlore Iridates, Topological semimetal, Strongly Correlated System, Strain Engineering

Sr₂IrO₄/Sr₃Ir₂O superlattice for a model 2D quantum Heisenberg antiferromagnet

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Abstract:

Spin-orbit entangled pseudospins have attracted much attention as a promising route to realize a wide range of exotic magnetism, as manifested by the pseudospins in IrO₆ octahedra, which stabilize either Heisenberg- or Ising-antiferromagnet depending on whether placed in the single-layer Sr₂IrO₄ or double-layer Sr₃Ir₂O₇ [1-3]. However, they are recently found to have structural distortions of unusual kinds [4, 5] and strong magnetoelastic couplings [6, 7], possibly due to the dominant orbital characters of the pseudospins, which leads to deviation from idealized lattice and adds complexity to theory models. In this talk, we will show that such complexity in the pseudospin systems can be engineered away through the synthesis of a Sr₂IrO₄/Sr₃Ir₂O₇ superlattice, where the single- and the double-layer iridates are alternately stacked along the c-axis. We have previously presented that the superlattice preserves the magnetic orders and pseudospin dynamics inherited from the parent phases, evidencing the quasi-2D nature of their magnetism. Recently, we find that the superlattice is also free from the structural distortions reported for the parent phases and has a higher point group symmetry, using rotational anisotropy third harmonic generation measurements. Moreover, based on the Raman scattering results, the pseudospin-lattice coupling is significantly reduced in the superlattice, disentangling the magnetic degrees of freedom from the lattice. Thus, our result shows that distinct quasi-2D pseudospin orders can be compounded into a superlattice to realize a pseudospin system closer to an ideal model.

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Keywords:

Pseudospin, Superlattice, Exotic magnetism, Iridates

Giant enhancement of electron-phonon coupling in SrRuO₃ ultrathin film

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Abstract:

In strongly correlated materials, electron-phonon coupling is one of key concept in understanding noble phenomena such as polar metal and superconductivity. In this work, we investigate the electron-phonon coupling of SrRuO₃ ultrathin films grown on SrTiO₃ substrate by using an optical pump-probe technique and two-temperature model analysis. Whereas the electron-phonon coupling is considered to be relatively weak in bulk SrRuO₃, we observed its dramatic enhancement by three orders of magnitude as the film thickness decreases to a nm scale. We observed also that the electron-phonon coupling strength is further enhanced for the superlattice of SrRuO₃/SrTiO₃. From these observations, we consider that the interface between SrRuO₃ and SrTiO₃ is a key to understand the giant enhancement of electron-phonon coupling, and discuss the results by considering the contribution of the transverse optical phonon of the SrTiO₃ layer.

Keywords:

Strong correlated, electron-phonon coupling , SrRuO₃, pump-probe measurement

Electronic properties of f electrons via a comparative study of CeCoIn₅ with LaCoIn₅

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Abstract:

We investigate CeCoIn₅ and LaCoIn₅ single crystals using optical spectroscopy technique. CeCoIn₅ and LaCoIn₅ have the same HoCoGa₅ type tetragonal crystal structure. However, while CeCoIn₅ has 4f electrons LaCoIn₅ does not. We are able to extract electronic properties of f electrons by comparing these two material systems. We find that differences caused by f electrons appear mostly in low-energy optical spectra at low temperatures. We define a complex optical resistivity and find that the difference optical resistivity between the two material systems exhibits the f electron response, which is intimately associated with the Kondo and Kondo lattice coherence (f-electron) phenomena. From the temperature- dependent difference optical resistivity, we find that the onset temperature of Kondo effects is much higher than that has been known. We also obtain large mass enhancement factor and the electronic density of states of 4f electrons for CeCoIn₅ by applying the extended Drude model formalism. The mass enhancement factor exhibits a huge contrast between the two systems.

Keywords:

Heavy fermion, Hybridization gap, f-electron

X-Ray diffraction study of selenium hydride to 182 GPa

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Abstract:

The recent discovery of superconductivity in H₃S at 203K under 155GPa has inspired extensive research on hydrogen-rich materials toward room temperature superconductors as an alternative approach to metallic hydrogen. As the sister chalcogen, selenium hydride is expected to exhibit high T_c under high pressure and theoretical studies have predicted H₃Se could reach a T_c of 120K above megabar pressure. However, no experimental evidence has been reported yet and the synthesis of (H₂Se)₂H₂ or H₃Se remains at pressure lower than 40 GPa. Here, we extend the structure study of selenium hydride to 182 GPa by X-Ray diffraction. By compressing selenium in hydrogen pressure medium through diamond anvil cell, several new phases were found at pressure below 50 GPa. A phase transition from β-Po type to bcc took place at around 150 GPa, which was also reported in elemental selenium. The results indicate that the selenium hydride decomposes at megabar regime but does not exclude the possibility of the predicted H₃Se with the same Im-3m structure. Furthermore, our recent attempt to synthesis tellurium hydride with laser heating up to 2200K at 80 GPa will be discussed.

Keywords:

high pressure, hydride superconductor, synchrotron X-ray diffraction

Electrical and structural properties of VO₂ in an electric field

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Abstract:

We examined the electrical and local structural properties of a VO₂ film at different electric fields using electrical resistance and x-ray absorption fine structure (XAFS) measurements at the V K edge in the temperature range of 30–100°C. The T_c value of the metal-to-insulator transition (MIT) during both heating and cooling decreases with electric field. When the electric field exceeds a certain value, the MIT becomes sharper due to Joule heating. The MIT, the structural phase transition (SPT), and the pre-edge peak transition of the VO₂ do not congruently occur at a uniform temperature. A metallic VO₂ is observed in only the rutile (or M2) symmetry. An electric field induces a substantial amount of conduction electrons in insulating VO₂. Simultaneously measured resistance and XAFS reveal that Joule heating caused by an external electric field significantly affects the MIT and SPT of VO₂.

Keywords:

VO₂, metal-insulator transition, XAFS, electric field, structural phase transition

Octupolar orthogonal magnetization in fully-strained antiferromagnetic Nd₂Ir₂O₇ thin film

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Abstract:

In magnetic materials, an applied magnetic field, H_{ext} competes with intrinsic magnetic structures, leading to complex and intriguing magnetic behavior such as anomalous Hall effect. While most of studies have been on ferromagnetic materials, the progress on antiferromagnetic (AFM) materials has been limited due to their robustness of external perturbation and vanishingly small magnetization. Recently, the torque-magnetometry study on AFM Eu₂Ir₂O₇ suggests that applying H_{ext} in-plane direction on Eu₂Ir₂O₇ can produce nonlinear magnetization M , which is orthogonal to the H_{ext} [1].

Theoretically, such $M \perp M_{\perp}$ could originate from higher magnetic ordering, octupole [1]. However, the further experimental study of octupolar orthogonal magnetization, M^o , remains elusive. Here, we present the study of M^o in M_{\perp} AFM fully-strained Nd₂Ir₂O₇ thin film using various magneto-transport technique. Nd₂Ir₂O₇ belongs to one of All-in-All-out (AIAO) antiferromagnetic pyrochlore irdate family. With the epitaxial strain, Nd₂Ir₂O₇ becomes metallic and the AIAO ordering experience spin canting. Such canted AIAO are known as the addition of three spin clusters (Dipole, A₂-octupole and T₁-octupole) [2]. The generation of two octupolar ordering creates non-vanishing Berry curvature and induces anomalous Hall effect. Moreover, using in-plane rotational transport measurement, we found that the two octupoles can induce $M^o \perp M_{\perp}$ and affect in-plane anomalous and planar Hall effect in Nd₂Ir₂O₇ thin film. Our work highlights on the interplay of strain, topology, and magnetism in antiferromagnetic materials.

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Keywords:

antiferromagnet, orthogonal magnetization, planar Hall effect

Temperature dependence of magnetic excitations of Sr_2IrO_4

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Abstract:

We use resonant inelastic X-ray scattering (RIXS) at the Ir L_3 -edge to study the anomalous temperature behavior of the magnetic excitations of a pseudospin-1/2 Heisenberg antiferromagnet on a square lattice, Sr_2IrO_4 . We measure the excitation spectra of Sr_2IrO_4 along a Brillouin zone boundary from $(\pi/2, \pi/2)$ to $(\pi, 0)$, varying its temperature from 10 K to 350 K. We observe that Sr_2IrO_4 also exhibits the $(\pi, 0)$ anomaly, which manifests as a reduced single-magnon spectral weight and a high-energy continuum. By peak-fitting analyses, we reveal that the single magnon at $(\pi, 0)$ is more fragile upon heating and vanishes right above T_N (~ 240 K), whereas the single-magnon at $(\pi/2, \pi/2)$ survives up to 350 K. Our work demonstrates that the square lattice iridate, Sr_2IrO_4 , resembles the quantum part of magnetism of a square lattice cuprate such as La_2CuO_4 as well as its classical part which can be described by the spin-wave theory.

Keywords:

Antiferromagnet, Resonant inelastic X-ray scattering, Magnetism, Square lattice iridate

Temperature-dependent and resonant angle resolved photoemission spectroscopy study of CeNiSn

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Abstract:

Kondo insulators are the materials that form a hybridized band gap due to the interaction between the localized f-electrons and conduction electrons. Recently, great attention has been paid to the topological Kondo insulators (TKIs), having metallic topological surface states. CeNiSn has been proposed as a candidate TKI material [1]. CeNiSn possesses the non-symmorphic symmetry, so there may be a protected topological surface state while the Kondo hybridized gap is open. The electrical resistance of the synthesized CeNiSn has been reported to have a low temperature resistivity plateau [2]. However, the TKI nature of CeNiSn has not been confirmed experimentally yet. Therefore, it is important to study the electronic structure of CeNiSn experimentally. We have investigated the electronic structure of CeNiSn by performing temperature-dependent angle resolved photoemission spectroscopy (ARPES) measurements near the Ce 4f resonance. In this presentation, we will discuss on the role of the Ce 4f electrons in CeNiSn, based on the measured T-dependence of the Ce 4f Kondo states.

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Keywords:

Kondo insulator, CeNiSn, ARPES

Large enhancement of magnetic moment in nitridated CeFe₁₂

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Abstract:

Due to the success of desired doping, ion implantation has been widely used for semiconductor processing. In this work, we used nitrogen ion implantation to enhance magnetism in CeFe₁₂ epitaxial thin films. To optimize nitrogen contents in CeFe₁₂ and minimize the damage caused by the high-energy ion beam (50 and 100 keV), we varied the thickness of the capping amorphous Mo layer (10, 50, 100 nm). The saturation magnetization was increased by nearly 25% by nitrogen ion implantation into CeFe₁₂ thin film. To understand this phenomenon, we traced the change in physical properties through X-ray diffractometer (XRD), fast Fourier transformation (FFT) of transmission electron microscopy, vibrating sample magnetometer (VSM) and electron spin resonance (ESR). Energy dispersive x-ray spectroscopy (EDS) and secondary ion mass spectrometer (SIMS) were performed to see chemical changes. This phenomenon is explained by density functional theory (DFT) calculations and confirmed by the magnetic resonance technique. The ion implantation and design strategy can be used for light-ion implantation into lattices to modulate magnetic, optical, and electrical properties.

Keywords:

CeFe₁₂, Nitrogen ion implantation, Magnetism

Observation of Nonlinear Hall effect in the half-Heusler Weyl Semimetal GdPtBi

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Abstract:

Hall effect is the phenomenon that the voltage difference occurs, which is transverse to the induced current. The essential condition for this effect is a time-reversal symmetry (TRS) breaking, which corresponds to either the existence of a magnetic field or magnetization. These results in the normal Hall effect or anomalous Hall effect, respectively.

Recently, a new type of the Hall effect has been discovered, called the nonlinear Hall effect (NLHE). The nonlinear Hall effect shows nonlinear dependence on the current that has many origins, as reported.^{1,2} One of the remarkable origins of this effect is the Berry curvature dipole, which is related to the inversion symmetry broken system. Thus, the NLHE originated from this can exist even in the time-reversal symmetric system.

We observed a second-order nonlinear hall effect (NLHE) in a bulk sample of a half-Heusler Weyl semimetal GdPtBi. It is an inversion symmetry broken material that develops the Weyl-like band structure in the presence of an external magnetic field.³ The NLHE is observed up to 90K without an external magnetic field and shown an anisotropy with the applied current direction along the crystal axis, which contrasts with the standard Hall effect. The anisotropy follows our prediction from considering the symmetry of Berry curvature dipole from the crystal axis.⁴

Additionally, It manifests a clear tendency when the external magnetic field is applied. We observed both odd and even terms of the nonlinear hall voltage for the applied magnetic fields. However, the anisotropy for the crystal axis only exists in the odd term of the Hall voltage. We can explain this from the induced magnetization, which is related to the Berry curvature dipole.

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Keywords:

nonlinear Hall effect, Berry curvature dipole, half-Heusler, inversion symmetry broken, Weyl semimetal

Large Enhancement of Spin Hall Conductivities in W-N Alloys

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Abstract:

Recently in spintronics, W compounds have attracted attentions owing to large spin Hall angle [1]. Motivated by recent experiment [2], we investigate spin Hall conductivities (SHC) of W-N alloys using density functional theory. Among various compositions of W-N alloys [3], W₂N and WN are intensively examined. Pure W, without N, SHC of α -W and β -W are -744 and -818 \hbar/e S/cm, respectively, which are consistent with previous study [4]. For WN alloys, W₂N exhibits large SHC of -937 \hbar/e S/cm, whose magnitude is enhanced 14.54 % over β -W, respectively, elucidated by large Berry curvature around $2/3$ MF. On the other hand, in WN case, three structures, NaCl-type, hexagonal and NbO-type, are taken into account, whose thermodynamical average SHC is around -194 \hbar/e S/cm.

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Keywords:

spin Hall angle, spin Hall conductivities, density functional theory, Berry curvature, thermodynamical average

Spin-lattice coupling in monolayer VTe₂

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Abstract:

Two-dimensional magnetic materials have attracted a lot of attention because of their interesting phenomena related to dimensional crossover and spin-lattice couplings. Among them, the interplay between magnetic spin interactions and their lattice correlations pave the way for manipulating a new quantum phase in two-dimensional magnetic materials. Recently, It is reported that spin-lattice coupling plays a crucial role in charge density waves (CDW) in bulk vanadium ditelluride (VTe₂) [1]. Here, we present the first-principles calculation results for various CDW phases in monolayer VTe₂. Our calculations show that the magnetic interaction is a key to understand recently reported CDW phases in low-dimensional VTe₂. Furthermore, the bi-axial strain changes not only the CDW states of VTe₂ but also the magnetic ground state from antiferromagnetism to ferromagnetism. This type of spin-lattice coupling in monolayer VTe₂, which could be used for novel quantum manipulation in future device applications.

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Keywords:

VTe₂, charge density wave, magnetism, spin-lattice coupling, first-principles calculation

Commensurate C₆₀ thin film crystal on black phosphorus for van der Waals vertical transistors

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Abstract:

Two-dimensional (2D) materials can serve as templates for fabrication of new van der Waals (vdW) heterostructures hosting other 2D materials, inorganic nanostructures, and organic molecules. Novel physical properties can emerge from the coherent interaction of components in various vdW heterostructures. Among available 2D materials, black phosphorus (BP) is a unique 2D template due to its anisotropic puckered atomic structure, which may lead to the strong epitaxial growth of organic molecules through guided vdW assembly. We directly observe the epitaxial molecular assembly of C₆₀ on BP using transmission electron microscopy. Theoretical analysis of the C₆₀/BP vdW heterostructure confirms that the atomic troughs of puckered BP surface can induce the alignment of C₆₀ molecules along the zigzag lattice of BP and its alignment forms higher order commensurim of C₆₀ on BP. We also fabricate the lateral and vertical devices with C₆₀/BP junction via lithography-free clean process to minimize any contamination at C₆₀/BP junction and study the charge transfer in lateral devices and charge transport behavior across C₆₀ and BP interface in vertical devices showing tunable barrier from 0.2 to 0.5 eV. Optoelectrical properties of vertical devices are also investigated under infrared and visible light illumination yielding high photo-responsivities up to ~100 A/W under visible light and showing fast response time.

Keywords:

Organic/2D materials, black phosphorus, vdW heterostructure

Raman scattering studies of two dimensional MoS₂/WS₂, WS₂, /MoS₂, heterostructures

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Abstract:

Raman scattering spectroscopy is a widely used method to research intrinsic properties of transition metal dichalcogenide (TMD) materials. As the interest in TMD materials increased, their heterostructures also attract attention and the importance of precise characterization of the heterostructures is also growing. In this study, we use CVD-grown MoS₂, WS₂, MoS₂/WS₂ and WS₂/MoS₂ heterostructures to investigate the effect of stacking order change in MoS₂, WS₂ heterostructures. We analyzed the changes in the Raman peak position, intensity and the ratio between phonons with different symmetry that occurred from whether we measured a single material or two types of heterostructures. Optical properties, especially absorption of each material, are observed to affect the heterostructure with different stacking order and these results are also supported by the Finite-difference time-domain (FDTD) simulations. Additionally, to identify any unusual properties of heterostructures at low temperature, we performed temperature dependent Raman measurement and observed a strong exciton Raman resonance of WS₂ caused by B exciton when using 488nm laser at 80K.

Keywords:

MoS₂, WS₂, Raman scattering, heterostructure, resonance

Mechanical failures in the two-dimensional materials/polymer substrates by interfacial stress transfer

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Abstract:

Two-dimensional (2D) materials such as Graphene and MoS₂ are promising candidates for flexible electronic devices. In such devices, polymers are usually utilized as substrates due to its stability, transparency, and flexibility. Therefore, it is essential to understand mechanical properties of the interface between 2D materials and polymer substrates, especially when the device structure is deformed.

In this study, Graphene or MoS₂ on Poly methyl methacrylate (PMMA) substrates is studied as a model system. After Graphene or MoS₂ is transferred onto PMMA substrates, the PMMA substrates are swollen by absorption of methanol. Biaxial tensile strain induced at the interface with the swelling, leads to not only the failure of 2D materials in the form of cracks but also the propagation of cracks deep into the PMMA substrates. The characteristics of the cracks are studied with various tools such as atomic force microscopy and Raman spectroscopy. The crack formations in the system are analyzed with a fracture mechanics approach, which indicates inevitable mechanical failures in such systems.

Keywords:

Graphene, MoS₂, Mechanical failure, Crack generation, Atomic Force Microscopy

VdW Schottky gate metal-semiconductor field-effect approaching the Boltzmann switching limit

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Abstract:

Van der Waals (*vdW*) semiconductors such as transition metal dichalcogenides (TMDs) have emerged as a promising material for next-generation electronics due to excellent gate coupling and immunity to short channel effects even at the ultimate scaling. To achieve high-performance electronic device, the gate stack that enables the effective electrostatic control of the TMD channel is necessary. In this regard, the metal-semiconductor junction can be a promising alternative considering that appropriate gate dielectrics are not available except hexagonal boron nitride for a conventional metal-oxide-semiconductor (MOS) structure. Nevertheless, control of the metal-*vdW* semiconductor junction is still challenging because of unavoidable Fermi-level (E_F) pinning originated from either metal-induced gap states (MIGS) or disorder-induced gap states (DIGS). Here, we propose a new device architecture of *vdW* metal-semiconductor field-effect transistors (MESFETs) with the E_F pinning-free Schottky gate. The E_F depinning is achieved by forming the *vdW* metal-semiconductor junction between the TMDs and the surface-oxidized metals due to the suppression of both DIGS and MIGS. Utilizing such a *vdW* Schottky gate, the *vdW* MESFETs with low-power and stable operation were demonstrated. The ON/OFF switching via the E_F modulation of the TMD channel occurred at $V_g < 0.6$ V owing to effective gate coupling. More importantly, the devices exhibited excellent transfer characteristics with the subthreshold swing of 60 mV/dec and negligible hysteresis, approaching the nearly intrinsic Boltzmann limit. In addition, the E_F depinning effects were verified in various *vdW* junctions with different metals through Kelvin probe force microscopy and temperature-dependent transport measurements. Furthermore, scalability of the device concept has been proven by fabricating the wafer-scale array of MoS₂ MESFETs.

Keywords:

Van der Waals, MESFET, Fermi-level depinning

Valley splitting and enhanced anomalous Hall effect in Mn impurity doped $WS_2/CrGeSe_3$ heterostructure

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Abstract:

Valleytronics is attracting extensive research effort for next generation potential device applications [1-3]. Mostly, the lifting of valley degeneracy was achieved by the incorporation of the magnetic layer induced the proximity effect or the magnetic impurity doping effect. However, it is rare to find reports regarding the valley splitting induced by impurity doping combined with the proximity effect. Thus, we investigated the possibility of enhancing the valley splitting and anomalous Hall conductivity by the combination of two methods in $WS_2/CrGeSe_3$ heterostructure. In the pure $WS_2/CrGeSe_3$ heterostructure, we obtained a small valley splitting of 1 meV at K^+ and K^- valleys due to the weak hybridization between the WS_2 and $CrGeSe_3$ layers. However, we obtained a large valley splitting of 68 meV in the Mn impurity doped $WS_2/CrGeSe_3$ heterostructure owing to the Mn doping effect and also the K valley dependent proximity effect. Consequently, this led to a sizable difference in the out-of-plane Berry curvature. We obtained anomalous Hall conductivity (AHC) of 110 S/cm in the Mn doped $WS_2/CrGeSe_3$ system, and this is 20 times larger than that found in the pristine $WS_2/CrGeSe_3$ heterostructure. Our results may provide a new platform through the combination of the two approaches for potential valleytronics applications.

Keywords:

anomalous Hall effect, valley splitting

Enhancing hot carrier transfer at the MoS₂/metal interface

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Abstract:

Charge transfer at the interface between 2D material and metal is of great importance for the next generation two-dimensional material-based optoelectronic application. Although hot carrier transfer between 2D materials and metals has attracted much attention due to its feature of high energy efficiency and ultrafast transfer time, the underlying mechanism behind the hot carrier transfer are still not understood. Here, we discuss the hot carrier extraction rates at the MoS₂ and metal interfaces in terms of coupling strength, interface cleanliness and Schottky junction using ultrafast transient absorption spectroscopy. Our study can pave the way for the development of hot carrier-based 2D material optoelectronics development and contribute to improving the energy efficiency of the optoelectronic devices.

Keywords:

2D materials, hot carrier, ultrafast spectroscopy, interface

Ferroelastic Domain Switching in 1T'-MoTe₂

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Abstract:

Transition metal dichalcogenides (TMDs) in the 1T' phase have recently been theoretically suggested as potential two-dimensional (2D) ferroelastic and shape memory materials. Realising this potential requires precisely controlled ferroelastic phase switching based on the fundamental understanding of domain and boundary formation. Herein, we introduce a novel method for such structural redesign and report the first experimental demonstration of controlled and reproducible ferroelastic switching between three orientational variants of the 1T' phase of MoTe₂ using the tip of a scanning tunnelling microscope (STM). Using the controllability of the STM tip at the nanoscale, we selectively modify the tensile strain on the 1T'-MoTe₂ surface via direct mechanical stress from the tip motion and via the electric field from the voltage pulses applied in the in-plane direction, which leads to uniquely patterned domains and boundaries.

Keywords:

STM, Transition Metal Dichalcogenide, Ferroelasticity, Domain Boundary

Spectroscopic Investigation of Spin and Exciton Dynamics in van der Waals Magnets

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Abstract:

A recent surge of interest in van der Waals magnets centers around the unusual dynamics of spin excitations and exciton formation. We employ terahertz and optical spectroscopy to systematically investigate the rich physics of such excitations in representative van der Waals magnets. Zhang-Rice singlet-triplet excitons are commonly found due to a strong hybridization between the metal d- and the ligand p- orbitals. The temperature dependence of their spectral characteristics points to a close connection with the formation of the underlying magnetic or multiferroic order, in which peculiar spin excitations are visible in the magnon spectra.

Keywords:

van der Waals, Spectroscopy, terahertz, exciton

Evolution of Ferroelectric Hysteresis Loops by 90° Domain Wall Pinning in $\text{Bi}_{1/2}(\text{Na}_{0.82}\text{K}_{0.18})_{1/2}\text{TiO}_3$ Thin Films

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Abstract:

우리는 PLD 방법으로 증착한 에피텍셜 $\text{Bi}_{1/2}(\text{Na}_{0.82}\text{K}_{0.18})_{1/2}\text{TiO}_3$ (BNKT) 박막의 증착 온도 변화에 따른 강유전 이력곡선 변화를 설명할 것이다. 낮은 증착 온도 (540도-560도)에서 증착한 BNKT 박막은 단일구역 (*c* domain)과 단일 강유전 이력곡선을 나타내었다. 그러나, 높은 증착 온도 (570도 이상)에서 증착한 BNKT 박막은 *c*와 *a* 혼합 구역과 이중 강유전 이력곡선을 나타내었으며, 혼합 구역을 가지는 박막의 표면에서 나사 전위 (screw dislocation)의 형태로 나선 성장이 발생하였다. BNKT 박막은 570도 이상의 고온에서 양이온 (Bi, Na 또는 K) 결함이 형성되고 그에 따라 부적합 변형 (misfit strain)도 발생한다. 그리고, 혼합 구역에서 내부 응력을 수용하기 위해 90도 구역 벽 경계에서 나사 전위가 발생한다. 이것은 90도 구역 벽 고정을 일으켜 분극 변화를 방해하고 강유전 이력곡선을 조이게 (pinch)한다. 따라서, BNKT의 단일 강유전 이력곡선은 이중 강유전 이력 곡선으로 변화한다.

Keywords:

Ferroelectric, Hysteresis loop, Domain wall pinning, $\text{Bi}_{1/2}(\text{Na}_{0.82}\text{K}_{0.18})_{1/2}\text{TiO}_3$, Thin films

The study on the electrical characteristics and compositional film density of TFT according to the concentration of solution processed a-IGZO

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Abstract:

Amorphous In-Ga-Zn-Oxide(a-IGZO)는 대표적인 산화물 반도체로 투명하면서 기존의 실리콘 기반의 반도체에 비해 비교적 높은 전하이동도와 균일성 등을 가진 Thin film transistor(TFT)의 채널물질로 많은 연구가 되어왔다. 특히 용액 공정기반 a-IGZO는 폴리머 기판이 요구하는 저온공정이 가능할 뿐만 아니라 저비용, 대량생산이 가능하여 차세대 플렉서블 디스플레이의 TFT 채널물질로 각광을 받고 있다. 하지만 용액 공정 a-IGZO TFT는 소자특성이 불안정하다는 문제점이 있고, 이를 해결하기 위해서는 소자의 불안정성을 유발하는 요인을 찾을 필요성이 있다. 본 연구에서는 농도에 따른 소자의 특성과 조성 막밀도의 연관성에 대하여 연구하였다. 서로 다른 농도의 IGZO채널을 가진 소자의 전기적 수송 특성 및 stress test 데이터를 분석하여 낮은 농도일수록 안정적인 소자임을 확인하였다. X-ray reflectometry(XRR) 분석을 통해 농도가 낮은 박막이 막밀도가 높고 두께가 얇은 것으로 나타났다. 또한 X-ray photoelectron spectroscopy(XPS) 분석으로 용액 공정 중 박막에서 In, Ga, Zn 원소들의 농도 별 조성차이를 분석하였다. 서로 다른 농도의 IGZO TFT의 전기적 특성과 박막의 특성을 분석의 결과, 박막 내의 In, Ga, Zn 원소의 조성 차이가 불안정성을 유발할 수 있음을 제시한다.

Keywords:

a-IGZO, solution process, film density, XPS

Neuromorphic devices based on electrochemical metallization in the ferroelectric material.

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Abstract:

최근 4차 산업 혁명에 대한 관심이 나날이 증가하면서 인간의 뇌를 모방하는 인공지능 시스템에 대한 수요가 높아지고 있다. 이에 맞춰, 반도체 소자들로 학습, 추론 등이 가능한 인간 뇌의 핵심 역할인 뉴런과 시냅스를 모방하는 연구들이 활발해 지고 있다. 특히, 전기화학적 금속화 방법을 이용하는 소자는 뉴런과 시냅스 소자로 응용 가능하여 뉴로모픽 시스템에 응용 시, 공정 단순화, 높은 소자 집적도 및 설계 단순화 등의 장점이 있을 것으로 예상된다. 하지만, 이온 거동 기반의 동작원리로 인해 소자의 제어가 어렵다는 단점이 있다. 이로 인해, 생물학적 뉴런과 시냅스 각각의 특성을 동일한 시스템 내에서 구현하기 어려울 것으로 예상된다. 우리는 강유전체 물질과 전기화학적 금속화 방법을 동시에 이용하여, 이온 거동을 조작하여 동일한 시스템 기반 생물학적 뉴런과 시냅스 특성을 구현하여 신개념 소자를 제작하였다.

Keywords:

neuromorphic, ferroelectric, electrochemical metallization

Transient photoinduced sulfur-vacancy absorption in MoS₂

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Abstract:

Atomic defects play a vital role in governing the carrier dynamics and mostly restrict the optoelectronic applications of two-dimensional (2D) transition metal dichalcogenides, thus controlling and utilizing defects have attracted significant attention recently. Transient photoinduced absorption is one of the powerful tools to study the transport, trapping and recombination of excess carriers in semiconductors. Here, we provide a facile and efficient route to use point defects in monolayer Molybdenum disulfide for prolonging carrier lifetime through mid-gap states by using transient absorption spectroscopy in the near-infrared (NIR) range. We also reveal a significantly elongated decay time, caused by the intraband transition between defect states and C-exciton states. This phenomenon originates from the momentum mismatch where carriers in band-nesting region adhere to an exceptional relaxation mechanism, compared to the process of band-edge excitons. Our results not solely indicate the expedient aspect of point defects but also open the applications of point defects in intermediated solar cells.

Keywords:

transient absorption, mid-gap states, ultrafast spectroscopy, Defect, 2D materials

NaF doping layer in flexible $\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ thin film solar cells: improvement of photogenerated carrier transport

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Abstract:

Earth-abundant kesterite $\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ (CZTSSe) is promising material as low cost light absorber for thin film solar cells. Similar with $\text{Cu}(\text{In},\text{Ga})\text{Se}_2$ thin film solar cells, incorporation of sodium is well known method to improve the solar cell performances. However, flexible substrate does not contain sodium element therefore, artificial doping of sodium is required to fabricate the highly efficient flexible CZTSSe solar cells. Herein, we studied the optimized precursor structure deposited on flexible metal foil with various insertion location of NaF doping layer and their electrical properties. Five CZTSSe samples were prepared with different insertion location of 10 nm-thickness NaF doping layer within Zn, Cu, Sn metal precursors and without doping layer. To investigate the photogenerated electrical properties of CZTSSe samples, photo-assisted Kelvin probe force microscopy (KPFM) was utilized. Spectral contact potential difference (CPD) shift, which is defined as surface photovoltage (SPV), was occurred at the surface of CZTSSe absorber under 532 nm wavelength illuminated condition. Defect states existed in CZTSSe limited the generation of SPV because the photogenerated charge carriers were trapped. Samples with various NaF insertion showed different magnitude of SPV referring the defect passivation by Na doping affected by the location of Na doping layer. The maximized passivation effect was observed in samples with NaF doping layer between the Zn and Mo back contact and with NaF layer between Zn and Cu precursors. In addition, improved carrier separation at grain boundaries (GBs) was observed in Na passivated CZTSSe samples. As a result, this study proposes that the passivation of defects in CZTSSe thin film improved the carrier transport at GBs as well.

Keywords:

flexible CZTSSe thin film solar cells, alkali doping in CZTSSe, photo-assisted Kelvin probe force microscopy, photogenerated carrier transport

Reduced Interfacial Non-Radiative Recombination Losses with Ammonium Chloride Passivation in SnO₂-Based Planar Perovskite Solar Cells

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Abstract:

Metal halide perovskite solar cells (PSCs) have proved to be a recorded power conversion efficiency (PCE) reaching 25.5% with a great commercial application potential in photovoltaic technology. However, many defect states that affect to charge transporting at the interface between perovskite and SnO₂ which is electron transport layer (ETL) material in the continuous PCE enhancement of planar PSCs. In this report, ammonium chloride (NH₄Cl) passivation on the upper or lower surface of SnO₂ adjacent to ITO substrates and perovskite interfaces at a low temperature process is reported, following previous studies on SnO₂ surface passivation by ozone and NH₄Cl treatment [1]. Effects of the passivation on carrier concentration of the SnO₂ layers were observed by current-voltage measurement. NH₄Cl passivated SnO₂ is shown that reducing considerably the trap states and the improvement of charge mobility, conductivity and electron concentration at the interfaces between the perovskites and the SnO₂ ETL. Furthermore, the reduced non-radiative recombination at the NH₄Cl passivation interfaces with ITO and perovskite has been observed by photoluminescence (PL) measurement and exhibited enhancement of electron transfer and suppression of the interfacial recombination.

[1] J. H. Kim, Y. S. Kim, H. R. Jung, and W. Jo, "Chlorine-passivation of the ozone-treated SnO₂ thin films: occurrence of oxygen vacancies for manipulation of conducting states and bipolarities in resistive switching", Applied Surface Science 555, 149625 (2021).

Keywords:

Perovskite solar cell , Ammonium chloride, Surface passivation, SnO₂ electron transport layer

Hot Electron Tunneling in Pt/LaAlO₃/SrTiO₃ Heterostructures for Enhanced Photodetection

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Abstract:

The LaAlO₃/SrTiO₃ (LAO/STO) heterostructures, in which a conducting two-dimensional electron gas (2DEG) is formed, have attracted research interest due to their great potential for electronic and optoelectronic applications. However, the metallic nature of the 2DEG makes it hard to observe the photo-induced phenomena in the oxide heterostructures. Here, we report that a strong photoresponse of 2DEG can be achieved by employing a vertical tunneling configuration. The tunneling of the 2DEG through an ultrathin LAO layer is greatly enhanced by UV light irradiation, showing a maximum photoresponsivity of $\sim 1.11 \times 10^7\%$. This strong photoresponse can be explained by the thermionic emission of photoexcited hot electrons from the oxygen-deficient STO. We also found that oxygen vacancy defects play an important role to enhance the tunneling photocurrent. This result provides opportunities for developing a novel photoconductive devices based on the 2DEG in ultrathin oxide heterostructures.

Keywords:

LaAlO₃/SrTiO₃, 2D electron gas, tunneling devices, tunneling photocurrent, hot electrons, oxygen vacancy

Magnetometry based on solid-state spin qubits

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Abstract:

In this talk, I will introduce quantum sensing based on diamond nitrogen-vacancy (NV) centers. Diamond NV centers are solid-state spin qubits possessing remarkable quantum properties applicable to various fields including quantum information science and quantum sensing. For instance, its atomic-scale size, long spin coherence times, and high magnetic field sensitivity are suitable for nanometer and nanotesla magnetometry. I will present several magnetic field sensing and imaging examples using single NV centers and NV ensembles.

Keywords:

magnetometry, diamond NV center, quantum sensing

Quantum Information processing based on trapped ion system

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Abstract:

Quantum computers are expected to overcome limitations of classical computers in specific calculations. To realize quantum computation various platforms and quantum information processing have been developed and tested rapidly in a recent decade. Among the platforms, the trapped ion system has lots of advantages such as good gate fidelity, long coherence time, all-to-all entanglement connectivity and stability. In addition to the application of quantum computing, quantum processing based on the trapped ion system has been used for the experiment of atomic clocks, quantum physics, quantum thermodynamics and quantum simulations.

In the trapped ion system, the qubit structure can be divided into optical qubit and hyperfine qubit by energy level and qubit processing method. In this presentation, quantum information processing based on the different qubit structure of the trapped ion system will be introduced. And experimental examples at each qubit system also will be shown briefly, i.e. experimental result of single atom energy conversion device, achieving 10 min. coherence time and quantum thermometry.

Keywords:

trapped ion system, quantum information processing,, quantum computing, long coherence time, quantum thermodynamics

Ultracold molecules as a new quantum platform

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Abstract:

Diatomic polar molecules are a promising new quantum platform thanks to their rich internal structures and large electric dipole moments. They are expected to enable brand-new experiments in quantum simulations/computations of strongly correlated systems, as well as quantum chemistry and precision measurements. Plentiful internal states of molecules form qubit states with long coherence times, as well as additional knobs for many body Hamiltonian. The strong electric dipole-dipole interaction of molecules allows simulations of strongly correlated systems with anisotropic long-range interaction. It also enables new qubit entanglement methods for quantum gate operations.

In this talk, two experiments using ultracold molecules will be introduced. I will first start with the CaF experiment at Harvard, where we achieved a long coherence time of molecular qubit states. Here, rotational states of the molecules are adapted as the qubit states, and their coherence time is measured in optical tweezers. By carefully adjusting the polarization of the optical tweezers, a coherence time up to 100 ms is achieved which enables 10s of qubit operations in a typical experimental condition. In the second part of the talk, a scheme to entangle two polar molecules using the strong electric dipole-dipole interaction will be discussed. At the end of the talk, I will also briefly introduce a new MgF experiment at Korea University.

Keywords:

quantum simulations/computations, ultracold molecules

Spreading phenomena in biological and social complex networks

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Abstract:

In this talk, we study the spread of information and disease in complex networks, one of the most important topics in complex systems. In particular, we focus on the damage spreading on the Boolean network and the spread of infectious disease on metapopulation networks. We reveal that i) the correlation between degree and Boolean function can have a significant impact on the stability of the Boolean network and ii) the topological location of seeds in epidemic spread can decisively influence the final outcome of an epidemic.

Keywords:

boolean networks, metapopulation model, epidemic spreading, complex networks

Structure and dynamics of urban flows: people, cars, and bicycles

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Abstract:

Everyday millions of people, cars, bicycles, and other vehicles move around or stay in cities. Characterizing such urban flows is essential not only to understand collective dynamics and emergent structure in cities but also to support better urban life. Recent data deluge enables us to keep track of urban flows and thus provide interesting research opportunities. In this talk, we introduce three such studies of urban flows. The first, second, and third study investigates road traffic flow, spatial distribution of population and its dynamics, and bicycle flow in Seoul respectively.

Keywords:

cities, complex systems, collective flows, network analysis, percolation, potential analysis

The dynamics of faculty hiring networks

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Abstract:

Faculty hiring networks—who hires whose graduates as faculty—exhibit steep hierarchies, which can reinforce both social and epistemic inequalities in academia. Understanding the mechanisms driving these patterns would inform efforts to diversify the academy and shed new light on the role of hiring in shaping which scientific discoveries are made. Here, we investigate the degree to which structural mechanisms can explain hierarchy and other network characteristics observed in empirical faculty hiring networks. We study a family of adaptive rewiring network models, which reinforce institutional prestige within the hierarchy in five distinct ways. Each mechanism determines the probability that a new hire comes from a particular institution according to that institution's prestige score, which is inferred from the hiring network's existing structure. We find that structural inequalities and centrality patterns in real hiring networks are best reproduced by a mechanism of global placement power, in which a new hire is drawn from a particular institution in proportion to the number of previously drawn hires anywhere. On the other hand, network measures of biased visibility are better recapitulated by a mechanism of local placement power, in which a new hire is drawn from a particular institution in proportion to the number of its previous hires already present at the hiring institution. These contrasting results suggest that the underlying structural mechanism reinforcing hierarchies in faculty hiring networks is a mixture of global and local preference for institutional prestige. Under these dynamics, we show that each institution's position in the hierarchy is remarkably stable, due to a dynamic competition that overwhelmingly favors more prestigious institutions. These results highlight the reinforcing effects of a prestige-based faculty hiring system, and the importance of understanding its ramifications on diversity and innovation in academia.

Keywords:

hiring networks, prestige, hiring inequality, network model

Classification of Seoul metropolitan subway stations using K-means cluster analysis and principal component analysis

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Abstract:

Using K-means clustering, a kind of unsupervised learning, we study passengers' entry and exit patterns in the stations of the metropolitan subway network. We use smart card data of the numbers of boarding and alighting passengers in each station to investigate the characteristics of stations. When analyzing with K-means clustering, we use 36-dimensional data. Using K-means analysis, we examined how many groups it is appropriate to classify and found four groups are proper to distinguish commercial and residential areas. Principal components analysis (PCA) reveals that the cumulative variance ratio is about 95% when reduced to two dimensions. Therefore, we conclude that two-dimensional data alone are sufficient to group subway stations. Data from passengers boarding and alighting trains during rush hour are the two essential components. Therefore, we conclude that the two dominant components reflect each station's characteristics well. Besides, the four groups present the characteristics of Seoul, centered on commercial and residential areas. We believe that this study will be helpful in grouping nodes of various networks and understanding their common characteristics.

Keywords:

K-means clustering, Principal components analysis, Smart card Data

팜 오일 선물 시장과 원유 선물 시장 사이의 정보 흐름 분석

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Abstract:

본 연구는 팜 오일(CPO) 선물 시장이 작은 시장 유동성과 규모에도 불구하고 서부 텍사스 중질유(WTI) 선물 시장에 정보를 비대칭적으로 제공하는 역할을 한다는 것을 발견했고, 이 관계는 두 상품의 거래 통화 차이를 고려하여도 변하지 않았다. 그리고 두 시장 간 정보 흐름의 비대칭성은 코로나 바이러스 2019 팬데믹 선언 이후 더 강해진 것을 확인했다. CPO 선물 시장에서 WTI 선물 시장으로 흐르는 이러한 비대칭적 정보 흐름은, WTI 선물 시장의 시장효율성이 큰 유동성으로 인해 증가하는 정도보다, 투기 거래로 인해 감소하는 정도가 더 크기 때문에 나타난다고 설명될 수 있다.

Keywords:

Crude palm oil futures, WTI futures, Information flow, Market efficiency

Time-varying spatial distribution of hospitals minimizing the population-weighted fatality rate of tuberculosis

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Abstract:

Diverse facilities are distributed for their own purposes. Quantifying objective functions in terms of the spatial distribution of facilities can help understand the principles underlying the current facility distribution and make plans and decisions for the future. Here we apply the random-walk framework relating the tuberculosis fatality rate to the hospital density to understand the time-varying spatial distribution of general hospitals in Korea. To be specific, by minimizing the sum of the population-weighted fatality rates over districts, we predict the optimal locations of new hospitals. A scaling exponent is introduced to the objective function to gauge the relative weights on the districts of low and high population density. Fitting the prediction to the empirical data of the hospital distribution in the period 2014 to 2021 by various measures, we identify the scaling exponent giving the least difference between theory and data, which reveals how the optimization principle for the hospital distribution has varied in the studied period.

Keywords:

complex system, facility distribution, optimization

One-dimensional quantum plasmons and their applications

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Abstract:

Squeezing electrons into low dimension introduces strong quantum effects, resulting in unique properties that cannot be found in higher-dimensional counterparts. Electrons in one-dimensional (1D) metals are no longer quasi-free particles, but they behave collectively as a strongly correlated quantum matter, namely, a Luttinger liquid. The quantum plasmons in 1D exhibit intriguing electrical and optical properties: the spin-charge separation, the power-law scaling of tunneling conductance, and the forbidden backscattering of plasmons. These quantum properties are not only of fundamental interest but also have a great potential for electro-optical applications. In this talk, we review the fundamentals of the Luttinger liquid and the experimental observation. We also introduce our recent works on the Luttinger liquid plasmons: (1) electrically tunable optical plasmons in mixed dimensional van der Waals heterostructures and (2) the Luttinger liquid-based infrared light-emitting devices.

Keywords:

Quantum optics, Carbon nanotubes, Low-dimensional materials, LEDs, Optoelectronics

Strong Light-Matter Interactions in Two-Dimensional Materials Mediated by Surface Polaritons for Ultrasensitive Molecular Fingerprinting

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Abstract:

Two-dimensional (2D) materials have been extensively studied due to their exceptional electrical and optical properties that have enabled a variety of exciting nanophotonic applications including ultrafast photodetectors and tunable metasurfaces. Weak light-matter interaction is one of grand challenges for practical applications of nanophotonic devices based on 2D materials so far. A number of photonic devices including silicon waveguides, microcavities, and plasmonic antennas have been utilized to achieve strong light-matter interactions in 2D materials. In these photonic devices, however, the physical dimensions of hot spots are considerably larger than that of a 2D material layer, which in turn, limits the light-matter interactions. The extreme level of field confinement enabled by surface polaritons is expected to significantly enhance the light-matter interactions. However, the efficiencies for coupling far-field radiation to the surface polaritons is inherently low due to their extreme momentum mismatch.

In this presentation, we present how the efficiencies for coupling far-field radiation to the surface polaritons in 2D materials can be boosted up to near-unity efficiencies. The near-unity efficiency becomes possible by the newly suggested coupling mechanism that collects multiple surface polaritons excited by different optical antennas. Our highly efficient polariton resonator based on this coupling mechanism enables ultrasensitive molecular fingerprinting in the mid-infrared regime.

Keywords:

2D materials, plasmonics, surface polaritons

Scalable visible-infrared camouflage with multispectral selective absorber

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Abstract:

With the development of electro-optic device, various military armament in conjunction with visible-infrared (IR) sensor as well as radar have been adopted. For instance, heat seeking missile or laser guided-missile lock-on and chase an enemy plane with collecting IR signal from the object. To enhance survivability against these armaments, light engineering from visible to IR frequency is required so that the object can be perfectly assimilated to environment by deceiving the detection systems.

Here, we show visible-IR camouflage with multispectral selective absorber for stealth technology.

Firstly, we propose the multispectral selective absorber (MSA) composed of plasmonic resonator for IR stealth technology. Designed MSA exhibits low observability against laser guidance system (wavelength of 1.06 μm), short-wave IR camera, and thermal camera with covering the whole MIR spectrum. Next, for practical application to military vehicle, we present the MSA consisting of two dimensional (2D) MXene in conjunction with multilayers without nanostructure, which can be fabricated in large-area with a low cost. While 2D MXene shows high electrical conductivity, it exhibits extremely low thermal conductivity, which can be advantageous to reduce thermal and reflection signal for IR camouflage.

Further, we show engineering of surface color of the MSA for visible camouflage. We expect that MXene based MSA can be practically applied to military industry.

Keywords:

visible camouflage, infrared camouflage, infrared stealth, multispectral selective absorber, MXene

Observation of magnetic-field-induced optical vortex-antivortex pair

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Abstract:

Optical vortices, topological textures in electromagnetic waves, received significant attention for quantum optic communication and optical trapping applications. Unlike the topological textures in other physical systems, optical vortices have been considered passive field distribution, non-interactive to the external stimulus. This work demonstrated magnetic field-induced generation and manipulation of optical vortex-antivortex pair in a gradient-thickness optical cavity. Gradient-thickness optical cavity consists of Al/SiO₂/Ni/SiO₂ quad-layer with two-dimensional thickness variation in the top and bottom SiO₂ layers, which constructs macroscopic photonic lattice. Regarding the thickness of the Ni layer, the thickness-gradient optical cavity shows photonic topological phase transition from trivial photonic lattices to optical vortex-antivortex pair crystal. Here, the magnetic field's role is an effective thickness change in the Ni layer by a magneto-optic effect that affects the formation of the vortex crystal and induces a photonic topological phase transition of the cavity. We experimentally investigated the photonic topological phase transition of the gradient-thickness optical cavity by observing the optical vortex in the specific Ni layer thickness. Under the external magnetic field, we observed two fascinating phenomena; 1) effective spin-orbit interaction mediated optical vortex dynamics and 2) generation and annihilation of the optical vortex-antivortex pair. We believe that our study opens new perspectives in topological photonics to develop active topological photonic devices.

Keywords:

Topological photonics, Optical vortex, Magneto-optics

Electrical properties of TMDS-based field effect transistors treated with organic molecules

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Abstract:

Transition metal dichalcogenide (TMDC) two-dimensional layered materials have recently drawn considerable attention as promising semiconductors for future ultrathin layered nanoelectronic device applications. In this talk, I will present our group recent research works on TMDC-based field effect transistors (FETs). In particular, I explain the following topics on the electrical properties of TMDC FETs treated with organic molecules [1]; sulfur vacancy passivation of TMDC FETs by treatment with alkanethiol molecules [2], contact-engineering of TMDC FETs via selectively deposited thiol molecules [3], and doping effect of TMDC FETs by molecular surface-charge-transfer treatment [4].

Keywords:

graphene, FET, 이머징 로직 소자, barristor structure, bistable resistor, neuromorphic device

Evolved Transistor with Transient Characteristics

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Abstract:

A metal-oxide-semiconductor field-effect transistor (MOSFET) has been scaled down according to Moore's law. And the end point of a roadmap is in sight. Thus, it is timely to explore a new perspective of a MOSFET with a different manner beyond straightforward miniaturization. A conventional planar-typed MOSFET has evolved to a gate-all-around (GAA) based MOSFET that would be an ultimate structure, by way of a 3-D FinFET. It is worth noting that a channel is completely surrounded by the GAA thus a floating body is unavoidable. Channel potential is unstable owing to a floating body and induced instability becomes usually problematic. Conversely, unstable floating body effects are favorably utilized.

In this work, three applications to positively use the floating body effects are presented. First, a MOSFET can be restructured by removing a gate electrode and thus it is named a bistable resistor (abbreviated as biristor). It is simply comprised of an n-type source, a p-type body and an n-type drain. The biristor is served as a novel DRAM cell without a capacitor and a gate, unlike a conventional DRAM composed of 1-transistor and 1-capacitor. Stable binary states are realized by use of single transistor latch (STL), which is a kind of transient characteristic in a floating body.

Second, the abovementioned gate-less biristor is utilized as a true random generator. A conventional MOSFET produces DC output current according to input voltage. In the case of the biristor, oscillating output voltage comes out from the drain because of the STL, when constant current (I_{in}) is applied to a drain. Frequency and amplitude of the output voltage is random due to the instability of the floating body.

Third, a MOSFET with a floating body is served as a leaky-integrate-fire (LIF) neuron applicable to a neuromorphic device. When I_{in} collected from differently weighted synapses is forced to a drain, stored charges in a floating body is abruptly escaped from the drain by the STL. This abrupt discharging is analogous to firing operation in an artificial neuron. Even though miniaturization of a transistor becomes eventually stopped, a variety of applications can make a trend of 'small is big' be still alive by restructuring or revisiting a transistor.

Keywords:

graphene, FET, 이머징 로직 소자, barristor structure, bistable resistor, neuromorphic device

Barristor-based Sensor Platform with Extreme Sensitivity

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Abstract:

Since graphene has unique properties such as unprecedentedly high electron mobility up to 140,000 $\text{cm}^2/\text{V}\cdot\text{s}$ and extreme sensitivity to accumulated charge on the graphene, it has been in the spotlight for years. Thus, the graphene has been adopted as a novel channel material of field-effect transistor (FET) as a sensor platform since graphene detects gas, DNA, antigen and even photon when the graphene is coated with quantum dots. However, owing to graphene FET's low switching ratio ($I_{\text{ON}}/I_{\text{OFF}}$), the sensitivity of the sensors has not been satisfied.

In this talk, a new sensor platform will be suggested, by adopting barristor structure [1], instead of the FET structure. The experiments exhibit that the platform has extreme sensitivity. The barristor-based DNA sensors could detect 1 aM with $\sim 100\%$ sensitivity and separate 1 base-pair error. The barristor-based gas sensor could detect 25-ppb of NO_2 with 1000% sensitivity and the sensitivity could be projected to detect sub-ppb. Finally, the origin of the extreme sensitivity and the potential of the platform will be discussed.

Keywords:

graphene, FET, 이머징 로직 소자, barristor structure, bistable resistor, neuromorphic device

Novel transistors beyond MOSFETs

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Abstract:

실리콘 CMOS 트랜지스터의 구조적인 스케일링이 물리적 한계까지 도달함에 따라, 여러가지 새로운 소자, 구조를 적용함으로써 전통적인 집적회로 스케일링을 연장하고자 하는 연구가 매우 활발하다. 물리적 한계에 달한 CMOS의 스케일링을 연장하기 위한 접근 방법은 이중 집적 기술을 통하여 무어의 법칙에 따른 스케일링을 구현하는 접근법인 "More Moore" 방법과 새로운 소자, 공정, 재료, 기술을 적용하여 새로운 패러다임을 구현하는 접근법인 "Beyond CMOS" 방법이 있다. "Beyond CMOS" 기술은 같은 크기의 기술 노드에서 "More Moore" 보다 고성능, 고효율의 시스템을 구현할 수 있는 접근 방법으로 AI, 빅데이터 등의 고속, 고성능의 컴퓨팅 분야에서 "More than Moore" 를 구현할 수 있다. "Beyond CMOS" 기술은 재료, Transistor/공정, 구조의 각 세분야에서 기존 기술을 뛰어넘는 이머징 기술로 나눌 수 있는데, 이머징 소자로서는 이머징 메모리 소자, 이머징 로직 소자로 크게 구분 할 수 있다. 본 강연에서는 다양한 이머징 로직 소자를 소개하며, 각 소자들의 장단점, 그리고 이머징 재료 등을 소개하고자 한다.

Keywords:

graphene, FET, 이머징 로직 소자, barristor structure, bistable resistor, neuromorphic device

Observation of Unipolar p-Type Transport Behavior in a Monolayer MoTe₂ Field-Effect Transistor with Polymer-Superacid Treatment

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Abstract:

Among all layered transition metal dichalcogenides (TMDCs), molybdenum ditelluride (MoTe₂) has recently received attention in post Silicon technology due to its potential moderate energy bandgap. Recent reported chemical methods had been utilized for electron doping of few or multi-layer MoTe₂, and an extra encapsulation layer is needed to maintain the stability of the device, making it a challenge to find a practical doping approach to obtain a stable p-type monolayer (ML) MoTe₂. Herein, a distinct doping technique using a composite of a superacid, bis(trifluoromethane)sulfonamide (TFSI), and polymeric thin film, poly (methyl methacrylate) (PMMA) is reported to improve the stability and electrical properties of ML MoTe₂. We observed a conversion from the initial ambipolar to unipolar p-type MoTe₂ field-effect transistor (FET), with the current on/off ratio increased three orders, and the hole mobility boosted up to 250 times after optimized doping conditions. More in-depth insights from Raman spectroscopy and atomic force microscopy studies illustrate that the enhancement mechanism is from the strong hydrogen-bonding interaction between the polymer and superacid, which endow the composite with abundant TFSI molecules and superior isolation from the ambient environment. This method opens up more possibilities for both electronic and optoelectronic device applications.

Keywords:

transition metal dichalcogenide, composite, surface charge transfer doping, hydrogen-bonding interaction, field-effect transistors.

Focused-ion-beam induced nanoscale luminescence quenching for high purity quantum emitters

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Abstract:

The focused ion beam (FIB) method has been used in diverse applications such as etching, microscopy, and milling for various kinds of samples, especially in the field of solid-state physics. However, FIB causes an unavoidable quenching of luminescence from optoelectronics. When FIB is irradiated on emitters, there is momentum transfer to atomic structure, which undergoes severe optical degradation due to the formation of defects. Contrary to this, we utilize this FIB-induced optical quenching phenomenon and subsequently developed a novel high-resolution optical picking technique of a few or even single nanoscale quantum emitter by actively removing (quenching) the unwanted emissions from the vicinity of the targeted nanoscale emitter.

In this talk, we applied this FIB-induced optical quenching method, which is capable of solely remaining the targeted emitter brightly luminescent with nanoscale spatial resolution and precision, to the site-controlled quantum dot (QD) embedded in the apex of pyramid for improving the single photon purity [1]. The single photon emission from the QD formed at the apex is hampered by the quantum well emission from the side facets of the pyramid which behaves as the unwanted noise. We have realized the enhancement of signal-to-noise ratio and the improvement of the single photon purity of the QD without any degradation of the QD properties such as brightness, linewidth, and spectral diffusion after the FIB-induced quenching process. Furthermore, the suppressed background emission from the quantum well could make it possible for the QD emission to survive at an elevated temperature.

[1] "Nanoscale focus pinspot for high-purity quantum emitters via focused-ion-beam induced luminescence quenching", M. Choi, S. Jun, K. Y. Woo, H. K. Song, H. S. Yeo, S. Choi, D. Park, C. H. Park, and Y. H. Cho*, ACS Nano 15, 11317 (2021).

Keywords:

focused ion beam, luminescence quenching, quantum dot, single-photon source, single-photon purity

Study of correlation between tunneling layer and current level for controlling multi-level

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Abstract:

With the advent of the 4th industrial revolution, interest in AI is increasing day by day. Accordingly, the importance of a high-density memory that can quickly process information even with a small electronic device is increasing. However, it is approaching the physical limit that can increase the degree of integration of semiconductor devices. So, recently, instead of binary memory, interest is focused on multi-level memory. The multi-level memory means to a memory device that has multiple states in which information can be stored, unlike binary memory. By utilizing such multi-level memory devices, it is possible to construct ultra-small, ultra-low-power devices by dramatically reducing the space and number required to store the same information as compared to a binary memory. Among them, the floating gate memory is the most researched structure among various types of memory devices, and it is having difficulties in improving integration in the trend of AI getting more and more attention. However, if the limitation of the floating gate memory can be overcome, the existing process can be maintained, which is a great advantage, so research is still being actively conducted. In this regard, many researchers have conducted studies on multi-level memory devices using various structures and materials, but basic studies such as principles and mechanisms are insufficient. Thereupon, we fabricated floating gate memory devices using two-dimensional materials with unique electrical properties of changing the bandgap according to the constituent atoms. The device structure was fabricated using graphene as a floating gate, hexagonal boron nitride (hBN) as a tunneling layer, and molybdenum disulfide (MoS_2) as a channel on a SiO_2/Si wafer. Finally, we found a way to control the number of bits by revealing the correlation between the tunneling layer and the current level in a floating gate memory.

Keywords:

two-dimensional material, floating gate memory, multi-level

Photobleaching of autofluorescence from human dentin ex vivo

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Abstract:

Autofluorescence exploits fluorescence characteristics from endogenous molecules in a biological sample such as collagen and melanin. Due to its' extremely low dependency on the chemical process, it is considered to be a non-invasive method. However, the autofluorescence image might avoid chemical alteration, physical and photochemical damage from heavy photon flux cannot be neglected. The photobleaching not only lowers the signal-to-noise ratio of an image but also affects resolution. Furthermore, as the damage can be permanent, the continuity of biological sample will be threatened. Therefore, in this study, we evaluated the photobleaching phenomenon of human teeth. The teeth sample was extracted from 24 female. The teeth were solidified inside of crystal resin and sliced to a thin slice. After, the sample slice was polished to maintain surface flatness over the region of interest. The dentin was selectively excited by two photon microscopy with 780nm of wavelength. The target region was exposed for 5minute under various intensities. Each scan took 0.55s and the intensity of the same region for each scanned image was compared. The decrease in fluorescence intensity was measured over time. The curvature was compared with various light intensities and obtained more acute decrease curvature toward higher exposure intensity. The visible change in colour at the region of interest was also measured through two photon imaging. The results suggest that autofluorescent fluorophores inside of dentin can be photobleached under repetitive laser scanning microscopy imaging.

Keywords:

Autofluorescence, Two photon microscopy, Photobleaching, Dentin

비표지 간섭산란현미경(interferometric scattering microscopy)을 이용한 세포 동력학 연구: 불특정 소포들(cargos)의 이동 궤적 추적을 통한 세포 내부 골격망 (cytoskeleton network) 구조 및 수송 흐름의 시각화

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Abstract:

소포 수송 (cargo trafficking) 현상은 세포 기능에 필요한 다양한 물질들을 세포 내부의 특정 위치에 원활히 공급하기 위한 주요 작용 중 하나이다. 그러나, 복잡하게 얽힌 세포 골격망(cytoskeleton network)으로 가득 찬 세포 내부의 밀집된 환경에서, 어떻게 소포들의 수송이 정확히 이루어지고 있는지에 관한 이해는 여전히 제한적이다. 형광 현미경 기법은 세포 속 특정 소포들의 운동을 선택적으로 추적 가능하게 하지만, 형광 표지가 된 목표물을 제외한 주변 세포 속 물리적 환경 정보는 대부분 소실되는 단점이 있다. 이에 본 연구에서는 나노/바이오 입자 위치의 정밀 추적이 가능한 간섭산란 현미경을 이용하여, 살아있는 세포 속 다수의 소포들의 수송 현상 관찰이 가능함을 알 수 있었다. 간섭산란 현미경은 시간차 미분 이미징 기법을 적용함으로써, 이동 중인 소포의 산란 신호를 주변 세포 환경에서 비롯된 정적 신호로부터 분리하는 것이 가능하다. 이를 통하여, 세포 층상위족 (lamellipodium) 영역에서 100여 개의 소포들에 대한 실시간 위치 정보를 정확히 추적하는 것이 가능하였다. 이렇게 획득한 백만 개 이상의 소포 위치 정보로부터 소포 수송에 사용되는 주요 세포 골격망의 구조를 어떠한 표지도 없이 고해상도로 재구성할 수 있을 뿐 아니라, 시간에 따라 변화하는 골격망 위에서의 소포들의 교통 흐름에 대한 시각화가 가능함을 보였다. 본 연구를 통해 소포 수송 현상의 보편적인 동력학적 특징 뿐 아니라 세포의 시공간적 맥락에서 수송 현상을 전체적으로 파악하는 것이 가능함을 알 수 있었다.

Keywords:

간섭산란현미경, 비표지 세포 이미징, 소포 수송 (cargo trafficking), 골격망 (cytoskeleton network), 교통 흐름 (traffic flow)

Molecular mechanism of DNA loop extrusion mediated by the SMC protein

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Abstract:

The structural maintenance of chromosome (SMC) proteins organize chromosomal structure by extruding loops of DNA. Its ATP-dependent motor mechanism remains unclear but likely involves steps associated with large conformational changes within the ~50 nm protein complex. Here, using various single-molecule techniques such as single-molecule DNA tethered assay (1), liquid-phase High-Speed Atomic Force Microscopy (HS AFM) (2), and magnetic tweezers (MT) (3), we obtained experimental evidence that supports a scrunching model for DNA loop extrusion. We observed that the condensin SMC protein cycles dynamically over time between open 'O' shapes and collapsed 'B' shapes, with ATP binding inducing the O to B transition. Condensin binds DNA via its globular domain and, surprisingly, also via the hinge domain. In addition, using high-resolution magnetic tweezers, we show median step sizes are DNA-length dependent, ranging between 20-50 nm at forces of 1.0–0.2 pN, respectively. This demonstrates the important role of the structural flexibility of the un-stretched DNA polymer at these low forces. Furthermore, using ATP-binding-impaired and ATP-hydrolysis-deficient mutants, we find that ATP binding is the primary step-generating stage underlying DNA loop extrusion. We discuss the findings in terms of a scrunching model where a stepwise DNA loop extrusion is generated by an ATP-binding-induced engagement of the hinge and the globular domain of the SMC complex.

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Keywords:

condensin, Structural maintenance of chromosome (SMC) protein, DNA loop extrusion, HS AFM, scrunching model

Structural dissection of human glucose transporter folding reveals evolutionary balancing between foldability and functionality

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Abstract:

Despite advances in resolving structures of multi-pass membrane proteins, little remains known about how these complex structures form in ER membranes. Using single-molecule magnetic tweezers, we report a complete folding pathway of human glucose transporter 3 (GLUT3). The N-terminal major facilitator superfamily (MFS) fold strictly forms first, serving as structural templates for its C-terminal counterpart that defines most of the glucose binding site. Our data further reveal folding pathways for individual MFS folds, where polar residues comprising the membrane-embedded conduit for glucose molecules present major folding challenges. The ER membrane protein complex facilitates insertion of all TMHs, thrusting GLUT3's microstate sampling toward folded structures. Final assembly between the N- and C-terminal MFS folds depends on specific lipids that ease desolvation of lipid shells surrounding the domain interfaces. This asymmetric folding propensity across the N- and C-terminal MFS folds is found for all metazoan sugar porters, revealing evolutionary conflicts between foldability and functionality faced by many multi-pass membrane proteins.

Keywords:

Single-molecule magnetic tweezers, Membrane protein folding, Glucose transporter, Major facilitator superfamily

Chemotherapeutic Drugs Regulating Structure and Flexural Rigidity of Microtubules

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Abstract:

Microtubules (MTs) are hollow 25 nm diameter protein nanotubes comprised of dimeric $\alpha\beta$ -tubulin subunits. MTs are one of the major components of the eukaryotic cytoskeleton, essentially involved in cell morphology, intracellular trafficking, and cell division. MT-targeting anticancer drugs, paclitaxel (PTX) and laulimalide (LMD), attach to specific binding sites of tubulin dimer, suppressing MT dynamics and cell mitosis, yet their influence on the mechanical properties of MTs is not clearly understood. We show our recent findings on the effects of PTX and LMD regulating the lattice structure and flexural rigidity of MTs by using synchrotron X-ray scattering, cryogenic transmission electron microscopy, and fluorescence imaging.

Keywords:

microtubules, lattice structure, flexural rigidity, MT-targeting anticancer drugs, synchrotron X-ray scattering and cryo-TEM

α -Synuclein disease mutant-type dependent inhibition of SNARE-driven vesicle fusion by two mechanisms

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Abstract:

Synaptic accumulation of α -synuclein (α -Syn) oligomers and their interactions with VAMP2, a vesicular SNARE protein, have been reported to be the basis of synaptic dysfunction in Parkinson's disease (PD). α -Syn mutants linked with familial PD have also been known to be capable of interacting with VAMP2, but the exact mechanisms resulting from those interactions to eventual synaptic dysfunction are still unclear. Here, we investigate the effect of α -Syn mutant oligomers comprising A30P, E46K, and A53T on synaptic vesicle mimics, VAMP2-embedded vesicles. Also, we propose a potential model for the clinical and pathological heterogeneity of familial PD caused by each mutation: A30P and A53T cause severe PD, but E46K is associated with rapidly developing dementia with Lewy bodies (DLB), where α -Syn aggregates are more diffusely distributed in the brain.

Keywords:

α -synuclein, Parkinson's disease, SNARE protein, FRET, artificial membrane

양자정보물리학: 새로운 교과목

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Abstract:

최근 양자정보 및 양자계산에 관한 기본적인 개념과 원리적인 아이디어를 체계적으로 소개할 새로운 전공 과목, 즉 "양자정보 물리학"에 대한 필요성과 요구가 대두 되었다. 이 과목은 양자역학 및 관련 수학 과목 (선형대수학, 복소함수론 등)의 표준교육과정을 마친 학생들이 이해할 수 있는 수준에서, 해당 분야를 이해하는 데 필요한 물리학, 수학, 컴퓨터과학의 배경지식과 학습 방법을 제공하기를 기대한다.

한국물리학회 교육위원회 산하 대학커리큘럼소위원회 활동의 하나로 위 과목에 관한 확장형 강의계획서를 마련하였고, 2021년 7월 26일부터 8월 5일까지 여름학교를 시범 운영하였다. 강의계획서와 여름학교의 경험을 토대로 새 교과목에 관해 소개한다.

Keywords:

양자정보물리학

물리학과 머신러닝

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Abstract:

물리학과에서 머신러닝을 배워야 할까? 머신러닝의 발전에 물리학의 아이디어가 큰 기여를 하고 있고, 한편 머신러닝이 물리학 연구와 교육에 큰 도움을 주고 있다. 물리학과에서 “머신러닝”이라는 교과목이 개설된다면 어떤 주제를 다루고 어떤 방식으로 교육이 이루어지는 것이 효과적일까? 한국물리학회 대학커리큘럼소위원회에서도 머신러닝 교과목에 대한 이런 고민을 진행하고 있다. 그 동안 머신러닝 소위원회에서 개발한 강의계획을 소개하고 물리학회 회원들의 귀중한 조언을 듣고자 한다.

Keywords:

머신러닝, 물리교육

New wine in a new bottle: 새로운 물리 교육과정에 담겨야 할 내용 과 과제

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Abstract:

과학기술의 급격한 성장과 기술의 사회적 적용은 점점 사회문화적 환경의 변화를 가속화하고 있다. 이러한 변화는 교육 역시 예외가 아니다. 인공지능, 빅데이터, 반도체, 증강현실, 사물인터넷 등 다양한 기술적 변화로 인해 이와 관련된 기술의 적용이 교육 환경에서의 온라인 학습과 가상현실을 활용한 원격실험실, 인공지능을 활용한 맞춤형 학습 등 다양한 형태로 일어나고 있다. 그러나 이러한 교육환경의 변화를 단순히 새로운 기술의 적용에 따른 교육 방법의 전환으로만 이해하는 것은 시대적 변화를 아주 좁은 틈으로만 해석하는 것이라 할 수 있다. 이러한 변화는 16~17세기 과학혁명이나 20세기 초반 현대물리학으로의 전환에 비견될 만큼 시대적 전환의 의미를 담고 있다. 특히, 오랫동안 교육학의 주류 이론이었던 개인적 인지주의 및 구성주의적 전략을 넘어서서 포스트휴먼 및 연결주의로의 전환에 따라 기존의 교육방법 외에도 내용과 평가 등 다양한 여러 영역에서 전환이 이뤄져야 한다. 특히, 국가 교육과정은 미래사회를 살아갈 인재를 양성하고 변화에 대응하고 적응할 능력을 기른다는 점에서 미래사회의 변화 방향에 맞추어 필요한 경험과 노하우를 쌓도록 하는 것이 매우 중요하다. 이에 본 발표에서는 구성주의와 연결주의의 큰 틀을 중심으로 새로운 교육과정에서 다뤄야 할 주요 내용 및 과제에 대해 제안하고자 한다.

Keywords:

4차 산업혁명, 인공지능, 메타버스, 교육과정, 거울 세계

Offline Data Quality Monitoring for the CMS GEM Detector

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Abstract:

The first phase of the new Gas Electron Multiplier (GEM) detector system was installed last year in the endcaps of the CMS experiment. Combined with the existing Cathode Strip Chambers (CSC) detector, the GEM detector will increase the muon triggering performance while being robust against the harsh radiation environment of the High-Luminosity LHC. The GEM detector system has been integrated into the CMS online and offline data quality monitoring (DQM) system. The online DQM for GEM provides real-time feedback about the operation status, while the offline DQM conducts the detection efficiency measurement with promptly reconstructed data for data certification. The online and offline DQMs for GEM were tested successfully during a cosmic data-taking run called Cosmic RUn at ZERo Tesla (CRUZET), and we present the efficiency results from the CRUZET commissioning.

Keywords:

CMS, GE1/1, GEM, DQM

An online monitoring system for status and quality of the GEM detector system in CMS

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Abstract:

In Run III of the LHC, the first phase of the Gas Electron Multiplier (GEM) detector system will operate in the muon endcap system. The GEM detector is expected to improve the performance of muon triggering, reconstruction, and identification in the high-eta region. For the successful operation of GEM detectors, real-time information is required to monitor the status and quality of GEM detectors. We introduce a visualized monitoring system, so-called online DQM (Data Quality Monitoring) for the GEM detector. We have tested the online DQM system with the cosmic run so-called zerotesla commissioning run.

Keywords:

LHC, CMS, GEM, DQM, detector

GEM Foil Production and Quality Control in Korea

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Abstract:

The Compact Muon Solenoid (CMS) experiment of the Large Hadron Collider will upgrade the forward muon system for the Phase-2 run. One of the key additions is the triple-layer gas electron multiplier (GEM) detectors. In total, three layers of GEM detectors will be installed, which are known as GE1/1, GE2/1, and GE0. One of the key components of the GEM detector is the GEM foils which are inherently intricate, making them difficult to produce. MECARO, a company based in Korea together with the collaboration of the Korea-CMS group is producing half of the GEM foils for GE2/1. In this presentation, we present the status and the Quality Control process involved in the production of the GEM foils in Korea.

Keywords:

CMS, Muon Detector, GEM, GE2/1, MECARO

Status of CMS LGAD Sensor Testing in Korea

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Abstract:

As part of the CMS Phase 2 upgrade, MIP Timing Detector is planned to be installed in order to mitigate the impact of pileup that is expected to reach 200 in HL-LHC. In the endcap region, silicon-based Low Gain Avalanche Detector (LGAD) sensors that allow timing resolution of a few tens of picoseconds are used. The sensor design needs to be optimized considering several factors, including radiation resistance, uniformity of gain, and long-term stability. At Korea University, we have set up a sensor testing facility using an IR laser and the status of the sensor testing will be discussed in this talk.

Keywords:

CMS, MTD, ETL, LGAD, Silicon sensor

R&D status of the compact Time Projection Chamber (cTPC) for the 3D beam monitor

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Abstract:

To measure the precise three-dimensional (3D) beam profile of electron and ion beam, a compact Time Projection Chamber (TPC) has been developed recently. In the late 1970s, a large TPC has been developed as the main tracker for the high-energy physics experiment at SLAC. High electric and magnetic fields in the drift volume of TPC have been applied to measure the particle trajectory. The drift volume is surrounded by the field cage, cathode, preamplifier, and readout electrode. Recently, the most popular preamplifier of Micro-Pattern Gaseous Detector (MPGD) is a Gas Electron Multiplier (GEM) to make the avalanche amplification. The motion and amplification of electrons in the Ar-based gases have been simulating to design the drift volume and preamplifier by using Garfield++. The compact TPC with multiple GEM layers will be designed for a high rate and precision 3D beam monitor. We will present the R&D status of the beam monitoring system based on small-size GEM-TPC.

Keywords:

Time Projection Chamber, GEM-TPC, Garfield++, beam diagnostic, COMSOL

Semileptoni B decays - recent results from Belle and Belle II

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Abstract:

Though the Belle experiment has stopped data taking more than a decade ago, new results on B meson decays are still being obtained. This is in part due to new experimental tools elaborated for Belle II applied to the Belle data set, such as the FEI (Full Event Interpretation) hadronic and semileptonic tag which enables new measurements of inclusive $B \rightarrow X_u \ell \nu$ for $|V_{ub}|$. Other analyses are motivated by the progress in theory such as the measurement of q^2 moments in $B \rightarrow X_c \ell \nu$, which allows for a determination of $|V_{cb}|$ up to the order $1/(m_b)^4$. In this talk, we present recent highlights on semileptonic B-meson decays from Belle and Belle II, and comment on the existing 'Inclusive vs. Exclusive tension' of $|V_{cb}|$ and $|V_{ub}|$.

Keywords:

ALICE실험 FoCal 검출기에 사용할 PIN구조를 갖는 실리콘 센서의 양성자 빔에 의한 손상 평가

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Abstract:

CERN LHC ALICE 실험은 Long shutdown 3 (LS3) 기간 동안 Forward Calorimeter (FoCal) 추가를 통한 성능향상을 준비하고 있다. 충돌지점으로부터 7 m 거리에 위치할 FoCal은 Electro-magnetic 열량계 FoCal-E와 Hadronic 열량계 FoCal-H로 나뉜다. FoCal-E는 Si-W 샌드위치 구조를 갖으며 2,000여 개의 PIN구조를 갖는 Si센서가 에너지를 측정하는 핵심 센서가 된다.

PIN구조는 고저항의 진성 Si기판의 양면에 붕소와 인을 도핑한 구조를 말한다. 일본 그룹들과 (주)Hamamasu, 인도 그룹들과 인도의 센서 회사, 그리고 한국 그룹들과 한국전자통신연구원(ETRI)가 PIN형 실리콘 제작 가능성을 검토하고 있다.

본 연구는 FoCal의 요구사항을 만족하도록 제작된 n형 및 p형 PIN구조 실리콘 센서의 기초적인 특성을 분석하고, 경주에 위치한 한국원자력연구원 양성자과학연구단(KOMAC)의 양성자 조사시설을 활용하여 양성자 손상평가를 수행하였다. ALICE LS3 기간 동안 예상되는 총 누적 플루언스 1×10^{13} (1 MeV equivalent neutrons/cm²) 수준까지 양성자를 조사하였으며, 이 때 양성자 조사 전후 IV/CV 특성 분석을 바탕으로 한 full depletion voltage, breakdown voltage, type inversion, damage rate, annealing 결과를 보고하고 이에 대한 토론이 이루어질 것이다.

Keywords:

CERN LHC ALICE experiment, Silicon PIN Sensor, Radiation Hardness, Proton Damage

Search for Charged Higgs Boson Decaying to W Boson and Pseudo-scalar Higgs Boson at $\sqrt{s} = 13$ TeV with CMS Run2 dataset

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Abstract:

A search for charged Higgs boson decaying to W boson and pseudo-scalar Higgs boson is presented. The analysis is based on the dataset of proton-proton collision at center of mass energy 13TeV collected with CMS experiment at the CERN LHC, corresponding to an integrated luminosity of 137/fb. The search is performed with trilepton plus multijet final state events including at least 2 muons with opposite charge. Charged Higgs bosons' mass from 70 to 160 GeV with corresponding pseudo-scalar Higgs bosons' mass from 15 to $m(H_c) - 5$ GeV is investigated. Signals are discriminated from the backgrounds using the deep learning techniques to maximize their sensitivity.

Keywords:

2HDM, Charged Higgs, LHC, CMS, Deep Learning

The Status of the Deep Underground Neutrino Experiment (DUNE)

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Abstract:

The Deep Underground Neutrino Experiment (DUNE) is under construction at the far site in South Dakota and at the near site in Fermilab with an accelerator upgrade. It detects beam-generated neutrinos to measure their flavor transformations or oscillations through the matter effect. Subsystems of DUNE include liquid argon (Ar) time projection chambers (TPC), gaseous Ar TPCs, muon spectrometers, and beam monitoring trackers. We report the current status of DUNE and discuss Korean involvement to the collaboration.

Keywords:

DUNE, neutrino, oscillations

Constructing the general three-point vertices effectively

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Abstract:

An efficient algorithm is developed for constructing all the Lorentz covariant effective three-point vertices of the decay of a massive particle into two particles of different masses and different spins. For the development, the closely-related equivalence between the helicity formalism and the covariant formulation is exploited for counting the number of independent terms and identifying the basic covariant three-point vertices. Assembling the basic operators according to the compact algorithm enables us to construct all the covariant three-point vertices.

Keywords:

three-point vertices, helicity formalism, covariant formulation

Four-form flux-mediated dark matter

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Abstract:

We propose a new mechanism to communicate between fermion dark matter and the Standard Model (SM) only through the four-form flux. In this scenario, the relaxation of Higgs mass and cosmological constant as well as the dark matter production are achieved simultaneously due to the four-form couplings. In this case, 1-loop correction can be sizable for direct detection, so we consider that. We show that the simultaneous presence of the pseudo-scalar coupling to fermion dark matter and the flux induced Higgs mixing gives rise to unsuppressed annihilations of dark matter into the SM particles at present, whereas the direct detection bounds from XENON1T can be avoided.

Keywords:

Four-form, Dark matter, Beyond Standard Model, Higgs Physics

Calculating WIMP direct detection signals in practically any scenario with WimPyDD

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Abstract:

We introduce WimPyDD, a modular, object-oriented and customizable Python code that calculates accurate predictions for the expected rates in WIMP direct-detection experiments within the framework of Galilean-invariant non-relativistic effective theory in virtually any scenario, including inelastic scattering, an arbitrary WIMP spin and a generic WIMP velocity distribution in the Galactic halo. WimPyDD exploits the factorization of the three main components that enter in the calculation of direct detection signals: i) the Wilson coefficients of the effective theory, that encode the dependence of the signals on the ultraviolet completion of the effective theory; ii) a response function that depends on the nuclear physics and on the features of the experimental detector (acceptance, energy resolution, response to nuclear recoils); iii) a halo function that depends on the WIMP velocity distribution and that encodes the astrophysical inputs. In WimPyDD these three components are calculated and stored separately for later interpolation and combined together only as the last step of the signal evaluation procedure. This makes the phenomenological study of the direct detection scattering rate with WimPyDD transparent and fast also when the parameter space of the WIMP model has a large dimensionality.

We briefly summarize some of several published results obtained with WimPyDD so far as illustrative examples of its power and flexibility.

Keywords:

Dark Matter, Dark Matter direct detection, Particle Physics, Phenomenology, Python

Sterile neutrino dark matter with dipole interaction

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Abstract:

We consider the possibility of the lightest sterile neutrino dark matter which has dipole interaction with heavier sterile neutrinos. The lifetime can be long enough to be a dark matter candidate without violating other constraints and the correct amount of relic abundance can be produced in the early Universe. We find that a sterile neutrino with a mass of around MeV and the dimension-five non-renormalizable dipole interaction suppressed by $\Lambda_5 \gtrsim 10^{15}$ GeV can be a good candidate of dark matter, while heavier sterile neutrinos with masses of the order of GeV can explain the active neutrino oscillations.

Keywords:

Particle Dark Matter, Dipolar interaction, Sterile Neutrino

Self-Resonant Dark Matter

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Abstract:

We present a novel mechanism for Sommerfeld enhancement for dark matter interactions without necessity of light mediator. We consider two-component scalar dark matter model with a triple coupling, and find there appears an u-channel resonance in dark matter elastic scattering. By summing corresponding ladder diagrams, we obtain a Bethe-Salpeter equation with a delay term and identify the Sommerfeld factor for two-component dark matter from the effective Yukawa potential for the first time. We discuss the implications of our results for dark matter self-scattering enhancement and annihilation cases.

Keywords:

Dark Matter, Sommerfeld effect, Bethe-Salpeter Equation

Vacuum stability of conformally invariant dark matter models

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Abstract:

We discuss the vacuum stability issue of the scalar couplings in two classically scale-invariant models with an anomaly-free set of two fermionic dark matters and with a scalar dark matter multiplet of global $O(N)$ symmetry. In the fermionic dark matter model, we introduce $U(1)_X$ gauge symmetry with new charge X in the dark sector in order to stabilize the mass of the scalar singlet with a new gauge boson. Our conformally invariant scalar potential generates the electroweak symmetry breaking via the Coleman-Weinberg mechanism, and a new scalar singlet mediator acquires its mass through radiative corrections of the fermionic dark matters and the new gauge boson or of the scalar dark matter as well as of the SM particles. Taking into account the collider bounds, we present the allowed region of new physics parameters satisfying the recent measurement of relic abundance and the direct detection bounds.

Keywords:

vacuum stability, conformal invariance, dark matter

정전형 중이온 가속기 - 무한한 활용 가능성

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Abstract:

정전형 중이온 가속기는 대표적인 중소형 입자가속기 중 하나로, 20세기 초반 핵물리 연구를 위한 주요 장비 중 하나로 개발되었다. 그러나 1960년대 이후, 보다 높은 에너지를 제공하는 대형 가속기에 그 수요를 내어주고 점차 쇠퇴되어 갔다. 그러나 70년대 이후 다층 반도체, 초전도 박막, 특수 코팅 등 박막 내부나 표면의 물성이 절대적으로 중요한 물질들이 첨단 산업의 모든 분야에서 핵심적인 역할을 수행하게 되면서 양상이 바뀌었다. 그러한 물질들의 물성 정보를 얻어내기 위한 도구로 수 MeV 급 에너지를 갖는 양성자나 중이온을 이용한 표면 분석법들이 속속 개발되면서 이들 가속기의 수요가 폭발적으로 증가하게 되었다. 본 강연에서는 정전형 중이온 가속기의 활용을 다음과 같이 크게 세 가지 분야로 나누어 다룬다. 정전형 중이온 가속기 활용의 양대 활용분야인 이온빔 공학과 이온빔 분석, 그리고 이제는 중이온 가속기 제작수요의 절반을 차지하게 된 가속기 질량분석법(Accelerator Mass Spectrometry, AMS)이다. 이온빔 공학에 대하여는 이온 주입에 의한 표면 개질, 이온빔 MEMS, 이온빔 lithography를 중심으로 소개하며, 이온빔 분석에서는 RBS(Rutherford Backscattering), PIXE(Particle Induced X-ray Emission), ERD(Elastic Recoil Detection), NRA(Nuclear Resonance Analysis) 등의 표면 분석법에 대한 개괄적인 원리와 그 활용도를 소개한다. 그리고 마지막으로 방사성탄소 연대측정으로 대표되는 초극미량 동위원소 분석법인 AMS(Accelerator Mass Spectrometry)의 기본 원리 및 활용분야에 대하여 논한다. AMS는 고고학이나 인류학 등 인문분야부터, 지구과학, 우주 환경, 지구 환경, 신약 개발에 이르기까지 폭넓은 활용 분야를 갖는 대표적인 중이온 가속기 활용 분석법이다.

Keywords:

electrostatic accelerator, ionbeam analysis, ionbeam engineering, AMS, radiocarbon dating

Status of Nuclear Physics Application Research at KAERI: Nuclear Fusion and Data

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Abstract:

Nuclear physics application research at KAERI have been performed with focusing on nuclear fusion engineering, fusion plasma heating, and nuclear data.

For nuclear fusion engineering, we have joined the ITER construction project, especially for the blanket first wall procurement and breeding blanket testing. High temperature material, component design, fabrication technology, and testing methods were developed. To extract heat from fusion neutron and generate electricity, breeding blanket technology have been developed focusing on design, fabrication, cooling, safety analysis and so on.

For fusion plasma heating, firstly, NBI(Neutral Beam Injection) and ICRF(Ion Cyclotron Range of Frequency) system have been researched and developed through KSTAR project. Three 2 MW KSTAR NBI ion sources have been successfully developed and contributed the long pulse operation of more than 50 seconds of KSTAR plasmas. ICRF heating and current drive system in 20~60 MHz has been developed to provide 2MW power for KSTAR high beta long pulse operation, in which about 1 MW power was coupled to KSTAR plasma.

For nuclear data, KAERI atomic/nuclear data project aims to become self-reliant in nuclear-based technology and to provide reliable data for nuclear-related fields. Our main activities are to measure, evaluate and validate atomic/nuclear data, and to provide those data through domestic and international network. As recent activities, we have provided above 40 neutron data and 130 photo-nuclear data for the latest evaluated nuclear data library, ENDF/B-VIII.0. Those data play an important role for R&D of back-end nuclear fuel cycle and next generation nuclear/raditaion, nuclear fusion technology and basic science.

Currently, we are developing the various neutrons based on ion sources and accelerators for fusion engineering, nuclear data, and practical application for industry, defence, and so on.

Keywords:

Nuclear fusion, ITER TBM, breeding blanket, Plasma heating system, nuclear data, atomic data, neutron source

Neutron detection system status of Nuclear Data Production System

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Abstract:

The NDPS, neutron time-of-flight(TOF) experimental facility of RAON, is being constructed with a goal of completion in 2021. The proton and deuteron beams accelerated by the SCL3 have energies of up to 83 and 98 MeV respectively. The proton and deuteron beams can generate mono-energy neutrons through p(Li,n) reactions and continuous energy white neutrons through d(C,n) reactions respectively. The produced neutrons pass through a 4 m long neutron collimator and reach the experimental room. To obtain precise nuclear data, it is important to measure the incident neutron flux accurately. The energy of neutrons will be measured using the TOF method. To monitor the neutron flux the MICROMEGAS and PPAC are manufactured. The PPAC can measure the position of incident particles, and thus the neutron beam profile could be obtained. In order to convert fast neutron to charged particles, we made thorium converters. The electrodeposition method was used with isopropyl alcohol as a solvent for thorium nitrate powder. The test results of these two monitoring detectors will be presented.

Keywords:

RAON, NDPS, Neutron detector, MICROMEGAS, PPAC

Characterization of a CLYC detector for gamma and neutron measurement

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Abstract:

A Cs₂LiYCl₆:Ce (CLYC:Ce) scintillation crystal was known for a good energy resolution (~4% at 661 keV) and a high separation power between gamma and neutron signals. Depending on the enrichment fraction of ⁶Li and ⁷Li, neutron responses of CLYC on thermal and fast neutrons are different. Characteristics of two scintillation detectors with ⁶Li-enriched and ⁷Li-enriched CLYC:Ce crystals were studied using gamma and neutron sources. This presentation will show the characterization and pulse shape discrimination study of CLYC detectors.

Keywords:

neutron measurement, pulse shape discrimination, CLYC

Simulation of the neutron measurement using LANA

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Abstract:

The Large Area Neutron Array (LANA) is used to measure the neutrons in heavy-ion collisions at about 100 MeV/u at the National Superconducting Cyclotron Laboratory (NSCL) at the Michigan State University (MSU). The LANA consists of the two large neutron walls and a veto wall. Each neutron wall consists of 25 rectangular-shape cases filled with liquid scintillator (Model No. NE-213). In order to estimate the absolute detection efficiency of LANA and eventually the neutron yield we employ the SCINFUL-QMD simulation program. Because the SCINFUL-QMD program does not allow us to modify the detector geometry, we have implemented the physics processes in SCINFUL-QMD to the GEANT4 simulation package. In this presentation, we present the current status of the development of the GEANT4 simulation code for the neutron measurement by using LANA.

Keywords:

LANA, NSCL, MSU, SCINFUL-QMD, GEANT4

MC-based feasibility study of a new sampling calorimeter for measuring the γ incident angle

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Abstract:

We present studies on Monte Carlo based detector configuration to measure the incident angle of the γ . The Geant4 and the XGBoost packages are used to simulate interactions of electromagnetic showers with detector materials and to reconstruct the incident angle with the machine learning method. The sampling calorimeter is configured with alternating 5-mm-thick scintillator strips and 1-mm-thick lead plates. We find that the configuration with 15-mm-wide scintillator strips provides 1.3 deg resolution, and the same resolution is expected with only front part of the detector in 4.6- radiation-length in thickness with 5.8% inefficiency. Furthermore, the incident angle dependency of the angular resolution and the incident energy dependency will be presented.

Keywords:

KOTO, J-PARC, EM shower, ML, XGBOOST

Study of Tracking RPC System for Cosmic-Ray Monitoring of Nuclear Reactors

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Abstract:

In the present research, a muon tracking system composed of multi-layer RPCs has been studied for real-time monitoring of nuclear reactors. A 1.4-mm-thick gas-volume single-gap prototype RPC with a two-dimensional readout scheme was constructed with 1.5-mm thick soda-lime glass and 6-mm-pitch readout strips, and tested with cosmic muons and gamma rays emitted from ^{60}Co sources. For the present prototype RPC, the coincident muon efficiency requiring both anode- and cathode-strip responses, measured with a typical tetrafluoroethane (TFE, R134a Freon)-based gas, exceeds 0.95. The position resolution measured by illuminating the gamma rays of the ^{60}Co sources on the present detector through a 6-mm-wide a lead collimator is approximately 3.0 mm, which satisfies the desired angular resolution of about 3 mrad and enables us to inspect a typical nuclear reactor core when the muon tracking system is constructed with eight-layer RPC tracking detectors as predicted in a previous simulation study.

Keywords:

Muon Radiography, Resistive Plate Chambers, Nuclear Reactors

Development of the tracking algorithm of the Beam Drift Chamber (BDC) for LAMPS at RAON

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Abstract:

LAMPS (Large Acceptance Multi-Purpose Spectrometer) at RAON is an experimental system mainly for the nuclear symmetry energy, which is crucial to understand the strong interaction in dense matter such as the core of neutron stars. For LAMPS we have developed the BDC to diagnose the trajectories of the beam particles. In this presentation, we present the development of the track-reconstruction algorithm and its performance.

Keywords:

LAMPS, RAON, Wire Chamber, Track Reconstruction, Beam Drift Chamber

Simulation of active target time projection chamber for LAMPS experiment.

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Abstract:

Active Target Time Project Chamber(AT-TPC) is a novel type of TPC in which the drift gases are used as the target. As the collision happens in the active volume of TPC, tracks of the incident beam and scattered particles can be reconstructed with 4-pi acceptance. To investigate the performance of AT-TPC for the low-energy LAMPS experiment at RAON, we build the full simulation package. The package is constructed based on Geant4 and for the fast simulation, we use a toy Monte Carlo to calculate the electron showers, effective gain. It works as follows: 1. When primary electrons are created by charged particles, the number of ionized electrons is determined using a W value in gases. 2. The transverse and longitude diffusion width in the electric field and the electron amplification coefficient by Gas Electron multiplier(GEM) are determined using toy Monte Carlo. 3. The response of the readout pad is estimated from the number of electrons that fall in the area of each pad. In this process, the effective gain distribution by GEM and diffusion of drifted electrons were calibrated using cosmic muon data. It is expected that this simulation package will facilitate the use of AT-TPC detector for the low energy LAMPS experiment at RAON.

Keywords:

Active Target Time Project Chamber(AT-TPC), Fast simulation, LAMPS experiment

Single-Atom Qubits on a Surface - Pulsed Electron Spin Resonance in an STM

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Abstract:

Recently, the ability to drive electron spin resonance (ESR) of individual atoms using a scanning tunneling microscope (STM) provided a major step forward in sensing and manipulating magnetism at the atomic scale [1, 2]. Combining pulsed ESR with STM allows for the coherent spin rotations of individual atoms on a surface with control at the nanosecond timescale. By modulating the atomically-confined magnetic interaction between the STM tip and surface atoms [3], the large oscillating electric field in the STM junction induces quantum Rabi oscillations between spin-up and spin-down states in as little as ~20 nanoseconds [4]. Ramsey fringes and spin echo signals allow us to understand and improve quantum coherence. I will also show the coherent operations on the coupled-spin states of engineered atomic dimers. Coherent control of spins arranged with atomic precision provides a solid-state platform for quantum simulation of many-body systems.

[1] S. Baumann et al., *Science* **350**, 417 (2015)

[2] T. Choi et al. *Nat. Nanotechnol.* **12**, 420 (2017)

[3] K. Yang et al., *Phys. Rev. Lett.* **122**, 227203 (2019)

[4] K. Yang, et al., *Science* **366**, 509 (2019)

Keywords:

Electron spin resonance (ESR), Scanning tunneling microscope (STM), Pulsed ESR, Rabi oscillation

Free coherent evolution of a coupled atomic spin system initialized by electron scattering

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Abstract:

Full insight into the dynamics of a coupled quantum system depends on the ability to follow the effect of a local excitation in real-time. Here, we trace the free coherent evolution of a pair of coupled atomic spins by means of scanning tunneling microscopy. Rather than using microwave pulses, we use a direct-current pump-probe scheme to detect the local magnetization after a current-induced excitation performed on one of the spins. By making use of magnetic interaction with the probe tip, we are able to tune the relative precession of the spins. We show that only if their Larmor frequencies match, the two spins can entangle, causing angular momentum to be swapped back and forth. These results provide insight into the locality of electron spin scattering and set the stage for controlled migration of a quantum state through an extended spin lattice.

Keywords:

Electron spin resonance (ESR), Scanning tunneling microscope (STM), Pulsed ESR, Rabi oscillation

Double Electron Spin Resonance of Engineered Atomic Structures on a Surface

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Abstract:

Atomic-scale control of multiple spins with individual addressability enables the bottom-up design of functional quantum devices. Tailored nanostructures can be built with atomic precision using scanning tunneling microscopes, but quantum-coherent driving has thus far been limited to a spin in the tunnel junction. Here we show the ability to drive and detect the spin resonance of a remote spin using the electric field from the tip and a single-atom magnet placed nearby. Read-out was achieved via a weakly coupled second spin in the tunnel junction that acted as a quantum sensor. We simultaneously and independently drove the sensor and remote spins by two radio frequency voltages in double resonance experiments, which provides a path to quantum-coherent multi-spin manipulation in customized spin structures on surfaces.

Keywords:

double electron spin resonance, scanning tunneling microscope, quantum sensor, quantum coherent control

Spin sensing with stochastic dynamics in few-atom quantum magnets

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Abstract:

Few-atom nanomagnets can be designed with great precision and a high degree of flexibility using atom manipulation in the scanning tunneling microscope. They exhibit collective quantum states of their magnetic moment that couple to the dissipative electron bath of the substrate they were built on. As such these quantum magnets are noisy and their time evolution exhibits randomness. I will introduce how these stochastic dynamics can be measured using time-resolved scanning tunneling microscopy and how nanomagnets can be designed such that their spin dynamics become particularly sensitive to the interaction with the environment. This increased sensitivity can be used for sensing surface-mediated magnetic interaction [1], non-invasive remote measurements of spin states [2], and to detect the crossover from quantum to classical stochastic dynamics [3].

[1] S. Yan, et al., *Science Adv.* 3, e1603137 (2017).

[2] L. Malavolti, et al., *Nanoscale* 12 11619 (2020).

[3] M. Hänze, et al. *Science Adv.* 7, eabg2616 (2021).

Keywords:

spin dynamics, scanning tunneling microscope (STM), quantum magnets, stochastic resonance

Nano-imaging and microbeam diffraction at the coherent x-ray scattering beamline of PLS-II

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Abstract:

The coherent x-ray scattering beamline of PLS-II is dedicated to nano-imaging techniques based on coherent x-ray diffraction. Hard x-rays generated by an undulator are focused using Kirkpatrick-Baez (KB) mirrors in the beamline. Intense and coherent microbeam made it possible to perform not only coherent x-ray diffraction imaging (CDI), but also in-situ microbeam diffraction experiments. Strain evolution in a single particle of catalytic or battery materials has been studied using Bragg CDI. In addition, structural evolution of functional oxide materials with respect to external stimuli has been explored using microbeam diffraction coupled with a unique probe station chamber. In order to enhance the imaging capability of the beamline, we recently demonstrated hard x-ray nano-scanning transmission x-ray microscopy (STXM) and x-ray fluorescence (XRF), in which absorption contrast and spectroscopic images are acquired simultaneously. In this presentation, details of beamline specifications and representative experimental results will be introduced, and also recent demonstration of hard x-ray nano-STXM/XRF will be briefly summarized.

Keywords:

Coherent x-ray diffraction imaging, Microbeam diffraction, nano-STXM/XRF, Hard x-rays

Phase transition in VO₂ polymorphs studied by X-ray radiation

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Abstract:

Vanadium dioxide (VO₂) exists in several polymorphs. Among these, VO₂ (M1) and VO₂ (B) polymorph are particularly attractive to the researchers across the globe due to their rich physics and potential for various applications. The stabilization of these phases in bulk and thin film form is very much driven by the growth parameters. We prepared VO₂(M1) and VO₂(B) phase thin films by controlling the deposition parameters and studied their phase transition mainly using X-ray radiation. The phase transition of these films were examined by performing the temperature dependent X-ray diffraction measurements and X-ray absorption spectroscopy measurements.

Keywords:

VO₂, phase transition, XRD, XAS

Intermediate phase for highly-oriented MAPbI₃ perovskite in ambient air

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Abstract:

In single-step perovskite fabrication process, which is commonly called anti-solvent process, a state of the as-deposited film after dripping anti-solvent is one of important factor for high quality resulting perovskite film. If an orthogonal solvent with weak interaction to DMSO (such as DE) is used as an anti-solvent, DMSO remains in the as-deposited film. Residual DMSO interferes with the rapid MAPbI₃ crystal structure formation which is caused from the strong interaction between MAI-PbI₂ and induces MAI-PbI₂-DMSO adduct, i.e., intermediate phase state. On the other hand, EA, which quickly extracts DMSO from the anti-solvent dripping process due to its strong interaction with DMSO, has a predominantly MAPbI₃ structure in the as-deposited film. In this work, we induced intermediate phase formation by adjusting anti-solvent ratio to obtain high quality MAPbI₃ perovskite crystal in the regulated ambient air conditions (RH 20-30%). The deposited perovskite layer with the pure intermediate phase via extremely slow crystallization showed higher absorption, fewer grain boundaries, and suppressed defect recombination losses than the fast crystallized perovskite crystals without the intermediate phase formation. We obtained higher stability and high power conversion efficiency of up to 18.56% in a p-i-n-structured MAPbI₃-based perovskite solar cell under ambient air with RH 20%–30%. In addition, we also present the multifunctional film for perovskite PV. The multifunctional film was fabricated using a Cu-assisted chemical etch process and exhibited improved anti-reflective properties and superhydrophobicity. Due to the anti-reflection effect, the power conversion efficiency was increased by about 1.8% by attaching a multifunctional film to the glass.

Keywords:

perovskite PV, synchrotron x-rays, crystal

빛이 페로브스카이트 태양전지 열화를 일으키는가?

방준혁*1

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Abstract:

최근 페로브스카이트 태양전지는 차세대 태양전지로 많은 관심을 모으며, 많은 응용연구가 진행되고 있다. 하지만 이 페로브스카이트 태양전지 응용에 있어 가장 큰 걸림돌 중 하나는 소자의 짧은 수명과 낮은 신뢰성이다. 그 중 빛에 의한 소자 열화가 일어난다는 많은 실험적 보고가 있으나, 이에 대한 메커니즘은 아직 불분명한 상태이다. 본 연구에서는 제일원리 이론 계산을 바탕으로 페로브스카이트 태양전지의 빛에 의한 열화 가능성에 대해서 분석하였다. 기존 실험 연구에서 제안한 빛에 의한 유기물 분해 과정은 실제 이론 계산시 어려운 것으로 확인 되었다. 또 빛이 페로브스카이트 물질의 변성에 미치는 영향이 거의 없는 것으로 확인 되었다. 본 이론 계산을 통해 결함 생성에 의한 페로브스카이트 물질의 열화 과정을 제안하였으며, 이를 기반으로 실험적으로 보고된 열화 현상들을 설명하였다.

Keywords:

페로브스카이트

Nature of electronic correlations in a strongly correlated system

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Abstract:

Strongly correlated systems show interesting physical phenomena including superconductivity, magnetism, and metal-insulator transitions. In order to study the origin and nature of electronic correlations in a strongly correlated system, first-principle calculations including density-functional theory (DFT) and DFT plus dynamical mean-field theory (DFT+DMFT) were performed. In the infinite-layer nickelate, the optical conductivity calculations enable us to identify the origin and nature of electronic correlations. Besides, we found a crossover from Mott to Hund region in the nickelate systems, where Hund's physics is hidden at low energies but noticeable at intermediate energies. This kind of hidden Hund's physics is quite new and thus opening a new research area in the theory of correlated systems.

In the second topic of this talk, we will discuss the methodology of computational correlated material design. The design of correlated materials challenges researchers to combine the maturing, high throughput framework of DFT-based materials design with the rapidly-developing first-principles theory for correlated electron systems. We introduce a material design workflow, and illustrate it via some examples, highlighting the interplay between theory and experiment with a view towards finding new materials. We review the statistical formulation of the errors of currently available methods to estimate formation energies. We formulate an approach for estimating a lower bound for the probability of a new compound to form. Correlation effects have to be considered in all the material design steps. These include bridging between structure and property, obtaining the correct structure, and predicting material stability.

Keywords:

Strongly correlated system, DFT+DMFT, Computational material design

Tensor Network Application to Many-body Physics

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Abstract:

Tensor networks have emerged as a powerful and useful language to describe many-body systems in recent years. The scope of its application covers from the evaluation of the partition function of the classical many-body systems to representing strongly entangled quantum many-body states. One of the most successful applications of the tensor network is the celebrated "density matrix renormalization group", which have been attempted to apply for the first principle calculations and to study the electronic structures. In addition, higher dimensional applications of tensor networks are also successful providing intuitive pictures of the exotic quantum ground states such as the quantum spin liquid in compact and efficient representations. The tensor network has attracted a lot of attention even in the research area of the field theory.

In this talk, I will give a brief introduction to the tensor network in the condensed matter physics. The fundamental ideas behind that will be discussed: why it should work, how efficient it is for many-body systems. Then, if time allows, I will discuss the Kitaev spin liquid in the spin representation which is represented by the tensor network in a compact way.

Keywords:

Tensor Network, DMRG, Entanglement

Nonreciprocal thermal transport realized by spin superfluids

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Abstract:

In chiral magnets with intrinsic inversion-symmetry breaking, it has been predicted that two spin waves propagating along a particular direction and the opposite direction can propagate with different velocities. This novel phenomenon, called magnetochiral nonreciprocity, allows for efficient magnonic logic device applications such as a spin-wave diode. Here we theoretically demonstrate that the spin-wave nonreciprocity can be non-locally induced in easy-cone magnets with no inversion-symmetry breaking. We show that the non-local injection of the spin current into the easy-cone magnet leads to the Doppler shift of the spin wave spectrum on top of a spin superfluid and produces the spin wave nonreciprocity in the bulk. The resultant nonreciprocal thermal transport driven by a temperature gradient, which realized a thermal diode, is discussed as a practical application.

Keywords:

spin superfluid, easy-cone magnet, spin wave

Topological origin of the stability of Flat band in Kagome lattice and that of the Fermi surface of the Kondo lattice.

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Abstract:

The flat band associated with Kagome lattice and Kondo lattice provide a natural ground to play with the strongly correlated system.

We argue that Stability of Flat band in Kagome lattice and that of the Fermi surface of the Kondo lattice have the same origin by using the holographic set up. IN holographic space, there is a topological zero mode localized at the boundary of the holographic space.

Keywords:

flat band, Kagome, Kondo

Ergodicity breaking in flatbands

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Abstract:

Flatbands are dispersionless single particle bands. The quenched kinetic energy (due to the absence of dispersion), makes them promising hosts for unconventional and exotic phases of matter in presence of perturbations, like disorder or interactions. I am going to discuss how the presence of interactions in flat band models can realise several scenarios of ergodicity breaking: many-body localisation and many-body flatband localisation (with connections to percolation transitions), as well as weak ergodicity breaking.

Keywords:

flatbands, ergodicity breaking, localisation

Electric field induced anomalous Hall effects and nematic phases in carrier doped rhombohedral trilayer graphene

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Abstract:

The enhanced density of states near charge neutrality due to the flattening of the bands in ABC trilayers makes this type of multilayer graphene systems prone to form correlated ordered phases in sufficiently clean devices. We show by means of mean-field Hartree-Fock calculations with long-range Coulomb interactions that the energetically favored ground state for ABC trilayer graphene turns from the layer antiferromagnetic phase to the valley polarized anomalous Hall phase upon a small carrier doping and application of a perpendicular electric field, leading to different Hall conductivities depending on the polarization of the valley-spin flavors. The uneven filling of the three electron or hole pockets near the band edges upon carrier doping makes the system prone to form nematic phases with broken rotational symmetry due to momentum space condensation, an exchange driven mechanism that tends to lower the energies of electronic states that are closer together in momentum space. Our result suggests the possibility of switching electrically on and off spontaneous Hall effects at zero magnetic fields and altering the trigonal C_3 rotational symmetry of the carrier doped ground states.

Keywords:

Quantum anomalous valley-spin Hall effects , ABC trilayer graphene, Nematic phases

Causal optimization method for imaginary-time simulation of interacting electron systems

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Abstract:

The causality is a principle that a cause should precede its effects. In imaginary time, this principle leads to constraints for the Green's function. However, such constraints are frequently violated in practical calculations, resulting in noncausal Green's function. In this work, we develop a causal optimization method which ensures causality in numerical calculations of interacting electron systems. We validated our method with an exactly calculable model and practical dynamical mean field calculations. And we find that the causality determines intermediate frequency behaviors of Green's functions and eliminates noncausal statistical errors. Moreover, we show that our method can be generalized to a bosonic and a matrix-valued Green's function. Finally, by using our causal optimization method, we show that the physical branch of the Luttinger-Ward functional can be stabilized by ensuring causality of the noninteracting Green's function. This work was supported by NRF of Korea (Grant No. 2020R1A2C3013673) and KISTI supercomputing center (Project No. KSC-2019-CRE-0195), and the Graduate School of Yonsei University Research Scholarship Grants in 2018.

Keywords:

Green's function, Self energy, Causality, Imaginary time

Hund physics landscape of two-orbital Hubbard models

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Abstract:

Motivated by the recent discovery of superconductivity in infinite-layer nickelates, the role of Hund coupling is investigated in quarter-filled two-orbital Hubbard models which has been on the periphery of the attention. We have identified distinctive regimes including four different correlated metals, one of which stems from the proximity to a Mott insulator while the other three, namely "intermediate" metal, weak Hund's metal, and valence-skipping metal, from the effect of Hund coupling being away from Mottness. Defining criteria characterizing these metals will be suggested. If time permits, I will also briefly discuss implications of our results for infinite-layer nickelates.

Reference:

S. Ryee, M. J. Han, and S. Choi, Phys. Rev. Lett. **126**, 206401 (2021)

Keywords:

Confocal Raman Spectroscopy of Jahn-Teller Plane in LaMnO_3 thin films on a (110)-oriented GdScO_3 Substrate

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Abstract:

Jahn-Teller (JT) distortion plays a significant role to determine physical properties in complex oxides. In this work, we investigate the symmetry analysis of JT-originated phonon modes in LaMnO_3 (LMO) film grown on a (110)-oriented GdScO_3 (GSO) substrate via confocal Raman spectroscopy. We deposited a 55-nm thick epitaxial thin film and an ultrathin film of LMO using pulsed laser deposition. Based on the lattice dynamic calculation, the phonon with B_{2g} (A_g) symmetry near $\sim 610 \text{ cm}^{-1}$ ($\sim 490 \text{ cm}^{-1}$) corresponds to the (anti-)symmetric stretching of basal oxygens of the MnO_6 . According to the symmetry analysis of the Raman spectra, we conclude that the orientation of JT plane of LMO is parallel to the GSO substrate for the thick LMO and ultrathin film LMO. Our finding offers a base for understanding the interplay of cooperative JT distortion and magnetism in the ultrathin regime.

Keywords:

Lanthanum Manganite Oxide (LMO), Jahn-Teller Distorsion, Raman Spectroscopy

Possible Raman single-magnon scattering mechanism in the spin-orbital entangled system

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Abstract:

Electric-dipole transition on a pure spin configuration has been well-known as the origin of magnetic excitations in Raman spectra. Based on this configuration, the two-magnon scattering mechanism has long been a reasonable explanation for many of the Raman magnon scattering signals. However, recent Raman studies obtained single-magnon scattering signals on the iridates and ruthenates. And additional RIXS measurements supported these results.

In this study, we propose a possible mechanism of the Raman single-magnon scattering based on the pseudospin configuration. Because of the strong spin-orbit coupling that entangles the spin and orbital states in iridates and ruthenates, the electric-dipole transition can flip the pseudospin directions without violating the selection rule. In addition, we suggest experimental evidence of Raman single-magnon scattering for the pseudospin configuration in the case of pyrochlore iridates.

Keywords:

single-magnon scattering, pyrochlore iridate, strong spin-orbit coupling, pseudospin

Single atom spin resonance on a surface in a home-built scanning tunneling microscope

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Abstract:

Scanning tunneling microscopy is a powerful tool to characterize the electronic and magnetic properties of atomic structures on a surface. Recent advances in increasing spectroscopic energy resolutions have been achieved functionalizing the STM tip by a well-characterized molecule [1,2] or integrating electron spin resonance with STM (ESR-STM) [3]. We present the design and performance of home-built STM with high frequency cabling, which is incorporated with a Joule-Thomson refrigerator and 2-axes vector magnets. While ESR-STM in the early-design applied the radiofrequency (RF) voltages to the tunnel junction using the STM tip, we introduced an RF antenna to maximize the transmissions of RF voltages to the junction. Applying the RF voltages using the antenna terminated at 50 Ohm reduces the formation of standing waves and enables us to apply RF power in a larger frequency range (5—40 GHz). Considering many of STM operate at 2-4 Kelvin temperature, around 2 T of external magnetic field is required for the polarization of surface spins and, thus, RF powers in the frequency range of 30-40 GHz should be available at the STM junction. Our new design of ESR-STM using the additional antenna enables for the ESR-STM measurement at higher temperature and for the simple modification of the existing STM system, which accelerates a generalized use of ESR-STM.

[1] M. Ormaza et al., *Nano let.* **17**, 1877-1882 (2017)

[2] G. Czap et al., *Science*, **364**, 670-673 (2019)

[3] S. Baumann et al., *Science*, **350**, 417-420 (2015)

Keywords:

Electron spin resonance-scanning tunneling microscope, ESR-STM, Scanning tunneling microscopy, Scanning tunneling spectroscopy, Radiofrequency antenna

Characterization of magnetic interactions using a single atomic sensor in a tunnel junction

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Abstract:

Single spins are widely regarded as a leading candidate for realizing next-generation quantum devices for sensing and quantum processing. In order to detect and coherently control single spins, it is crucial to localize single spins and characterize the interactions with its surroundings. Scanning tunneling microscopy (STM) in combination with electron spin resonance (ESR) technique [1] enables a direct access to the quantum states of single magnetic atoms or molecules on surfaces. We investigate ESR of hydrogenated Ti (TiH) atoms adsorbed on bridge binding site of MgO while rotating a two-dimensional vector magnetic field. Spin-1/2 TiH atoms with no magnetic anisotropy are utilized as a probe to identify magnetic surroundings in the tunnel junction of STM. We found significant changes of ESR amplitude as a function of the direction of magnetic fields. The evolution of ESR amplitudes in rotating magnetic fields reveals the interplay of ESR detection and ESR driving strength, which is determined by the spin-polarization of the tip and the magnetic interaction between the magnetic tip and TiH. We also confirmed a remarkable degree of reproducibility of the basic features of the magnetic field angle dependence of ESR signals for different tips and different Ti atoms. Our results will enable predictions of novel ESR active spin centers on different substrates as well as in other quantum-nanoscience platforms.

[1] Susanne Baumann et al., Electron paramagnetic resonance of individual atoms on a surface, *Science*, 350, 6259, 417-420 (2015)

Keywords:

Scanning Tunneling Microscopy, Electron Spin Resonance, ESR-STM, Single spin sensing

Evidence for quantum critical charge delocalization in the unconventional superconductor CeRhIn5

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Abstract:

Quantum criticality arises when a continuous phase transition is driven to absolute zero temperature by a non-thermal parameter. Recent studies in antiferromagnetic heavy-fermion compounds have revealed that different types of quantum phase transitions are induced by tuning hybridization, carrier density or magnetic frustration. CeRhIn5 is considered as the candidate heavy fermion superconductor with Kondo breakdown type quantum criticality, where the Kondo destruction energy scale (TL) that characterizes the delocalization of the local moments is suppressed to zero Kelvin at the AFM quantum critical point. Here, we report a systematic investigation of the transport properties of both pure and Sn-doped CeRhIn5 under pressure. Our results suggest that the nature of unconventional Kondo-destruction quantum criticality in CeRhIn5 is transformed to a conventional spin-density-wave type by slight Sn substitution.

Keywords:

Quantum phase transition, Heavy fermion, Kondo destruction quantum criticality, Spin density wave quantum criticality, Charge delocalization

Topological Superconductivity and Majorana fermions in doped Dirac semimetals under lattice distortions

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Abstract:

In recent years, the search for topological superconductors (TSCs) has been an exciting topic in condensed matter physics. The TSCs have a full pairing gap in the bulk and gapless surface states consisting of Majorana fermions. The TSC is of great importance, as it is not only a new kind of exotic superconductor but also one source of Majorana fermions for future applications in quantum computations. Recently, unconventional superconductivity having a zero-bias conductance peak is reported in doped topological Dirac semimetal (DSM) with lattice distortion. Motivated by the experiments, we theoretically study the possible symmetry-lowering lattice distortions and their effects on the emergence of unconventional superconductivity in doped topological DSM. We find four types of symmetry-lowering lattice distortions that reproduce the crystal symmetries relevant to experiments from the group-theoretical analysis. Considering inter-orbital and intra-orbital electron density-density interactions, we calculate superconducting phase diagrams. We find that the lattice distortions can induce unconventional superconductivity hosting gapless surface Andreev bound states (SABS). Depending on the lattice distortions and superconducting pairing interactions, the unconventional inversion-odd-parity superconductivity can be either topological nodal superconductivity hosting a flat SABS or topological crystalline superconductivity hosting a gapless SABS. Remarkably, the lattice distortions increase the superconducting critical temperature, which is consistent with the experiments. Our work opens a pathway to explore and control pressure-induced topological superconductivity in doped topological semimetals.

Keywords:

Topological superconductivity, Majorana fermion, Lattice distortion, Andreev bound state

Giant Thermoelectric Seebeck Coefficients in Tellurium Quantum Wires Formed Vertically in Aluminum Oxide Layer by Electrical Breakdown

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Abstract:

High efficiency thermoelectric (TE) materials still require high thermopower for energy harvesting applications. A simple elemental metallic semiconductor, tellurium (Te), has been considered critical to realize highly efficient TE conversion due to having large effective band valley degeneracy. This paper demonstrates a novel approach to directly probe out-of-plane Seebeck coefficient for one-dimensional Te quantum wires (QWs) formed locally in the aluminum oxide layer by well-controlled electrical breakdown at 300 K. Surprisingly, the out-of-plane Seebeck coefficient for these Te QWs ≈ 0.8 mV/K at 300 K. This thermopower enhancement for Te QWs is due to Te intrinsic nested band structure and enhanced energy filtering at Te/AO interfaces. Theoretical calculations support the enhanced high Seebeck coefficient for elemental Te QWs in the oxide layer. The local-probed observation and detecting methodology used here offers a novel route to designing enhanced thermoelectric materials and devices in the future.

Keywords:

1D quantum wire, Seebeck coefficients, Electrical breakdown, Conducting filament

Layer pseudospin magnetism and Berry curvatures in ABC trilayer graphene

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Abstract:

Layer pseudospin magnetism and Berry curvatures in ABC-trilayer graphene is a subject of ongoing research where layer polarization of charge carriers is associated with the opening of a band gap and with the generation of spin-valley flavor resolved Hall effects, where Coulomb interaction effects are relatively enhanced with respect to bilayer graphene thanks to the flattening of bands in rhombohedrally stacked graphene multilayers. We show by means of Hartree-Fock calculations the possibility of achieving different closely competing spontaneous Hall effects due to the finite Berry curvatures generated near the band edges when a gap is present. Carrier doping in the presence of a perpendicular electric field leads to spontaneous valley polarization thanks to momentum space exchange condensation, which is often accompanied by the appearance of nematic phases. Furthermore, we show how a moire pattern produced by an aligned hexagonal boron nitride substrate allows the generation of topological isolated bands whose bandwidths can be tuned by an external electric field.

Keywords:

Pseudospin magnetism, graphene, moire pattern, ABC trilayer graphene

Magnetic properties unique to van der Waals magnetic materials

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Abstract:

The discovery of intrinsic magnetism in thin exfoliated van der Waals (vdW) magnetic materials has led to extensive investigation on its fundamental material properties and potential device applications. The layered structures, well-defined interfaces, and weak interlayer coupling of vdW magnets suggest that these are ideal material systems to study two-dimensional (2D) magnetic properties. Despite the promise on providing unique opportunities to study 2D magnetic phenomena, there has been a lack of reports on properties unique to vdW magnets that truly distinguish them from ultrathin epitaxial magnetic films (e.g. Co, Ni, Fe), the historical material-of-choice for investigating low-dimensional magnetism.

In this work, we report a magnetic characteristic unique to vdW magnetic materials. We thereby provide very strong evidence that magnetic properties of vdW magnetic materials could be fundamentally different from conventional magnetic materials. An exchange bias effect is observed in a naturally oxidized vdW ferromagnet Fe₃GeTe₂, owing to the emergence of antiferromagnetic ordering in the surface oxide layer [1]. Surprisingly, the magnitude and thickness dependence of the exchange bias effect is considerably different from those expected in conventional magnetic thin films. Using macro-spin and analytical calculations based on textbook energy equations, we find that these observations are the consequence of the weak interlayer magnetic exchange interaction (J_{inter}) inherent to vdW magnets. Our "weak J_{inter} model" proposes a new exchange bias mechanism exclusive to vdW magnets, demonstrating unique magnetic energetics of these materials [1].

References

[1] H. K. Gweon et al., *Nano Lett.* 21, 1672-1678 (2021).

Keywords:

van der Waals magnetic materials, exchange bias, interlayer coupling

Simulation web platforms from the view point of research industry

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Abstract:

New research equipment and methods that improve time-efficiency and reduce difficulty of using have a wide impact, even if it does not provide new functionality that was not available previously, and require continuous development. In particular, in Korea, it is clear that the number of new researchers will decrease rapidly due to the low birth rate, thus it is necessary to raise labor efficiency in the research field to maintain national research competitiveness. From this view point of research industry, there is a problem that materials simulations are still used only by some specialized research teams although it is more widely used in engineering and industry than before. In addition, material simulations are still labor-intensive even to simulation experts. A web platform can be an alternative to solving this problem by providing computing resources and all necessary software at once. If it is typical research problem that methods and procedure are well-established, even undergraduate students can perform professional simulations on the web platform without the help from experts, so simulations can be easily and widely used from education to industrial research. To the simulation experts, it allows to focus on the purpose of the study by reducing the time-consuming and meaningless procedure, such as building material model, typing many commands, transferring data and post-processing. Newly developed formalisms and methods can be applied to the platform so that they can be spread quickly, and the developers can be compensated appropriately. Web platforms have a potential to build the simulation echo system that method developers, general users from academy and industry, simulation industries all participate; it can support developers, provide convenience to users, validate methods and help to commercialize them.

Keywords:

web platform; research industry; time-efficiency

An Introduction to ChemAI: Platform for Data-Driven Material Chemistry Research

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Abstract:

Machine learning (ML) has been applied to various materials research fields and achieved great results because it allows us to predict important material properties for a variety of materials rapidly. This trend has been promoted the construction of a vast material database and has influenced a positive impact on various fields of material research, such as the development of algorithms for more sophisticated predictions, optimization of experimental conditions, or material screening through it. However, these studies are mainly carried out by code-based studies of specific material-research groups. To promote material development through artificial intelligence, various material researchers should be able to create predictive models with high accuracy through simple manipulations from their own databases. ChemAI is a platform for data-driven materials research to support users to build their own predictive models with their own datasets and provides various types of toolkits implemented by advanced deep learning models. In particular, ChemAI can predict structure-based properties using material structure information such as CIF or SMILES. All ML tasks are conducted under a web-based environment, and a user interface environment has been built so that even researchers with little experience in code development can freely use them. In this presentation, I would like to introduce the main functions provided by ChemAI. We expect that ChemAI will serve as a catalyst for many researchers in the field of material chemistry to conduct advanced material research through ML.

Keywords:

Machine learning, Platform, Material Chemistry Research, ChemAI, Toolkit

Designs of semiconductor-based quantum logic gates and programmable circuits

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Abstract:

Quantum computers, processing the logic information with a sequence of the quantum bit (qubit), have obtained keen attention due to their strong potential for efficient tackling of some large-scale problems that would be in principle hard to be done with traditional high-performance computers. Silicon (Si), a well-known semiconductor material, has been regarded as a great material candidate for designs of universal quantum gates due to the feasibility to achieve extremely long coherence time. In this talk, we discuss a computing-efficient modeling approach that can be used for predesigns of quantum logic gates & circuits based on electrode-driven Si quantum dot (QD) platform, and introduce some of ongoing research works with a focus on designs of cost-efficient basic universal quantum logic gates and programmable quantum circuits (quantum processors).

Keywords:

Computational Nanoelectronics, Simulations of Semiconductor Electronic Device, Multi-scale Modeling Approach, Silicon-based Quantum Processor

세라믹 소재 및 공정에서의 다중스케일-다중물리 시뮬레이션 그리고 디지털 전환 전략

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Abstract:

전산재료과학을 비롯한 계산과학의 발전은 여러 산업분야에서 큰 파급력을 불러왔고, 각 산업분야의 디지털 전환을 가속화하고 있다. 하지만 세라믹 소재와 그를 활용한 부품, 장비 산업은 아직 시뮬레이션과 같은 방법론이 아직은 널리 활용되고 있지 않다. 이는 세라믹 소재에서 일어나는 현상들이 전자단위, 원자단위, 그레인 단위, 도메인 단위, 형상 단위 등 다중스케일에 걸쳐 일어나는 현상들이 많고, 관련된 공정 또한 열, 유동, 화학, 구조, 전자기 등 다양한 물리현상들이 복합적으로 상호작용하기 때문에 복잡한 모델링을 피할 수 없기 때문이다. 이로 인해 세라믹 소재에 대한 시뮬레이션은 다중스케일, 다중물리현상에 대한 고려가 필요한 경우가 많다.

예를 들어 확산공정을 이용하여 세라믹 압전소재를 합성하게 될 경우, 이 확산공정 때문에 조성에 대한 농도 구배가 발생하게고, 또 이러한 농도 구배가 소재의 압전물성에 영향을 주는 동시에, 응력-변형에도 영향을 미쳐 최종적으로 측정되는 특성에 영향을 미치게 된다. 이와 같은 문제를 시뮬레이션을 통해 풀기 위해서는 조성변화에 따른 제일원리계산을 활용한 압전 물성, 기계적 물성 계산 외에도 연속체 단위에서의 확산방정식, 구조역학 방정식 등이 유기적으로 연결되어야 한다. 이와 같이 다중스케일-다중물리 시뮬레이션을 통해 보다 현실적인 세라믹 소재 및 공정에 대한 기술이 가능하며 이를 통해 산업계 문제를 푸는데 활용할 수 있다.

하지만 이와 같은 다중스케일-다중물리 시뮬레이션도 세라믹 소재 분야에서 일부의 문제만 해결할 수 있을 뿐이다. 왜냐하면 실제로 산업계에서 활용되는 많은 세라믹 소재 공정 중에 오직 일부만이 이론적인 지배방정식이 개발되었을 뿐이며, 실제로 세라믹 공정은 4M1E (Machine, Method, Man, Material, Environment)와 같은 생산변수에도 많은 영향을 받기 때문이다. 이런 문제에 대해서 시뮬레이션 방법은 매우 제한된 영역에서의 해답만 줄 수 있을 뿐이기 때문에, 실험데이터를 축적하여 기계학습을 통해 해석하는 것이 일반적이다. 하지만, 기계학습을 원활히 적용할 수 있을 정도로 충분한 실험데이터를 축적하는 것은 쉬운 일이 아니기 때문에 불완전하지만 시뮬레이션 데이터를 함께 활용하는 것이 보다 현실적인 방법이다.

본 발표에서는 다중스케일-다중물리 시뮬레이션을 활용하여 세라믹 분야에서의 기초과학 문제를 해결하고 산업체를 지원하기 위한 전략과 그 성공사례를 소개하고, 더 나아가 시뮬레이션 방법을 기계학습에 효과적으로 적용하기 위한 방안에 대해 논의하고자 한다.

Keywords:

제일원리계산, 유한요소해석, 제조지능화, 멀티스케일 시뮬레이션, 멀티피직스 시뮬레이션

Progress of blade trap-based Yb⁺ qubit experiment

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Abstract:

Quantum computers are expected to be more efficient in solving certain problems than conventional computers since one can utilize quantum properties for computation. Ion trap-based architecture, which is one of the various methodologies for implementing quantum computers, has the advantages of having longer qubit coherent time and high quantum gate fidelity compared to other systems. In order to levitate ions in space, RF and DC are applied to each of the four blade-type electrodes to create a pseudo-potential and two additional rods are used to compensate the difference of null lines between RF and DC potentials. We discuss these processes through COMSOL simulation to understand how the pseudo-potential is formed at the actual trap scale, how the principal axis can be rotated by controlling the RF and DC voltages, and how to match the null lines using the compensation rods in order to minimize micromotion of the trapped ions. Based on the simulation results, we plan to trap Yb⁺ ions and to perform quantum gates in blade-trap architecture. We acknowledge the financial supports from Samsung Science & Technology foundation - SRFC-IT1901-09 and National Research Foundation of Korea - 2019R1A4A1029052 and 2021M3E4A1038534 and the collaboration with Prof. Taehyun Kim for uses of the COMSOL software.

Keywords:

trapped ion, pseudo-potential, COMSOL simulation

Fundamental thresholds of realistic quantum error correction circuits for 1-D repetition code from statistical physics

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Abstract:

Through mapping the decoding of quantum error correction codes to disordered classical statistical mechanics models, we study the critical error thresholds of QEC codes under phenomenological noise models. In this work, we extend the mapping from the well-known simple quantum error models to realistic, multi-parameter noise models of faulty QEC circuits, and study phase diagram of the models by Monte Carlo method, and then compare our results with minimum-weight perfect matching decoder. We argue that the presented method provides a way to assess fundamental thresholds of QEC circuits and can help the development of near-term QEC hardware.

Keywords:

quantum error correction, Monte Carlo simulation, statistical mechanics model, 1-d repetition code, threshold probability

Polarized-Raman scattering study of methylammonium ion orientation in hybrid halide perovskite $\text{CH}_3\text{NH}_3\text{PbCl}_3$ single crystals

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Abstract:

For increasing the efficiency and attaining better chemical stability, intense research activities on hybrid organic-inorganic perovskites (HOIPs) have been performed over the last few years. There are some unresolved issues in properties of HOIPs such as relation between the configuration of methylammonium (MA) ions and electronic/structural properties. For example, it is theoretically suggested that bandgap change from direct to indirect and/or structural distortion can be caused by orientational change of the MA ions with respect to the PbX_3 cage in $\text{CH}_3\text{NH}_3\text{PbX}_3$ ($\text{X}=\text{I}, \text{Br}$ or Cl). By using polarized Raman scattering spectroscopy, we experimentally show that the MA ions in $\text{CH}_3\text{NH}_3\text{PbCl}_3$ single crystals are oriented towards a special crystallographic direction in the low temperature orthorhombic phase at least in our measurement scale of $\sim\text{mm}^2$. Our results are completely consistent with the DFT calculations that predict the existence of macroscopic domain consists of a parallel arrangement of the MA ions

Keywords:

Perovskite, Polarized-Raman, MA orientation, structural property, $\text{CH}_3\text{NH}_3\text{PbCl}_3$

Complex spatial light modulators based on symmetry of birefringence materials configuration

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Abstract:

고급 광학 및 신호 시스템은 공간 상에서 위상 및 진폭의 전기적 제어가 필요하며, 이를 위한 장치가 공간 광 변조기다. 일반적인 공간 광 변조기는 진폭 혹은 위상만을 제어하거나, 복소 공간의 일부 영역에서만 복소 진폭 (진폭과 위상)의 제어가 가능하며, 제한적이다.

복소 공간 전 영역에서 복소 진폭을 조절하기 위해서는 다수의 공간 광 변조기를 이용하거나 다수의 화소를 이용한 일종의 super-pixel을 이용하는 것이 일반적이며, 메타 물질을 이용한 일부 공간 광 변조기의 경우 단일 화소로 복소 공간 전 영역에서 복소 진폭의 제어가 가능하지만, 특정 파장에서만 구동하며, 에너지 효율 또한 매우 낮다.

본 연구는 단축 복굴절 물질의 대칭성을 이용하여 일반화된 공간광 변조기의 구조와 조건을 제시한다. 본 구조는 다양한 파장 영역과 물질에 적용이 가능한 일반화된 구조로, 단일 화소로 복소 공간 전 영역의 제어를 특징으로 하며, 구조 제약이 적어 상대적으로 높은 에너지 효율을 기대한다.

본 연구의 구조는 홀로그램, VR, AR, 자율주행, 생의학, 광통신 등 다양한 광, 양자 실험 및 시스템에 큰 역할을 할 것으로 보인다.

Keywords:

Spatial Light Modulators, Complex SLM, Birefringence, Liquid Crystal Display

Highly efficient photonic crystal phosphor structure with high index contrast and flat surface

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Abstract:

백색LED 구성에 있어 형광체는 청색LED와 함께 매우 중요한 역할을 담당하고 있다. 본 연구진은 그동안 광자결정 구조를 형광체 물질에 접목함으로써 형광체의 색변환 효율을 획기적으로 향상시킬 수 있는 구조 공학적 방법을 제안 및 시연하였을 뿐만 아니라 이를 지속적으로 발전시켜 왔다. 본 연구에서는 지금까지 개발된 광자결정 형광체의 성능을 진일보시키기 위해 두 가지 개선을 시도하였다. 하나는 광자결정 구조를 구성하는 골격 물질을 기존 Si_3N_4 에서 굴절률이 더 높은 TiO_2 로 교체한 것이며, 또 하나는 형광물질로 사용한 콜로이드 양자점을 도포한 후 이를 표면 평탄화 하기 위한 추가 공정을 도입한 것이다. 시뮬레이션을 통해 이러한 두 가지 개선책이 광자결정 형광체의 효율을 크게 향상시킬 수 있음을 확인하였다. 이를 실험적으로 구현 및 확인하기 위해 레이저 인터피어런스 리쓰그리피와 반응이온식각 방법을 사용하여 TiO_2 골격층에 2차원 정사각 격자 구조의 구멍 어레이를 형성하였다. 이어 콜로이드 양자점을 도포한 후 부드러운 스퀴지를 이용한 쓸어내기 공정으로 표면 평탄화를 이루었다. 이렇게 완성된 광자결정 형광체의 특성을 조사한 결과, 기존 광자결정 형광체에 비해 광변환 효율이 2배 이상 향상됨을 확인하였다.

Keywords:

Phosphor, Photonic crystal, Photonic band-edge, Colloidal quantum dot, flatten

주기열파법을 이용한 이방성 광학결정의 열확산도 측정

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Abstract:

물체의 온도분포가 균일하지 않아 물체 내부에서 열이 전달되는 현상을 열확산이라고 하며, 열확산도는 재료의 물리적 특성 중 하나인 열적 특성 중 하나이다. 열확산도를 측정하는 방법은 크게 섬광법과 열파법으로 나뉜다. 섬광법은 순간적인 빛을 재료에 조사하여 열확산도를 측정하는 방법이며, 열확산도 측정에 널리 사용되는 방법이지만, 재료의 두께에 따라 수십 ns 이하의 펄스레이저를 사용해야 하기에 고가의 장비가 필요하며, 재료가 투명할 경우에는 빛의 흡수를 위해 흡수코팅을 해야 하기에 별도의 공정요소가 추가된다. 열파법은 열에 의해 재료의 굴절률이 달라지는 현상을 이용한 방법으로, 재료에 인가되는 열파와 재료를 통과하는 광파의 시간지연을 측정하여 열확산도를 구하는 방법이다. 열파법을 이용한 열확산도 측정은 상대적으로 저가인 CW레이저 사용 및 재료의 추가공정이 필요없다는 장점이 있다.

광학결정은 특징에 따라 결정의 모든 방향에 대해 동일한 특성을 보이는 등방성과 결정의 방향에 따라 특성의 차이가 나타나는 이방성으로 나뉜다. 이방성 광학결정은 빛의 편광성을 이용하여 광통신, 극미소 관찰, 레이저 위상매칭 등의 분야에서 널리 사용되고 있는 물질이다.

본 연구에서는 열파법을 이용하여 이방적 광학결정인 Potassium Dihydrogen Phosphate(KDP), Ammonium Dihydrogen Phosphate(ADP)의 열확산도를 측정하였다. 온도에 따른 KDP, ADP의 열확산도를 측정하기 위해 상온~80 °C의 온도범위에서 측정하였으며, KDP, ADP 결정의 이방적 광학특성을 관찰하기 위해 (100), (010), (001) 면으로 레이저를 조사한 후 각 면에서 측정된 열확산도 값을 비교하였다.

Keywords:

Thermal wave technique, Anisotropy crystal, Thermal diffusivity

FCOC 단위 셀 메타 표면에 의한 음파의 진행 방향 전환

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Abstract:

FCOC(Face centered orifice cubic) 단위 셀은 단위 셀의 부피와 오리피스의 직경을 변화시킴으로써 음파에 대한 음향 굴절률 값을 변화시킬 수 있다. 만일 인접된 FCOC 단위 셀의 음향 굴절률 값을 일정한 값만큼 달리하여 입사 방향에 수직하게 연속적으로 배열시키게 되면, 인접된 단위 셀에 입사되어 통과되는 음향파의 위상 차이가 일정한 값을 가지며 그 값이 0에서 2π 까지 변화하는 한 개의 주기 셀을 구성할 수 있다. 이 같은 주기 셀을 연속적으로 배열하게 되면 마치 광학에서의 회절 발과 같은 효과를 줄 수 있다. 우리는 FCOC 단위 셀을 이용하여 이 같은 효과를 갖는 메타 표면을 설계하였으며 여기에 일반화된 스넬의 법칙을 적용하여 가능한 방향 전환 정도를 살펴보았다. 또한 이 메타 표면에 대한 전산 시뮬을 수행함으로써 설계된 메타 표면이 입사되는 음향 파의 진행 방향을 바꿀 수 있음을 확인하였으며 그 방향 전환 각은 FCOC 단위 셀로 이루어진 주기 셀의 기하학적 크기에 관련됨을 확인할 수 있었다.

Keywords:

acoustic metamaterial , acoustic metasurface, Redirection of acoustic waves, acoustic grating, generalized snell's law

Complex interplay between socio-spatial components of cities

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Abstract:

With rapid urbanization, cities have pushed the boundaries of human productivity, innovation, and success, while becoming more complex. The science of urban complexity has successfully explained many nontrivial regularities in urban systems with a framework of interactions. Yet, the nature of urban phenomena spanning multiple social components, such as social relations, politics, economy, mobility, technology, and environment, makes it difficult to understand such phenomena. Here I present a conceptual framework of the interplay between socio-spatial components of cities and explain several key phenomena in cities with this framework. These phenomena include the evolution of urban economies, dynamics on socio-political networks, general patterns of urban mobility, and the interplay of health and urban environments. More precisely, the universal pathway of urban economies is explained by urban scaling, social mobilization and protests are modeled by socio-political and spatial networks, urban mobility is described by the gravity and radiation models, and happiness of people is related to urban green space. These findings shed light on the increasing demand for studies to encompass several different regularities and universal laws in cities.

Keywords:

urban complexity, social components, urban dynamics

Social norms in indirect reciprocity with ternary reputations

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Abstract:

Indirect reciprocity is one of the fundamental mechanisms that promotes cooperative behavior among self-interested individuals by means of reputation when cooperative behaviour benefits the society at an individual cost. Most of the previous studies have assumed that reputation is either good or bad, but such a binary-reputation system is a crude approximation to reality. In this work, we add another reputation called 'neutral' and fully identify ternary norms that achieve cooperation and possess evolutionary stability against behavioural mutants. Comparison with the results from the binary-reputation system suggests universal features of successful norms, that is, maintenance of cooperation by the majority, identification of defectors to punish them, justification of the punishment, and apology with forgiveness.

Keywords:

Indirect reciprocity, Reputation dynamics, Leading eight

Symmetric Nash equilibrium of political polarization in a two-party system

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Abstract:

The median-voter hypothesis (MVH) predicts convergence of two party platforms across a one-dimensional political spectrum during majoritarian elections. From the viewpoint of the MVH, an explanation of polarization is that each election has a different median voter so that a party cannot please all the median voters at the same time. We consider two parties competing to win voters along a one-dimensional axis and assume that each party nominates one out of two candidates in the primary election, for which the electorates represent only one side of the whole population. We argue that all the four candidates will come to the same distance from the median of the total population by calculating the best responses.

Keywords:

polarization, median-voter hypothesis, best-response dynamics

Does revisit help target search on complex networks?

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Abstract:

Exploitation is ubiquitous in various exploration processes, e.g., animal foraging, innovation, web surfing, etc. To reveal the benefit of these behaviors, we study random walk with stochastic revisit on complex networks. We investigate cover times for several synthetic networks analytically and for a large and diverse set of 550 real-world networks by simulations. Counterintuitively, stochastic revisit can reduce the cover time in many networks. Building on the finding that the lollipop network has the greatest benefit of revisit, we define *lollipop-likeness* and explain the benefits of stochastic revisit by the lollipop-likeness.

Keywords:

Random Target Search, Stochastic Revisit, Complex Networks

Hypergraph model with higher-order connectivity between hyperedges

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Abstract:

Hypergraphs are the generalization of networks. The networks can only deal with pair-wise interaction, but the hypergraphs can handle the interaction of multiple nodes. There are two kinds of higher-order interactions in the hypergraphs. The first is the interaction of multiple nodes within one hyperedge, and the second is the interaction between hyperedges. Most hypergraph researches hitherto have been focused on understanding the first interaction. However, in various real-world hypergraphs, the higher-order connectivity between hyperedges is commonly observed. Therefore, in this study, as a first step in understanding the higher-order connectivity between hyperedges, we propose a new hypergraph model in which higher-order connectivity substantially exists. In the model, there are N nodes, H hyperedges, and G groups. We define the size of the group as the number of nodes that belong to the group. The size of each group could follow diverse probability distribution, like Poisson, power-law, or delta distribution. Each group contains random nodes according to their size. Each step, a randomly chosen node (group) among N nodes (G groups) is included in a randomly chosen hyperedge with probability $1-p$ (p). When the mean degree reaches the desired value, the process is terminated. We define s -connectivity as connectivity between two hyperedges which have s common nodes, and s -component is a component that is connected only through s - or higher connectivities. The giant- s -component can be calculated by series of self-consistence equations in the model. We anticipate that this model provides a framework to understand higher-order connectivity between hyperedges on hypergraphs.

Keywords:

Hypergraph, Higher-order interaction, Higher-order connectivity, Higher-order component

Analytical approach to the generalized friendship paradox in networks with correlated attributes

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Abstract:

One of the interesting phenomena due to the topological heterogeneities in complex networks is the friendship paradox, stating that your friends have on average more friends than you do. Recently, this paradox has been generalized for arbitrary nodal attributes, called a generalized friendship paradox (GFP). In this paper, we analyze the GFP for the networks in which the attributes of neighboring nodes are correlated with each other. The correlation structure between attributes of neighboring nodes is modeled by the Farlie-Gumbel-Morgenstern copula, enabling us to derive approximate analytical solutions of the GFP for three kinds of methods summarizing the neighborhood of the focal node, i.e., mean-based, median-based, and fraction-based methods. The analytical solutions are comparable to simulation results, while some systematic deviations between them might be attributed to the higher-order correlations between nodal attributes. These results help us get deeper insight into how various summarization methods as well as the correlation structure of nodal attributes affect the GFP behavior, hence better understand various related phenomena in complex networks.

Keywords:

generalized friendship paradox, complex networks, copula

코로나19 확산 예측의 문제점: 향후 유효 감염재생산지수 시나리오 설정

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Abstract:

코로나19 유행 장기화에 따른 공중보건 위기 상황에서, 향후 감염 확산 예측에 대한 요구가 높아지고 있다. 특히, 코로나19 확산 예측은 향후 발생 가능한 중환자 규모에 대비하여 병상을 미리 준비하거나 또는 가용 병상 이하로 신규 중환자 규모를 감소시키기 위한 방역 정책 수립 등에 이용되고 있다. 코로나19 향후 확산 예측을 위해서는 국내 발생 가능한 유효 감염재생산지수 시나리오 설정이 필요한데, 현재까지 국내 유효 감염재생산지수 시계열 결과를 바탕으로 향후 시나리오를 설정하게 된다. 이 연구를 통해, 향후 유효 감염재생산지수 시나리오 설정과 관련한 다양한 방법들을 적용하고, 국내 코로나19 확진 자료를 이용한 후향적(retrospective) 연구를 통해 각 시나리오 설정 방법들의 장단점에 대하여 정성적, 정량적으로 분석하였다.

Keywords:

감염병 확산 예측, 유효 감염재생산지수, particle filtering

Generalization of bibliographic coupling and co-citation using node split network.

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Abstract:

Bibliographic coupling and co-citation are the two most common citation-based coupling similarities between scientific items, e.g. papers and patents, which can be interpreted as the strength of relatedness in citation network on second neighbor relations by the direction of citations. A bibliographic coupling is a similarity between two citing items, whereas co-citation is those between two cited items; thus, it can be interpreted as a two-layer network as proposed in our previous research. One can emulate clusters with the node split network, yet it is impossible to yield coupling similarities directly because there is no intra-layer link between items. Here, we propose two different methods that can estimate intra-layer similarity using the structure of the node split network: i) personalized PageRank (PPR) and ii) node2vec embedding (EMB). First, we demonstrated proposed measures are highly correlated with the target coupling measures. Our proposed method can yield the exact similarity between items, even if they are not neighbors in the original coupling networks. We also observe the missing links in the target coupling network that show strong relations in the node split network, which suggests that it is essential to consider the long-range similarity for the coupling measures. We also perform comparative tests on global and local sampling strategies, which can conclude a local sampling is stable for both PPRs and EMBs. This analysis offers valuable insights into how we retrieve strongly related items regarding the perspective of each coupling measure.

Keywords:

citation network, bibliographic coupling, co-citation, personalized page rank, node2vec

In vivo photoacoustic imaging and applications

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Abstract:

Three-dimensional & high-resolution optical imaging techniques including confocal microscopy (CFM), multi-photon microscopy (MPM), and optical coherence tomography (OCT) became an essential tool in biomedical and life science studies. Unfortunately, because of unavoidable photon scattering (e.g., the one optical transport mean free path: ~ 1 mm) in biological tissues, it is difficult to maintain a high spatial resolution beyond this depth with pure optical methods. Diffuse optical tomography (DOT) can provide optical scattering and absorption information by collecting diffuse photons and calculating photon motion in deep tissue, but the spatial resolution is relatively low. Photoacoustic imaging (PAI) is regarded as a promising imaging technique based on both optical and ultrasonic methods. The contrast level of PAI is derived from optical absorption by laser excitation in biological tissues, while spatial resolution is usually determined by the ultrasound parameters in the detection mode. Thanks to its convergent nature, PAI can visualize deep tissue of several centimeters while maintaining high ultrasound resolution. This presentation introduces various scale PAI systems and their biomedical imaging applications.

Keywords:

Photoacoustic effect, Photoacoustic imaging, Multi-scale imaging, Molecular imaging

Dynamic speckle correlation imaging using rolling shutter image sensors

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Abstract:

We report on a speckle correlation imaging technique using commercial rolling shutter (RS) image sensors (CIS) for imaging fast temporal dynamics of scattering media. While spatial speckle contrast analysis has been widely used to visualize the dynamic behavior of biological tissue, temporal speckle correlation analysis using high-speed cameras has shown to provide a more robust and quantitative measurement of the speckle decorrelation by directly measuring the intensity fluctuations of the speckle field. However, for most dynamic processes in living tissues, for example, blood flow, have small speckle decorrelation time in the order of microseconds, requiring cameras with very high frame rates (>10000 fps).

We propose a method to directly measure local intensity fluctuations in a speckle field using a consumer-grade video-rate RS CIS instead of expensive high-speed cameras. Adjacent rows of the RS CIS record intensities of the field at different moments with a constant time interval. Typical row times ($\sim 10\mu\text{s}$) of RS in image sensors provide a short time interval, corresponding to that of high frame rate cameras above 10000 fps. To take advantage of this row time, we generate elongated speckles occupying several rows of the image sensor by placing an elliptical aperture in the imaging system. Within a single speckle image captured with RS CIS, we can directly image the temporal decorrelation of the speckle field from intensity correlations between rows within the region of interest (ROI), with row intervals representing time intervals in multiples of row time. We can scan the ROI across the entire image to obtain a 2D image of local speckle decorrelation times.

To compute the decorrelation time from row correlations of RS speckle image, we derived a spatiotemporal intensity correlation function that considers both spatial and temporal speckle correlation. We show that our model, which is a modified version of the Siegert relation with a spatial correlation term, matches the simulated row intensity correlations of elongated speckles, and our model can be used to compute the speckle decorrelation times from row correlations. We also show that our model can consider the finite integration time of the camera that exceeds the row interval and is still able to compute the decorrelation time from the intensity correlations in blurred speckle images. We report on the derivation and validation of our model via simulation and the preliminary experimental results.

Keywords:

laser speckle imaging, dynamic light scattering, blood flow imaging, scattering media

Disorder-based X-ray imaging

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Abstract:

Refractive lenses for X-rays are not as efficient as those for visible lenses because of the intrinsic low refractive index differences of materials in the X-ray frequency regime. Even though the diffractive lenses such as zone plates are frequently utilized as an alternative, the imaging resolution has been limited by the quality of lithography techniques.

In order to overcome the issue, various lensless imaging techniques has been studied extensively. The crux of the lensless methods is the measurement of sample complex amplitudes, which enables the numerical introduction of a perfect X-ray lens that does not exist in nature. Unfortunately, the complex values are the physically measurable quantity. Accordingly, retrieving the lost phase or solving the *phase problem* has been a common goal of the lensless methods.

Additional information is generally required to specify the correct phase solution. For example, in coherent diffractive imaging (CDI) techniques, a sample support constraint are utilized; in ptychography, multiples measurements are required to solve the phase ambiguity. Because the single-shot requirement is an important trait to overcome the resolution limit of sample radiation damage, a single-shot and general X-ray imaging method is still demanding technology.

Here, we propose disorder-based X-ray imaging as a solution. Our method requires neither sample constraints nor multiple measurements. Instead, we exploit the unique mathematical relations of speckle patterns, which is generated by random diffractions. We designed a disordered X-ray diffuser and placed after a sample to transform arbitrary sample diffraction fields into a speckle pattern. From a speckle pattern measured, we successfully retrieve the complex-amplitude of the sample. We achieved 13.9 nm image resolution at 5.456 keV. The experiments were conducted at the coherent X-ray scattering (CXS) beamline of the Pohang Accelerator Laboratory.

Keywords:

speckle, X-ray imaging, diffuser, disorder, random

Stimulated X-ray Raman Spectroscopy and Time-resolved X-ray Diffraction of Conical Intersections in Thiophenol

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Abstract:

Ultrafast nonadiabatic dynamics through conical intersections are of central interest for understanding the function and the relaxation mechanisms of photoexcited molecules in virtually all photochemical processes. Direct real-time measurement and characterization are essential to monitor conical intersections and their paths. Despite many attempts, direct measurement of conical intersection is still elusive due to the stringent requirements on temporal and spectral resolutions that are not met by optical laser sources.

In this work, a stimulated X-ray Raman spectroscopy (SXRS) technique is proposed to probe the conical intersection dynamics in thiophenol which passes through two conical intersections. The technique employs hard X-ray narrowband/broadband hybrid probe fields to probe electronic coherences at the level crossing region via a resonant Raman transition to an X-ray chromophore (sulfur K-edge in thiophenol). The signal carries phase information of the valence-to-core electronic coupling in the vicinity of conical intersections.

We demonstrate that the two conical intersections in thiophenol can be distinguished by the valence-to-core transition frequency since the first conical intersection (CI-1) couples strongly to higher-lying states in sulfur K-edge while the second conical intersection (CI-2) couples to the lowest state in the same edge, and due to the stabilization of the lowest core state in the sulfur K-edge due to the S-H bond dissociation. Simulations of the real-time measurement of the two conical intersections in thiophenol reveal the entire photochemical pathway.

Keywords:

Stimulated X-ray Raman Spectroscopy, Time-resolved X-ray Diffraction, nonadiabatic dynamics, conical Intersection

Studies of electrocatalysts for water and CO₂ electrolysis via X-ray absorption spectroscopy (XAS)

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Abstract:

Nanoscale catalytic materials are key components of various electrochemical devices for storing and converting renewable energy, such as fuel cell, water splitting and CO₂ electrolysis system. Their successful development and optimization require insight into the relations between atomic-scale structure of the catalytic interface and their electronic structure to improve the catalytic activity and stability. In this talk, we will highlight some of our recent work on the design and understanding of precious/non-precious metal and metal oxide catalyst materials for oxygen evolution reaction (OER) and CO₂ reduction reaction (CO₂RR). Especially, their electronic structure and electrochemical stability during operating condition were analysed by using *in-situ/operando* X-ray absorption spectroscopy. *In-situ/operando* ICP-MS technique was also used to measure the dissolved electrocatalysts and quantify the degree of durability degradation. Based on these results, we will outline the preparation, characterization, and catalytic performance of metal and metal oxide model catalysts and discuss fundamental aspects of their structure-activity and –stability relationships.

Keywords:

Water splitting, CO₂ electrolysis, Oxygen evolution reaction (OER), CO₂ reduction reaction (CO₂RR), *in-situ/operando* analysis

Transparent photovoltaics and applications

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Abstract:

Transparent photovoltaics (TPVs) enable transparency in visible regime with the conversion of light into electrical energy. TPVs can be used to replace conventional dark solar cells in parts of buildings and vehicles to enable onsite power generation. Moreover, TPVs can be applied in the emerging technologies such as bio and transparent optoelectronics with the benefits of transparency and self-power supply.

Bio-inspired electronic devices have significant potential for use in memory devices of the future, including in the context of neuromorphic computing and architecture. This study proposes a transparent heterojunction device for the artificial human visual cortex. Owing to their high transparency, such devices directly react to incoming light to mimic neurological and biological processes in the nervous system. Metal–oxide materials are applied to form a transparent heterojunction (n-type ZnO/p-type NiO) in the proposed device that also provides the photovoltaic function to realize the optic nerve system. The device also exhibits nociceptive features. Its transparent photovoltaic feature endows it with self-powered operation that ensures long-term reliability without needing to replace the power system. This self-powered and highly transparent visual electronic device can provide a route for sustainable applications of neuromorphic computing, including artificial eyes.

Optoelectronic devices that are self-powered and have a high transparency are of interest for application in versatile next-generation “see-through” platforms. However, current optoelectronic photodetectors often have drawbacks including a high driving power and a relatively slow response speed. In this work, large-area transparent photovoltaic devices (TPVD) are reported that can be easily prepared at room temperature from eco-friendly and abundant materials. The TPVD consists of a zinc oxide/nickel oxide heterostructure as the light-harvester and ultraviolet (UV) blocker, and its photovoltaic performance is evaluated using silver nanowire (AgNW) electrodes composed of NWs with varying diameters. As a result of surface plasmons in the AgNW electrode, TPVDs with AgNWs that have a larger diameter exhibit enhanced transparency and photovoltaic performance, with a photovoltage of 520 mV under standard AM1.5 light illumination. Importantly, the binary electric signal produced can be decoded without the need for electronic filter circuits or a threshold. A UV communication system is further designed based on the TPVD for application as a self-powered, binary Morse-code signal with a high response speed. This work integrates the features of a transparent power generator and transparent optoelectronics into a UV photodetector, and it can enable the application of self-reliant devices for communications, imaging, and sensors.

Keywords:

Transparent photovoltaics, Memory devices, window communication

금속-유기 골격체기반 계층적 나노구조 물질의 합성 및 슈퍼커패시터 응용

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Abstract:

전 세계 에너지 소비 증가, 화석 연료와 같은 재생 불가능 자원의 고갈, 환경 오염 증가 등으로 인해 재생 가능하고 무공해 에너지 저장 및 변환 시스템의 개발이 요구되고 있다. 다양한 에너지 저장소자중에 슈퍼커패시터 (supercapacitor: SC)는 높은 안전성, 긴 내구성, 높은 전력 밀도, 빠른 재충전 속도 및 동작 용이성과 같은 유리한 특성을 가진 친환경 시스템으로 간주되고 있다. 배터리 및 SC형 재료를 하나의 구성으로 혼성화하면 에너지밀도를 증가시켜 에너지 저장 특성을 높일 수 있다. 지난 몇 년 동안 탄소계 물질과 전이금속 산화물/칼코게나이드는 각각 정전용량형과 전지형 소재로 널리 사용되어 왔다. 최근, 금속-유기 골격체 (metal-organic frame: MOF)는 금속이온/클러스터 및 유기 리간드의 배위 결합에 의해 상호 연결되는 높은 결정도와 장주기 규칙도 (long-range order)를 가진 새로운 종류의 다공성 물질로 에너지저장 응용에서 더 높은 화학적 안정성, 전자 전도성 및 전기 화학적 성능을 보유한다. 또한 기존 공정에서 파생된 0차원에서 3차원 재료와 같은 다른 종류의 나노구조 물질은 구조적 변형을 재현하기에 충분한 다공성 구조를 가지고 있다. 따라서 본 발표에서는 다양한 합성법을 이용하여 금속-유기 골격체기반 계층적 나노구조 물질의 제작을 발표한다. 제작된 계층적 나노구조 물질의 물성이 분석되었고, 슈퍼커패시터 소자의 전극을 위해 CV (cyclic voltammetry), GCD (galvanostatic charge-discharge), EIS (electrochemical impedance spectroscopy) 등의 전기화학적 특성들이 측정 및 분석되었다. 얻어진 결과로부터, 금속-유기 골격체기반 계층적 나노구조 물질이 고 에너지밀도 슈퍼커패시터의 전극 물질로써 효율적으로 제공될 수 있음을 나타낸다.

Keywords:

금속-유기 골격체, 계층적 나노구조, 전기화학적특성, 슈퍼커패시터

Energy conversion and storage in piezoelectric driven self-charging supercapacitor power cell

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Abstract:

The design and development of piezoelectric self-charging supercapacitor power cell (SCSPC) is rapidly increasing due to the integrability of energy conversion and storage in a single device. In this research, the utilization of various components such as electrode materials (EDLC, intrinsic/extrinsic pseudocapacitors, redox capacitors) and electrolytes (solid proton conducting electrolyte and gel polymer with aqueous and ionic liquid electrolytes) plays the major role in the self-charging performance, and the origin of better performance of charge storage was discussed. The solid state SCSPC was fabricated with the help of a piezo-electrolyte film comprising of ionogelled siloxene-PVDF which is utilized as the free-standing film as separator cum electrolyte in SCSPC devices. The intrinsic role of electrode, electrolyte, and piezo-separator on the overall performance metrics of a SCSPC was discussed compared to the state of art of SCSPC. The mechanism involved in the energy conversion and storage in a SCSPC device is explained based on the piezo-electrochemical process for the first-time using piezo-electrochemical spectroscopy (PECS) measurements. The concept of piezo-ionic or mechano-ionic mediated charge injection from electrolyte to electrode via piezo-electrochemical process was experimentally demonstrated using the PECS analysis and theoretically discussed in accordance with the Nernst theory. Further, a new paradigm paves a way in the field of integrated SCSPC for next generation energy device and novel strategies to improve their self-charging efficiency are discussed. Future experimental considerations for appropriate evaluation on understanding the mechanism of the piezo-electrically driven electrochemical energy conversion process in SCSPC are adequately discussed.

Keywords:

Self-charging power cell, Supercapacitors, solid-proton conducting electrolyte, Piezo-electrochemical spectroscopy

Triboelectricity based energy harvesting technologies and its applications

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Abstract:

With the rapid advancement of the Internet of things (IoT), security issues of the IoT are emerging because the wireless networks for conventional IoT are easily exposed to hacking. By storing the critical data in a physically separate space, these issues can be suppressed. The nonvolatile memory (NVM) is an attractive solution because the stored data are not erased even after turning off the power. However, the NVM consumes the power for operating and the remaining data are exposed to attack. Hence, NVM with high security and low power operation is highly required for IoT platforms. Herein, a disk triboelectric nanogenerator-based NVM (DTNVM) is developed. The DTNVM can be operated with low power because the reading process of stored data is conducted with triboelectricity. Since the ternary system is adopted, 23 to 119 trits can be stored at the DTNVM by changing the sampling time. The identification information is stored at the DTNVM and 91.3% of consistency of the data with a range of 10% tolerance is recorded as a result of the reading. Based on the result, the DTNVM is expected to be utilized in the near future as a next-generation NVM and for safe identification systems at the IoT.

Keywords:

triboelectricity, energy harvesting, memory, security, identification

Revealing Berry curvature in high-order harmonic generation

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Abstract:

Net Berry curvature is an important but difficult property to measure in the study of material science. We investigate circular dichroism of high-order harmonic generation (HHG) in monolayer **MoS₂** with strain and bias field where the system has an unbalanced Berry curvature structure at the high symmetry point K and $-K$ valleys. Breaking the 3-fold rotational symmetry, we find that the $3n$ th-order dichroic signals ($n = 1, 2, 3, \dots$) show dynamical net Berry curvature induced by the pump pulse. Furthermore, we calculate the harmonic emission delays which have behavior like the dichroic high-order harmonic generation according to the external manipulations. This finding presents a possible method to observe the net Berry curvature of the system through HHG and an understanding of the underlying physical process for HHG in valley magnetic materials.

Keywords:

High-order harmonic generation, Circular dichroism, Transition metal dichalcogenides, Berry curvature

Effects of laser irradiation on two-dimensional Bi₂Te₃/MoS₂

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Abstract:

단일 층 MoS₂ 위에 Bi₂Te₃ 박막이 성장된 이차원 헤테로구조에 대한 라만 산란 및 광 발광 연구 결과를 보고한다. 라만 산란 실험에 의하면 입사 레이저의 세기가 약할 때는 Bi₂Te₃에서의 광학 포논만 관측되었지만, 일정한 세기 이상에서는 단일 층 MoS₂에서의 광학 포논인 E'과 A₁' 포논 모드도 관측되었다. 레이저 세기가 증가할수록 두 포논의 에너지가 점차 변화했는데, 포논 에너지 사이의 라만 상관관계 분석 결과 이는 도핑 및 발열 효과와 연관이 있음을 알 수 있었다. 특히, Bi₂Te₃로부터 단일 층 MoS₂로 추가적인 도핑 현상이 있음을 알 수 있었다. 광 발광 실험 결과 레이저 세기 변화에 따른 도핑 수치의 변화는 라만 상관관계 분석 결과로부터 얻은 수치와 일치하였다. [이 성과는 2019년도 정부(과학기술정보통신부)의 재원으로 한국연구재단의 지원을 받아 수행된 연구임 (No. 2019R1A2C1003366)]

Keywords:

MoS₂, Bi₂Te₃, 광학 포논, 엑시톤, 트라이온

Nanoscale trion-exciton conversion in a MoSe₂ monolayer via tip-enhanced cavity-spectroscopy

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Abstract:

We present tip-induced trion emission combined with tip enhanced photoluminescence (TEPL) spectroscopy in MoSe₂/AuNW structure. This tip-enhanced cavity-spectroscopy approach not only probes excitonic properties with high spatial resolution, but also allows to control and modify the carrier dynamics because the tip can act as a controlled plasmonic nano-cavity. In addition, we investigate the influence of metal tip/nanowire plasmons, and demonstrate the interactions between plasmons and carriers in MoSe₂.

Keywords:

Tip-enhanced cavity-spectroscopy, Transition metal dicalcogenides (TMD), Excitonic emission

Nano-thermal Analysis of Defect-induced Surface Pre-melting in 2D Tellurium

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Abstract:

p-type 2D tellurium (2D Te) synthesized via the hydrothermal method demonstrated excellent electrical properties, such as a fast field-effect mobility of approximately $700 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$ and outstanding thermoelectricity, with a Seebeck coefficient of $413 \text{ } \mu\text{V} \cdot \text{K}^{-1}$ and a ZT value of 0.63 at room temperature, resulting from high electrical conductivity and low thermal conductivity. 2D Te exhibits several superior properties for many applications, but the thermal properties that can determine the operating temperatures of devices have not yet been elucidated. In addition, the efficiency and stability of 2D Te devices are significantly affected by the thermal properties resulting from the change in the kinetic or potential energies of constituent atoms or molecules of the material. Moreover, the degradation of thermal properties from bulk to nanostructure implies that the operating temperature of a device with 2D Te can be more tightly limited. Therefore, it is essential to understand the thermal properties of 2D Te to maximize the performance and lifetime of 2D Te devices.

In this study, we investigated the melting behavior of 2D Te using nano-thermal analysis (Nano TA). Unusual melting characteristics were observed before melting and, through theoretical calculation, were revealed as surface pre-melting. Different surface pre-melting rates were demonstrated in 2D Te for thicknesses of 50 nm and 80 nm. A significant occurrence of surface pre-melting in 50-nm 2D Te was observed. We suggest that the defects on the surface of 2D Te affect the melting properties, resulting in fast surface pre-melting in 2D Te at 50 nm. Raman measurements were conducted to confirm the distribution of defects and the Raman intensity map demonstrated the non-uniformity of the sample surface.

Keywords:

2D Tellurium, Nano Thermal Analysis (Nano TA), Surface Pre-melting

Boosting dark matter by neutrinos

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Abstract:

A novel mechanism of boosting dark matter by cosmic neutrinos is proposed. The new mechanism is so significant that the arriving flux of dark matter in the mass window $1 \text{ keV} \lesssim m_{\text{DM}} \lesssim 1 \text{ MeV}$ on Earth can be enhanced by two to four orders of magnitude compared to one only by cosmic electrons. Thereby we firstly derive conservative but still stringent bounds and future sensitivity limits for such cosmic-neutrino-boosted dark matter (νBDM) from advanced underground experiments such as Borexino, PandaX, XENON1T, and JUNO.

Keywords:

boost dark matter, neutrino dark matter interaction,

Searching for Sterile Neutrinos and Non-Standard Interactions Using the IsoDAR Neutrino Source at Yemilab

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Abstract:

IsoDAR is a novel, pure electron antineutrino source that, when paired with a large hydrogen-based neutrino detector, allows state-of-the-art beyond Standard Model searches for sterile neutrinos and non-standard interactions. In this talk, we will present the world-leading physics capabilities of IsoDAR paired with a 2.5 kiloton detector at Yemilab. Further, we will discuss progress towards completing the design of the IsoDAR cyclotron and antineutrino-producing target.

Keywords:

neutrinos, sterile neutrinos, non-standard interaction, cyclotrons

Dark Matter Searches with Global Networks of Atomic Magnetometers

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Abstract:

A host of astrophysical and cosmological measurements suggest that the majority of matter in the Universe is an invisible substance we term "dark matter." Understanding its nature is of paramount importance to astrophysics, cosmology, and particle physics. A well-motivated possibility is that dark matter consists of ultralight bosons such as axions or hidden photons, with masses far smaller than 1 eV, in which case they are well-described as a classical field. Axions and hidden photons can, in principle, generate signals measurable with atomic magnetometers. We describe recent and ongoing searches for such dark matter signals using global magnetometer networks. For example, the Global Network of Optical Magnetometers for Exotic physics searches (GNOME) is an international collaboration operating more than a dozen time-synchronized optical atomic magnetometers inside multi-layer shielding systems, with stations in Europe, North America, Asia, the Middle East, and Australia. The GNOME is being used to search for large compact composite dark matter objects (such as topological defects and boson stars), stochastic fluctuations of dark matter fields, and bursts of exotic low-mass fields (ELFs) from cataclysmic astrophysical events (like black hole mergers). We will also discuss recent results showing how the Earth itself acts as a transducer for hidden-photon dark matter to generate real global magnetic field patterns, enabling searches for hidden photon dark matter with networks of unshielded magnetometers.

Keywords:

GNOME, dark matter, axion

Deuteron production in ultrarelativistic heavy ion collisions

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Abstract:

To understand the production of light nuclei and/or molecular configuration in a ultrarelativistic heavy ion collision, we calculate the transverse momentum distribution of deuteron using coalescence model. We first parametrize the transverse momentum distribution of proton measured at 2.76 Pb-Pb collision by the ALICE collaboration. We then use the coalescence model to calculate the production of deuteron assuming that they are formed by a proton and neutron at the freeze-out point. We find good agreement with transverse momentum distribution of the Deuteron measured at the same collision by the ALICE collaboration.

We finally discuss how the result can be used to understand and to explain production of molecular configuration in a heavy ion collision.

Keywords:

coalescence model, heavy ion collisions, deuteron

Quarkonium properties in bulk viscous QGP medium

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Abstract:

The relativistic heavy ion collisions at RHIC and LHC produce a phase of matter known as Quark Gluon Plasma (QGP). Recently, the role of bulk viscosity is gaining an increasing attention in relation to the beam energy scan program, since the non-equilibrium bulk viscous effect is expected to be enhanced as the system approaches a critical point. In this work, we address the question of whether heavy quarkonia are sensitive to the bulk viscous nature of the plasma. If this is the case, we might be able to use heavy quarkonia as a probe of the non-equilibrium properties of the plasma. We incorporate the bulk-viscous nature of the medium by deforming the distribution functions of thermal quarks and gluons, with which the dielectric permittivity is computed within the hard thermal loop approximation at one-loop. The modified dielectric permittivity is used to calculate the in-medium heavy quark complex potential, which includes both perturbative Coulombic as well as non-perturbative string-like terms. Based on the modified heavy quark complex potential, we compute the quarkonium spectral function, with which the physical properties such as binding energies and decay widths are computed. We will discuss the implications of the bulk viscous effect on the physical observables such as Ψ to J/Ψ ratio and the nuclear modification factor R_{AA} .

Keywords:

Quark Gluon Plasma, heavy quarkonia, bulk viscosity, heavy quark potential, spectral function

Measurement of electrons from beauty-hadron decays in pp collisions at $\sqrt{s} = 13$ TeV with ALICE

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Abstract:

Heavy quarks (i.e., charm and beauty) are mainly produced in the early stage of ultrarelativistic heavy-ion collisions via initial hard scattering processes due to their large masses. They can experience the entire evolution of the system created by such collisions. Therefore heavy quarks are regarded as effective probes to investigate the quark-gluon plasma (QGP), a state of matter in which colored partons are deconfined. In pp collisions, the measurement of the production cross section of heavy flavor hadrons can be used to test our understanding of the Quantum Chromodynamics (QCD) in the perturbative regime. In addition, pp collisions provide the reference for measurements in heavy-ion collisions such as the nuclear modification factor (R_{AA}).

In this contribution, the p_T -differential production cross section of electrons from beauty hadron decays in pp collisions at $\sqrt{s} = 13$ TeV at midrapidity ($|\eta| < 0.8$) with ALICE detector is reported. Also, comparison of the result with FONLL (Fixed-Order and Next-to-Leading Logarithms) pQCD calculations will be shown.

Keywords:

CERN, ALICE, QGP

Ξ_c^0 production in p+Pb collisions at 5.02 TeV

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Abstract:

Studying charmed baryon production could play an important role in examining strongly interacting matters at extreme temperatures and densities in heavy ion collisions because heavy quarks go through the entire evolutionary process of a medium. The measurement in proton-nuclear collisions is important to separate the cold nuclear material effect from the effects associated with the formation of Quark Gluon Plasma. In this study, The Ξ_c^0 is reconstructed via the semileptonic channel $\Xi_c^0 \rightarrow \Xi^- e^+ \nu_e$ (and charge conjugates) using ALICE detector.

Keywords:

Heavy Ion Collisions , Quark Gluon Plasma , Charmed Baryon , ALICE

Study on the flow of the identified particles in p-Pb collisions

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Abstract:

In heavy-ion collisions at relativistic energies, a hot and dense medium called Quark-Gluon Plasma (QGP) is created. Intriguingly, the collective motion of produced particles, which is thought to be strong evidence of the formation of QGP, is also seen in small systems like pp and pPb collisions. Such a study can be done in the ALICE experiment at the LHC via long-range two-particle correlations. Recently, the flow coefficients of unidentified charged particles have been measured in high-multiplicity pp collisions at 13 TeV using the template fit method. We are interested in extending the analysis with the pPb data collected in the LHC Run2 and data from other small systems like pO and OO which will be collected in the LHC Run 3. We also are keen on measuring the flow of identified particles to further understand the origin of collective behaviour in small collision systems. An additional model study has been performed to compare the behaviour of identified particles in different models. In this talk, the status of ALICE data analysis and the model study will be presented.

Keywords:

LHC, ALICE, Small System, Flow, Model

Study of differential jet fragmentation in pp and p-Pb collisions at ALICE

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Abstract:

Jets are a useful probe for the study of the early stage of Quark-Gluon Plasma (QGP) as they're created in the initial hard scatterings. By measuring the jets' yield and substructure, detailed information on how hard partons interact with the medium and formed into hadrons can be studied.

Jet fragment transverse momentum (j_T) is calculated with charged particles inside a jet cone. We are analyzing data of proton-proton (pp) and proton-lead ($p-Pb$) collisions at $\sqrt{s_{NN}} = 5.02$ TeV to measure j_T distributions in various longitudinal fragmentation function (z) bins. This analysis can test the current understanding of jet fragmentation and possible nuclear effects in $p-Pb$ collisions, and the developed analysis framework would be extended to analyses of heavy-ion data. A model study utilizing the JETSCAPE framework has been performed to extend the model optimized for heavy-ion collisions to small collision systems. In this presentation, the current status and future plan of the data analysis will be presented

Keywords:

QGP, heavy ion collision, jet fragment transverse momentum, jet fragmentation function, JETSCAPE

Heavy-flavor and quarkonia measurements with ALICE 3

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Abstract:

After the LHC Long Shutdown 4(LS4), the luminosity of the LHC beam will significantly increase about factor 20 to 50. The ALICE experiment can cover this high luminosity beam using the apparatus, which consists of a silicon tracker made with Complementary Metal-Oxide-Silicon (CMOS) Monolithic Active Pixel Sensors (MAPS) technology.

The new detector concept provides unprecedented physics performance for heavy flavour studies, enabling the measurement of the production of exotic quarkonia and Multiple Heavy Flavoured (MHF) baryons and mesons in pp, p-A, and nuclear collisions, for which theoretical uncertainties on the cross section span across orders of magnitude. The measurements of exotic hadrons would provide a direct window on hadron formation from a deconfined Quark-Gluon Plasma, and spectacular effects would be expected for MHF baryons and mesons in high luminosity collisions system. In such a scenario, the yields of MHF baryons relative to the number of produced charm quarks are predicted to be enhanced in AA relative to pp collisions. Enhancements are expected by as much as a factor of 100 for the recently discovered Ξ_{cc} baryon and even by as much as a factor of 1000 for the as yet undiscovered Ω_{ccc} baryon. The observation and precise quantification of such effects would represent a quantum jump to study the properties of deconfined matter. Furthermore, observing the effect in MHF hadrons would provide a key confirmation of the current interpretation of the LHC quarkonium results and open a crucial new window to study the mechanisms of hadron formation from a deconfined Quark-Gluon Plasma.

Keywords:

Heavy-Flavour, Quarkonia, QGP, ALICE3

Preparation of electron ion collider (EIC) experiment and potential contribution of Korean researchers

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Abstract:

The electron ion collider (EIC) is the future particle accelerator to be built at the Brookhaven National Laboratory (BNL). It will collide electrons and various nuclei to precisely measure the internal structure of nuclei, including the spin and momentum distribution of quarks and gluons. The construction of EIC is planned to be done in the early 2030s, and this idea is now materialized by getting the critical decision 1 (CD-1) from the US DOE in July 2021. To participate in this future experiment, 13 faculties from 9 Korean institutions made a consortium and submitted the expression of interest to BNL. In this presentation, we will review the potential contribution of Korean nuclear and particle physics groups in terms of detector R&Ds and physics studies.

Keywords:

eic

Introduction to CQeST

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Abstract:

I will give a short introduction on the Center for Quantum Space Time (CQeST) in Sogang University and report about its activity since June 2020.

Keywords:

Cosmology, Particle Physics, Astroparticle Physics

Cosmology and Particle Physics

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Abstract:

In this talk, I will discuss some recent developments in particle cosmology, particularly focusing on the role of particle physics to understand the cosmology.

Keywords:

cosmology, particle physics

Recent Developments in Cosmology

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Abstract:

Cosmology is currently faced with a series of challenges, in the sense that the standard model is in tension with an increasing number of data sets. In this talk I review the current status of the standard cosmological model, including recent notable observational, theoretical and computational advances in the field. I will briefly discuss how these open questions might be resolved in the near future with upcoming data sets.

Keywords:

Cosmology

AV_3Sb_5 (A=K, Rb, Cs): A new class of topological kagome metals with superconducting and charge density wave instabilities

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Abstract:

Kagome metals are compelling materials platforms for hosting electronic states that feature an interplay between topologically nontrivial electronic states and correlated electron phenomena. These two features can, for instance, arise from the Dirac points, flatbands, and saddle-points endemic to the kagome lattice type in simple tight-binding models. Recently in this field, the discovery of a new class of kagome metals of the form AV_3Sb_5 with A=K, Cs, or Rb has provided a unique setting for exploring the interplay between Z_2 electronic topology and intertwined charge density wave and superconducting orders. These metals realize a kagome lattice of nonmagnetic vanadium ions with an electron-filling that populates saddle-points and their corresponding van Hove singularities in the electronic density of states near the Fermi level. Nesting effects in this setting are predicted to stabilize a variety of unusual states, ranging from charge density wave order that breaks time reversal symmetry to unconventional superconductivity. Here I will present some of our recent work exploring the phase transitions and broken symmetries in these materials. Particular attention will be given to the nature of the charge density wave instability

Keywords:

superconductivity, kagome lattice, charge density wave order, topological metal

Electrical manipulation of the antiferromagnetic Weyl semimetal state in Mn₃Sn

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Abstract:

Electrical manipulation of emergent phenomena due to nontrivial band topology is a key to realize next-generation technology using topological protection. Recent discovery of the magnetic Weyl fermions in the antiferromagnet Mn₃Sn has attracted significant attention [1], as it exhibits various exotic phenomena with robust properties due to the Weyl nodes and magnetic octupole on a kagome lattice [2-6]. Given the prospects of antiferromagnetic (AF) spintronics for realizing high-density devices with ultrafast operation, it would be ideal if one could electrically manipulate an AF Weyl semimetal. Here we discuss our recent discovery of the electrical switching phenomena in a Weyl semimetal state and its detection by anomalous Hall effect (AHE) [8,9]. In particular, we employ a polycrystalline thin film of the AF Weyl metal Mn₃Sn. Using the bilayer device of Mn₃Sn and nonmagnetic metals (NMs), we find that an electrical current density of $\sim 10^{10}$ - 10^{11} A/m² in NMs induces the magnetic switching with a large change in Hall voltage, and besides, the current polarity along a bias field and the sign of the spin Hall angle of NMs determines the sign of the Hall voltage. Notably, the electrical switching in the antiferromagnet is made using the same protocol as the one used for ferromagnetic metals. Our observation may well lead to another leap in science and technology for topological magnetism and AF spintronics. This is the work in collaboration with H. Tsai, T. Higo, K. Kondou, T. Nomoto, A. Sakai, A. Kobayashi, T. Nakano, K. Yakushiji, T. Koretsune, M. Suzuki, R. Arita, S. Miwa, Y. Otani, H. Chen, A. MacDonald.

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- [5] T. Matsuda et al., Nat. Comm. 11, 2863 (2020).
- [6] M. Kimata et al., Nature 565, 627-630 (2019).
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Keywords:

magnetic Weyl semimetal, kagome metal, electrical switching, antiferromagnetic spintronics

Exotic physical properties of a kagome superconductor CsV₃Sb₅

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Abstract:

The recently discovered layered kagome metal AV_3Sb_5 ($A = K, Rb, \text{ and } Cs$) provides us a new playground to study the interplay of superconductivity and charge-density-wave (CDW) state by involving nontrivial topology of band structures. Here, we reported the novel CDW state, nontrivial band topology and unusual competition between superconductivity and CDW in CsV_3Sb_5 . We have observed a giant AHE in kagome superconductor CsV_3Sb_5 which exactly follows the higher-temperature CDW transition, indicating a strong correlation between the CDW state and AHE. Our nuclear magnetic resonance (NMR) measurements reveal first-order phase transition associated with orbital ordering at the structural transition temperature, and suggest that the CDW order is a secondary electronic order. Our scanning tunneling microscopy (STM) measurements reveal a robust zero-bias conductance peak inside the superconducting vortex, resembling the Majorana bound states. Both NMR and STM measurements suggested a three-dimensional structural modulation with a $2a \times 2a \times 2c$ period. The CDW state can be completely suppressed at a critical pressure ~ 2 GPa together with a maximum T_c of about 8 K revealed by the high-pressure transport measurements. In contrast to a common dome-like behavior, the pressure-dependent T_c shows an unexpected double-peak behavior. These discoveries make CsV_3Sb_5 an ideal platform to study the interplay among nontrivial band topology, CDW, and unconventional superconductivity.

1. F. H. Yu et al., Nature Communications 12, 3645 (2021).
2. Z. W. Liang et al., Physical Review X 11,031026 (2021).
3. F. H. Yu et al., Phys. Rev. B 104, L041103 (2021).
4. D. W. Song et al., arXiv:2104.09173

Keywords:

kagome lattice, nontrivial band topology, charge density wave, unconventional superconductivity

V-based kagome metals in two dimensions

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Abstract:

The kagome metals refer to a two-dimensional lattice made of metal atoms that are arranged in a lattice resembling the Japanese kagome basket weaving pattern. Recently, significant attention has been paid to a newly synthesized family of V-based kagome metals AV_3Sb_5 , where $A = K, Rb, \text{ and } Cs$. Many exotic physical phenomena have been reported in AV_3Sb_5 , ranging from nontrivial band topology, unconventional superconductivity, and charge density ordering concurrent with breaking of time-reversal symmetry. In this talk, after quickly reviewing the current developments and issues of the V-based kagome metals, I will present our recent study of V-based Kagome metals in two dimensions. Using first-principles calculations, we show that the V-based kagome can be stabilized in its single-layered form. The AV_3Sb_5 monolayer will be discussed in view of topological phases and strong correlations of electron. Our results suggest the existence of a new two-dimensional platform, which could help reveal the enriched connection between band topology and strong correlations.

Keywords:

kagome metal, two-dimensional materials, charge density waves, topological insulators, first-principles calculations

Superconductivity in low-valence layered nickelates

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Abstract:

The physics behind high-temperature superconductivity in cuprates remains a defining problem in condensed matter physics. Among the myriad approaches to addressing this problem has been the study of alternative transition metal oxides with similar structures and electron count. After a 30 year quest, a non-cuprate compound with a cuprate-like structure that exhibits superconductivity has been found: hole-doped NdNiO₂. Given that this material is one of the members of a larger series of layered nickelates, this result opens up the possibility of a new family of unconventional superconductors. By means of first-principles calculations, we have analyzed the similarities and differences between this family of low-valence planar nickelates and cuprates. Even though these nickel oxide materials possess a combination of traits that are widely considered as crucial ingredients for superconductivity in cuprates (a square-planar nature, combined with the appropriate 3*d*-electron count, and a large orbital polarization) they also exhibit some important differences (a larger *p*-*d* energy splitting, and lack of magnetism in the parent compounds). Our results show that low-valence layered nickelates offer a new way of interrogating the cuprate phase diagram and are singularly promising candidates for unconventional superconductivity.

Keywords:

nickelates, superconductivity, first-principles

Weak Hund Metals and Infinite-Layer Nickelates

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Abstract:

The recent and exciting discovery of superconductivity in the hole-doped infinite-layer nickelate draws strong attention to correlated quantum materials. From a theoretical viewpoint, this new class of unconventional superconducting materials provides an opportunity to unveil new physics in correlated quantum materials. In this talk, we will discuss a new correlated metallic phase, weak Hund metal, and its possible realization in the infinite-layer nickelates. By using a generic two orbital model away from half-filling, we identify weak Hund metallic phase and suggest its defining criteria [1]. This establishes the existence of Hund metallicity in two-orbital systems. Furthermore, by using ab initio LQSGW+DMFT methodology, we show that onsite Hund's coupling in Ni-d orbitals gives rise to multiple signatures of Hund's metallic phase in Ni-eg orbitals [2]. The proposed picture of the nickelates as a two-orbital weak Hund metal differs from the picture of the Fe-based superconductors as a five-orbital Hund metal as well as the picture of the cuprates as doped charge transfer insulators. Our finding provides a new scenario to understand electron correlation in infinite-layer nickelates and has potential implications for the broad range of correlated two-orbital systems away from half-filling.

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[2] B. Kang, C. Melnick, P. Semon, S. Ryee, M. J. Han, G. Kotliar, and S. Choi, ArXiv:2007.14610.

Keywords:

Hund metal, infinite-layer nickelates, Dynamical mean field theory, ab initio GW, first principles

Nature of electronic correlations in the infinite-layer nickelates and hidden Hund's physics

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Abstract:

We investigate the electronic structure and optical properties of the normal state of the infinite-layer nickelates using density-functional theory plus dynamical mean-field theory. We find a correlated metal which exhibits substantial transfer of spectral weight to high energies relative to the density functional theory. The correlations are not due to Mott physics, which would suppress the charge fluctuations and the integrated optical spectral weight as we approach a putative insulating state. Instead, we find the unusual situation, that the integrated optical spectral weight decreases with doping and increases with increasing temperature. We contrast this with the coherent component of the optical conductivity, which decreases with increasing temperature as a result of a coherence-incoherence crossover. Our studies reveal that the effective crystal field splitting is dynamical and increases strongly at low frequency. This leads to a picture of a Hund's metallic state, where dynamical orbital fluctuations are visible at intermediate energies, while at low energies a Fermi surface with primarily dx^2-y^2 character emerges. The nickelates are thus in an intermediate position between the iron-based high-temperature superconductors where multiorbital Hund's physics dominates, and a one band system such as the cuprates.

Keywords:

Infinite-layer nickelates, Hidden Hund's physics, Optical spectroscopy, DFT+DMFT

The role of Hund's coupling and its manifestation in the correlated metallic phase of $\text{NiS}_{2-x}\text{Se}_x$

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Abstract:

Understanding the characteristic energy scale is a fundamental issue in a strongly correlated electron system. In multiband system, the energy scale is affected by the Hund's coupling by nature as well as the effective Coulomb interaction. Recently, the evolution of kink driven by Hund' coupling has been observed in $\text{NiS}_{2-x}\text{Se}_x$ system, and it was demonstrated that this kink is directly related to the coherence-incoherence crossover temperature scale. [1,2] In addition, the same Hund's physics was observed in pressure-induced metal-insulator transition of pure NiS_2 . In optical conductivity, the anomalous frequency dependence away from the Drude behavior was observed in the intermediate frequency range, which is produced by the redistribution of the quasiparticle states near the Fermi energy. Our results proposes that investigating the optical conductivity of NiS_2 system can offer good pathway to study rich fundamentals including the Hund's physics as well as the non Fermi-liquid phase of multiband system.

[1] Chang-Youn Moon, *et al.*, *Phys. Rev. B* **92**, 235130 (2015).

[2] Bo Gyu Jang, *et al.*, *Nat. Commun.* **12**, 1208 (2021).

Keywords:

Hund' coupling, strongly correlated electron system, NiS_2

Exploration of vdW ferromagnets CrXTe_3 (X=Si, Ge) under high pressure conditions

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Abstract:

Opportunities for investigating correlated electronic systems using extreme physical conditions such as high fields and high-pressures are greatly developing in recent years. In particular, high pressure is as an effective route for tuning electronic states of solids, of which applications to solids can lead to findings of e.g., unexplored exotic phases of various quantum matters or their putative quantum mechanical ground states. With such recent developments of techniques, one can now apply conventionally up to ~200 GPa in diamond anvil cells and high quality hydrostatic pressure up to ~20 GPa at high field and low temperature environment. Herein, reapid developments of high-pressure research tools will be summarized with emphasis on recently commercialized DAC cells for magnetization, Raman, transport measurements at CeNSCMR. For updating exciting science progresses, pressure induced tuning of band topologoloy and temperature induced gap reduction in CrSiTe_3 and CrGeTe_3 with simultaneous development ferromagnetic order nearly up to room temperature will be updated. We also comment on the possibility of observing superconductivity in these system. We also discuss the anomalous Hall effects mainly originating from the nontrivial topology change in the band structure of CrSiTe_3 with pressure, mainly due to the presence of 2D honeycomb lattice.

Keywords:

CrXTe_3

Emerging phenomena in the layered chalcogenides at high pressure

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Abstract:

Layered chalcogenides have recently attracted significant interests due to their unique physical properties, together with the potential applications in optoelectronics, energy and catalysts fields. Due to the unique layered structure, their electronic band structures are especially sensitive to the variation of the interatomic distances, and therefore can be effectively tuned by the application of pressure or compressive strain. Pressure is also expected to drive the correlated chalcogenides into a new quantum states with novel functionalities. In this talk, I will present our recent works that demonstrate the emergence of new physical phenomena on layered chalcogenides under high pressures. First, a significant enhancement of the charge density wave transition towards room temperature are observed in the 1T-VSe₂ under pressure, in which we attributed to the improvement of the out-of-plane component of the Fermi surface nesting with pressure [1]. Our attempts to tune the opto-electronic properties of layered CrPS₄ led to the observation of direct-to-indirect band gap crossover followed by the insulator-metal transition at high pressures [2]. Lastly, I will discuss our current high pressure investigations on the layered topological magnets.

[1] Jiajia Feng, Resta A. Susilo et al., Adv. Electron. Mater. **6**, 1901427 (2020)

[2] Resta A. Susilo, Bo Gyu Jang et al., npj Quantum Mater. **5**, 58 (2020)

Keywords:

high pressure, layered chalcogenides, transport phenomena, optical properties

Spectroscopic observation of crystallizations in water and aqueous solution under dynamic pressure

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Abstract:

Pressure-induced crystallization of water is complex and elusive because water molecules forming strong hydrogen bonds with neighboring molecules tune specific structures through bond length change and angular distortion in confined volume (or under given density) under high pressure. In addition, freezing of an aqueous solution under high pressure is even complex because solute ions interact with water molecules, modify hydrogen bonds in water and finally can promote or prohibit crystal nucleation in the solution. In order to observe in-situ crystallization of ice in water and aqueous solution, we use an advanced dynamic-diamond anvil cell (d-DAC) which combines d-DAC with two micro Raman spectrometers and high-speed camera. In detail, two spectrometers make possible to measure both molecular vibrations and pressure of a sample simultaneously with sub-ms time resolution.

By smooth compression with d-DAC highly compressed water above 1.6 GPa can be easily obtained and this frequently produces metastable ice VII coexisting with water even at room temperature. In few compressions water is compressed less than 1.6 GPa and freezes into stable ice VI coexisting with water. Finally, freezing and melting cycles through the metastable and stable ice phases are classified into five different pathways even under an identical and repetitive dynamic operation. Furthermore, dense NaCl solution higher than $S=0.2$ shows interesting two-step crystallization behavior. In order to identify the crystallized phases from water and solution we use the micro Raman spectroscopy during high pressure experiments. Although water or ice signal is significantly weak compared to Ruby fluorescence we could successfully record Raman spectra of supercompressed water and several ice phases appeared during dynamic (de)compression. A series of Raman spectra for highly supercompressed water shows that O-H stretching mode related to tetrahedral bonding overwhelm that from distorted tetrahedral bonding. Raman spectra of stable ice VI and metastable ice VII are also clearly recorded with short laser exposure of 2-5 s during d-DAC operation. Ice VI and VII showed main peak center ~ 3210 and ~ 3340 cm^{-1} , respectively, at 1.1 and 1.6 GPa. Raman spectra of other ices occurring transiently during (de)compression of water and NaCl solution were also measured and discussed based on the already known ice spectra.

Keywords:

Pressure-induced crystallization, water, aqueous solution, Raman spectroscopy

Study of hot liquid metals using electrostatic levitation over 3000 K

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Abstract:

Nucleation is the first step for crystallization from metastable liquids. This phenomenon is the result of competition between surface energy and bulk energy on phase formation (e.g., ice or snow formation). Understanding and controlling nucleation is very important in fundamental viewpoint and to design materials in electronics, semiconductor, steels and car, pharmaceutical, food and cosmetics industries. However, it is very hard to get thermophysical quantities governing the nucleation at high temperature materials, since high reactivity and easy contamination is inevitable at high temperature in most cases. Moreover, the crystal nucleation should occur in a metastable state, such as supercooled liquid, which is often prevented from a container to retain the liquid, since the container wall plays a role of impurity preventing from supercooling. In addition, the liquid is easily contaminated by reacting with the wall, which make difficult to get pure materials properties.

Here, we introduce a levitation technique, called electrostatic levitation (ESL), which can study supercooled liquid and high melting temperature materials. Using this containerless technique, we can measure various thermophysical properties, such as melting temperature, density and thermal expansion, viscosity and surface tension, specific heat, and so on, over 3000 K. Finally, we can calculate the crystal-liquid interfacial free energy which governs the nucleation phenomenon. In this talk, we will demonstrate the capability of the ESL, and some results about nucleation study of metals and solutions with synchrotron X-ray scattering study. ESL study will be useful to develop high melting materials for nuclear fusion plant, aerospace and defense industries.

Keywords:

High temperature, containerless technique, Thermophysical properties, Nucleation

Spin-Phonon Coupling in SrRuO₃/SrTiO₃ Artificial Superlattices

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Abstract:

Artificial crystals synthesized by atomic-scale precision epitaxy is a suitable platform for exploring, controlling, and understanding the intriguing coupling between different degrees of freedom with similar energy scale. The excellent tunability of the crystal itself enables observation of exotic phenomena, that are not attainable in natural crystals.

In this presentation, we demonstrate the extraordinary spiral spin structure in synthetic SrRuO₃ crystal. The spin state of each SrRuO₃ layer (with a few atomic unit cell thicknesses) within the SrRuO₃/SrTiO₃ superlattices were characterized using polarized neutron reflectivity (PNR). Exploiting the superlattice structure with the help of magnetization measurements, we proved that the in-plane spin rotation prevails in the SrRuO₃ layers dependent on the SrTiO₃ layer thickness. Based on the spiral spin structure, a novel exchange interaction was proposed, based on chiral symmetry breaking of phonons. The strong spin-phonon coupling previously suggested in the complex Ruthenate takes a new turn owing to the discovery of the chiral spin mediated interlayer exchange coupling in the current study.

Jeong *et al.*, *Appl. Phys. Lett.* **115**, 092905 (2019).

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Seo *et al.*, *Phys. Rev. B* **103**, 045104 (2021).

Jeong *et al.*, *ACS Appl. Nano Mater.* **4**, 2160 (2021).

Cho *et al.*, *Acta Mater.* **216**, 117153 (2021).

Jeong *et al.*, submitted (2021).

Keywords:

Chiral Phonon, Spin-Phonon Coupling, Oxide Superlattice, SrRuO₃

Flexo-Polar Phase Transition in a Metal

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Abstract:

The nonpolar-to-polar phase transition has long been considered inconceivable in a metal, as itinerant electrons screen the long-range electrostatic fields that are responsible for spontaneous polar distortion. Nevertheless, in 1965, Anderson and Blount (AB) proposed that a second-order structural transition in a metal may be accompanied by polar distortion, leading to a so-called polar metal. AB postulated an important criterion that itinerant electrons should be weakly coupled with transverse optical phonons in such a polar metal. On this basis, recent works have successfully discovered the rare polar metal phase in several complex materials, such as LiOsO_3 . However, the polar distortion in these polar metals have mainly aroused from ions whose orbital states barely contribute to the electronic states at the Fermi level, thus limiting the range of exotic properties and practical applications of polar metals.

Here, we propose an alternative mechanism to achieve polar phase transition in metals without the constraint of electron-lattice decoupling. When a material with lower lattice symmetry is coherently grown on a substrate with higher lattice symmetry, the in-plane lattice coherence can force a shear strain in the overlaid film. Provided that this shear strain gradually evolves at the nanoscale throughout the film (depending on the extent of interfacial coupling and lattice misfit), a giant strain gradient could occur and then universally polarize the film via flexoelectricity. We found that the gradient of this shear strain can flexoelectrically polarize the bulk of metallic SrRuO_3 , leading to a polar metal phase with substantial Ru off-center displacement. As Ru also dominantly contributes to the electronic states at the Fermi level, the flexo-polar metal phase of SrRuO_3 exhibits a variety of interesting electronic properties. Moreover, the so-called flexo-polar phase transition could naturally accompany a continuous structure transition with temperature, which occurs via a structure symmetry change.

Keywords:

polar metal, flexoelectricity, perovskite oxides

Time-resolved X-ray microdiffraction for ferroelectric thin film under electric field

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Abstract:

We present a new experimental strategy based on a combination of time-resolved X-ray microdiffraction technique and in situ strain engineering for real time observation of atomic movement in ferroelectric perovskite (ABO_3) thin film under external stimuli, i.e., electric field and mechanical stress. Along with important finding on atomic position dependent-diffracted X-ray intensities, we could experimentally as well as theoretically monitor constituent atomic positions in ferroelectric thin film under electric field.

Keywords:

ferroelectric, thin film, time-resolved X-ray microdiffraction

Resonant inelastic x-ray scattering study of topological states of matter in Weyl semimetals

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Abstract:

Topological insulator has a topologically trivial bulk property, and its topological states of matter can be only studied by a surface-sensitive spectroscopy such as angle-resolved photoelectron spectroscopy (ARPES). On the other hand, Weyl semimetals feature a topologically non-trivial bulk Fermi surfaces, i.e., Weyl nodes. [1] Recent studies show that RIXS particle-hole excitation spectrum probes the element specific band structure. [2,3] Interestingly, recent theoretical work [4] proposed that resonant inelastic x-ray scattering (RIXS) provides direct measurement of the topological invariant of nondegenerate band crossings in Weyl semimetals. In this talk, we present resonant inelastic x-ray scattering measurements for a signature of nontrivial band topology in the three-dimensional Weyl semimetals. A space inversion breaking TaAs is the first experimentally discovered and verified Weyl semimetal which possesses 12 pairs of Weyl nodes in bulk: one type (W1) of Weyl node in TaAs reside at 21 meV below the Fermi level and the other (W2) reside at 2 meV above the Fermi level. [5,6] TaAs is a best candidate for a proof of principle RIXS measurement on Weyl semimetals. We developed the 12 meV energy resolution at the Ta L2 edge (11.136 keV) using the state-of-the-art quartz based RIXS analyzer to obtain low energy excitation spectra of TaAs. [7] We focused on the momentum transfers between W1 Weyl nodes whose observation is possible in our 12 meV energy resolution. We could probe a low energy scattering feature below 40 meV which consists of quasi-elastic and energy loss scattering at around 20 meV which is resonated at the Ta t_{2g} absorption energy. We suggest that this 20 meV feature is a Weyl node related scattering.

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Keywords:

Topological insulator, RIXS, Weyl semimetal

강상관 이종구조를 이용한 양자 자성 상태 구현 및 제어

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Abstract:

스핀-궤도 상호작용이 큰 자성 물질은 저차원 자성, 양자 이상 홀 효과, 그리고 양자 스핀 액상과 같이 흥미로운 양자 상태를 나타낼 수 있어 많은 관심을 받고 있다. 이 발표에서는 스핀-궤도 상호작용이 큰 산화물 물질인 Re 더블 페로브스카이트와 Co 벌집구조 물질을 이종구조의 형태로 제작하여 양자 자성 상태를 구현하고 제어하는 연구를 소개하고자 한다. 이종구조는 물질의 차원, 계면, 대칭성, 그리고 응력 등을 조절하여 물질의 해밀토니안을 넓은 범위에서 조절하여 원하는 양자 자성 상태를 만들어 낼 수 있는 가능성이 있다. 이 발표에서는 1) 초격자 구조를 통한 고온 저차원 강자성 상태와 2) 양자 스핀 액상 후보물질의 이종구조 합성 및 응력 연구에 대해 논의할 것이다.

Keywords:

강상관 이종구조, 스핀-궤도 결합, 양자 스핀 액상, 2차원 자성

Visualizing Quantum Materials using Advanced Hard X-ray Scattering Techniques

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Abstract:

Quantum materials originated from electron-electron correlation have been intensively investigated using various experimental techniques. Moreover, many researchers have tried to search for new physical properties and offered new insights into topological states or spin-orbit entangled states. However, understanding of the physical properties of some model systems is yet incomplete due to experimental limitations, specifically hard X-ray-based scattering techniques.

Here, we introduce our experimental approach, e.g., Coherent Bragg Rod Analysis (COBRA) and resonant magnetic x-ray diffraction combined with full-field microscopy. Using the advanced X-ray techniques, we will systematically investigate emergent properties of quantum materials, e.g., ruthenate and iridate. Our studies also offer a comprehensive understanding based on the theoretical calculations combined with advanced hard x-ray scattering techniques. Moreover, we were able to visualize structural and antiferromagnetic domains of thin films and single crystals. We propose that the techniques combined with high pressure and electric field can explore and create new phases and emergent physical properties.

Keywords:

Quantum Materials

칼코지나이드 태양전지에서의 결함과 결함 제어

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Abstract:

최근, 칼코지나이드 기반 Cu(In,Ga)Se_2 , $\text{Cu}_2\text{ZnSnSe}_4$ 소재가 박막 태양전지 광흡수층으로 활발히 연구되고 있다. Cu(In,Ga)Se_2 (CIGS) 와 $\text{Cu}_2\text{ZnSnSe}_4$ (CZTSe) 태양전지는 현재 최고 광전변환효율이 23.35 %와 12.6%에 이르고 있다. 태양전지 효율 향상을 위한 부단한 노력이 이루어지고 있지만, 효율 향상 속도는 더딘편인데, 태양전지 효율 향상에 큰 걸림돌은 광흡수층에 존재하는 결함(defect)에 있다. 화합물 반도체인 CIGS와 CZTSe 에는 다양한 결함이 존재한다. 그 중에서 Se vacancy, cation antisite 들이 전하 재결합 중심으로 작용해서 태양전지 효율을 저하시킨다. 본 발표에서는 이러한 결함들을 살펴보고, 결함 분석과 결함제어가 어떤 방향으로 발전해 오고 있는지 소개하고자 한다.

Keywords:

칼코지나이드, 태양전지, Defect, CIGS, CZTSe

Theoretical limit to the photovoltaic efficiency of imperfect crystals

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Abstract:

The Shockley–Queisser (SQ) limit provides a convenient metric for predicting the light-to-electricity conversion efficiency of a solar cell based on the sole parameter of a band gap. However, the efficiencies of solar cells are often significantly below the SQ limit and are limited by nonradiative recombination which is unavoidable due to the formation of native point defects [1]. We develop a formalism and computational method to predict the maximum photovoltaic efficiency of imperfect crystals from first principles [2, 3]. The trap-limited conversion efficiency includes equilibrium concentrations of native defects, their carrier-capture coefficients, and the associated nonradiative recombination rates. To verify the validity of our method, we estimate an intrinsic limit of around 20 % for kesterites solar cells which falls far below the SQ limit above 30%. We suggest atomic substitution and extrinsic doping lead to pathways for enhanced efficiency of 31%. This approach can be applied to support high-throughput computational screening for future solar-energy technologies.

[1] Point defect engineering in thin-film solar cell. *Nat. Rev. Mat.* 3, 194 (2018); <https://doi.org/10.1038/s41578-018-0026-7>

[2] Upper limit to the photovoltaic efficiency of imperfect crystals, *Energy Environ. Sci.* 13, 1481 (2020); <https://doi.org/10.1039/D0EE00291G>

[3] Ab initio calculation of the detailed balance limit to the photovoltaic efficiency of single p-n junction kesterite solar cells, *Appl. Phys. Lett.* 118, 243905 (2021); <https://doi.org/10.1063/5.0049143>

Keywords:

DFT, Density functional theory, Photovoltaics, Solar cell

First-principles studies of planar defects in semiconductors for photovoltaic applications

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Abstract:

Inorganic materials used to make high-efficiency solar cells have structural similarities. In particular, Si, CdTe, and Cu(In,Ga)(S,Se)₂ all are stable in the so-called 3C structure, which can be understood as stacking of A, B, and C layers. Unless the same type of layer is stacked in the vicinity, the Octet rule is not broken. Therefore, AB stacking can be formed locally, which is also known as the stacking defect. Generally speaking, stacking faults are known to be detrimental to solar cell efficiency due to defect accumulation and reduced transport properties. Therefore the physical properties of stacking faults in ternary and quaternary semiconductors should be documented for future research.

In this presentation, we discuss the stability and the electronic structure of planar defects in chalcogenides and kesterites. In our hybrid density functional theory (DFT) calculation, in Cu₂ZnSnS₄, the stacking fault makes the electron barrier but the anti-site domain boundary act as an electron well [1]. Our DFT calculation also shows that, in chalcogenides, the substitution of Cu by Ag promotes the generation of stacking defects. On the other hand, Ga and Al-containing materials have a higher stacking defect energy than materials having In. The anti-site domain boundary does not change the band edge positions much in CuInS₂, and incorporation of Ag, Ga, and Al increase its formation energy.

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[2] Kanghyeon Park, Byeong-Hyeon Jeong, Hui Yeor Lim, and Ji-Sang Park, J. Appl. Phys. 129, 025703 (2021).

Keywords:

defect, stacking fault, antisite domain boundary, dft, cigs

Defect related charge transport within the metal halide perovskites

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Abstract:

Metal halide perovskite semiconductors have sprung to the forefront of optoelectronic device and materials research, largely due to their remarkable photovoltaic efficiency records above 25% in single junction devices, and 28% in tandem solar cells, achieved within a decade of research. Despite this rapid progress, ionic conduction within the semiconductor still puzzles the community and can have a significant impact on all metal halide perovskite-based optoelectronic devices due to its influence upon electronic and optoelectronic processes. This phenomenon thus also makes the interpretation of electrical characterisation techniques, which probe the fundamental properties of these materials, delicate and complex. For example, space-charge limited current measurements are widely used to probe defect densities and carrier mobilities in perovskites. However, the influence of mobile ions upon these measurements is significant but has yet to be considered. Here we report the effect of mobile ions upon electronic conductivity during space-charge limited current measurements of MAPbBr₃ single crystals, and show that conventional interpretations deliver erroneous results. We introduce a pulsed-voltage space-charge limited current procedure to achieve reproducible current-voltage characteristics without hysteresis. From this revised pulsed current-voltage sweep, we elucidate a lower bound trap-density value of $2.8 \pm 1.8 \times 10^{12} \text{ cm}^{-3}$ in MAPbBr₃ single crystals. This work will lead to more accurate characterisation of halide perovskite semiconductors and ultimately more effective device optimization.

Keywords:

Metal halide perovskite, Space charge, mobile ions, Pulse voltage-SCLC

Strong exciton-light interaction in bare 2D layered materials and its applications

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Abstract:

The emergence of 2D materials stimulated intensive research on both electronic and photonic applications. Especially, transition metal dichalcogenides (TMDs) provided an excellent platform for photonic applications due to their strong light-exciton interaction. Various photonic devices such as a light-emitting device, laser, exciton-polariton device have been successfully demonstrated experimentally using TMD monolayers. However, multilayered TMDs has attracted far less attention than TMD monolayers because they become indirect bandgap materials. Here we show that multilayered TMD itself is a good platform for controlling light-matter interaction without integrating an external photonic structure. A TMD multilayer can be utilized for a passive optical structure because it possesses a high dielectric constant. For example, light guiding is possible along a multilayered TMD, which is very thin compared to the wavelength of the light. Because a high dielectric constant is owing to the exciton resonances, guided light along a TMD layer is referred to an exciton-polariton. The dispersion relation of the exciton-polariton in a TMD layer is very similar to that of surface plasmon polariton. Interestingly, we observed that the polarization of the exciton polaritons in a TMD layer is distinctive to surface plasmon polaritons because it inherits valley-dependent optical response from excitons in TMDs. We will also show that light can be further controlled using a patterned TMD multilayer. First of all, we designed an ultra-thin flat lens using a patterned TMD layer. We will show the optimized thickness and design of a TMD flat lens for efficient light focusing. Lastly, we will present the experimental observation on the lasing action in a bare TMD disk. A 50-nm thick TMD disk exhibits whispering gallery modes with a quality factor of ~ 400 . The disk structure has a very high confinement factor for lasing action because the TMD disk offers both optical modes and optical gains. As a result, we observed the lasing operation under continuous-wave excitation at room temperature. We believe our results show a potential for the TMD-based nanophotonics offering a small mode volume but with a lower loss compared to the surface plasmon polaritons.

Keywords:

2D semiconductor , Exciton polariton, Nano laser

Manipulating exciton lifetime for efficient light emission of 2D semiconductors

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Abstract:

Efficiency of the light emission is an important issue for monolayer transition metal dichalcogenides (1L-TMDs) to be used as two-dimensional (2D) photonic devices. While the lattice defects limit the quantum yield (QY) of 1L-TMDs at low exciton density, exciton-exciton annihilation (EEA) acts as the major decay channel of excitons beyond the exciton density of $\sim 2 \times 10^8 \text{ cm}^{-2}$. We demonstrate that combined use of proximal Au plate and out-of-plane electric field for 1L-WS₂ provides the dramatic enhancement of exciton lifetime and QY at high exciton density. By preparing 1L-WS₂ on hBN on Au with the gate bias to apply the electric field, we maintained the PL lifetime of 2.1 ns through the exciton density range of $2 \times 10^7 - 2 \times 10^{10} \text{ cm}^{-2}$. QY was also enhanced by ~ 20 times and the EEA rate constant decreased by ~ 80 times, compared to the samples on SiO₂ substrate without the gate bias. The increased exciton lifetime is attributed to the reduction of the dipolar interaction energy between excitons. Our results suggest a synergetic solution to cope with EEA to realize the high-intensity 2D light emitters using 1L-TMDs. This work was supported by the Samsung Research Funding & Incubation Center of Samsung Electronics, under project no. SRFC-MA1802-02.

Keywords:

2D semiconductors, exciton, EEA, quantum yield, lifetime

Microscopic Investigation of Two-dimensional Materials by Raman Spectroscopy

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Abstract:

Raman spectroscopy has become an essential tool to study two-dimensional materials due to its versatile capabilities. When the monochromatic light is shone onto crystals, inelastic scattering with quantized states such as phonons leads to rich spectra. By careful investigation, the physical properties of 2D materials can be characterized and studied. In this presentation, I will discuss the optical methods/systems to extract the physical properties of few-atom-thick materials, which are sometimes difficult to measure via other techniques.

Keywords:

Two-dimensional materials, Raman spectroscopy

Observation of Biexcitons in Three-Dimensional Halide Perovskite Single Crystals

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Abstract:

Halide perovskites (HP's) have emerged as novel materials for optoelectronic applications owing to excellent optical properties and cost-effective solution-based preparation methods. Nevertheless, there are still ongoing debate over the nature of optical properties such as Rashba effect, polaronic effect, and exciton-exciton interactions. High-quality single crystals have been widely used to analyze pure optical properties. In the previous reports, Rashba and polaronic effects in three-dimensional (3D) HP single crystals have been revealed to some extent. However, exciton physics in 3D HP single crystals is still elusive due to low exciton binding energy and instability of exciton compared to low-dimensional HP's. Particularly, it is believed that excitonic molecules so-called biexcitons are stable only in low-dimensional HP's where exciton-exciton binding is strongly enhanced by quantum and dielectric confinements. In this presentation, by comparing the photoluminescence (PL) spectra between cleaved internal pristine surface and ordinary external surface, we demonstrate that they indeed do exist in pristine-quality 3D HP single crystals for the first time. The existence of biexcitons is clearly evidenced at low temperature with a binding energy of $\sim 3.9 \pm 0.3$ meV according to i) exciton-biexciton population dynamics, ii) biexcitonic spectral feature of inverted Boltzmann shape, iii) resonant two-photon excitation of biexciton, and iv) optical selection rule under resonant circularly polarized two-photon excitation. By using fine-scale PL excitation spectroscopy, we identified polariton effects and unique exciton fine structures, leading to longitudinal (L) and transverse (T) exciton splitting of 3.7 meV. In contrast, the PL spectrum for ordinary external surface is dominated by P-band emission arising from inelastic exciton-exciton scattering and biexciton peak is entirely vanished. This implies that defects play an important role in many-body exciton-exciton interactions. The discovery of the biexcitons in 3D HP crystals improves fundamental understanding of many-body exciton physics and biexciton-based optoelectronic applications.

Keywords:

Halide perovskite, Photoluminescence, Exciton, Biexciton, Single crystal

Highly efficient carrier multiplication in monolayer 2H-MoSe₂

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Abstract:

Carrier multiplication (CM) is a photo-physical process to generate multiple electron-hole pairs by exploiting excess photon energy larger than a material's bandgap. In previous reports, we have found efficient CM phenomena in two-dimensional (2D) van der Waals layered bulk materials with ideal threshold energy of twice the bandgap and CM conversion efficiency of ~99%. However, the dependencies on the thickness in 2D materials are not fully understood. Here, by using ultrafast transient absorption spectroscopy, we report the CM efficiency of 2D van der Waals MoSe₂ monolayer with the CM conversion efficiency of ~100% that commences at the energy conversion limit. The stronger Coulombic interaction and carrier mobility in monolayer MoSe₂ could contribute to the improved CM efficiency. The combination of CM and the thin and flexible advantages of the van der Waals materials suggests promising hot carrier optoelectronic applications.

Keywords:

Carrier multiplication, 2D materials, hot carrier, ultrafast spectroscopy, transient absorption

Machine learning promoted complex system

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Abstract:

In this talk, I introduce various examples of combinatorial studies between physics and complex systems. Here, the complex systems are in terms of many-body quantum systems and living systems. Specifically, It would be examples of the pattern recognition/generation in the quantum many-body systems, and the application of machine learning methodology onto the modeling of mesoscopic living systems. I will focus on why and how to achieve previous research by sharing my viewpoint about machine learning, then discuss where I heading toward.

Keywords:

Machine Learning, Complex system, Biophysics

Thermodynamics of an active Brownian gyrotor driven by chemical fuel

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Abstract:

Recent experiments have reported that, by utilizing active particles as working substance, colloidal heat engines can apparently achieve unconventionally high efficiency. But we still lack a full thermodynamic picture of how such engines operate far from equilibrium. In particular, there has been much debate on how the parity of the self-propulsion under time reversal affects the engine performance. To systematically address these issues, we introduce a simple, thermodynamically consistent model of an active dimer driven by a chemical fuel. By letting the dimer gyrate under a potential in contact with two different heat reservoirs, work can be extracted from the system. Considering the system as a minimal heat engine, we define an efficiency measure which naturally contains contributions from both fuel consumption and injected heat. This 'composite' efficiency, whose upper bound is precisely given by the second law of thermodynamics, exhibits drastically different behaviors depending on the parity of self-propulsion force. If the parity is even, the engine is efficient when the period of each gyration and the persistent time of the active particle are comparable. In contrast, if the parity is odd, the engine is efficient when the particle's persistent time is much shorter. Furthermore, by investigating more detailed structure of the nonequilibrium entropy production, we obtain even tighter upper bounds on the engine efficiency. Based on these observations, we discuss design principles which optimize the engine's performance under prescribed spatiotemporal scale and self-propulsion mechanism.

Keywords:

active matter, heat engine, efficiency, stochastic thermodynamics

Multiple phase transitions at interface induced by orientational interaction

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Abstract:

The microscopic kinetics near the interface plays a critical role in crystal growth and it varies with the properties of individual particles. Here, employing Janus spheres, we showed that orientational interaction contributes to generating secondary solid structures at an interface between the crystal and the liquid state. At the interface, the secondary structure acts as a barrier to prevent a crystal from growing continuously and eventually causes discrete crystal growth. Also, non-homogeneous local transitions from a secondary structure to crystal lead to irregular morphologies of their nucleus. This work will probably help us understand the microscopic kinetics of crystallization where components' orientational interaction exists.

Keywords:

Janus particle, metastable state, interface, solid-solid transition

Bias-variance tradeoff in unsupervised learning of Restricted Boltzmann Machine

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Abstract:

In machine learning, understanding how the minimum generalization error can be achieved is a question of great importance. As for supervised learning, it is well known that the generalization error is the sum of two different error components, namely the "bias" of the model and the "variance" of the model output. In more traditional examples of learning (such as linear regression and k-means clustering), lowering the bias by making the model more complex typically entails an increase in the variance, producing a U-shaped dependence of the generalization error on the model complexity. This phenomenon, termed the bias-variance tradeoff, has long been regarded as a generic property of supervised learning. Meanwhile, as for unsupervised learning, it is unclear whether such phenomenon even occurs. In this study, we examine the dynamics of unsupervised learning and evaluate the model's generalization error exactly by focusing on the Restricted Boltzmann Machine (RBM), a basic artificial neural network that performs unsupervised learning. Training the RBM with the 2-d Ising model data, we numerically show that the RBMs also exhibit the bias-variance tradeoff behaviors. We also discuss how the optimal model complexity depends on the complexity of the training data, which is controlled by the temperature of the 2-d Ising model.

Keywords:

unsupervised learning, Restricted Boltzmann Machine, Bias-variance tradeoff

Alpha-divergence Improves the Estimation of Entropy Production via Machine Learning

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Abstract:

Recent years have seen a surge of interest in the algorithmic estimation of stochastic entropy production (EP) from the trajectory data via machine learning. A crucial element of such algorithms is the identification of a loss function whose minimization guarantees the accurate EP estimation. In this study, we show that there exists a host of loss functions, namely those implementing a variational representation of alpha-divergence, which can be used for the EP estimation. Among these loss functions, the one corresponding to $\alpha = -0.5$ provides the most robust estimation of EP, maintaining high accuracy even when the existing method based on Kullback-Leibler divergence (corresponding to $\alpha = 0$) becomes inaccurate in the presence of strong nonequilibrium driving. To describe this phenomenon, we present an exactly solvable simplification of the EP estimation problem, which shows that the minimum of the loss function is least affected by the insufficient sampling of rare data precisely when $\alpha = -0.5$. While we illustrate our findings using the method of deep learning, they are also applicable to other machine learning techniques in general.

Keywords:

alpha-divergence, entropy production, machine learning, deep learning

Extension of thermodynamic uncertainty relation to underdamped Langevin systems

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Abstract:

We derive a modification of the thermodynamic uncertainty relation (TUR) applicable to general underdamped Langevin systems with velocity-dependent forces or time-dependent driving. The TUR provides a relation between fluctuations in nonequilibrium currents and the entropy production. Although variants of the TUR have been steadily found for overdamped systems, its extension to the underdamped systems has not been derived. In underdamped systems, nonequilibrium currents and the entropy production are only associated with the irreversible part of the probability current, unlike the overdamped system. This gives rise to the difficulty to derive an extended TUR in a unified way. We resolve this obstacle by introducing an auxiliary parameter that multiplies the reversible part of external force. By means of this idea, we derive the extended TUR in a similar form to the TUR derived for the general overdamped systems. The result is independent of any experimentally inaccessible quantities, such as the dynamical activity that is contained in the previously derived underdamped TUR. We find that the original TUR is restored in the overdamped limit. The validity of the result is confirmed in prototypical underdamped Langevin systems.

[1] Jae Sung Lee, Jong-Min Park, and Hyunggyu Park, arXiv:2106.01599 (2021).

Keywords:

thermodynamic uncertainty relation, stochastic thermodynamics, nonequilibrium thermodynamics

Dynamic Scaling of Growing Interfaces coupled with Ising spin dynamics

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Abstract:

We revisit the sign-order phase transition problem in terms of the detailed study of stationary states and dynamic properties of Ising degree of freedom coupled to the Kardar-Parisi-Zhang (KPZ) surface growth in one-dimensional systems. The process we consider addresses the so-called sign-ordering in the directed polymer process in 1+1 dimensions, as well as the question whether the reconstruction disorder can exist in the stationary states of growing interfaces. We confirm that no such order and no sign-ordering phase transitions in a formal sense. The stationary state has always zero magnetization, but we identify in detail that as the function of the various parameters a threshold is passed where Ising spin dynamics changes dramatically, such that in temporal simulations starting from an ordered state the magnetization decays suddenly much slower to zero, and where the surface enters a dynamic meso-scopic faceted state.

Keywords:

sign-order phase transition, KPZ-surface growth, dynamic scaling, meso-scopic faceted state

Recent progress of RAON Beam diagnostics system

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Abstract:

The goal of RAON accelerator of RISP is to accelerate heavy ion beams up to 200 MeV/u with a maximum beam currents of 8.3 pA. The RAON is divided into several sections: low energy superconducting linac SCL3, charge stripper section, and high energy superconducting linac (SCL2). Various types of beam diagnostic devices such as beam current monitor, beam position monitor, beam profile monitor, and beam loss monitor, etc. are required for the setting of accelerator parameters, the monitoring and control of beam acceleration and transport, and improvement of accelerator system. More than 600 devices will be installed for commissioning and normal operation. This report introduces the overall layout of the beam diagnostic system and presents status of the system construction including results of beam diagnostics at injector beam commissioning.

Keywords:

accelerator, RAON, beam diagnostics, Beam viewer, wire scanner

Development of an on-line bunch length monitoring system at PLS-II using an ultrafast photodiode

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Abstract:

Users of time-resolving experiments at 3rd generation synchrotron light sources deem online bunch length and filling pattern monitoring as an important real-time diagnostic. We developed an on-line monitoring system that can measure bunch lengths and filling pattern using a photodiode, a wideband pre-amplifier, and a sampling digitizer. Two different methods were evaluated to reconstruct the bunch lengths: Gaussian deconvolution method as an approximation scheme and Fourier analysis as a method to restore the original signal by using the power transmission characteristics of the electronic devices in the system, including a bias-tee, a wide band amplifier and cables, as well as the photodiode. A bunch lengthening experiment has been conducted to compare and verify the results of those two methods of the photodiode and the result of the streak camera images by changing the overall gap voltage of the superconducting RF cavities. In this paper, we elaborate upon the said photodiode-based measurement techniques, and present the experimental results.

Keywords:

Bunch length, Filling pattern, Photodiode

Diagnosics for PAL-XFEL operation

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Abstract:

Diagnostic systems are "eyes" and "ears" of an accelerator. The stable operation of an accelerator heavily depends on its diagnostic systems. X-ray Free Electron Laser of Pohang Accelerator Laboratory (PAL-XFEL) is not an exception. Various kinds of diagnostics are continuously monitoring the electron beam in the PAL-XFEL. In this talk, PAL-XFEL will be introduced with its diagnostic systems and the operation status of PAL-XFEL will be presented including the recent progress of PAL-XFEL.

Keywords:

PAL-XFEL, Diagnostics

Improvement of the Beam Diagnostic System at KOMAC

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Abstract:

To serve the stable and high-quality proton beam to accelerator users, it is important to characterize the beam accurately and precisely. Thus, various work on the beam diagnostics was carried out. Improvement of the operated diagnostics was conducted. Tomography technology was applied to a quadrupole scan emittance measurement. It can measure beam profile on the phase space. In addition, a test-stand for the beam diagnostics was developed. The test stand consists of a microwave ion source, low energy beam transport(LEBT), an RFQ, and beamlines. A spectrometer for optical emission spectroscopy to measure the plasma properties of the ion source, and a two-dimensional beam profile monitor using a scintillating screen and an optical sensor were developed. A beam position and phase monitor(BPM), a wire scanner, a multi-wire grid will be studied at the test stand. Also, machine learning technique has been introduced to enhance beam quality, and advance the accelerator operation system. It is expected that the machine learning technique can contribute to the advancement of accelerator operation in spite of limited beam diagnostic information.

Acknowledgments

This work has been supported through KOMAC operation fund of KAERI by the Korean government (MSIT).

Keywords:

Proton accelerator, Beam diagnostics, Tomography, Machine learning

Telecom-wavelength single photon source based on quantum dots in a tapered nanobeam

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Abstract:

Telecom-wavelength single photons are critical components for long-distance quantum networks. However, bright and pure single photon sources at telecom wavelengths are still challenging to achieve. Here, we demonstrate a bright telecom-wavelength single photon source based on a tapered nanobeam containing InAs/InP quantum dots. The tapered nanobeam enables directional and Gaussian-like far-field emission of the quantum dots. Consequently, using above-band excitation we obtain an end-to-end brightness of $4.1 \pm 0.1\%$ and first-lens brightness of $27.0 \pm 0.1\%$ at the ~ 1300 nm wavelength. Furthermore, we adopt quasi-resonant excitation to reduce both multiphoton emission and decoherence from unwanted charge carriers. As a result, we achieve a coherence time of 523 ± 16 ps and post-selected Hong-Ou-Mandel visibility of 0.91 ± 0.09 . These results mark a step toward a practical fiber-based single photon source at telecom wavelengths for long-distance quantum networks.

Keywords:

single photon sources, quantum dots, telecom wavelength, two-photon interference

Large-scale nanowatt programmable photonic circuits

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Abstract:

Integrated photonics provides an efficient way to implement complex optical systems on a single high-performance chip. The integration density of photonic integrated circuits (PICs) has grown rapidly over the last decade, based on advanced semiconductor manufacturing processes. Most of the development work to date has focused on application-specific PICs that are targeted at only one application and cannot be reused for other purposes. On the other hand, a general-purpose programmable PICs can significantly reduce development time and costs by using a general purpose programmable PIC similar to a field programmable gate array (FPGA) in electronics. In recent years, several groups have reported programmable photonic circuits (PPCs) consisting of the identical waveguide mesh array. The connections between them are reconfigurable and the functionality of the circuit can be programmed as needed. However, the demonstration scale is still in its infancy compared to the FPGA scale. This is mainly due to the high-power consumption of the tuning mechanism (that is, the phase shifter) and the large area per unit element.

In this talk, we'll show you a promising way to scale PPC based on Silicon Photonic MEMS technology. Tuning is done by charging a MEMS capacitor rather than constantly passing current through the metal heater, dramatically reducing the power consumption of the tuning element to nanowatt levels. In addition, PPC requires fewer elements to implement a single mesh. In contrast to the MZI-based 2x2 adjustable coupler, which requires a long thermo-optical phase adjustment arm and two 3dB directional couplers, the coupling is directly tuned by a MEMS operation. Therefore, the area occupied by the mesh is significantly reduced compared to thermo-optic based work, especially for recirculating meshes arranged in two dimensions. Here we show a programmable photonic array consisting of 16 identical meshes. The coupling between these meshes is controlled by an electrostatic MEMS actuator. Arrays have been used to demonstrate a variety of optical circuits with nanowatt-level power consumption.

Keywords:

Programmable photonic circuits, low power consumption, large-scale

All-optically programmable nanophotonics

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Abstract:

Advances in nanoscale optical resonators such as microdisk, photonic crystal resonators, plasmonic nanogap have realized significantly enhanced light-matter interactions in an extremely small volume that reads new physics and has made various applications feasible. Light focusing beyond the diffraction limit by nanoplasmonics, fabrication of nanoscale lasers, ultra-enhanced nonlinear optics in high-Q micro/nano optical resonators, a single nanoparticle monitoring, ultra-sensitive sensing of the various physical units might be good examples. However, without precision and high-functional control of such nanodevices in desired time and desired position, it is impossible to implement such useful applications. Especially, all-optical controls of nanodevices have been intensely studied since it has its unique advantage such as non-contact, high-controllability origin from many degrees of freedom of the light, the existence of superposition and interference, and ultra-fast modulation. In this presentation, we report two different topics that one is optical trapping and monitoring of a single nanoparticle in a metallic nanogap cavity and the other is an all-optically programmable nanolaser array with switchable modal interference. Our researches are feasible only when all-optical control is implemented, and it is expected to be applied to advanced research such as single-molecule unit bio/chemical sensing and all-optically operating optical computing in the future.

Keywords:

nanophotonics, photonic crystal nanolasers, metallic nanogap

Large, Individually-addressable Ion-based Quantum Information Processor : Performance and Applications

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Abstract:

Under the IARPA LogiQ program, in a collaboration between universities and industrial partners, we have constructed a complex ion-based quantum processor and used it to encode a logical quantum bit. I will report on the performance and verification of our system, its limitations, and its application to simulations of nuclear magnetic resonance and many-body dynamics.

We acknowledge support by the ARO through the IARPA LogiQ program (11IARPA1008), the NSF STAQ Program (PHY-1818914), the AFOSR MURIs on Dissipation Engineering in Open Quantum Systems (FA9550-19-1-0399) and Quantum Interactive Protocols for Quantum Computation (FA9550-18-1-0161), the ARO MURI on Modular Quantum Circuits (W911NF1610349), and the U.S. Department of Energy Quantum Systems Accelerator (QSA) Research Center (DE-FOA-0002253).

Keywords:

Ion trap

An open quantum testbed based on trapped ions

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Abstract:

At Sandia National Laboratories, we are developing and operating an open user testbed for quantum information protocols based on trapped ions, known as the Quantum Scientific Computing Open User Testbed, or QSCOUT. This testbed provides not only the opportunity to perform quantum algorithms and study noisy-intermediate-scale quantum (NISQ) systems, but unlike many commercial testbeds, it also allows users control of the system both at the quantum-circuit level and at the more fundamental pulse-control level to study alternate methods of gate construction and optimization. The system consists of a Sandia microfabricated surface-electrode trap which hosts our qubit register, a chain of Yb-171 ions. Trapped ions provide indistinguishability, high-fidelity gate operations, long coherence times, and all-to-all connectivity. Single- and two-qubit gates are performed with optical Raman transitions, and a multi-channel modulator allows for individual addressing. Here, we present our progress thus far in developing the testbed and running algorithms with two to three ions for our first group of users, as well as some of the experimental challenges encountered in developing such a system. We also discuss the current and anticipated capabilities of QSCOUT, including future testbed developments such as longer ion chains, a cryogenic system, and measuring subsets of qubits mid-circuit. In addition, we will look at QSCOUT's own intuitive quantum programming language, Just Another Quantum Assembly Language (Jaqal), as well as the ability for users to specify their own gate pulses via Jaqal Pulses and Waveforms (JaqalPaw). As such, QSCOUT provides the scientific community a unique opportunity for low-level access to a NISQ trapped-ion system.

Sandia National Laboratories is managed and operated by NTESS, LLC, a subsidiary of Honeywell International, Inc. for the US DOE NNSA under contract DE-NA0003525. This work is funded by the US DOE Office of Science ASCR Quantum Testbed Program. The views expressed here do not necessarily represent the views of the DOE of the US Government.

Keywords:

trapped ions, quantum computing, open user

Engineering an ion trap to build a practical quantum computer

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Abstract:

An ion trap is an exotic quantum system which reveals novel quantum phenomena and has become one of the leading quantum computing platforms. Its promising features include long qubit coherence time, low SPAM (state-preparation and detection) error, high gate-fidelity, and all-to-all qubit connectivity. Building a practical quantum computer with trapped-ion system requires not only an ion trap apparatus but also the whole stack of quantum controls. In this talk, we present the recent progress on building a full-stack trapped-ion quantum computer.

Keywords:

Ion trap

2D Transistors: Promises, Pitfalls and Prospects

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Abstract:

Two-dimensional (2D) semiconductors have attracted tremendous interest as an atomically thin channel for the continued transistor scaling. However, despite many proof-of-concept demonstrations, the full potential of 2D transistors remains elusive. To this end, the fundamental merits and technological limits of 2D transistors need a critical assessment, reality check and objective projection. In this talk, I will briefly review the promises and the current status of 2D transistors, and highlight the widely used device parameters (e.g., carrier mobility, contact resistance) could be frequently misestimated or misinterpreted, and may not be the most reliable performance metrics for benchmarking 2D transistors. We suggest the saturation or on-state current density, especially in the short channel limit, could provide a more reliable measure for assessing the potential of diverse 2D semiconductors, and should be applied for cross-checking different studies, especially when milestone performance metrics are claimed. We next summarize the key technical challenges in optimizing the channel, contacts, dielectric and substrate interfaces and outline the potential pathways to push the limit of 2D transistors; and lastly conclude with a prospect on the critical technical targets, the key technological hurdles to enable the lab-to-fab transition, and the potential opportunities arising in these atomically thin semiconductors.

Keywords:

Computational Electronics, MoS₂, floating-gate field-effect transistors, TMD monolayer, FET

Ultimate scaled devices enabled by two-dimensional materials

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Abstract:

The quest for keeping the pace of Moore's law, so to obtain more complex and performing circuits and systems, can find an ally in new materials and new devices able to work in the very low voltage power supply regime. Two-dimensional materials have shown excellent electronic performance that could enable the development of next-generation devices, but their fabrication still present open issues that have to be solved (as for example the presence of defects, intrinsic hysteresis of the I-V characteristics and son on).

From this perspective, assessing the ultimate performance of two-dimensional materials-based devices (2DMs) can only be addressed through accurate numerical simulations, which can eventually provide fabrication guidelines to the experimental side, and pick the most promising materials out of the more than thousands available layered materials.

Here, we will provide perspectives on the performance to be expected from ultimately scaled devices, in which 2DMs are exploited as channel material. To this purpose, we will present our method of choice i.e. a multi-scale approach, based on DFT and NEGF calculations.

Attention will be focused on the evaluation of the main figures of merit for digital applications, and the exploitation of alternative mechanisms for transport as compared to thermionic emission, as for example tunneling transport or spin transport enabled by new 2DMs.

Keywords:

Computational Electronics, MoS₂, floating-gate field-effect transistors, TMD monolayer, FET

Logic-in-Memory Based on an Atomically Thin Semiconductor

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Abstract:

The growing importance of applications based on machine learning is driving the need to develop dedicated, energy-efficient electronic hardware. Compared with von-Neumann architectures, brain-inspired in-memory computing uses the same basic device structure for logic operations and data storage, thus promising to reduce the energy cost of data-centric computing significantly. Two-dimensional materials such as semiconducting MoS₂ could stand out as a promising candidate to face this obstacle thanks to their exceptional electrical and mechanical properties. Here, we show that wafer-scale grown MoS₂ can be used as an active channel material for developing logic-in-memory devices and circuits based on floating-gate field-effect transistors (FGFET). The conductance of our FGFETs can be precisely and continuously tuned, allowing us to use them as building blocks for reconfigurable logic circuits where logic operations can be directly performed using the memory elements. We show that this design can be simply extended to implement more complex programmable logic and functionally complete sets of functions. Our findings highlight the potential of atomically thin semiconductors for the development of next-generation low-power electronics.

Keywords:

Computational Electronics, MoS₂, floating-gate field-effect transistors, TMD monolayer, FET

Multilevel memory and multivalued logic devices using two dimensional TMD heterostack channel FETs

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Abstract:

Applications of two dimensional (2D) semiconductors have been much oriented to various electron devices, which include multivalued field-effect transistors (FETs). The 2D channel multivalued FETs may resolve power consumption issue in modern integrated circuits. Several n-channel devices are thus reported along with few p-channel devices. Here, both n- and p-channel multivalued FETs are fabricated using p-MoTe₂/n-MoS₂ heterostack channel architecture, where either p- or n-channel ternary value FET is reproducible by switching the stacking order of p- and n-channel layer. Main ternary value mechanism originates from resonant tunnel injection and channel inversion which take place during device operation. For a state-of-the-art device application in 2D electronics, quaternary NAND logic circuit is first time demonstrated by integrating two ternary n-channel FETs and complementary ternary inverter is also fabricated by integrating multivalued p-channel and plain n-channel FET. Beyond multivalued logic devices, we also demonstrate multilevel long-term memory functions operating at maximum 7 V under minimum 60 μs-short pulse, based on van der Waals heterostack n-MoSe₂/n-MoS₂ channel field effect transistors (FETs), to cope with the fourth industrial revolution demanding more efficient data process, memory capacity, and synaptic memory. For multilevel memory mechanism, trap density at the heterostack interface is responsible. Further details of heterostack multilevel memory are to be discussed at the presentation.

Keywords:

Computational Electronics, MoS₂, floating-gate field-effect transistors, TMD monolayer, FET

Highly Efficient Solar Vapor Generation via a Simple Morphological Alteration of TiO₂ Film Grown on a Glassy Carbon Foam

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Abstract:

Effectively utilizing eco-friendly solar energy for desalination and waste water purification has immense potential to overcome the global water crisis. Herein, we demonstrate a highly efficient solar vapor generator (SVG) developed via a simple morphological alteration, from a two-dimensional (2D) TiO₂ film (TF) to one-dimensional (1D) TiO₂ nanorods (TNRs) grown on a glassy carbon foam (CF). Given that evaporation is primarily a surface physical phenomenon, the 1D morphology of TNRs provides a higher evaporation surface area compared to its 2D counterpart. Additionally, the super hydrophilic nature of TNRs ensures an adequate supply of water to the evaporation surface via effective capillary action. Consequently, the 1D TNRs properly utilize photothermal heat, which results in a significant reduction in the convection heat loss. Owing to the synergistic effect of these characteristics, TNRs/CF acquired a high evaporation rate $\sim 2.23 \text{ kg m}^{-2} \text{ h}^{-1}$ and an energy utilization efficiency $\sim 67.1\%$ under one sun irradiation. Moreover, the excellent stability, desalination and self-cleaning capabilities and the facile fabrication method make TNRs/CF suitable for the cost-effective, large-scale device application.

Keywords:

Solar vapor generaiton, Enhanced evaporation surface area, Water management, One-dimensional TiO₂ nanorods

Enhanced Performance of a Flexible and Wearable Piezoelectric Nanogenerator using Semi-insulating GaN:Mg/ZnO Coaxial Nanowires

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Abstract:

Flexible piezoelectric nanogenerators (PNGs) with high power-conversion efficiency are of great interest. Here, we propose wearable PNGs based on pristine magnesium (Mg)-doped GaN (GaN:Mg) and GaN:Mg/ZnO coaxial nanowires (NWs) exhibiting state-of-the-art high-voltage and -current outputs. The PNGs were designed to suppress internal screening by the successful incorporation of Mg in GaN NWs as a p-type dopant and by deposition of a ZnO shell on the GaN:Mg NWs. To deplete the NWs fully of free carriers, Mg is incorporated without activation, which enhanced the resistivity of GaN:Mg NWs by forming inactive Mg-H complexes. The flexible PNG fabricated with pristine GaN:Mg NWs exhibited the maximum output voltage and current of 52 V and 23 μ A, respectively. The junction current screening was suppressed by depositing a ZnO shell with an optimized thickness of 10 nm on GaN:Mg NWs. The PNG fabricated with GaN:Mg/ZnO coaxial NWs showed an enhanced output voltage and current of 66 V and 40 μ A and demonstrated a state-of-the-art high power density of 170 μ W/cm² at an optimum load resistance of 2.5 M Ω . When mounted on the wrist as a wearable healthcare monitoring device, it successfully detected the movement of tendons and muscles as soon as the fingers were moved and exhibited a corresponding change in voltage response.

Keywords:

GaN, nanowire, coaxial, piezoelectric, nanogenerator

Ultrathin CdS-anchored MOCVD-grown Hierarchical ZnO-Si Nanowires for Improved Photoelectrochemical Water Splitting

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Abstract:

To meet the ever-increasing energy demands, development of hierarchical nanostructures with controlled sizes and morphologies is important for achieving efficient light absorption in energy harvesting/conversion devices. We report the sequential fabrication of a three-dimensional hierarchical ZnO-Si nanowires (NW) structure (ZnO-Si HNWs) utilizing metal organic chemical vapor deposition technique for photoelectrochemical water splitting. High quality ZnO NWs were grown on SiNWs precoated with low temperature ZnO buffer layer emphasizing plausible growth mechanism. An ultrathin layer of CdS shell/nanoparticles was chemically anchored to ZnO-Si HNWs to improve visible-light absorption. When compared to bare ZnO-Si HNWs, the optimally designed CdS/ZnO-Si HNWs showed an 8- and 14-fold increase in photocurrent density and photoconversion efficiency at 0 V vs Ag/AgCl, respectively. The enhanced performance of the hierarchical photoanodes was attributed to their improved photoabsorption by the trapping and scattering of the incident photons and suppressed the internal charge recombination by forming a type-II staggered band alignment with ZnO. The facile integration of group II-VI materials with Si could open the path for next-generation applications.

Keywords:

hierarchical, nanowire, ZnO, photoelectrochemical, water splitting

Enhanced Photoelectrochemical water splitting performance of Au- Nanoparticles decorated gallium nitride photoanode

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Abstract:

Photoelectrochemical (PEC) water splitting is a promising approach to generate sustainable clean fuels using two of the most abundant resources on earth sunlight and water. Still, it needs a lot of effort to approach commercial scale production. A key issue in PEC water splitting is the evolution of photoelectrodes, which needs to be optically efficient and chemically stable. Coupling of noble metal nanoparticles with semiconductors is a promising approach to boost up the PEC water splitting efficiency of photoelectrodes. Here, we report a facile fabrication method for photoanodes by depositing gold nanoparticles (Au NPs) on gallium nitride (GaN). The Au NPs/GaN photoanode have shown 13% improvement in photocurrent density compared to bare GaN, at zero bias. The photoconversion efficiency of Au NPs/GaN photoanode is enhanced 1.15 times with respect to pristine GaN at -0.5V versus Ag/AgCl. The stability of Au NPs/GaN photoanode is also improved. These significant improvements in efficiency and stability of Au NPs/GaN photoanodes are associated with light harvesting and trapping of hot electrons from Au NPs at GaN photoelectrode.

Keywords:

GaN, nanowire, photoelectrochemical, water splitting, Au nanoparticle

Connecting Qubits to Quantum Algorithms

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Abstract:

In this presentation, Jan Benhelm and Sadik Hafizovic will give a brief introduction to Zurich Instruments' Quantum Computing Control System. They will show how Zurich Instruments helps customers speed up their experiments, linking their qubits to quantum algorithms. They will also report on recent hardware and software developments that are essential for scaling up to 100 qubits and more. Finally, they will take a quick look at the roadmap to sketch the next steps for Zurich Instruments and for the quantum technology community.

Keywords:

Quantum, Computing, Qubit, Algorithms

The Next Generation of Qubit Control: SHFSG Signal Generator

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Abstract:

In this video, Jan, Mark and Bruno present the SHFSG Signal Generator and discuss how this instrument represents the next step for quantum computing control systems. The presentation includes practical demonstrations showing how to operate the instrument at 8.5 GHz without mixer calibration, how to maximize quantum gate fidelities thanks to high-purity signals, and how to control up to 8 superconducting or spin qubits per instrument.

Keywords:

Quantum, Control, Qubit

Transient acquisition using LabOne (DLTS)

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Abstract:

This tutorial is an introduction to capacitance transient acquisition with the MFIA Impedance Analyzer and the LabOne instrument control software. Learn how to produce voltage pulses, optimise settings and get to know the Plotter and DAQ Modules of LabOne. This tutorial was part of the first Zurich Instruments DLTS User Meeting.

Keywords:

Impedance, DLTS, Deep-level transient spectroscopy

The Short-Baseline Sterile Neutrino Oscillation Program at Fermilab

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Abstract:

This talk will present an introduction to the Short-Baseline Neutrino (SBN) Program at Fermilab that includes the MicroBooNE, ICARUS, and SBND experiments. The status of the program and expectations for probing sterile neutrino oscillations will be presented.

Keywords:

SBND, MicroBooNE, ICARUS, Sterile Neutrino, LArTPC

First Results from the Muon $g-2$ Experiment at Fermilab's Muon Campus

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Abstract:

The much anticipated initial results from the Muon $g-2$ experiment at Fermilab's Muon Campus were released earlier in the year. The new determination of the muon's anomalous magnetic moment is in good agreement with the intriguing value obtained at Brookhaven National Laboratory 20 years ago. The Muon Campus at Fermilab is a new accelerator facility capable of delivering the intense beams of muons required for the Muon $g-2$ and Mu2e experiments. This talk will discuss the Muon Campus physics program with an emphasis on the recent Muon $g-2$ results.

Keywords:

muon $g-2$, Mu2e, Muon Campus

Neutrinoless double beta decay experiments - Focusing on AMoRE project

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Abstract:

I will briefly review the neutrino physics related to neutrinoless double beta decay observation, the meaning of the discovery, and the relationship with other experimental observations in the laboratory and cosmology on the neutrino mass and properties. And I will describe the experimental status of the double beta decay experiments, and present the perspectives in the near future. Then, I will present the status of AMoRE project in IBS, Korea, which is one of the near future experiments. The results of the experiments obtained up to now will be described, and the preparation and perspectives of the full scale of the experiment will be presented.

Keywords:

Neutrinos, Double beta decay, Mass ordering, Majorana particle

Axion dark matter searches at CAPP

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Abstract:

IBS-CAPP is currently performing a number of high sensitivity axion dark matter experiments in the frequency range above 1 GHz, placing it on the top of its field internationally. This is the culmination of several innovations developed at CAPP combined with the highest magnetic fields based on new technology. CAPP proved that Korea can be successful in high-risk, high-physics potential projects when superb engineering skills are properly matched with breakthrough accomplishments in our field. For the first time in the world we are able to produce a functional superconducting cavity capable of maintaining its superconductivity in the presence of strong external magnetic field, tested up to 8 Tesla. We have developed high efficiency microwave cavities capable of probing high frequency axions without loss of volume, while the total physical and noise temperature of our systems are the best in the world. Combined with large magnetic fields (12 Tesla), based on Nb₃Sn and conventional NbTi superconducting (SC) coils, with a total stored magnetic energy of 5.6 MJ, we are ready to scan the 1-8 GHz axion frequency range with better than DFSZ sensitivity, placing us on the top of our field internationally.

Further innovations and improvements in our system will enable us to maintain the leadership position beyond the 8 GHz frequency range.

Furthermore, a combination of the high-sensitivity EDM experiments and experiments testing monopole-dipole forces, can illuminate the axion physics without requiring it to be the dominant dark matter in our galaxy.

Keywords:

Axions, dark matter, Storage ring EDM

The ALICE experiment at the CERN LHC

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Abstract:

After close to 20 years of preparation, the dedicated heavy-ion experiment "A Large Ion Collider Experiment (ALICE)" at the CERN Large Hadron Collider (LHC) accelerator has run successfully for the last 10 years to investigate the properties of the Quark-Gluon Plasma that is the hottest and densest matter in the Universe. The matter is reproduced in the center of the ALICE by accelerating and colliding two lead ions at a few TeV in the LHC accelerator. After a short introduction into the physics of ultra-relativistic heavy-ion collisions, this talk recalls the main design choices made for the detector, the performance and important outputs of ALICE for the last 10 years. Finally, it summarizes the subject by addressing the promising outlook of heavy-ion experiment for the next 10 years that ALICE Collaboration is willing to achieve.

Keywords:

LHC, ALICE, heavy-ion collisions

Study of partonic structure of nucleon and nucleus at the Electron Ion Collider

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Abstract:

The Electron-Ion Collider (EIC), which will be constructed at Brookhaven National Laboratory, is planned to be operational in the 2030s. The primary purpose of experiments at the EIC is to resolve unanswered questions on the partonic structure of nucleons and nuclei from the early deep-inelastic scattering experiments. Remarkable developments are ongoing on the experimental side, such as accelerator, detector, data analysis technique, and others to improve the precision of the measurement.

Key questions that the EIC will address are the origin of mass and spin of nucleon, the partonic structure of nucleon in spatial and momentum space, the gluon saturation in a dense environment inside nuclei, and the interaction of partons with normal nuclear matters. In this presentation, these physics topics and on-going studies for the EIC will be introduced

Keywords:

Electron Ion Collider

Simulation study of dual-readout calorimeter for the ECCE experiment at the Electron Ion Collider

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Abstract:

A Dual-readout Calorimeter(DRC) consisting of Cherenkov fibers and Scintillating fibers has been developed for future collider experiment. Using two types of fiber with different responses allows us to measure electromagnetic and hadronic shower simultaneously with a high resolution. The DRC is proposed as a candidate calorimeter at forward rapidity for the ECCE experiment at the Electron Ion Collider(EIC). For detailed performance study of the DRC in ECCE, a simulation framework such as detector geometry, readout, data structure is being implemented based on the framework developed for the future collider experiments. In this presentation, the status of simulation study of the DRC for the EIC and future plan will be present.

Keywords:

ECCE, Electron Ion Collider, Dual Readout Calorimeter

Study of jet measurements with a dual-readout calorimeter for the EIC

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Abstract:

The Electron Ion Collider (EIC) to explore the partonic structure of nucleon and nucleus will be constructed at Brookhaven National Laboratory. The Dual-Readout Calorimeter (DRC) proposed for the future collider experiments is also considered as a candidate calorimeter system for the experiment at the EIC. The DRC consisting of Cherenkov and scintillating fibers can measure electromagnetic and hadronic energy showers event-by-event basis, and this allows a high precision energy resolution for hadrons and jets. A simulation study on the jet reconstruction performance with the DRC at forward rapidity for the EIC has been performed. In this presentation, the current status of on-going study on jet measurements with the DRC for the EIC will be presented.

Keywords:

EIC, Dual-Readout Calorimeter (DRC), jet

Simulation study of b -jet tagging algorithms for sPHENIX at RHIC

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Abstract:

Jets including heavy flavor quarks (HF-jets) are mostly produced from initial hard scattering in relativistic heavy ion collisions. Therefore it is a good probe to study the properties of quark gluon plasma produced from heavy ion collisions. Jets initiating from bottom quarks (b -jets) can be identified by the characteristic of long lifetime of b -hadrons. sPHENIX experiment at Relativistic Heavy Ion Collider is a dedicated experiment for precise measurements of b -jets with a MAPS based vertex tracker (MVTX). Extensive simulation study has been performed to develop and test b -jet tagging algorithms such as secondary vertex method and displaced track counting method. In this talk, simulation study on b -jet tagging algorithms and their performance at sPHENIX will be presented.

Keywords:

sPHENIX, b -jet

Material studies of Dual-Readout calorimeters for future collider experiments

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Abstract:

The electron ion collider (EIC) is the future particle accelerator to be built at the Brookhaven National Laboratory. It will collide electrons and various nuclei to study the internal structure of nuclei, including the spin and momentum distribution of quarks and gluons. To fit the high resolution for the hadron energy reconstruction at forward region, we propose to construct the dual readout calorimeter (DRC). In this presentation, we report the performance of the DRC whose dimension is adjusted to fit EIC. In addition, we investigate the utility of Tungsten as an alternative material as it has different Moliere radius from the default one, copper. To achieve better energy resolution, we also study the only-scintillating fiber configuration without Cerenkov channel. For these performance study, we simulate the response of DRC by electrons, pions, photons, and jets using GEANT4 package.

Keywords:

future collider experiments, The electron ion collider (EIC), Dual-Readout calorimeter, GEANT4 simulation

Artificial neural network description of light nuclei

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Abstract:

We describe the ground states of light nuclei by using neural network wavefunctions with the variational principle. The accuracy of the variational principle is determined by the ansatz for the trial wavefunctions. Such a limitation is removed in the artificial neural network calculations. In the artificial neural wavefunctions, we need not specify any particular form of the ansatz, and the accuracy is limited only by neural network configurations such as the number of layers and nodes. We obtain the ground states of a few nucleon systems such as deuteron, triton, ${}^3\text{He}$, and ${}^4\text{He}$. Extensions of our work to the light hypernuclei and alpha cluster systems will also be discussed.

Keywords:

Artificial neural network, variational principle, light nuclei

Covariant Density Functional Theory with Localized Exchange Terms

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Abstract:

The covariant density functional theory (CDFT) provides a unified and successful description on almost all the nuclides in the nuclear chart. It has been found that the exchange terms can play an important role in the CDF, which, however, are neglected in most of the widely used CDFs due to the nonlocal feature. In this work, a new covariant density functional PC-PKF with localized exchange terms is proposed, which is built based on the relativistic point-coupling models. The exchange terms from the four-fermion interactions can be easily treated via Fierz transformation. The new density functional PC-PKF is determined by the empirical saturation properties and the *ab initio* calculations for nuclear matter, and the ground-state properties of spherical nuclei. The success of PC-PKF is illustrated by studying the infinite nuclear matter and finite nuclei including the ground-state properties and the Gamow-Teller resonance. Particularly, PC-PKF eliminates the spurious shell closures at $Z=58$ and 92 , which emerges in most of the existing CDFs. It also provides a self-consistent description for Gamow-Teller resonances (GTR) without any additional parameters by considering the localized exchange terms. The observed excitation energies of GTR are reproduced nicely by PC-PKF.

Keywords:

Covariant Density Functional Theory, Localized exchange terms, Fierz transformation, Spurious shell structure, Gamow-Teller resonance

Effects of deformation and pairing correlations in the nuclear structure

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Abstract:

The TF is introduced in the pairing interaction in the residual interaction added to the meanfield described by a deformed Woods Saxon potential. The BCS type pairing interactions comprising isoscalar and isovector parts are treated by the Brueckner G-matrix based on the CD Bonn potential. By switching on and off the TF and varying the deformation parameter in the ground state of the nuclei we deduce meaningful correlations between the TF and the deformation on the GT strength distributions.

Keywords:

deformation, Tensor force

Probing Gravity through Cosmology

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Abstract:

TBD

Keywords:

cosmology, gravity

Understanding the interaction between dark sectors from BINGO telescope

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Abstract:

In this talk I will review the interaction model between dark energy and dark matter. I will introduce the observational signatures of such interaction and especially I will describe the forthcoming observation from BINGO telescope, which will allow a clear understanding of the physics of the dark sector.

Keywords:

Dark energy, Dark Matter, Observation, BINGO telescope

Correlated nodal surface semimetal in Mn-based kagome compound $\text{Sc}_3\text{Mn}_3\text{Al}_7\text{Si}_5$

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Abstract:

Topological semimetals hosting zero-dimensional (Weyl, Dirac semimetals) and one-dimensional (nodal line, nodal link semimetals) Fermi surfaces have been actively investigated for their topological protections and interesting bulk-boundary correspondences. Even more interestingly, recently a new kind of topological semimetal, the so-called nodal surface semimetal, has been reported where the two-fold degeneracy is enforced on a two-dimensional surface in the three-dimensional momentum space. Here we employ ab-initio electronic structure calculations to report that $\text{Sc}_3\text{Mn}_3\text{Al}_7\text{Si}_5$, a metallic compound with layered Mn-based kagome planes and with no reported magnetic order down to $T = 1.8\text{K}$, is a nodal surface semimetal protected by non-symmorphic symmetries. Even more interestingly, dynamical mean-field theory calculations reveal that electronic correlations flatten the band dispersion and induce magnetic fluctuations within the nodal surface bands. This compound can be a rare example hosting weakly-dispersive bands with the so-called Hund's metal character, manifesting a van Hove singularity close to the Fermi level and may give rise to interesting instabilities. We conclude this talk by comparing our findings with preliminary experimental results.

Keywords:

nodal surface semimetal, Hund's metal, kagome lattice, dynamical mean-field theory, ab-initio electronic structure calculation

Origin of the charge density wave in the kagome metal CsV₃Sb₅: an optical study

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Abstract:

The recently discovered kagome metals AV_3Sb_5 ($A = K, Rb, \text{ or } Cs$) have aroused considerable interest, as these materials exhibit multiple quantum states, such as charge density wave (CDW), superconductivity and non-trivial topological states. In this talk, we present a detailed study of the optical properties of CsV₃Sb₅ for a large number of temperatures above and below the CDW transition. Above T_{CDW} , the optical conductivity reveals two Drude components: a narrow one and a broad one. An investigation into the calculated band structure suggests that the narrow Drude component is associated with a light electron-like and multiple Dirac bands, while the broad Drude component arises from heavy-hole bands with saddle points near the Fermi level at the M points of the Brillouin zone. Below T_{CDW} , the opening of the CDW gap is clearly observed in the optical conductivity spectrum. The spectral weight of the broad Drude component is substantially suppressed by the gap, while the narrow Drude component remains unchanged. In addition, interband transitions that involve the electronic states near the saddle points at M gain some weight and shift to higher energy. These observations attest to the importance of saddle point nesting in driving the CDW instability in CsV₃Sb₅.

Keywords:

kagome metal, charge density wave, optical spectroscopy

A flat band-induced correlated kagome metal

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Abstract:

The notion of an electronic flat band refers to a collectively degenerate set of quantum mechanical eigenstates in periodic solids. The vanishing kinetic energy of flat bands relative to the electron-electron interaction is expected to result in a variety of many-body quantum phases of matter. Despite intense theoretical interest, systematic design and experimental realization of such flat band-driven correlated states in natural crystals have remained a challenge. Here we report the realization of a partially filled flat band in a new single crystalline kagome metal Ni₃In. This flat band is found to arise from the Ni-orbital wave functions localized at triangular motifs within the kagome lattice plane, where an underlying destructive interference among hopping paths flattens the dispersion. We discuss unusual metallic and thermodynamic responses suggestive of the presence of local fluctuating magnetic moments originating from the flat band states, as well as an observed non-Fermi liquid behavior. These findings demonstrate a lattice and orbital engineering approach to designing flat band materials, which may be applied as a novel means to construct correlated electronic states (arXiv/2106.10824).

Keywords:

kagome lattice, flat band, non-Fermi liquid

Twofold van Hove singularity and origin of charge order in topological kagome superconductor CsV_3Sb_5

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Abstract:

The layered vanadium antimonides AV_3Sb_5 ($A = \text{K, Rb, Cs}$) are a recently discovered family of topological kagome metals with a rich phenomenology of strongly correlated electronic phases including charge order and superconductivity. Understanding how the singularities inherent to the kagome electronic structure are linked to the observed many-body phases is a topic of great interest and relevance. Here, we combine angle-resolved photoemission spectroscopy and density functional theory to reveal multiple kagome-derived van Hove singularities (vHs) coexisting near the Fermi level of CsV_3Sb_5 and analyze their contribution to electronic symmetry breaking. Intriguingly, the vHs in CsV_3Sb_5 have two distinct flavors – p -type and m -type – which originate from their *pure* and *mixed* sublattice characters, respectively. This twofold vHs is unique property of the kagome lattice, and its flavor critically determines the pairing symmetry and ground states emerging in AV_3Sb_5 series. We establish that, among the multiple vHs in CsV_3Sb_5 , the m -type vHs of the d_{xz}/d_{yz} kagome band and the p -type vHs of the $d_{xy}/d_{x^2-y^2}$ kagome band cross the Fermi level to set the stage for electronic symmetry breaking. The former band exhibits pronounced Fermi surface nesting, while the latter contributes via higher-order vHs. Our work reveals the essential role of kagome-derived vHs for the collective phenomena realized in the AV_3Sb_5 family, paving the way to a deeper understanding of strongly correlated topological kagome systems.

Keywords:

kagome lattice, Angle-resolved photoemission spectroscopy

High-harmonic polarimetry to resolve coherences in Van der waals crystals

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Abstract:

I will show how the polarization of high-order harmonics reveals interference between multiple quantum paths responsible for harmonic emission from the 2-dimensional van der Waals crystals MoS₂ and ReS₂. Our results reveal the microscopic high-field physics inside these materials with exquisite detail and suggest a simple path towards controlling their high-field response.

Keywords:

High-harmonic generation, polarimetry, quantum materials

Ultrafast nonlinear photonics in Kane-Mele two-dimensional topological insulators

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Abstract:

The strong intrinsic spin-orbit coupling in two-dimensional materials described by the Kane-Mele model provide a unique platform for achieving a multitude of topological states. The mass gap in the energy band structure of these systems can be manipulated on-demand via interaction with, for instance, static electric and magnetic fields, off-resonance circularly polarized lasers, or antiferromagnetic exchange fields, allowing for the monolayer to be driven through various topological phase transitions. In the last decade, several studies have investigated the optoelectronic properties of these monolayers in the linear regime. Nevertheless, the crossroads between spin-orbit-interactions, topology, Dirac physics, and ultrafast nonlinear photonics in Kane-Mele materials, potentially allowing access to topological phase transition signatures, material symmetries, selection rules, and relaxation mechanisms otherwise screened by spurious effects in the linear response, remains uncharted to date. Here we will discuss our recent investigations in these topics and show that the ultrafast nonlinear response in time and frequency domains encodes fingerprints of the topology of Kane-Mele systems, which could potentially be detected experimentally.

Keywords:

Kane-Mele Topol. Insulators, Ultrafast Nonlinear Photonics, Topol. Phase Transitions

Dynamical magnetoelectric coupling and optical effect in Ni_3TeO_6 : from ab-initio simulation of optical d-d excitation spectra

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Abstract:

Nonreciprocal directional dichroism is an unusual light-matter interaction that gives rise to diode-like behavior in low symmetry materials. The chiral varieties of nonreciprocal directional dichroism are particularly scarce due to the requirements for strong spin-orbit coupling, broken time reversal symmetry, and a chiral axis. We bring together magneto-optical spectroscopy and first principles calculations to reveal high energy, broad band nonreciprocal directional dichroism in Ni_3TeO_6 with special focus on behavior in the metamagnetic phase above 52 T. Using first-principles-based methods it is shown how the Ni^{2+} d-to-d on-site excitations develop magnetoelectric character via relativistic spin-orbit coupling, which present a microscopic model that unlocks the door to theory-driven discovery of chiral magnets with nonreciprocal directional dichroism.

Keywords:

nonreciprocal directional dichroism, optical diode effect, spin-orbit coupling, first-principles electronic structure calculation, Ni_3TeO_6

High-non linear optical spectroscopy in quantum materials

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Abstract:

The next technological revolution will lie on ultrafast electronic devices, our capability to control the transistor speeds and create those ultrafast or quantum transistors by using quantum materials. However, I believe, this is yet an interesting fundamental and technological challenge. Instances, how to control the electron-structure to build the unique duo of conducting (surface/edge state)-isolating (bulk states) features in physics material. The latter material typically is named topological material. In this talk, I will address the above question by means of the paradigmatic Haldane model as a source of toy-ideal description of a real topological insulator. I numerically calculate high-order harmonic generation (HHG) spectra and analyze the circular dichroism. This shows that nonlinear optical emission can surprisingly capture signatures of topology and topological phases transition in the paradigmatic Haldane model, specially when the driven field is circularly-polarized, both left-hand and right-hand.

I will conclude my presentation with the test of my theoretical discoveries in common cooperation with the Stanford University (USA) and SLAC. We probe that topological current states manifest a new regime not before measured in terms of what we named Anomalous Ellipticity Yield if the high harmonics in Bi₂Se₃

Keywords:

Ultrafast Nonlinear Optical Spectroscopy, Quantum Materials, Topological Insulators, Haldane Model, Topological phases and Topological Phase Transitions

Multi-extreme conditions induced by shock compression

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Abstract:

Shock compression is a unique technique to generate multi extreme conditions in materials for a short time (nanoseconds to microseconds) because shock wave propagates as fast as tens micrometers per nanosecond and because pressures exceeding the material strength can be generated. The shock compressed state is determined through the Rankine-Hugoniot relations when we measure two parameters such as shock velocity and particle velocity. Strain rate at the shock front is 10^6 s^{-1} to 10^9 s^{-1} , depending upon how we generate a shock wave. Temperature induced by shock compression depends upon the pressure and compressibility of material. Most of insulators become reflective at shock pressures over about 200 GPa and thermally delocalized electrons play an important role to change material properties of warm dense matters. There are versatile applications of shock wave in physics, chemistry, Earth and planetary science, etc. I will show some experimental results on dynamic behaviors of materials at multi extreme conditions as well as recent experimental developments using x-ray free electron laser (XFEL). Although non-equilibrium states are known such as kinetic problems historically, we may have a chance to observe materials formed under metastable conditions in a shock compression process including compression, steady state, and release state realized by shock wave and subsequent rarefaction wave. Using shock compression techniques, novel materials are to be quenched at extreme fast rates.

Partial support by NSFC No. 41974099 is acknowledged.

Keywords:

Shock wave, Shock compression process, Dynamic behaviors, Warm dense matter, High strain rate phenomena

Ultrafast electron beam, a tool for exploring microscopic dynamics of materials

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Abstract:

In the process of knowing something, 'light' is one of the most important means of recognition for mankind. Humans have been able to increase their understanding of the world by observing distant universes and very tiny atoms. In the 20th century, the 'new light' based on the understanding of matter and wave has expanded to include laser, synchrotron radiation, and particle beam. This study focuses on ultrafast electron beam technology that observes the movement of fast-moving atoms. Recently, the Korea Atomic Energy Research Institute has built the fastest electron diffraction facility in the world to observe the motion of atoms or molecules. We introduce the achievements of dramatically increasing the electron beam brightness and fundamentally eliminating timing jitter between pumping optical pulses and probing electron beams. It concludes with an overview of the current application experiments and the challenge of ultrafast electron diffraction technology with a timing resolution of several femtoseconds or less.

Keywords:

Ultrafast electron diffraction, femtosecond laser pulse, dynamics of atoms and molecules

Interplay between defect-dipole and spontaneous polarization in a square tensile strained ferroelectric

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Abstract:

The ground states manipulation of complex oxides using heterostructures offers a breakthrough for creating/enhancing advanced functionalities and understanding their fundamental nature. The feasible materials and physical properties strongly depend on the symmetry and misfit lattice constant of substrates for the epitaxial heterostructures and free-standing membranes. So far, prevalent perovskite oxide substrates, such as cubic SrTiO₃ and orthorhombic $R(\text{Al}/\text{Sc}/\text{Lu})\text{O}_3$ (R = rare earth), have been prominently employed. However, their congenital symmetry and limited lattice constants circumscribe advances in the functionality and material diversity of the heterostructures. Recently, we developed a new substrate of cubic perovskite BaZrO₃ to boost square tensile strain. The +8.7 % larger lattice constant of BaZrO₃ than that of SrTiO₃ enables the application of a very large tensile strength, and its cubic symmetry provides a 4-fold symmetric square lattice on the (001) surface. We found that oddly uncommon square tensile strain among perovskite substrates coins intriguing physical phenomena, in which controllable defect-dipoles cooperate with spontaneous ferroelectric polarization. In this talk, we will discuss the emergent ferroelectric/dielectric properties in the square tensile strained ferroelectric thin film on the BaZrO₃ substrate.

Keywords:

new perovskite substrate, defect-dipole, ferroelectric, square tensile strain

Rashba effects on the transport properties of low-dimensional systems

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Abstract:

Systems having inherent structural asymmetry retain the Rashba-type spin-orbit interaction, which ties spin and momentum of electrons in the band structure leading to coupled spin and charge transport. This coupled spin-charge transports have been evidenced in various experimental platforms and could be utilized for various electronics. In this talk, I will present Rashba effects on the transport properties of low-dimensional systems, such as LAO/STO interface and PtSe₂. The broken inversion symmetry in these systems can induce intriguing transport properties. When the time-reversal symmetry is further broken, the system could exhibit directional propagation of itinerant electrons, i.e. the rightward and leftward currents differ from each other. In addition, the Rashba spin-orbit interaction can be further tuned by applying gate bias, so does the nonreciprocal charge transport

Keywords:

Rashba spin-orbit interaction, oxide interface, nonreciprocal charge transport

Template Engineering of Metal-to-Insulator Transitions in Epitaxial Bilayer Nickelate Thin Films

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Abstract:

Understanding metal-to-insulator phase transitions in solids has been a keystone not only for discovering novel physical phenomena in condensed-matter physics but also for achieving scientific breakthroughs in materials science. In this work, we demonstrate that the transport properties (i.e., resistivity and transition temperature) in the metal-to-insulator transitions of perovskite nickelates are tunable via the epitaxial heterojunctions of LaNiO_3 and NdNiO_3 thin films. A mismatch in the oxygen coordination environment and interfacial octahedral coupling at the oxide heterointerface allows us to realize an exotic phase that is unattainable in the parent compound. With oxygen vacancy formation for strain accommodation, the topmost LaNiO_3 layer in $\text{LaNiO}_3/\text{NdNiO}_3$ bilayer thin films is structurally engineered and it electrically undergoes a metal-to-insulator transition which does not appear in metallic LaNiO_3 . Modification of the NdNiO_3 template-layer thickness provides an additional knob for tailoring the tilting angles of corner-connected NiO_6 octahedra and the linked transport characteristics further. Our approaches can be harnessed as practical routes for controlling the degrees of correlation between order parameters in complex oxides precisely and for designing new functional materials through oxide thin-film heterostructuring.

Keywords:

metal-to-insulator phase transition, template engineering, oxide, thin film, heteroepitaxy

Energy-efficient mechanical switching of metastable (111)-oriented perovskite ferroelectric oxides

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Abstract:

Switching ferroelectric polarization via mechanical force has recently emerged as a fascinating alternative to conventional switching of polarization using electric fields. Its broad implementation in nanoelectronics requires not only improving energy efficiency, but also the ability to write high-density ferroelectric nanodomains. However, it remains a challenge to meet both requirements simultaneously. In this presentation, we propose a general strategy exploiting metastable ferroelectrics to realize energy-efficient mechanical writing of high-density nanodomains. In an artificial metastable ferroelectric, i.e., CaTiO₃ (111) film, we demonstrate mechanical switching of polarization using remarkably low mechanical forces down to 100 nN. Furthermore, we succeed in mechanically writing ferroelectric domain lines as narrow as 10 nm, promising the ultrahigh data-storage density of up to 1 Tbit cm⁻². Our work sheds light on the mechanical switching of ferroelectric polarization as a viable key element for next-generation energy-efficient nanoelectronics and nanoelectromechanics.

Keywords:

Flexoelectrics, Mechanical switching, Metastable ferroelectrics

Microscopic theory and machine-learning driven simulation of atomic heat transport

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Abstract:

The linear response theory of atomic heat transport relies on the ambiguous decomposition of total energy into energies of individual atoms. However, such ambiguity is *not* a drawback in itself; rather, it can be used to formulate a physical theory of heat transport by requiring it to take the same form for *all* the possible ways of distributing energy among atoms. Here, we show that the general invariance principle dictates the theory of atomic heat transport in the linear response regime [1]. Using machine-learning driven molecular dynamics simulations of a solid-liquid hybrid phase of Cu₂S, we demonstrate that heat conductivity is invariant under general transformations (e.g., random permutation) of atomic energies.

[1] S. Kim and J. Kang, *Phys. Rev. B* **103**, 174209 (2021).

Keywords:

Linear response theory, Heat conductivity, Machine learning

Unraveling the effect for the durability of Pt-Co alloy nanoparticle electrocatalyst via kinetic Monte Carlo simulation driven by machine learning potential

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Abstract:

Global warming and skyrocketing energy demand invoke the energy paradigm shift from fossil fuel to the eco-friendly clean energy source. Fuel cells are one of the pioneers that produce only water as a product. Hyundai and Toyota have already implemented the fuel cell in their electric vehicles.

However, the fuel cell yet is applied in limited application due to the high cost of platinum, known for superior activity in the catalyst. Alloying platinum catalyst with 3d transition metal such as Co and Ni enhances the activity of catalyst even with less amount of platinum. On the other hand, the active dissolution of transition metal from nanoparticles catalyst highlights the durability issue. Although many researchers have suggested methods tailoring for size, shape, and atomic ordering of nanoparticles for more durable catalysts, it is hard to evaluate the effect of each of them independently in the experiment.

Therefore, several papers employed kinetic Monte Carlo (KMC) simulation to describe the degradation of nanoparticle catalysts at the atomic level. However, they cannot connect the temporal evolution of experiments due to the inaccurate force-field or fixed lattice model. Herein, we propose the off-lattice KMC simulation driven by machine-learning potential, which provides the accuracy of density functional theory, to understand the effect of suggestions for better catalyst design.

Keywords:

fuel cell, machine learning potential, kinetic Monte Carlo, Pt alloy

Quantum capacitance of vertical tunnel field-effect transistors: A first-principles study

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Abstract:

The vertical two-dimensional (2D) van der Waals (vdW) heterostructure has been intensively studied for the application of tunnel field-effect transistor (TFET) devices. Despite the similarities between TFET and capacitor architectures, the correlations between quantum capacitance and quantum transport characteristics have been rarely discussed. Carrying out first-principles finite-bias non-equilibrium TFET simulations within the multi-space constrained-search density functional theory (MS-DFT) formalism we have recently developed [1], we elucidate the quantum transport and quantum capacitance properties of the graphene-based TFET in atomistic details. We show that the total capacitance of graphene-based TFET significantly deviates from the classical geometric capacitance due to the low quantum capacitance of graphene electrodes. Under applying the gate-bias, we extract electrode-specific quantum capacitances and find that electrodes exhibit negative quantum capacitances raising the total capacitance at the resonant-tunneling regime. Finally, we extend the study for the defective channel case and study how a point defect introduced within the inner channel region affects the capacitance and transport properties. Our findings provide fundamental insight into the non-equilibrium device characteristics of low-dimensional quantum devices and point towards a future direction for the design of 2D vdW heterojunction devices.

Keywords:

Quantum capacitance, Tunnel field-effect transistor, Non-equilibrium, Density functional theory, Graphene

First-principles calculation of stacking fault energy in semiconductors for solar cell applications

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Abstract:

Stacking fault is one of the main crystal defects which can be found in semiconductor growth like epitaxy or vapor deposition [1]. Stacking faults can be a missing layer or an additional layer in the crystal lattice. As the translational symmetry is broken along the normal direction to the fault, this planar defect potentially has different band edge positions than the host materials. Therefore, the performance of the solar cells can be reduced as the movement of electrons are impeded and recombination is promoted.

In this study, we performed first-principles density functional theory (DFT) calculations to obtain stacking fault energy of several materials. We also constructed Anisotropic Next Nearest Neighbor Ising (ANNNI) models using the total energy of several polytypes with a small number of layers [2]. The predicted stacking fault energy from the ANNNI models was in good agreement with the DFT calculated energies, showing the usefulness of the ANNNI models [3]. The error of the models was reduced by considering the interaction between the three adjacent layers. We also discuss how to suppress the formation of the planar defects in ternary semiconductors such as Cu(In,Ga)Se₂ and ZnSnN₂ [4, 5].

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- [2] *Infinitely Many Commensurate Phases in a Simple Ising Model*, Michael E., Fisher and Walter Selke, *Phys. Rev. Lett.* **44**, 1502 (1980).
- [3] *Calculation of stacking fault energy using anisotropic next-nearest neighbor Ising model*, B.-H. Jeong and J.-S. Park., *New Phys. Sae Mulli* **70**, 630 (2020).
- [4] *Stability and electronic structure of stacking faults and polytypes in ZnSnN₂, ZnGeN₂, ZnSiN₂*, B.-H. Jeong and J.-S. Park., *J. Korean Phys. Soc.* (2021).
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Keywords:

Density Functional Theory, Ising model, Stacking Fault, Chalcopyrite, Solar cells

Berry curvature imprinted in pumped photoemission delay

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Abstract:

Berry curvature determines the topological properties of a material. In recent, the signature of the Berry curvature is observed by various physical quantities like anomalous hall current and circular dichroism. In this research, we theoretically present a new fingerprint of the local Berry curvature by the photoemission delay. Specifically, we calculate the attosecond streaking of angle-resolved photoemission spectroscopy spectra in the Haldane model. The resultant numerical calculations show that the inter-band transition induced by a pump pulse generates the transient photoemission delay, and this delay has an evident dependence on the local Berry curvature. It is agreed with our analytic calculation using time-dependent perturbation theory. This result indicates that the pumped photoemission delay in two-dimensional systems offers information of local Berry curvature.

Keywords:

Attosecond, Photoemission delay, Berry curvature, 2D materials

Topological Tuning in $\text{NiTe}_{2-x}\text{Se}_x$ alloys

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Abstract:

The group-X transition-metal dichalcogenides (TMDs) MX_2 (M=Ni, Pd, Pt; X=Se, Te) recently have attracted considerable interest as topological semimetals hosting new types of low-energy quasiparticles such as type-I and type-II Dirac fermions. The significant feature of this material classification is the strong tilted 3D Dirac cone, where electron/hole-like pockets touch at the Dirac point along a certain momentum direction in the electronic band structure. The symmetry-protected band crossing of the $p_{x,y}$ and p_z derived states of chalcogen atoms, abiding by intralayer hopping, crystal field splitting, and spin-orbit interaction effects, which gives rise to the formation of type-II bulk Dirac point (BDP-II). Here, by performing density functional theory (DFT) calculations combined with scanning tunnelling microscopy (STM), we systematically study the electronic and topological properties of type-II Dirac semimetal NiTe_2 via alloying with metastable NiSe_2 . We find that alloying breaks electron-hole symmetry and then strongly modulate the electronic and topological properties of type-II Dirac semimetal NiTe_2 . In this presentation, the underlying mechanism related to the topological tuning in $\text{NiTe}_{2-x}\text{Se}_x$ alloys will be discussed in detail

Keywords:

NiTe_2 , Type-II bulk Dirac point, alloying, DFT calculations

First-principles study on possible phonon-mediated superconductivity in lacunar spinel GaTa_4Se_8 under pressure

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Abstract:

GaTa_4Se_8 has attracted attention for its interesting physics, such as $J_{\text{eff}} = 3/2$ Mott insulating phase, insulator-metal transition, and superconducting phase under high pressure. Due to the intriguing spin-orbital coupled $J_{\text{eff}}=3/2$ ground state, pressure-induced superconductivity has been studied in the viewpoint of unconventional superconductivity [1, 2]. In this work, we calculated electron-phonon coupling and phonon-mediated superconducting critical temperature (T_c) under pressure via the first-principles method. We found that the calculated T_c by the Allen-Dynes equation yielded 8.4 K at 20 GPa, which is close to the experimental result [3]. This implies that the electron-phonon coupling can play the main role in the superconductivity of GaTa_4Se_8 . Additionally, we examined the dynamical stability of the cubic structure and found that the cubic phase becomes stable at 20 GPa.

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Keywords:

GaTa_4Se_8 , lacunar spinel, first-principles, superconductivity

Assembly of Atomically Thin Crystals for Nano-topotechnology

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Abstract:

Nanoscale materials with functionalities driven from their topology are at the heart of solving many engineering challenges. Two dimensional (2D) materials have been considered as building blocks to artificially construct novel nano-materials, however atomically precise determination of structures is a challenging task. Here, I present versatile and scalable techniques to assemble 2D crystals by stacking and stitching for generating deterministic atomic structures. The 2D films with programmable atomic configurations provide a widely tunable material platform for advanced electrical, chemical and mechanical properties, opening a new era of nano-topotechnology.

Keywords:

2D materials, Assembly

Solution-Processed 2D Nanomaterials Based van der Waals Heterostructures in Wafer-Scale

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Abstract:

Two-dimensional (2D) van der Waals (vdW) materials have been considered as potential building blocks for use in fundamental elements of electronic and optoelectronic devices, such as electrodes, channels, and dielectrics, because of their diverse and remarkable electrical properties. Furthermore, two or more building blocks of different electronic types can be stacked vertically to generate vdW heterostructures with desired electrical behaviors. However, such fundamental approaches cannot directly be applied practically because of issues such as precise alignment/positioning and large-quantity material production. I will demonstrate wafer-scale vdW heterostructures by exploiting the lateral and vertical assembly of solution-processed 2D vdW materials. The high exfoliation yield of the molecular intercalation-assisted approach enables the production of micron-sized nanosheets in large quantities and its lateral assembly in a wafer-scale *via* vdW interactions. Subsequently, the laterally assembled vdW thin-films were vertically assembled to demonstrate various electronic device applications, such as transistors and photodetectors. Furthermore, multi-dimensional vdW heterostructures were demonstrated by integrating one-dimensional carbon nanotubes as a p-type semiconductor to fabricate p–n diodes and complementary logic gates. Lastly, electronic devices were fabricated *via* inkjet printing as a lithography-free manner based on the stable nanomaterial dispersions.

Keywords:

two-dimensional materials, van der Waals heterostructures, solution processing, waferscale, electronics

Growth of 2D layered metal chalcogenides and oxides using MOCVD

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Abstract:

The 2D layered materials are the potential components in next-generation semiconductor devices and quantum devices. For exploring possible applications of 2D layered materials, high-quality and large-scale materials grown by a gas-phase process are required. In this talk, I will introduce recent advances in gas-phase growth of 2D layered materials, including transition metal dichalcogenides, metal oxy-chalcogenides, and metal oxides.

Keywords:

MOCVD, 2D materials, metal-chalcogenides, metal oxides

Improved efficiency and stability of perovskite solar cells with metal-free phthalocyanine as a hole transporting material

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Abstract:

Perovskite solar cells have achieved power conversion efficiency above 25 % in small-area single junction devices and 29% in dual-junction tandem devices with silicon solar cells. Nowadays the substantial progresses have been achieved to commercialize PSCs based on such as high PCE with developing large-area compatible process and improving long-term stability. In this talk, the progress in the stability of PSCs by controlling defects and ion migration at the interface between a hole transport layer and the perovskite layer. Notably, we focused on the stability of hole transport materials and their interfaces. Lewis acid-base interfacial interaction between the perovskite and the phthalocyanine results to surface passivation effects. The passivation induces higher open circuit voltage and fill factor of PSCs. We also demonstrated the long-term thermal stability of phthalocyanine-applied PSCs.

Keywords:

perovskite solar cells, stability, defect, interface, phthalocyanine

Ambient Air Stable Halide Perovskite Solar Cells via Defect Engineering

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Abstract:

The degradation of perovskite solar cells in the presence of trace water and oxygen poses a challenge for their commercial impact given the appreciable permeability of cost-effective encapsulants. Point defects were recently shown to be a major source of decomposition due to their high affinity for water and oxygen molecules. Here, we report that, in single-cation/halide perovskites, local lattice strain facilitates the formation of vacancies and that cation/halide mixing suppresses their formation via strain relaxation. We then show that judiciously selected dopants can maximize the formation energy of defects responsible for degradation. Cd-containing cells show an order of magnitude enhanced unencapsulated stability compared to state-of-art mixed perovskite solar cells, for both shelf storage and maximum power point operation in ambient air at a relative humidity of 50%. We conclude by testing the generalizability of the defect engineering concept, demonstrating both vacancy-formation suppressors (such as Zn) and promoters (such as Hg).

Keywords:

perovskites, solar cells, defect, lattice strain

Effect of cation/anion engineering on defects in perovskite materials for highly efficient tandem devices

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Abstract:

Controlling defects in perovskite materials with cation/anion engineering is one of the effective strategies for highly efficient solar cells. Here, we discuss the electrical properties of rubidium-incorporated methylammonium lead iodide ((Rb_xMA_{1-x})PbI₃) films and the photovoltaic performance of (Rb_xMA_{1-x})PbI₃ film-based p-i-n-type perovskite solar cells (PSCs). The incorporation of a small amount of Rb⁺ (x=0.05) increases both the open-circuit voltage (V_{oc}) and the short circuit photocurrent density (J_{sc}) of the PSCs, leading to an improved power conversion efficiency (PCE). However, a high fraction of Rb⁺ incorporation (x=0.1 and 0.2) decreases the J_{sc} and thus the PCE, which is attributed to the phase segregation of the single tetragonal perovskite phase to a MA-rich tetragonal perovskite phase and a RbPbI₃ orthorhombic phase at high Rb fractions. Conductive atomic force microscopic and admittance spectroscopic analyses reveal that the single-phase (Rb_{0.05}MA_{0.95})PbI₃ film has a high electrical conductivity due to a reduced deep-level trap density. We also found that Rb substitution enhances the diode characteristics of the PSC, as evidenced by the reduced reverse saturation current (J_0). The optimized (Rb_xMA_{1-x})PbI₃ PSCs exhibited a PCE of 18.8% with negligible hysteresis in the photocurrent-voltage curve. The results from this work enhance the understanding of the effect of Rb incorporation into organic-inorganic hybrid halide perovskites and enables highly efficient perovskite/Si tandem devices.

Keywords:

perovskite, solar cells, defects, tandem

Effect of defect on energy level alignment in perovskite solar cells

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Abstract:

Perovskite solar cells (PSCs) have received tremendous attention as a promising renewable energy resource. To achieve a high power conversion efficiency (PCE) in PSCs, the efficient charge transport by a suitable energy level alignment is significantly important. To determine the energy level alignment in PSCs, photoelectron spectroscopy and inverse photoelectron spectroscopy analyses are necessary. In this presentation, defects in the perovskite/TiO₂ interface and CuSCN-doped perovskite are investigated. Such defects generate the energy offset in charge transport levels, decreasing the PCE of PSCs. In addition, a method to decrease the energy offset is also suggested.

Keywords:

perovskite solar cell, photoelectron spectroscopy, defect

Microsphere-coupled light emission control of 2D van der Waals materials

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Abstract:

Two-dimensional transition metal dichalcogenides (TMDCs) integrated with photonic structures provide an intriguing playground for the development of novel optoelectronic devices with new functionalities. In this talk, we show that light emission from monolayer TMDC can be controlled through coupling with microsphere cavities. By varying the size of the coupled microsphere and thickness of the oxide substrate supporting the cavity system, we could observe an order of magnitude enhancement of the light extraction of TMDC photoluminescence. Furthermore, we report microsphere-enhanced electroluminescence of monolayer TMDC by fabricating cavity-coupled van der Waals light emitting transistors, showing the potential of 2D material-based hybrid optoelectronic device applications.

Keywords:

2D materials, Microsphere, Cavity, van der Waals heterostructures

Investigation of Defects in 2D Nanomaterials using Tip-Enhanced Raman Scattering

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Abstract:

Recently, interest in two-dimensional nanomaterials such as graphene or transition metal dichalcogenide is rapidly increasing to overcome the limitations of traditional materials and find new applications. The high surface area of 2D nanomaterials and the layered structure conducive to ion transport can be used as electrode materials in electrochemical energy storage applications. The atomic-level thickness can enable inorganic flexible optoelectronic devices. For practical applications with 2D nanomaterials, the quality of the materials should be controlled. However, reliable evaluation protocols for 2D nanomaterials are not yet developed. In this presentation, the process of finding new physics that enables a quality analysis of 2D materials through Tip-enhanced Raman scattering research will be introduced.

Keywords:

TERS, 2D nanomaterial

Study of excitons and amplified spontaneous emission in monolayer WS₂

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Abstract:

본 발표에서는 2차원 전이금속 칼코겐 화합물 반도체인 단층 WS₂의 엑시톤 물성 및 제어에 관한 연구 결과를 소개하고자 한다. 특히 h-BN/WS₂ 반데르발스 이중접합 구조에서 나타나는 엑시톤 특성과 복굴절 광공진기와 결합된 WS₂에서 관찰된 amplified spontaneous emission 현상에 대해 논의하고자 한다. 우선 h-BN/WS₂ 반데르발스 이중접합 구조에서 측정된 엑시톤 확산 계수의 정량적 측정 결과 및 h-BN bottom layer가 엑시톤 확산에 미치는 영향에 대해 논의하고자 한다. 그리고 h-BN encapsulation이 WS₂ 엑시톤 물성에 미치는 영향 및 역할에 대해 논의할 것이다. 마지막으로 복굴절 마이크로 광공진기가 결합된 WS₂ 구조에서 관찰된 polarization-controlled amplified excitonic emission 현상에 대한 최근 결과를 소개하고자 한다.

Keywords:

단층 WS₂, exciton, amplified spontaneous emission

Network Analysis of Power Grids: Synchronization Stability and Sustainability

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Abstract:

A power grid is one of the largest engineering systems that runs over the globe. Machines and devices were developed to safely operate the power systems, and they have worked mostly fine. However, as the electrification of society and the modernization of power systems are accelerated, it raised the expectations that network science can provide insight to understand the power dynamics and help to transform its structure and function to the next-level smart grid. In this talk, we are going to see some of the recent approaches of network science on power system analysis and discuss where to go for the next step.

Keywords:

Network analysis, Power grid, Synchronization

확률과정 모형을 적용한 음악 데이터 분석: 국내 대중가요를 대상으로

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Abstract:

본 연구는 Vasicek 모델을 이용하여 음악을 확률과정 모델로 분석하였다. 이 접근법은 곡 내에서 음의 진행을 평균회귀 과정으로 해석하여 회귀 속도, 평균값, 변동성의 세 가지 매개변수를 추정할 수 있도록 한다. 또한, 각 곡의 엔트로피를 구하여 장르별 곡 진행 패턴의 무작위성을 파악할 수 있다. 이 결과를 통해 특정 장르의 음악을 특징짓고 음악 분류에 사용될 수 있는 새로운 지표를 제안할 수 있다.

Keywords:

Vasicek Model, Symbolic Time-series Analysis, Shannon entropy

청정 에너지 주식 시장과 S&P 500 사이의 정보 흐름 관계 분석

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Abstract:

본 논문은 이전 엔트로피(Transfer Entropy)를 이용하여 Clean energy stocks와 전체 주식 시장의 인과관계를 살펴보았습니다. Wilder Hill Clean Energy(ECO) 및 S&P 500 지수를 각 시장의 대표로 사용하였습니다. ECO와 S&P 500 사이에 시장 통합(Market Integration)이 존재함에도 불구하고 둘 사이의 정보 흐름은 일방적임을 확인할 수 있었습니다. ECO는 주식 시장에 정보를 제공하지 못하고 일방적으로 받기만 하는 모습을 확인하였습니다. 연구 결과에 따르면 청정 에너지 주식 시장(Clean energy stocks)은 아직 성숙 단계에 이르지 못하였습니다.

Keywords:

transfer entropy, 정보흐름, clean energy stocks

심층신경망을 이용한 부동산 가격 추정: 부산 사례연구

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Abstract:

본 연구는 주택 가격을 추정함에 있어서 심층신경망 모델의 은닉층 개수가 예측 정확도와 효율성에 유의한 영향을 미치는 지에 대하여 조사한다. 다양한 헤도닉 변수를 포함한 우리의 데이터셋에서 심층신경망은 적은 수의 은닉층으로도 높은 예측 정확도를 달성할 수 있음을 보인다. 또한 모델의 학습과정에서 다른 매개변수를 통제하고 은닉층의 개수만을 다르게 하여 실험을 진행함으로써 반드시 많은 수의 은닉층 구조가 모델의 예측 정확도와 계산 시간의 효율성을 보장하는 것은 아님을 제시한다.

Keywords:

심층신경망, 부동산, 헤도닉, 가격 추정, 은닉층

Stabilizing Effect of Impinging Cold Plasma Jet on Water Surface

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Abstract:

Weakly ionized gas jet, so-called cold plasma jet, has the merit of being able to release plasma into target liquids, and thus plasma jet processing is increasingly gaining attention and diversifying into various scientific and industrial fields. Since impinging plasma jet on the liquid surface has been considered as a basis of plasma jet processing, active efforts to assess the transport of low-energy electrons and other reactive species from plasma to liquid have been made. However, despite its scientific and practical significance, surprisingly little attention has been given to the stabilizing effect of plasma jets on plasma–liquid interfaces thus far. In this presentation, we report the stabilization of liquid instabilities by weakly ionized gas for the case of a helium gas jet impinging on water, which profoundly affects the free water surface. Special attention is given to the interfacial dynamics relevant to electrohydrodynamic (EHD) gas flow (also called electric or ionic wind) induced by the momentum transfer from accelerated charged particles to neutral gas under a strong electric field. A plasma jet consisting of periodic pulsed ionization waves, called plasma bullets, exerts more force via electrohydrodynamic flow on the water surface than a neutral gas jet alone, resulting in cavity expansion without destabilization. Furthermore, both the bidirectional EHD gas flow and parallel electric field to the gas–water interface caused by plasma interacting ‘in the cavity’ render the surface more stable. Our case study demonstrates the dynamics of liquids subjected to a plasma-induced force, offering new insights into physical processes and revealing an interdependence between weakly ionized gases and deformable dielectric matter, including plasma–water systems, and their potential stabilization.

Keywords:

Weakly ionized gas jet, plasma bullet, electrohydrodynamic wind, hydrodynamic instability

The first result of UNIST EBIT

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Abstract:

UNIST CHEA(Center for High Energy Astrophysics) developed an electron beam ion trap (EBIT) to study highly charged ions(HCIs).The UNIST-EBIT has up to 8 keV energy of electron beam with 0.86 T magnetic field by permeant magnets to perform the X-ray spectroscopy of the HCIs in a cost-effective and low maintenance way. The main target is to measure X-ray transition spectrum of highly-charged iron ion (FeXXV) to investigate the formation of the universe by comparison with satellite X-ray observatory data. In this presentation, we will report the first spectrum result of KLL dielectronic recombination of highly-charged argon ions and the following research plan.

Keywords:

Electron Beam Ion Trap, EBIT, Spectroscopy, Highly Charged Ion , Argon

Mode transitions (γ - α) and hysteresis in microwave-driven low-temperature plasmas

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Abstract:

We found a hysteresis in microwave-driven low-temperature plasmas across the discharge mode transition (α - γ). For the same global operation parameters (pressure, power, gas composition), the discharge mode differs depending on the pressure change direction. This observation suggests that the plasma under the same operation parameters can have two different stable states. The experiment was conducted for argon plasma generated by a cylindrical resonator electrode at 900 MHz with varying pressure. Mode transition was identified by a rapid change of the argon ion population or the electron temperature (both are estimated from Ar emission lines). The hysteresis found in the experiment was analyzed by examining the rotational and vibrational temperature measured from the OH (A-X) emission lines. Additionally, the relation between the rotational and translational temperature was explained by applying simple physical models. The analysis reveals that the cause of the hysteresis is the difference in the neutral gas density inside the plasma at the same pressure point depending on the direction of pressure change. The neutral density depends on the gas temperature of the plasma, which is larger for the γ -mode due to the fast gas heating. This interpretation is confirmed by the disappearance of the hysteresis when the experimental data is displayed with the estimated gas density instead of pressure.

* Work supported by the BK21+ program of the National Research Foundation (NRF).

Keywords:

hysteresis, discharge mode, microwave, low-temperature plasma, rotational temperature

고해상도 TOF(Time of Flight) 중성자 실험을 위한 단일 번치 빔 생성 시스템 제작 연구

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Abstract:

중성자 실험에서, 가속된 양성자 혹은 중양자를 타겟에 충돌시켜 중성자를 생성시키는 방식이 전 세계적으로 널리 사용되고 있다. 이러한 방법으로 발생된 중성자 빔 다발(Beam bunch)과 다발 사이의 간격은 필연적으로 중성자 발생에 사용된 양성자 및 중양자 번치의 반복시간(repetition time)과 같게 된다. 일반적인 RF기반 입자가속기의 반복시간은 수십 나노초 정도인데, 이 시간은 고해상도 Time of Flight (TOF) 중성자 실험 상황에는 부적합한 짧은 시간이다.

따라서 이 연구에서는 수십나노초의 rising time을 가지는 200kHz Fast chopper를 사용하여 연속적인 DC 빔을 수십나노초의 번치길이(bunch length)로 자른 후, DGB(Double Gap Buncher)를 이용하여 RFQ에 입사되는 위치에서의 번치길이를 12.3ns 이하로 억제시키는 방식을 통해 충분히 긴 반복시간과 높은 빔전류의 두가지 목표를 모두 달성하고자 한다.

이번 발표에서는 빔 역학 시뮬레이션을 통해 연구된 DGB의 설계와 제작, 그리고 DGB의 정상적 운전을 위해 요구되는 RF전압 공급 장치에 대해 논의하고자 한다.

Keywords:

중성자원, TOF 실험, Fast Chopper, Double Gap Buncher

Particle-in-cell simulations of THz emission from a plasma by oblique-collision of two electron beams

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Abstract:

A promising way for generating a powerful electromagnetic radiation in THz range by using electron beams rather than short laser pulses, because electron beam is able to transfer more energy into the plasma oscillations, which can enhance the efficiency compared to laser-based scheme. We studied and demonstrated that using two-dimensional particle-in-cell simulations. The Langmuir waves excited by two counter-propagating electron beams via two-stream instability, collide to each other at an oblique angle, which forms a high beam-density modulation near the colliding region, where the both beam electrons are trapped. As a result, spatially-localized Langmuir wave-packets with large amplitude of longitudinal electric field are formed, which give rise to the bursts of electromagnetic radiation. Our 2D-PIC simulations for oblique-collision ($\theta_{\text{collision}} \sim 20^\circ$) of low-density electron beams ($\sim 0.0018n_{0e}$) with different transverse sizes ($d_{b1}=400\mu\text{m}$ and $d_{b2}=300\mu\text{m}$), show that a strong THz emission is obtained at second-harmonic of plasma frequency with a narrow spectral-width in vacuum, which is enhanced significantly compared to the head-on-collision case. The efficiency of power conversion from electron beams to THz wave in vacuum is reached around ~ 0.0289 , for the continuous injection of beams into plasma. We also noted that the interaction region in the oblique-collision case begins to emit the radiation in earlier time compared to the head-on-collision case.

Keywords:

THz radiation, electron beam, oblique-collision, PIC simulation, plasma

Charge and energy confinement of strongly coupled plasma within a phase-coexisting supercritical fluid

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Abstract:

Neutron stars, white dwarfs, and cores of Jovian planets are believed to be in the strongly coupled plasma (SCP) state. For decades, theoretical models and numerical simulations have been developed to describe the particle interactions in SCPs, while the basic equation of states (EOS) is yet to be verified by experiments. The measurement of EOS or plasma density and temperature has been considerably difficult due to the transient nature of SCP states in the existing experiments, where the central issue is to maintain the high energy density state for a sufficiently long time. We demonstrate a method to enhance the charge and energy confinement of SCPs produced in supercritical fluid medium by a high-power pulsed laser. We recently discovered that both liquid-like and gas-like phases can coexist in supercritical fluids unlike the conventional wisdom that supercritical fluids are homogenous and at a mono-phase [1]. In the experiments using such a supercritical fluid containing a dense population of long-lived submicron-size droplets and nano-size clusters, we found that the droplets and clusters affect the charge and energy transport in SCPs, and extend the relaxation time of the plasma up to about a microsecond. Furthermore, applying a high voltage pulse to the laser produced SCPs to increase the plasma lifetime allows more detailed measurements of the plasma parameters. Our experimental method alleviates the problem of short timescales and will enable determination of the EOS of SCP.

*Work supported by the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (No. 2019R1A2C3011474 and 2016K1A4A4A01922028) and Ministry of Education (No. 2019R1A6A3A13091407).

[1] S. Lee et al., Quasi-equilibrium phase coexistence in single component supercritical fluids, *Nature Communications* **12**, 4630 (2021)

Keywords:

Supercritical fluid, Non-equilibrium phase coexistence, Strongly Coupled Plasma

A comprehensive study on discharge physics and quasi-atomic layer etching using a radio-frequency biased inductively coupled plasma in Ar/C₄F₆ mixture

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Abstract:

Recently, as the demand for a low-damage and precise etching technology increases in the semiconductor industry, an interest in the atomic layer etching (ALE) process has significantly increased. Even in high aspect ratio (HAR) etching process, the ALE can be used as a final etch technique to achieve a flat bottom and vertical side-wall. Although studies on the ALE process are being actively conducted, most of researches are focused on the process result, and it is necessary to study the correlation between discharge physics and the ALE process. As an etching gas for the ALE, C₄F₆ (hexafluoro-1,3-butadiene) with a low global warming potential is one of the challenging topics in the ALE because it generates excessive polymer film. In this study, we comprehensively studied the discharge physics and the ALE process using a RF biased inductively coupled plasma (ICP) in Ar/ C₄F₆ mixture¹. For the modification step of the ALE process, the ICP characteristics were investigated in pure Ar and Ar/C₄F₆ mixture, and the RF biased ICP characteristics were investigated for the removal step of the ALE process. Based on this discharge characteristics, the ALE windows for silicon-based thin films such as a-Si, poly c-Si, SiO₂, and Si₃N₄ were found, and flat and vertical etch profile was obtained through the ALE even on patterned wafer.

¹M.Y. Yoon, H.J. Yeom, J.H. Kim, W. Chegal, Y.J. Cho, D.C. Kwon, J.R. Jeong, and H.C. Lee, *Physics of Plasmas* 28, 063504 (2021)

(Invited paper, featured article 선정)

Keywords:

Atomic layer etching, inductively coupled plasma, C₄F₆ (Hexafluoro-1,3-butadiene)

Optically triggered phase transition droplet: ultrasound-photoacoustic dual theranostic agent

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Abstract:

Phase-transition droplets have been proposed as promising contrast agents for ultrasound and photoacoustic imaging. Short pulse laser activated perfluorocarbon-based droplets, especially when in a medium with a temperature below their boiling point, undergo phase changes of vaporization and recondensation in response to pulsed laser irradiation. Here, we report and discuss the optical vaporization and recondensation dynamics of perfluoropentane (PFP) droplets containing indocyanine green with optical and acoustic measurements. To investigate the effect of temperature on the vaporization process, the vaporization event was recorded at 5 million frames per second via the ultrafast camera. The ultrafast movies show that most of the droplets within the laser beam area expanded rapidly as soon as they were exposed to the laser pulse and immediately recondensed within 1-2 μ s. The vaporization/recondensation process was consistently reproduced in six consecutive laser pulses to the same area. As the temperature of the media was increased above the boiling point of the PFP, the droplets were less likely to recondense and remained in a gas phase after the first vaporization. In this talk, we will discuss the underlying processes of the vaporization and recondensation process and its potential applications.

Keywords:

Photoacoustic imaging, Contrast agent, Perfluorocarbon, phase-transition, vaporizaion

Design of metalens consists of cylindrical Si nanorods working at 780nm

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Abstract:

Using subwavelength periodic array of dielectric nanostructure, dielectric metasurfaces have the ability to shape wavefronts of incident illumination. Replacement of traditional bulk optical components with metasurfaces could reduce the size and weight of optical systems while improving them. Metasurfaces have already been integrated with functional devices such as image sensors, cameras, and microscopes using nanolithography techniques. Here we performed the FDTD simulations and analyzed the transmission efficiency and phase of the periodic silicon nanorods. The operation wavelength is 780nm. The simulation results show that full 2π phase coverage is realized and the transmittance reaches over 85%. We were able to find the optimal condition by adjusting the unit cell size, diameter and height of Si nanorods. In addition, we designed a transmissive metalens of 2cm radius and performed the FDTD simulation on 15 μ m diameter metalens because 2cm scale lens requires a huge computing resource.

Keywords:

metasurface, metalens, FDTD simulation

메타표면을 보다 효율적으로 설계하기 위한 broadband FDTD simulation 방법에 대한 연구

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Abstract:

메타물질과 메타표면 등 빛과 파장 크기의 물질 구조 사이의 상호작용을 활용하는 연구에서 광학 전산모사는 매우 중요하다. FDTD(Finite-Difference Time-Domain)는 그 대표적인 방법으로 시간 영역에서 직접 Maxwell 방정식의 해를 수치적으로 구함으로써 다양한 파장의 빛의 행동을 단 한 번의 전산모사를 통해 얻을 수 있다는 장점을 갖는다. 이러한 광대역(broadband) 계산을 위해 일반적으로 Gaussian 펄스 형태의 소스가 사용된다. 그런데 Gaussian 펄스는 세기가 최대가 되는 중심 진동수에서 벗어날수록 파장별 빛의 세기가 선폭(linewidth)에 반비례하여 감소하는 특징을 갖기 때문에 고려하는 파장 범위 내에서 최대한 균일한 세기의 소스를 인가하기 위해서는 매우 큰 선폭을 갖는 소스가 사용되어야 한다. 그러나 선폭을 증가시킬 경우 고려하는 진동수 영역을 크게 벗어나는 소스가 함께 인가되며, 그 중에서 특히 단파장 소스는 적절한 공간해상도가 사용되지 않으면 불필요한 수치 에러를 발생시켜 전산모사의 신뢰도를 떨어뜨린다는 문제가 있다. 본 연구에서는 이러한 Gaussian 펄스의 단점을 극복할 수 있는 방법으로 Band 소스

$f(t) = \frac{\cos(n\omega_0 t) - \cos(\omega_0 t)}{\omega_0 t}$ 를 제안하고 기존의 Gaussian 펄스와 비교하였다.

Keywords:

FDTD, broadband, Gaussian pulse source, Band source

소용돌이 파면을 가지는 방사형 편광 레이저 빔 생성

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Abstract:

라게르-가우시안 모드 빔(Laguerre-Gaussian, LG)은 원통형 좌표계 레이저의 근본 모드로 일반적인 직교 좌표계의 허마이트-가우시안 모드 빔(Hermite-Gaussian, HG)이 가질 수 없는 빔 특성을 지닌다. LG 모드는 도넛 모양의 공간 세기 분포를 띄며 소용돌이 위상 파면과 방사형/방위형 편광을 가질 수 있다는 특징이 있다. LG 모드 빔이 알짜 궤도 각운동량(orbital angular momentum)을 가지고 있다면 동일 위상 파면이 소용돌이 모양으로 회전하며 진행하게 되는데 이때 빔 파면의 방위각 위상이 $\exp(\pm il\varphi)$ 일 때 광자는 $\pm l \frac{\hbar}{2\pi}$ 의 궤도 각운동량을 가지게 된다. 이러한 특징을 이용하여 소용돌이 파면을 가지는 LG 모드 빔은 광 집게, 나노 입자 포획 및 조절, 양자정보 전송 등 다양한 분야에 응용되고 있다. 또한 방사형/방위형으로 편광된 빔은 축 편광 대칭이라는 특징을 가지고 회절 한계보다 작게 포커싱 시킬 수 있기 때문에 고해상도 현미경, 광학 트래핑, 재료 가공 및 고밀도 데이터 저장 등 다양한 분야에 응용되고 있다. 이와 같은 소용돌이 파면과 방사형/방위형 편광을 동시에 갖는 LG 모드 빔을 생성한다면 매우 유용할 것이다. 그러므로 본 연구에서는 텔레스코픽 공진기를 구축하고 공진기 내부에 s 파장판과 에탈론을 삽입하여 소용돌이 파면과 방사형/방위형 편광의 특성을 동시에 지니는 LG 모드 레이저 빔을 발진시켰다.

Keywords:

라게르-가우시안 모드, 방사형/방위형 편광, 소용돌이 파면, Nd:YVO4 레이저

고출력 1018nm Yb첨가 광섬유 MOPA 시스템

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Abstract:

Yb 첨가 광섬유를 이용한 레이저 시스템은 주로 1030 nm 이상 파장 영역에서 이루어졌는데, 최근 들어 1020 nm 이하의 파장 영역에서 발진하는 단파장 고출력 Yb 광섬유 레이저가 광섬유 레이저의 출력 증강을 위한 탠덤 펌핑 레이저 시스템용 펌핑 광원으로 많은 관심을 받고 있다. 1030 nm 이하의 파장 대역에서 Yb 광섬유는 흡수율이 높은 반면 이득률은 낮아 레이저 동작 시 기생 발진이나 자발 방출 빛의 증폭(ASE, amplified spontaneous emission)이 쉽게 발생하여 고출력 발진이 매우 어려워 고출력 레이저 동작은 대부분 원하는 신호에서 강한 되먹임 신호를 유지할 수 있는 공진기 시스템을 채택하고 있다. 하지만 좁은 선폭의 레이저 발진과, 출력 증강, 발생하는 열의 단계적 제거 등을 위해서는 증폭기 구조를 이용한 레이저 시스템, 즉 MOPA 시스템이 필요한데, Yb 광섬유 증폭기에 이득률이 낮은 파장 대역인 1030 nm 이하 씨앗빔을 입사하여 증폭하면 1030~1080 nm 파장 영역에서 발생하는 넓은 대역의 ASE가 씨앗 공진기로 되돌아가 씨앗 공진기의 안정적인 발진을 방해하여 고출력 발진 동작을 획득하기 어려워서 관련된 연구가 많이 이루어지지 않고 있다. 따라서 본 연구에서는 회절 격자를 사용하여 MOPA 구조를 제작하고, 1018 nm 단파장 영역의 레이저 씨앗빔을 고출력으로 증폭한 연구 결과를 발표한다.

본 연구의 MOPA 시스템에서 약 1.5 W의 1018 nm 씨앗 빔이 증폭기에 입사되었을 때 증폭된 최고 출력은 220 W 였고, 입사된 펌프 출력 대비 기율기 효율은 66.2%로 측정되었다. 출력 스펙트럼에서 1018 nm 레이저 발진 파장과 >1030 nm 대역의 ASE 출력이 약 43 dB 이상 차이가 나므로 본 연구의 MOPA 시스템이 1018 nm에서 안정적으로 동작하고 있음을 확인할 수 있었다.

Keywords:

Yb 광섬유 레이저, 탠덤 펌핑, MOPA

Controlling Ion Qubits

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Abstract:

Ion trap quantum computers currently have high-fidelity quantum gates and long coherence times. How can we make these fidelities higher and how can we further increase the coherence time? I will describe work at Duke on reducing systematic errors through constructing more stable systems [1], removing the residual errors through quantum control [2], and progress towards quantum error correction that will increase qubit memory times [3,4].

[1] *Hardware design of a trapped-ion quantum computer for Software-Tailored Architecture for Quantum co-design (STAQ) project*, J. Kim, T. Chen, J. Whitlow, S. Phiri, B. Bondurant, M. Kuzyk, S. Crain, K. Brown and J. Kim, in *OSA Quantum 2.0 Conference*, M. Raymer, C. Monroe, and R. Holzwarth, eds., OSA Technical Digest (Optical Society of America, 2020), paper QM6A.2.

[2] *Batch Optimization of Frequency-Modulated Pulses for Robust Two-Qubit Gates in Ion Chains*, M. Kang, Q. Liang, B. Zhang, S. Huang, Y. Wang, C. Fang, J. Kim and K. R. Brown, *Phys. Rev. Applied* **16**, 024039 (2021)

[3] *Fault-Tolerant Operation of a Quantum Error-Correction Code*, L. Egan, D.M. Debroy, C. Noel, A. Risinger, D. Zhu, D. Biswas, M. Newman, M. Li, K. R. Brown, M. Cetina and C. Monroe, arXiv:2009.11482

[4] *Optimizing Stabilizer Parities for Improved Logical Qubit Memories*, D.M. Debroy, L. Egan, C. Noel, A. Risinger, D. Zhu, D. Biswas, M. Cetina, C. Monroe and K. R. Brown, arXiv:2105.05068

Keywords:

Ion trap

Integrated photonic control of trapped ion qubits

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Abstract:

Integrating quantum and classical technologies with systems like trapped ions is critical to enable the Moore's law like scaling of qubits necessary to develop practical quantum computers. Recently, our team at MIT LL demonstrated operation of an ion-trap chip where integrated photonics delivered all of the required wavelengths, from violet to infrared, necessary for control and read-out of Sr⁺ qubits[1]. Laser light was coupled onto the chip via an optical-fiber array, creating an inherently stable optical path that we use to demonstrate qubit coherence resilient to platform vibrations. We also explore using multiple zones of interaction to perform parallel qubit operations on multiple ions using parallel integrated beam paths.

[1] Niffenegger, R. J., et al. "Integrated multi-wavelength control of an ion qubit." Nature 586.7830 (2020): 538-542.

Keywords:

Ion trap

Fabrication of MEMS-based surface trap and development towards full-stack quantum computer based on ion trap

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Abstract:

In this talk, I will present our progress and effort in developing a full-stack quantum computer using trapped ions. We have developed several versions of surface traps with different MEMS-fabrication processes to build a scalable ion trap system, and basic shuttling, Rabi oscillation, and Raman transition with Yb ions have been demonstrated using these chips. Currently we are working to improve the visibility of the Raman transition before we will focus on the sideband cooling and the implementation of two-qubit gate. To avoid some of the limitations with our current chip design, new versions of ion trap chips are currently being designed and some of the design will be shared during the talk. We also recently reached a mean phonon number less than 0.5 with a sideband cooling in a macroscopic trap and we are currently working to implement spin-motion entanglement and eventually two-qubit gate and some of the progress will be presented. Finally, we also developed remote job submission systems for both experimental setups, and demonstrated that they can be accessed through standard qiskit packages and a web interface which are necessary to build a full-stack quantum computing system.

Keywords:

ion trap, surface trap, Raman transition, sideband cooling, full-stack quantum computer

Emerging Steep-Slope and Ferroelectric devices for Low Power Applications

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Abstract:

This talk will discuss the potentials and challenges of steep-slope devices for low power logic applications and ferroelectric devices for low power neuromorphic computing. A new steep-slope device, MFSB TFET, with hybrid operation mechanism will be presented and experimentally demonstrated which exhibits the state-of-the-art comprehensive electric properties, particularly with much enhanced drive current than conventional TFETs. Hafnium oxide based ferroelectric devices, with fully CMOS compatibility and favorable scalability, will also be discussed both as steep-slope NCFET for logic switcher and ferroelectric-based artificial neurons and synapses for neuromorphic computing systems with low hardware cost and high energy efficiency.

Keywords:

Computational Electronics, MoS₂, floating-gate field-effect transistors, TMD monolayer, FET

Enabling energy efficiency beyond Morre's law: negative capacitance in ferroelectrics as technology booster for FETs and tunnel FETs

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Abstract:

In this talk we will present and discuss different use scenarios of negative capacitance in doped high-k dielectrics as technology booster for 1D and 2D FET and tunnel FETs. We will discuss extensive experimental results of device characterization from cryogenic to high temperature and the related internal gains obtained with NC technology booster. We will also report on the role that NC can play on improving the energy efficiency characteristics of junctionless FETs for sub-5nm scaling.

Keywords:

FET

Continuing Device Scaling with 2D Layered Materials

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Abstract:

Internet of things demand large performance improvements in integrated circuit systems. The major approach for advancing performance of future electronics is to continue the transistor scaling (Moore's Law). With the scaling for future technology nodes, the gate controllability becomes weaker owing to the pronounced source-drain tunneling. Hence, the transistor body thickness needs to be reduced to ensure efficient electrostatic control. Thin materials with perfect surfaces such as transition metal dichalcogenide (TMD) monolayers offer a great chance to continue the scaling,^[1] and the selection of 2D materials shall be discussed [2]. Other challenges including the growth of wafer-scale single-crystal 2D materials^[3-4] and the metal contact^[5] to 2D layers have thus become central research topics.

Keywords:

Computational Electronics, MoS₂, floating-gate field-effect transistors, TMD monolayer, FET

Prospects and challenges of 2D materials for low power transistor application

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Abstract:

Two dimensional (2D) materials have been investigated extensively, some of them holding great promise as emerging semiconducting materials for future low power transistor application beyond Moore's law, since they present ultra-thin body and short channel effect-free state with efficient electrostatic control. These properties enable 2D materials to be very promising candidates that can meet major requirements for CMOS-based low power memory and logic transistor application towards the future mobile and IoT environment. However, research towards the realization of the 2D material-based CMOS semiconductor transistors faces serious challenges which require various innovative technical breakthroughs. In this talk, I would like to firstly address prospects of 2D transistor devices for the future semiconductor applications. Then, I would like to address challenges from the semiconductor device processing point of view, mainly on doping of charge carriers into 2D substrates, Fermi level pinning from surface defects sensitive material properties, contact resistance at the interfaces with metal electrodes, and interface traps affecting carrier concentration and conductance.

Keywords:

Computational Electronics, MoS₂, floating-gate field-effect transistors, TMD monolayer, FET

리튬이온 배터리용 전극으로 전기방사된 $MgV_3O_8@C$ 복합 나노섬유 제작 및 특성

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Abstract:

1차원 탄소나노섬유와 나노입자의 혼성화는 리튬이온 배터리용 첨단 전극재 개발에 매우 바람직하다. 본 발표에서는 전기방사 기술을 사용하여 1차원 $MgV_3O_8@C$ 복합 나노섬유를 형성하기 위해 1차원 탄소 나노섬유 위에 균일하게 분산된 MgV_3O_8 나노입자를 설계했다. X선 회절과 X선 광전자 분광법을 이용하여 각각 준비된 시료의 상 조성과 화학적 상태를 확인하였다. 에너지분산분광기를 이용한 주사전자현미경을 통해 제작된 샘플의 형태와 원소가 각각 존재함을 확인하였다. 새로 제작된 복합 재료는 리튬이온 배터리의 음극 재료로 조사되었다. $MgV_3O_8@C$ 복합 나노 섬유는 뛰어난 가역성과 더 나은 속도 성능을 보여준다. 복합재료의 뛰어난 전기화학적 성능은 MgV_3O_8 과 1차원 탄소나노섬유의 시너지 효과 때문이다.

MgV_3O_8 로 장식된 1차원 탄소나노섬유는 전기전도도를 향상시킬 뿐만 아니라 리튬이온 확산 길이를 단축시켜 우수한 전기화학적 성능을 나타냈다.

1차원 탄소나노섬유와 나노입자의 혼성화는 리튬이온 배터리용 첨단 전극재 개발에 매우 바람직하다. 본 발표에서는 전기방사 기술을 사용하여 1차원 $MgV_3O_8@C$ 복합 나노섬유를 형성하기 위해 1차원 탄소 나노섬유 위에 균일하게 분산된 MgV_3O_8 나노입자를 설계했다. X선 회절과 X선 광전자 분광법을 이용하여 각각 준비된 시료의 상 조성과 화학적 상태를 확인하였다. 에너지분산분광기를 이용한 주사전자현미경을 통해 제작된 샘플의 형태와 원소가 각각 존재함을 확인하였다. 새로 제작된 복합 재료는 리튬이온 배터리의 음극 재료로 조사되었다. $MgV_3O_8@C$ 복합 나노 섬유는 뛰어난 가역성과 더 나은 속도 성능을 보여준다. 복합재료의 뛰어난 전기화학적 성능은 MgV_3O_8 과 1차원 탄소나노섬유의 시너지 효과 때문이다.

MgV_3O_8 로 장식된 1차원 탄소나노섬유는 전기전도도를 향상시킬 뿐만 아니라 리튬이온 확산 길이를 단축시켜 우수한 전기화학적 성능을 나타냈다.

Keywords:

전기방사, 복합 나노섬유, 리튬이온 배터리

A Shape-Variable, Low-Temperature Liquid Metal–Conductive Polymer Aqueous Secondary Battery

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Abstract:

The rapid growth of smart wearable electronics such as soft robotics and wearable sensors has raised the bar on requirements such as elasticity, deformability, low operating temperature, and excellent safety, in addition to flexibility for advanced energy storage devices. Here, a shape-variable aqueous secondary battery operating at low temperature is developed using Ga₆₈In₂₂Sn₁₀ (wt%) as a liquid metal anode and a conductive polymer (polyaniline (PANI)) cathode. In the GaInSn alloy anode, Ga is the active component, while Sn and In increase the acid resistance and decrease the eutectic point to -19 °C. This enables the use of strongly acidic aqueous electrolytes (here, pH 0.9), thereby improving the activity and stability of the PANI cathode. Consequently, the battery exhibits excellent electrochemical performance and mechanical stability. The GaInSn–PANI battery operates via a hybrid mechanism of Ga³⁺ stripping/plating and Cl⁻ insertion/extraction and delivers a high reversible capacity of over 223.9 mAh g⁻¹ and an 80.3% retention rate at 0.2 A g⁻¹ after 500 cycles, as well as outstanding power and energy densities of 4300 mW g⁻¹ and 98.7 mWh g⁻¹, respectively. Because of the liquid anode, the battery without packaging can be deformed with a small force of several millinewtons without any capacity loss. Moreover, at approximately -5 °C, the battery delivers a capacity of 67.8 mAh g⁻¹ at 0.2 A g⁻¹ with 100% elasticity. Thus, the battery is promising as a deformable energy device at low temperatures and in demanding environments.

Keywords:

liquid metal, GaInSn alloy, aqueous secondary battery, deformability, low-temperature battery

Wearable eutectic gallium-indium liquid fuel cells

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Abstract:

With the rapid growth of wearable electronics, the development of wearable fuel cells as a smart power source is receiving ever more attention due to their high energy conversion efficiency, modest operating temperature, and ease of handling. To address the most notable limiting factor, the rigid electrodes, of fuel cells, herein, a eutectic gallium-indium liquid metal with excellent deformability and redox ability has been employed to wearable and rechargeable fuel cells with high performance. Thanks to the optimized Ga/In ratio, which is achieved by balancing the anticorrosion and electrochemical activity of the liquid metal anode, the power density of the fuel cell is as high as 72.8 mW cm⁻²; to our knowledge, this is the highest power density among existing wearable liquid fuel cells at room temperature. Due to the stable redox properties of liquid metal, the fuel cell was stably cycled for 96 h at 2 mA cm⁻² as a rechargeable metal-air battery. Meanwhile, running in feed mode to maintain the proportion of Ga in the anode, the fuel cell and the rechargeable liquid metal fuel cell exhibited stable discharging and cycling performances, respectively, and delivered exemplary performances under various flexibility and stretchability measurements. Based on the fluent and renewable liquid metal anode, this novel high-performance wearable liquid fuel cell shows great promise as a shape-variable energy supply for bionic soft robots and wearable devices.

Keywords:

Liquid metal, Wearable fuel cell, Rechargeable fuel cell, High performance, Working mode

Polarization-insensitive broadband omni-directional anti-reflection in ZnO nanoneedle array for efficient solar energy harvesting

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Abstract:

In this study, we investigated the optical properties of ZnO nanoneedle (NN) arrays for the use of polarization-insensitive broadband omni-directional anti-reflection (AR) layer. Using finite-difference time-domain (FDTD) method, we demonstrated that the ZnO NN array exhibited the broadband omni-directional AR characteristics. To verify these effects on photovoltaic devices, we fabricated and characterized Si p-n junction solar cells with the ZnO NN arrays in comparison to conventional SiN_x AR-coated solar cells. The results clearly showed that the ZnO NN array enables the broadband AR effect over a wide wavelength range from visible to NIR, resulting in a nearly 20% improvement in the power conversion efficiency of the ZnO NN array solar cells, compared to the SiN_x AR-coated solar cells. Furthermore, the angle-resolved photocurrent results of the ZnO NN array solar cells showed the excellent omni-directionality and polarization insensitivity. Our results demonstrate the optical multi-functionality of ZnO NN arrays and pave the way for high performance optoelectronic devices that require the broadband omni-directional AR and polarization insensitivity.

Keywords:

Polarization insensitivity, Omni-directionality, Broadband anti-reflection, ZnO nanoneedle array, Si solar cells

Integrative Biophysical Investigation on DNA-high Order Structure Formation

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Abstract:

The fundamental unit of chromatin, the nucleosome, is an intricate structure that requires histone chaperones for assembly. ATAD2 AAA+ ATPases are a family of histone chaperones that regulate nucleosome density and chromatin dynamics. Here, we demonstrate that the fission yeast ATAD2 homolog, Abo1, deposits histone H3–H4 onto DNA in an ATP-hydrolysis-dependent manner by in vitro reconstitution and single-tethered DNA curtain assays. We present cryo-EM structures of an ATAD2 family ATPase to atomic resolution in three different nucleotide states, revealing unique structural features required for histone loading on DNA, and directly visualize the transitions of Abo1 from an asymmetric spiral (ATP-state) to a symmetric ring (ADP- and apo-states) using high-speed atomic force microscopy (HS-AFM). Furthermore, we find that the acidic pore of ATP-Abo1 binds a peptide substrate which is suggestive of a histone tail. Based on these results, we propose a model whereby Abo1 facilitates H3–H4 loading by utilizing ATP.

Keywords:

Cryo-EM, single-molecule DNA curtain, High-Speed AFM, Chromatin, Nucleosome, DNA

Gating mechanism of gap junction intercellular channels

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Abstract:

Connexin family proteins assemble into hexameric hemichannels in a cell membrane, which dock together between two adjacent membranes to form gap junction intercellular channels (GJICs). The most ubiquitously expressed connexin Cx43 plays important roles in numerous biological processes. We determined cryo-EM structures of Cx43 GJICs at 3.1-3.6 Å resolutions, which showed dynamic conformational changes of N-terminal helices (NTHs) caused by pH change or C-terminal truncation. Cx43 GJICs in a channel-closing condition contain 12 protomers in gate-covering NTH (GCN) conformation, while those in opening conditions have varying compositions of GCNs and pore-lining NTHs (PLNs) resulting in various pore dimensions and electrostatic surface potentials. GCN-to-PLN transition accompanies π -helix formation in the first transmembrane helix (TM1), movement of TM2-4 that creates a side opening to the membrane, and structural stabilization of the cytoplasmic loop. Our study provides structural insights into the intercellular ion/metabolite transfer and the lateral lipid transport through Cx43 GJIC.

Keywords:

cryo-EM, gap junction intercellular channel, gating mechanism, conformational change, N-terminal helix, pore size, ion selectivity, π -helix

Mechanism and Regulation of V-ATPase Proton Pump

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Abstract:

The vacuolar ATPase (V-ATPase) is a rotary motor proton pump that is regulated by an assembly equilibrium between active holoenzyme and autoinhibited V₁-ATPase and V_o proton channel subcomplexes. Here, we report cryoEM structures of yeast V-ATPase assembled *in vitro* from lipid nanodisc reconstituted V_o and mutant V₁. Our analysis identified holoenzymes in three active rotary states, indicating that binding of V₁ to V_o provides sufficient free energy to overcome V_o autoinhibition. Moreover, the structures suggest that the unequal spacing of V_o's proton-carrying glutamic acid residues serves to alleviate the symmetry mismatch between V₁ and V_o motors, a notion that is supported by mutagenesis experiments. We also uncover a structure of free V₁ bound to Oxr1p, a conserved but poorly characterized factor involved in the oxidative stress response. Biochemical experiments show that Oxr1p inhibits V₁-ATPase and causes disassembly of the holoenzyme, suggesting that Oxr1p plays a direct role in V-ATPase regulation.

Keywords:

V-ATPase, CryoEM, Proton translocation, Regulation

Structural basis for transcription complex disruption by the Mfd translocase

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Abstract:

Transcription-coupled repair (TCR) is a sub-pathway of nucleotide excision repair (NER) that preferentially removes lesions on a DNA from the template-strand (t-strand) rather than non-template strand or non-transcriptional region. Mfd mediates TCR in bacteria by removing the RNA polymerase (RNAP) stalled on the lesion and recruiting Uvr(A)BC. By using cryo-electron microscopy, we visualized seven distinct Mfd-EC complexes in both ATP and ADP-bound states. The structures explain (1) how Mfd is remodeled from its repressed conformation, (2) how the UvrA-interacting surface of Mfd is hidden during most of the remodeling process to prevent premature engagement with the NER pathway, and (3) how Mfd alters the RNAP conformation to facilitate disassembly. Our results reveal an elaborate mechanism for how Mfd kinetically discriminates paused from stalled ECs and disassembles stalled ECs to initiate TCR.

Keywords:

Transcription-coupled repair, RNA polymerase, Mfd, transcription, cryo-EM

Study on the materials using radiation and magnetic resonance spectroscopy

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Abstract:

In this talk, we introduce radiation technology to make a functional material and magnetic resonance spectroscopy to uncover the physical properties of materials. Here, we provide two examples of how we study matter using ion beam irradiation. First, hydrogen donors in ZnO created by proton beam irradiation would be introduced using nuclear magnetic resonance spectroscopy. Second, study on quantum matter using beam irradiation may be one of the important application fields for radiation technology to develop the matter in the future.

Keywords:

radiation, magnetic resonance spectroscopy, quantum matter, proton beam, ZnO

Molecular structural dynamics study using MeV ultrafast electron diffraction

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Abstract:

Several short-lived species so-called reaction intermediates exist and change their three-dimensional molecular structures during chemical, physical, and biologically relevant reactions of various molecules in various phases. Determining molecular structures of reaction intermediates is important to assemble a puzzle of structure, dynamics, and function of the molecule and thus it is necessary to know in detail how a reaction proceeds. For studying molecular structural dynamics, there are two major experimental techniques. One is time-resolved optical spectroscopy and another is time-resolved diffraction that replaces the optical probe pulse with structural probe pulses, such as X-rays or electrons. Here we introduce time-resolved electron diffraction (also known as ultrafast electron diffraction) and time-resolved X-ray diffraction and compare their application fields.

Keywords:

Molecular structural dynamics, Time-resolved electron diffraction, Time-resolved X-ray diffraction, Reaction mechanism

The current status of collaborative study about ion sources between KBSI and KU-Sejong Campus

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Abstract:

After development of ECR ion source at Busan Center of Korea Basic Science Institute, KBSI and Korea University Sejong Campus were started new topic for analytical instruments. The researchers of bio-medical, industrial application and basic science will be new target of compact ion accelerator with new ideas. We have been performing the various studies for adoptable system design using ECR ion source of Korea University Sejong Campus and have been installing 2nd generation ECR ion source. Also, KBSI is developing miniaturized ion source for multiplexed ion beam imaging (MIBI) and is designing cryogenic permanent magnet undulators (CPMU) for synchrotron radiation facility. In this presentation, we introduced the current status of collaboration with KU-Sejong Campus, designs related on MIBI ion source and CPMU.

Keywords:

ECR ion source, Compact ion accelerator, Mutiplexed ion beam imaging, Cryogenic permanet magnet undulators

반도체 공정용 플라즈마 시뮬레이션 및 플라즈마 물성 데이터 개발

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Abstract:

신뢰성 높은 플라즈마 시뮬레이션을 위해서는 적절한 물리적 모델을 적용하는 것도 중요하지만 플라즈마 내부에서 일어나는 화학적 반응들을 정확히 다루는 것도 중요하다. 주요한 반응들이 모두 고려된 set이어야 하며 각 반응에 대해 적절한 속도상수를 사용해야 한다. 이 발표에서는 화학반응 set 개발을 위한 전반적인 과정과 속도상수의 수치적 최적화, 화학반응 set의 압축 등을 다룬다. 특히 반도체 식각 공정에 필수적인 fluorocarbon 플라즈마 물성 데이터 set을 기반으로 각 과정을 설명한다. 또한, 반도체 공정용 플라즈마 시뮬레이션에 자주 사용되는 0차원 공간평균 플라즈마 시뮬레이터 및 관련 활용에 관해서도 소개한다.

Keywords:

플라즈마

Superconductor; Physics and Engineering

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Abstract:

Recent big science such as, LHC, Large Hadron Collider of CERN or ITER, International Thermonuclear Experimental Reactor, employs a lot of cutting edge technology such as large scale superconducting magnet technology. We've joined the ITER magnet project since 2005 and our first mission was to clarify engineering critical current density of superconducting wire, based on physical principal, BCS, Bardeen-Cooper-Schrieffer theory. We have demonstrated that by using physical law, we can formulate an engineering formula, less number of parameters and better accuracy. At the same time, this research led us to another related physics study on vortex pinning which gave us a deeper understanding on pinning mechanism of superconductivity in general. These are typical examples how physics and engineering can be complementary with each other. Our final example is located at a niche market. As we are involved in KDEM0 project, Korean fusion reactor project after the ITER, we are responsible for the design of KDEM0 magnet. Various commercial FEM, finite element method, tools are used. We found that one of FEM tools is quite useful to study critical state model for type II superconductor. This problem is, we argued as located at a niche market, as physicists do not usually enjoy using commercial FEM tool and engineers do not want to study about the validity of physical models. From this study we can elucidate the physical origin of a decade long mystery, so-called paramagnetic Meissner effect, starting from engineering curiosity to physical understanding.

Keywords:

Superconductivity, Superconducting magnet, Scaling law, Vortex dynamics

분자분석 및 물성연구를 위한 고자기장 인프라 개발

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Abstract:

자기장은 응집물질의 상전이 유발하는 매개변수로서, 고자기장은 신물질 탐색에 필수적인 발현물성 연구를 가능케 하는 극한환경을 제공한다. 뿐만 아니라, 자기장은 소재의 분자구조를 비침습적으로 탐침할 수 있는 역할도 수행한다. 이 발표에서는 이렇듯 제반 기초과학 연구에 미치는 영향이 큰 고자기장 자석의 최근 개발 동향을 리뷰한다. 특히 최근 한국기초과학지원연구원에서 2세대 고온초전도 ReBCO 선재를 사용하여 개발된 400MHz(9.4T) NMR 자석을 소개하고, 그 자석기술을 적용하여 더욱 높은 자기장의 연구용 자석을, 개발을 통해 구축함으로써 국가고자기장연구소를 설립하고자 하는 최근의 흐름을 알아본다.

Keywords:

고자기장, 고자기장 연구용 자석 개발, 국가고자기장연구소

Leptonic CPV from sterile neutrinos

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Abstract:

I will talk on possible leptonic CP violation via almost degenerate two sterile neutrinos, which may be relevant for leptogenesis.

Keywords:

CPV

JSNS2 for Sterile Neutrino Search

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Abstract:

JSNS2 (J-PARC Sterile Neutrino Search at the J-PARC Spallation Neutron Source) experiment aims to search for neutrino oscillations with Δm^2 near 1 eV^2 using an intense neutrino beam from muon decay at rest (μDAR) at the J-PARC Materials and Life Science Experimental Facility. The experiment search for muon antineutrino to electron antineutrino oscillations which are detected by the inverse beta decay interaction in Gd-loaded liquid scintillation detector and the detector has a fiducial volume of 17 tons and is located 24 meters away from the target of short-pulsed 3 GeV proton beam. The JSNS2 result will offer the direct test of the LSND anomaly by replicating nearly identical conditions with much better signal to noise ratio. In June 2021, JSNS2 successfully finished the first long-term operation for half-year data and JSNS2 collaborator is preparing the second phase of the JSNS2 experiment with second detector which has 35 tons of fiducial weight and a 48 m baseline. Two detectors will improve the sensitivity of the search for sterile neutrinos, especially in the low Δm^2 region which has been indicated by the global fit of the appearance mode. In this talk, the analysis status with half-year data and prospect of the JSNS2-II will be reported.

Keywords:

Sterile Neutrino, Gd-loaded liquid Scintillation Detector, Neutrino beam from muon decay at rest

Search for sterile neutrino with light gauge interactions

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Abstract:

We investigate features of the sterile neutrinos in the presence of a light gauge boson X that couples to the neutrino sector.

The novel bounds on the active-sterile neutrino mixings $|U_{l4}|^2$, especially for tau flavor ($l = \tau$), from various collider and fixed target experiments are explored. Also, taking into account the additional decay channel of the sterile neutrino into a light gauge boson ($\nu_4 \rightarrow \nu e + e^-$), we explore and constrain a parameter space for low energy excess in neutrino oscillation experiments.

Keywords:

Sterile neutrino, light gauge boson

Search for sterile neutrino oscillation using RENO and NEOS data

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Abstract:

Reactor have been playing an important role in determination of the neutrino oscillation parameters. Existence of an additional neutrino mass state for mass-squared split at around 1 eV^2 and a sterile flavor state has been proposed to solve the so-called reactor antineutrino anomaly. By comparison of shapes of the antineutrino energy spectra, one measured by NEOS for 180 days of reactor operation at 24 m distance and the other by RENO for 2509 days at 294 m effective baseline, the parameters for 3+1 active-to-sterile neutrino oscillation model can be constrained in the mass-squared split range between 0.1 eV^2 and 10 eV^2 . The reactor related systematic uncertainties are suppressed for both detector share the Hanbit reactor complex as common antineutrino source. The sensitivity at lower range of Δm^2 range has been improved compared to the previous NEOS analysis based on the Daya Bay data. It is intriguing that the best fit was found at $\Delta m^2 = 2.41 \pm 0.03 \text{ eV}^2$, which is closed to the reactor antineutrino anomaly best fit value. We compare the antineutrino spectra among RENO, NEOS and Daya Bay to find a possible spectral variation.

Keywords:

neutrino oscillation, reactor antineutrino anomaly, sterile neutrino, RENO, NEOS

Islands in charged linear dilaton black holes

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Abstract:

We investigate the Page curve for a non-standard black hole which is asymptotically non-flat/AdS/dS. For this purpose, we apply the island prescription to a four-dimensional charged black hole that asymptotes to the linear dilaton background. We analyze the entanglement entropy of Hawking radiation for both the non-extremal case and the extremal case, ignoring the backreaction of the matter fields. For the non-extremal case, we find the unitary Page curve that is consistent with the finiteness of the entanglement entropy for the Hawking radiation from an eternal black hole. In this case we discuss the Page time and scrambling time. For the extremal case, we observe that the island prescription provides the well-defined entanglement entropy only in the presence of the island, which can not be obtained from the continuous limit of the non-extremal case. This implies that the unitary Page curve for an extremal black hole may not be reproduced in this method, and further investigation is needed.

Keywords:

Black Holes, Entanglement Entropy

The upper bound of charge diffusion constant in holography

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Abstract:

We investigate the upper bound of the charge diffusion constant in holography. For this purpose, we apply the conjectured upper bound proposal identified by the equilibration scales $(\omega_{\text{eq}}, k_{\text{eq}})$ to the neutral linear axion model. $(\omega_{\text{eq}}, k_{\text{eq}})$ are defined as the collision point between the diffusive hydrodynamic mode and the first non-hydrodynamic mode, setting the upper bound of the diffusion constant D at low temperature T as $D \leq \omega_{\text{eq}} / k_{\text{eq}}^2$. We show that $(\omega_{\text{eq}}, k_{\text{eq}})$ at low T is determined by the diffusion constant D and the scaling dimension $\Delta(0)$ of an infra-red operator as $(\omega_{\text{eq}}, k_{\text{eq}}^2) = (2\pi T \Delta(0), \omega_{\text{eq}} / D)$, which is the common property also appeared in previous studies with other diffusion constants. However, we found some novel features for the charge diffusion case. For the charge diffusion, the collision occurs at the real wave vector, while it is at the complex wave vector for other diffusion constants. Moreover, the charge diffusion constant may have a subtlety for its upper bound because the origin of the collision point may not be well defined in that, at zero wave vector, both the hydrodynamic mode and the non-hydrodynamic mode correspond to the pole-skipping point. Therefore, our work may imply that the conjectured upper bound proposal can have the issue on the charge diffusion case.

Keywords:

Holography, Black Holes, Hydrodynamics, Charge diffusion

Competition of two interaction in holographic lifshitz fermion spectral function.

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Abstract:

We consider a holographic theory as a Ginzberg-Landau theory working for strongly interacting system near the quantum critical point. the dual of the fermion bilinear. We has already been calculated and classified the fermion spectral functions in the presence of such orders. Also we can see this in lifshitz space. We selected two of the 16 interactions in our perivious study to investigate what happens when two interactions enter, and the competition between the two phases. We classified according to the type of influence of the two interactions, and identified critical point in phase of two interaction competition, stability of each mode(gap, flat band, fermi arc etc) in this process.

Keywords:

spectral funtion, Holography, Competition, Critical point

Holographic Flat Band

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Abstract:

We investigate Flat Band's properties used by AdS/CFT Correspondence. First, we show analytic solution of fermionic Green function which is coupled with tensor bilinear. From this result, we prove the stability of flat band. And solving the Green function on the Black hole Background, we give the Phase diagram of this system. Finally, we try to match the Holographic result with real condensed matter system.

Keywords:

Flat Band, Holography, Strongly Correlated System, Finite Temperature Green Function, Phase Diagram

Impurity induced metal-insulator transition in holography

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Abstract:

We study metal-insulator transition in the context of gauge/gravity duality. We introduce neutral scalar field in Einstein-Maxwell-Axion system. Depending on the temperature and charge density, we find that the scalar field can be condensed and this condensation suppress electron-hole pair creation. We calculate DC conductivity using holographic technique and find transition between metallic phase and insulating phase. This phase transition is highly dependent on the impurity density and hence the insulating phase can be identified to the Anderson insulator.

Keywords:

gauge/gravity duality, metal-insulator transition, strongly correlated system, Anderson insulator

Color decorations of Jackiw-Teitelboim gravity and Schwarzian action

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Abstract:

We introduce the colored version of Jackiw-Teitelboim gravity which is the model describing the dilaton gravity interacting with non-Abelian gauge fields along with colored metric and dilatons fields.

Keywords:

quantum gravity, colored gravity, Low-dimensional gravity

On the Superconformal Index of Chern-Simons theories and their KK Spectrometry

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Abstract:

We study the large- N limit of superconformal index for two strongly interacting Chern-Simons theories in three dimensions with $\mathcal{N}=2$ supersymmetry, and compare the result against the AdS/CFT dual, namely the data of full Kaluza-Klein reduction spectra obtained using the exceptional field theory technique. The two theories of interest are mABJM and GJV theories, which are obtained as IR fixed point of RG whose UV description is ABJM and maximally supersymmetric Yang-Mills theory respectively. We confirm agreement and the duality persists. For the case of mABJM it turns out that we need a refinement of the gravity index which reflects the fact that the UV description on the field theory side has enhanced global symmetry.

Keywords:

Gravitational collapse and Quantum radiation of a shell in three-dimensional AdS spacetime revisited

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Abstract:

In three-dimensional AdS spacetime, we study a collapsing shell of dust to form the BTZ black hole and then investigate the emitted quantum radiation during the collapsing by using the functional Schrödinger equation. The interior geometry of the shell can be chosen as either the massless black hole or the global AdS space. In the incipient black hole limit, we obtain the analytic expression of the wave function satisfying the time-dependent Schrödinger equation for a massless scalar field. Then, we calculate the occupation number of excited states from the wave function. It turns out that the radiation temperature finally becomes the Hawking temperature of the BTZ black hole, irrespective of the specific choice of the interior geometries.

Keywords:

anti-de Sitter space, lower-dimensional black holes, collapsing shells, Israel junction conditions, functional Schrödinger equation

Identifying Riemannian Singularity With Non-Riemannian Regularity

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Abstract:

Admitting non-Riemannian geometries, Double Field Theory extends the notion of spacetime beyond the Riemannian paradigm. We identify a class of singular spacetimes known in General Relativity with regular non-Riemannian geometries. The former divergences merely correspond to coordinate singularities of the generalised metric for the latter. Computed in string frame, they feature an impenetrable non-Riemannian sphere outside of which geodesics are complete with no singular deviation. Approaching the non-Riemannian points, particles freeze and strings become (anti-)chiral.

Keywords:

singularity, curvature singularity, double field theory, geodesic, geodesic deviation, Riemannian, non-Riemannian, geodesically complete

Design of KoBRA and Beam Commissioning Plan

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Abstract:

Installation of KoBRA was completed in last June 30. We are now preparing the beam commissioning for KoBRA using a Ar-40 beam.

The detailed design of KoBRA will be presented along with a brief history. Furthermore, a beam tuning method using user friendly control panel will be presented for KoBRA users.

As a first step to test of KoBRA, we have a plan to produce rare isotopes (RI) beams using Ar-40 delivered from SCL3 with graphite target. The experiment plan using RI beam is also introduced, briefly.

Keywords:

RISP, RAON, KoBRA

Installation and Current Status of KoBRA facility

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Abstract:

Total weight of KoBRA is about 200 ton corresponding to the weight of 133 midsize cars. The installation of such heavy device is not easy.

The fabrication and installation procedures of KoBRA will be presented together with an introduction to each device.

We will present a current status of KoBRA consisting of a wide variety, such as, magnets, vacuum chambers, detectors, beam dump, water-cooled collimator, target, several sensors, control system, and utilities.

Keywords:

RAON, RISP

Nuclear Astrophysics Studies with RAON/KoBRA First Beams

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Abstract:

Nuclear physics studies with rare isotope beams are crucial to answer fundamental questions about nuclear structure, the origin of the elements in the cosmos, and the forces that shaped the evolution of the universe. While the research is still very limited by no access to the rarest isotopes, there are now many opportunities to address the challenges with advances in rare-isotope production around the world.

The Rare isotope Accelerator complex for ON-line experiments (RAON) will produce stable and rare heavy isotope beams in 2022, enabling scientists to make discoveries about the properties of rare isotopes. The Civil construction of the RAON site is already completed and the installation of the heavy ion accelerator systems is currently being progressed toward commissioning of RAON at 2022. Stable beams of noble gases including Oxygen, Neon and Argon are expected to be accelerated during the commissioning.

With the advantage of the RAON and Korea Broad acceptance Recoil spectrometer and Apparatus (KoBRA) experimental facility, we would like to propose nuclear astrophysics experiments utilizing the stable beams which will be produced and accelerated in the early stage of the RAON. Details of the experiments will be presented. We will also discuss plans to develop detector systems optimized for experiments of nuclear reactions using radioactive ion beams.

Keywords:

Nuclear Astrophysics, Nuclear Reactions, RAON, KoBRA, Stable beams

Optical model potential studies using stable beams at KoBRA

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Abstract:

The Korea Broad acceptance Recoil spectrometer and Apparatus (KoBRA) facility at the Rare isotope Accelerator complex for ON-line experiment (RAON) is already installed for the low energy nuclear physics, and is being scheduled on outset experiments with stable beams. Expected stable beams in the early phase of RAON are Oxygen, Neon and Argon, and will be accelerated into the KoBRA beamline. Such stable isotopes can be utilized to investigate the nuclear optical model potential (OMP) study, which became one of important questions in recent nuclear reaction research.

Global OMPs have been widely used to describe nuclear reaction data, but the empirical approach cannot be applied to nuclear reactions involving rare isotopes since the parameters were extracted from stable nuclear experimental data. Therefore, more OMP experiments using rare isotopes are necessary to reduce uncertainties of the global OMP parameters.

The ATOM-X, an Active Target Time Projection Chamber detector at Center for Exotic Nuclear Studies, will be used to measure angular distribution of elastic scatterings for the study of OMP related to rare isotopes. In order to validate the experimental method, elastic scattering experiments such as (d,d), (p,p) and (a,a) with the stable beams at KoBRA are considered for the outset experiments to study the OMP, and the experimental technique will be extended toward rare isotopes.

Keywords:

Stable beam, Neon isotope, Elastic scattering, Optical model, KoBRA

Total Absorption Spectroscopy (TAS): a versatile tool for nuclear decay studies

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Abstract:

Total Absorption Spectroscopy (TAS) has been demonstrated as a prominent tool to understand the beta-decay properties of atomic nuclei. Through the use of high-efficiency gamma-ray calorimeters, the TAS mitigates the so-called pandemonium effect by which the beta-strength distributions are not properly accounted for feeding. This technique has various applications, from inferring nuclear shapes [1,2] to decay heat measurements for nuclear reactors [3]. In this presentation, an overview of the TAS concepts and their applications are introduced. An example of a TAS measurement is discussed from the perspective of early experiments at the RAON.

References

- [1] E. Nacher et al., Phys. Rev. Lett. 92, 232501 (2004).
- [2] E. Poirier et al., Phys. Rev. C 69, 034307 (2004).
- [3] A. Algora et al., Phys. Rev. Lett. 105, 202501 (2010).

Keywords:

beta decay, nuclear structure

Identifying and diagnosing coherent association and causalities of multi-channel noise couplings in the gravitational-wave detectors

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Abstract:

We investigate noise association and coupling of multi-channels in the gravitational-wave detectors and present a novel tool for diagnosing its correlation and causality, called CAGMon tool, via linear and non-linear correlation measures such as Pearson's correlation coefficient (PCC), Kendall's tau coefficient (Ktau), and maximal information coefficient (MIC). By preliminary studies, we optimize the parameters of MIC for reliable and efficient interpretation. We apply this tool to three examples that appeared in the KAGRA gravitational-wave detector - lightning strike event, air compressor noise, and underground propagation of wind effect.

Keywords:

gravitational-wave detector, data analysis, detector's characterization, noise mitigation

Can we constrain eccentricity from compact object inspirals ?

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Abstract:

Since the original discovery of GW150914, about 50 compact binary coalescences (CBCs) have been confirmed by the advanced LIGO-Virgo gravitational-wave (GW) detector network. Many of them would have originated from the galactic plane following the standard binary evolution scenario. Some of them are possibly formed through stellar dynamics in dense environments. Eccentricity and misaligned spin(s) are suggested as signatures of dynamical origin of CBCs. In this work, we examine if the advanced LIGO-Virgo detector sensitivity is enough to constrain eccentricity from the GW signal. We consider two binary black holes (GW151226, GW170608), and one neutron star - black hole binary (GW200105), which are dominated by the inspiral phase. For GW151226, we use both Fisher matrix and Bayesian-inference-based Markov Chain Monte Carlo (MCMC) methods. We find good agreement between the two approaches (for both statistical and systematic errors) in the appropriate signal-to-noise ratio regime. For GW170608 and GW200105, we present more recent results from the MCMC method. This study helps to quantify how effectively one can use eccentricity measurements as a probe of binary formation channels.

Keywords:

gravitational waves, black holes, neutron stars, parameter estimation

Adaptive Mesh Refinement (AMR) in Relativistic Hydrodynamics

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Abstract:

Adaptive mesh refinement refers to a technique that increases or decreases the number of meshes according to physical conditions in order to increase simulation efficiency. This technique can dramatically improve computational efficiency. In particular, this method can be applied to cases such as neutron star, black hole simulations, and cosmological simulations when there is a very high density or change in the gravitational field in a specific region or when the calculated region is very wide. In this presentation, we are going to present the development process and test of numerical simulation using the AMR technique and its application to relativistic hydrodynamics.

Keywords:

Numerical, Hydrodynamics, AMR, Neutron star

Negative Turbulent Magnetic Diffusivity Beta effect in a Magnetically Forced System

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Abstract:

We studied the large scale dynamo process in a system forced by helical magnetic field. The dynamo process is basically nonlinear, but can be linearized with alpha & beta coefficients and large scale magnetic field. A coupled semi-analytic equations based on statistical mechanics are used to investigate their temporal evolutions. Since the equation set needs only large scale magnetic helicity $\langle A \cdot B \rangle$ (A: vector potential, B: magnetic field) and magnetic energy $\langle B \cdot B \rangle / 2$, their exact profiles can be traced without ambiguity. Alpha effect has been thought to be related to magnetic field amplification. However, its averaged effect decreases so fast without a significant contribution to B field amplification. Conversely, beta effect contributing to the magnetic diffusion maintains a negative value indicating it plays a key role in the amplification with Laplacian for the large scale regime. On the other hand, the negative magnetic diffusion, which elevates the magnetic field, accounts for the attenuation of plasma kinetic energy. The negative magnetic diffusion is from the interaction of the advective term and helical velocity field. In more detail, when the turbulent plasma velocity is divided into the poloidal component and toroidal one, they interact with the electromotive force leading to the alpha and (negative) beta effect. We discussed this process using the theoretical method and intuitive field structure model supported by the simulation result.

Keywords:

Plasma, Magnetohydrodynamics, Turbulence, Dynamo, Solar magnetic field

Observational Constraints on dense matter EoS of a neutron star in Multi-Messenger Astrophysics

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Abstract:

Observations of GW170817 and its electromagnetic (EM) counterparts, GRB170817 and AT2017gfo opened a new era of multimessenger astronomy (MMA). The first MMA event provided a strong evidence of the origins of short-gamma ray burst and kilo-nova, and it leads to the implication on the origin of neutron-rich elements produced by r-process. The underlying physics for all of the above can be understood by equation of state (EoS) of dense matter.

In this work, to study the effect of dense matter EoS on neutron star (NS) properties in MMA, we adopted Bayesian analysis on the observational results with density functional EoS like KIDS, and specially we sampled nuclear symmetry energy parameters based on Bayesian inference. Through the posterior samples, we show the relation of nuclear symmetry energy parameters and NS properties such as mass and radius. In conclusion, we discuss prospects for LIGO/Virgo/KAGRA O4 observation.

Keywords:

neutron star, equation of state, bayesian inference, gravitational wave, x-ray burst

Data Analysis for Multi-channel Gravitational Wave Detectors

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Abstract:

There have been proposals for multi-channel gravitational wave detectors that take several components rather than just one component of gravitational waves. Corresponding these proposals, we intend to establish a general data analysis methodology in a multi-channel detector. Diagonalizing noise correlations for all pairs, we propose a matched filtering method for a transient signal and a correlation method for a stochastic source. Finally, as an example, we apply the method to the SOGRO(Superconducting Omni-directional Gravitational Radiation Observatory).

Keywords:

multi-channel gravitational wave detector

Deep learning classification of transient noises using LIGO's auxiliary channel data

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Abstract:

We demonstrate that a deep learning classifier that only uses to gravitational wave (GW) detector's auxiliary channel data can distinguish various types of non-Gaussian noise transients (glitches) with significant accuracy, i.e., $\geq 80\%$. The classifier is implemented using the multi-scale neural networks (MSNN) with PyTorch. The glitches appearing in the GW strain data have been one of the main obstacles that degrade the sensitivity of the gravitational detectors, consequently hindering the detection and parameterization of the GW signals. Numerous efforts have been devoted to tracking down their origins and to mitigating them. However, there remain many glitches of which origins are not unveiled. We apply the MSNN classifier to the auxiliary channel data corresponding to publicly available GravitySpy glitch samples of LIGO O1 run without using GW strain data. Investigation of the auxiliary channel data of the segments that coincide with the glitches in the GW strain channel is particularly useful for finding the noise sources because they record physical and environmental conditions and the status of each part of the detector. By only using the auxiliary channel data, this classifier can provide us with an independent view on the data quality and potentially gives us hints to the origins of the glitches when using the explainable AI technique such as Layer-wise Relevance Propagation or GradCAM.

Keywords:

Detchar, Glitch Classification, Deep Learning

Simulation of Gravitational Wave Detection Using Intensity Interferometer for the Stellar Interferometer Experiment

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Abstract:

The SI (Stellar Interferometer) has been newly proposed to detect Gravitational Wave, using spatial coherence of star light. The observation system consists of two detectors looking at the same star source. For the SI experiment in space Intensity interferometer could be chosen because it has many advantages over amplitude interferometer from the experimental point of view. Intensity interferometers have been used widely to measure the size of stars. The determination of the second order correction function of the Intensity Interferometer depends on the distance between the two detectors so called baseline, and the time delay in measurement. If gravitational waves passes around the detector, they create a delay in the photon stream at the two detectors. This delay changes the second order correction function, which allows us to detect gravitational waves. We present the effect of gravitational waves on the intensity interferometer of SI by using Monte Carlo simulations.

Keywords:

gravitational wave, stellar interferometer, spatial coherence, laser interferometer, LISA

Study of 2nd Order Correlation Perturbed by Gravitational Waves Using Pseudo-thermal Light for the Stellar Interferometer Experiment.

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Abstract:

We did laboratory test using pseudo-thermal light of the SI (Stellar Interferometer), a new method for gravitational wave detection. The SI experiment is an experiment to detect gravitational waves using the 2nd order coherence of star light. 2nd order of coherence is a characteristic of thermal light like a star light which has intensity fluctuation. In the laboratory, we used pseudo-thermal light as an alternative to thermal light. Pseudo-thermal light can be created by passing a laser through a rotating ground glass plate. The generated pseudo-thermal light has intensity fluctuations like thermal light and has the 2nd order of coherence of light. As a test of the SI experiment in the laboratory, we use pseudo-thermal light and virtual GW effect. In this work, we confirm the expected data value and the possibility in the actual SI experiment.

Keywords:

gravitational wave, stellar interferometer, pseudo-thermal light, intensity interferometer, 2nd order coherence

Spin-orbit Torque Switching in an All-Van der Waals Heterostructure

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Abstract:

Current-induced control of magnetization in ferromagnets using spin-orbit torque (SOT) has drawn attention as a new mechanism for fast and energy efficient magnetic memory devices. Energy-efficient spintronic devices require a spin-current source with a large SOT efficiency (ξ) and electrical conductivity (σ), and an efficient spin injection across a transparent interface. Herein, we use single crystals of the van der Waals (vdW) topological semimetal WTe_2 and vdW ferromagnet Fe_3GeTe_2 to satisfy the requirements in their all-vdW-heterostructure with an atomically sharp interface. The results exhibit values of $\xi \approx 4.6$ and $\sigma \approx 2.25 \times 10^5 \Omega^{-1} m^{-1}$ for WTe_2 . Moreover, we obtain the significantly reduced switching current density of $3.90 \times 10^6 A/cm^2$ at 150 K, which is an order of magnitude smaller than those of conventional heavy-metal/ferromagnet thin films. These findings highlight that engineering vdW-type topological materials and magnets offers a promising route to energy-efficient magnetization control in SOT-based spintronics.

Keywords:

Spin orbit torque, van der Waals, FGT, WTe_2

Stability of spin superfluid transport in spin-triplet superconductor

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Abstract:

It has been recognized that the condensation of spin-triplet Cooper pairs requires not only broken gauge symmetry but also spin ordering as well. One consequence of this is the possibility of a Cooper-pair spin current analogous to the magnon spin current in magnetic insulators, the analogy also extending to the existence of the Gilbert damping of the collective spin-triplet dynamics. I will discuss how the long-range spin valve can be realized with the ferromagnet / spin-triplet superconductor heterostructure, representing a novel experimental realization of superfluid spin transport and a transport signature of the spin-triplet superconductivity therein. To achieve such a superconducting device at nanoscale, it further needs to be examined how robust its spin transport property is against vortex fluctuations. I will show that while the long-range spin transport persists in absence of vortex proliferation, half-quantum vortices can have qualitative effects even as bound pairs.

[Ref] S B Chung, S K Kim, K-H Lee and Y Tserkovnyak, Phys. Rev. Lett. **121** 167001 (2018)

S B Chung and S K Kim, arXiv: 2105.05261

Keywords:

spin superfluid transport, spin-triplet superconductivity, half-quantum vortex, Kosterlitz-Thouless transition

Tunable spin injection across a van der Waals interface: Electronic control and polarization reversal

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Abstract:

Van der Waals (vdW) heterostructures with two-dimensional magnets offer an idealized magnetic junction with an atomically sharp and clean interface. This unique physical attribute ensures that the magnetic layers maintain their intrinsic spin-polarized electronic states and spin-flipping scattering processes a minimum level, a trait that can expand spintronic device functionalities. Here, using a vdW assembly of ferromagnetic Fe_3GeTe_2 and semiconducting WSe_2 layers, we demonstrate electronically tunable, high transparent spin injection across the vdW interface. By changing an electric bias, the net spin polarization of the injected carriers can be modulated and even reversed in polarity, which leads to a compelling sign change of the tunneling magnetoresistance. The unique spin polarization reversal can be attributed to sizable contributions from high-energy localized spin states in the metallic ferromagnet, so far inaccessible in conventional magnetic junctions. Such tunability of the spin injections opens a promising route for the electronic control of upcoming low-dimensional spintronic device operations.

Keywords:

two-dimensional ferromagnet, van der Waals interface, spin injection/detection

Controlling the Magnetic Properties of the Van der Waals Ferromagnet Fe_3GeTe_2

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Abstract:

Identifying material parameters that affect magnetic properties of ferromagnets is key to optimize materials better suited for spintronics applications. Here, we propose an effective hole doping method to modulate the magnetic anisotropy of a van der Waals ferromagnet, and explore the physical origin of this effect. Experimental measurements of the doping and thickness dependent magnetic properties of thin $\text{Fe}_{3-x}\text{GeTe}_2$ show a significant suppression of the magnetic anisotropy with hole doping. From the measured and calculated doping dependent electronic structure, we find that the energy gain by the spin-orbit induced band splitting is reduced by the chemical potential shift associated with hole doping, which in turn reduce the magnetic anisotropy energy. The identified mechanism provides an understanding of the doping induced modulation of magnetic properties in Fe_3GeTe_2 thin films.

Keywords:

Van der Waals Ferromagnet, Electronic structure, Fe_3GeTe_2

Light-matter Quantum Materials engineering from first principles

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Abstract:

An appealing and challenging route towards engineering materials with specific properties is to find ways of designing or selectively manipulate materials, especially at the quantum level. We will discuss new states of matter that are optically induced and have no equilibrium counterparts, and we will identify the fingerprints of these novel states that will be probed with pump-probe spectroscopies. A particular appeal of light dressing is the possibility to engineer symmetry breaking which can lead to novel properties of materials, e.g coupling to circularly polarized photons leads to local breaking of time-reversal symmetry enabling the control over a large variety of materials properties (e.g.topology). We show that the new quantum electrodynamics density-functional formalism (QEDFT) can account for those effects. For example, the concept of symmetry breaking with light to induce topological phases with linearly and circularly polarized light will be presented to show the transition to topologically non-trivial states in 2D materials. By controlling the Berry curvature in 2D layered materials (metal/insulator transition metal dichalcogenides, or TMD), a new class of quantum Hall states can be induced. In these states, the valley degree of freedom can be tuned with light. The theory for such states requires the treatment of strong electric fields; that is, low driving frequencies and the inclusion of dissipation and lattice degree of freedom.

Keywords:

Quantum Materials

Non-integer high-harmonic generation in a topological insulator

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Abstract:

When the carrier field of intense light pulses drives electrons through a solid, the emerging high-order harmonic radiation offers key insights into the material. Topologically non-trivial matter with invariants that are robust against imperfections has been predicted to support a new quality of high-harmonic generation (HHG). Here, we present our results on multi-THz HHG in the topological insulator bismuth telluride. The frequency of the driving field sharply discriminates between HHG from the bulk and the topological surface, where long scattering times and the quasi-relativistic dispersion enable unusually efficient HHG. Intriguingly, all observed orders, generated in the surface state, can be continuously shifted to arbitrary non-integer multiples of the driving frequency by varying the carrier-envelope phase of the driving field. The anomalous Berry curvature warranted by the non-trivial topology enforces meandering ballistic trajectories of the Dirac fermions, causing a hallmark high-harmonic polarization pattern. Our study provides a fascinating new platform to explore topology and relativistic strong-field quantum physics and sparks hope for non-dissipative topological electronics at infrared frequencies.

Keywords:

High-harmonic generation, topological insulators

Ultrafast dynamics of Berry curvature and topology in Dirac semiconductors

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Abstract:

First, on the Floquet Dirac cone of the graphene/h-BN (Gr/h-BN) heterostructure under the circularly polarized pulse pumping, the fluctuating topological order (FTO) is discovered to exist between topologically trivial and optically induced nontrivial phases. Second, on the Dirac cone of graphene with the electron-phonon coupling, a controlled generation of phonon is found to induce nonzero Berry curvatures and possibly topologically nontrivial states. Our findings in Dirac semiconductors builds up a new roadmap for engineering the Berry curvature and developing topology.

Keywords:

Dirac semiconductors, Berry curvature, electron-phonon coupling

Investigation of High-Energy-Density Matter with Ultrafast and Ultraintense Lasers

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Abstract:

Recent advent of X-ray Free Electron Laser (XFEL) and Peta-watt (PW) class lasers, delivering light with extreme brilliance, opens up the new era for various fields of research. The study of matter at extremely high pressures and temperatures, so called high-energy-density (HED) matter, is one of those benefited enormously from these light sources. As a new subfield of physics intersecting multiple disciplines, such as plasma, condensed matter, and astrophysics, it is a field rich in new physics phenomena and compelling applications, propelled by advances in high performance computing and advanced measuring techniques. In this talk, I'll introduce some experiments using these light sources such as x-ray heating of matter, saturable and reverse saturable x-ray absorptions, ultrafast XANES for warm dense matter. I will also conjecture on some of the future directions in this field that can be exploited with these light sources.

Keywords:

warm dense matter, xfel, laser

Pulsed-magnets and its application to quantum materials research

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Abstract:

In recent years, a broad category of materials termed as “quantum materials” have attracted considerable interest in condensed matter physics community. They refer specifically to solids with exotic physical properties that arise from quantum mechanical properties of its constituent electrons. Salient features of quantum mechanics such as entanglement, coherence, and quantum fluctuations directly impact its physical properties to create exotic phenomena at a macroscopic scale. The relevant electron and/or spin degree of freedom in these systems couple strongly to external magnetic field and provide important information on its electronic structure or even induce exotic phases. In this talk, I will introduce various experimental methods specialized for use in pulse magnetic field and personal experience on high magnetic field study including the world-record non-destructive pulse magnetic field of 100 T, achieved in 2012 by National High Magnetic Field Laboratory and Los Alamos National Laboratory.

Keywords:

Pulse magnetic field, Quantum material, High magnetic field

The role of oxygen on the structural stability and electron correlation effect of Iron alloy at Earth's inner Core Conditions

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Abstract:

The structure of iron at high pressure and temperature is critical to understand the physical properties of Earth's inner core (IC) and a realistic model of IC is considered to include a bit of volatiles. Although light elements have been intensively considered to explain the density and velocity deficits of IC, their effects on the structure and electron-electron scattering of the iron alloy have not been properly investigated.

Here, we predicted energetically stable iron oxides using density functional theory plus dynamic mean field theory (DFT+DMFT). Our DFT+DMFT calculations correctly describe the stable phase of FeO in the experiment, while standard DFT failed to predict the stable phase of FeO, indicating the importance of the electronic correlation effect even under high pressure. We found that iron-rich oxides can be stabilized under IC conditions (300 GPa, 5800 K). This new iron oxide series has a universal structural motif with intercalated oxygen atoms and a bit of oxygen atoms increases the electronic correlation effect. Our calculated electrical resistivity supports the conventional thermal convection model of IC and our calculated seismic velocity also exhibits a quantitative match with experimentally observed PREM data.

Keywords:

high pressure, electron correlation effect

Single-component inhomogeneous supercritical fluids with clusters and droplets

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Abstract:

Non-equilibrium aspects of supercritical fluids (SCFs) are often overlooked in their industrial applications and meteorological processes in high-density planetary atmospheres since SCFs are treated as single-phase homogenous media. We produced argon SCFs through successive compression-expansion cycles of argon injected into a high-pressure chamber, traversing the critical pressure at two times the critical temperature. Due to expansion cooling, the fluid temporarily becomes sub-critical and attains an inhomogeneous state characterized by nanometer-scale clusters and even sub-micron-sized liquidlike droplets. They are distinct from spontaneous density fluctuations near the critical point as the experiment was done far from it. Furthermore, the droplets and clusters persist for a surprisingly long time on the order of an hour. A kinetic model of mass transport mediated by clusters can explain the quasi-steady state of the liquidlike droplets (Lee et al. 2021 Nature Commun. 12, 4630) and suggests that the presence of clusters is critical for mass and energy transport processes in SCFs. *Work supported by the National Research Foundation of Korea (NRF) (grant Nos. 2019R1A2C3011474 and 2016K1A4A4A01922028) and BK21+ program.

Keywords:

supercritical fluid, phase coexistence, clusters, mass transport

Thermoelectric Properties of Tungsten Oxide Epitaxial Films

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Abstract:

Thermoelectric materials are required three conflicting properties; high electrical conductivity, large thermopower, and low thermal conductivity. Especially, the coexistence of high electron conduction and low heat conduction is essentially important to realize efficient thermoelectric materials. Although introducing 0D point defects or 2D layers is known as an effective way to reduce the heat conduction, there is a dilemma that the electron conduction is also reduced since electrons and phonons are scattered simultaneously by impurities, defects, and boundaries. Here, we show that introducing a 1D atomic defect tunnel which is epitaxially stabilized in oxygen deficient tungsten oxide WO_x films is an excellent solution to solve this dilemma.

The WO_x films ($2.7 < x < 3.0$) were heteroepitaxially grown on (001) and (110) $LaAlO_3$ single crystal substrates by PLD. HAADF-STEM observation revealed that the resultant WO_x epitaxial films contain 1D atomic defect tunnel in the in-plane direction and the density increased with decreasing x . The 1D atomic defect tunnels were formed along [001] with extremely high density.

The thermal conductivity (κ) of the films drastically decreased from ~ 7 to ~ 1.5 $W\ m^{-1}\ K^{-1}$ with increasing 1D defects. The lowest κ values of WO_x films are closed to that of amorphous WO_x ^[1], which shows minimum κ . The introduction of 1D defect tunnels effectively suppress the phonon propagation.

^[2] On the other hand, the electrical conductivity (σ) in the in-plane direction of WO_x film dramatically increased from $\sim 10^{-1}$ to $\sim 10^3$ $S\ cm^{-1}$. Since the oxygen removal reduces the valence state of tungsten from +6 to +5, free carrier concentration increases with increasing 1D defects. The σ along the tunnels is 5 times larger than that across the tunnels.^[3] These results clearly reveal that high electron conduction and low heat conduction coexist in the oxygen-deficient tungsten oxide epitaxial films. The present finding would be useful to design efficient thermoelectric materials.

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Keywords:

thermoelectric, thermal conductivity, tungsten oxide, epitaxial film

Spectroscopic-Imaging Scanning Tunneling Microscopy of Rh-doped Iridates

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Abstract:

It has been known that high-temperature superconductivity emerges from a doped Mott insulating state in the cuprates. When extra carriers are doped into the parent state, inhomogeneous electronic order, a mysterious pseudogap, and eventually, superconductivity appear. However, we still lack an atomistic understanding of the exact role of the dopant atoms and how dopants drive the evolution. In this regard, the iridates show similar behavior and phase diagrams, making them a promising complementary material to study. In particular, Sr_2IrO_4 shows strong similarities to the cuprates: crystallographic, magnetic and electronic structures as well as the emergence on doping of pseudogap region and a low temperature *d*-wave gap, but has the additional feature of strong spin-orbit coupling. In this talk, I will report spectroscopic-imaging scanning tunneling microscopy (SI-STM) of Rh-doped Sr_2IrO_4 for several different doping concentrations to investigate the evolution of the electronic structure and local effects of substitutional impurities. To analyze the massive SI-STM data, we introduced a machine learning, i.e. *k*-means clustering and principle component analysis, and the results show several interesting physical properties related to the evolution from an insulating state: inhomogeneous defects distribution, features like phase separation of the Mott gap, and development of a pseudogap. Our SI-STM also provides a local picture of the electronic structure to visualize the evolution of new states and connection to impurity locations.

Keywords:

Scanning Tunneling Microscope, Iridates, Mott gap, Pseudogap

Colossal angular magnetoresistance in ferrimagnetic nodal-line semiconductors

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Abstract:

Efficient magnetic control of electronic conduction is at the heart of spintronic functionality for memory and logic applications. Magnets with topological band crossings serve as a good material platform for such control, because their topological band degeneracy can be readily tuned by spin configurations, dramatically modulating electronic conduction. Here we propose that the topological nodal-line degeneracy of spin-polarized bands in magnetic semiconductors induces an extremely large angular response of magnetotransport. Taking a layered ferrimagnet $\text{Mn}_3\text{Si}_2\text{Te}_6$ and its derived compounds as a model system, we show that the topological band degeneracy, driven by chiral molecular orbital states, is lifted depending on spin orientation, which leads to a metal-insulator transition in the same ferrimagnetic phase. The resulting variation of angular magnetoresistance with rotating magnetization exceeds a trillion percent per radian, which we call colossal angular magnetoresistance. Our findings demonstrate that magnetic nodal-line semiconductors are a promising platform for realizing extremely sensitive spin- and orbital-dependent functionalities.

Keywords:

Topological magnet, van der Waals magnet, angular magnetoresistance, nodal-line semiconductor

Novel Stabilization Mechanism on Polar Oxide Surface

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Abstract:

The stability of polar oxide surfaces has long been an interesting topic in surface science. Since the electrostatic potential diverges with increasing polar oxide thickness, various screening processes involve such as surface reconstruction, charge transfer, and adsorption of foreign charged species. Here, combining the density functional theory calculations and molecular dynamic simulations, we report that the vicinal surface steps can completely stabilize the polar oxide surface without introducing defects and excess charge. The evolution of steps at the vicinal surface, and resulting stabilized polar surface will be discussed and associated underlying mechanism will be introduced along with atomic-scale scanning transmission electron microscopy images.

Keywords:

Molecular Dynamic Simulations, Density Functional Theory Calculations, Step at Vicinal Surface, Polar Surface

Ab initio prediction of topological superconductivity in metallic Si allotropes

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Abstract:

Based on first-principles calculations, we find the presence of both non-trivial topological band and superconductivity in three metallic Si allotropes, termed $Cmcm - Si_4$, $Cmmm - Si_4$, and $I4/mmm - Si_4$. The $Cmcm - Si_4$ allotrope is newly predicted using a data-based structure search method and the $I4/mmm - Si_4$ allotrope can be derived from $Cmcm - Si_4$ by displacing zigzag Si chains. On the other hand, it was theoretically proposed that the $Cmmm - Si_4$ allotrope can be obtained by removing Li from a $Cmmm - LiSi_4$ precursor. We find that three metallic Si allotropes are mechanically and dynamically stable, retain their crystalline structures at ambient pressure, and exhibit superconductivity at the critical temperatures of 1.2 – 11.4 K. We investigate the topological characteristics of the electronic states and find the weak topological nature for all three allotropes. In particular, for $Cmcm - Si_4$, we confirm the formation of Dirac point in the surface electronic band.

Keywords:

topological material, superconductivity, inverse material design, variational auto-encoder

First-principles study of the functionalized-MXene for Li-ion battery application

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Abstract:

Two-dimensional (2D) transition-metal carbides/nitrides (MXenes) have been highlighted as one of the promising battery anode materials due to their longer cycle lifetime, low diffusion barrier, and controllable interlayer distance using surface functionalization. Tailored introduction of functional groups on the surfaces of MXenes can further enhance their physical and chemical properties, extending possible applications of MXenes to a wider set of fields. In this presentation, we carried out first-principles calculation and studied the effect of functionalization of MXene in the aspect of the anode application for Li-ion battery. Calculating the binding energy, diffusion barrier, and diffusion path of a Li atom, we first evaluate the Li-ion battery anode performance of pristine Ti_3C_2 as well as functionalized MXenes ($Ti_3C_2T_x$, $T_x = -F, -O$) and exhibited that these MXene-based anodes show better performance than conventional graphite anode as reported [1,2]. Next, we consider $Ti_3C_2O_2$ with nitrobenzene-termination ($C_6H_4NO_2$), which was experimentally obtained recently [3] and demonstrated that the Li ion diffusion paths can be controlled using nitrobenzene-termination with low diffusion barrier heights. This study will offer promising strategies for the design of advanced MXene-based battery materials.

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Keywords:

MXene, Li-ion battery, Functionalization, Density functional theory, First-principles calculation

Search of chalcopyrite materials based on density functional theory calculation

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Abstract:

Cu(In, Ga)(S, Se)₂ (CIGS) is a material mainly used for photovoltaic applications [1]. The best solar conversion efficiency of thin-film CIGS solar cells exceeds 20 % due to a high absorption coefficient and direct bandgap [2, 3]. The efficiency has grown for more than several decades, however, the improvement has been slow down recently. For this reason, partial replacement of Cu by Ag has been attempted [4], and Ag incorporation shows a better current density [5]. In this research trend, atoms in the same group are exchanged or substituted, but some elements such as transition metals have been generally overlooked.

In this presentation, we discuss the stability and the electronic structure of chalcopyrite materials. We combinatorially generated 96 materials in the chalcopyrite structure, and the stability and the electronic bandgap were investigated by performing density functional theory calculation. Some materials with suitable bandgaps for solar cell applications were screened. We also check whether the screened materials favor other stacking sequences or not.

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Keywords:

DFT, chalcopyrite, solar cell

Theoretical study of spin decoherence in transition metal dichalcogenides

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Abstract:

Transition metal dichalcogenides (TMDC) have recently emerged as potential candidates to host coherent qubits to realize quantum information technologies in two-dimensional materials platforms [1]. Prospective qubit candidates include quantum dots, valley qubits, and spin defects [2,3,4]. Notably, a recent experimental study reported the creation of a localized electron spin by using a carbon radical ion in WS₂, which could be further developed to a spin qubit system [5]. In this study, we theoretically investigate the decoherence time of spin defects in MX₂ TMDC materials (M=Mo, W and X=S, Se, Te). We compute the Hahn-echo decoherence time (T₂) of an electron spin associated with carbon radical ions in TMDC by combining a cluster correlation expansion method (CCE) and density functional theory (DFT)[6]. We found that the T₂ time of TMDC materials ranges from 1.6 ms to 36 ms, and the longest T₂ time was found for WS₂. We also discuss the microscopic mechanism of the decoherence in TMDC materials by analyzing their spin Hamiltonian terms. Our results show that TMDCs are promising materials to host robust spin qubits with long coherence time, which would be crucial for their potential applications in quantum sensing and quantum information processing.

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Keywords:

Qubit, Decoherence, Spin, TMDC

Promising photovoltaic efficiency of a layered silicon oxide crystal Si_3O

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Abstract:

Computational searching and screening of new functional materials exploiting Earth abundant elements can accelerate the development of their energy applications. Based on the state-of-the-art material search algorithm and ab initio calculations, we demonstrate a recently suggested stable silicon oxide with a layered structure (Si_3O) as an ideal photovoltaic material. With many-body first-principles approaches, the monolayer and layered bulk of Si_3O show direct quasiparticle gaps of 1.85 eV and 1.25 eV, respectively, while an optical gap of about 1.2 eV is nearly independent of the number of layers. Spectroscopic limited maximum efficiency (SLME) is estimated to be 27% for a thickness of 0.5 μm , making it a promising candidate for solar energy applications.

Keywords:

photovoltaic materials, first-principles calculation, 2d materials

First-principles study of the chemically reversible isomerization of cadmium sulfide nanoclusters

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Abstract:

Magic-size nanoclusters can involve as intermediates in the synthesis of colloidal quantum dots (QDs). For a controlled synthesis of QDs, it is thus imperative to characterize and understand the atomic structures of nanoclusters and their structural transformations. Here, using first-principles calculations, we reveal a microscopic mechanism of the recent experimental finding of chemically reversible transformation between a pair of CdS cluster isomers [1]. From the comparison with the UV-vis absorption, XRD pattern, FTIR spectra in the experiment, we propose a new Cd₄₁S₂₀ nanocluster and its isomer to explain the isomerization process of CdS clusters at the atomic level. We find that the isomerization involves the formation of point-like defects, which are analogous to DX and AX centers in semiconductors but are stabilized by a different mechanism, namely, ligand self-passivation. We also discuss how the chemically reversible isomerization is driven by methanol adsorption on the cluster surfaces.

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Keywords:

Colloidal quantum dots, Magic-size nanoclusters, Isomerization, First-principles calculations

Exploring materials big-data for advanced data-driven approach by using web-based data platform: Materials Data eXplorer

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Abstract:

For the last 20 years, many big-data web services in the world have been developed to provide materials information to materials scientists, in order to discover new materials based on a data-driven approach. Since such big-data has been dispersed over the world, integration of materials data that can be extracted from multiple databases is required for advanced data-driven materials science, and it helps to accelerate the development of new materials.

Materials Data eXplorer, MatDX, has presented an efficient interface to explore materials big-data integrated from various databases in the field of data-driven materials science. A concept of data warehouse solution has clearly worked to construct the web-based materials big-data platform in a more innovative way. In addition, an user-friendly search interface based on displaying material tags in MatDX lets users explore materials information quickly and easily, and reach detailed information about composition, structure, properties for interesting materials. Further process of 'Analysis' functionality to visualize statistically meaningful relationships has been served in interactive web display.

MatDX enables researchers to discover candidates for new materials based on big-data in the materials science community. Two sub-categories of PubDX (for the published data) and CalcDX (for the calculated data), can be found on the web site can be accessed by <http://materials.chemdx.org>.

Keywords:

Data-driven materials science, Materials informatics, Materials big-data, Research platform, Materials database

KIST 계산과학연구센터의 Research Activity: 계산과학 기반 촉매 개발 사례 중심으로

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Abstract:

KIST 계산과학연구센터는 2007년 설립되어 소재, 물리, 화학, 수학경제 등의 다양한 분야에서 활발한 연구를 수행해오고 있다. 특히, 최근에는 계산과학을 기반으로 한 신소재 설계 및 개발, 나노소재 설계용 시뮬레이션 플랫폼 개발, 인공지능 기술 기반의 자율실험실 (autonomous lab: 사람의 개입 없이 AI 로봇이 스스로 신소재를 개발하는 실험실) 개발 및 코로나 대응 기술 (감염병 전파 예측 등) 등에 활발한 연구를 수행하고 있다. 이번 발표에서는 이에 대한 최근 연구활동에 대해 간략히 리뷰하고, 제일원리 및 분자동역학 등의 계산과학기술을 기반으로 실제 신소재를 개발한 성공사례를 중점적으로 공유하고자 한다. 소재 분야에서 계산과학기술은 실험현상을 해석하는 역할과 실험에 앞서 신소재를 설계하는 역할 크게 두가지로 나눌 수 있고, 이 역할에 따라 계산과학 활용전략도 조금을 달라져야 할 필요가 있다. 계산과학 기반의 소재 개발을 위해서는 무엇보다 빠르게 소재를 설계하고 이에 대한 정보를 실험연구자에게 빠르게 전달한 후 실험연구자로부터 피드백을 듣는 것이 매우 중요하다. 하지만 응용분야에 따라 계산과학을 통해 소재물성을 예측하는 데 많은 시간이 소요되어, 경우에 따라서는 계산과학을 기반으로 소재를 설계하는 것보다 실험을 하는 것이 더 빠른 경우가 있다. 예를 들어, 촉매의 경우 촉매표면에서 화학반응경로를 탐색하는 것이 매우 중요한데 제일원리계산을 가지고 화학반응의 전이상태(Transition state)를 계산하기 위해서는 많은 시간이 소요된다. 최근 본 연구팀은 소재의 전자구조를 기반으로 빠르게 신소재를 탐색하고 이를 실험 연구자와 긴밀한 협력을 통해 신촉매를 개발할 수 있는 프로토콜을 개발하였다. 이번 발표에서는 계산과학 기반의 촉매 개발 프로토콜을 소개하고, 이를 기반으로 촉매 개발 성공사례 몇가지를 공유하고자 한다.

Keywords:

계산과학

개방형 소재 전산모사 웹플랫폼을 위한 계산 자동화 기술

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Abstract:

개방형 소재 전산모사 웹플랫폼을 위해 개발된 계산 자동화 기술을 소개한다. 자세히는 촉매소재 DFT 계산의 전처리 자동화 기술을 설명하고, 해당 기술을 활용한 에너지소재 연구 예제들을 소개한다. 마지막으로 해당 기술이 가지는 의미를 간단하게 논의해보고자 한다.

Keywords:

계산자동화, 소재플랫폼, 소재웹플랫폼, 에너지소재, 촉매소재

Computation and Data-driven Research on Thermoelectric Materials and Devices Design

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Abstract:

Thermoelectric (TE) phenomena refer to direct energy conversion between thermal and electrical energy. In a certain solid material, TE voltage can be generated under temperature difference via Seebeck effect. Or, the electrical current can carry heat current via Peltier effect. These TE effects can be applied for industrial applications such as power generation from unused/waste heat and solid state cooling. TE phenomena are governed by three TE transport properties : Seebeck coefficient, electrical and thermal conductivity. Classically, TE efficiency is determined by the ratio of three parameters given by the so-called zT . Hence balancing three parameters are key strategy toward high material efficiency. Advanced design of TE devices and their fabrications are also important topic for TE industrialization.

However, there have been a mismatch between material and device efficiency owing to many missing and unknown parameters in the devices. For materials, it is very difficult to simulate TE transport properties using 1st-principles calculations though there have been many successes in other fields. It might be owing to the complex microstructure of materials and the dimension mismatch between bulk TE materials and simulations.

In this presentation, I will present the present and future of TE in **KERI** that will overcome such issues. We have performed the computational simulations for materials and devices for TE applications. We are searching for metastable phase that can exist within materials. As TE semiconductors are very defective, we have investigated defect diffusion and interaction within lattices.

Our final goal is to understand TE materials system fully. So we have compared the computational simulation results to the experimental measurement data to find the hidden parameters and phenomena in TE physics and applications. For this purpose, we have gathered and managed TE data. We have collected approximately a thousand TE property data set from literatures and our own experimental measurements, wishing that the abundant material data help to correct or minimize the mismatch between physics and application, and between theory and experiment. We have started to learn TE properties and materials process for TE materials using our own machine learning algorithm that can guide composition and process for further experiments.

We also have developed the computational algorithm for TE conversion efficiency so called TE degrees of freedom. In future, we will report a *TE performance map for reported materials* over approximately 10,000 samples to draw TE performance map of reported materials, in strong collaboration with **Starrydata** team at Japan.

Next step will be the module related part. With developing computational algorithm and experimental data, we will assign the key problems in thermoelectric devices in terms of energy flow and loss, that can shift the focus of thermoelectrics from materials to devices.

Keywords:

thermoelectric, data, material, device, design

Three-dimensional exchange bias control by spin-orbit torque

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Abstract:

Exchange coupling between antiferromagnet (AFM) and ferromagnet (FM) spins at the FM/AFM interface leads an exchange bias (EB), essential for designing of modern spintronic devices. In order to control EB, which is insensitive to the external magnetic field, generally field-cooling method is required. Here we show spin-orbit torque (SOT) driven 3D control of the EB in a Pt/Co/IrMn tri-layer. We successfully control EB directions by the external magnetic field directions with SOT. Furthermore, field-free SOT switching is achieved for perpendicular magnetized FM with the in-plane EB. Related experiment and macro-spin simulation suggest that the main origin of SOT driven EB control is the THz oscillation of interfacial AFM spins. It implies that SOT has the similar role as heat in the traditional field-cooling by exciting AFM spins from their ground state.

Keywords:

spin orbit torque, exchange bias, spintronics

Chaotic information generation from nanocontact vortex oscillators

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Abstract:

Chaos is a framework with which many phenomena in nonlinear dynamical systems can be understood. Chaos dynamics is deterministic but extremely sensitive to its initial conditions; therefore, the temporal evolution is generally unpredictable on the long term. From the perspective of applications, the chaos dynamics can be a promising avenue toward unconventional information processing technologies, such as encrypted communications, ultrafast random number generation, and encoding information [1-3]. Spintronic systems can be good candidates for chaos-based applications, because magnetization dynamics is intrinsically nonlinear. In addition, such dynamics can be driven and detected by spin-dependent transport phenomena which can be readily integrated into conventional semi-conductor electronics. In this presentation, we show that spintronic devices can be used for chaotic information generation using nanocontact vortex oscillators [4].

In this presentation, we first present the vortex-core dynamics. we derive equations of motion of the vortex-core dynamics based on Döring's kinetic field [5], which can describe the deformation amplitudes that couple to the motion of the core. With the equations, complex inertial motion can be understood. Next, we introduce nanocontact vortex oscillators (NCVOs) where large current densities drive vortex-core gyration around a nanocontact in a magnetoresistive stack. NCVOs exhibit unique dynamical states caused by the self-phase locking between the vortex core gyration and periodic switching of the core. When the ratio between these two frequencies is irrational, chaotic dynamics appears [4]. Finally, we investigate the chaotic time-series data generated from an NCVO. From the measured output signals, we were able to identify a well-defined series of patterns. These can be encoded into bit sequences, which are correlated with the core-polarity state of the magnetic vortex. We calculate the probability of each bit and their moving as a function of the input current amplitudes, which shows we can control the characteristics of the chaotic sequences electrically. These results illustrate the feasibility of chaos-based information processing using spintronic nanodevices.

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Keywords:

Magnetism, Spintronic devices, Magnetic vortices, Nonlinear phenomena

Spintronics application to neuromorphic computing units: from domain-wall to skyrmion.

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Abstract:

With intensive advances in computing hardware technologies, novel neural-network algorithms such as deep neural networks are underway to be implemented using reasonable amount of computing hardware resources, called neuromorphic computing. However, even complementary metal-oxide semiconductor (CMOS), one of the most mature hardware technologies, presented significant disadvantages of a high power consumption, large-area density for hardware implementation of the neural-network algorithms. In this regard, the emerging in-memory analog computing technologies, including spintronics technology, have demonstrated their effectiveness in neuromorphic computing, compared to the CMOS technology. Here, we present three different spintronics-based neuromorphic computing devices operated using domain-wall, half-skyrmion and skyrmion. Comparing the distinct characteristic device performances, we discuss the future spintronics-based neuromorphic computing device architecture. These experimental studies will provide a new route to establish more efficient neuromorphic computing hardware units.

Keywords:

Spintronics, Neuromorphic computing, Domain-wall, Half-skyrmion, Skyrmion

Topological Spin Textures: Magnetic skyrmion and Domain Wall Skyrmion

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Abstract:

Magnetic systems exhibit a variety of fascinating spin textures, which can be classified by their characteristic topological numbers. For example, magnetic skyrmions are of particular interest due to their emergent electromagnetism and their potential for the information carriers at the nanoscale. As an essential prerequisite for implementing skyrmion-based devices, in this talk, we present simple schemes for writing and deleting skyrmions using a conventional current pulse in a two-terminal device. Utilizing different spatial and current dependences of Joule heating and Oersted field effects, which are by-products of a conventional current, one can either write or delete skyrmions by simply reversing the current direction in a switchable way. We show that a domain wall skyrmion, a novel type of topological excitation that resides in skyrmions, plays an essential role in creating skyrmion and its topological evolution. We found that the sequence of the annihilation of the DW skyrmions and their combination result in different final states.

Keywords:

skyrmion, domain wall skyrmion, topological charge, skyrmion writing, skyrmion deletion

Investigation on the electronic structure of Van der Waals heterointerfaces: 2D semiconductor with functional organic molecules

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Abstract:

Recent Van der Waals heterointerfaces consist of two-dimensional (2D) materials, the organic molecules of which have been intensively studied to enable the enhancement of their excellent optoelectrical properties. For instance, if the organic molecules are properly designed, it enables manipulation of the electronic structure of 2D materials, as well as their energy level alignment. The type of energy level alignment, which generally can be classified as straddling type-I and staggered type-II, can significantly impact the optical behavior at the heterointerfaces. In conventional materials, this energy level alignment can be predicted using their ionization energies, i.e. the rule of vacuum level alignment. However, this rule is sometimes no longer valid without the consideration of unique 2D properties stemming from the atomical thin thickness. Furthermore, the mechanism of the aforementioned electronic structure turning is not properly understood so far. In this contribution, first, we demonstrate the controlling of the electronic structure of 2D materials itself using the model functional (acceptor for 2,3,5,6-Tetrafluoro-7,7,8,8-tetracyanoquinodimethane) and (donor for Dichloro[hexamethylbenzene] ruthenium[III] dimer) organic molecules. Those are evidenced by the measurement of the angle-resolved and X-ray photoelectron spectroscopy. In the same manner, the turning of energy level alignment between heterointerfaces was also discussed. The impact of the surrounding environment i.e. the substrate effect on its control and their mechanism will be addressed. In line with that, how the type of energy level alignment influences the optical properties were investigated by time-resolved PL and transient absorption spectroscopy. Our findings reveal that the type of energy level alignment at the heterointerfaces determines interface carrier dynamics: (1) type-I for the "resonance energy transfer, i.e., electron-hole pair transfer" and (2) type-II for the "direct excited charge transfer." These results help not only to understand interfacial physical phenomena, but also helps design optimized optoelectrical applications.

Keywords:

Van der Waals heterointerfaces, 2D semiconductor, ARPES, UPS, functional organic molecules

Transport Gap Measurement of Organic Electronic Materials using Photomeission and Inverse Photoemission Spectroscopy

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Abstract:

We measured the transport energy gaps of several organic electronic materials including pentacene and C₆₀ by the combination of ultraviolet photoemission spectroscopy for the highest occupied molecular orbital measurements and inverse photoemission spectroscopy for lowest unoccupied molecular orbitals. In particular, we optimized the performance of low-energy inverse photoemission (LEIPS) using an in-vacuo parabolic mirror. With the improved LEIPS sensitivity, we were able to follow the evolution of the transport gap values as a function of organic film thickness on substrates with different surface work functions. We will describe the details of the LEIPS optimization and discuss the implication of the transport gap evolution on the carrier injection efficiency of the organic/substrate interface.

Keywords:

Mixed-halide Zero-dimensional Perovskites Synthesized via Mechanochemistry for Visible Emission Over a Wide Color Spectrum

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Abstract:

Recent remarkable progress in the field of lead halide perovskites has accelerated novel studies regarding low-dimensional-networked perovskites as an emerging class of light emitters due to their enhanced luminescence stability than the three-dimensional (3D) perovskites [1]. Specifically, green-emitting zero-dimensional (0D) perovskite Cs_4PbBr_6 has been the main trigger in this field owing to their robust emission properties. However, studies on halogen counterparts other than Br-based 0D perovskite remains highly elusive and the advantages of perovskites with facile halogen site engineering are not well utilized in this phase yet. In this study, we synthesized 0D mixed-halide perovskites with a diverse range of halogen compositions ($\text{Cs}_4\text{PbCl}_x\text{Br}_{6-x}$ and $\text{Cs}_4\text{PbBr}_x\text{I}_{6-x}$) through mechanochemical synthesis (MCS), a solvent-free synthetic method where solid-state reactions are induced by the mechanical energy of grinding balls. From the synthesized perovskite powders by MCS, we identified photoluminescence (PL) peaks spanning the entire visible spectrum range (421-685 nm) according to the stoichiometrically controlled halogen ratio. Moreover, a structural analysis of the synthesized powders demonstrated that the halogen atoms are uniformly distributed in mixed-halide perovskite samples, and the origin of PL for each composition is most likely the inclusion of 3D phases, similar to the previously studied Br-based counterpart [2]. Finally, we fabricated thin films of mixed-halide 0D perovskites through fast single-source vacuum deposition of the as-synthesized powders, and observed that the PL properties were nearly preserved, exhibiting the full visible spectrum range similarly to the powder samples. Our results demonstrate the versatility of MCS for synthesizing 0D perovskites within a wide range of compositional space, which may offer a new avenue for light-emitting applications.

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Keywords:

mixed-halide perovskite, zero-dimensional, mechanochemical synthesis, photoluminescence, nanocrystals

Blended Hole Transport Layer for Blue Perovskite Light Emitting Diodes

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Abstract:

Metal halide based perovskite light-emitting diodes (PeLEDs) are promising candidates for next generation commercial display products due to the gradual refinement of device preparation strategies in recent years. However, the performance of blue PeLEDs falls far short of the requirements of commercialization, the main reason is the wide band gap of blue perovskite, resulting in inferior hole injection and imbalanced carrier transport in active layer. Here we synthesized a blended hole transport layer (HTL) with excellent hole injection ability by blending poly(9-vinylcarbazole) (PVK) with 2-(4-biphenyl)-5-(4-tert-butylphenyl)-1,3,4oxadiazole) (PBD), which is beneficial to charge transport balance, resulting in effective recombination of electrons and holes in perovskite layer. In particular, the PeLED based on optimal blended HTL exhibits a high external quantum efficiency (EQE) of 4.53% with emission peak at 477 nm. Our work proves the importance of energy ladder for charge transport, and provides a simple and effective idea for the research of high performance blue PeLEDs.

Keywords:

Blue PeLEDs, quasi-2D, hole transport layer, energy ladder, charge balance

Proton irradiation effect on organic–inorganic lead halide perovskites synthesized by mechanochemical synthesis and flash evaporation

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Abstract:

Organic–inorganic lead halide perovskites have emerged as promising materials for solar cell due to high power conversion efficiencies, large charge carrier diffusion length, large absorption coefficient, and tunable direct bandgap. Also, perovskites have potential to be used in the space application due to their characteristics of ultralight, flexible, and high energy harvesting efficient [1]. In this study, we studied the irradiation effect of highly energetic proton beams on methylammonium lead iodide (MAPbI₃) perovskites synthesized by two methods; mechanochemical synthesis and flash evaporation methods. We irradiated proton beams of 10 MeV under various dose conditions of 10¹¹, 10¹², 10¹³, and 4 × 10¹³ protons/cm², and examined the changes in physical properties of MAPbI₃ perovskites before and after the proton irradiation. As a result, no significant change in physical properties was observed for the mechanochemically synthesized MAPbI₃ perovskites after the proton irradiation. But in the case of the MAPbI₃ perovskites synthesized by flash evaporation, a new peak in X-ray diffraction appeared and fluorescence life time in time-resolved photoluminescence increased after long dose conditions, suggesting changes in physical properties by the proton beams. These results can be attributed to the difference in radiation hardness in terms of the bonding strength of the constituents (especially Pb-I bonds) in the perovskites according to the different synthesis methods [2]. Our study will help understanding the radiation effect of proton beams on organometallic halide perovskite materials.

References

- [1] J. Yang et al., Nano Energy, 76, 105019 (2020).
- [2] López, C. A., et al., Scientific reports, 10.1, 1-11 (2020).

Keywords:

perovskite, MAPbI₃, mechanochemical synthesis, radiation hardness, proton irradiation

네마틱 액정의 변형을 이용한 전기에너지 생성

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Abstract:

액정은 고체와 액체의 중간상을 가지는 물질이다. 네마틱 액정은 위치질서는 없으나 방향질서를 가지고 있다. 이 때, 액정분자들이 이루는 평균적인 방향을 방향자(director)라고 한다. 균일하게 배향된 액정에 변형을 일으키면 방향자의 왜곡에 의해 전기분극이 발생하는데, 이 현상을 flexoelectric effect 라고 한다. 이 연구에서는 네마틱 액정(5CB)를 사용해 유연한 전극기판에서 수직 또는 수평배향하는 균일한 방향으로 정렬된 액정 셀(cell)을 제작하고, 셀의 굽힘 변형을 통해 액정의 방향자의 왜곡에 의해서 발생하는 기전력을 측정했다. 동시에 계산을 통해 flexoelectric effect 에 의해 발생하는 기전력과 그에 따른 전기에너지를 확인했다. 결과적으로 변형의 크기와 셀의 구조에 따라서 기전력의 크기가 변하는 것을 확인했다. 변형에 의해 생성된 전기에너지는 약 $10^{-10} J$ 이며, 액정이 energy harvesting의 재료로서 사용될 수 있음을 확인했다.

Keywords:

네마틱 액정, Flexoelectric effect, 굽힘변형, 기전력, energy harvesting

Field-induced reconfiguration of double-twist director configuration of liquid crystal in cylindrical confinement

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Abstract:

Lytotropic chromonic liquid crystals often exhibit spontaneous chiral symmetry breaking under confinement. Despite the absence of intrinsic chirality, their unusual elastic moduli, such as large saddle-splay and small twist modulus compared to splay and bend modulus, make a twisted director configuration along the radius, the so-called double-twist configuration. In this study, we investigate how the external magnetic field along the capillary affects the double-twist configuration. As the magnetic field strength increase, the twist profile along the radius changes its shape from a convex to concave curve, and the twist angle at the cylindrical wall converges to 90 deg. Our experimental data agree with the elastic free energy model, matching with the Jones-calculus-simulated optical textures of the numerically calculated energy-minimizing configuration. The model also elucidates the energetics behind this reconfiguration in terms of the delicate interplay among elasticity, geometry, and external field.

The authors acknowledge the support from the Korean National Research Foundation through NRF-2021R1A2C1011163.

Keywords:

Lytotropic chromonic liquid crystal, Cylindrical confinement, Magnetic field effect

Accelerating Langevin Field-Theoretic Simulation of Polymers with Deep Learning

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Abstract:

Langevin field-theoretic simulation (L-FTS) can account for the fluctuation effect in a polymer system which is ignored in the self-consistent mean-field theory. Even though L-FTS is computationally efficient compared to traditional particle-based polymer simulations, it requires large computation effort. In order to accelerate the L-FTS, we introduce deep learning (DL). In L-FTS, the functional integral over the pressure field is evaluated using saddle-point approximation whereas the exchange field fluctuates according to the Langevin equation. Using fully convolutional network (FCN), we directly generate saddle point pressure field for given exchange field. Training data are collected at the early stage of simulation so that the pretrained neural network is not necessary prior to the simulation. By combining DL and traditional iteration method, we do not sacrifice the accuracy and we manage to achieve 30 ~ 60 % reduction in simulation time. This approach is very versatile and could be applied to a variety of systems without prior data collection or pre-trained neural network.

Keywords:

Polymer, Field-theoretic simulation, Deep learning

Disynaptic Effect of Hilar Cells on Pattern Separation in A Spiking Neural Network of Hippocampal Dentate Gyrus

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Abstract:

We investigate the disynaptic effect of the hilar cells on pattern separation in a spiking neural network of the hippocampal dentate gyrus (DG). The principal granule cells (GCs) in the granular layer of the DG perform pattern separation, transforming similar input patterns into less-similar output patterns. In our DG network, the hilus consists of two types of hilar cells: excitatory mossy cells (MCs) and inhibitory HIPP (hilar perforant path-associated) cells. Here, we consider the disynaptic effects of the MCs and the HIPP cells on the GCs, mediated by the inhibitory basket cells (BCs) in the granular layer; MC \rightarrow BC \rightarrow GC and HIPP \rightarrow BC \rightarrow GC. Disynaptic inhibition of the MCs tends to decrease the firing activity of the GCs. On the other hand, the HIPP cells disinhibit the intermediate BCs, which leads to increasing the activity of the GCs. By changing the synaptic strength $K^{(BC,X)}$ [from the presynaptic X (= MC or HIPP) to the postsynaptic BC] from the default value $K^{(BC,X)*}$, we study the change in the pattern separation degree \mathcal{S}_d . When decreasing $K^{(BC,MC)}$ or independently increasing $K^{(BC,HIPP)}$ from their default values, \mathcal{S}_d is found to decrease (i.e., pattern separation is reduced). On the other hand, as $K^{(BC,MC)}$ is increased or independently $K^{(BC,HIPP)}$ is decreased from their default values, pattern separation becomes enhanced (i.e., \mathcal{S}_d increases). In this way, their disynaptic effects are opposite ones. Thus, when simultaneously varying both $K^{(BC,MC)}$ and $K^{(BC,HIPP)}$, as a result of the two competing disynaptic effects of the MCs and the HIPP cells, \mathcal{S}_d forms a bell-shaped curve with an optimal maximum at their default values. In this case, the activation degree of the GCs, $D_a^{(GC)}$, forms a well-shaped curve with an optimal minimum at the default values. Moreover, we also investigate the population and the individual activities of sparsely synchronized rhythms of the GCs, the MCs, and the BCs in the GC-MC-BC loop, and find that their population and individual activity degrees, \mathcal{A}_P and \mathcal{A}_I , are correlated with the pattern separation degree \mathcal{S}_d . Consequently, the larger the activity degree of the GC-MC-BC loop becomes, the more the pattern separation becomes enhanced.

Keywords:

Hippocampal Dentate Gyrus, Pattern Separation, Disynaptic Effect, Activity Degree of the GC-MC-BC Loop

Orientalional fluctuations and bimodality in semiflexible nunchucks

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Abstract:

Semiflexible nunchucks are block copolymers consisting of two rather stiff arms linked together with a softer polymer segment. Recently, nunchucks consisting of DNA nanorods linked with a segment of dsDNA have been used as a tool to measure the bending stiffness of dsDNA (Fygenson *et al.*, Nano Lett. 2020). The same geometry also appears in dsDNA with a hinge defect (*e.g.*, a long lived bubble) or in end linked F-actin filaments. In this talk, we present a theoretical analysis of the conformational fluctuations of this system. In particular, we focus on the bimodality in the transverse fluctuations of the free end of a grafted nunchuck. We also consider a nunchuck under tension and show the emergence of bimodality in the elastic response as a function of the hinge position.

P. Benetatos and M. Razbin, *Polymers* 2021, 13(12), 2031

Keywords:

semiflexible polymers, DNA, wormlike chain

Giant Charge Reconstruction in Lipid Vesicles : Optical Bottle Study

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Abstract:

Microions distribution around charged system plays crucial roles in various fields. However, identifying exactly the microion distribution in nanoscale systems is challenging because of their small sizes and the lack of suitable experimental tools. In this study, we describe an B_2 -mediated electric double layer profiling strategy to investigate the electrochemical parameters such as renormalization factor and Debye length in addition to the microionic distribution and composition. Surprisingly, in our experiment using lipid vesicles, the attachment of ions into adsorption layer can be strongly increased, accordingly with the effective valence of vesicles be reduced. It is largely due to the two reasons: (i) intervention of water-originated H^+ ions in charge regulation and (ii) the existence of DOPC entrapping Na^+ ions. Further, PEGylation can cause Na^+ ions entrapping in PEG resulting in the charge reconstruction property changes. This is the first paper to address that the giant charge reconstruction can occur with the ionic adsorption and it provides a guideline for refining the effective charge of nanoparticles depending on the surface property and volume fraction.

Keywords:

charge renormalization, effective charge, electric double layer

플라즈마 이온에너지 분포의 특이 거동 해석

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Abstract:

최근 반도체 산업안에서 주목되고 있는 고증횡비 식각공정에서는 이온에너지를 극대화하기 위해 400 kHz 근방 저주파수 RF 전력을 인가해주고 있다. 저주파수 RF 전력은 잘 사용되고 있는것에 반해, 그 특정 저주파수 사용에 대한 명확한 이유는 잘 알려져있지 않다. 따라서, 본 연구에서는 전형적인 1차원 시간 의존된 충돌 쉬스 모델을 전산모사하여 제어변수에 따른 이온에너지분포를 조사하였다. 그 결과, 저압, 저주파수에서 저에너지영역의 이온선속이 줄어드는 계단식 이온에너지분포를 확인하였다. 이 결과의 물리적인 원인을 찾고자, 진동 쉬스 안에서의 이온 거동을 확인하였고, 계단식 이온에너지분포는 이온의 초기속도와 플라즈마-쉬스 경계선 속도의 관계와 밀접하게 연관되어 있음을 확인하였다. 이 결과로부터, 저주파수 RF 전력의 사용에 대해 더 깊게 이해할수 있을거라고 기대한다.

Keywords:

Plasma, IEDF, MCC

반도체 산업의 플라즈마 시뮬레이션 방법론 (Plasma Simulation for Semiconductor Manufacturing)

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Abstract:

저온 플라즈마 장비의 모델링이 어려운 이유는 공정에 따라 운전 압력의 범위나 Gas Mixture가 다양하기 때문에, 일부 세부적인 물리현상을 간소화 시키더라도 충분한 Flexibility를 확보하는 것이 관건입니다. 플라즈마를 가장 정확하게 모사하는 방법으로 Particle-in-cell 방법이 있지만, 반도체 제조 공정 장비의 플라즈마 모델링으로는 활용하기 어려운 이유가 바로, Plasma Etch/Deposition에 사용되는 다양한 Gas Mixture에 대한 반응 모델을 구성하기 어렵고, 설사 반응 모델이 있다고 하더라도 컴퓨팅 시간이 오래 걸리기 때문에, 현업에 빠른 대응이 어려워 다른 방식의 모델링 기법을 선호합니다. 하이브리드 모델링은 에치 공정과 같이 낮은 운전 압력에서 정확도가 향상될 뿐만 아니라, 압력이 높은 증착 공정에 까지 해석이 가능하고, 다양한 화학 반응을 고려하더라도 빠르게 계산이 되기 때문에, 산업체에서 많이 쓰고 있습니다. 하이브리드 모델은 다양한 물리 현상에 대해 각각 모듈화하여 타임 스케일을 다르게 적용하여 서로 결합시키는 방식이고, 각 모듈에서 계산하는 물리 현상에 적합한 알고리즘을 사용하기 때문에 효율적으로 컴퓨팅 파워를 분배하여 복잡한 화학 반응이 다수 들어간 계산도 빠르게 처리 가능한 장점이 있습니다. 이런 하이브리드 플라즈마 모델링 기법에 대해 설명하겠습니다.

Keywords:

플라즈마, 반도체, 에치, 증착, 하이브리드

비충돌 Child-Langmuir 쉬스 형성에 이온 충돌이 미치는 영향 연구 (Investigation of Ion Collision Effect on Child-Langmuir Collisionless Sheath Formation)

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Abstract:

일반적인 저온 진공 플라즈마에서는 플라즈마와 벽면 (대면재료)와 사이에서 비충돌 Child-Langmuir Sheath (CL)가 형성된다고 알려져 있다. 플라즈마는 양극성 확산하여 벽으로 다가가면서, 이온이 Bohm 속도를 가지는 쉬스 경계로부터 CL 전위 분포를 형성하게 된다. 이를 해석하는 모델로서, 쉬스 경계로부터 전자가 거의 존재하지 않고 이온은 지속적으로 가속이 되어 벽면에 입사하는 모델을 사용하며, 이를 이온 쉬스라 하는 비충돌 Child-Langmuir sheath 특성을 해석하는데 이용한다. 여기서 사용한 가정에 따르면 CL 쉬스 내에는 이온만 존재하는 쉬스로서, 프리쉬스에서 전위가 급격하게 감소하는 불연속성이 발생한다. 쉬스 경계에서 프리쉬스와 부드럽게 이으려는 접합(match) 또는 이어붙임(Patch)의 모델들이 개발되어 왔고, 이 정합 공간을 쉬스-프리쉬스 전이층(transit layer)이라 가정하였다. 대표적인 모델로 Godyak 은 Debye 차폐 영역에서 이뤄지는 접합 모델을 제안했고, Riemann은 이온출동 거리의 특성을 가지는 이어 붙임 영역이 존재할 것으로 예상하였다. 본 연구에서는 Reimann의 전이층이 쉬스 내에서 전자-이온 층으로 구성됨을 확인하는 실험을 진행하였다. 실험은 낮은 압력 (비충돌 조건)의 아르곤 플라즈마의 Bias 전극 앞에 형성되는 쉬스의 경계 영역 근방에서의 전위 분포와 이온의 속도를 측정하고, Belinov 모델에 기초해서 전자-이온층의 두께와 에너지 크기를 분석하였다. 이는 Reimann의 전이층이 쉬스와 프리쉬스, 특히 쉬스 내로 크게 분포함을 확인할 수 있었으며 이는 양극성 확산이 비충돌 CL 쉬스 내로 연장되고 있음을 설명한다. 쉬스 경계에서의 이온 충돌성의 영향은 이중 이온이 존재하는 플라즈마에서도 관찰된다. 서로 다른 이온들 흐름에서 발생하는 이온과 이온의 충돌로 두 이온의 속도가 유사해지는 전이 공간이 각각의 Bohm 속도를 가지는 쉬스 내에서 연장되어 존재하고 이는 Hershkovitz와 Baalrud 예상을 잘 설명한다. 또한 자기장이 존재하는 경우에도 Chodura의 자화 쉬스 해석 결과 Debye 쉬스 (CL)로 이온의 입사가 이온 충돌을 고려한 Ahedo의 모델이 이를 잘 설명함을 확인하였다. 이는 자기장의 입사각이 대면재료와 거의 평행인 경우 ($<5^\circ$) 이온의 확산이 쉬스 내 이온 거동을 지배한다는 Stangeby 예측도 잘 설명한다. 이를 종합하면 쉬스 경계에서 이온 충돌에 의한 쉬스 입사는 전위 분포를 부드럽게 이어주는 주요 현상임을 확인할 수 있었다. 본 연구는 RF 에 의한 쉬스 내의 하전 입자의 가열과 핵융합 조건의 PMI 현상 해석에 기반을 제공할 것으로 예상된다.

Keywords:

Child-Langmuir Sheath, Ion Collision, Ion-Electron Layer, Transit Layer

열플라즈마 공정의 혼합기체 확산 영향에 관한 수치해석적 연구 (Numerical analysis of the effect of gas mixtures in thermal plasma processes)

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Abstract:

열플라즈마 공정은 플라즈마의 초고온 열에너지를 이용하는 공정으로써 아크용접, 플라즈마용사, 플라즈마 절단 등과 같이 산업 현장에서 많이 사용되고 있다. 아르곤 및 아르곤 혼합 가스는 열플라즈마 공정에서 플라즈마 방전을 위해 이용되며 공정의 최적화를 위해서 혼합 가스에 대한 진단계측뿐만 아니라 많은 전산 해석 연구가 진행되고 있다. 특히 2종 이상의 혼합가스의 영향은 실험적으로 규명하기가 쉽지 않아 모델링 기법을 이용하고 있으며 최근 확장된 Combined diffusion coefficients 방법을 이용하여 3종의 혼합기체 확산까지 예측이 가능하다. 본 연구에서는 Combined diffusion coefficients 방법을 적용한 확산 모델을 이용하여 아크 용접과 같은 열플라즈마 공정에서 예측한 결과와 실험 결과와의 비교를 통해 혼합기체 확산 모델의 타당성을 검토하였다. 특히 혼합 공정 가스뿐만 아니라 금속 증기 확산의 영향에 대한 전산 시뮬레이션 결과를 통해 플라즈마 특성에 대한 금속 증기의 영향에 대해 보다 정확하게 이해하고자 한다.

Keywords:

Thermal plasma modeling, combined diffusion coefficients, numerical analysis, CFD

전자 에너지 분포 함수 측정을 통한 RF 플라즈마 소스물리 (RF plasma source physics through the electron energy distribution function (EEDF) measurements)

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Abstract:

반도체 공정 플라즈마 소스로 유도 결합 플라즈마(ICP)와 축전 결합 플라즈마(CCP)가 널리 사용되고 있다. 특히 ICP는 저압에서 고밀도 플라즈마가 가능하여 플라즈마 유지 메커니즘 연구가 활발히 되어 왔다. RF 플라즈마에서 랑뮤어 탐침으로 전자 에너지 분포 함수 측정하는 방법을 제시하고, RF filter설계에 대한 논의를 제시한다. 또한 유도 전기장과 전자의 상호 작용을 분석하고, 이러한 상호 작용이 전자 에너지 분포의 어떤 변화가 생기는지 제시한다.

Keywords:

유도 결합 플라즈마, 축전 결합 플라즈마, 전자 에너지 분포 함수, 랑뮤어 탐침

Nanophotonic waveguides using $X^{(2)}$ materials for quantum applications.

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Abstract:

Quantum devices using nanophotonics have attracted great attention, and related papers have been reported recently. The initial material for on-chip waveguides are mainly silicon owing to its long history in nanophotonics. Recently, many research results based on other materials with better properties have been demonstrated. Especially $X^{(2)}$ materials, such as lithium niobate or aluminum nitride, have second-order nonlinearity which is a great property for quantum application. They can be used for entangled single photon source generation using spontaneous parametric down-conversion (SPDC). Also high-speed modulation from electro-optic effect enables fast optical switching which is necessary for quantum communication or quantum computing. In this talk, the recent progress on nanophotonics using $X^{(2)}$ materials are introduced, and their application in quantum applications are discussed.

Keywords:

2nd nonlinear material, Lithium niobate, Aluminum nitride, Quantum nanophotonics

Study of second-order optical nonlinearity in twisted few-layer graphene

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Abstract:

Graphene, a single sheet of carbon atoms forming a hexagonal structure, has received increasing attention as a promising material for nonlinear optic applications. Since monolayer graphene (MLG) possesses inversion symmetry, second-order nonlinearity is not allowed. Thus, the third-order optical nonlinearity, called Kerr nonlinearity, becomes the primary nonlinear response. However, the centrosymmetric property can be eliminated in multi-layer graphene by stacking the graphene layers with some twist angle or ABA tri-layer structure, which allows second-order optical nonlinearity in graphene layers. In this work, we investigated a second-order optical nonlinearity in twisted few-layer graphene (tFLG). We observed a large second harmonic generation (SHG) signal in a specific tFLG. Raman spectroscopic measurement showed that this tFLG includes a twisted angle of about 16° and 9°. We expect that the enhanced SHG signal originates from the resonant nonlinear coupling of tFLG with the pump laser.

Keywords:

Second order optical nonlinearity, Twisted few-layer graphene, Harmonic generation, Graphene

Optical energy-difference conservation in a synthetic anti-PT symmetric system

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Abstract:

Anti-parity-time (APT) symmetry is associated with various effects beyond the fundamental limitations implied in the standard Hermitian-Hamiltonian dynamics. Here, we create an optical APT-symmetric system in a synthetic frequency domain using a conventional fiber without intrinsic gain/loss and experimentally reveal photonic APT-symmetric effects, including energy-difference conservation and synchronized power oscillation, which have not yet been confirmed experimentally in the optical domain. The optical fiber-based APT-symmetric system has a long interaction length because of its negligible loss, and the APT-symmetric Hamiltonian is precisely tunable with optical pumping density and phase mismatch. On this basis, we observe the phase transition at exceptional points, energy-difference conservation, and synchronized power oscillation. Our results provide a robust theoretical and experimental framework connecting the emerging non-Hermitian physics with technologically important nonlinear fiber-optic interactions.

Keywords:

APT symmetry, Four-wave-mixing, non-Hermitian optics

금속-유기 분해법으로 실리콘 기판 상에 제조된 비스무트 치환 가넷 박막의 1310 nm 및 1550 nm 파장대에서의 자기 광학 상수 비교

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Abstract:

본 연구에서는 비스무트 치환 가넷(garnet) 자기광학 물질을 스피ن 코팅을 통한 금속 유기 분해법(Metal Organic Deposition; MOD)으로 실리콘 상에 제조된 각각 다른 구조식을 가지는 Bi1:YIG ($\text{Bi}_1\text{Y}_2\text{Fe}_5\text{O}_{12}$), Bi2:YIG ($\text{Bi}_2\text{Y}_1\text{Fe}_5\text{O}_{12}$), Bi1:NIGG ($\text{Bi}_1\text{Nd}_2\text{Ga}_1\text{Fe}_4\text{O}_{12}$) 박막의 자기광학 특성을 낮은 자기장 영역에서 자화도가 포화되지 않고 선형적으로 변하는 구간에서의 베르데(Verdet) 상수를 측정하고, 측정된 결과의 비교 특성을 보고한다.

각 비스무트 치환 가넷 박막은 실리콘 기판 위에 앞서 언급한 조성비의 비스무트(Bi), 이트륨(Y), 철(Fe) 또는 비스무트(Bi), 네오디뮴(Nd), 갈륨(Ga), 철(Fe)이 있는 카르복시산염(carboxylate) 혼합물을 스피ن 코팅 한 뒤 건조, 전기로를 이용하여 Pre-Baking, 주된 열처리 과정으로 분당 1도씩 증가시킨 뒤 700도에서 1시간 유지하고 그 이후로 분당 1도씩 감소하는 방식으로 형성되었다. 이러한 과정을 박막의 두께가 ~700 nm 될 때까지 반복하여 진행하였다. 제작된 박막의 결정성, 표면 및 두께의 분석에는 XRD, 주사전자현미경 및 원자현미경을 이용하여 각 박막의 엑스선 회절 패턴 및 표면 상태를 확인하였다. 또한 이 샘플들은 분광 광도계를 통하여 투과 스펙트럼 특성이 측정되었고, 이를 통해 이들 박막의 굴절률 및 흡수 계수를 계산하였다.

제작한 박막의 선형적인 자성 영역에서 가지는 자기 광학 상수인 베르데(Verdet) 상수를 약한 교류 자기장 (~100 Gauss)과 편광 빔 분파기, 자동 평형 광검출기(Auto-balanced detector), 로크인증폭기(lock-in amplifier)를 이용하여 측정하였다. 이때 입력한 파장대별 광원으로서는 1310 nm 에서는 고출력 반도체 레이저와 1550 nm 파장대에서는 DFB-LD와 이 레이저 신호를 증폭하기 위한 EDFA를 통과한 빛을 사용하였다. 제작된 박막의 베르데 상수는 이 박막을 솔레노이드의 교류 자기장이 걸리는 조건에서 이 박막을 지나가는 1310 nm 및 1550-nm 광원 빔의 편광이 박막의 자기광학 효과에 의한 변화를 측정하여 도출되었다. 실리콘 위에 형성된 자기광학 박막의 베르데 상수는 실리콘 기판 자체의 자기광학 특성을 빼주는 방법으로 측정하여 측정된 Bi1:YIG, Bi2:YIG, Bi1:NIGG 박막의 베르데 상수는 1310 nm 에서 1,485,500, 1,048,500, 808,333 deg/T/m 이고 1550 nm 에서 807,500, 411,500, 623,000 deg/T/m 으로 계산되었다.

Keywords:

자기광학, 금속 유기 분해법, Bi-substituted garnet

simulation results of the light scattering by a cylinder and a planar substrate

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Abstract:

In this presentation, we will show the simulation results of the light scattering by a cylinder and a planar substrate. We can calculate the scattered, reflected, transmitted fields without any restriction on the properties of either the cylinder or the substrate. We checked the results in special cases by comparing with the published references and the agreement was within a theoretical limit. We can utilize the results in many fields like remote sensing, geophysical exploration, nano-optics etc. with applications of detecting and ranging objects, tailoring directional scattering of a system, maximizing or minimizing scattering efficiency, scattering enhancement and suppression in dielectric nanoantennas and so on.

Keywords:

Probing electronic and magnetic properties of two-dimensional materials via tunneling spectroscopy

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Abstract:

Two-dimensional (2-D) materials exhibit novel properties such as linear dispersion relation in graphene, evolution from indirect to direct band gap in TMDCs. Tunneling spectroscopy based on van der Waals heterostructure is a powerful tool to probe electronic and magnetic properties of 2D materials. We will introduce fabrication of various tunneling transistors and intrinsic properties probing, including band gap of TMDCs, quantum oscillation of Dirac fermion and spin flip of CrI₃. The band structures and giant Stark effect of TMDCs (MoS₂ and WS₂) were probed by resonant tunneling spectroscopy without debatable quasiparticle effects in TMDC/h-BN/TMDC heterostructures. Landau levels and quantum oscillation of graphene at low magnetic field (2 Tesla) were observed at room temperature in lattice-oriented graphene/h-BN/graphene resonant tunneling transistor. Spin flip of CrI₃ at the interface are investigated in graphene/CrI₃/graphene tunneling transistor and gate-controllable spin flip are achieved. Therefore, van der Waals tunneling spectroscopy reveals powerful capacity to explore novel properties of 2-D materials and potential device applications.

Keywords:

Two-dimensional (2-D) materials, tunneling transistors, MoS₂, WS₂

Efficient and Tunable Mechanoluminescence from TM-Activated wide band-gap semiconductor of MZnSO

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Abstract:

Mechanoluminescence (ML) is a classical optical phenomenon that is induced by mechanical stimulus, and it can be applied to stress sensors, imaging, self-powered display/lighting and anti-counterfeiting. However, the realization of determining the magnitude of stress in real time by the changes of colors for stress-induced display/lighting has been fundamentally challenging. Herein, novel efficient and tunable mechanoluminescent *TM*-activated *MZnSO* (*TM*= transition metal, *M*=Ca, Sr) were successfully synthesized by solid-state reaction at high temperature. Photoluminescence (PL) and mechanoluminescence (ML) properties of *TM*-activated *MZnSO* phosphors were investigated for the first time. The high PL/ML efficiency and tunable emission color of these phosphors make them to show potential applications in self-diagnosis systems, human-machine interfacing, information encryption, and smart-skin.

References

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Keywords:

mechanoluminescence, MZnOS, bandgap, energy transfer

Unusual Stacking in MoS₂ and WS₂ Vertical Heterostructure via One-pot Chemical Vapor Deposition

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Abstract:

One-pot synthesis is an efficient strategy for producing complex chemical compounds in chemistry. It has been modified and adopted in the synthesis of transition metal dichalcogenide (TMD) heterostructures in chemical vapor deposition (CVD). Here, we investigate the stacking sequences of MoS₂ and WS₂ vertical heterostructures grown by one-pot CVD approach. Controlled Ar-ion bombardment on as-grown heterostructure induces damages on the exposed layers, resulting in significant reduction or elimination of Raman signal, while the intensity from bottom layer remained unchanged. The process indicates that the primary stacking sequence is WS₂/MoS₂/substrate in our samples, which is identical with the conventional reports. However, we also found that MoS₂ grows rarely on inactive W precursor and later H₂ injection activates WS₂ growth forming inverted one, MoS₂/WS₂. Our result opens the possibility of stacking sequence modulation in one-pot CVD process, but ironically, it also implies the stacking sequence of heterostructure should be carefully monitored in one-pot grown materials.

Keywords:

MoS₂, WS₂, heterostructures, RIE etching,
chemical vapor deposition, transition metal dichalcogenides, Raman spectroscopy

The high-performance micro-nano lasers based on low dimensional perovskites

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Abstract:

Micro-nano light source plays an important role in the fields of optoelectronic integration, sensing and optical communication. The emerging metal halide perovskite nanomaterials are one of the ideal gain media for the future integrated micro-nano laser devices in the fields of optoelectronics due to their advantages of high gain, low defect density, narrow emission peak, high photoluminescence quantum yield, etc. In view of this, we have fabricated high quality perovskites with different structures and realized the subwavelength single-mode nanolasers from low-dimensional perovskites. Firstly, we successfully realized the single-mode laser from 3D perovskite nanocubes with sizes of (~ 400 nm)³, which displayed low threshold and narrow linewidth. The lasing mechanism was also revealed by transient absorption spectroscopy. In addition, through molecular engineering, the 2D and 0D perovskite micro/nanoplates were synthesized. Based on their intrinsic structures, the single-mode lasers were demonstrated in submicron scale with good performance. To further improve the lasing behavior, we prepared quasi-2D perovskite thin film by solution method, and analyzed the optical gain mechanism and luminescence characteristics. Inspired by the gain characteristic, we successfully overcome the trade-off between small size and good performance for miniaturized lasers and shrank the quasi-2D perovskites laser to the deep-subwavelength scale (~ 50 nm) using only a layer of ultraviolet glue and a glass substrate in the vertical dimension with a highly linear polarization degree of 81% and a quality factor of 1635. These results are expected to provide insights into next-generation integrated laser sources.

Keywords:

perovskite, micro-nano laser, optical gain

Perovskite-Based Monolithic Tandem Solar Cells with Si or CIGS

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Abstract:

One promising approach to surpassing the Shockley-Queisser efficiency limits of single-junction photovoltaic devices is to form multi-junction structures. The tandem architecture consisting of multiple subcells with different bandgaps can minimize the thermalization loss of carriers excited by photons with greater energies than the bandgap, resulting in device performance that exceeds that of single-junction solar cells. Since the advent of perovskite-based solar cells, they were quickly recognized as potential top cell candidate due to several advantages including high efficiency, excellent optoelectronic properties, bandgap tunability and low-cost processability. So, over the past few years, perovskite-based tandem solar cells have made great strides, with efficiencies reaching nearly 30%. In this study, we discuss critical aspects associated with the recombination junction for constructing efficient monolithic perovskite/Al-BSF Si tandem devices. To improve the compatibility between subcells, the recombination junction was deliberately modified with a thin organic layer, resulting in the substantial decrease of interfacial resistance. As a result, a monolithic perovskite/Si tandem device with an efficiency of 21.7% was demonstrated. In addition, preliminary results of perovskite/ultra-thin Si tandem devices for the realization of flexible tandem devices are introduced, suggesting various approaches that can compensate for the current reduction due to the thinning of Si subcell. We also report the improvement of matching current by optimizing the optical design of perovskite/CIGS tandem devices to realize high-efficiency thin-film tandem solar cells.

Keywords:

perovskite, tandem solar cell, Si, CIGS

Carrier-resolved photo-Hall effect: application to halide perovskite

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Abstract:

Majority and minority carrier properties represent fundamental parameters governing semiconductor device performance. Obtaining this information simultaneously under light illumination would unlock many critical parameters such as recombination lifetime, recombination coefficient, and diffusion length; while of critical importance for optoelectronic devices and solar cells, this goal has remained elusive. Studies to collect both majority/minority carrier properties for high-performance light absorbing materials have been attempted, but require a wide range of experimental techniques, which typically use different sample configurations and illumination levels thereby presenting additional complications in the analysis. Here, we demonstrate a carrier-resolved photo Hall technique that rests on a new identity relating hole-electron Hall mobility difference, Hall coefficient and conductivity. This discovery, together with advances in ac-field Hall measurement using a rotating parallel dipole line system, allows us to *unlock a host of critical parameters for both majority and minority carriers*. We successfully apply this technique to organometal lead halide perovskites, (FA,MA)Pb(I,Br)₃ and map the results against varying light intensities, demonstrating unprecedented simultaneous access to these parameters. This information, buried in the photo-Hall measurement, has so far been elusive for 140 years since the original discovery of Hall effect. Beyond historical significance, the applications of simultaneous majority and minority carrier measurement are broad, including photovoltaics, optoelectronics and various electronic devices.

Keywords:

halide perovskite, photo-Hall effect, light absorbing, optoelectronic devices

Optical characterizations of WS₂ multilayers on Au nanogratings

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Abstract:

There have been growing research attention for optoelectronic device applications of 2D atomically thin transition metal dichalcogenide (TMD) materials due to their intriguing physical characteristics. To prepare TMD materials on substrates, there are many methods available, including wet-transfer, dry-transfer, and chemical vapor deposition. Each technique has its own advantages and limitations. The dry-transfer method allows us to transfer any flake anywhere on the substrate we want, without much concern about residue on the TMD surface. In this work, exfoliated WS₂ multilayer flakes were dry-transferred on Au nanogratings, which were fabricated by coating Au thin films on blue-ray disks. The thickness of the flake was identified by atomic force microscope measurements. Micro-reflectance spectra of the WS₂ flakes with a few tens of nm thickness exhibited clear thickness-dependence, originated from Fabry-Perot (FP) resonance. The FP cavity modes can appear in visible wavelength range, due to the exceptionally large refractive indices of WS₂. Comparative characterizations of the flakes on the nanogratings and flat Au surface allowed us to reveal how the surface plasmon effects in the periodic Au nanostructures influenced the light-matter interaction in TMD layers.

Keywords:

WS₂, surface plasmon, Fabry-Perot, nanograting

Low-threshold exciton transport and control in atomically thin semiconductors

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Abstract:

Understanding and controlling the nanoscale transport of excitonic quasiparticles in atomically thin 2D semiconductors, e.g., drift-induced excitonic flux and diffusion-induced energy conversion for neutral- and charged excitons, is a pressing matter to produce highly-efficient nano-excitonic devices. Here we present a metal nano-gap device to selectively confine excitons or trions of 2D transition metal dichalcogenides (TMDs) at the nanoscale by facilitating the drift-dominant exciton dynamics through the local strain-gradient engineering. We investigate the spatio-spectral characteristics of the confined excitons of a WSe₂ monolayer (ML) and trions of a MoS₂ ML using hyperspectral tip-enhanced photoluminescence (TEPL) imaging with <15 nm spatial resolution. In addition, we control the exciton funneling and trion conversion rate of 2D TMDs at the nano-gap in a reversible manner through the atomic force tip control, which allows GPa scale pressure engineering. Through a drift-diffusion model, we confirm an exciton funneling efficiency of ~25 % at the nanoscale region which much exceeds the efficiency (~3 %) of previous studies. This work provides a new strategy to dynamically tune the exciton transport and trion conversion of 2D semiconductor devices.

Keywords:

TEPL, Exciton dynamics, Exciton funneling, Trion conversion

Near-Field Photoluminescence Control of Intra- and Inter-Layer Excitons in $WSe_2/Mo_{0.5}W_{0.5}Se_2$ Heterobilayer

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Abstract:

Heterostructures of two-dimensional van der Waals (vdW) materials provide a range of intriguing physical properties distinct from monolayer crystals. Specifically, transition metal dichalcogenide (TMD) heterobilayers have received extensive attention owing to their new emerging semiconducting properties, e.g., interlayer bandstructure and its interlayer excitons. In general, optical properties of interlayer excitons are highly inhomogeneous due to the local heterogeneities of interlayer coupling and surface roughness of a substrate, as well as corresponding variations in field intensity and local polarization. Hence, systematic nano-optical characterizations and local modifications of interlayer exciton properties are highly desirable.

Here, we investigate a spatial heterogeneity of interlayer excitons in $WSe_2/Mo_{0.5}W_{0.5}Se_2$ heterobilayer using hyperspectral adaptive tip-enhanced photoluminescence (*a*-TEPL) imaging with spatial resolution of <20 nm. In addition, we present tip-enhanced near-field PL controls of interlayer excitons through nano-mechanical strain-engineering and near-field polarization control.

Keywords:

TMD, heterostructure, heterobilayer, Tip-enhanced PL spectroscopy, pressure-engineering

Surface functional group에 따른 MXene hydrogel의 자가 회복 특성 변화 연구

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Abstract:

최근 우수한 전기적, 광학적 특성을 가지고 있는 2차원 층상 구조 재료를 기반으로 하는 transistor, photodetector 등 다양한 소자 응용 연구가 활발히 진행되고 있다. Transition metal carbide and nitride (MXene)은 2차원 재료 중 하나로 높은 전기 전도도와 기계적 특성, 친수성 표면을 가지고 있어 센서, 촉매, 에너지 저장 장치 등에 이용된다. wearable device에 적용하기 위해 MXene과 고분자 재료를 이용한 hydrogel 연구가 각광받고 있으며 [1-3] 대면적 전극 array로 활용한 연구도 보고되었다 [4]. 본 연구에서는 wearable device의 파괴에 대한 회복 특성 (self healing)을 관찰하고자 (Ti₃C₂T_x)과 polyvinyl alcohol (PVA)를 이용하여 hydrogel을 제작하였다. PVA와 sodium borate의 농도를 조절하여 hydrogel의 조건을 최적화하였고 MXene의 HF 처리를 통해 잔류 MAX(Ti₃AlC₂) 제거와 MXene 표면의 functional group을 치환하였다. Hydrogel의 self healing 특성 측정은 샘플 절단 후 다시 결합하는 과정에서 나타나는 전기적 특성을 이용하여 분석하였고 MXene의 유무 및 functional group에 따라 hydrogel의 chemical bonding의 수와 세기가 변화하여 hydrogel의 self healing 특성이 달라지며 HF처리된 MXene을 사용한 hydrogel이 가장 우수한 self healing 특성을 보였다.

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Keywords:

MXene, Ti₃C₂, hydrogel, self healing

Potential Gradient of the fluorinated graphene via an atomic force microscopy

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Abstract:

Graphene shows interesting responses such as Casimir effect, ambipolar electron and hole transport, and chiral half-integer quantum Hall effect associated with energy band structure [1]. One can expect that the surface energy would be tuned by attaching fluorine atoms on the graphene surface with specific treatment, so called fluorinated graphene. Recent, Jonathan et al. show direct mechanochemical cleavage of functional groups from graphene including fluorinated graphene via a mechanical forcing by a sharp tip of atomic force microscope (AFM) [2]. Here, we demonstrate the gradient mechanochemical cleavage of the fluorinated graphene sample via an atomic force microscopy with defining the surface characteristics by using a frictional force microscopy which is one of the powerful methods for revealing materials' intrinsic properties at nanoscale. Furthermore, we performed the cleaning process of the measured frictional force data via a classification data processing method.

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Keywords:

Fluorinated graphene, Atomic force microscopy, Frictional force microscopy, Classification data processing

Subtype-dependent single-molecule mechanics for integrin activation, mechanotransduction and cytoskeleton remodeling

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Abstract:

Integrins are mechano-sensitive adhesion receptors. Using double-stranded DNA-based tension sensors, we discovered that two subtypes of integrins require markedly different single-molecule tensions to stabilize cell spreading, <12 pN for integrin $\alpha4\beta1$ and >33 pN for RGD-binding integrins, primarily $\alphaV\beta1$. Activation of $\alphaV\beta1$ occurs below 23 pN, suggesting that the higher threshold for spreading is determined not by the force required for integrin activation but by high force applied to $\alphaV\beta1$ by the cytoskeleton. Actin assembled by $\alpha4\beta1$ forms a cross-linked network in circularly spread cells, is in rapid retrograde flow, and exerts low forces primarily from actin polymerization. Actin assembled by $\alphaV\beta1$ forms stress fibers flanked by focal adhesions in elongated cells, is in slow retrograde flow, and ramps up to high forces (>54 pN) via myosin II. Overall, our data reveal layers of single molecule mechanics underlying integrin activation, mechanotransduction and cytoskeleton remodeling and their modulation by integrin subtypes.

Keywords:

Integrin

Nucleic acid-based artificial gene regulators for biosensing and diagnosis

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Abstract:

Synthetic biology aims at providing solutions for the challenges of modern society and paving new ways to understand life. Realizing the true potential of synthetic biology is dependent on our ability to regulate gene expression. Nucleic acids offer new opportunities for developing artificial gene regulators based on their programmability, versatility, low genetic footprint, and economic production both in vivo or in vitro. In this presentation, I am going to introduce examples showing how human design can cooperate with nature's power to develop artificial gene regulators for biosensing based on nucleic acids. Specifically, a new development process for RNA-based gene regulators and their application to intracellular sensing of small molecules will be presented. In addition, a rationally designed nucleic acid-based molecular program for rapid diagnosis of pathogens called SENSR will be discussed.

Keywords:

Synthetic Biology, Nucleic Acid, Artificial Gene Regulator, Biosensor, Artificial Evolution, Metabolic Engineering, Molecular Diagnosis

A DNA walker that traverses a microparticle surface

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Abstract:

Molecular machines have previously been designed that are propelled by DNAzymes, protein enzymes and strand displacement. These engineered machines typically move along precisely defined one- and two-dimensional tracks. Here, we report two different DNA walker systems that use hybridization to drive walking on DNA-coated microparticle surfaces. Through purely DNA:DNA hybridization reactions, the nanoscale movements of the walker can lead to the generation of a single-stranded product and the subsequent immobilization of fluorescent labels on the microparticle surface. The first walker (bipedal) can take more than 30 continuous steps and then it is released from the microparticle surface. The second walker (unipedal) is designed to stay persistently bound to the particle surface through multiple turnovers, and can take at least 47 (and likely more) steps without release. We have developed engineering principles for the unipedal walkers that dictate partition between release, walking, and staying in place. These autonomous walkers may be of use in analytical and diagnostic applications, similar to how strand exchange reactions in solution have been used for transducing and quantifying signals from isothermal molecular amplification assays.

Keywords:

DNA walker, catalytic hairpin assembly, microparticle, proton

Exploring advanced molecular tools based on nucleic acid-processing enzymes and probes for applications in biosensing and bioimaging

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Abstract:

DNA has been a central focus of biomedical research because of its potential as a genetic molecule as well as its value as a material. Since then, various DNA-processing enzymes have been discovered, including ligase, exo-/endo-nuclease, and polymerase, and provided excellent tools to process and manipulate DNA in a sophisticated manner combined with an increased understanding of their functions. The co-employment of such enzymes and specifically designed DNA strands has shown great potential to use them as molecular tools for advanced biosensing and bioimaging. In this work, we have shown a few examples of using various nuclease enzymes to develop new biosensors for sensitive detection of biomarkers and to construct DNA- or RNA-inorganic hybrid particles for applications in biocatalysts and biosensors. Firstly, we co-employed different types of DNA-functionalized nanoparticles (e.g., magnetic nanoparticles, quantum dots, gold nanoparticles) with nuclease enzymes (e.g., duplex specific endonuclease, nicking endonuclease) to induce enzyme-triggered signal amplification, achieving ultrasensitive and selective detection of nucleic acids. We have also developed robust and straightforward strategies using isothermal rolling circle amplification (RCA) that enable the facile synthesis of DNA strands to induce signal amplification. Finally, we showed aptasensor-encoded DNA constructs using RCA and demonstrated their application for ratiometric imaging of intracellular target molecules. Therefore, given the versatility and robustness of the proposed approaches, these designer platforms represent a promising opportunity to develop new functional DNA-based materials that can substantially advance numerous applications of nucleic acids in biomedical research.

Keywords:

isothermal nucleic amplification, molecular diagnostics, bioanalysis, bioimaging

국내 입자물리학_내가 보는 반세기의 이야기

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Abstract:

지난 반세기 동안 눈부신 성장을 한 국내의 물리학 분야 중 입자물리학 분야에 국한하여 개인적인 경험과 시각으로 재조명해 보고자 한다. 이어, 국내의 입자물리학 분야 연구와 교육의 현실을 돌아보고, 향후 발전방향에 대한 견해도 피력해 보고자 한다.

Keywords:

입자물리학

물리학자의 물리교육학 답사기

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Abstract:

나는 물리학에 입문하고 20년을 보냈다. 우리나라 과학교육에 문제가 있다는 것을 안 이후 그 이후 과학교육으로 20년을 보냈다. 최근 30년 동안 세상의 과학교육은 크게 변했는데, 우리나라 과학교육은 그렇지 못했다. 보다 많은 사람이 과학교육에 관심을 가져야 하겠다.

Keywords:

과학교육

What can I do for You?

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Abstract:

궁금하면 못 참는 성격에 IMF라는 범 국가적 경제위기 상황에 얼떨결에 창업을 하게 되었고 사업을 교육 및 연구와 병행한지 어언 20년이 지나고 있습니다. 물리학자로 발을 딛게된 계기와 성장과정 그리고 그리고 앞으로 하고자 하는 일 등에 관해 말씀드리고자 합니다.

Keywords:

물리학자

Particle identification for Dual-Readout calorimeter

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Abstract:

The dual-readout calorimeter consists of scintillating and Cerenkov fibers read out together to measure hadronic showers with high energy precision. for future colliders. Currently, it is under development and neural network-based machine learning (deep learning) implementations are under investigation to maximize the physics potential. Classification using deep learning is applied to identify particle showers with their incident particles. Image-based deep learning models analyze pixelated energy deposits with convolutional neural networks, while point cloud-based deep learning methods train using lists of energy deposits. We compare the performance of these methods when trained to identify various electromagnetically and hadronically showering particles using the dual-readout calorimeter.

Keywords:

Dual-readout calorimeter, Deep learning, Particle identification

Vision Transformer based Hadronic Tau Identification for the Dual-Readout Calorimeter

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Abstract:

Future electron-positron colliders will serve as Higgs factories, and the tau lepton identification with high performance will be quite important because the tau might be a key role to understand various interesting theoretical models. The dual-readout calorimeter provides high resolution for both charged and neutral particles, making it an ideal candidate detector for future colliders. We investigate the usage of modern neural networks, especially the vision transformer, for tau identification with the dual-readout Calorimeter.

Keywords:

Machine Learning, Calorimeter

Status of module R&D for a dual-readout calorimeter

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Abstract:

The dual-readout calorimeter (DRC) is one of calorimeter candidates to achieve very high energy resolutions for both EM and hadronic particles in future e+e- colliders. The unit structure of the consists of two optical fibers with 1 mm diameter and wall thickness between them is 0.5 mm. To form such fine structure with the copper (absorber) and assemble fibers into them, engineering questions should be resolved. We will show the progress of various module R&D studies, based on innovative 3D printing technology and classical stacking method in this presentation.

Keywords:

dual-readout calorimeter, future collider, 3D printing

Status of calibration and energy resolution study with 4pi dual-readout calorimeter

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Abstract:

Dual-Readout Calorimeter (DRC) is proposed as a calorimeter candidate for future e+e- collider such as FCC-ee and CEPC. DRC implemented by two different types of optical fibers, Cerenkov and scintillation fibers, allowing simultaneous measurement of electromagnetic and hadronic particles. Two different types of fiber have different h/e responses, DRC can measure the electromagnetic shower fraction in a hadronic shower and corrects the hadronic shower energy on an event-by-event basis, reaching a higher level of precision on energy resolution for hadrons and jets. This presentation will cover the result of calibration and the estimation for the energy resolution of the electromagnetic particles, hadrons, and jets of the dual-readout calorimeter based on the simulation carried out in GEANT4.

Keywords:

Dual-readout, Future Collider, Energy Resolution, Calibration

Status of preparation of dual-readout calorimeter module for first test beam

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Abstract:

Calorimeters have been an important role in high energy physics experiments since they provide four-vector of both neutral and charged particles. Future lepton collider experiments (FCC-ee and CEPC) are proposed for the Higgs factory to understand the property of Higgs (origin of mass and its relation to the Higgs mechanism). High-quality energy measurements for these experiments are essential to study couplings between Higgs and all decay products. The dual read calorimeter (DRC) is considered a good option to allow this requirement. The KFC-DREAM (Korea Future Collider Dual-READout Method calorimeter) collaboration plans to have a beam test with two copper-fiber calorimeters at CERN. The main programs measure the nuclear interaction lengths and study the performance of the copper-fiber calorimeters. And our main goal is to build two modules which have different configurations for DRC. In this talk, we will present our status of build two modules for DRC.

Keywords:

Dual-readout (DR) calorimeter, Fcc-ee, CEPC, Future lepton collider experiments

Fast Simulation for the Dual-Readout calorimeter using GAN

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Abstract:

The dual-readout calorimeter is designed with scintillating and Cerenkov fibers to measure electromagnetic and hadronic showers with high resolution. The dual-readout calorimeter simulation performed with GEANT4 is an extremely computational-intensive task, leading to limited statistics for physics studies. To speed up the simulation step by several orders of magnitude, we adopt Generative Adversarial Network (GAN), a machine learning technique that can teach a Deep Learning network to mimic the output of the GEANT4 simulation. We present the dual-readout calorimeter responses generated by a GAN.

Keywords:

Dual-readout calorimeter, KFC, GAN, Fast simulation, deep learning

Migration of the dual-readout calorimeter simulation to Key4HEP common software stack for future HEP collider experiments

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Abstract:

The Key4HEP is a common software stack encompassing the needs of all future HEP collider experiments, including ILC, CLIC, FCC, and CEPC. Key4HEP offers software tools for various HEP libraries such as Podio, GEANT4, and DD4hep. The dual-readout calorimeter simulation has been migrated from standalone GEANT4 to Key4hep, allowing easier collaboration with broader communities of future HEP colliders. We present the dual-readout calorimeter simulation using the Key4hep framework and potential applications associated with future e+e- collider activities.

Keywords:

Key4HEP, GEANT4, DD4hep, Dual-readout, FCC

The jet energy resolution of the 4pi dual-readout fiber calorimeter

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Abstract:

Jet is the fundamental physics object to understand the relation between Higgs mechanism and mass in future lepton collider experiments such as FCC-ee and CEPC. High precision four-vector reconstruction of jets is essential for the experiments since the hadronic decay probability of W and Z bosons is larger than the leptonic decay by a factor of approximately 3-10. We studied the intrinsic performance of the 4pi dual-readout calorimeter for jets designed for future collider experiments using GEANT4 simulations and present the results in this talk.

Keywords:

dual-readout calorimeter, future collider, jet, GEANT4

Status of readout system R&D of a dual-readout calorimeter for future e+e- collider

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Abstract:

To explore the origin of mass and its correlation with Higgs particles, High-Energy Physics (HEP) experiments with future e+e- colliders, such as FCC-ee and CEPC, are proposed and the main detection system has been designed. Dual-Readout Calorimeter (DRC), which uses two different types of optical fibers, is the one of subsystems to measure the energy and momentum of leptonic particles and hadrons in future HEP experiments. In early 2022, KFC DREAM (Korea Future Collider Dual-REAdout Method) team will request the lepton and hadron beams to measure the nuclear interaction length and the operational performance of two prototype DRC modules at CERN. The prototype DRC consists of 2.5 m optical fibers (scintillation and Cerenkov), absorber (Cu), readout detectors (MCP-PMTs, PMTs, and SiPMs), and a data acquisition (DAQ) system. The readout detectors of one module are two MCP-PMTs and 6 PMTs and the other module will be connected with 400 SiPMs and 16 PMTs. The DAQ system has two operational modes, fast DAQ and waveform modes, with bin event mode and to obtain an excellent position and time resolution (<50 ps), DRS (Domino Ring Sampler) chip has been used. We have designed the mounting frames of readout detectors and the bottom base for the absorber including the optical fibers. We will present the status of the DAQ system R&D of prototype DRC with the latest design.

Keywords:

FCC-ee, CEPC, dual-readout calorimeter, Test Beam, readout DAQ system

Status of NEON Experiment

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Abstract:

The NEON (Neutrino Elastic-scattering Observation with NaI(Tl)) experiment aims to observe a Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) using reactor electron anti-neutrino which has not been measured with NaI(Tl) crystals.

The measurement can provide interesting new physics such as a neutrino magnetic moment and non-standard interactions.

The NEON detector consists of a total of 15 kg NaI(Tl) crystals in radiation shielding structures including ~700 L liquid scintillator.

In November 2020, the NEON detector was installed 24-m distance away from the active reactor core at the Hanbit nuclear power plant in YeongGwang.

Data taking has been started right after installation, and it includes both reactor-on and reactor-off data.

We report current status of the NEON experiment in this talk.

Keywords:

NEON, Neutrino, Reactor

Status of NEOS-2 experiment

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Abstract:

NEOS is an experiment to measure the energy spectrum of anti-neutrinos from a reactor core to search for a possible solution of the reactor antineutrino anomaly. The experiment has been carried out at 24-m distance from the active reactor core, in the tendon gallery of the Hanbit-5 reactor. We received one full reactor operation cycle data and reactor off data for about 2 years until August 2020. In this talk, we report the overall status and preliminary results of the experiment.

Keywords:

NEOS, Neutrino, reactor, particle physics

Pulse Shape Discrimination using Convolutional Neural Network for NEOS-II

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Abstract:

In the NEOS-II experiment, an inverse beta decay of a reactor antineutrino produces a correlated pair of scintillation signals of a prompt stopping positron and a delayed neutron capture. It is important to distinguish the scintillation signals for the inverse beta decay from the ones for fast neutron signals to improve the ratio of signal to background. Utilization of a convolutional neural network technique for the pulse shape discrimination can improve the discrimination power compared to the conventional method using the fractional areas of pulse tails.

Keywords:

Pulse shape discrimination, CNN

Study of various backgrounds in the monopole experiment (KAEM) using GEANT4 simulation

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Abstract:

Korea Experiment on Magnetic Monopole (KAEM) searches for fundamental magnetic monopoles in the e^+e^- annihilation process at low-mass and low-charge. The thin aluminum target and sodium-22, a positron source, enable the e^+e^- annihilation, and two 1T solenoids generate a magnetic field to accelerate the magnetic monopoles to energies above source energies. The LYSO crystals, which act as an electromagnetic calorimeter trigger-veto, surround the positron source, and LYSO EM calorimeters are located at the end of the solenoids to detect magnetic monopoles from the target. In this talk, we investigated various backgrounds with GEANT4 simulations that can happen in this experiment and present the results of these studies.

Keywords:

Magnetic monopole, KAEM, GEANT4

Measurement reactor neutrino flux and spectrum at RENO

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Abstract:

The RENO experiment reports measured flux and energy spectrum of reactor electron antineutrinos $\bar{\nu}_e$ from the six reactors at Hanbit Nuclear Power Plant. The measurements use 966,094 $\bar{\nu}_e$ candidate events with a background fraction of 2.39% (5.13%), acquired in the near (far) detector, from August 2011 to March 2020. A reactor $\bar{\nu}_e$ spectrum is obtained by unfolding a measured IBD prompt spectrum. In this presentation, we will report a detailed description of the unfolding and a study of its systematic bias. The obtained reactor $\bar{\nu}_e$ spectrum will be useful for understanding unknown neutrino properties and reactor models.

Keywords:

RENO, neutrino, reactor

The status of the GroundBIRD telescope

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Abstract:

GroundBIRD (Ground-based Background Image Radiation Detector) is a ground-based experiment that measures the polarization of the CMB radiation. It will cover about 45% of the sky from the Teide Observatory in Tenerife, at two frequencies (145 and 220 GHz). We present the main concept of the telescope, installation, and the current status of the commissioning.

Keywords:

CMB

Detector system verification for CPT violation study in KAPAE

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Abstract:

The KNU Advanced Positronium Annihilation Experiment (KAPAE) studies various physical phenomena by measuring the decay of positronium. The first goal is the study of CPT violations, which is suitable because Positronium is the simplest system to study CPT violations in the lepton sector. The KAPAE detector has a compact size and fine segmentation into 200 BGO scintillators, enabling precise measurement of gamma generated by positronium decay. Since direction information of the positron can be obtained from the trigger, CPT amplification can be measured as the relationship between the spin direction of the positronium and the plane of gamma. In this study, the symmetry of the detector itself is also important parameter. We show verification of the detector symmetry through the preliminary data obtained from the KAPAE detector and suggests upgrade direction.

Keywords:

CPT violation, KAPAE, Positronium

Measurement of cosmogenic Li/He production rate at RENO

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Abstract:

A high energy cosmic muon produces various spallation isotopes in the RENO detector. Among them, unstable isotopes of ^9Li and ^8He can mimic reactor neutrino candidate events and become one of the most serious backgrounds in precise determination of the neutrino mixing angle θ_{13} . The spectral shape of the $^9\text{Li}/^8\text{He}$ is measured using the time correlation relative to their preceding muon. The fractional ratio of ^9Li and ^8He is also measured from the energy spectrum of $^9\text{Li}/^8\text{He}$ decay products. The production rate of $^9\text{Li}/^8\text{He}$ was measured at $7\sim 12\text{MeV}$ and extrapolated to 1.2MeV . In this talk, we present the measured production rate of cosmogenic $^9\text{Li}/^8\text{He}$ background in the RENO detector.

Keywords:

RENO

Neutrino Event Reconstruction in the KNO Detector

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Abstract:

The KNO (Korean Neutrino Observatory) project has been proposed as a next-generation water Cherenkov neutrino detector, and it is expected to make important discoveries such as CP violation, proton decays, and neutrinos from supernovae. In order to understand the detector performance, we are developing a neutrino event reconstruction tool. In this presentation, we introduce the current status of our neutrino event reconstruction tool and the plan to improve the tool.

Keywords:

neutrino, KNO, Korean Neutrino Observatory, reconstruction

Precise mass measurements for exotic nuclei using MR-TOF at RAON

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Abstract:

Nuclear mass is one of the most fundamentals for studies on the structure of nuclei and nucleosynthesis in stars. For instance, the calculations of the shell gap energy, alpha preformation, and half-life of exotic isotopes are very sensitive to the nuclear mass; Studies on reaction rates and isotopic abundance in the nucleosynthesis via rp- or r-process also strongly depend on the accuracy of the mass. However, the nuclear mass of many neutron-rich and neutron-deficient nuclei, which play a key role in the mentioned studies, is missing or very uncertain. Therefore, precise mass measurements for such isotopes are highly recommended to modern radioactive-ion beam facilities. In this study, we investigate the feasibility of the measurements for the proton-rich ^{41}Ti , $^{43,44}\text{V}$, $^{44,45}\text{Cr}$, $^{45-47}\text{Mn}$, $^{46-48}\text{Fe}$ and neutron-rich $^{136-140}\text{Sn}$ nuclei, which are important for studies on the shell-closure structure at $N = 20, 90$ and r- and rp-process nucleosynthesis. The production yields using the Isotope Separation On-Line (ISOL) method and feasibility of mass measurements using the Multiple-Reflection Time-of-Flight (MR-TOF) technique are considered. The results show that the nickel and UCx targets are appropriate for the productions of the proton-rich and neutron-rich $^{136-140}\text{Sn}$ nuclei, respectively. The main isobar contaminants of $^{136-140}\text{I}$, $^{136-140}\text{Sb}$, and $^{136-140}\text{Te}$ can be separated from the $^{136-140}\text{Sn}$ nuclei at a mass resolving power of 10^5 . Under developments of the ISOL and MR-TOF systems, the RAON facility enables the precise mass measurements of the investigated nuclei in near future.

Keywords:

Precise mass, rp-process, Shell-closure, MR-TOF, Exotic nuclei

Fission experiments at the NDPS

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Abstract:

The Nuclear Data Production System (NDPS) is an experimental system for measuring nuclear data by use of mainly neutron Time-of-Flight detection systems. The RAON provides deuterons and protons up to 98 MeV and 83 MeV, respectively. They are accelerated by a superconducting driver LINAC (SCL3) and are delivered to the neutron production target to produce neutrons. Pulsed beams with intensity up to $\sim 12 \mu\text{A}$ can be used to do experiments for measuring neutron-induced cross sections. Nuclear data such as $(n, \text{fission})$, (n, xn) , and (n, γ) cross sections can be measured. Beam lines for charged particles and neutrons together with a neutron collimator and beam dumps are under construction. Experiments for fission (n, f) and (n, xn) reactions can be done with various detectors. As a commissioning experiment, we propose the measurement of fission fragments and their total kinetic energies of Th-232 for high energy neutrons. The current status of the construction of the NDPS and the experimental system will be presented.

Keywords:

NDPS, Neutron TOF, Th-232, Fission fragments

Measurements of spectroscopic factors for studies of nuclear structure by QFS (Quasi-Free Scattering) reaction

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Abstract:

The quasi-free scattering (QFS) reaction allows for the optimum condition to probe the shell structure by removing a nucleon in a target nucleus without touching spectator nucleons. An advantage of such an undisturbed nucleon knockout reaction is that it can provide a clue for understanding how individual nucleon interacts with the other nucleons in the nucleus. Measurement of spectroscopic factor is used to quantify deviation from the single particle system or the shell structure. Reduction factor, the ratio of experimental to theoretical spectroscopic factor, is a very effective quantity to explain properties of nuclei because it may be associated with missing correlations beyond the current standard nuclear models. Several literatures suggest that asymmetry of the neutron and proton binding energy contributes to quenching of spectroscopic factors. However, it is still puzzling that asymmetry of nucleon separation energy is strongly correlated with quenching of spectroscopic factors. In this work, we will introduce dependence of nucleon separation energy asymmetry on reduction factor of neutron rich isotopes ^{58,60,62,68}Ni, using the QFS reactions in an inversed manner.

Keywords:

quasi-free scattering, reduction factor, quenching of spectroscopic factors

Study of the nuclear skin with the LAMPS detector

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Abstract:

In heavy nuclei, a neutron-rich skin is expected to be formed near the surface. The thickness of the skin is sensitive to the density dependence of the symmetry energy which is poorly known yet. Therefore, a precise measurement of the neutron skin thickness would provide a strong constraint on the slope parameter of the symmetry energy. The LAMPS (Large Acceptance Multi-Purpose Spectrometer) experiment at RAON mainly focuses on the nuclear symmetry energy at saturation density. In this presentation, a preliminary study of neutron-skin measurements using the LAMPS apparatus will be introduced.

Keywords:

LAMPS, RAON, Neutron skin

Energy-dissipation reactions with the low-energy beams

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Abstract:

Energy-dissipation reactions, which are generally governed by the fusion (compound) and the pre-equilibrium processes at low energies about a few tens of MeV/u or less, are one of the prominent tools to produce unstable nuclei in their excited states. In the reaction mechanisms with such a reaction energy, the kinetic energy of a projectile is *dissipated* into other nucleons in a target by the above processes. Since a lot of excited states including high-spin ones can be populated in the produced nuclei using those processes, the spectroscopic structure can be investigated by applying γ -ray detection technique (e.g. introducing an array of germanium detectors). Fusion or fusion-evaporation is one of the methods using energy-dissipation reactions, which has the long history in the studies of the nuclear structure using the stable beam and the stable target. Light-particle induced energy-dissipation reactions, which employs a target of light particles such as proton, deuteron, etc., are one of the novel ways to produce unstable nuclei, in particular, the proton-rich ones. In this talk, the reaction mechanisms of such reactions, their potential to produce exotic nuclei, and the possible experimental studies at KoBRA or other beamlines in RAON will be presented.

Keywords:

RAON, KoBRA, Fusion, Compound nucleus reaction, Pre-equilibrium reaction

High-resolution in-beam gamma-ray experiments at RAON: Perspective on early experiments

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Abstract:

Nuclear shells are created by the large energy gaps between two nucleonic orbitals, induced explicitly by the high-angular momentum partner orbital split, the intruder orbitals. These energy gaps so-called magic numbers are one of the major milestones of nuclear structure. As the era of rare-isotope (RI) beams opened, the more exotic region far off the beta-stability line could be reached. Subsequently, much experimental evidence and theoretical predictions showed the change of these magic numbers, which is strongly related to the interactions of valence nucleons. Consequently, nuclear shell evolution, like the magic number change, is one of the major topics in nuclear physics. Thus, it is of great importance to investigate nuclei in terms of spectroscopy which requires a dedicated state-of-the-art detector system.

In the Center for Exotic Nuclear Studies (CENS), several instruments are being developed to achieve such scientific goals, like the ASGARD (Array of Super clover GAMMA-Ray Detectors) and STARK Jr. (Silicon Telescope Array for Reaction studies in inverse Kinematics Junior) for the gamma-ray and charged particle measurements, respectively. Moreover, the new heavy-ion accelerator RAON in Korea will be soon operated and start to transport the primary stable beam to the experimental instrument, for example KoBRA (Korea Broad acceptance Recoil spectrometer and Apparatus), in the very beginning stage. Therefore, an in-beam gamma-ray experimental setup can be then installed at the end stage of the KoBRA beam line to perform the high-resolution spectroscopy experiments for nuclear structure with various reaction channels.

In this talk, the possible high-resolution in-beam gamma-ray experiments, which can be carried out at the KoBRA beam line, will be discussed. In particular, the experiments by using the ^{40}Ar stable beam and various nuclear reactions such as direct reactions and Coulomb excitations will be introduced. Furthermore, the design of the spectrometer, experimental plan, and construction status will be also represented.

Keywords:

RAON, KoBRA, In-beam gamma-ray experiment, Nuclear structure, Nuclear reaction

Results from a search for secluded dark matter in the Sun using 6 Years of IceCube data

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Abstract:

The IceCube neutrino observatory is the to-date largest neutrino telescope installed in the Antarctic ice. It consists of 5,160 photomultiplier-tubes spread among 86 vertical strings making a total detector volume of more than a cubic kilometer. It detects neutrinos via Cherenkov light of charged relativistic particles from neutrino interactions within the detector volume. IceCube is particularly sensitive to high-energy neutrinos due to its size and photosensor spacing. In this analysis a search is performed looking for dark matter that annihilates into a metastable mediator that subsequently decays into Standard Model particles. As absorption of signal neutrinos in the solar plasma can be avoided for sufficiently long-lived mediators the expected high energy neutrino signal is enhanced in those cases. IceCube is ideal to search for this enhanced high-energy neutrino signal. We present the results of an analysis of six years of IceCube data looking for dark matter in the Sun and an ongoing update to the analysis using 9 years of data. Mediator decay lengths between 0.01 and 10 solar radii and dark matter masses between 100 GeV and 75 TeV are considered in this analysis.

Keywords:

IceCube, Dark Matter, Neutrino, Sun, Secluded dark matter

Search for Decaying Dark Matter in Galaxy Clusters and Galaxies with IceCube

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Abstract:

Heavy decaying dark matter is a well motivated candidate for dark matter. When it decays into Standard Model particles, neutrinos can be produced directly or through the subsequent decay of the particles. Thus, models for the decay of heavy dark matter can be probed using a neutrino telescope. We search for decaying dark matter in galaxy clusters, dwarf galaxies, and the Andromeda galaxy using neutrino events observed at IceCube. IceCube is to date the world's largest neutrino telescope. The telescope is sensitive to high-energy neutrinos which could be produced when dark matter decays in extragalactic objects. We focus on heavy dark matter with masses between 10 TeV and 10 PeV, decaying into a pair of Standard Model particles. Sources in the northern sky are considered as targets. To optimise the sensitivities of the analysis, we consider stacking multiple targets. The analysis uses muon neutrinos events that have been selected with standard selection criteria developed within the IceCube Collaboration. In this talk, the sensitivities of the analysis will be presented.

Keywords:

dark matter, neutrino, IceCube

Camera system for the IceCube neutrino telescope upgrade and IceCube Gen-2

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Abstract:

The IceCube upgrade is an ongoing expansion to the IceCube neutrino observatory containing 7 new strings equipped with optical modules.

These new strings are placed in the center of the IceCube detector and are densely instrumented to lower the experiment's energy threshold.

To achieve the primary scientific objectives of the upgrade, the measurement of the unitarity of the PMNS matrix, it is essential that the detector medium is extremely well understood.

Hence, a key objective of the upgrade is to employ new calibration devices to measure ice properties.

The team at SKKU has design a new camera-based calibration system for this purpose that was selected by the IceCube Collaboration to be deployed on all 700 of the new detector modules.

The Korea camera system consists of three cameras per optical module, each having a high sensitivity image sensor and a 175 degree field of view lens.

Each camera is connected to an illumination system using a 470nm LED emitting a light cone with a full width at half intensity of 80 degrees.

The production of the camera system is on-going at SKKU and more than half of the cameras have already been installed.

In preparation of an efficient camera data analysis after deployment of the system, we have designed a camera simulation package. To simulate the LED light signatures captured by the cameras in the Antarctic ice medium and to develop an image analysis method a series of simulation studies are in progress. The simulation tool, which is used for the standard IceCube analysis framework, can be utilised to simulate the proposed operation modes of the camera system with a simplified detector geometry and modified LED emission characteristics. The framework consists of the simulation tool and process wrapping scripts in Python with a set of configuration files. Using the produced simulated images an analysis framework is being developed.

Keywords:

Camera, IceCube, Neutrino, Antarctica, Calibration

Constraining Primordial Black Holes with Dwarf Galaxy Heating

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Abstract:

Primordial Black Holes (PBH) in the intermediate mass range can be seeds for supermassive black holes and recent LIGO detections of black hole mergers in the mass gap suggest PBH progenitors. I present a novel constraint on the PBH mass fraction spanning PBH masses of 10 - 10^7 solar masses from thermal equilibrium considerations. A population of PBH in the central region of the dwarf galaxy Leo T will accrete gas from the interstellar medium and emit high energy photons and protons, depositing heat back into the ISM gas. Using semi-analytical accretion disk modeling, we balance the heating and cooling rates of the Leo T gas to derive competitive bounds. We extend our results to spinning PBH with projected jet contribution.

Keywords:

Primordial Black Hole, Dark Matter, Accretion Disk

Accelerated protons produced by magnetic Penrose process in Sgr A*

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Abstract:

Particle acceleration by magnetic Penrose process (MPP) on super massive black hole (SMBH) was produced by A. Tununov et al 2020. We studied high energy cosmic ray production, where neutrons produced in the accretion flow are injected into the magnetic field close to SMBH and accelerated by this MPP. We estimated high energy cosmic ray production rate and spectrum from Sgr A*. Typical energy of accelerated cosmic ray is found to be around 10^{15} eV, and we also estimated the flux of these PeV cosmic ray and compared with the observed cosmic ray flux on Earth

Keywords:

Sgr A*, black hole, cosmic ray

Topological spin transport in two-dimensional magnets

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Abstract:

Recently discovered two-dimensional magnets have been shown to support a variety of new spin-transport phenomena, which have not been found in bulk magnets. In this talk, we will discuss two illuminating examples in this research direction. The first topic is a magnonic topological insulator realized in an easy-axis two-dimensional ferromagnet such as CrI₃, which is shown to give rise to the thermal Hall effect via the finite Berry curvature of magnons [1]. The second one is a magnetic Berezinskii-Kosterlitz-Thouless (BKT) transition in easy-plane 2D magnets [2]. The talk will be concluded with a future outlook on novel types of spin-transport phenomena in more general two-dimensional magnets.

[1] S. K. Kim, H. Ochoa, R. Zarzuela, and Y. Tserkovnyak, "Realization of the Haldane-Kane-Mele Model in a System of Localized Spins," Phys. Rev. Lett. 117, 227201 (2016)

[2] S. K. Kim and S. B. Chung, "Transport Signature of the Magnetic Berezinskii-Kosterlitz-Thouless Transition," SciPost Phys. 10, 068 (2021)

Keywords:

2D magnet, magnon, spin transport

Skyrmionics: Can we reach the quantum limit?

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Abstract:

Topological swirling spin textures, magnetic skyrmions, have been intensively studied in spintronics as a prospective information carrier due to distinct topological features. Therefore, stabilization of magnetic skyrmions is the key technology for realizing skyrmion-based spintronic devices. However, to date, skyrmions have only been stabilized in extremely narrow ranges of material parameters. For example, more than 10 repeated numbers of multilayers are required to induce a large dipole field, or the thickness control within 0.1 nm is essential for achieving a particular magnetic anisotropy. The other key issue is to intentionally create a magnetic skyrmion. Therefore, experimental demonstrations of skyrmion creation have been achieved using diverse methods, including a pulsed local magnetic field or by a spin-orbit torque (SOT)-based perturbation. However, most of them utilized a randomly created defect site as a source of skyrmion creation, which disturbs the skyrmion motion after the creation. The above mentioned limitations in skyrmion creation are the key challenges in skyrmion research. We present a fine tuning method of material parameters for stabilizing magnetic skyrmions and also provide a defect-free skyrmion creation in general PMA films using external magnetic field. With this skyrmion at hand, we can decrease the size of the skyrmion down to few nano-meter scale. Then the interactions between skyrmions can create the quantum behavior, which will open the new fields in quantum computing. A few examples will be introduced.

Keywords:

스핀트로닉스, 스커미온, 양자스핀

Helical Magnetism and spin transport of the $\text{Fe}_{5-x}\text{GeTe}_2$ crystal

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Abstract:

In this presentation, microscopic structures and magnetic properties of the $\text{Fe}_{5-x}\text{GeTe}_2$ single crystal, recently discovered as a promising van der Waals (vdW) ferromagnet, are introduced. Our study demonstrate that the $\sqrt{3} \times \sqrt{3}$ superstructures have two different phases due to the symmetry of Fe(1) ordering. Intriguingly, the observed $\sqrt{3} \times \sqrt{3}$ ordering breaks the inversion symmetry of crystal, resulting in substantial antisymmetric exchange interaction. The temperature dependence of magnetization reveals a sharp magnetic anomaly suggesting helical magnetism of the $\text{Fe}_{5-x}\text{GeTe}_2$ due to its non-centrosymmetry. Analytical study also supports that the observed ordering can give rise to the helimagnetism. I will also present the non-trivial magnetoresistance of the $\text{Fe}_{5-x}\text{GeTe}_2$ crystal. The work will provide essential information to understand the complex magnetic properties and the origin of the new vdW ferromagnet, $\text{Fe}_{5-x}\text{GeTe}_2$ for future topology-based spin devices.

Keywords:

Helimagnetism, van der Waals ferromagnet

Quantum dynamics of orbital angular momentum

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Abstract:

Roles of orbital angular momentum have received a great attention in the spintronics community because of its large Hall effect in general contexts. However, detection of the orbital angular momentum transport is very challenging due to similarity of spin and orbital dynamics. In this work, we reveal a fundamental difference between the orbital and spin angular momentum operators, in regard to their anticommutator algebra. The different algebraic properties result in oscillatory dynamics of orbital angular momentum, which is similar to the spin Hanle oscillation, but not requiring any symmetry breaking such as an external magnetic field. We identify a physical quantity named orbital torsion, which mediates the orbital Hanle oscillation. The relation between the orbital torsion and the orbital angular momentum is similar to that in the classical torsion pendulum. Since the orbital torsion and related phenomena have no spin counterpart, the orbital torsion would be greatly helpful for experimental distinction of orbital dynamics from spin dynamics. We propose that twisted heterostructures would be a platform for generating an orbital torsion which is measurable through magnetoresistance or orbital torque.

Keywords:

orbitronics, orbital angular momentum, orbital current

Proposal and experimental demonstration of single-frame coherent X-ray diffraction imaging using triangular aperture

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Abstract:

We propose a method of single-frame coherent diffraction imaging using a triangular aperture. This method can reconstruct the phase image of the projected area on the extended objects from a single-frame coherent diffraction pattern by using a phase retrieval algorithm without any support constraints. We numerically simulated feasible experimental setups in the hard X-ray regime and experimentally demonstrated the setup with a Fresnel zone plate using 5 keV X-rays at BL29XUL in SPring-8, Japan. We successfully reconstructed the object image of the locally illuminated area without using prior information about the sample. The spatial resolution of the reconstructed image was 17 nm with a 10 s exposure time and was still higher than 50 nm with an 0.1 s exposure time. We believe that the present method can open new frontiers in the study of dynamics at the nanoscale by using next-generation synchrotron radiation X-rays/free-electron lasers as light sources.

Keywords:

Single-frame coherent X-ray diffraction imaging, Synchrotron radiation, Triangular aperture, Phase retrieval algorithm

Offline correction of hysteresis and mirroring artifacts in high-speed atomic force microscopy images

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Abstract:

Scan range is often sacrificed to achieve fast lateral scanning in high-speed atomic force microscopy (HS-AFM). In the absence of scanner-installed displacement sensors, images obtained by utilizing the entire scan range often contain a significant level of hysteresis-induced non-linearity. Additionally, as the image acquisition rate is increased, the phase lag introduced by the scanner and/or any of the electronic components in the path between the controller and the scanner leads to more artifacts. It has been typical to compensate for the mentioned artifacts online using feedforward techniques in open-loop configurations. In this work, we present an offline method to correct for hysteresis and phase-lag artifacts in HS-AFM images. The images are first corrected for the phase-lag using the scanner's phase response. Thereafter, a hysteresis model is used to reduce the level of hysteretic non-linearity. The proposed method is applied to the images acquired using a home-made HS-AFM, and the results are compared with conventional commercial atomic force microscope (AFM) scan results.

Keywords:

atomic force microscope, high-speed atomic force microscope, open-loop control, hysteresis, phase lag

Crystal growth and physico-chemical properties of Organic scintillator: $C_{11}H_{16}N_2O_4$

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Abstract:

The 2-amino 4-methylpyridinium glutaric acid (2A4MGA) compound was synthesis and the crystal has been grown by slow evaporation solution growth method for the first time. The crystal structure of the grown crystal was determined by single crystal X-ray diffraction measurement. It reveals that the grown crystal belongs to the Monoclinic crystal system with space group of P21/n. The calculated unit cell parameters are as follows: $a = 7.1853(7) \text{ \AA}$, $b = 9.5314(9) \text{ \AA}$, $c = 11.0896(11) \text{ \AA}$, $\alpha = \gamma = 90^\circ$, $\beta = 105.665(3)^\circ$ and Volume = $731.27(12) \text{ \AA}^3$.

The crystal structure connected with the protonated 2-amino 4-methylpyridinium cations along with the H-atom in the carboxylic group of glutaric acid anion. The presence of various functional groups such as stretching in-plane, out-plane and symmetric, asymmetric vibrations were identified by Fourier transform infrared (FTIR) spectral analysis. Thermal stability of the grown crystal was analysed by using thermogravimetry (TG) and differential scanning calorimetry (DSC) measurements. Photoluminescence (PL) spectra of the grown crystal was measured at room temperature and the peak emission was observed at 364 nm upon the excitation of 340 nm. X-ray induced emission spectrum shows a maximum peak at 364 nm. It has a fast scintillation decay time of 16 ns under α -particle excitation from ^{241}Am radiation source.

Keywords:

A. Organic crystal; B. Crystal Structure; C. Growth from solutions; D. Spectral characterization E. Scintillation decay time

A thin defective layer formation in yttria-stabilized zirconia and its ferromagnetism

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Abstract:

Ferromagnetism in oxygen-deficient ZrO_2 has been reported. In this work, the nitrogen ion beam was irradiated to YSZ single crystals. To identify penetration depth of ion beam, simulation was proceeded. Defective thin layer was formed in the YSZ by ion beam. The thickness of defective layer was similar to the simulation, and the increase of the lattice constant was observed by x-ray diffraction. In addition, nitrogen depth profiling was obtained by secondary ion mass spectrometry (SIMS). Oxygen vacancy formation is evidenced by EDS/STEM analysis. Interestingly, ferromagnetic hysteresis is observed in the irradiated YSZs at room temperature. To find origin of such ferromagnetic behavior, we thermally created oxygen vacancies in YSZ and observed ferromagnetic behavior. We'll argue the origin of ferromagnetism in the defective layer.

Keywords:

Ferromagnetism, nitrogen ion beam

측도를 이용한 물리량과 단위의 정의

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Abstract:

측도를 이용한 물리량과 단위의 정의
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수학은 과학을 기술하는 언어이다. 따라서 과학의 내용을 수학을 이용하여 기술할 때 수학에서 잘 정의된 용어를 사용해야 한다. 수학적으로 잘 정의되지 않은 용어를 사용하는 것은 표준말이 아닌 사투리를 사용하는 것과 같이 소통에 지장을 가져온다. 기존의 물리량과 단위의 개념은 수학적으로 잘 정의되지 않은 개념이다. 가령 물리량의 표현 3 kg 에서 kg 의 실체가 무엇인지 수학적으로 정의하지도 않고 3과 kg 사이에 곱셈연산이 있는지 곱셈연산이 있다면 수학에서 어떤 곱셈연산인지 확실하지 않다. 이 연구에서는 수학에서의 측도를 물리량의 단위로 정의한다. 수학에서 측도란 어떤 대상들의 집합 X 에서 실수들의 집합 \mathbb{R} 로 가는 함수이다. 즉 임의의 원소 $x \in X$ 에 대하여 x 의 크기 $u(x) \in \mathbb{R}$ 를 대응시키는 $u : X \rightarrow \mathbb{R}$ 꼴의 함수가 측도이다.

길이의 단위 cm, m, km 등은 선분들의 집합을 INT 라 할 때 $cm : INT \rightarrow \mathbb{R}$, $m : INT \rightarrow \mathbb{R}$, $km : INT \rightarrow \mathbb{R}$ 꼴의 함수이고 이들은 모두 길이측도들이다. 두 단위 cm 와 m 는 임의의 선분 PQ 에 대하여 $cm(PQ) = 100m(PQ)$ (여기에서 $100m(PQ)$ 는 두 실수 100 과 $m(PQ)$ 의 곱이다)인 관계를 가지고 있다. 집합론에서의 관계와 함수의 표현방식을 빌리면 $cm(PQ) = a$ 일 때 " PQ 의 길이 = a cm " 로 표현할 수 있고 이 표현은 기존 단위체계에서의 표현과 일치한다.

마찬가지로 질량의 단위는 모든 물체들의 집합을 $BODY$ 라 할 때 $g : BODY \rightarrow \mathbb{R}$, $kg : BODY \rightarrow \mathbb{R}$ 꼴의 함수이다.

시간의 단위들 초, 시간, 년, 등등의 정의역은 모든 가측성질들의 집합 Σ 이고

초 : $\Sigma \rightarrow \mathbb{R}$, 시간 : $\Sigma \rightarrow \mathbb{R}$, 년 : $\Sigma \rightarrow \mathbb{R}$ 꼴의 함수이다.

물리량과 단위를 수학에서의 측도를 이용하여 정의함으로써 물리법칙을 표현하는 식이나 함수를 보다 유연하게 다룰 수 있다.

Keywords:

Electrocatalytically-relevant depth in atomically precise $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ heterostructures

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Abstract:

Epitaxial transition metal oxide (TMO) thin films provide an optimal model system for scrutinizing the fundamental mechanisms of electrocatalytic reactions, e.g. oxygen evolution reaction (OER). The main advantage of the use of epitaxial thin film originates from the facile controllability over hybridization strength between TM-O bond, epitaxial strain, film thickness, and heterostructuring. Especially, the TMO heterostructures with atomic-scale precision control offer a direct mean to investigate the "electrocatalytically-relevant depth", defined as a certain sub-surface region that might also be activated during the electrocatalytic reactions, in addition to the nominal surface.

In this study, to study the contribution of sub-surface activity, we employ the $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ (LSMO) epitaxial thin films on both bare Nb doped SrTiO_3 (NSTO) and SrRuO_3 (SRO, ~5 nm) covered NSTO fabricated by using pulsed laser epitaxy. The LSMO thickness (t) was systematically controlled with atomic-scale precision from 2 (ultra-thin limit) to 70 unit cells (u.c., ~30 nm). First, in the LSMO//NSTO single thin films, the electrocatalytic activities show a non-monotonic trend with increasing t , owing to the competition between the electronic transport property and sub-surface activity. Second, in the LSMO/SRO//NSTO heterostructures, the electrocatalytic activities are systematically decreased as the increase of t , owing to the suppression of the contribution for the underlying SRO which plays a role of the active sub-surface layer. Using these results, we introduce the concept of "electrocatalytically-relevant depth", in the order of 10 unit cells in depth from the nominal surface for the LSMO thin film.

Keywords:

Transition metal oxide, Epitaxial thin film, Electrocatalyst, Oxygen evolution reaction, Sub-surface activity

Quantitative iDPC-STEM observations of oxygen octahedral connectivity control at perovskite oxide interfaces via epitaxial strain engineering

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Abstract:

Since the oxygen octahedral rotation (OOR) of ABO_3 perovskite oxide provides various functionalities, controlling the OOR plays an important role in device applications development and fundamental physics exploration. One of the most efficient ways to control the OOR is using the oxygen octahedral coupling at heterointerfaces which have two different structural symmetries. [1] Thanks to the interfacial coupling, structures that cannot be accessed in bulk systems can be realized in thin films. [2-4] For exploring further functionalities, investigating and engineering the length-scale of the interfacial coupling is an important issue. However, precise length-scale and control method of the oxygen octahedral coupling remain open questions.

Here, we made $SrRuO_3/SrTiO_3$ (SRO/STO) heterostructure on various substrates by pulsed laser deposition and succeeded controlling the length-scale of the oxygen octahedral coupling via epitaxial strain. Since SRO has $a^-b^+c^-$ (in pseudo-cubic notation) and STO has $a^0a^0c^0$ rotating pattern, we could observe how the $a^0a^0c^0$ symmetry of STO penetrates into SRO. The precise OOR angle depending on the each atomic layer was investigated using integrated differential phase contrast-scanning transmission electron microscopy (iDPC-STEM) technique. We found that the critical thickness for saturated OOR angle is engineered via epitaxial strain from 3 unit cells to 13 unit cells of SRO. This study provides an effective method to control the oxygen octahedral interfacial coupling, and suggests a potential model system for investigating how the interfacial coupling occurs between the two different symmetries.

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[2] T. H. Kim et al., Nature 553, 68 (2016)

[3] J. R. Kim et al., Nature Communications 11, 4944 (2020)

[4] S. G. Jeong et al., Advanced Science 7, 2001643 (2020)

Keywords:

$SrRuO_3$, oxygen octahedral connectivity, perovskite oxide, pulsed laser deposition, iDPC-STEM

Dispersion and Stability Mechanism of Pt Nanoparticles on Transition-Metal Oxides

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Abstract:

The influence of hydrogen peroxide (H_2O_2) on the dispersion and stability of Pt nanoparticles on titania-incorporated fumed silica (Pt/Ti-FS) supports was examined using x-ray absorption fine structure (XAFS) measurements at Pt L_3 - and Ti K-edges and density functional (DFT) calculations. The heterogeneous catalysts of Pt/transition-metal oxides are typically synthesized by calcining at $500^\circ C$ and Pt nanoparticles are uniformly and highly dispersed when H_2O_2 is applied before calcination. The structural and chemical properties around Pt and Ti atoms of Pt/Ti-FS with and without an H_2O_2 treatment were monitored using *in-situ* XAFS during heating from room temperature to $500^\circ C$. XAFS revealed that the Pt nanoparticles of H_2O_2 -Pt/Ti-FS have a high stability and that the Ti atoms of H_2O_2 -Pt/Ti-FS support form into a distorted-anatase TiO_2 . DFT calculations showed that Pt atoms more stably bond to oxidized- TiO_2 facets, compared to bare- and reduced- TiO_2 facets. XAFS measurements and DFT calculations clarified that extra oxygen atoms due to an H_2O_2 treatment play a critical role in a strong bond of Pt atoms to TiO_2 facets.

Keywords:

Pt nanoparticles, XAFS, DFT, supports, Heterogeneous catalysts

Exploring surface chemical states of Pt-based bimetallic alloys (M=Ti,V) during CO oxidation by ambient pressure XPS

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Abstract:

With ambient pressure X-ray photoelectron spectroscopy (AP-XPS) and quadrupole mass spectrometer (QMS), the surface segregation and oxidation of polycrystalline Pt₃M (M=Ti,V) alloys are investigated during CO oxidation reaction. As temperature increases, Pt-skin of Pt₃V (poly) changes to the oxides covered surface formed by segregation and oxidation of V atoms. For the case of Pt₃Ti (poly), Pt and Ti oxide mixed surface undergoes further oxidation process. Additionally, a sign of pure metallic Pt state of both alloy surface increases at Pt 4f XP spectra, suggesting the redistribution of electrons from the 3d transition metals to Pt. This work provide the fundamental knowledge on the roles of 3d transition metal atoms in Pt₃M alloys during CO oxidation reaction.

Keywords:

AP-XPS, Pt-bimetallic alloy, Surface oxides, CO oxidation

Coupling between surface photovoltage and 2DEG on the topological insulator Bi_2Te_3

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Abstract:

We observe ultrafast dynamics of optically excited surface of the topological insulator Bi_2Te_3 via time-resolved THz spectroscopy and angle-resolved photoemission spectroscopy (ARPES). The ARPES result show that two types of surface photovoltages (SPV) with lifetimes over 4 μs coexist on our sample. A composite band-bending with downward band-bending on the surface and upward band-bending within the surface can explain the result. There, quantized two-dimensional electronic gas (2DEG) states should be formed with the downward band-bending. The time-resolved THz spectroscopy shows a long-lived Drude response change and a 3 meV peak suppression. We assign such results to the long-lived population enhancement and quantized level modification of 2DEG by quantitative analysis and numerical simulation. Our result is a first demonstration of the interaction between 2DEG and SPV.

Keywords:

topological insulator, surface photovoltage, 2deg

Observation of band renormalization and pseudogap in surface-doped black phosphorus

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Abstract:

To understand how electrons behave in a material, it is essential to see its band structure. Although a band structure of a material can be defined based on the existence of the periodicity (or long-range order), a material which has only short-range order such as liquids and amorphous solids can also have a band structure by the coherent part of electron waves. From more than 60 years ago, lots of theoretical studies describing the characteristic band structure of liquid or disordered metal have been proposed. In addition, there have been several experimental approaches to directly study the band structure of liquids. However, so far, no such characteristic band structure has been observed experimentally. Here, I will introduce the first experimental observation of the band structure of liquid metals by studying the interface of a crystalline insulator (black phosphorus) and disordered dopants (alkali metals) using angle-resolved photoemission spectroscopy (ARPES). We find a conventional band structure of black phosphorus bends back towards zero momentum and a pseudogap up to 240 meV appears from the Fermi level. These are the consequences of resonance scattering by the formation of quasi-bound states of the electron waves around the scattering potential of alkali metals distributed to have short-range order just like a liquid. By using different kinds of dopants (Na, K, Rb, Cs) the depth of the scattering potential can be tuned, and this leads to the different characters of resonance, which results in the different size of the pseudogap.

Keywords:

Black phosphorus, ARPES, Short-range order, Pseudogap

Optical conductivity and valley Hall effect in alternating-twisted multiple monolayer graphene

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Abstract:

We investigate the optical conductivity and the valley Hall effect in alternating-twisted multiple monolayer graphene (ATMMG). Similarly as in Bernal stacked multilayer graphene, the continuum model of ATMMG can be decomposed into a set of twisted bilayer graphene at different angles with an additional linear band for an odd number of layers [1]. We show that the optical conductivity of ATMMG is described by interband transitions within the decoupled bands following a similar selection rule of Bernal stacked multilayer graphene, and the valley Hall conductivity remains zero due to the symmetry associated with C_{2x} . In the presence of a vertical electric field or a layer sliding, this picture breaks down, showing additional interband transitions in the optical conductivity and nonvanishing valley Hall effect.

References:

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Acknowledgments:

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Keywords:

Graphene, Twisted system, Optical conductivity, Valley Hall effect, Two-dimensional materials

Dichotomy of saddle points in energy bands of monolayer NbSe₂

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Abstract:

We theoretically show that two distinctive spin textures manifest themselves around saddle points in energy bands of monolayer NbSe₂ under external gate potentials. While the density of states at all saddle points diverge logarithmically, ones at the zone boundaries display a windmill-shaped spin texture while the others unidirectional spin orientations. The disparate spin-resolved states are demonstrated to contribute an intrinsic spin Hall conductivity significantly while their characteristics differ from each other. Based on a minimal but essential tight-binding approximation reproducing first-principles computation results, we established distinct effective Rashba Hamiltonians for each saddle point, realizing the unique spin textures depending on their momentum. Energetic positions of the saddle points in a single layer NbSe₂ are shown to be well controlled by a gate potential so that it could be a prototypical system to test a competition between various collective phenomena triggered by diverging density of states and their spin textures in low dimension.

Keywords:

Transition-Metal Dichalcogenide (TMDC), Electronic Structures, Spin-Orbit Coupling, van Hove Singularity, Spin Hall Effect

Experimental observation of hydrodynamic-like behavior in 3D topological semimetal ZrTe₅

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Abstract:

Hydrodynamic fluidity in condensed matter physics has been experimentally demonstrated only in a limited number of compounds due to the stringent conditions that must be met. Herein, we demonstrate phonon hydrodynamic-like properties in three-dimensional topological semimetal ZrTe₅ thanks to its ultrahigh-purity and intrinsic structural instability. By measuring the thermal properties in a wide temperature range, two representative experimental evidences of phonon hydrodynamics are seen in an interesting temperature window between the ballistic and diffusive regimes: a faster evolution of the thermal conductivity than in the ballistic regime and the non-monotonic temperature-dependent effective phonon mean-free-path. In addition, magneto-thermal conductivity results indicate us that charged quasiparticles, as well as phonons, may also play an important role in the hydrodynamic flow in the ZrTe₅ system.

Keywords:

hydrodynamics, Phonon, Thermal Conductivity

Realization of the Kane-Mele-Hubbard System in K-adsorbed 1T-TaS₂

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Abstract:

A flat-band system is prone to have an instability with the presence of a weak perturbation due to its metallic electrons with small kinetic energy, resulting in exotic quantum phases. More interestingly, in a two-dimensional honeycomb lattice, they are combined with Dirac bands and topological properties, described by the Kane-Mele-Hubbard model. With an electronic many-body interaction and the spin-orbit coupling, various exotic phases have been proposed theoretically such as topologically non-trivial states, quantum spin liquids, charge density waves, superconductivity, and topological Mott insulator at or near the half-filling. However, the material realization of the Kane-Mele-Hubbard system has not been identified yet. Here we show a unique approach to realize a Kane-Mele-Hubbard system with strongly interacting 5d transition metals. We utilized K adatoms as lattice manipulators, and at the optimum coverage, they deplete one third of the unpaired 5d electrons in a triangular lattice of 1T-TaS₂ and the remaining electrons form a honeycomb lattice. As the mother compound, 1T-TaS₂ is well known to have flat bands, the honeycomb-lattice flat-band system is realized. The density functional theory calculations show flat Z₂ topological bands and an order of magnitude larger charge gap measured by scanning tunneling microscopy confirms the substantial electron correlation. This correlation gap is well reproduced by our dynamical mean-field theory calculations. This could be the first realization of the Kane-Mele-Hubbard system and an artificial honeycomb-lattice Mott insulator with a finite spin Chern number. The lattice manipulation by adsorbates can be exploited with an atom-manipulation technique to realize various flat-band structures such as one-dimensional or kagome-lattice flat-band systems.

Keywords:

Kane-Mele-Hubbard systems, flat-band systems, Mott insulator, 2D materials, scanning tunneling microscopy

Homotopic Action: A Generic Pathway to Convergent Feynman Diagrammatic Theories

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Abstract:

The series slow convergence or divergence problem is the major obstacle preventing Feynman diagrammatic expansions from accurately solving many-fermion systems in strongly correlated regimes. Various techniques have been proposed to address this issue: series resummation by conformal mapping, changing the nature of the expansion point by shifted action tools, and applying the homotopy analysis method to the Dyson-Schwinger equation. They emerge as dissimilar mathematical procedures aimed at different aspects of the problem. The proposed homotopic action offers a universal and systematic framework for unifying the existing—and generating new—methods and ideas to formulate a physical system in terms of a convergent diagrammatic series. It eliminates the need for resummation, allows one to introduce effective interactions, enables a controlled ultraviolet regularization of continuous-space theories, and reduces the intrinsic polynomial complexity of the diagrammatic Monte Carlo method. We illustrate this approach by an application to the 2D Hubbard model.

Keywords:

homotopic action, diagrammatic Monte Carlo method, 2D Hubbard model

Decoherence of nitrogen-vacancy spin ensembles in diamond in the nitrogen electron-nuclear spin bath

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Abstract:

Nitrogen-vacancy (NV) centers in diamond have been developed into essential hardware units to develop a wide range of solid-state quantum technologies. For such applications, the long coherence time of NV centers is crucial. Numerous previous studies identified that the NV's decoherence is often governed by the magnetic noise produced by the ^{13}C nuclear spin bath and the nitrogen (P1) electron spin bath in a diamond. While the ^{13}C -induced decoherence has been well understood, the understanding of the P1-driven decoherence is still incomplete. In this study, we aim at a systematic investigation on the P1-driven decoherence of NV ensembles with varying P1 concentrations from 1ppm to 100ppm by combining a first-principles cluster expansion theory and an optically detected magnetic resonance experiment. We find an excellent agreement between the theoretical and experimental results. We also discuss the microscopic mechanism of the P1-induced decoherence of the diamond NV center in detail. Our results pave the way to optimize the NV's performance in various quantum applications such as NV-based magnetometry and NV-based quantum registers.

Keywords:

Diamond NV center, Decoherence dynamics, Cluster-expansion theory, Optically detected magnetic resonance

Atomistic study of site-selective doping behavior in SnO₂

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Abstract:

SnO₂ has been identified as one of the promising and suitable oxide-based photocatalytic semiconductors. However, wide band gap of SnO₂ with rutile crystal structure limits its photocatalytic activity to the visible region. Doping is one of the efficient ways to optimize the materials properties and further enhance the photocatalytic performance. Here, using the first-principles density functional theory calculations, we find that Fe atoms tend to occupy interstitial sites while Cr atoms prefer to occupy substitutional sites accompanied with oxygen vacancies. In particular, substitutional Cr-vacancy cooperation and interstitial Fe-strain coupling produce defect levels in the band gap and introduce excess electrons, narrowing the band gap and sifting the Fermi level up, which significantly improve their photocatalytic properties compared to that of the pristine one. Bandgap narrowing, O-K edge X-ray absorption near edge structure (XANES) spectra due to the oxygen vacancy, and resulting enhanced photocatalytic behavior of visible light will be discussed and associated underlying mechanism will be introduced along with atomic-scale STEM imaging on defective SnO₂.

Keywords:

doping, atomic defect, photocatalyst, oxygen vacancy

Hybrid density functional theory calculation of II-IV-V₂ materials for photovoltaic applications

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Abstract:

Finding new materials has been a successful approach in the solar cell community. Remarkably, materials for high-performance solar cells, such as CdTe and Cu(In,Ga)Se₂, can be made from cation mutation from Si. Furthermore, dozens of materials can be generated by substituting constituting elements with another having the same oxidation number.

In this presentation, we discuss our recent computational work on the stability and the electronic structure of II-IV-V₂ materials that are generated by applying the design principle to III-V [1]. Through density functional theory (DFT) calculations, the stable structure of each material was identified, and an accurate band gap was obtained by using a hybrid density functional. Nitrides favored an orthorhombic polymorph with the AB stacking sequence, while phosphides, arsenides, and antimonides favor the chalcopyrite structure having the ABC sequence. General trends found in the band gap will be discussed as well. The materials having an ideal band gap for photovoltaic applications were screened, and their optical properties were compared to each other.

Keywords:

DFT, solar cell, cation mutation, polymorph, band gap

Design principles of graphene/nanoporous graphene heterostructures with new functionality

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Abstract:

Recent bottom-up synthesis of nanoporous graphene (NPG) offers new opportunities for tuning graphene's properties by forming graphene/NPG heterostructures. Depending on the pore sizes, shapes, and arrangements of NPG, graphene/NPG heterostructures can have different low-energy electronic structures that can be further controlled by applying an electric field. Here, we show that the electronic structure of the graphene/NPG system can be described by a simple model Hamiltonian, whose low-energy property is determined by the way the graphene's linear bands interact with the NPG's flat bands. We propose two mechanisms for electric-field-induced bandgap opening in graphene-based on either breaking sublattice symmetry or merging the two Dirac points of graphene. Using the model Hamiltonian analysis combined with first-principles calculations, we discuss design principles of graphene/NPG heterostructures with desired functionality.

Keywords:

Nanoporous graphene, Graphene superlattice, Heterostructure, First-principles calculation, Low-energy physics

Hund metal perspective on van der Waals material Fe_3GeTe_2

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Abstract:

Fe_3GeTe_2 is one of the most famous van der Waals materials receiving much attention due to its high Curie temperature ($T_c \sim 220$ K) and stable ferromagnetism maintained up to an atomically thin layer. In addition, signatures for strong electron correlation, such as the large Sommerfeld coefficient observed in this material, enrich the material properties. However, despite such great interest, most of the theoretical studies on this material are conducted at the level of the conventional density functional theory, and the studies targeting the nature of electron correlation are relatively scarce. In this presentation, we report the properties of the correlation of representative two-dimensional magnetic material, Fe_3GeTe_2 , employing the density functional theory combined with dynamical mean-field theory (DFT+DMFT). Our results show that the two inequivalent irons (Fe-I and Fe-II) of Fe_3GeTe_2 are differentiated in terms of correlation: Fe-I is localized and shows a stronger correlation while Fe-II tends to be itinerant, showing the weaker correlation. Furthermore, this dichotomy between Fe-I and Fe-II is originated from the interplay between Hund physics and microscopic details in the underlying band structure. Our picture for Fe_3GeTe_2 provides not only an important key to understand various observations including the ones that are seemingly contradictory to each other but also a new perspective on two-dimensional multiorbital systems.

Keywords:

van der Waals materials, 2D materials, Density functional theory, Dynamical mean-field theory

Anisotropic Orbital Hybridization induced Breathing Kagome Lattice and Higher Order Topology in Monolayer Hexagonal Transition Metal Dichalcogenides

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Abstract:

A breathing Kagome lattice, which is formed by triangles of anisotropic bond strength, can become a higher-order topological insulator (HOTI). Topologically protected corner states have been realized experimentally on various artificial breathing Kagome lattices. However, there have been no reports on natural materials, which is an electronic breathing Kagome lattice. Here we theoretically suggest that a breathing Kagome lattice is hidden inside a monolayer hexagonal transition metal dichalcogenide (h-TMDs). Due to trigonal prismatic symmetry, sp^2 -like hybrid d orbitals are formed. The hybridization pattern creates a breathing Kagome lattice. Inter-site hoppings are found to be stronger than on-site ones, hence h-TMDs are HOTI. Nanoflakes of h-TMD host localized corner states. Since they are easily synthesizable and stable at ambient conditions, our research can provide an easily accessible platform for quantum physics on condensed matter systems.

Keywords:

Transition Metal Dichalcogenide, Breathing Kagome Lattice, Higher-Order Topological Insulator, First-Principles Calculation

Electrochemical Generation of Mesopores and Residual Oxygen for the Enhanced Activity of Silver Electrocatalysts

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Abstract:

The development of stable and efficient electrocatalysts is of key importance for the establishment of a sustainable society. The activity of a metal electrocatalyst is determined by its electrochemically active surface area and intrinsic activity, which can be increased using highly porous structures and heteroatomic doping, respectively. Herein, we propose a general strategy of generating mesopores and residual oxygen in metal electrocatalysts by reduction of metastable metal oxides using Ag_2O_3 electrodeposited onto carbon paper as a model system and demonstrating that the obtained multipurpose porous Ag electrocatalyst has high activity for the electroreduction of O_2 and CO_2 . The presence of mesopores and residual oxygen is confirmed by electrochemical and spectroscopic techniques, and quantum mechanical simulations prove the importance of residual oxygen for electrocatalytic activity enhancement. Thus, the adopted strategy is concluded to allow the synthesis of highly active metal catalysts with controlled mesoporosity and residual oxygen content.

Keywords:

Oxygen reduction reaction catalyst, Residual oxygen, Density functional theory

Evolution of Barristor's Reversed-biased Current with Temperature

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Abstract:

Since graphene has unprecedently high electron mobility up to 140,000 cm²/V-s, attention has been drawn for decades. While the graphene field-effect transistor (GFET) has been failed to achieve industry-acceptable I_{ON}/I_{OFF} , inherently [1], graphene barristor has achieved $I_{ON}/I_{OFF} \sim 10^5$ by adopting a novel device structure of graphene-semiconductor junction and novel switching mechanism of the barrier modulation [2].

In this talk, the demonstration of a semiconductor-less transistor will be presented, which switches the Fowler-Nordheim tunneling current by modulating the tunneling barrier height [3]. Then, the evolution of the reverse-biased current with temperature will be discussed[4].

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[3] J.-H. Lee, *et al.*, Semiconductor-less vertical transistor with I_{ON}/I_{OFF} of 10^6 . *Nat Commun*. **12**, 1000 (2021).

[4] I. Choi, *et al.*, (in preparation)

Keywords:

graphene barristor, Fowler-Nordheim Tunneling, Thermionic Emission

Electrical characterization of 2D magnetic-heterojunction devices

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Abstract:

The representative 2D materials, graphene, h-BN, and MoS₂, have interesting mechanical, electrical and optical properties and have exhibited fascinating physical phenomena so far. However, they mostly lack one important physical property in physics, magnetism. The new 2D materials such as CrSiTe₃, CrI₃, and FePS₃, which began to be studied recently, possess ferro- or antiferro-magnetic properties even in atomic level thickness and are expected to reveal deep level of physics in 2-dimensional confinement. In this talk, our recent works on heterojunction devices of a ternary 2D material, Fe₃GeTe₂, which shows the ferromagnetic behavior, will be presented. The devices were studied with hall measurement. From the hall measurement, it exhibited the anomalous hall effect due to its intrinsic ferromagnetism. Interestingly, the magnetic properties such as coercivity changed significantly with decreasing thickness changing from weak ferromagnet to strong ferromagnet. Also, we found some mixed magnetic behavior of ferromagnetism and anti-ferromagnetism, which seems to be due to partial oxidation. Fe₃GeTe₂ was made into hetero-junctions with graphene, graphite, and CrPS₄. Through the interface coupling with these materials, Mott insulator, spin-orbit coupling and exchange bias effect could be observed.

Keywords:

2D magnetic material, heterojunction, Hall measurement

Oriented atomic and molecular assembly on two-dimensional crystals for hybrid van der Waals heterostructures

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Abstract:

The atomic and molecular assembly processes on the surface of two-dimensional (2D) layered crystals have gained significant research interest for fabrication of well-ordered nanostructures and vertical heterostructures based on 2D crystals. The structure and quality at the 2D heterointerfaces have great influence on the properties and performance of heterostructures. Therefore, the direct observation of the interfacial structure of 2D heterostructure can provide insight for understanding the fundamental aspects of the system and can also lead to a better design of a new 2D heterostructure.

In this talk, I will present various oriented self-assembly phenomena on 2D crystals. Advanced transmission electron microscopy (TEM) techniques are utilized to elucidate the atomic-scale structure of assemblies and their relative epitaxial relations with respect to 2D substrates. For example, one-dimensional metal-cyanide atomic chains exhibit universal oriented van der Waals epitaxy on various 2D crystals. I will also discuss the unidirectional assembly phenomena on various distorted 2D crystals, namely black phosphorus (BP) and distorted transition metal dichalcogenides (TMDCs). These atomically puckered 2D crystals can induce the unidirectional assembly along the directions of the crystal distortion. Finally, various electrical and optical properties of these hybrid heterostructures will be discussed.

Keywords:

oriented assembly, 2D crystals, van der Waals heterostructures

Characterization of electrically induced break junction in graphene

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Abstract:

Graphene, one of the representatives in 2D materials, has been noted as a next-generation optoelectronic device. Especially, graphene under the high electric field shows bright thermal radiation up to 3,000K in the visible range with non-equilibrium phonon modes and direct thermal radiation modulation up to 10 GHz. Here, I will talk about the graphene break junctions which are induced by the high electric field and their properties. In this talk, I will present the unconventional electrical switching behavior and memory characteristics as well as optical properties such as photoluminescence and electroluminescence around 400-600 nm visible range.

Keywords:

graphene, break junction, thermal radiation, switching, memory

Electrical manipulation of exchange bias in IrMn/NiFe bilayer structures

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Abstract:

Electrical control of antiferromagnetic moments is a key technological goal of antiferromagnet-based spintronics, which promises favourable device characteristics such as ultrafast operation and high-density integration as compared to conventional ferromagnet-based devices. In this talk, we report current-induced manipulation of the exchange bias in IrMn/NiFe bilayers without a heavy metal layer. We show that the direction of the exchange bias (φ_{EB}) is gradually modulated up to ± 22 degrees by an in-plane current. Interestingly, φ_{EB} remains constant regardless of the NiFe thickness up to 10 nm. This indicates that spin-orbit torque (SOT) caused by a spin current generated from IrMn is not applied directly to the ferromagnetic NiFe layer. Instead, it is applied to uncompensated AFM moments at the IrMn/NiFe interface, subsequently triggering the collective rotation of the magnetization the exchange-coupled IrMn/NiFe bilayers. Furthermore, we show that the reversible memristive features of the SOT-induced AFM switching are maintained in a 500-nm-sized device, offering a route for developing nanoscale AFM spintronics devices for applications in neuromorphic computing.

Keywords:

Antiferromagnetic spintronics, exchange bias, spin-orbit torque, neuromorphic computing

Tunable dynamics of exchange-biased domain wall with spin current induced antiferromagnet switching

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Abstract:

Magnetic domain wall (DW) motion in ultrathin ferromagnetic (FM) films with Dzyaloshinskii-Moriya interaction (DMI) is drawing increased attention with the prospect of developing new mechanism for information storage and processing technologies. In order to augment as well as to fine-tune the functionalities of DW motion-based devices, it is necessary to further enhance the controllability over the DW motions. Application of a magnetic field is a well-known procedure to enable the DW dynamics by rotating the individual magnetizations in the DW and consequently modulating the chiral DW structures. However, applying an external bias field is not a viable approach for the miniaturized devices as the external field acts globally hence severely limit the localized action of the spin devices. Therefore, the spin polarized current, typically generated from conventional electrical current, is noted as it can apply torques to the magnetic moments in the ferromagnet and turn the magnetic moments to induce the unidirectional shifting of a train of DWs. In the meantime, it is also noted that the DW motions of FM layer can be influenced by the exchange coupling interactions of an adjacent antiferromagnet (AFM) but it has been rarely studied despite the more than 50 years of studies on exchange-bias phenomenon of AFM/FM system.

In the present work, we investigated the field-driven DW motion in the ultrathin FM films with perpendicular magnetic anisotropy (PMA) and DMI effect under the influence of exchange-coupling with the AFM IrMn layer. It was found that DW exhibits asymmetric propagation without an application of in-plane magnetic field due to the aid of an alignment of AFM spins. Interestingly, the direction of the exchange bias field can also be reconfigured by simply injecting spin currents through the device, enabling electrical and programmable operation of the device. Our work suggests a prototype DW motion-based device mechanism based on the AFM/FM heterostructure, which could be utilized as a logic device.

Keywords:

Domain Wall, Antiferromagnet Switching, Exchange Coupling

Spin pumping induced by metamagnetic phase transition of FeRh

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Abstract:

The dynamics of magnetization generates a spin current, which is referred to as spin pumping [1]. The spin pumping has been intensively studied because it can be utilized in quantifying spin related parameters, such as spin Hall angle, spin diffusion length and spin mixing conductance [2, 3]. In ferromagnet (FM) / heavy metal (HM) layers, which has been a central focus of research during last decade [2-4], the magnetization dynamics of FM generates a spin current in the HM layer, and the spin current is converted into the tangible charge current via inverse spin Hall effect (ISHE) [2-4]. However, the spin pumping efficiency is still low to be used directly for spintronic applications.

Here we demonstrate a giant spin pumping induced by a phase transition of FeRh. FeRh is metallic alloy with CsCl structure which undergoes a phase transition from antiferromagnetic to ferromagnetic phase near 370 K [5]. We measured the transient ISHE voltage in FeRh/Pt bi-layer and found that the spin pumping signal appears during the phase transition of FeRh. Notably, the observed spin pumping signal is at least 2 orders of magnitude larger than those of previous reports [6, 7], suggesting that the spin pumping can be utilized in spintronic applications, e.g., magnetization switching [8]. The large transient spin pumping signal is ascribed to the total angular momentum change between antiferromagnet and ferromagnet during the phase transition, which accompanies the sign change of the exchange interaction. Our work provides a novel method to generate a large spin current, which could be utilized in spintronics application.

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Keywords:

spin pumping, metamagnetic phase transition, FeRh

Measurement of Bulk spin-orbit torques in van der Waals ferromagnet Fe₃GeTe₂

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Abstract:

The emergence of magnetic van der Waals materials opens a new variety of material systems to investigate the current induced magnetization manipulation in two dimensional materials. Especially by utilizing spin-orbit torques in combination with the magnetic van der Waals materials the efficient current induced magnetization manipulation can be achieved. In the unique system of Fe₃GeTe₂, there have been theoretical predictions of the presence of a unique bulk spin-orbit torque due to its crystal structure [1]. Thus, we quantify the spin-orbit torque induced effective fields using the harmonic analysis and from the symmetry of the measured torques we find a dominant bulk spin-orbit torque that arise from the symmetry in the crystal structure. Additionally, we have measured the temperature dependence of the bulk spin-orbit torques which show a peculiar behavior which could imply an additional component of the spin-orbit torque. The results show that Fe₃GeTe₂ exhibits a unique bulk spin-orbit torque in addition to the conventional interfacial spin-orbit torque enabling magnetization manipulation in single layers without the need for multilayer engineering.

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Keywords:

2D material, spin-orbit torque

Development of high performance halide perovskite transistors

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Abstract:

Perovskites have been intensively investigated for their use in solar cells and light-emitting diodes. However, research on their applications in thin-film transistors (TFTs) has drawn less attention despite their high intrinsic charge carrier mobility. In this study, we report the universal approaches for high-performance and reliable p-channel lead-free tin perovskite TFTs. These include self-passivation for grain boundary by excess cesium iodide, grain crystallisation control by adduct, and iodide vacancy passivation treatment. We found that the grain boundary passivation can increase TFT reproducibility and reliability, and the grain size enlargement can hike the TFT performance; thus, enabling the perovskite-based complementary inverter demonstration with n-channel indium gallium zinc oxide (IGZO) TFTs. Details of performance will be discussed in my presentation. The inverter exhibits a high gain over 100 with an excellent noise margin. This work aims to provide widely applicable and repeatable methods to make the gate more open for intensive efforts towards high-performance printed perovskite TFTs.

Keywords:

perovskite, thin film transistors, charge transport

New approaches of organic semiconductors for next-generation chiroptical optoelectronics and neuromorphic electronics

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Abstract:

Facing the era of big data and artificial intelligence, optical computing capable of extremely fast data processing, and neuromorphic electronics capable of massively parallel information processing have garnered intensive attention as the most promising next-generation semiconductor technologies. Recently, organic semiconductors are attracting new attention as promising semiconductor materials that can implement chiro-optic optoelectronic devices and mimic biological neuronal systems. In this talk, recent our demonstrations of chiroptical photodetectors and neuromorphic transistors based on organic semiconductors will be introduced. To realize high-performance chiroptical phototransistors detecting the circularly polarized light, polymer semiconductor photoactive material and device architecture of organic thin-film transistors have been newly designed. In addition, by introducing fibrous architecture and implementing a reversible electrochemical reaction between organic semiconductors and ions, we succeeded in neurofiber transistors with enhanced memory cyclic endurance.

Keywords:

Organic transistor, organic semiconductor, chiroptical optoelectronics, neuromorphic computing

Conjugated polymer–inorganic porous material hybrids for robust gas sensors

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Abstract:

Organic semiconductor-based chemical sensors have shown substantial promise for use in next-generation sensor devices even though such sensors currently exhibit poor responsivity and instability under ambient conditions. This research demonstrates an organic–inorganic hybrid gas sensor based on porous material and a conjugated polymer; compared with a reference sensor, the hybrid sensor not only exhibits enhanced chemical sensitivity toward hazardous NO₂ gas but also improved durability against oxidation under ambient conditions.

We demonstrate that the metal-organic framework or zeolite in the conjugated polymer matrix offers a high surface-to-volume ratio to ensure strong adsorption ability and establish a correlation between particle nanostructure and NO₂ sensing performance in a polymeric transistor-based sensor. We provide a guide to enhancing the sensing ability of organic chemical sensors such that their sensitivity and stability are preserved.

This study demonstrates the systematic evolution of an organic–inorganic hybrid device when various types of zeolite and MOF material are blended with the conjugated polymer and proposes an effective strategy with strong technological relevance. Given the large potential impact of our results, we believe that the broad audience of Korean Physical Society, which includes material scientists, chemists, and physicist, is best suited for receiving them.

Keywords:

P3HT, MOF, Zeolite, OFET, Gas sensor

Photo-modulated Molecular Devices Sensitized by Perovskite/Graphene Heterostructure

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Abstract:

Photo-modulating and switchable molecular junctions were implemented by introducing perovskite/graphene heterostructured top electrodes to a large-area molecular device platform. For molecular junctions made with self-assembled monolayers (SAM) of biphenyl thiol (BPT), an increase of current density was observed with light irradiation, which is due to the injection of photo generated charges from perovskite to the graphene electrodes. The degree of current increase was different depending on the molecular kinds in terms of their intrinsic molecular dipoles. In particular, we observed a maximum of ~500% increase in current for the molecular junctions made with pentafluorobenzene thiol (PFBT). Theoretical analysis was also conducted on transport characteristics with work function measurements. Our study will give us better understanding on the photo-induced charge transport in molecular junctions with perovskite/graphene heterointerfaces.

Keywords:

molecular electronics

Solution processable small molecules as efficient electron transport layers in organic optoelectronic devices

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Abstract:

Organic semiconductor-based optoelectronic devices, organic light-emitting diodes (OLEDs), have been investigated for solution-processable roll-to-roll electronic devices. However, for commercial applications, OLEDs require highly efficient device performance and effective fabrication processing methods. To achieve this, this work reports the use of solution-processable quinoxaline-phosphine oxide based small molecules (QPSMs) as electron transport layers (ETLs) in OLEDs. QPSMs can be dissolved in alcohol owing to the strong dipole moments within their molecular structures, thereby resulting in simple and effective processing during device fabrication. Moreover, QPSMs improve electron injection/extraction via the well-matched energy levels in OLEDs.

Keywords:

OLED, small molecules, ETLs

IRE Prediction Using Visible Fast Camera Images in VEST

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Abstract:

Internal reconnection event (IRE) is one of the most destructive magnetohydrodynamic (MHD) events in spherical toruses (ST). IRE has a similar eruption process with disruption in conventional tokamaks, including thermal and current quenches with the global relaxation of current distribution [1, 2], but it is fundamentally different from disruption in that IRE hardly terminates a plasma current. Predicting IRE can be important because it leads to the loss of about 30% stored energy in a reactor-scale ST, but also because it can be connected to the prediction for other types of explosive MHD instabilities as well, which represents similar nonlinear and time-transient features.

Here, we present a new method to predict the onset of IRE, using 2D visible camera images. In particular, a new onset mechanism for IRE that features at the plasma edge is found in the camera images in versatile experiment spherical torus (VEST). Through the MHD frequency filtering of visible camera images [3], it was observed that not only MHD modes inside the plasma boundary contribute to the onset of IRE but also the phase locking of coherent structures outside the plasma boundary to the MHD modes affects the onset of the global eruptive event. Using the mechanism observed from the camera images, the IRE prediction based on the matching between internal and external emission movements in sequential visible camera images (20 μ s exposure, 50kFrame s^{-1}) is developed. The emission-movement velocities are measured from the pyramidal Lucas-Kanade feature tracking algorithm [4]. The internal and the external velocities become consistent almost 0.7 ms before the onset of IRE and this method enables to distinguish two almost identical plasmas, one with IRE and the other without IRE. This result implies that IRE can be predicted from one of the most accessible diagnostics in fusion devices, i.e. visible fast camera and the plasma boundary emission includes information about the onset of IRE.

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Keywords:

explosive MHD instability, Spherical torus, IRE prediction, visible fast camera

Vortex flow evolution in magnetic island

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Abstract:

In magnetized fusion plasmas, a magnetic island is often formed by intrinsic tearing instability [1,2] or by externally imposed magnetic perturbations [3,4]. The magnetic island is typically thought to be undesirable due to confinement degradation in the island region. However, further experimental [5,6] and simulation [7,8] studies have shown that island-induced shear flow can significantly suppress microturbulence and turbulent transport around the island. In particular, fluid and gyrokinetic simulations [8-10] have revealed that microturbulence can generate vortex flow, which has the same structure as the magnetic island and can regulate the turbulence. A recent theoretical study [11] shows an anisotropic feature of the vortex flow shearing, giving new insight for the interpretation of experimental observations. Meanwhile, there has been no analytic work on the time evolution of the vortex flow. In this work, we extend gyrokinetic theories of residual zonal flows in tokamak [12,13] to show that there exists undamped residual vortex flow after a fast collisionless relaxation in an island. The residual level appears to be magnetic surface-dependent. The inhomogeneity of the residual vortex flow amplitude becomes more robust after a longer-term evolution. Work supported by National R&D Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and Future Planning (NRF-2019M1A7A1A02088355), and by R&D Program of "Development of Electromagnetic Gyrokinetic Model Describing Trapped Particles in Magnetic Field(code No. IN2104)" through the Korea Institute of Fusion Energy(KFE) funded by the Government funds, Republic of Korea.

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Keywords:

Tokamak, Magnetic island, Turbulence, Vortex flow, Gyrokinetics

Investigation of core turbulence generated by ECCD during sawtooth oscillations in L-mode discharge

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Abstract:

The effect of electron cyclotron current drive (ECCD) on the turbulent fluctuations of electron temperature is investigated. With the electron cyclotron emission imaging (ECEI) system installed on the KSTAR tokamak, it is possible to analyze large-scale instabilities and small-scale turbulence with high spatial resolution (~ 2 cm). To investigate the dynamics of sawtooth oscillation for ECCD-heated plasma, we have studied an L-mode discharge with a high guide field (2.9 T), off-axis NBI, and modulated ECCD (5 Hz). We utilize the repetitive nature of sawtooth oscillation to obtain ensemble-average over similar phases. Then, we apply multichannel correlation analysis to understand the plasma response to the ECCD blip. The correlation analysis shows an increase of coherent fluctuation during ECCD blip near the deposition layer (close to the sawtooth inversion radius). In addition, electron temperature gradient and broadband magnetic fluctuation increases during ECCD blip, suggesting that the sources of turbulence are electron/ion temperature gradient (ETG/ITG) and stochastization of the magnetic topology due to current filaments induced by ECCD. This work is supported by NRF of Korea under grant no. NRF-2019M1A7A1A03088456.

Keywords:

KSTAR, ECEI, Sawtooth oscillation, Plasma turbulence, ECCD

Gyrokinetic simulation studies of ExB staircase in KSTAR L-mode plasmas

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Abstract:

It was found that turbulence in hot magnetized plasmas generates a self-organized flow structure which is called ExB staircase [1]. We investigate KSTAR L-mode plasma using global nonlinear gyrokinetic code gyroKinetic Plasma Simulation Program (gKPSP) [2] to study the role of ExB staircase. Nonlinear simulations for Linear Ohmic Confinement (LOC) and Saturated Ohmic Confinement (SOC) plasmas with KSTAR parameters have been performed. In case of Tore Supra experiments, ExB staircase is not observed in LOC plasma and only observed in SOC plasma [3]. In addition, it has been reported that ExB staircase structure was observed by KSTAR experiments [4] and nonlinear gKPSP simulations based on KSTAR parameters [5]. We compare the gKPSP simulation results to analyze the interaction between ExB staircase and avalanche transport in KSTAR. Their role and transport properties for each plasma operating mode are being investigated.

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Keywords:

ExB staircase, KSTAR, L-mode plasma, turbulence

Impurity transport analysis based on KSTAR impurity injection experiment in high toroidal rotation

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Abstract:

High-Z impurities like tungsten in a tokamak tend to move to the core of a plasma according to neoclassical or turbulent inward particle flux and induce radiation loss, which is expected to deteriorate fusion performance. Several methods to mitigate impurity accumulation in the core [1] have been studied both experimentally and theoretically. In this work, we numerically investigated the impurity neoclassical/turbulent transport by NEO [2], CGYRO [3] simulations and compared the estimations with a KSTAR experiment of tungsten impurity injection in high toroidal rotation. First, we found that the effect of plasma toroidal rotation speed on the neoclassical impurity transport coefficients is significant, giving the sign change of the impurity neoclassical particle flux. Additionally, the density or temperature gradient of not only main ion but impurity can be also important to determine the impurity neoclassical particle flux. Second, we found that the dominant turbulent mode changes from parallel velocity shear (PVS) instability [4] to ion temperature gradient (ITG) instability [5] after the tungsten impurity injection. The PVS instability depends on magnetic configuration and it is stabilized by decreasing safety factor and increasing magnetic shear.

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Keywords:

Nuclear Fusion, Plasma, Neoclassical Transport, Turbulent Transport, Impurity

Implement of machine learning U-net model for automatic ELM-burst detection in the KSTAR tokamak

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Abstract:

Edge localized modes (ELM)-burst events during the H-mode operation in a tokamak, which can be detected by $D\alpha$ line radiation signals, degrade confinement performance and make a harmful impact on the first wall due to the high heat flux density. The manual detection of ELM region by examining $D\alpha$ signals has physical limitations on the time and effort due to the large amount of data as the KSTAR experimental data on many discharges accumulate. To resolve this manual difficulties, the prominence algorithm or simply judging by differential methods [1] have been introduced, but we found that they have some limitations on the sensitivity of threshold decision and the detection of small ELM-burst. In this study, we develop a neural network model inspired by 1D convolution U-net [2] for the automatic ELM-burst detection from $D\alpha$ signals. Ten discharge data of KSTAR were labeled and used for the training model, and 20% of them was employed for validation. To prevent overfitting, training finished when True Positive (TP) and False Positive (FP) values are both maximized. The results of the model provide better results by comparing the conventional methods as ROC curves. The detection model developed in this study can be applied on a larger amount of KSTAR data, and it is expected to useful to find out how quantitative properties such as ELM frequency are related to the state of plasmas such as the collisionality.

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Keywords:

tokamak, Peak detection, ELM

Real-time signal analysis using 5 GS/s data acquisition system for KSTAR Thomson Scattering Diagnostic

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Abstract:

For the control of tokamak machine like as Korea Superconducting Tokamak Advanced Research (KSTAR), a real-time diagnostic data is very important to the delicate control of Tokamak plasm. In KSTAR some of diagnostic systems Two Colour Interferometer system (TCI), Electron Cyclotron Emission (ECE) etc., offer the real-time data to the KSTAR plasma control system (PCS) to control the KSTAR plasma. Building a real-time Thomson system is important because Thomson scattering diagnostic is the most important diagnostic systems for measuring electron temperature (T_e) and electron density (n_e) profiles in high-temperature plasma, such as fusion plasma physics studies. Real-time Thomson scattering data is a very powerful diagnostic device for real-time observation of plasma conditions because it is unaffected by Tokamak's operating conditions (such as magnetic fields in tokamak) and provides absolute values for electron temperature and electron density. For this reason, this study conducted a real-time analysis of Thomson scattering data. For this study, 5GS/s digitizer have installed two years ago in KSTAR, these digitizers are widely used, for example, in Large Helical Device (LHD), HL-2A, HL-2M, and which is selected for the edge Thomson scattering digitizing system candidate in the ITER. In this study, the 5GS/s digitizer's pulse-type Thomson scattering signal was fitted in real-time using GPUs, and T_e was estimated in real-time on GPUs using parameters learned from neural network analysis. This presentation introduces KSTAR Thomson scattering diagnostics and explains how to analyze real-time Thomson data. As a result, we were able to analyze the T_e value within 20ms and will be expanded to the n_e value in the near future.

This work was supported by KOREA HYDRO & NUCLEAR POWER CO., LTD (No. 2019-Tech-G19IO16)

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Keywords:

Thomson scattering , KSTAR

Study of beam-emission spectra in a second motional Stark effect diagnostic system on KSTAR for radial electric field measurements

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Abstract:

Motional Stark Effect (MSE) diagnostic on KSTAR has been installed to measure the magnetic pitch angle profiles in neutral beam heated plasma. The MSE system on KSTAR measures the local electric field direction by measuring the polarization angle of Doppler-shifted Balmer-alpha decay emission from an energetic neutral beam. Measured the magnetic pitch angle is used to calculate the safety-factor and current density profiles as internal constraints to be an equilibrium reconstruction code such as EFIT. Previous studies show the intrinsic local radial electric (E_r) can significantly affect the MSE measurements. Thus, it is planned to add a second MSE system with a new viewing location on KSTAR to obtain values of E_r .

For the design of the new second MSE system, a preliminary study on the MSE spectrum at a new viewing location has been performed. This study has been applied to optimize the front optics and design new sets of band-pass filters.

Keywords:

Motional Stark effect, q profile, current density profile, KSTAR, beam emission spectra

Design, fabrication and characterization of micro-optical filters for infrared multispectral imaging

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Abstract:

Multispectral imaging has evolved into a powerful analytical tool in the fields of remote sensing, environmental monitoring, vegetation mapping, food quality, and biomedical imaging. It provides a much improved capability of identification and discrimination of objects by collecting both spectral and spatial information simultaneously. To date, it has been predominantly implemented in visible and near-infrared (IR) bands, using bulky and heavy optical elements including rotating bandpass filters integrated with a complementary metal oxide semiconductor or a charge coupled device image sensor. In this talk, we will introduce the design, fabrication and characterization of micro-optical filters that can be used as multispectral filters operating in the short-wave (1–3 μm , SW) and mid-wave (3–5 μm , MW) IR bands. A Si/SiO₂ based Fabry-Perot bandpass filter structure and its filtering performance will be presented for the SWIR band. Furthermore, a quasi-three-dimensional nanopillar array structure consisting of an Au disk, a dielectric cavity, and an Au hole and its plasmonic characteristics such as resonance wavelength tunability and incident angular tolerance will be addressed for the MWIR band.

Keywords:

multispectral imaging

Investigation of interface electronic states from InAs/GaSb multi quantum wells

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Abstract:

We have investigated optical transitions in the InAs/GaSb multiple quantum wells (MQWs) by photoreflectance (PR) spectroscopy with various temperatures and excitation intensities. The PR was employed to investigate the inter-band transitions such band-to-band (E_{GaSb}), spin-orbit split off (Δ_0), E_1 and of GaSb [1] as well as their interface quantum states (IQS).

The room temperature PR spectra show near band transitions and above band transition for InAs/GaSb (5 ML/50 nm) MQW, respectively. PR spectra of the InAs/GaSb MQWs showed the E_{GaSb} , the Franz-Keldysh oscillation (FKO) and IQS. We confirmed the transition energies from 0.72 eV, 1.52 eV, 2.07 eV and 2.53 eV corresponding to the E_{GaSb} , $E_{\text{GaSb}} + \Delta_0$, E_1 and $E_1 + \Delta_1$, respectively. Moreover, at room temperature PR spectrum, we observed sharp transition features due to the IQSs from the interface of InAs/GaSb. At near 1.2 eV region, we found unidentified transitions (UIS) and which were investigated by excitation intensity and temperature dependent PR. At low temperature PR result, we found the transitions between confined electrons states in InAs QW and GaSb valence band at energy of 0.506 eV.

Keywords:

multi quantum wells

Ultrasensitive Molecule Detection Based on Infrared Metamaterial Absorber with Vertical Nanogap

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Abstract:

Surface-enhanced infrared absorption (SEIRA) spectroscopy is a powerful methodology for sensing and identifying small quantities of analyte molecules via coupling between molecular vibrations and an enhanced near-field induced in engineered structures. A metamaterial absorber (MA) was proposed as an efficient SEIRA platform; however, its efficiency is limited because it requires the appropriate insulator thickness and has a limited accessible area for sensing. We propose SEIRA spectroscopy using an MA with a 10 nm-thick vertical nanogap, and we experimentally achieved a record-high reflection difference SEIRA signal of 36% using a 1-octacanthiol monolayer target molecule. Theoretical and experimental comparative studies were conducted using MAs with three different vertical nanogaps. The MAs with a vertical nanogap were processed using nanoimprint lithography and isotropic dry-etching, which allowed cost-effective large-area patterning and mass production. The proposed structure may provide promising routes for ultrasensitive sensing and detection applications.

Keywords:

plasmonics(플라즈몬닉), metamaterial(메타물질), nanogap(나노갭)

Low Noise Avalanche Photodiodes for Short-Wavelength Infrared Applications

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Abstract:

APDs are useful components for signal detection in many applications due to their internal gain, M , which provides high sensitivity. However, the multiplicative gain comes along with the avalanche noise, $F(M)$, caused by gain fluctuations because of the stochastic nature of the avalanche process. Additionally, the dark current is also one of the critical parameters which can degrade an APD's sensitivity. Therefore, reducing the noise components (avalanche noise and the dark current) is required to achieve highly sensitive APDs.

Recently, we have studied the multiplication characteristics of two different quaternary materials, AlGaAsSb [1] and AlInAsSb [2], on InP substrates. These two materials have demonstrated the extremely low avalanche noise (FM) ~ 2 at a gain of 10) and the low dark current density ($< 100 \mu\text{A}/\text{cm}^2$ at a gain of 10) at room temperature. These noise characteristics show that the AlGaAsSb and AlInAsSb material systems are promising multipliers for high-performance APDs. We discuss the material growth, characterization, and APD performance of these two multipliers.

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Keywords:

APD

Protein dynamics in water observed with 2D-IR spectroscopy

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Abstract:

The femtosecond nonlinear infrared (IR) spectroscopy has been contributed to studies of molecular dynamics and various chemical reactions such as energy transfer, proton hopping, protein denaturation, and chemical exchanges. With the advances in laser technology and optics, there has been improvements in spectral- and time-resolution, signal to noise ratio, and spatial resolution through adapting the development in microscopies. However, the application of advanced spectroscopies and microscopies still have been limited to studies of samples optimized for spectroscopic observation rather than function or performance of the sample. To expand the application of time-resolved vibrational spectroscopies, our group have been developing various methods to combine chemical reactor, a living cell, and electronic devices with nonlinear spectroscopies like polarization selective pump-probe (IR-PP), transient two-dimensional IR (2D-IR), time-resolved THz, IR-Vis sum-frequency generation (SFG), two-dimensional electronic spectroscopy (2D-ES).

In this talk, nonlinear spectroscopies installed in our lab will be briefly introduced. Then, protein aggregation dynamics with 2D-IR will be discussed. The structural dynamics of proteins have been studied for a long time because all biological processes involve changes in the conformation of the protein. Many protein dynamics studies use X-ray crystallography and NMR spectroscopy; however, these methods have limitations in measuring proteins undergoing structural rearrangements over a range of time scales, from 10^{-13} to 10^4 s. on the other hand, IR spectroscopy has a higher sensitivity, especially for the secondary structure of a protein. Even with the big advances in IR and time-resolved IR spectroscopies, the observation of protein structure and dynamics in aqueous solutions could not be done due to the strong and broad absorption band of H_2O . To avoid water absorption, D_2O has been used. However, various effects including H/D exchange raise the question about the observed protein dynamics in D_2O . To observe the protein dynamics in H_2O , two approaches are developed. First, an external IR probe are designed to have its vibrational frequency within water transparent window. Here we will present our rational design rule to increase IR absorption and vibrational lifetime. The other direction is to utilize the advantage of 2D-IR spectroscopy to avoid the absorption of water in time-domain. We will present our strategy and show the 2D-IR results monitoring the evolution of secondary structure during the protein aggregation in H_2O .

Keywords:

Two-Dimensional Infrared Spectroscopy, Protein Dynamics

Quantitative phase imaging and artificial intelligence: label-free 3D imaging, classification, and inference

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Abstract:

Quantitative phase imaging (QPI) exploits refractive index (RI) distributions in cells and tissues as intrinsic imaging contrast^{1,2}. Optical diffraction tomography (ODT) is one of the 3D QPI techniques³. ODT is an optical analogous to X-ray computed tomography; multiple 2-D holograms of a sample are measured with various illumination angles, from which a 3-D RI distribution of the sample is reconstructed by inversely solving the wave equation.

When label-free and quantitative 3D imaging capability of ODT is combined machine learning, it can provide synergistic capability in bioimaging and clinical diagnosis. We will discuss potentials and challenges of combining QPI and artificial intelligence in terms of various aspects of imaging and analysis, including phase retrieval⁴, tomographic reconstruction⁵, segmentation⁶, imaging inference⁷, and noise reduction⁸. In particular, we discuss the segmentation of cellular and subcellular features, the classification of bacterial cell types, and the inference of molecular information from unlabeled RI tomogram of live cells.

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Keywords:

quantitative phase imaging, machine learning, artificial intelligence, live cell imaging

Unprecedented View of Human Diseases by Intravital Confocal and Two-photon Microscopy

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Abstract:

Intravital microscopy is a high-resolution imaging technique based on laser-scanning two-photon and confocal microscopy, which can visualize various cellular-level dynamics such as cell trafficking, cell-to-cell or cell-to-microenvironment interactions inside a living animal *in vivo*. During the last decade, intravital microscopy has become a highly valuable indispensable technique in wide area of biomedical science such as molecular and cell biology, immunology, neuroscience, developmental and tumor biology. It can provide an unprecedented view in the processes of human disease development for the development of new therapeutics and diagnostics by identifying and validating of new molecular- and cellular-level targets and biomarkers using various preclinical animal models. Furthermore, intravital imaging of pathophysiological cellular dynamics in endogenous *in vivo* microenvironment is highly valuable for novel drug development by providing improved accuracy and reliability in the process of *in vivo* validation of mode of action (MoA) and efficacy assessment. In this talk, a custom-built laser-scanning intravital microscopy system and its application for biomedical research and development will be introduced.

Keywords:

Intravital microscopy, Two-photon microscopy, Confocal microscopy, In vivo imaging, Diseases

Multi-modal Imaging: Photoacoustic Imaging Plus More

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Abstract:

Trans-energy imaging modalities have been significantly explored to overcome existing problems in conventional imaging modalities with respect to spatial/temporal resolutions, penetration depth, signal-to-noise ratio, contrast, and so on. Among them, photoacoustic imaging, an emerging hybrid modality that can provide strong endogenous and exogenous optical absorption contrasts with high ultrasonic spatial resolution, has overcome the fundamental depth limitation while keeping the spatial resolution. The image resolution, as well as the maximum imaging depth, is scalable with ultrasonic frequency within the reach of diffuse photons. In this presentation, the following topics will be discussed; (1) multiscale and multiparametric trans-energy imaging systems, (2) novel deep-learning powered image processing, (3) recent clinical study results, and (4) efforts to commercialization.

Keywords:

photoacoustic, ultrasound, medical imaging, clinical translation

TF QKD 네트워크 시스템

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Abstract:

최근 차세대 보안통신 기술인 양자키분배 (QKD, quantum key distribution) 분야에서 거리 증가와 네트워크로의 확장 연구가 활발히 이루어지고 있다. 거리 증가 측면에서는 2018년 양자키분배 거리를 획기적으로 증가시킬 수 있는 twin-field QKD가 이론적으로 제시된 이후 428, 511, 605km 거리에서 구현 가능성을 보여주는 연구 결과가 발표 되었다. 네트워크 연구에서는 4,600km에 이르는 양자암호 네트워크 구축이 발표 되었으나 구현 난이도가 높은 twin-field QKD의 특징 때문에 twin-field QKD 네트워크에 대한 연구는 미비한 실정이다. 본 논문에서는 TF-QKD 네트워크 구조를 제안하고 실험적으로 검증할 결과를 발표한다. 제안하는 구조는 플러그앤플레이 아키텍처를 기반으로 하고 있다. 2x16 네트워크 구조에 대한 실험 검증을 수행했으며 1.91×10^{-4} bit per pulse의 비밀키 생성률과 4% 수준의 QBER을 얻었다.

Keywords:

quantum key distribution, twin-field

Quantum Electromechanical Systems and Their Applications

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Abstract:

Quantum electromechanical systems are electronic devices that utilize resonant mechanical modes as harmonic oscillators for the applications in quantum technology. Recently, these devices emerged as a promising platform for quantum information processing as operations near ground states and coherent coupling to other quantum systems were demonstrated. In this talk, I will describe two examples of nanomechanical devices developed with the aim of advancing quantum electromechanical devices and expanding their application area[1,2]. First, we report a cavity electromechanical system based on niobium demonstrating substantial improvements in operating conditions of temperature and magnetic field compared to the conventional aluminum devices. The device manifests optomechanical effects in the microwave domain up to 4 Kelvin and 0.9 Tesla, and it could be utilized for the quantum-limited sensing in magnetic environments. Second, a nanowire mechanical oscillator realizes a microwave bolometer at millikelvin temperatures. We implement a suspended InAs nanowire in a superconducting microwave resonator such that its nanomechanical resonance frequency becomes sensitive to its microwave absorption. The nanomechanical bolometer handles a few nanowatts with picowatt resolution, and extends the power range that bolometric technique applies, complementing Josephson bolometers.

[1] J. Cha et.al., Nano Lett. 21, 1800 (2021).

[2] J. Kim et.al., Phys. Rev. Applied 15, 034075 (2021).

Keywords:

nanoelectromechanical system, quantum device, quantum electromechanical system

냉각 원자를 이용한 고정밀 중력센서

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Abstract:

본 학회에서는 냉각 원자의 양자 중첩현상을 기반으로 하는 원자간섭계를 이용한 여러가지 물리현상 규명 및 정밀 측정에 관한 연구들을 소개하고, 특히 정밀 중력 측정에 대한 국내외 연구 동향 및 현재 연구 진행 현황들을 소개한다.

Keywords:

양자중첩, 원자간섭계

양자머신러닝을 활용한 양자광학계 정밀 제어/측정

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Abstract:

머신러닝을 이용한 양자정보처리에의 장점 및 양자이득 등에 대한 연구가 활발히 이루어지고 있다. 최근, 단일측정(single-shot measurement) 기반의 새로운 양자머신러닝 학습 알고리즘이 개발/제안되었고 미지 양자상태 추정에서의 양자-최적 정확도의 달성이 가능함이 입증되었다 [1]. 해당 방법은 기존의 양자단층촬영(quantum state tomography) 방식보다 효율적이며 계산상 요구사항이 훨씬 적다. 이같은 장점은, 학습을 위한 파라미터 탐색경로를 설정하는 규칙에 무작위성을 포함시켰기 때문이다. 이같은 단일측정 기반 양자학습은 양자광학계에서 실험적으로 구현되었고, 실험장비의 결함보상 없이도 세계 최고 수준의 정확도를 보였다. 본 발표에서는 이같은 결과에 대해 논의하고, 해당 알고리즘의 양자암호, 양자시뮬레이션 등의 활용방안 등을 소개하고자 한다.

[1] Phys. Rev. A 103, 042409 (2021); Phys. Rev. Lett. 126, 170504(2021).

Keywords:

머신러닝, 양자정보

Study of a novel approach for the identification of the tt +heavy flavor events

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Abstract:

After the Higgs (H) boson discovery in 2012, from initial measurements the properties of the Higgs boson seem to be consistent with those from the H boson in the standard model of particle physics. Furthermore, from analyzing the proton collision data of the LHC the couplings of a top quark and a bottom quark in the standard model with the H boson was recently (2018) discovered in different processes. However, the confirmation that both couplings are simultaneously consistent with the predictions, is only possible by measuring the unique process where top-quark pairs are produced in association with the H boson where the H boson decays a pair of bottom-quarks ($ttH(bb)$). This process is yet to be discovered in the data. Therefore, the main objective of our study is to prepare and finally make this discovery. The main obstacles emerge from the overwhelming background processes of top-quark pair production in association with heavy-flavor quarks such as bottom-quarks (b-quarks) or charm quarks (c-quarks). It is very challenging to identify those additional heavy quarks, e.g. b-quarks are also produced in the top quark decays and c-quarks are in general difficult to identify. In this study, a deep learning technique with an innovative approach of so-called "event-by-event" instead of traditional "jet-by-jet" approach will be used to tackle this problem.

Keywords:

top quark, deep learning

Data-driven background rate estimation with neural networks

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Abstract:

The ABCD method is one of the most widely used data-driven background estimation techniques in high energy physics. Cuts on two classifiers separate signal and background into four regions, so that background in the signal region can be estimated using the other three control regions. However, the accuracy of this method depends largely on the statistical independence of the two classifiers, which are often chosen on a per study basis. Also, incorporating additional classifiers are difficult, since the method cannot easily be extended to higher dimensions. We show that these constraints of the ABCD method may be resolved by using neural networks (ABCDnn). In both the 3-d Gaussian and $t\bar{t}$ + multi jet MC data, ABCDnn reliably estimated the background regardless of the correlation between chosen classifiers.

Keywords:

Data driven, background, neural network

Graph Neural Network for event classification of four-top process in the fully hadronic channel

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Abstract:

Deep Learning is a powerful tool to analyze the big data of high-energy physics. Typical problems in the high energy hadron collision are classifying events that consist of feature variables of multiple physics objects such as Jet's four-momentum, flavor tagging information. Convolutional Neural Network (CNN) can be used for event classification, although CNN has limitations with irregular geometry of detectors or sparse data. In this study, we adopt an advanced Deep Learning architecture, Graph Neural Network (GNN) to discriminate between four-top, ttbar, and QCD events.

Keywords:

GNN, four-top, Deep Learning

Search for flavor-changing neutral current interaction of the top quark and the Higgs boson decaying into $b\bar{b}$ at 13 TeV with CMS Run 2 data

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Abstract:

A search for flavor-changing neutral current interactions of the top quark and the Higgs boson is presented. The search is based on a data sample corresponding to an integrated luminosity of 137 /fb recorded by the CMS experiment at the LHC in proton-proton collisions at 13 TeV. Events containing exactly one lepton (muon or electron) and at least three jets, among which at least two are identified as originating from the hadronization of a bottom quark, are analyzed. Selected events are separated into five categories based on the jet and bottom quark jet multiplicities. A deep neural network is used to associate the reconstructed objects to the partonic final state, while boosted decision trees are used to distinguish the signal from the background events. No significant excess over the background predictions is observed, and upper limits on the signal production cross sections are set. These limits are interpreted in terms of top quark decay branching fractions.

Keywords:

top quark, Higgs boson, CMS

A study of V_{cb} measurement in semi-leptonic decay channel of top pair events at the LHC

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Abstract:

We present a study of V_{cb} measurement in semi-leptonic decay channel of top pair events at the LHC. The current measurements have a tension in two decay modes (exclusive and inclusive decays) of B meson. V_{cb} measurement in $W \rightarrow cb$ from top decays is free from any non-perturbative effect of B meson and can contribute to resolving the tension. We use analysis tools developed to perform search for $H^+ \rightarrow cb$ in semi-leptonic $t\bar{t}$ events which has the same final state. Since the $H^+ \rightarrow cb$ study has set the most stringent limit, it is expected that the use of the same tool will produce meaningful results in the $W \rightarrow cb$ measurement

Keywords:

V_{cb} , CMS, top pair

Search for heavy neutrinos in top quark decays at CMS

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Abstract:

Heavy neutrinos can be produced in decays of top quarks, which are abundantly produced in LHC experiments. We analyze the data of proton-proton collisions at 13 TeV, recorded by CMS detector in Run-2, to search for these events. Neutrino mass values between 20 and 100 GeV, and final states with same-sign dimuon or dielectron are considered. The Gradient Boosted Decision Tree method is used to identify the hypothetical neutrinos. Expectation on the background and signal processes, and the resulting search sensitivity is studied.

Keywords:

Neutrino, top, CMS

RPV SUSY search in single-lepton final state in CMS

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Abstract:

At the LHC, R-Parity Violating (RPV) SUSY models typically give signatures without missing transverse energy (MET). Since searches targeting R-Parity Conserving models use the high MET feature due to the existence of stable neutral LSPs, their sensitivity to RPV models is limited. This motivates searches that probe high energy regime without a MET requirement. We search for new physics in the final state with single lepton, large jet and bottom quark jet multiplicities, and high sum of large-radius jet masses, without any requirement on MET. In this talk, the status of the search using the full Run2 data will be discussed.

Keywords:

R-Parity Violating SUSY, RPV, LHC, CMS

Performance of the PF hadron calibration algorithm for Run III at CMS experiments

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Abstract:

Jets are essential objects to search particles predicted by new physics models and detect bosons and heavy quarks in Standard Model. At the CMS experiment of CERN, jets are calibrated to have the correct energy scale: the jet energy corrections (JEC). The understanding of JEC is crucial for many physics analyses, which include jets as their final states. It successfully worked on the CMS experiments with an integrated luminosity of 137 fb^{-1} collected in proton-proton collisions at a center-of-mass energy of 13 TeV. The Particle Flow (PF) hadron calibration is the initial step of the JEC procedure, which is performed with charged hadrons. This talk explains the PF hadron calibration and reports its performance at High Level Trigger (HLT) for the upcoming Run 3.

Keywords:

CMS, PF hadron calibration, High Level Trigger, Jet energy correction

Update of Herwig 7 for BSM radiations and search for the radiated BSM particle inside jets

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Abstract:

Since the establishment of the LHC, isolated leptons have been used to search new physics according to various Beyond the Standard Model(BSM) scenarios. However, there is no direct signal for new physics yet. It is a catastrophe for physicists, but on the contrary it also gives a great opportunity to explore a new phase space. Thus, we perform a search for BSM bosons inside a jet using non-isolated muons. Because this is a brand new challenge, there is no shower generator to execute the BSM particle radiations. We thus implement the BSM parton showers in Herwig 7. This presentation informs a preliminary result of anomalous non-isolated dimuon productions inside a jet and also necessary steps to implement the BSM shower which can generate the signal of the this study.

Keywords:

LHC, non-isolated lepton, Herwig 7

Target optimization of magnetic monopole experiment (KAEM) using GEANT4 simulation

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Abstract:

KoreA Experiment on Magnetic Monopole (KAEM) searches elementary magnetic monopoles, which has been a question of electromagnetism last 150 years. We will explore the mass and charge region below the mass and charge of the electron. We configured the experiment in which positrons interact with atomic electrons in an aluminum target. We assume that electron-positron annihilation can produce magnetic monopoles. In this talk, we will present the results of the target optimization obtained with GEANT4 simulations.

Keywords:

Magnetic monopole, KAEM, GEANT4

Performance test of LYSO crystal for monopole experiment (KAEM)

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Abstract:

KoreA Experiment on Magnetic Monopole (KAEM) searches for fundamental magnetic monopoles in the low-mass, low-charge region. KAEM should be configured with a thin aluminum target, sodium-22 source, two 1 Tm solenoids, 2.5 m long vacuum chamber, crystal electromagnetic calorimeters, and crystal trigger-veto. The LYSO crystal is a candidate for trigger-veto and electromagnetic calorimeters. Therefore, we investigated the characteristics of the LYSO crystal and its background activity.

Keywords:

KAEM, monopole

The performance of the self-grown NaI(Tl) crystal

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Abstract:

COSINE-100 is a direct dark matter search experiment that uses low-background NaI(Tl) crystals as the target/detector material. The development of higher purity NaI(Tl) crystals with much lower radioactive backgrounds is an essential requirement for the next phase of the experiment. Since crystals that meet our requirements are not commercially available, we have developed techniques to purify the crystal materials and procedures to grow ultra-low background crystals autonomously in the Center for Undergrond Physics (CUP) laboratory's crystal growing facility. Measurements show that our most recently produced crystals have a higher radio-purity than any of those that are currently operating in the COSINE-100 detector. This presentation will elucidate the improvements and the performance of the upgraded crystals.

Keywords:

NaI(Tl), COSINE-100

Update on dark matter searches using annual modulation in NaI crystals at COSINE-100

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Abstract:

COSINE-100 is a dark matter detection experiment designed with the goal of testing the long-standing but contested positive dark matter signal from the DAMA/LIBRA collaboration using the same target material and search method. In this talk the most recent results from three years of data taking are presented, alongside discussion of improved event selection resulting in a lowered energy threshold compared to previous modulation searches, and an improved background model to improve the modulating fitting procedure.

Keywords:

Dark matter, dark matter detection, COSINE-100

Status of COSINE-100

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Abstract:

There is strong evidence for the existence of dark matter from astrophysical observations, and the DAMA/LIBRA collaboration has claimed to have observed an annual modulation signal that could possibly be attributed to being induced by dark matter interactions with nuclei in NaI(Tl) crystals. COSINE-100 is an experiment aimed at the direct detection of dark matter using NaI(Tl) crystal as the target/detector material to test the DAMA/LIBRA collaboration's claim. The COSINE-100 detector is situated 700 meters underground in the Yangyang Laboratory, and data have been continuously collected since September 2016. In this presentation, we report the status of COSINE-100, including the recent results on WIMP extraction analysis and a search for dark matter using Migdal-effect-induced signals. In addition, plans and sensitivities for the next phase, COSINE-200, will also be presented.

Keywords:

Dark matter, WIMP, Migdal effect, NaI(Tl)

New test results of Molybdate crystals for AMoRE-II R&D

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Abstract:

The Advanced Mo-based Rare process Experiment (AMoRE) is an international experiment searching for the neutrinoless double-beta decay of ^{100}Mo using molybdenum-based crystals with a cryogenic sensor.

The AMoRE is considering lithium molybdate crystals for its phase-II experiment. It is necessary to understand various conditions such as different dimensions (5 cm (F) x 5 cm (H) and 6 cm (F) x 6 cm (H)) and different crystal surface treatments (polishing and lapping). We present the performances of lithium molybdate crystal detectors and a sodium molybdate crystal on energy resolution, the separation between alpha and beta/gamma, and alpha background in this talk.

Keywords:

Neutrinoless double beta decay, cryogenic crystal detector, Lithium molybdate, Sodium molybdate

Status of AMoRE-I

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Abstract:

AMoRE (Advanced Mo-based Rare process experiment) is an international collaboration project searching for the neutrinoless double-beta ($0\nu\beta\beta$) decay of ^{100}Mo in enriched molybdenum-based scintillating crystals with metallic magnetic calorimeters in a cryogenic system at 10~20 mK. The AMoRE aims at zero background in the region of interest near 3.034 MeV using simultaneous measurement of phonons and photons and pulse shape discrimination which provide good background rejection and high resolution. AMoRE-I, following the successfully completed AMoRE-pilot, has been running with thirteen $^{48\text{depleted}}\text{Ca}^{100}\text{MoO}_4$ and five $\text{Li}_2^{100}\text{MoO}_4$ crystals in the Yangyang underground laboratory since August 2020, and we have collected more than half a year of physics data. We present the current status of the experiment, its analysis method and the most recent analysis results.

Keywords:

Neutrinoless Double Beta Decay, Underground experiment, AMoRE, Cryogenic experiment

Half-life limit on neutrinoless double-beta decay using AMoRE-pilot data

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Abstract:

AMoRE (Advanced Mo-based Rare process Experiment) is searching for the neutrinoless double-beta decay of ^{100}Mo with the help of molybdenum-based scintillation bolometric detectors operating at a few tens of milli-Kelvin temperatures. Simultaneous detection of scintillation light and heat (phonon) signals makes it possible to discriminate between gamma/beta- and alpha-particles to reject the background signals caused by trace U/Th contamination in the detector materials. A pilot experiment, AMoRE-Pilot, was completed in 2018 with six $^{48\text{depl}}\text{Ca}^{100}\text{MoO}_4$ crystals, a total mass of ~ 1.9 kg, in a low-background cryostat at the Yangyang underground laboratory with the minimum overburden of 700 m. In the pilot phase, we tried to understand and reduce the background of the detector. A Monte Carlo simulation was performed together with a background modeling to understand the background level. We estimated the neutrinoless double-beta decay half-life of ^{100}Mo in consideration of the understood background. By comparing the data and estimated backgrounds, we obtained the limit of 3.43×10^{23} years on the half-life of neutrinoless double-beta decay of ^{100}Mo .

Keywords:

neutrino, double beta decay, underground

Status of Muon Veto detector development for AMoREII

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Abstract:

The AMoRE experiment is a neutrinoless double-beta decay search of CUP, IBS, using ^{100}Mo , and AMoREII, 2nd phase of this experiment, will begin soon. AMoRE experiment is aiming to reach zero-background, and one of the ways is cosmic ray background rejection. For this reason, it is planned that the muon veto detector system for AMoREII will be operating in Yemi-Lab, and their development is ongoing now.

AMoREII will have 2 types of muon veto detectors, which are a Plastic Scintillator for the 1st floor, and a Water Cherenkov detector for the 2nd floor. For the plastic scintillator, We will install about 130 detector boxes outside of the 1st-floor wall. this detector box design for construction was finalized and mass production is started recently. For the water Cherenkov detector, we are performing several tests using a prototype detector before construction in Yemi-Lab. In this talk, the introduction of muon veto detector of AMoREII and its development in these days.

Keywords:

AMoRE, Muon Veto detector, Plastic Scintillator, Water Cherenkov detector

Static properties of multi-quark states

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Abstract:

We study static properties of light and heavy baryons, based on a pion mean-field approach. A pion mean-field approach allows one to investigate light and singly heavy baryons on an equal footing. In the large N_c limit, the light and heavy baryons are viewed respectively as N_c and $(N_c - \text{number of heavy quarks})$ valence quarks bound by the pion mean fields created self-consistently, since a heavy quark can be regarded as a static color source in the limit of the infinitely heavy quark mass. The important observables of multi-quark states will be discussed with recent experimental data.

Keywords:

baryons, pion mean field, multi-quark states

The masses of hadrons in the chiral symmetry restored vacuum

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Abstract:

We calculate the masses of the vector and axial-vector mesons, as well as the nucleon and delta resonance in the chiral symmetry, restored vacuum. This is accomplished by separating the quark operators appearing in the QCD sum rules for these hadrons into chiral symmetric and symmetry breaking parts depending on the contribution of the fermion zero modes. We then extract the vacuum expectation values of all these quark operators using the QCD sum rule relations for these hadrons with their vacuum masses and widths. By taking the chiral symmetry breaking parts to be zero while keeping the symmetric operators to their vacuum values, we obtain the chiral symmetric part of the hadron masses. We find that the masses of chiral partners become degenerate in the chiral symmetry restored vacuum, while parity partners that are chiral partners only in the limit where the disconnect diagrams are neglected remain non-degenerate. We find that while chiral symmetry breaking is responsible for the mass difference between chiral partners, a large fraction of the symmetric part of the mass has other origins.

Keywords:

QCD sum rules, Chiral partner, Symmetry restoration

The axial-vector meson a_1 (1260) as a molecular state

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Abstract:

We investigate the axial-vector meson a_1 (1260) resonance from $\pi\rho$ scattering based on the fully off-mass-shell coupled-channel formalism. The $\pi\rho$ channel is coupled to the $K\bar{K}^*$ channel, which generates the a_1 (1260) below the $K\bar{K}^*$ threshold. This shows a certain similarity to the scalar meson f_0 (980) resonance that arises as a $K\bar{K}$ molecular or quasi-bound state. This implies that the a_1 (1260) resonance can be theoretically interpreted as the $K\bar{K}^*$ molecular state. As a result, the experimental data on the total cross section of $\pi\rho$ scattering are described very well by this $\pi\rho$ and $K\bar{K}^*$ coupled channels.

Keywords:

Coupled channel, Molecular state, Axial-vector meson

Structures of the Ω baryon with the effects of the kaon cloud

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Abstract:

The Ω baryon is an isosinglet baryon and consists solely of the strange valence quarks. This means that the kaon cloud will come into essential play in describing the structure of the Ω baryon.

In any SU(3) chiral solitonic approach, all the baryons have the pion tail because of the hedgehog symmetry, which requires the embedding of the SU(2) soliton into SU(3).

This indicates that the Ω baryon contains inevitably the pion tail within this standard method.

In the present talk, we show how one can incorporate the effects of the kaon cloud to describe the Ω baryon. Replacing the average of the up and down quark masses with the large valence quark mass, we are able to produce self-consistently the profile function for the kaon cloud.

We then evaluate the properties of the Ω baryon. We present the results for the EM and axial-vector form factors of the Ω baryon with the effects of the kaon cloud and compare the results with those from lattice QCD.

Keywords:

Ω baryon, kaon mean field, the chiral quark-soliton model, EM form factors, Axial-vector form factors

Singly-heavy baryon in baryonic matter

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Abstract:

We investigate how the masses of singly heavy baryons undergo changes in nuclear matter, employing the framework of the in-medium modified chiral soliton model. The internal parameters are determined based on nuclear phenomenology at non-strange light baryonic matter and fitted by reproducing nuclear matter properties near the saturation density. We discuss the dependence of the in-medium masses of singly heavy baryons on strangeness and the portion of the neutrons in surrounding matter.

Keywords:

Singly-heavy baryon,

Doubly heavy tetraquarks, $qq\bar{Q}\bar{Q}'$, in a nonrelativistic quark model with a complete set of harmonic oscillator bases

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Abstract:

We improve our previous variational method based nonrelativistic quark model by introducing a complete set of three-dimensional harmonic oscillator bases as the spatial part of the total wave function. After fitting to the masses of the ground state hadrons, we apply our new method to analyzing the doubly heavy tetraquark states $qq\bar{Q}\bar{Q}'$. In particular, we compare the result for T_{cc} to the result in the recent discovery at LHCb. We also calculate the ground state masses of T_{sc} ($u\bar{s}\bar{c}$) and T_{sb} ($u\bar{s}\bar{b}$) with $(I,S) = (0,1), (0,2)$. We find that T_{bb} ($u\bar{b}\bar{b}$) and $u\bar{s}\bar{b}\bar{b}$, both with $(I,S) = (0,1)$, are stable against the two lowest threshold meson states with binding energies -145 MeV and -42 MeV, respectively. We further find that T_{cb} ($u\bar{c}\bar{b}$) is near the lowest threshold. The relative positions of the quarks in the tetraquark structure are also discussed.

Keywords:

Quark model, Tetraquark, T_{cc} , Variational method

Singly charmed baryons in nuclear matter based on a chiral soliton model

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Abstract:

We present in this talk a recent investigation on properties of singly charmed heavy baryons in nuclear matter. The calculation is performed, based on an SU(3) Skyrme model with π , ρ and ω mesons together with heavy mesons. The medium modifications of the charmed baryons are achieved by implementing the changes of properties of the light π , ρ and ω mesons, and the heavy D meson mass in nuclear matter. The parameters of the density functions entering into the medium-modified Lagrangian are fitted to various properties of nuclear matter around the saturation point at normal nuclear matter density. We discuss the results, focussing on how the masses of the charmed baryons undergo changes in nuclear matter.

Keywords:

Skyrme model

Charmonium spectrum from the instanton vacuum

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Abstract:

In this talk, we present recent results for the charmonium spectrum, incorporating the heavy-quark potential derived from the instanton vacuum. We plug it into the Cornell-type potential that consists of the confining potential and Coulomb-like potential that arises from one-gluon exchange. In addition, we also consider the instanton effects on one-gluon exchange, which leads to the Yukawa-type potential. Combining all together, we compute the masses of charmonia. The results are in good agreement with the experimental data, fitting only four parameters. We discuss the effects from the instanton vacuum. In addition, we discuss the results for radiative decays of charmonia.

Keywords:

Instanton, Charmonia, Radiative decay width

Finding the missing Roper-like resonances

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Abstract:

It is observed that the Roper-like resonances with various quark flavors have similar excitation energy of around 500 MeV. For Ξ baryon, there are several resonances observed in this energy range such as $\Xi(1690)$, $\Xi(1820)$, and $\Xi(1950)$. However, none of them is identified as the Roper-like resonance in the Particle Data Group (PDG). In this talk, we will investigate the possibility of the existence of the Roper-like Ξ resonance by studying their decay properties in the constituent quark model with the relativistic effect included. Furthermore, the analogous state for Ω baryon is also discussed.

Keywords:

Hadron decay, Roper-like resonance, Quark model

The status of the GroundBIRD telescope

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Abstract:

GroundBIRD (Ground-based Background Image Radiation Detector) is a ground-based experiment that measures the polarization of the CMB radiation. It will cover about 45% of the sky from the Teide Observatory in Tenerife, at two frequencies (145 and 220 GHz). We present the main concept of the telescope, installation, and the current status of the commissioning.

Keywords:

CMB

A forecast of the sensitivity on the measurement of the optical depth to reionization with the GroundBIRD experiment

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Abstract:

We report our recent simulation studies on the forecast of the sensitivity on the optical depth to reionization with the GroundBIRD experiment. We simulate the polarization skies at 145 and 220 GHz, and apply the map-making pipeline of the GroundBIRD experiment to obtain the simulated GroundBIRD sky maps. The noise levels for the polarization maps are estimated as 110 $\mu\text{K arcmin}$ and 780 $\mu\text{K arcmin}$ for each frequency by assuming three-year observation and sky coverages of 0.537 and 0.462. We extract the optical depth to reionization with pixel-based likelihood analysis. The sensitivities for the optical depth to reionization are found to be 0.030 with the simulated GroundBIRD maps, and 0.012 by combining with the simulated QUIJOTE maps at 11, 13, 17, 19, 30, and 40 GHz when we assume the central value to be 0.050.

Keywords:

cosmic microwave background, optical depth to reionization, early universe

Final parsec problem of binary black holes and ultralight dark matter

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Abstract:

When two galaxies merge, a massive binary black hole forms at the center of the new galaxy. Theoretical calculations suggest that all black hole binaries stall out at $O(\text{pc})$ apart and take too long time before strong gravitational wave generation and coalescence. In this talk we suggest that the binary black holes can generate ultralight (fuzzy) dark matter waves which can effectively carry out energy and angular momentum of the black holes. This can solve the final parsec problem.

Keywords:

binary black hole, fuzzy dark matter, final parsec problem

Quantum boundary condition inside a black hole

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Abstract:

We study quantum gravitational boundary conditions inside a black hole. The vanishing boundary condition can be provided, where this can be generalized to gravitational collapsing cases. We further investigate possible physical implications.

Keywords:

black holes, Wheeler-DeWitt equation

Cosmic distance duality as a probe of minimally extended varying speed of light.

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Abstract:

We obtain the current constraint on the minimally extended varying speed of light (meVSL) model by analyzing cosmic distance duality relation (CDDR) of it, $DL/DA(1+z)^{-2} = (1+z)^b/8$. We use the Pantheon type Ia supernova (SNIa) data, the Hubble parameter $H(z)$ using the cosmic chronometers, the cosmic microwave background (CMB) distance priors from the latest Planck data, and the Baryon Oscillation Spectroscopic Survey (BOSS) data. We find that the constrain on the time variation of physical constants at 1 and 2-sigma confidence levels.

Keywords:

dark energy, general relativity, modified gravity theories, time varying constants,

Unparticle Cosmology: an unexpected detour to Holographic Dark Energy

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Abstract:

H_0 -tension is one of the recent Λ CDM challenges at late time cosmology originating from the discrepancy between measurements of Hubble parameter $H(z=0)$ by Local Distant Ladder and CMB. There are various efforts to alleviate this tension mostly by models with extra parameters. Holographic dark energy is one of the scenarios recently suggested to ameliorate H_0 -tension. Here we investigate a modification for late-time Λ CDM defined by an extra energy density of the form $\rho_u = cT^{4+\delta}$ inherited from unparticle cosmology. A detailed confrontation with data shows this Ansatz not to ameliorate H_0 -tension as it predicts $H(z)$ to be zero or constant in the future for most values of δ . Nevertheless, it remarkably provides a pointer to holography by giving $\delta \simeq -2$ as the best fit to data, persistent for all values of $z_{max} \in [0.07, 2]$. Although the model can not relax H_0 -tension, the appearance of $\rho \propto T^2$ gives credence to a holographic dark energy, making it a powerful candidate for governing the late-time universe.

Keywords:

Unparticle Cosmology, Late-time universe, Holographic Dark Energy, H_0 -Tension, Holography

Resonance from antiferromagnetic spin fluctuations for spin-triplet candidate superconductor UTe_2

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Abstract:

Superconductivity has its universal origin in the formation of bound (Cooper) pairs of electrons that can move through the lattice without resistance below the superconducting transition temperature T_C . While electron Cooper pairs in most superconductors form anti-parallel spin-singlets with total spin $S = 0$, they can also form parallel spin-triplet Cooper pairs with $S = 1$ and an odd parity wavefunction, analogous to the equal spin pairing state in the superfluid ^3He . Spin-triplet pairing is important because it can host topological states and Majorana fermions relevant for fault tolerant quantum computation. However, spin-triplet pairing is rare and has not been unambiguously identified in any solid state systems. Since spin-triplet pairing is usually mediated by ferromagnetic (FM) spin fluctuations, uranium based heavy-fermion materials near a FM instability are considered ideal candidates for realizing spin-triplet superconductivity. Indeed, UTe_2 , which has a $T_C = 1.6$ K, has been identified as a strong candidate for chiral spin-triplet topological superconductor near a FM instability, although the system also exhibits antiferromagnetic (AF) spin fluctuations. Here we use inelastic neutron scattering (INS) to show that superconductivity in UTe_2 is coupled with a sharp magnetic excitation at the Brillouin zone (BZ) boundary near AF order, analogous to the resonance seen in high- T_C copper oxides, iron-based, and heavy-fermion superconductors. We find that the resonance in UTe_2 occurs below T_C at an energy $E_r = 7.9k_B T_C$ (k_B is Boltzmann's constant) and at the expense of low-energy spin fluctuations. Since the resonance has only been found in spin-singlet superconductors near an AF instability, its discovery in UTe_2 suggests that AF spin fluctuations can may also induce spin-triplet pairing for superconductivity or that electron pairing in UTe_2 has a spin-singlet component.

Keywords:

Neutron scattering, Spin-triplet superconductivity, Heavy fermion

Topological magnons in a honeycomb lattice quantum XY magnet CoTiO_3

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Abstract:

Recent experimental and theoretical interests in the thermal Hall effect in various magnetic insulators have put a spotlight on the role magnons play in heat transport. In particular, magnons with topologically protected band structures, topological magnons, have been drawing much attention. In this talk, we report our inelastic neutron scattering investigation of topological magnons in a honeycomb lattice XY magnet CoTiO_3 , which features ferromagnetic layers of Co^{2+} , stacked antiferromagnetically along the c axis. Its energy-momentum resolved magnon spectrum is consistent with a simple XXZ Hamiltonian with a Dirac-cone-like dispersion [1,2]. A recent high-resolution neutron scattering measurement revealed important details of the magnon dispersion, namely a magnon gap at the Brillouin zone center as well as at the Dirac point. To explain the origin of the zone-center gap and the Dirac gap, anisotropic interactions beyond the XXZ model are required. We show that magnetic field dependence provides us with strong constraints for the forms of the anisotropic interactions in this material. Another interesting aspect of CoTiO_3 is the strong temperature dependence of the high energy modes observed in our neutron scattering measurements. These high-energy dispersive modes are attributed to the spin-orbit exciton modes arising from the entangled spin and orbital degrees of freedom. The observed strong temperature dependence is quantitatively explained by including mixing between the ground state and excited state multiplets [3].

[1] Bo Yuan, et al. Phys. Rev. X 10, 011062 (2020).

[2] M. Elliot, et al. Nat. Comm. 12, 3936 (2021)

[3] B. Yuan, et al. Phys. Rev. B 102, 134404 (2020).

Keywords:

inelastic neutron scattering, transition metal oxide, magnon band structure, spin-orbit coupling

Magnon Pairing, Interactions, and Decay in the Spin-orbital Magnet FeI₂

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Abstract:

One of the scientific frontiers in quantum magnetism is the discovery and understanding of quantum entangled and topologically ordered states in real bulk materials. At the focal point of the experimental investigation of these quantum spin networks is the identification of fractionalized excitations in transport and spectroscopic measurements. Inelastic neutron scattering has proved a powerful technique to reveal such signatures in a variety of systems ranging from quasi-1D magnets to kagome compounds and more. Recent and on-going developments with neutron scattering instrumentation have allowed the characterization of magnetic excitations in entire volumes of momentum-energy space with high resolution. This has prompted revisiting long overlooked materials in search for exotic spin dynamics despite seemingly classical magnetically ordered ground-states. In this talk, I will discuss such experiments on a long-known material, FeI₂, and show how high-fidelity modeling brings new insights on its spin dynamics [1]. I will describe the mechanism that endows low energy quadrupolar fluctuations in FeI₂ with large spectral weight and how these can be completely understood using a SU(3) representation of spin degrees of freedom. I will discuss the consequence of the having several quasiparticles as the low-energy degrees of freedom in this system including formation of heavy bound-states [2] and their mutual decay [3]. This work was supported by DOE/BES under award DE-SC-0018660.

[1] X. Bai, S.-S. Zhang, Z. L. Dun, H. Zhang, Q. Huang, H. D. Zhou, M. B. Stone, A. I. Kolesnikov, F. Ye, C. D. Batista, M. Mourigal, "Hybridized quadrupolar excitations in the frustrated and spin-anisotropic magnet FeI₂", Nature Physics 17, 467-472 (2021), <https://doi.org/10.1038/s41567-020-01110-1>.

[2] A. Legros, S.-S. Zhang, X. Bai, H. Zhang, Z. L. Dun, W. A. Phelan, C. D. Batista, M. Mourigal, and N. P. Armitage, "Observation of 4- and 6-magnon bound-states in the spin-anisotropic frustrated antiferromagnet FeI₂", Submitted, <https://arxiv.org/abs/2012.04205>.

[3] Xiaojian Bai, Shang-Shun Zhang, Hao Zhang, Zhiling Dun, W. Adam Phelan, V. Ovidiu Garlea, Martin Mourigal, Cristian D. Batista, "Instabilities of heavy magnons in an anisotropic magnet", Submitted, <https://arxiv.org/abs/2012.04205>.

Keywords:

quantum magnetism, magnetic multipoles, van der Waals materials, magnon bound-states, anisotropic exchange

Neutron Spectroscopy on Topological Magnons

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Abstract:

Neutron spectroscopy, an energy- and momentum-resolved tool is powerful in probing the lattice and spin excitations of quantum materials. However, it is rarely utilized to explore the topological properties in these materials. According to the topological band theory, bosons such as magnons can also exhibit topological band structures. In this talk, I will show several examples on how we used neutron spectroscopy to study topological magnons, which revealed: 1) Coexisting Dirac and triply-degenerate magnons in Cu_3TeO_6 [1,2]; 2) and, Topological magnon insulator in a van der Waals magnet CrBr_3 [3].

References:

- 1, Bao *et al.*, Discovery of coexisting Dirac and triply degenerate magnons in a three-dimensional antiferromagnet, Nat. Commun. 9, 2591 (2018).
- 2, Bao *et al.*, Evidence for magnon-phonon coupling in the topological magnet Cu_3TeO_6 , Phys. Rev. B 101, 214419 (2020).
- 3, Cai *et al.*, Topological magnon insulator spin excitations in the two-dimensional ferromagnet CrBr_3 , Phys. Rev. B 102, L020402 (2021).

Keywords:

Neutron spectroscopy, Topological magnons, Magnon-phonon interactions

X-ray imaging of topological meron pairs in permalloy rectangular elements

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Abstract:

The topology has been considered as a key concept to understand the physical behavior of spin structures [1]. Owing to the topological protection, the topologically non-trivial spin structure (skyrmion number, $|q| = 1$) has high stability compared to the topologically trivial spin structure ($q = 0$). The topological meron is a spin structure characterized by $|q| = 1/2$. The meron consists of the in-plane swirling magnetic components and out-of-plane core (polarity, $p = \pm 1$). In the soft magnetic materials, the merons with $n = +1$ and -1 correspond to the magnetic vortex and antivortex, respectively. Depending on the p of magnetic vortex and antivortex, the meron pair (vortex-antivortex pair) can be topologically trivial (meron-antimeron pair, $q = 0$) or non-trivial (bimeron, $|q| = 1$) structures [2]. Based on the topological properties, the meron pair has attracted a lot of interest for the device application [3]. However, the topology-dependent properties of the meron pair have not been experimentally addressed yet since it is challenging to establish the meron pairs with different topologies in the ferromagnetic element.

In this work, we observed topologically different 3D meron pairs in a 100 nm-thick permalloy rectangular element by utilizing magnetic transmission soft x-ray microscopy (MTXM) [4]. We found that the meron-antimeron pair is easily annihilated during its field-driven motion while the bimeron stays stable. We experimentally demonstrated that the non-trivial topology guarantees higher stability of the meron pair.

Keywords:

Meron pair, Magnetic vortex, Magnetic antivortex, X-ray imaging, Topological structure

Electronic and Magnetic Properties of Epitaxial 2D Layers

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Abstract:

Two-dimensional transition metal chalcogenides (TMC) draw much attention, because of its fascinating optical, electronic, and magnetic properties. However, intrinsic electronic band structure and ferromagnetic properties are unveiled for limited number of ultrathin TMC materials. So, it is desired to study band structure of single-crystalline films and to discover room temperature ferromagnets among TMC compounds for future electronics development.

In this study, we present our recent studies of TMC series, such as metallic ferromagnet Cr₂Te₃[1] and correlated metal VSe₂[2]. We successfully synthesized epitaxial thin films with monolayer to few layer thicknesses by using molecular beam epitaxy (MBE). Then, we analyzed intrinsic electronic and magnetic properties of the ultrathin epitaxial films by using angle-resolved photoemission spectroscopy (ARPES) and x-ray magnetic circular dichroism (XMCD). Our results unambiguously reveal the intrinsic electronic and magnetic properties, useful for potential electronic, magnetic, and electrochemical applications.

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1. **ACS Applied Nano Materials** 4, 4810 (2021) & in-preparation

2. **Nano Letters** 18, 5432 (2018), **Nanoscale** 11, 20096 (2019), **Nano Letters** 21, 1968 (2021), **Nanotechnology** 32, 364002 (2021), **ACS Nano** 15, 7756 (2021)

Keywords:

transition metal chalcogenides, molecular beam epitaxy, ferromagnet, ARPES, XMCD

Ultrafast dynamics studies investigated at Pohang Accelerator Laboratory X-ray Free Electron Laser

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Abstract:

An X-ray free electron laser (XFEL) delivers brilliant, transversely coherent, and extremely short pulses is a powerful tool for carrying out ultrafast study in many disciplines including physics, chemistry, biology, material, and etc. However, realizing its full potential usually is difficult without characterization, control, and data processing because XFEL pulses exhibit stochastic fluctuations in all physical attributes of the beam since it originates from the shot noise in the electron bunch during the self-amplified spontaneous emission (SASE) process. Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL-XFEL) provides optimized experimental conditions for optical laser pump and XFEL probe experiment with remarkably stable XFEL pulses which has world recording minimal temporal jitters. I will introduce the recent progress of research regarding ultrafast dynamics performed at PAL-XFEL.

Keywords:

XFEL, ultrafast dynamics, pump-probe

Study of strongly correlated Vanadium dioxide thin films using synchrotron radiation

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Abstract:

Vanadium dioxide (VO₂) is one kind of desired thermochromic material for many smart devices because of its notable temperature-responsive infrared modulation and metal–insulator transition with underlying structural phase transition. VO₂ involves remarkably complex physics due to the strong electron correlations, and it cannot be understood within the conventional theories of metals and insulators. In VO₂, the fundamental understanding of the phase transition and the desired modulation of phase transition is the central issue for most of the research studies. We prepared VO₂ thin films and studied their phase transition mainly using synchrotron radiation. The phase transition of VO₂ thin films was examined by performing the temperature dependent X-ray diffraction measurements and X-ray absorption spectroscopy measurements.

Keywords:

VO₂, structural phase transition, X-ray diffraction, X-ray absorption Spectroscopy

Ambient Pressure X-ray Photoelectron Spectroscopy (AP-XPS) of Strontium Titanium Oxysulfide

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Abstract:

Oxysulfide photocatalyst is of great interest for water splitting and hydrogen production applications due to its tunability of bandgap from ultraviolet to visible-light region and high reactivity for redox reaction [1,2]. Understanding the interaction between oxysulfide surface and water is essential to enhance catalytic performance. However, fundamental understanding during catalytic reactions at the interface have not been remained in its infancy yet. Ambient pressure X-ray photoemission spectroscopy (AP-XPS) is useful to investigate chemical bonding characteristics of the solid surfaces exposed with various gas environments, such as water (H₂O), up to a few millibar pressure [3]. Here, we examined surface bonding characteristics of both SrTiO₃ (STO) and sulfur-doped SrTiO₃ (STO-S) in H₂O gas environment using the AP-XPS. We revealed that surface oxygen states (O²⁻) is a dominant constituent at STO-S surface when H₂O gas is adsorbed on the surface. Our results suggest that the active surface states are largely enhanced in the STO-S compared to the STO and propose potential application of STO-S for the photocatalytic applications. (NRF-2019K1A3A7A09033389, NRF-2020R1A2C200373211, This work is financially supported by Korea Ministry of Land, Infrastructure and Transport(MOLIT) as [Innovative Talent Education Program for Smart City].)

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[2] Q. Wang *et al.*, Oxysulfide photocatalyst for visible-light-driven overall water splitting, *Nat. Mater.* **18** (2019) 827–832.

[3] N. Domingo *et al.*, Water adsorption, dissociation and oxidation on SrTiO₃ and ferroelectric surfaces revealed by ambient pressure X-ray photoelectron spectroscopy, *Phys. Chem. Chem. Phys.* **21** (2019) 4920–4930.

Keywords:

AP-XPS, Strontium Titanium Oxysulfide

High energy-resolution tunneling spectroscopy of Andreev bound state in graphene Josephson junction

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Abstract:

A Josephson junction consists of two superconductors separated by a non-superconducting material. Josephson junctions allow the supercurrent by forming Andreev bound states (ABSs) of electron- and hole-like quasiparticles, which are correlated by Andreev reflections [1]. As ABS determines microscopic behavior of Josephson junctions, it is important to understand its energy spectrum. However, the quantitative analysis has been limited by the low energy-resolutions of tunneling spectroscopy [1, 2]. Moreover most of studies have been focused in the short junction regimes [3]. Here, we report the direct observations of ABSs in both short and long junction regimes using newly developed superconducting tunneling spectroscopy of energy resolution of around 20 μeV . We fabricated graphene Josephson junctions using aluminum and molybdenum rhenium together with superconducting tunnel probes at the edge of the graphene and performed the tunneling spectroscopy on ABS with varying superconducting phase. Our study provides fundamental understanding of how the Josephson coupling forms through the graphene. This study can be extended to topological materials, studying for Majorana zero modes [4-6].

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Keywords:

Andreev bound states, Josephson Junction, Superconducting Tunnelling spectroscopy

Electromechanical frequency combs in a superconducting electromechanical device

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Abstract:

Superconducting electromechanical devices exhibit diverse optomechanical phenomena originating from the interaction of microwave photons and mechanical phonons. In this talk, we discuss the generation of frequency combs and their dynamics in a niobium-based superconducting electromechanical device. Our device consists of a superconducting LC resonator and a free-standing, circular nanomechanical resonator. Their fundamental resonant frequencies are 3.78 GHz and 8 MHz respectively. A dispersive electromechanical coupling between the two resonant modes is realized, as the mechanical resonator forming the vacuum-gap capacitor in the LC circuit shifts the microwave resonant frequency as its motion is electrically induced. When we drive the coupled system with a microwave pump above certain threshold powers, we observe that the device starts to emit a train of periodic microwave pulses with a repetition rate equal to the mechanical resonant frequency. This pulse train corresponds to a frequency comb which denotes evenly spaced peaks in the microwave power spectrum with the frequency spacing identical to the mechanical resonant frequency. This comb generation attributes to nonlinear effects of the intracavity field above the threshold powers, inducing electromechanical instability and thus the frequency comb. To investigate their dynamics in detail, we study the formation of frequency combs at various pump frequencies and powers. We find that the experimental results are consistent to our analytical model computed without linear approximations. In addition, we study the behavior of threshold powers at various cavity decay rate by applying external magnetic fields. Most interestingly, we observe that the pump-power thresholds exhibit two local minima at the lowest cavity decay rate; one near the microwave resonant frequency and the other near the sum of the microwave resonant frequency and the mechanical resonant frequency. This electromechanical comb effect we realized in this work could be utilized in sensing and signal processing applications that require facile and precise frequency measurements.

Keywords:

superconducting electromechanical devices, frequency combs

Revised diffusion constant derived from the vertex corrections to the density-density response function

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Abstract:

For isotropic single-band systems, it is well known that in the many-body diagrammatic approach, the diffusion constant is obtained by considering the vertex corrections to the density-density response function in the presence of impurities. In this work, we study the way to correctly consider the vertex corrections using the Ward identities and revise the known expression for the diffusion constant. We also extend this approach to anisotropic multiband systems to obtain the general expression for the vertex corrections and the corresponding diffusion constant. We find that the diffusion constant is characterized by the combination of the transport relaxation time, quasiparticle lifetime and velocities on the Fermi surface. Furthermore, we compare two diffusion constants derived from the density-density response function and the Einstein relation, and demonstrate how the chirality and anisotropy of the system give a discrepancy between them.

Keywords:

vertex correction, Ward identity, diffusion constant, density-density response function

Flat bands with band crossings enforced by symmetry representation

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Abstract:

Flat bands have band crossing points with other dispersive bands in many systems including the canonical flat-band models in the Lieb and kagome lattices. Here we show that some of such band degeneracy points of nondegenerate flat bands are unavoidable because of the symmetry representation (SR) of flat bands under unitary symmetry. We refer to such a band degeneracy point of flat bands as a *SR-enforced band crossing*. SR-enforced band crossing is distinct from the conventional band degeneracy protected by symmetry eigenvalues or topological charges in that its protection requires both specific symmetry representation and band flatness of the flat band, simultaneously. Even n -fold rotation C_n ($n=2,3,4,6$) symmetry, which cannot protect band degeneracy without additional symmetries due to its abelian nature, can protect SR-enforced band crossings in flat-band systems. In two-dimensional flat-band systems with C_n symmetry, when the degeneracy of a SR-enforced band crossing is lifted by a C_n symmetry-preserving perturbation, we obtain a nearly flat Chern band. Our theory not only explains the origin of the band crossing points of FBs existing in various models, but also gives a strict no-go theorem for isolated FBs in a given lattice arising from the SR.

Keywords:

Flat band, Band structure, Symmetry, Topology, Semimetal

Non-linear conductivity as a probe for anyonic statistics in quantum Hall states

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Abstract:

Recent experimental developments allow one to investigate novel responses of quantum matter. Here we investigate the non-linear conductivity of both the Abelian and non-Abelian fractional quantum Hall effects, where the monodromy phases between the anyons manifests. Based on this, we propose to diagnose unambiguously the nature of the non-Abelian 5/2 quantum Hall states.

Keywords:

Non-Linear Response, Topological Insulator, Quantum Hall Effect

Kinetic orbital mechanism of spin-momentum coupling

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Abstract:

A microscopic mechanism of spin momentum coupling (SMC) is a long standing problem, despite its importance in modern spin physics. Although SMC may be qualitatively described as the Zeeman coupling between electron spin and an effective magnetic field under surface electric field, this description is far from being quantitatively satisfactory since the coupling by this description is far smaller (by factor 10^{-6}) than real coupling strengths. Recently, orbital angular momentum (OAM) has been proposed as an essential ingredient to induce the giant SMC, and kinetic energy at corrugated structure has been reported to generate large scale OAM. The mechanism based on the large OAM from the kinetic energy, or the *kinetic orbital mechanism*, provides a reasonably quantitative explanation of giant Rashba-type SMC in some corrugated surface systems, but this mechanism has been considered only for a few surface systems. Here, we demonstrate that the kinetic orbital mechanism can explain the Rashba SMC in representative surface and bulk Rashba systems, such as Bi/Ag(111), Au(111) and BiTeI. We also generalize this mechanism to explain the Dresselhaus-type SMC of GaAs thin film.

Keywords:

Rashba effect, Interface, Spin-orbit coupling, Orbital angular momentum

Electronic transport in conducting networks with decoherence

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Abstract:

Coherent, non-interacting electronic conduction in low-dimensional systems is well described by the Landauer-Buttiker formula. However, in real specimens, decoherence due to external environment is unavoidable. Here, we propose a new formalism for the transport with decoherence based on the discrete time-evolution of a density matrix. We demonstrate applications of our formalism to the 1D and 2D networks including twisted bilayer graphene, crossover from disorder-driven Anderson localization to classical diffusive metals, and the Chalker-Coddington model. We also discuss the hidden link between our formalism and the random quantum walk problem.

Keywords:

Network, Decoherence

Non-divergent chiral charge pumping in Weyl Semimetal

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Abstract:

Chiral anomaly is one of the crucial features that make transport in Weyl semimetal (WSM) distinctive to other conventional materials. Characteristic transport properties of WSMs include chiral magnetic effect (CME), negative longitudinal magnetoresistance, nonreciprocal currents in noncentrosymmetric WSM [1], and nonlinear currents in time-reversal-symmetry-broken WSM [2]. Their theoretical analyses adopt various approximations. Unfortunately, the validity of the approximation is not carefully checked. Here, we point out some of higher order terms, commonly ignored in those analyses, are not negligible when Fermi level is close to Weyl nodes, as exemplified by TaAs or $\text{Bi}_{1-x}\text{Sb}_x$. In particular, we show that CME can be non-divergent when such terms are included.

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[2] Shin, D., *et al.*, *Nature Mater* **16**, 1096–1099 (2017)

Keywords:

Weyl semimetal, Chiral anomaly, Chiral charge pumping, Nonlinear current

Magic-Angle Twisted Trilayer Graphene: Ultra-Tunable Platform for Moiré Superconductivity

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Abstract:

Since the discovery of magic-angle twisted bilayer graphene (MATBG), moiré superlattices have become a playground for exploring strongly correlated physics and topologically nontrivial phenomena. Despite the presence of interesting correlated effects in several other moiré systems, superconductivity was reproducibly seen only in MATBG during the first few years. Here, I will talk about the recently discovered magic-angle twisted trilayer graphene (MATTG), which has shown robust superconductivity and correlated states with an additional knob for electric displacement field tunability. By exploring the entire phase space as a function of carrier density, electric and magnetic fields, and temperature, we determine the system's tunable phase boundaries and reveal the intimate connection between the superconducting state and the broken symmetry phase at two carriers per moiré unit cell. The suppression and bounding of superconductivity at the Van Hove singularities is difficult to reconcile with the weak-coupling BCS theory. The system can indeed be tuned to the ultra-strong coupling regime close to the two-dimensional BCS-BEC crossover, where the Ginzburg-Landau coherence length reaches the average inter-particle distance and T_{BKT}/T_F ratios are in excess of 0.1. More strikingly, the Pauli limit is consistently violated by a factor of 2~3 times in all superconducting phases spanning the carrier density axis, and re-entrant superconductivity at large magnetic fields is found in certain regions of the phase space. These findings suggest that the superconductivity in MATTG could be driven by a mechanism that involves non-spin-singlet Cooper pairs. Our system establishes a new generation of moiré platform for investigating correlated states, strong coupling superconductivity, and more, with unprecedented tunability.

Keywords:

Magic Angle Twisted Graphene, Moiré Quantum Matter, Superconductivity, Strongly Correlated Phenomena, Van der Waals Heterostructures

Twist angle controls interlayer exciton dynamics in van der Waals heterostructures

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Abstract:

The electronic properties of van der Waals heterostructures can be drastically modulated by a unique degree of freedom, the twist angle between the monolayers. By precisely controlling the twist angle, the period of moiré superlattice and the nature of interband optical transition are changed. The influence of moiré potential on optical properties, e.g., interlayer excitons in twisted bilayers of transition metal dichalcogenides (TMDs) is not yet fully understood. In this talk, I will discuss how the twist angle controls the recombination dynamics and diffusion properties of interlayer excitons in MoSe₂/WSe₂ twisted-bilayers. Furthermore, I will show that the presence of moiré potential influences on the temporal and spatial dynamics of excitons with different excitonic phases. We gratefully acknowledge funding NSF DMR-1808042 in the United States.

Keywords:

exciton, 2D materials

Emergent quantum phenomena under quantum confinement

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Abstract:

Quantum systems in confined geometries allow novel physical properties that cannot easily be attained in their bulk form. These properties are governed by the changes in the band structure and the lattice symmetry, and most pronounced in their single layer limit. Angle-resolved photoemission spectroscopy (ARPES) is a powerful tool to investigate the underlying changes of band structure to provide essential information for understanding and controlling such properties. In this talk, I will introduce recent studies of quantum phenomena under quantum confinement, combining molecular beam epitaxial (MBE) sample growth with layer-by-layer control of thickness and in-situ ARPES characterization.

Keywords:

Quantum confinement, Angle-resolved photoemission spectroscopy, Molecular beam epitaxy

빛-물질의 상호작용의 양자 기하학적 성질

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Abstract:

The concept of the geometry of quantum states has been useful for characterizing responses of electronic systems to static electromagnetic fields. On the other hand, it has been challenging to relate quantum geometry with resonant optical responses. The main obstacle is that optical transitions are properties of a pair of states, while geometrical properties are usually defined for a single state. In this talk, I will reveal the quantum geometric meaning of resonant optical transitions. This result suggests that light-matter interactions are in general manifestations of the geometry of quantum states. I will take linear, second-order, and third-order responses as examples to demonstrate our theory. I will discuss the implications of this perspective to multi-band physics in quantum materials.

Keywords:

Quantum geometry, optical response, multi-band physics, quantum materials

Pushing the limit of crystal structure prediction with machine learning potential: a first extensive blind test

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Abstract:

Recently advances in materials science are achieved by computational approaches which enable fast and low-cost evaluation of materials properties. However, most computational studies focus on materials that are already reported in the experimental repository such as ICSD. This is because computations of materials properties require crystal structures. Therefore, to discover completely new materials, crystal structure prediction (CSP) of unexplored compositions is in need. Data mining approaches and heuristic methods such as evolutionary algorithm and particle-swarm optimization are used to efficiently navigate the configurational space of inorganic materials. These methods require the evaluation of the free energies of structure candidates that emerge during the algorithms. Density functional theory (DFT) is the most popular method because this enables accurate evaluation of free energies without any experimental parameters. However, its low throughput hinders the extensive exploration of new materials.

In the previous work, we suggested that the machine-learning potential, trained over structures in melt-quench trajectories, can be an adequate surrogate model of DFT for evolutionary CSP [1]. Stepping over the previous achievement, we suggest a program named SPINNER (Structure Prediction of Inorganic crystals using Neural Network potentials with Evolutionary and Random searches) which enables efficient identification of crystal structures [2]. Starting from neural network potential (NNP) trained over disordered structures, we iteratively train NNP by using structures that emerge from the evolutionary runs and also monitor the accuracy of NNP regularly. In a blind test on 60 ternary materials selected from ICSD, we achieved an 80% of accuracy within 5000 generations of evolutionary algorithm. We also benchmark our method on data mining or DFT-based evolutionary algorithms and identify more stable structures in the majority of cases. We believe that this work paves the way for constructing a large database for unexplored inorganic materials.

[1] C. Hong, et al. Phys. Rev. B 102, 224104 (2020).

[2] S. Kang, et al. arXiv:2107.02594

Keywords:

Crystal structure prediction, Machine learning, first-principles calculations

The first-principles study for the electronic structure of GaTa₄Se₈ under high pressure

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Abstract:

The lacunar spinel GaTa₄Se₈ is a molecular Mott insulator known as the first established example of spin-orbital coupled $J_{\text{eff}}=3/2$ Mott insulator [1, 2]. As high pressure is applied, GaTa₄Se₈ exhibits superconductivity near 10 GPa [3, 4] after the insulator-to-metal transition at 5 GPa [5, 6]. With density functional theory (DFT) and dynamical mean field theory (DMFT) calculations, we investigated the electronic structure of GaTa₄Se₈ under pressure. We found that the $J_{\text{eff}}=3/2$ ground state survives from metallization, consistent with the resonant inelastic x-ray scattering (RIXS) experiments [7]. Moreover, a recent study showed the structural transition to the monoclinic symmetry for higher pressure (~25 GPa) [8]. The DFT calculations established the structural transition well and found that the structural transition destructs of not only $J_{\text{eff}}=3/2$ states but the molecular orbital scheme at the cubic structure.

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[2] M. Y. Jeong et al. Nat. Commun. 8, 782 (2017)

[3] M.M. Abd-Elmeguid et al. PRL 93, 126403 (2004)

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[6] A. Camjayi et al. PRL 113, 086404 (2014)

[7] M. Y. Jeong et al. PRB 103, L08112 (2021)

[8] H. Deng et al. J. Phys. Chem. Lett. 12, 5601 (2021)

Keywords:

spin-orbit coupling, Lacunar spinel, insulator-to-metal transition, $J_{\text{eff}}=3/2$

Berry curvature and topology induced by a controlled generation of phonon in graphene.

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Abstract:

Pseudospin, an additional degree of freedom of graphene caused by sublattice sites, brings exotic physics to graphene. However, studies for the role of the pseudospin rotation in the electron-phonon scattering process are still absent and have not been considered relating to the Berry curvature. Here, using the circular dichroism in time- and angle-resolved photoemission spectroscopy and an electron-phonon interaction Hamiltonian reflecting pseudospin symmetry with tight-binding Hamiltonian, we show that the interaction induces Berry curvatures on the scattered electrons and their net Berry curvature does not vanish when the pseudospin rotation occurs. Finally, we deduce that the motion of displacement of a phonon inducing pseudospin rotation is elliptic and the direction of the orbital magnetization induced by the phonon lives in the y-z plane based on the results of dichroic photoemission spectroscopy.

Keywords:

Graphene, Electron-phonon coupling, Pseudospin rotation, Berry curvature

Extending the coherence of spin qubits in hexagonal boron nitride by materials engineering

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Abstract:

A negatively charged boron vacancy (V_B^-) in hexagonal boron nitride (h-BN) has recently emerged as a new promising spin qubit candidate in 2-dimensional materials hosts for solid-state quantum applications. Their spin coherence time (T_2), however, was shown to be very short (a few microseconds), which is mainly due to their interaction to the inherent dense nuclear spin bath of the h-BN host. In this study, we theoretically propose ways to enhance the quantum coherence of the V_B^- spin in h-BN by using isotopic and strain engineering. We combine density functional theory and cluster correlation expansion to compute the decoherence of V_B^- spins induced by the dense nuclear spin bath of h-BN. We show that inhomogeneous strain can create spatially varying nuclear quadrupole interaction in h-BN, which can significantly suppress the nuclear spin flip-flop dynamics in the bath. Our results provide not only a fundamental understanding of the decoherence of V_B^- spins in h-BN, but pave the way to engineer their T_2 time, which is crucial for their practical applications.

Keywords:

Spin coherence time, Cluster correlation expansion, hexagonal boron nitride, Spin qubits, Quantum computing, Quantum sensing

Effect of oxygen vacancy on Li-ion diffusion in the Perovskite-Type Solid Electrolyte

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Abstract:

Solid electrolytes with a fast ion conduction are crucial for all-solid batteries. The perovskite-type lithium lanthanum titanate (LLTO) solid electrolytes have been known as one of promising next-generation lithium-ion batteries because they provide high-energy density and superior cyclic stability. However, in spite of these advantages, their practical application is plagued by low ionic conductivity at room temperature.

Here, using the first-principles density functional theory calculations, we report that the oxygen vacancies significantly expand the crystal lattice of LLTO solid electrolyte normal to the lithium migration path, resulting in two order of magnitude enhancement in ionic conductivity. Relevant structure reconstructions and underlying mechanism will be discussed in detail at the atomic scale.

Keywords:

Perovskite-Type Solid Electrolyte, Li ion diffusion

Molecular dynamics study of nano-scale ultrafast nonequilibrium phenomena

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Abstract:

We describe two-temperature molecular dynamics (TTMD) simulation method developed to study evolution of the electronic and lattice systems under femto-second laser irradiation. In the TTMD simulations, the electrons are selectively excited by absorbing energy from the ultrafast laser, which is then transferred to ions via electron-phonon coupling. Specifically, we investigated the ultrafast nonequilibrium phenomena occurring in gold and bismuth nanoparticles that agreed well with the experimental results. In a spherical gold nanoparticle system, surface plasmon excitation led to anisotropic melting and void formation. The bismuth nanoparticle displayed unusual faceting which may be explained in terms of system's free energy. The results together demonstrate the effectiveness of the TTMD in simulating and interpreting femto-second laser-driven ultrafast phenomena.

Keywords:

Ultrafast phenomena, Melting, Molecular dynamics, Nonequilibrium

First-principles calculation of the non-equilibrium quasi-Fermi levels in WSe₂ p-n junctions

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Abstract:

While the two-dimensional (2D) *p-n* junctions have been extensively studied for electronic and optoelectronic devices, the semiclassical approaches without considering atomistic details are still insufficient to describe its electronic structures, such as long depletion width and band edge profiles. To overcome such limitations, we combine the multi-space constrained-search density functional theory (MS-DFT) formalism [1] together with the simulated doping method [2] for describing the doped *p-n* junction under finite-bias conditions. Then, by calculating the lateral WSe₂ *p-n* junctions, we find that the depletion width calculated within the first-principles approach is several times longer than that of the analytic expressions, which affects the current-voltage characteristics in the 2D *p-n* junctions. Thanks to the MS-DFT that uniquely allows plotting quasi-Fermi levels (QFLs) profiles within the first-principles calculation [1], we also extract the QFLs profiles from the lateral WSe₂ *p-n* junctions under finite-bias conditions and show that the QFLs profiles gradually expand into the depletion region with increasing forward bias voltage. Our findings highlight the importance of the first-principles approaches for 2D *p-n* junction devices in terms of the design of next-generation 2D *p-n* junction devices.

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[2] O. Sinai and L. Kronik, Phys. Rev. B **87**, 235305 (2013).

Keywords:

nonequilibrium first-principles calculations, p-n junctions, quasi-Fermi levels, two-dimensional lateral junctions, simulated doping

Study of Charge transfer SERS by using InSe and GaSe

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Abstract:

Surface Enhanced Raman Spectroscopy (SERS) is a technique overcomes an inherently low sensitivity of Raman scattering by adsorbing molecules on metal or semiconductor substrates. There are two mechanisms in SERS, one is electromagnetic (EM) enhancement and the other is charge transfer (CT) enhancement. EM enhancement is the result of Localized Surface Plasmon Resonance (LSPR). CT enhancement is the result of charge transfer between a substrate and the adsorbate molecules caused by the light whose energy matches the energy difference between a substrate and the adsorbate molecules. By using the semiconductor as a substrate, we can study CT mechanism by excluding EM mechanism. We used InSe and GaSe that can be applied into electronic and photoelectric devices as substrate materials for SERS. We used lasers with 4 different wavelengths to observe the SERS effects between Rhodamine-6G (R6G) molecules and mechanically exfoliated InSe and GaSe. Despite of the similarity of structure of the substrate, the tendency of SERS enhancement is quite different depending on the excitation wavelength from which we can effectively study the importance of energy of incident light to enhance the charge transfer SERS.

Keywords:

SERS, Raman spectroscopy, Charge transfer, InSe, GaSe

Effective Work-function Tuning in Metal/SiO₂/Si Junction Achieved with Graphene Interlayer at Metal/SiO₂ Interface

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Abstract:

The work function of a metal electrode is one of the important factors determining the threshold voltage of metal/oxide/semiconductor (MOS) junction. Here, we report that the effective work function of Al electrode increases from 3.31 to 4.35 eV when a graphene interlayer is inserted at the Al/SiO₂ interface, which is confirmed from the capacitance-voltage (C-V) measurements. The graphene interlayer is p-type doped due to the oxygen dangling bonds on the surface of SiO₂ gate insulator, noticed from the transfer curve (drain-to-source current vs. gate voltage, $I_{DS}-V_G$) of graphene field-effect transistor (GFET). With the device parameters extracted from the measured C-V and $I_{DS}-V_G$ characteristics, we also performed the electrostatic analysis by solving Poisson equation for the flat-band junction. The electric dipole layer formed between Al electrode and graphene layer due to the electron orbital overlapping (interaction dipole layer) is found to induce the large effective work-function increase of Al electrode. In order to explain the effective work-function increase, the negative side of this interaction dipole layer should be toward the graphene layer so that the electron potential increases across the interface, going from Al electrode to graphene layer. The electrostatic effect of the interaction dipole layer is also observed with Pt electrode. This time, the effective work-function is measured to decrease from 4.85 to 4.68 eV, implying that the positive side of dipole layer is toward the graphene layer. Thanks to the large effective work-function tuning (1.04 eV) comparable to the Si band gap (1.12 eV) with the graphene interlayer, Al can be a proper metal for realizing the dual-gate operation of n-channel and p-channel MOSFETs.

Keywords:

MOS Junction, Effective Work-function, Graphene Interlayer, Interaction Dipole Layer

그래핀/그래핀 산화물 접합 소자에서의 전자기적 특성 연구

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Abstract:

지난 10년 동안, 그래핀 연구는 높은 유연성, 높은 열전도율, 높은 전자 이동성, 긴 스핀 확산 길이와 같은 경이적인 물리적, 전자기적 특성 때문에 굉장히 많이 이용되었다. 특히 그래핀의 긴 스핀 수명과 스핀 확산 길이를 이용한 연구는 스핀트로닉스에 적용하기 위해 광범위하게 조사되었다. 그러나 스핀트로닉 소자의 경우 그래핀의 낮은 스핀 주입 효율성(~1%)이 실현에 걸림돌이 되고 있다. 최근에는 절연체 산화막을 사용하거나, 강자성 전극과 그래핀 사이에 니켈(111)와 같은 그래핀의 육각 격자 상수가 유사한 물질을 사용하여 이 문제를 극복하는 연구가 보고되고 있다.[1] 또한 그래핀에 인접한 자기 절연체에 의해 유도되는 자기 교환장(MEF)은 소재의 구조적 특성을 변조하지 않고도 2D 장치의 국소 스핀 생성과 스핀 변조를 효과적으로 제어할 수 있는 것으로 알려져 있다.[2]

본 연구에서는 자외선(UV) 빛을 직접 조사하는 산화 방법에 의해 GO가 형성된 Graphene (G) / Graphene oxide (GO) 접합 소자를 제작하였다. 그래핀 표면의 오염을 최소화하면서 제조 장치의 공정을 쉽게 할 수 있는 넓은 면적의 GO를 가공하는 지름길 중 하나는 자외선에 의해 유도된 오존을 사용하는 것이다.[3] 우리는 이 G/GO 접합 소자에 외부 자기장을 인가했을 때 GO에 인접한 그래핀의 근접 효과를 연구하였다. 또한 Weak localization과 슈비니코프-데 하스 진동이 화학 기상 증착법(CVD)에 의해 성장한 자연 그대로의 그래핀보다 더 크다는 것을 보여주었다. 그리고 G/GO 접합 소자에서 저온에서 음의 MR을 나타내는 자기저항(MR)을 측정했다. 우리는 GO의 강자성 특성이 그래핀의 스핀-궤도 결합을 개선하고 이 접합 구조를 채널층으로 사용함으로써 스핀트로닉 소자로의 응용에 도움을 줄 것으로 기대한다.

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Keywords:

graphene, graphene oxide, heterostructure, Proximity Effect

Interfacial Electron States in Atomic-Layer-Deposited Al₂O₃/TiO₂ 2-dimensional Electron System Probed by Near-Total-Reflection Hard X-ray Photoelectron Spectroscopy

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Abstract:

The interfacial electronic structure in atomic-layer-deposited (ALD) Al₂O₃/TiO₂ thin films heterostructure, was investigated by hard X-ray photoelectron spectroscopy (HAXPES) under a near-total-reflection (NTR) regime. The evolutions of the photoemission intensities upon the incidence angle for each element's core level were analyzed in detail manifesting the layered sample structures. Also the emerging electronic structure near the Fermi level was clearly identified as it originates from the interface between Al₂O₃ and TiO₂ layers, suggesting a 2-dimensional electron gas (2DEG) states in the mass-production-compatible binary oxides heterostructure. The supports from Jean-Pascal Rueff and Masato Yoshimura for the synchrotron HAXPES are greatly acknowledged.

Keywords:

Hard X-ray photoelectron spectroscopy, TiO₂, 2-dimensional electron gas

Spin-Orbit Interaction and Magnetoresistance in Graphene-based Heterostructures

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Abstract:

In this work, we report the effects of Co ($x = 0.05$ -2.5 nm) insertion on graphene/Pt heterostructures. Co and Pt were deposited using the Ultra-High-Vacuum (UHV)-Molecular Beam Epitaxy (MBE) technique on top of the large-scale CVD-grown graphene films. The spin transport modulation of Co-dusting effects was investigated using Pt Hall bar devices provided beyond Si/SiO₂/graphene/Co heterostructures using *in-situ* shadow mask patterning technique. A comparative study of spin transport was carried out for the Si/SiO₂/graphene/Pt hetero devices with and without 25-Å-thick Co layer. The perpendicular magnetoresistance (MR) results clearly showed that the co-existence of weak localization (WL) as well as weak antilocalization (WAL) effects for the device for less than 2-Å-thick Co film. In addition, we observed the enhanced spin-orbit coupling effect at 77K as the Co thickness decreases down to 0.5 Å at the large applied perpendicular magnetic field.

Theoretical analysis was performed to understand the Co interlayer effects at the graphene/Pt interface. To extract the number of transport channels α and β at the small and large magnetic field, the phase coherent length (l_ϕ) and the elastic scattering length (l_ξ) from the MR curves, the modified Hikami-Larkin-Nagaoka (HLN) equation was utilized [1]. Our results highlight the aspect of interface engineering of 2-D materials with other ferromagnetic materials to develop highly effective spintronic devices with new functionalities for practical applications.

Reference:

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Keywords:

Localization effect, quantum interference, Graphene films, Two-dimensional materials

On-demand fabrication of Si nano/microstructures by tip-based lithography in conjunction with metal-assisted chemical etching

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Abstract:

Methods for on-demand fabrication of silicon (Si) nano/microstructures with a 100 nm resolution were developed using scanning probe lithography (SPL) in conjunction with metal-assisted chemical etching (MACE). In detail, protruding Si structures, including Si nanowires of over 10 μm in length and atypical shaped Si nano/micropillars, were obtained via the MACE of a patterned gold film (negative tone) on Si substrates by nanoshaving alkanethiol self-assembled monolayers (SAMs). Furthermore, recessed Si structures with arbitrary patterning and channels less than 160 nm wide and hundreds of nanometers in depth were obtained via the MACE of a patterned gold film (positive tone) on Si substrates by alkanethiol DPN. In particular, mass production of arbitrarily shaped Si microparticles with submicron resolution is developed using silicon-on-insulator substrates.

Compared to other state-of-the-art lithographies, the resolution, throughput, and design capability with a high degree of freedom in the vertical direction of the reported nano-/microfabrication method should be improved to be utilized in high-value applications. However, we believe that this fab-free process via tip-based lithography is useful for numerous applications utilizing Si nano-/micromaterials because of its convenient processing conditions, inexpensive processing cost, pattern-design capability, and mass production capability, in addition to its resolution in the hundreds of nanometers.

Keywords:

silicon nano/microstructure, scanning probe lithography, metal-assisted chemical etching, tip-based lithography

Fabrication of Nanopores on the various membranes with SiN, SiO₂, and Au membranes

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Abstract:

Melting and evaporation of the metallic film would depend on the temperature rise on the spot and the thermal energy transfer rate into the environmental atmosphere. For drilling of the metallic membrane using focused electron beam current, the rapid temperature rise above the vaporization or sublimation temperature as in the thermal spike model in the nanoscale region is critical, hence, it is important to have a stabilized focused electron beam on the nanometer size spot of ~ 1 nm over a few micro-seconds to achieve the local high temperature greater than sublimation temperature of the materials enough for the atoms to be vaporized. We reported previously drilling nanometre size holes on the various substrates including SiO₂, SiN, and Au films using focused electron beam at 200 keV. Our studies via electron beam-induced atomic diffusion techniques present the controllable Au nanopores with diameters ranging from ~ 100 nm down to a few nanometers. In these recent reports, our experimental investigation have found that for Au atom diffusion to form the nanopore, the electron current density of 10^6 /[(nm²) sec], however, for drilling the gold nanometer thick film, the electron current density with 10^9 / [(nm²)sec] is required. Fabrication processes of gold nanoholes on the 60 nm thick Au membrane will be presented; Test drilling on the microfabricated pyramidal membranes and the flat membranes with 20 nm thick SiO₂ or SiN by using a focused electron beam technique was carried out. Then, we have performed drilling on the Au films, resulted in the nanometer size elliptical voids with its size (less than 1 nm wide and 5 nm long) on the 60 nm thick Au film.

This work was supported by the research funding programs (Development of Biofriendly Optical Nanopore, 2018R1D1A1B07050106) under the Basic Science Research Program through the National Research Foundation (NRF), South Korea.

Keywords:

nanopore, Au, SiO₂, focused electron beam drilling, SiN, Thermal spike model

유기반도체 1차원 결정을 이용한 자외선 검출의 시각화

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Abstract:

전기 및 광특성이 우수하여 유기발광다이오드 (Organic light-emitting diode ;OLED)의 핵심소재인 대표적인 유기 단분자 tris-(8-hydroxyquinoline) aluminum (Alq3)를 사용하여 우리 눈에 보이지 않는 자외선 영역의 빛을 검출하고 광발광 (photoluminescence; PL) 특성을 활용하여 시각화하였다. Alq3는 자외선 영역의 흡수를 보이고, 녹색영역의 발광특성을 보여 Stokes 천이가 커서 자외선 시각화에 최적의 물질이다. 음이온 계면활성제가 분산된 물을 이용하여 자기조립 방법 (self-assembly method) 으로 육각기둥 모양의 1차원 Alq3 결정을 성장시키고, 광발광 효율을 극대화하였다. Polydimethylsiloxane (PDMS) 용액을 이용하여 Alq3 결정과 하이브리드 필름을 제작하여 자외선 세기에 따른 광발광 특성을 공초점 현미경을 통하여 관찰하였고, 태양광 빛 중 지표에 도달하는 미세한 자외선 빛의 세기에도 시각화가 가능함을 확인하였다. 마지막으로 셔츠 같은 구부러지기 쉬운 옷에 프린팅하여 시각화 함으로써 유연하거나 복잡한 물질에 부착하여 자외선 빛을 시각화 할 수 있음을 확인하였다.

Keywords:

Alq3, 하이브리드, 자외선 검출

Ab initio-based scanning Seebeck microscope simulation of moiré superlattice in 1H-MoS₂ on graphene

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Abstract:

Thermally driven charge transport has been proposed as a new microscopy method, so-called Scanning Thermoelectric Microscope (SThM), which makes it possible to measure not only the local level of conductance at the surface but also the charge carrier type. This microscope measures atomic-scale coherent voltage at the interface, determined by the coherent Seebeck coefficient from electrons and effective temperature drop by vertical phonon transport. The intriguing property of the Seebeck coefficient, defined as the normalized energy derivative of a density of states (DOS), has no dependence on the magnitude of DOS itself. Here, we will demonstrate the effective detection of weak van der Waals interactions present in moiré superlattice based on coherent Seebeck coefficient. The thready interaction between the π^* of graphene and the unoccupied d_{xz} , d_{yz} orbitals of Mo is observed by coherent Seebeck coefficient, suggesting that it could be a promising method for exploring the various systems with subtle electronic structure changes.

Keywords:

Thermoelectric, Seebeck effect, Scanning Thermoelectric Microscope, moiré structure

Modulating ferromagnetic insulating state in LaCoO₃ epitaxial thin films using surface orientation control

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Abstract:

The surface orientation of perovskite oxide thin films is an efficient tuning parameter of the correlated electronic structure and resultant electromagnetic properties. For example, the magnetic ground state including, thermoelectric property, and electrocatalytic reaction of SrRuO₃ thin film can be modulated as the surface orientation changes [1]. In La_{0.7}Sr_{0.3}MnO₃, it has been found that (110) and (111)-oriented La_{0.7}Sr_{0.3}MnO₃ on SrTiO₃ thin films exhibit larger spin moment values than that of (001)-oriented La_{0.7}Sr_{0.3}MnO₃ thin films, since the more bulklike interface in (110) and (111)-oriented thin films can partially relieve strain to recover spin moment as a bulk state with increasing thickness [2]. Perovskite LaCoO₃, with an emergent robust ferromagnetic insulating state in epitaxially strained thin film, would also offer an opportunity of surface orientation modulated electromagnetic ground state. More specifically, the strong coupling between the spin and lattice degrees of freedom enables the ferromagnetic properties of LaCoO₃ epitaxial thin film to be modulated via fine changes in lattice distortion. In this study, we demonstrate that the spin-state of LaCoO₃ thin films changes with the modification in the crystallographic orientation of LaCoO₃ thin films, facilitating a tunable ferromagnetic state. We fabricated LaCoO₃ epitaxial thin films on SrTiO₃ substrates with (001), (110), and (111) surface orientations. We obtained the enhancement of ferromagnetic properties with increase unit cell volume (decrease absolute value of out-of-plane stress) in the LaCoO₃ thin films. The smaller Co t_{2g} to e_g transition energy together with the larger spectral weight in Co t_{2g} to e_g electronic transition are accompanied to increment of ferromagnetic properties via control of surface orientation of LaCoO₃ thin films. Our study comprehensively provides the facile tunability of Co spin state and electronic transition of Co orbital, leading to better understanding of the ferromagnetic properties in LaCoO₃ thin film systems.

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Keywords:

LaCoO₃, Ferromagnetism, Surface orientation, Electronic structure, Pulsed laser epitaxy

Extremely large magnetoresistance in NbSb₂ and the effect of magnetic impurity

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Abstract:

Magnetoresistance (MR) in condensed matter systems has been intensively studied for both the fundamental understanding of magnetic responses and potential devices. Recently, the extremely large magnetoresistances (XMR) at low temperatures in Dirac materials have been reported and investigated. Various origins for the XMR have been suggested, but some ambiguity still exists [1,2,3]. For example, ultra-high mobility in Dirac semimetal is regarded as one of the origins of the XMR, but the backscattering suppression mechanism for such ultra-high mobility remains unclear [2]. Here, we report the XMR in massive Dirac semimetal NbSb₂. The XMR reaches 1,270,000% at 2 K and 7 T, which is, to our best knowledge, the largest reported value with a similar temperature and field range. The electron-hole compensation and ultra-high mobility ($\sim 18 \text{ m}^2/\text{Vs}$) give rise to the XMR. We compare the relaxation time from the transport measurement (MR and Hall measurement) t_{tr} and the relaxation time from the magnetic quantum oscillations t_{q} and recognize that t_{tr} is much larger than t_{q} such that $t_{\text{tr}}/t_{\text{q}} \sim 5.24$ implying suppression of backscattering. We dope magnetic and non-magnetic elements to NbSb₂ and study its effect on the transport and the magnetic quantum oscillations to give a clue to verify the origin of backscattering suppression.

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Keywords:

Dirac semimetal, Magnetoresistance, Magnetic quantum oscillation, Backscattering suppression

Optical detection of static and time-resolved magnetization vectors driven by spin Hall effect

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Abstract:

The spin generation mechanism driven by electrical current in nonmagnetic metals has been extensively studied. To measure the effects, electronics-based techniques have been widely used with ferromagnetic metal (FM) film layer to observe spin-orbit torque analysis, e.g. anomalous Hall measurement, planar Hall effect, and so on. However, it is hard to specify the physical origin of the spin-torque due to introduced other effects, e.g. Rashba interface states, anomalous spin-orbit torque in FM, and so on. Moreover, electronic measurement techniques usually detect static motion of the magnetization vector of the FM film and is difficult to see its detailed dynamic motion. Here, we introduce a measurement methodology for characterizing the spin polarization and spin-orbit torque effects in FM layers. At first, we observed magnetization vectors of a heavy metal(HM), Pt, without FM layer using magneto-optical Kerr effect (MOKE) with electric current. Second, we monitored the precessional motion of the magnetization vector of HM/FM heterostructure by utilizing time-resolved MOKE using femtosecond laser. We argue that this technique can pave the way of studying the current-driven spin-polarization and spin-orbit torque phenomena in static and time-domain regime.

Keywords:

spin Hall effect, Magneto-optical Kerr effect, spintronics, spin-orbit torque

X-ray-induced spin state trapping effects in Fe(II)-organics spin-crossover system probed by X-ray absorption spectroscopy

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Abstract:

Fe-organics-based spin-crossover (SCO) complexes exhibit a spin-state switching phenomenon subject to a variety of perturbations such as temperature, pressure, or forms of the specimen. We investigated the spin states and the vibrational modes in the Fe(pyridine)₂[M(CN)₄] (M=Pd or Pt) molecular complex using X-ray absorption spectroscopy (XAS). The results show that Fe L-edge (soft) XAS spectra show a systematic low spin (S=0) to high spin (S=2) transition even at low temperature as the time of x-ray exposure increases, as is so-called soft x-ray induced excited spin state trapping (SOXIESST). The SOXIESST effects were dependent on the time of x-ray exposure, photon flux, as well as the metal-ligand. The details of the SOXIESST were scrutinized by quantitative analyses on the time-dependent evolution in the HS/LS ratios and by adding Au mesh supports. This suggests that certain charge accumulation effects rather than the temperature itself or structural play the major role for the SOXIESST. We are indebted to Kosuke Kitase and Takafumi Kitazawa in Toho University (Japan) for providing us the Fe-organics powder samples.

Keywords:

Fe-organics complexes , spin-crossover, X-ray absorption spectroscopy, soft x-ray induced excited spin state trapping

Tailoring the interfacial band offset by the molecular dipole orientation for a molecular heterojunction selector

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Abstract:

Molecular functional devices have been investigated through the study of molecular structure and its corresponding discrete orbital states since it determines the transport behaviors. [1,2] In contrast to the conventional strategy, we recently demonstrated a novel strategy and design rule for realizing molecular-scale diode features based on the energy band engineering between simple alkanethiol or conjugated molecules and two-dimensional (2D) semiconductors.[3] Likewise, understanding and designing interfacial band alignment in a molecular heterojunction provides a foundation for realizing its desirable electronic functionality. In this study, we implemented the opposite direction of the molecular dipole moment in the molecular heterojunction with 2D semiconductors (1_L -MoS₂ or 1_L -WSe₂). The direction of the band bending of the 2D semiconductors were determined by the molecular dipole moment which could control the rectification direction. Notably, it widely adjusts the degree of the current increase and the nonlinearity of the rectification characteristics that it could be suggests as the tailored molecular-scale heterojunction selector that can prevent sneak current flow in a crossbar array structure. It was significantly affected by the molecular dipole moment direction, type of two-dimensional semiconductor, and metal work function. According to the choice of these heterojunction constituents, the nonlinearity is widely tuned from 1.0×10^1 to 3.6×10^4 for the reading voltage scheme and 1.0×10^1 to 3.6×10^4 for the half-voltage reading scheme, which could be scaled up to an ~482 Gbit crossbar array. In addition, based on understanding the molecular heterojunction system, we develop the study to other various molecular heterojunction devices with 2D semiconductors, such as molecular synapse.

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Keywords:

molecular heterojunction, 2D semiconductor, molecular electronics, molecular dipole moment

Phase separation of P3HT:PCBM organic photovoltaics by different solution stirring temperatures

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Abstract:

Phase separation of donor and acceptor materials in bulk heterojunction organic photovoltaics (OPVs) significantly affects the device performance. When preparing a solution for the fabrication of a light-absorbing layer, the difference in stirring temperature makes the difference in solubility. This results in the changes in phase separation in the solid-state film. Thus, an optimization of the stirring temperature is highly important to achieve efficient devices.

In this study, we investigated the effects of the stirring temperature on OPVs fabricated from poly(3-hexylthiophene-2,5-diyl) (P3HT):[6,6]-phenyl-C₆₁-butyric acid methyl ester (PCBM) solutions. The OPV performance was significantly deteriorated by lowering the stirring temperature. The changes in morphology and crystallinity of P3HT:PCBM films were observed using optical microscopy and X-ray diffraction. To understand the difference in exciton and charge transport mechanisms, we measured photoluminescence spectroscopy, UV-visible spectroscopy, and X-ray photoelectron spectroscopy. As a result, it was revealed that the PCBM aggregation hinders efficient charge transport in OPVs.

Keywords:

Organic photovoltaics, P3HT, PCBM, molecular aggregation

Effect of fluorine–fluorine repulsive coupling on charge transport in cyclopentadithiophene-based donor–acceptor-type conjugated copolymer films

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Abstract:

This study elucidates the effect of fluorine–fluorine interactions on the charge transport properties of semiconductor channels in polymer-based field effect transistors (PFETs) in which both a donor–acceptor (D–A)-type conjugated polymer and a polymer dielectric material contain fluorinated units. The fluorinated units on the benzothiadiazole (BTZ) block of cyclopentadithiophene-*alt*-benzothiadiazole (CDT-BTZ) allow conformation locking via F...S nonbonding interactions, which increases the planarity of cyclopentadithiophene-*alt*-fluoro-2,1,3-benzothiadiazole (CDT-FBTZ). Thus, the CDT-FBTZ copolymer films are highly crystalline and adopt the edge-on orientation, resulting in an eight-fold increase in the field-effect mobility for CDT-FBTZ-based PFETs coated with a poly(methyl methacrylate) (PMMA) dielectric layer compared with PMMA-coated CDT-BTZ-based PFETs. Meanwhile, the field-effect mobility of CDT-BTZ-based PFETs containing a fluorinated dielectric polymer (CYTOP) is double that of PMMA-coated CDT-BTZ-based PFETs. These enhanced electrical properties are attributed to surface polarization doping at the interface between the conjugated polymer and the fluorinated polymer dielectric. However, despite the effect of surface polarization doping, the electrical properties of CDT-FBTZ-based PFETs deteriorate when combined with the fluorinated CYTOP dielectric. Charge transport analyses based on the Gaussian disorder model reveal that, for CDT-based D–A-type conjugated copolymer PFETs, very few localized states in the semiconducting channel of PFET devices in which fluorine–fluorine interaction effects occur at the interface switch to delocalized states as the gate-bias increases. In contrast, the localized charge states in PFET channels without fluorine–fluorine interactions depend strongly on the applied gate-bias and become delocalized upon applying a gate-bias. Thus, it is inferred that the fluorine–fluorine repulsive coupling in D–A-type conjugated copolymers containing fluorinated functional moieties that interface with fluorinated polymer dielectric layers hinders the delocalization of charges induced by the gate-bias, thereby degrading the device performance.

Keywords:

donor–acceptor (D–A)-type conjugated polymer, fluorine–fluorine interactions, charge transport properties, polymer dielectric

Translational control of a specific gene by light-induced liquid-liquid phase separation

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Abstract:

Biological asymmetry originates from differential orchestration of gene expression. One of the ways to introduce cellular asymmetry is precise spatiotemporal control of translation. For example, mRNA localization with regulated translation is known to be essential for long-term plasticity in neurons. However, there lacks a tool which recapitulates this nature's ability to precisely control the translation of a specific gene. Here, we implemented a technique to control translation by light using a recently developed OptoDroplet system. We demonstrate that the OptoDroplet system can be applied to control translation of β -actin mRNA in neurons. Analysis of structural long-term potentiation (s-LTP) of dendritic spines during chemical long-term potentiation (c-LTP) revealed the role of newly synthesized β -actin in sculpting synaptic strengths in neurons.

Keywords:

MODULATION, TRANSLATION, cLTP

Aging Lévy walk with rest model for Arc and β -actin mRNA transport in neurons

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Abstract:

Localization of mRNA in neurons plays a fundamental role for long-term memory formation. Messenger ribonucleoproteins(mRNPs), packages of mRNAs and RNA binding proteins, are transported along cytoskeletons to their target sites by motor proteins. However, the mechanism for how mRNPs find their target location is still not well known. Here, we detected endogenous Arc and β -actin mRNA in living neurons known to be localized to activated synapses with the MS2/PP7 labeling system. Based on the results of the statistical properties of two different mRNA motion, we suggest an aging Lévy walk which has two dynamic phases: the motor-involved ballistic run and static localization as a model for the mRNA movement. This study proposes a theoretical model for the mRNP transport mechanism and provides a quantitative comparison between the model and the experimental data for mRNAs in neurons.

Keywords:

mRNA, transport, MODELING

Soft matter physics of the evolution of multicellularity

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Abstract:

The evolution of multicellularity set the stage for an incredible increase in the diversity and complexity of life on Earth. The increase in biological complexity associated with multicellularity required parallel innovation in the physical properties of multicellular bodies. Though a cursory review of any multicellular organism provides an appreciation of this intertwining of biological and physical complexity, little is known about how such physical properties may have evolved.

The success of multicellular organisms is due in part to their ability to assemble cells into complex, functional arrangements. Extant multicellular organisms do so through a coordinated developmental process involving genetic, chemical, mechanical, and bioelectric feedbacks between interacting cells. However, nascent multicellular organisms lack such developmental processes. Mutations produce changes at the individual cell level, which then have emergent consequences at the group level. For evolution to act on group level traits, they must be heritable, and thus these emergent traits must be reproduced reliably. However, it is unclear how unregulated assembly can reliably result in reproducible multicellular structures, and thus heritable multicellular properties.

We hypothesize that prior to the evolution of genetically-regulated development, physics scaffolds the evolution of multicellularity by initiating simple multicellular development. Through a combination of experimental evolution (which allows us to observe the evolution of multicellularity in the lab, as it occurs), the soft matter tool kit (microscopy, mechanical testing, and more), and numerical methods, we show that physics likely played a fundamental role in the evolution of complex multicellularity.

Keywords:

Multicellularity, evolution, heritability

Dynamic scaling behaviors of active phase separation

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Abstract:

How can a cluster of microscopic particles reliably, swiftly self-organize into target patterns? Embryonic cells during morphogenesis seem to achieve this goal by the combined effects of free energy minimization, individual self-propulsion, and nonequilibrium cell-to-cell interactions, which lead to a more rapid phase separation kinetics compared to the equilibrium counterpart. In this talk, I will first review previous literature about the interplay among these factors, describing how different dynamical regimes of pattern formation manifest themselves through the coarsening exponents. Then we report our investigations of the cellular-automata implementation of the process, focusing on how the excluded volume interactions among the active particles modify the picture.

Keywords:

active matter, phase separation, coarsening, differential adhesion hypothesis, cellular automata

Molecular Switch Triggering Phase Transitions of Microtubules

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Abstract:

Cells are working by well-designed molecular machines for a variety of tasks: to transfer genetic blueprint, to define cell shape and to transport nutrients. In particular, the cellular functions of cell division, intracellular trafficking and maintaining cell shape are attributed to the regulation of assembly/disassembly of tubulins, protein building blocks that are naturally preprogrammed to assemble into hollow cylinder of microtubules (MTs). In this talk, I will introduce my group researches on the molecular switches regulating tubulin-based nano architectures.

Keywords:

3D-induced polar order and topological defects in growing bacterial populations

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Abstract:

Rod-shaped bacteria, such as *Escherichia coli*, commonly live forming mounded colonies. They initially grow two-dimensionally on a surface and finally achieve three-dimensional growth. While a recent study on motile bacteria [1] showed that this switch is promoted by influx of cells toward $+1/2$ topological defects, how cellular alignment plays a role in non-motile cases is largely unknown. Here, we study the role of cellular alignment and especially topological defects in colony formation processes of non-motile *E. coli* populations, investigating cellular transports that are self-organized around defects and characterize the transition from the initial 2D growth to the beginning of the 3D growth. We show that, while initially only $+1/2$ topological defects attract cells and promote the three-dimensional growth, cells gradually flow toward $-1/2$ defects as well, leading to vertical growth around both types of defects. This is in sharp contrast to the known effect of defects in 2D active nematics, which leads cells to move away from $-1/2$ defects as observed in motile cells [1,2]. We reveal that the key is in three-dimensional tilting of cells, which turn out to be prominent around defects and result in the formation of polar order there. We then incorporate effects of this tilting and polar order into the 2D active nematics theory and successfully account for the influx toward $-1/2$ defects. Our work reveals that three-dimensional cell orientations may result in drastic changes in properties of active nematics, especially those of topological defects, which may be characteristic of such non-motile but growing active matter.

This work is a collaboration with Takuro Shimaya. More detailed information can be found in our preprint [3].

[1] K. Copenhagen et al., *Nature Physics* 17, 211 (2020)

[2] K. Kawaguchi, R. Kageyama, and M. Sano, *Nature* 545, 327 (2017); T. B. Saw et al., *Nature* 544, 212 (2017)

[3] T. Shimaya and K. A. Takeuchi, arXiv:2106.10954 .

Keywords:

bacteria, active nematics, topological defect

초등학교 과학 교과서 에너지 영역 단원의 핵심 개념에 대한 설명과 정의 구조 분석

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Abstract:

초등학교 과학 수업에서는 학생 중심 탐구활동을 통하여 과학 사실을 찾고 핵심 개념을 습득하도록 하고 있지만, 과학 개념이나 개념 사이의 관계 등에 관한 내용을 다룬 차시 학습에서는 개념에 대한 설명과 적용 활동 중심의 내용 전개를 하지 않을 수 없다. 그런데 초등학생들은 선수 학습된 개념이나 원리의 수가 작고 논리적 추리를 통한 이해과정에서도 어려움이 많으므로, 과학적인 논리를 온전히 활용하여 과학 사실이나 개념을 설명하는 데 한계가 있다.

이 연구에서는 초등학교 3학년 '자석의 이용' 단원, 4학년 '물체의 무게' 단원, 5학년 '온도와 열' 단원, 6학년 '전기의 작용' 단원에 제시된 핵심 개념들을 설명하기 위하여 과학 교과서에 제시된 탐구활동, 본문 설명 및 기타 자료들의 내용에서 사용한 설명 과정의 구조를 분석하였다. 연구 결과, 초등학교 에너지 영역 단원에서는 관찰과 실험이 제시된 차시에서는 귀납적으로 추리한 일반 서술을 주로 제시했으며, 관찰이나 실험이 없는 차시에서는 명제적 논리에 의한 연역 논리로 개념에 대해 설명하였다. 그러나 '무게', '열의 이동', '전류' 등의 개념을 설명할 때는 선행 관찰된 현상과 명료하게 연결되지 않은 단편적인 사실이나 명제를 제시함으로써 설명을 모호하게 이끌고 있었다. 또, 연역적 논리가긴 하지만 논리 과정이 상당히 복잡하여 초등학생의 수준으로 추론하기 어려운 설명도 일부 포함되기도 하였다. 이어 연구에서는 설명 논리의 유형, 특징, 장단점을 서술하고, 초등학교 과학 교과서에 핵심 개념을 설명할 때의 시사점을 제시하였다.

Keywords:

초등학교, 과학 교과서, 핵심 개념, 설명 과정, 탐구활동

Secondary students' conceptions on motion revealed in their own physics simulation by block coding tools

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Abstract:

The purpose of this study is to investigate the conceptual change of the motion of students while they construct their own simulations of the motion of objects using the block coding method. The subjects of this study were a few male and female students from middle and high school, and although the level of learning or ability to learn physics varies, in general, the understanding of physics concepts is not sufficient. With using the MIT Scratch program, these students were instructed to construct their own simulations using block coding methods for the constant and accelerated motions of an object. As a result, it can be shown that students do not understand the concept of the speed of an object properly, and because of this, various misconceptions about the speed of an object are revealed even in the process of realizing the simple phenomenon of constant motion. This study shows various types of these misconceptions and the changes of concepts about the motion of an object in the process of constructing simulations with block coding tools.

Keywords:

simulation, Scratch, misconception about motion

2015 개정 교육과정 물리학 교과서에 제시된 광전효과 내용 분석 : 새로운 교육과정 개발에 대한 함의를 중심으로

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Abstract:

광전효과는 고전 물리와 현대 물리를 연결짓는 매우 중요한 위치에 있는 개념으로 빛의 본성을 이해하는데 반드시 필요한 중요한 개념이다. 이에 현행 2015 개정교육과정에서는 물리학1, 물리학2에 관련 내용을 모두 편성하여 학생들이 광전효과 개념을 잘 이해하도록 고려하고 있다. 본 연구에서는 현행 고등학교 물리학 교과서에 제시된 광전 효과 내용의 전체적인 구성을 "도입", "광전효과의 발견", "광전효과의 정의", "탐구 활동", "광전효과 현상(실험 결과) 설명", "광전효과 원리 설명", "이전 이론과의 모순", "광전효과의 응용"의 8가지 기준을 설정하여 분석하였고, 이와 함께, 세부적인 내용을 "탐구 활동", "광전효과 현상(실험 결과) 설명", "광전효과 해석"의 3가지 기준으로 살펴보았다. 연구 결과 대체로 물리학1 교과서들은 광전효과의 응용에, 물리학2 교과서들은 광전효과의 현상(실험 결과) 설명에 지면을 많이 할애하고 있었으나, 구체적으로 들여다보면 현행 교과서들이 광전효과에 대해 다루고 있는 서술 방식이 상당히 다양한 편이었다. 하지만 제한된 지면에 필요한 주제를 다루는 과정에서 몇몇 교과서는 연구자들이 판단하기에 반드시 필요한 내용을 빠뜨리는 경우도 있었다. 또한 광전효과는 물리학1, 물리학2에 모두 편성된 주제지만, 교과서 분석 결과 각각의 교과서에서 내용 진술을 어디까지 해야할 것인지에 대해 명확하지 않은 측면도 있었다. 연구자들은 이러한 부분은 현행 교육과정에서 제시된 성취기준이 상당히 포괄적인 것에서 비롯되었다고 판단한다. 이에 본 발표에서는 향후 개정교육과정 문서(혹은 해설서)에서 성취기준을 넘어 특정 주제별 다루어야 할 필수적인 내용 요소 기준이나 교과서의 위계 수준에 대한 지침이 제공될 필요가 있다는 것을 제안하려고 한다.

Keywords:

광전효과, 교과서, 내용 분석, 2015 개정 교육과정, 2022 개정 교육과정

2015 개정 교육과정 실천과정에서 물리 교사가 겪는 어려움 해소를 위한 방안 모색 : 『The Evolution of Physics(1938)』의 전자기 내용 지식 구조도 분석을 중심으로

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Abstract:

교사는 교육과정의 목표 달성의 과정에서 실천의 주체로 핵심적인 역할을 수행한다. 한편, 교육과정 실천 과정에서 교사가 경험하는 어려움은 교육과정의 적정성과 관련된 중요한 평가자료가 될 수 있다. 본 연구는 연구자들 중 한 사람이 2015 개정 교육과정 물리학 I '전기와 자기' 영역을 가르치면서 경험한 어려움을 파악하고, 이를 해소하는 방안에 관한 연구 프로젝트의 일부로 수행된 것이다. 특히, 교과서 내용이 분절적이고, 학생의 이해를 도울 수 있는 개념간 연결이나 배경 맥락이 빈약하여 수업 진행에 어려움을 경험하였다. 즉, 본 연구에서 주목한 것은 교육과정 내용 지식 '이해가능성'의 문제였다. 이 문제를 해결하기 위한 한 가지 방안으로 본 연구가 초점을 둔 것은 Einstein(1938)이 일반인에게 물리학이라는 학문을 소개하기 위해 저술한 『The Evolution of Physics』(이하 EoP)였다. 구체적으로 본 연구자들은 EoP의 텍스트를 질적 내용 분석법을 통해 분석하였다. 특히, 분석의 과정에서 EoP의 '전기와 자기' 영역에 해당하는 내용 요소의 지식 구조를 Galili(2012)의 DC 구조도(Discipline-Culture Structure)를 바탕으로 표현하였다. 본 연구 결과를 바탕으로 교사가 경험한 어려움의 원인과 해결 가능성을 살펴보고, 향후 교육과정 및 교과서 내용의 개발에 관한 시사점에 관하여 논의하고자 한다.

Keywords:

2015 개정 교육과정, 물리 교사의 어려움, The Evolution of Physics, 아인슈타인, 전자기 내용 지식 구조도

물리교과 교육과정의 과제와 지향: '지식 vs. 흥미'를 중심으로

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Abstract:

최근 10여 년 동안 물리교육과정은 벌써 두 차례의 개정이 이루어졌다. 그리고 현재 새로운 교육과정의 개정작업이 진행 중에 있다. 급격한 교육과정 변화의 소용돌이 속에서 물리교육계는 체계적인 경험의 축적과 발전의 과정을 걸어오기보다는 사회의 요구를 반영하는데 급급하였고, 결과적으로 많은 혼란과 어려움을 겪어왔다. 온고지신의 지혜가 필요한 때라고 본다. 새로운 교육과정 개정 작업에 앞서 (혹은 그 작업과 함께) 우리는 다음과 같은 기본 질문들을 진지하게 고민하고 그 고민의 결과가 최대한 반영되도록 노력해야 한다고 본다. 기본 질문의 예로는, "그간의 교육과정 개정을 통하여 우리는 무엇을 이루었고, 무엇이 과제로 남아있는가? 남아있는 과제들 중 특히, 새로운 교육과정 개정작업을 위해 긴급하게 고려해야 할 과제는 무엇인가? 이 과제들을 해결하기 위한 방안은 무엇인가?" 등을 생각할 수 있다. 이와 같은 질문들에 답하기 위해서는 우선 교육과정의 변천과정과 그 과정에서 발생한 쟁점들을 돌아보면서 교육과정 연구의 핵심 개념인 '생활, 경험, 흥미와 필요, 지식' 등과 같은 개념의 의미를 고찰해볼 필요가 있다. 본 연구에서는 물리교과를 비롯하여 과학교과의 교육과정 개정 시 내용선정과정에서 부각되었던 문제들 중 하나인 '지식이 먼저인가? 흥미가 먼저인가?'라는 문제에 초점을 맞추었다. 특히, 이번 발표에서는 '지식 vs. 흥미'의 이분법적 대립구도를 넘어서기 위한 방안에 관하여 논의할 예정이다.

Keywords:

물리교육과정, 교과내용선정, 지식, 흥미

작용량 개념을 도입하는 물리 교수학습 방안의 탐색

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Abstract:

작용량(action) 및 이 개념에 기초한 정상 작용 원리(stational action principle)는 뉴턴 운동 방정식을 대체하는 해석역학의 기본 원리로서, 기초적인 기하광학을 설명하는 것에서부터 양자역학과 상대론에 이르기까지 자연 현상을 통합적으로 설명할 수 있는 개념적 도구가 될 수 있다. 하지만 작용량 개념은 물리학의 기초 개념이라기보다는 계산을 위한 인위적으로 도구로서 전공 역학 이상의 상급 수준의 대학 물리교육에 서나 간혹 도입된다. 개념적 도구로서 이점에도 불구하고 대학 기초물리학이나 그 이하의 수준에서 이를 도입하기에는 수학적 어려움과 개념적인 어려움이 뒤따른다. 이 연구에서는 고전물리와 현대물리를 연계하여 통합적으로 물리학을 이해하는데 개념적 도구로서 작용량 개념 및 정상 작용 원리를 도입하는 방안을 탐색한다. 특히 작용량 개념을 기초물리학 수준에서 교수학습할 수 있는 가능성을 고찰한다. 이를 위해 작용량 개념의 교수학습에 대한 기존 교육과정 및 문헌을 고찰하며, 작용량 개념 이해와 관련된 기초적인 물리 개념에 대한 대학생들의 선개념을 탐색적으로 조사한다.

Keywords:

작용량, 정상 작용 원리, 물리 교수학습, 대학 물리교육, 기초물리학

Three-body inertia tensor

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Abstract:

We derive a general formula for the inertia tensor of a rigid body consisting of three particles with which students can learn basic properties of the inertia tensor without calculus. The inertia-tensor operator is constructed by employing the Dirac's bra-ket notation to obtain the inertia tensor in an arbitrary frame of reference covariantly. The principal axes and moments of inertia are computed when the axis of rotation passes the center of mass. The formulas are expressed in terms of the relative displacements of particles that are determined by introducing Lagrange's undetermined multipliers. This is a heuristic example analogous to the addition of a gauge-fixing term to the Lagrangian density in gauge field theories. Two special cases are considered as pedagogical examples. One is a water-molecule-like system in which a particle is placed on the vertical bisector of two identical particles. The other is the case in which the center of mass coincides with the incenter of the triangle whose vertices are placed at the particles. The principal moment of the latter example about the normal axis is remarkably simple and proportional to the product 'abc' of the three relative distances. We expect that this new formula can be used in actual laboratory classes for general physics or undergraduate classical mechanics.

Keywords:

classical mechanics, inertia tensor, three-body system, Lagrange's multiplier, gauge fixing

Think about Future Korean Physics Education: Based on Present China's Artificial Intelligence Education

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Abstract:

Artificial intelligence is the driving force behind new technologies and new civilizations and is being used even in the technological hegemony war between the United States and China. Not only from the strategic point of view of national development, but also from the point of view that education is to learn the competencies, knowledge, and attitudes necessary for future generations to live in a future society, artificial intelligence should be applied to not only the curriculum and but also teaching and learning methods of all subjects. This study first describes the AI education trends in China and the application methods of AI that have been discussed in Korea's physics education and then intends to suggest implications for the issues that the physics education academia should work on together in the future.

Keywords:

AI, Future Education, Physics Education

핵융합 코어 플라즈마 붕괴 기작 및 제어 연구

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Abstract:

본 연구센터는 핵융합 장치에서 발생하는 코어 플라즈마 붕괴 현상의 기작을 이해하고 이를 제어하는 기술을 확보하여 핵융합로 운전의 신뢰도와 안정성을 높이고자 한다. 붕괴 기작 및 제어 연구를 위해서 구축된 VEST 장치에 필요한 진단계를 최적화하여 붕괴 특성 실험 데이터를 확보하고, KSTAR 붕괴 데이터를 더하여 딥러닝 기반의 붕괴 예측 도구를 개발하고, KSTAR SPI 실험결과를 비선형 자기유체학 코드로 분석하여 붕괴 완화 기작을 도출하고, 붕괴 시 발생하는 탈출전자를 고속파와의 상호작용을 활용하는 새로운 개념의 붕괴 완화 기법의 연구를 진행하고 있다. 1세부에서는 VEST 장치에서 발생하는 유사 붕괴 현상인 IRE (Internal Reconnection Event)에 초점을 맞추어 IRE 현상의 발생 기작 및 안정화와 관련된 다양한 현상의 진단 및 해석을 진행중에 있다. Mirnov 신호와 초고속 카메라 신호의 스펙트럼을 다양한 방법으로 분석하여 IRE 전후의 MHD 현상을 이해하여 IRE 발생 기작에 대한 연구를 수행하고 있으며 교차 검증을 위하여 Soft X-ray 진단을 구축하여 기초 측정 중에 있다. 도플러 분광계를 활용하여 IRE 전후의 이온 가열 및 회전 특성 변화를 파악하여 플라즈마 붕괴와 다른 IRE의 안정화 특성에 대한 단초를 얻는 연구를 진행하고 있다. 또한, 2세부에서 진행중인 붕괴 예측 기술 개발을 위하여 VEST의 붕괴 데이터를 선별하여 수집 중에 있다. 2세부에서는 KSTAR 붕괴 데이터를 이용하여 딥러닝 기술을 기반으로 하여 KSTAR에서 붕괴 현상이 일어나기 전 미리 예측할 수 있는 RNN(Recurrent Neural Network)을 구축하여 좋은 결과를 얻을 수 있었다. 이를 기반으로 VEST 장치에서 발생하는 유사 붕괴 현상 IRE를 예측할 수 있을지 확인해보기 위해 VEST 장치에서 IRE 현상과 관련된 여러 진단 데이터를 확보하고 있으며 이를 이용한 네트워크를 구축하는 연구를 진행 중이다. 또한, 2세부에서 비선형 MHD 코드를 통한 KSTAR 플라즈마 대상의 SPI (Shattered Pellet Injection) 전산 모사 결과 실제 실험에서 나타나는 시간 스케일의 Thermal Quench가 수치적으로도 관측되었으며, 실험 진단에서 확인될 수 있는 경향들과 일관된 수치해석 결과를 확보하였다. 3세부에서는 탈출전자와 고속파의 상호 작용을 연구하기 위해 Hard X-ray 진단 시스템을 구축하였다. 측정된 에너지 스펙트럼과 자장탐침으로 측정된 파동 특성과 비교 연구를 통해 탈출 전자와 특정 주파수의 파동과의 상관관계를 지니는 데이터를 확보하였다. 나 아가 고속파를 이용하여 탈출전자를 완화하는 연구를 진행중에 있다. 이러한 세 개의 세부과제의 연구 결과가 결합되면 붕괴 현상의 기작에 대한 이해와 더 나아가 이를 제어할 수 있는 방법을 찾을 수 있을 것으로 기대하고 있다.

Keywords:

코어 플라즈마 붕괴, 붕괴 기작 및 제어, 딥러닝 기반 붕괴 예측, 탈출전자와 고속파 상호작용

핵융합로를 위한 통합 안정화된 플라즈마 연구 개발 (경계면, 디버터 및 노심)

MHD-stabilized reactor-relevant fusion plasmas (with full integration of edge, divertor and core)

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Abstract:

UNIST 핵융합센터는 핵융합로를 위한 핵심기술연구로서, "핵융합 플라즈마 구속안정성을 유지한 상태에서, 경계면, 디버터 및 노심을 통합적으로 제어하기 위한 연구"를 수행하고 있다. 이를 위해 구체적으로는 1) 경계면에서의 공명자장 안정화, 2) 디버터에서의 열속제어, 3) 노심까지 안정화된 플라즈마를 통합적으로 제어할 수 있는 물리기반기술을 연구개발하고 있으며, 차세대 electron cyclotron emission (ECE) 영상 진단(ECEI)의 소형 고성능 수신장치를 개발해 오고 있다. 또한, KSTAR에서의 ECEI 및 고속 RF 진단시스템의 데이터 분석 및 활용 기술을 고도화하며, 이를 바탕으로 실증로에서도 적용가능한 노심진단 원천기술을 개발하고 있다. 고성능 핵융합로 운전을 저해하는 신고전터짐모드 (NTM)의 생성 및 거동 예측을 위한, 난류와 NTM의 상호작용을 전자기적 전산모사기술을 개발하고 있으며, 일차적으로 자기섬으로 인한 수송변화를 벤치마킹하고 있다.

최근 주요업적을 예로 들면, 공명자장 경계면 안정화를 유지하면서도, 노심을 안정적으로 유지함과 동시에 디버터에서의 열속증가를 획기적으로 낮출 수 있음을 KSTAR에서 구현했다 [1, 2]. 특히 기존 연구들에서 불순물과 디버터 가스주입으로만으로는 경계면 안정화유지를 저해하는 요소로 작용하는 것을 확산연료주입방법을 통해 최적조건을 발견했으며 [2], 2020년 $q_{95}=5$ 조건에서의 성공적으로 통합제어된 결과를 바탕으로 수행한 방식을 2021년 $q_{95}=4$ 조건에서도 적용 가능함을 확인하고, 그 실험결과분석을 진행 중이다 [3]. 이와 별도로 공명자장 경계면 안정화에서의 Up/Down Poloidal 비대칭적 의존성의 근본원인이 X-point 위치에 따른 영향이 아닐 가능성이 있는 실험적 증거를 포착함에 따라 ITER에서의 $q_{95}\sim 3$ 공명자장 경계면 안정화에 대한 예측 또한 추가 연구가 필요할 것으로 보인다 [3].

실증로에 적용 가능한 진단개발연구로서, ECE신호로부터 플라즈마 파동을 추출하는 방법을 개발하여, 이를 플라즈마 경계면 붕괴 [4], Runaway [5], 그리고 국소적 유체 요동 [6] 진단과 물리 해석에 적용하였다. 이외에 자기섬의 존재에 따른 수송의 증가를 자이로 동력학 코드 GENE을 통해 전산모사로 확인했으며 [7], ECEI 진단의 고분해능 안테나 개발, 이중렌즈를 통한 검파기의 소형화, 차세대 electronics모듈 개발에 각각 성공함에 따라 진단의 고도화에 적용을 모색하고 있다 [8].

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Keywords:

공명자장 경계면 안정화, ECE 영상진단, 자기섬 전산모사

나노 카바이드 석출물을 이용한 조사저항성 향상 신소재 개발

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Abstract:

핵융합로의 블랭킷(blanket)은 운전중 핵융합플라즈마에서 발생하는 14MeV의 에너지를 가지는 고속중성자에 지속적으로 노출되어 다양한 형태의 중성자 조사손상을 받게된다. 또한 중성자와 블랭킷 구성재료의 원소들간의 핵반응으로 인한 방사화를 최소화하는 것이 안전성 및 폐기물관리의 측면에서도 중요하게 간주되고 있다. 현재 가장 널리 연구개발되고 있는 블랭킷 구조재료는 저방사화 페리틱-마텐시틱강(reduced activation ferritic-martensitic steel, RA-FMS)이다. 이에 비해 오스테나이트계 스테인리스강(austenitic stainless steel)은 우수한 부식저항성, 조사취화저항성, 상자정특성에도 불구하고 취약한 스웰링(swelling)과 방사화특성으로 인해 핵융합 발전로의 블랭킷 소재로의 적용에 장애가 되고 있다.

이러한 문제를 해결하기 위해 본 연구에서는 1) 합금원소를 적절히 조절하여 오스테나이트상을 유지하면서도 저방사화특성을 확보하고, 2) 최적화된 열-기계적 공정을 개발/적용하여 10 nm 미만의 나노-카바이드를 기저에 다수 석출시키고, 3) 이온조사를 통해 최대 200 dpa의 조사량에도 우수한 스웰링저항성을 보이는 것을 확인하였다. 본 발표에서는 위 각각의 연구개발 내용을 상세히 소개할 예정이다.

Keywords:

조사저항성, 블랭킷, 오스테나이트계 스테인리스강, 나노-카바이드

Demonstration of multi-loop atom interferometer in a waveguide.

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Abstract:

Atom interferometers in which the atoms move inside waveguides can be much smaller than devices in which the atoms move in free space. The guided atom interferometer is a promising way to the goal of a sensitive compact atom interferometer. A potential issue with this approach is that fringe contrast can drop rapidly as the distance traveled inside the waveguide increases because of effects associated with residual curvature in the waveguide that limits the atomic coherence time to a hundred ms. We report a multi-loop guided atom interferometer in which the atoms make many small-amplitude round trips during the measurement cycle instead of a single large-amplitude round trip, and demonstrate a coherence time of seconds with high curvature waveguide. The matter-wave source is 39 Potassium BEC that suppresses the collisional loss of wavepacket. The modulated wavepacket momentum implements a dynamic decoupling and phase-sensitive sensing that significantly reduces the impact of technical phase noise in the interferometer, to the level where the reference frame does not require stabilization. This is a crucial feature for an atom interferometer to operate outside of the laboratory. The interferometer is suitable for multi-loop atomic Sagnac interferometer as well.

Keywords:

BEC, Atom interferometer

Coherent and incoherent oscillation of the spin spiral state near the quantum critical point

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Abstract:

In this talk, we report the dynamics of spin spiral state in a two-dimensional spinor Bose-Einstein condensate (BEC). The transverse spin spiral state is collective excitation mode in a ferromagnetic spinor BEC, and its stability depends on the quadratic Zeeman energy (q) and wavelength of the spin spiral state [1]. When the q is zero, the system has rotational symmetry, and the spiral state unwinds, while the finite q provides an effective potential barrier to sustain a collective oscillation. The ^7Li spinor BEC displays fast spin collision time [2] and negligible dipolar interaction compared to ^{87}Rb [3], providing an ideal platform to investigate coherent spin twisting and dissipative dynamics [4]. We investigate the stability of the spin spiral state and observe the critical spiral wavevector for the coherent oscillation to become smaller as we approach the quantum critical point, $q = 0$. This might be able to support the absence of the spin superfluidity at $q = 0$ [5].

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Keywords:

Bose-Einstein condensate (BEC), ferromagnetic spinor condensate, spin spiral state, coherent spin twisting, quantum critical point

Critical coarsening of a quenched Bose gas

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Abstract:

When a system passes through a critical point in a continuous phase transition, as the order parameter grows in the system, defects can be spontaneously formed due to the causal independence of far distant regions. This phenomenon has been well described in the framework of the Kibble-Zurek mechanism (KZM), but it was recently pointed that the critical coarsening in the early phase of the phase transition dynamics is very important, which would result in significant reduction or even saturation of the defect density. In this talk, we report our experimental investigation of the critical coarsening effect in a quenched ⁸⁷Rb Bose gas using a two-step quench protocol, where the sample is successively cooled with two different quench rates. We observed that the created defect number is affected not only by the quench rate at the critical point but also by that after passing the critical point, which directly demonstrates the critical coarsening effect. We will discuss the concrete dependency of the defect number on the later cooling rate and its implication on the conventional KZM scenario.

Keywords:

Bose-Einstein condensate, Kibble-Zurek mechanism, Quantum vortex, Critical coarsening, Spontaneous defect formation

Vortex shedding frequency of a moving penetrable obstacle in a Bose-Einstein condensate

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Abstract:

Vortex shedding by a moving obstacle is a classic problem in fluid dynamics. Recently, there have been many efforts to extend its study to a superfluid, where zero viscosity defies the Reynolds number. In this talk, we present our experimental study of the vortex shedding of a penetrable obstacle in a Bose-Einstein condensed gas of ^{87}Rb . The penetrable obstacle, whose potential height is lower than the chemical potential of the condensate, generates vortex dipoles when it moves faster than a certain critical velocity v_c . We measure the vortex shedding frequency f_v for a wide range of obstacle parameters such as velocity, strength, and size. Our measurement results confirm the previous suggestion of $f_v = a(v - v_c)$ with v being the obstacle velocity in the penetrable regime and show that the coefficient a linearly increases with increasing the obstacle strength and weakly decreases with increasing the obstacle size. We will discuss the physical interpretation of a in light of the Strouhal number for classical fluids.

Keywords:

Superfluid, Vortex shedding, Penetrable obstacle, Strouhal number

EIT cooling of neutral atoms in optical tweezers

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Abstract:

Freezing the mechanical motion of trapped particles can greatly improve their performance in quantum information applications. Here we implement a cooling method utilizing the electromagnetically-induced-transparency (EIT) phenomena to reduce to the temperature of neutral atoms in optical tweezer traps. While the EIT cooling principle has been used in neutral atoms in cavities and ion strings [1,2], our implementation of the EIT condition to both inhibiting the Raman carrier transition and maximizing the Raman red-sideband transition results in simultaneous cooling of N atoms in inhomogeneous optical potentials. Experiments are performed with rubidium

(^{87}Rb) individually trapped in an array of far-off optical dipole traps and cooled to $21 \mu\text{K}$ in a magneto-optical trap[3]. We used the λ -type three energy levels, $|\text{Wket}\{5S_{1/2}, F=2, m_{\{F\}}=2\}\rangle$, $|\text{Wket}\{5P_{3/2}, F'=2, m_{\{F'}=2\}\rangle$, and $|\text{Wket}\{5S_{1/2}, F=2, m_{\{F\}}=1\}\rangle$, and the atoms in $|\text{Wket}\{5S_{1/2}, F=2, m_{\{F\}}=2\}\rangle$ are vibrationally cooled at the EIT condition. While the ac-Stark shift is tuned around the vibrational level spacing (i.e., the trap frequency of optical tweezers), the single-atom temperatures are measured with the release and recapture method. The final temperature of up to 16 atoms in optical tweezers are measured below $10 \sim \mu\text{K}$ after the EIT cooling and below $1.0 \sim \mu\text{K}$ after additional adiabatic coolings. The final vibrational quantum number is estimated below $n=0.1$ and the cooling rate of 700 Hz is achieved.

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Keywords:

Atom Cooling, Atom trapping

Probing Hidden nonlocal parity order parameter in 2D optical lattice system

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Abstract:

Nonlocal order systems and topological phases are interesting topics in the field of condensed matter physics. Superfluid to Mott insulator in Bose-Hubbard model is a representative quantum phase transition which can be determined by the parity order parameter. Two-site parity correlation and the parity order parameter of the atoms in the optical lattice can be directly calculated from the single-site resolution image of the Quantum gas microscope [1]. However, it was proven that the parity order parameter converges to 0 in the 2D system [2]. In a recent paper [3], this problem can be circumvented by inserting an extra phase factor into the order parameter. In our experiment, using our recently developed 7Li quantum gas microscope system, we take images of the atoms on the optical lattice by changing the lattice parameter J/U and investigate the Superfluid to Mott insulator transition in a 2D optical lattice. We observe the parity order parameter starts to develop at the quantum critical point, while the density correlation function between neighboring sites is maximized.

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Keywords:

Optical lattice, Quantum gas Microscope, Bose-Hubbard model

Theoretical and Experimental Study of Optimization of Polarization Spectroscopy for the D2 Closed Transition Line of 87Rb Atom

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Abstract:

We experimentally and theoretically investigated the optimal condition of polarization spectroscopy for frequency stabilization on various pump beam intensities and vapor cell temperatures for the D2 closed transition line of 87Rb atoms. We compared the experimental results, such as the amplitude, width, and slope, of the polarization spectroscopy signal with the theoretical results. We found the optimal parameters, such as the pump beam intensity and vapor cell temperature, for polarization spectroscopy. The theoretically expected optimal parameters were, qualitatively, in good agreement with the experimental results.

Keywords:

Optimization of Polarization Spectroscopy

Magnetic-field enhanced modulation transfer spectroscopy : Theory and experiment

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Abstract:

We present a theoretical and experimental study on magnetic-field enhanced modulation transfer spectroscopy(MTS) for the $5S_{1/2}(F = 1) \rightarrow 5P_{3/2}(F' = 0, 1, \text{ and } 2)$ transitions of 87Rb atoms. To obtain the theoretical MTS spectra, the density matrix equations are solved numerically, and it has an excellent agreement with the experimental results. In particular, the enhancement of the MTS signal at the $F = 1 \rightarrow F' = 0$ transition in the presence of the magnetic field is directly verified based on the comparison results calculated by neglecting or including the Zeeman coherence in the $F = 1$ ground state. Also, the unexpected interesting behaviors of the $F = 1 \rightarrow F' = 1$ transition are examined with two different configurations of probe-pump beam polarization.

Keywords:

Magnetic-field enhanced modulation transfer spectroscopy

Modulation of electrical and optical properties in MoS₂

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Abstract:

Two-dimensional monolayer transition-metal dichalcogenides have numerous electrical and optical properties that have potential for use in many applications. These properties should be modulated properly according to situations being applied. Because intrinsic properties of 2D materials are affected by environmental parameters highly unlike bulk materials, properties of 2D materials can be modulated easily by changing the condition of environment. As one of the representative electrical property of materials, work function plays important role of formation of band diagram in junction device and have a major impact on the carrier transport phenomenon. By using an in-situ Kelvin probe and ultraviolet photoemission spectroscopy, we demonstrated that the work function of MoS₂ can be changed by 0.43 eV by exposing MoS₂ to O₂ gas. In addition, we also found out that intensity of MoS₂ photoluminescence as the one of representative optical property could be modulated by stacking materials and the thickness of spacer on substrate. Fabry-Perot interference happens in the spacer between MoS₂ and metal substrate due to high reflection at two interfaces, and resultantly the intensity of photoluminescence was enhanced at the specific thickness of spacer. This enhancement helps low efficiency of MoS₂ photoluminescence to be improved and opens possibility for MoS₂ to be used as gain materials in optoelectric devices such as light emitting diodes.

Keywords:

monolayer MoS₂, work function, Kelvin probe, photoluminescence, Fabry-Perot interference

Carrier multiplication for 2D ultimate solar cells

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Abstract:

Utilizing excess energy of photoexcited hot carriers in semiconductors is a major challenge to improve solar energy conversion. Carrier multiplication (CM), a photo-physics process in which high-energy free carriers relax by the generation of additional electron-hole pairs rather than by heat dissipation, is a promising disruptive concept in solar energy conversion and light detection technologies. CM in various nanostructures for different compositions such as quantum dots, nanorods, nanosheets, and bulk have been studied. However, none of the materials has demonstrated both ideal threshold energy of two times of bandgap (E_g) and near 100% CM conversion efficiency. In this talk, making use of state-of-the-art two-dimensional van der Waals layered materials, I will report highly efficient carrier multiplication, with ideal threshold energy of $2E_g$ and carrier multiplication conversion efficiency of nearly 100% in MoTe_2 and WSe_2 films, *the best record to date*. Furthermore, I will present a demonstration of the CM effect through simple photocurrent measurements by fabricating the dual-gate p-n junction of a MoTe_2 film.

Keywords:

2D materials, Ultrafast spectroscopy, Solar cell, Carrier multiplication, Hot carrier

Integration of single photon emitters in 2D materials with a nanophotonic structure

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Abstract:

Single photon emitters, the basic building blocks for quantum communications and information, have been developed 2D materials such as transition metal dichalcogenides and hexagonal-boron nitride (h-BN). Efficient integration of single photon emitters and nanophotonic structure is essential for quantum integrated circuits. In this study, I will discuss the integration of single photon emitters in 2D materials with a nanophotonic structure and their optical properties. First, I will talk about the efficient coupling of h-BN single photon emitters and Ag nanowire plasmonic waveguides. We performed 3D FDTD simulations to calculate the efficiency of light coupling from the emitter to the Ag plasmonic waveguide, depending on the position and polarization of the emitter. In the experiment, a Ag nanowire was accurately positioned close to the single photon emitter in h-BN flake using the PDMS/PPC stamping method. The optical properties of single-photon emitters were measured using a confocal microscope setup. In the last part, I will present the deterministic control of the position and polarization of single-photon sources formed in monolayer WSe₂. By applying a strain to monolayer WSe₂ using a Si₃N₄ rod structure with a nanogap, band engineering and single-photon generation were successfully achieved at a desired position. Additionally, we controlled the polarization of single photons by changing the nanogap size. We integrated the emitters with photonic crystal nanobeam cavities and measured the optical properties. We believe that our approach is a unique way to develop scalable and controllable photonic integrated circuit using single-photon emitters in 2D materials.

Keywords:

2D materials, single photon emitter, quantum photonics

Nanoscale sensing of photo-energy transport in atomically thin semiconductors

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Abstract:

Plasmonic nano-cavities can enhance and control a range of light-matter interactions at the nanoscale. This manipulation of optical properties through plasmon coupling is allowed even at room temperature with extremely small mode volume. Yet, in most studies, static geometries are used which put constraints on the ability to control coupling strength and induce coupling to different emitters with the same cavity. To achieve the desired dynamic nano-cavity, I present plasmonic tip-cavity which enables reversible control of light-matter interactions from weak to strong coupling regime. The tip-cavity is formed between a plasmonic tip and a metal substrate and the cavity gap is dynamically controlled by atomic force feedback between them. In this talk, I will demonstrate a range of light-matter interactions in low-dimensional quantum materials, which are probed and controlled by plasmonic tip-cavity.

Keywords:

Plasmonic nano-cavity, light-matter interactions, strong coupling, plasmonic tip-cavity, low-dimensional quantum materials

Transition metal ions doped colloidal quantum dots: synthesis, structural and optical properties

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Abstract:

Recently, colloidal quantum dots (QDs) have been highly attractive materials in the fields of light emitting diodes, photovoltaics, and biolabeling due to unique properties, including size dependent optical properties, large absorption coefficients and bright emission. Typically, most of QDs having outstanding properties include the heavy-metal atoms such as Cd, Pb and Hg etc. however, intrinsic toxicity of heavy-metal atoms may be difficult that they are applied to long-term commercial products. Therefore, relatively nontoxic QDs have been strongly studied such as InP, CuInS₂ and doped ZnSe. Among them, transition metal ions doped ZnSe offer not only wide wavelength region in visible light included short wavelength, but also can have the multi emission through co-doping. But doping of a variety of transition metal ion is difficult work without appropriate doping strategy and enough understanding between dopant and host materials. In this work, we used hot injection method to prepare all the QDs and selected Cu and Mn as transition metal ion to obtain a variety of wavelength region. The two dopants have been introduced into the host material by using the growth doping and the nucleation doping methods. X-ray diffraction and transmission electron microscopy measurements were performed to analyze the structural properties. Absorption and fluorescence measurements were carried out to investigate the optical properties of the QDs.

Keywords:

Quantum dots, ZnSe, Transition metal ions, Growth doping, Nucleation doping

Quasi-2D Halide Perovskite Memory Device Formed by Acid-Base Binary Ligand Solution Composed of Oleylamine and Oleic Acid

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Abstract:

Organometal halide perovskite materials are receiving significant attention for the fabrication of resistive-switching memory devices based on their high stability, low power consumption, rapid switching, and high ON/OFF ratios. In this study, we synthesized 3D FAPbBr₃ and quasi-2D (RNH₃)₂(FA)₁Pb₂Br₇ films using an acid–base binary ligand solution composed of oleylamine (OIAm) and oleic acid in toluene. The quasi-2D (RNH₃)₂(FA)₁Pb₂Br₇ films were synthesized by controlling the protonated OIAm (RNH₃⁺) solution concentration to replace FA⁺ cations with large organic RNH₃⁺ cations from 3D FAPbBr₃ perovskites. The quasi-2D (RNH₃)₂(FA)₁Pb₂Br₇ devices exhibited nonvolatile write-once read-many (WORM) memory characteristics, whereas the 3D FAPbBr₃ only exhibited hysteresis behavior. Analysis of the 3D FAPbBr₃ device indicated operation in the trap-limited space-charge-limited current region. In contrast, quasi-2D (RNH₃)₂(FA)₁Pb₂Br₇ devices provide low trap density that is completely filled by injected charge carriers and then subsequently form conductive filaments (CFs) to operate as WORM devices. Nanoscale morphology analysis and an associated current mapping study based on conductive atomic force microscopy measurements revealed that perovskite grain boundaries serve as major channels for high current, which may be correlated with the conductive low-resistive-switching behavior and formation of CFs in WORM devices.

Keywords:

Quasi-2D perovskite, Acide-base reaction,, Binary ligand, Write-Once Read-Many (WORM) memory device, Protonation

Growth and characterization of InGaN-based pyramidal quantum dots emitting wide range of visible wavelength

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Abstract:

For the last few decades, semiconductor quantum dots (QDs) have emerged as an ideal candidate for single photon source (SPS) which play a key role in quantum technology, due to their unique optical and material properties. Depending on alloy composition, III-nitride semiconductor materials can cover broad spectrum range from ultraviolet to near infrared. In this study, we tried to develop the InGaN/GaN QDs on GaN pyramids by adjusting effective In incorporation as a deterministic, site-controlled SPS with wide range of visible wavelength, which would be useful for various wireless communication applications in visible region. Previous researches on these InGaN/GaN QDs had limitations to pushing emitting wavelength of QDs towards longer wavelength with high In content. To overcome this limit, we imposed growth tactics like epitaxial lateral overgrowth of GaN core and InGaN interlayer for strain relaxation. Also, pyramids were designed to be triangular shaped for better uniformity. We pushed peak wavelength of QDs longer and made emission broadening from QDs as smaller as possible.

Keywords:

InGaN/GaN pyramidal quantum dots, epitaxial lateral overgrowth, InGaN interlayer, single photon source, wireless quantum communication

Light manipulation for mutual enhancement in cooling and energy harvesting of photovoltaics

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Abstract:

The introduction of radiative cooling lightens managing a heat load of photovoltaic (PV) without energy consumption. Owing to the passive and compact cooling principle, many scientists and engineers have studied a radiative cooler itself and effective integrating systems with PV. However, most research focused on the design of radiative cooler only considering thermal emission, not collecting solar energy more. Also, these reports have stayed within computational studies based on silicon solar cell, which uses only a part of solar spectrum. Herein, we present a high-efficient/radiatively cooled multi-junction solar cell (MJSC; InGaP/GaAs/Ge), which utilizes most solar spectrum, by introducing bi-functional solar window (BFSW), which separately works in solar and long wave infrared regions. The micro-patterns in BFSW brings to not only remarkable self-cooling feature resulted from amelioration of the emissivity loss, but also improved solar collecting capability owing to diffraction. By mounting the optimum BFSW on the MJSC, we confirm the improved cell efficiency from 25.4 to 26.7 % using solar simulator. Moreover, outdoor field tests successfully demonstrate the enhanced cooling performance and power conversion efficiency compared to conventional glass mounted MJSC under direct sunlight of $\sim 900 \text{ W/m}^2$: Temperature drop of $\sim 5^\circ\text{C}$ and minimizing the variation of open-circuit voltage as $\sim 6\%$.

Keywords:

Passive Radiative Cooling, Photovoltaic, optical, electrical, thermodynamic

First-principles study on electronic structures of InAs/GaSb superlattices

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Abstract:

The application of the first-principle calculations has the potential to greatly improve our understanding of semiconductor superlattices. Developing procedures for accurately predicting band gaps using density functional theory(DFT) becomes the groundwork for future research investigating more subtle characteristics of these structures. In this presentation, we present band gap data and band structures for various InAs/GaSb type-II superlattice structures calculated using the first-principles calculations. We also discuss various modern schemes on DFT such as Hubbard U, Hybrid functional (PBE0, HSE03/06 and B3LYP) and GW used to improve these bandgap results.

Keywords:

Density functional theory, electronic structures, InAs/GaSb, Superlattices

Investigation of Cation Exchange Behaviors of FAMAPbI₃ Films using Dynamic Spin-Coating

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Abstract:

We fabricated and characterized a uniform FAMAPbI₃ film. Using the dynamic spin coating method, we control the cation ratio in multi-cation perovskite materials by gradually increasing FA⁺ that replaces MA⁺ in the film. When FA⁺ concentration is below $x_{FA} \sim 0.415$ in the film, multi-cation perovskite becomes more stable. Above the concentration, the film exhibits the appearance of δ -phase FAPbI₃ in FAMAPbI₃ film. The formation of δ -phase FAPbI₃ disturbs the homogeneity of photoluminescence spectra and suppress the absorption spectral bandwidth with increasing the bandgap. More delicate control of cation ratio needs to be investigated in multi-cation perovskite film.

Keywords:

cation exchange, FAMAPbI₃, dynamic spin coating, δ -phase FAPbI₃, FA and MA cations

Search for new physics in final states with an energetic jet or a hadronically decaying W or Z boson and transverse momentum imbalance at $\sqrt{s} = 13$ TeV

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Abstract:

A search for new physics using events containing an imbalance in transverse momentum and one or more energetic jets arising from initial-state radiation or the hadronic decay of W or Z bosons is presented with full Run II data sample of proton-proton collisions at $\sqrt{s} = 13$ TeV, collected with the CMS detector at the LHC. The observed data are found to be in agreement with the expectation from standard model processes. The results are interpreted as limits on the dark matter production cross section in simplified models with vector, axial-vector, scalar, and pseudoscalar mediators. Interpretations in the context of fermion portal and nonthermal dark matter models are also provided. In addition, the results are interpreted in terms of invisible decays of the Higgs boson and set stringent limits on the fundamental Planck scale in the Arkani-Hamed, Dimopoulos, and Dvali model with large extra spatial dimensions.

Keywords:

CMS, LHC, Dark Matter,

Search for new physics in dilepton events using asymmetry

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Abstract:

We report a noble way to search for new physics in dilepton events using asymmetry at the LHC. Since the discovery of the Higgs particle, we have not observed any new physics signal yet in bump hunting. A tantalizing new physics signature can be hidden in the corners of kinematic phase space of the dilepton events. We measure differential asymmetry as functions of various kinematic variables to search for hints of new physics.

Keywords:

LHC, CMS, 13TeV, asymmetry, AFB

Search for new long-lived particles with disappearing track signature at CMS experiment

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Abstract:

The 'phenomenological Minimal Supersymmetric Standard Model(pMSSM)' expects new long-lived charged particle(called 'chargino') with its lifetime of the scale of the CMS pixel detector or longer(>10 cm). In this talk, we performed an analysis to search for new long-lived particles with disappearing track signature using 135.9 fb^{-1} proton-proton collision data collected by CMS detector at LHC. The signal candidate events are containing highly ionizing disappearing tracks embedded within a broad range of event topologies. The track length of disappearing tracks is considered in categories to target shorter lifetimes associated with pMSSM-like semi-stable winos and charginos arising from pure higgsino SUSY model points.

Keywords:

SUSY, long-lived, chargino, LSP, disappearing-track

Search for heavy neutral leptons at CMS using Run 2 data

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Abstract:

The discovery of non-zero neutrino masses has opened a new window for heavy neutrinos at TeV scale. The CMS experiment has performed many searches for heavy neutrinos at the LHC. We present an overview of these heavy neutrino (Majorana type) searches in events with leptons and jets, using proton-proton collision data in $\sqrt{s} = 13$ TeV.

Keywords:

Neutrino, Majorana, CMS

Search for Dark Matter in monophoton final state in proton-proton collisions at $\sqrt{s}=13$ TeV

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Abstract:

The LHC has really broken new ground in the search for dark matter in the form of weakly interacting massive particles, by covering a wide array of potential signals predicted by either production of dark matter, or production of the particles mediating its interactions with ordinary matter. The process of the $q\text{-}\bar{q}\text{-}\gamma\chi\chi$ where a single proton with large missing transverse momentum (known as Monophoton signature) emitted from incoming quarks can be the result of DM production. The elimination of background events from the Monophoton final state might give clear evidence beyond the standard model. In this talk, background estimation and the studies of various signal models will be presented.

Keywords:

Dark Matter, Monophoton, CMS, LHC

Search for Long-Lived Particle Using Delayed Photons at 13 TeV Using The CMS Detector

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Abstract:

Neutral particles with long lifetimes are predicted in many models of physics beyond the standard model (SM). A benchmark scenario of supersymmetry (SUSY) with gauge-mediated SUSY breaking (GMSB) referred to as the "Snowmass Points and Slopes 8" (SPS8) predicts such particles. In this scenario, pair-produced squarks and gluinos undergo cascade decays and eventually produce the lightest SUSY particle (LSP), the gravitino, which is stable and weakly interacting. The dominant final state in this model is one or two photons and missing transverse momentum (P_{miss}). Also, the Simplified Model predicts a process in which Z' decays into two scalars and each scalar decays into two photons. A study is also underway to find the long-lived particle, scalar, using the resulting resonant photon. In this talk, the study of background estimation using ABCD and the generator level studies using a simplified model with data of 59.83 fb^{-1} recorded in the 2018 CMS experiment will be presented

Keywords:

CMS

Search for new physics in the lepton plus missing transverse momentum final state in CMS

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Abstract:

A search for physics beyond the standard model (SM) in final states with an electron or muon and missing transverse momentum is presented. The analysis uses data from proton-proton collisions at a center-of-mass energy of 13 TeV, collected with the CMS detector at the LHC in 2016–2018, corresponding to an integrated luminosity of 137 fb^{-1} . No significant deviation from the SM prediction is observed. Combining the results from electron and muon decay channels, a W' boson with mass less than 5.7 TeV is excluded at 95% confidence level within the framework of the sequential SM. Several new interpretations in terms of different new physics models are addressed in this analysis. Results on oblique electroweak parameters, in particular on the W parameter, are also presented for the first time using LHC data. These results are combined with those from direct resonance searches in the same channel to set constraints on composite Higgs scenarios.

Keywords:

LHC, CMS, 13 TeV, W' Search, lepton

A lab-scale experiment for keV sterile neutrino search from tritium beta decay spectrum

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Abstract:

We developed a simple small-scale detection method for beta decay spectrum of ${}^3\text{H}$. This research is motivated to investigate the presence of sterile neutrinos in keV region. In our experiment, tritium nuclei are embedded in a $1\times 1\times 1\text{ cm}^3$ LiF crystal from ${}^6\text{Li}(n,{}^3\text{H}){}^4\text{He}$ reaction. The beta energy spectrum is measured with an MMC sensor, one of the high-resolution microcalorimeters operating at mK temperatures. We present the method for the sample preparation and the experiment together with the physics result from the first measurement set. Moreover, an expected sensitivity to search for the heavy neutrino is discussed for one year measurement with the setup.

Keywords:

sterile neutrino, tritium beta spectrum, calorimeter

Dielectric array axion haloscope with kirigami tuning structure

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Abstract:

The axion is a theoretically well-motivated solution to the strong CP problem of particle physics and it is also a promising candidate for dark matter. Most cavity haloscope experiments have searched at lower frequencies (< 10 GHz). A novel cavity design, consisting of a periodic array of dielectric cylinders in an ordinary cavity, was developed by CAPP to access high frequency regions above 10 GHz with highly enhanced quality factors. Inspired by the kirigami structure, a unique tuning mechanism was developed to tune the resonant frequency in 2-dimensions. We present the characteristics of this new cavity design and show its experimental feasibility.

Keywords:

Axion, Metamaterial

A Study on the Responses of Silicon Photodiode Detector to Gamma Radiation and Proton beams

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Abstract:

A Lunar Vehicle Radiation Dosimeter (LVRAD) has been proposed to study the understanding of the radiation environment on the lunar surface and the evaluation of impact on human health. The LVRAD payload is composed of four systems: Particle Dosimeter and Spectrometer (PDS), Tissue-Equivalent Dosimeter, Fast Neutron Spectrometer and Epithermal Neutron Spectrometer. The silicon photodiode sensor with a compact readout electronics is for the PDS. The PDS system aims to measure protons 1 to 100 MeV energy as well as dose assessment in the lunar space environment. We manufacture the photodiode sensor with an effective area 20 mm x 20 mm and a thickness of 650 um, and develop the electronics consisted of a charge sensitive amplifier, analog pulse processor for the silicon sensor signal readout. We study the responses of the manufactured silicon sensors with its dedicated electronics to gamma rays in a wide energy range and proton beams.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korea government (MSIP) (NRF-2017M1A3A4A01077173) and (NRF -2020M1A3B7108845). The authors express their sincere thanks to the staff of the MC-50 Cyclotron Laboratory (KIRAMS), for the excellent operation and their support during the experiment.

Keywords:

LVRAD, Silicon photodiode

Analysis method for the GNOME experiment using machine learning optimization

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Abstract:

Axion-like particles (ALPs) are ultra-light pseudo-scalar bosons resulting from a new spontaneously broken $U(1)$ symmetry beyond the Standard Model. They could form stable topological defects such as domain walls, which would be localized dark matter in our galaxy, instead of the homogeneously distributed one. The Global Network of Optical Magnetometers for Exotic physics searches (GNOME) is an experimental search for localized dark matter candidates, like ALP domain walls, from their transient events by synchronizing individual local sensors geographically spread over the Earth's surface. We introduce an analysis method based on stochastic optimization with machine learning applied to the datasets obtained from each sensor of the GNOME. The validity and reliability of this method are verified in means of binary classification and binomial proportions. The improved sensitivity by this new analysis method to the ALP domain-wall crossing event is also projected.

Keywords:

axion-like particle, domain wall, dark matter, data analysis, machine learning

High-sensitivity approach searching for new force-carrying particles beyond the Standard Model

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Abstract:

The axion is a hypothetical particle proposed to resolve the strong CP problem of particle physics. Axions can mediate long-range spin-dependent interactions between two fermions, which can be detected by high-sensitivity atomic magnetometry. Axion Resonant InterAction Detection Experiment (ARIADNE) is a collaboration formed to search for the axions by probing the nuclear spin-dependent interactions using the nuclear magnetic resonance technique. ARIADNE provides a methodological approach particularly sensitive to a high axion mass range from 0.1 meV to 6 meV. We perform dedicated studies on the critical ingredients of the experiment to improve sensitivity, such as noise estimation, superconducting magnetic shielding, new source mass design, and SQUID second order axial planar gradiometer.

Keywords:

Axion, Monopole-Dipole interaction, Beyond Standard Model, NMR, Strong CP problem

Addressing experimental issues in realistic designs of cavity haloscopes

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Abstract:

The cavity haloscope is one of the most sensitive methods to search for dark matter axions. Experimental attempts to improve the sensitivity have focused on major aspects, such as high magnet strength, large detection volume, high cavity quality factor, and low noise temperature. The experimental design can be optimized to improve the sensitivity for a given environment, but it has not been properly addressed so far. The associated elements include fringe magnetic fields due to the finite size of solenoid, propagation of microwave noise under attenuation with temperature gradient, and temperature difference between the cavity and tuning structure. We algebraically analyze these empirical issues and provide potential solutions for better sensitivity.

Keywords:

Axion, Dark matter, Cavity haloscope, Microwave noise

Search for Elementary Magnetic Monopoles in Electron-Positron Annihilation at Rest

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Abstract:

The ISU (Iowa State Univ.)-KNU (Kyungpook National Univ.) collaboration has designed and launched an experiment to search for elementary magnetic monopoles in the low-mass low-charge space. This experiment, called KAEM (KoreA Experiment on Magnetic Monopole), is configured with a thin metal target, two 1 Tm solenoids, a 2.5 m long vacuum chamber, electromagnetic calorimeters, and trigger-veto. In this talk, we will present the progress of our studies for the experiment, KAEM.

Keywords:

Magnetic monopoles, Crystals, Calorimeter, Magnetic mirror, Maxwell's equations

Development of low threshold detector for low mass dark matter search

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Abstract:

Most studies have focused on searching for dark matter with masses of $10\text{GeV}/c^2$, but recently an increasing interest points towards models involving lighter particles. So we started an experiment to detect low mass dark matter using a low threshold detector. Detector module consists of CaF_2 crystal and MMC (Metallic Magnetic Calorimeter) sensor. MMC is a sensor that can measure temperature changes and measures the phonon signal generated by the crystal. In this presentation, we will present CaF_2 detector set-up and analysis results.

Keywords:

CaF_2 , SQUID, MMC, Dark Matter

Recent progress on Solar Atmospheric Neutrino Searches with the IceCube detector

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Abstract:

Interactions between cosmic rays and the solar atmosphere are expected to result in the generation of particle showers, which produce gamma rays and neutrinos when decaying. While there has been evidence for high-energy gamma rays originating from the solar disk, a search for high-energy neutrinos from the Sun with 7 years (2010-2017) of IceCube data has not observed any evidence of a signal. There are indications for a possible enhancement in the high-energy neutrino flux during the solar minimum of 2018-2020. We present a progress update on a new solar atmospheric neutrino search that improves upon the previous analysis and extends it to cover periods of the solar minimum.

Keywords:

Neutrinos, Solar Physics, IceCube

Nuclear Equation of State for hot dense matter

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Abstract:

Nuclear equation of state (EOS) for hot dense matter is constructed with energy density functional (EDF) and liquid drop model (LDM) technique. The EDF is based on the theoretical calculations, nuclear experiments, and astrophysical observations. These constraints are included using the Bayesian techniques. Compared with the classical LDM approach containing alpha particle, deuteron, triton, and helio are added to construct nuclear EOS. The nuclear surface tension and the critical temperature necessary for the free energy of finite nuclei are calculated in a consistent way. In this talk, I will present and discuss the current results obtained from LDM and EDF with most recent parameters.

Keywords:

Nuclear matter, Neutron Stars, Supernovae

Evaluation on the strength of NiCu cycle in rp-process and its impact on X-ray bursts

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Abstract:

The $^{59}\text{Cu}(p,a)$ and $^{59}\text{Cu}(p,g)$ reaction rates determine the strength of NiCu cycle, $^{56}\text{Ni}(p,g)$, $^{57}\text{Cu}(p,g)$, $^{58}\text{Zn}(B^+ \nu)$, $^{58}\text{Cu}(p,g)$, $^{59}\text{Zn}(B^+ \nu)$, $^{59}\text{Cu}(p,a)$, ^{56}Ni , in rp-process. Numerous works have shown their importance in predictions of X-ray bursts (XRB) models, as a strong NiCu cycle will prevent the nucleosynthesis of heavier elements. The two reaction rates, however, currently have never been estimated by experiments.

Calculations of the two reactions were performed based on the published experimental data for the first time. Detail nuclear properties of ^{60}Zn , the compound nucleus, were evaluated based on the data. The reaction rates from the resonance contributions were determined through the nuclear properties. The obtained reaction rates were used for the XRB model calculations. The results show the two reactions don't strongly affect the XRB model predictions compared to the previous sensitivity studies. Detail analysis of the simulation results is ongoing.

Keywords:

X-ray bursts, XRB, NiCu cycle, $^{59}\text{Cu}(p,a)$, ^{56}Ni , $^{59}\text{Cu}(p,g)$, ^{60}Zn

The $^{14}\text{O}(\alpha,p)^{17}\text{F}$ Cross Section Measurement with the Texas Active Target detector

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Abstract:

Recent studies have shown that the $^{14}\text{O}(\alpha,p)^{17}\text{F}$ reaction rate is one of the important ones affecting a large variation of energy generation and final ash in X-ray burst models. In addition, the reaction rate is known to determine the break-out path from the hot CNO cycle to the rp-process at sufficiently high temperatures ($T_9 > 0.5$). In order to constrain the reaction rate, a direct measurement with 3.36MeV/u of the ^{14}O beam energy on the He gas target was proposed and will be performed at the CRIB facility. The TexAT detector, an active-target time projection chamber with highly-segmented silicon and CsI detectors, will be used in the $^{14}\text{O}(\alpha,p)^{17}\text{F}$ experiment for tracking the outgoing particles. The high beam rate test of the TexAT detector was performed at Texas A&M University. The stable ^{14}N beam of 2.9 MeV/u energy was delivered to the TexAT active target, and its beam intensity was 3×10^5 pps. The $^{14}\text{N} + \alpha$ elastic scattering data was obtained, and its data analysis is ongoing. More detailed results will be presented in the presentation.

Keywords:

$^{14}\text{O}(\alpha,p)^{17}\text{F}$, TexAT, AT-TPC

Single transverse spin asymmetry for the very forward neutral pion production

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Abstract:

We investigate the single transverse spin asymmetry for the forward neutral pion production using the interferences between proton, $\Delta(1232)$ and $N^*(1535)$ Reggeon exchanges. The Born amplitudes for the $p + p^\uparrow \rightarrow \pi^0 + X$ are expressed in terms of the hybridized Regge propagator and inclusive proton-baryon processes $A_{pB \rightarrow X}$. Since they are experimentally not known yet, one parametrizes $A_{p\Delta \rightarrow X}$ and $A_{pN^* \rightarrow X}$ as fitting parameters. We presented the numerical results for A_N as functions of p_T and x_F . The results describe very well recent experimental data from the RHICf Collaboration. The present study indicates that in the low p_T region A_N is governed by diffractive processes.

Keywords:

Diffractive process, Regge theory, Spin asymmetry

Temperature dependent of the QCD chiral condensate and quark mass in the non-local Nambu-Jona-Lasino model

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Abstract:

Chiral condensate and quark mass at nonvanishing temperature are studied in the non-local Nambu-Jona-Lasinio (NL-NJL) model with the help of the Schwinger proper-time representation. In the calculation, we perform the Gaussian, and Lorentzian types of momentum dependence functional forms with the ultraviolet (UV) cutoff. The UV-cutoff is determined by setting the IR-cutoff based on QCD value and fitting them with the pion mass and pion decay constant in vacuum. We first compare our model predictions on vacuum momentum-dependent chiral condensate and quark mass to the non-local chiral quark (NLCHq) model as well as the lattice QCD results. We then analyze the chiral quark condensate and the quark mass at nonvanishing temperature. Our interesting result on the chiral condensate, and quark mass as well as transition (critical) temperature at finite temperature will be presented and the implication of the spontaneously broken of chiral symmetry in the chiral condensates will be discussed.

Keywords:

QCD chiral condensate, Non-local NJL model, Schwinger proper-time representation, Finite temperature

Pion-proton elastic scattering at finite baryon density

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Abstract:

We study the density dependent of the $\pi^+ p$ elastic scattering around the threshold energy, considering the $\Delta(1232)$ baryon resonance which is the most likely propagating particle in the reaction. The effective baryon mass is obtained in the quark-meson coupling (QMC) model at quark level and the effective $\Delta(1232)$ baryon mass is then calculated using the effective nucleon mass via the SU(3) flavour symmetry rotation. With those medium quantities obtained from the QMC model, we calculate the cross section of hadron scattering as well as the angular distribution at higher baryon density. Our results on the cross section and angular distribution at finite density are presented and their implications to the properties of neutron stars will be discussed.

Keywords:

elastic scattering, Δ baryon resonance, quark meson coupling model, SU(3) flavour symmetry rotation, total cross section

$K^- p \rightarrow K \Xi$ reaction in a Regge model

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Abstract:

We investigate the $K^- p \rightarrow K \Xi$ reaction based on a hybridized Regge model. The Λ and Σ Regge trajectories are taken into account in the u-channel Feynman diagram as for a dominant background contribution. In addition, various Λ^* and Σ^* resonances are included in the s-channel to explain the bump structures at $W = 2.0$ and 2.2 GeV. The high-spin hyperon field is described by the Rarita-Schwinger formalism. The relevant experiment is ongoing at the J-PARC facility. Our results will be valuable for a deep understanding of multistrange systems.

Keywords:

Regge model, Hyperon resonances, Hyperon Regge trajectories

Two-dimensional transverse charge distributions of the nucleon and Abel transformations

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Abstract:

In the present talk we discuss a recent work on the transverse charge distributions of the transversely polarized nucleon with the nucleon momentum varied. As the longitudinal momentum (P_z) of the nucleon increases, the electric dipole moment is induced, which brings about the displacement of the transverse charge and magnetization distributions of the nucleon. The induced dipole moment of the proton reaches its maximum value at around $P_z=3.2$ GeV on account of the kinematical reason. We also show how the Abel transformations map the three-dimensional charge and magnetization distributions in the Breit frame onto the transverse charge and magnetization ones in the infinite momentum frame.

Keywords:

Electromagnetic structure of the nucleon, Transverse charge densities, Abel transform

Axial-vector transition form factors for the light baryons and the singly heavy baryons within a pion mean-field approach

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Abstract:

In the present talk, we report recent results for the axial-vector transition form factors from the baryon decuplet to the baryon octet, based on the self-consistent SU(3) chiral quark-soliton model. We consider the rotational $1/N_c$ corrections and the effects of explicit flavor SU(3) symmetry breaking. We compare the numerical results with those from lattice QCD. We also present the results for the axial-vector transition form factors of the singly charmed baryons and discuss physical implications of the results.

Keywords:

chiral quark-soliton model, pion mean-field approach, axial-vector transition form factor, axial-vector transition form factors of singly heavy baryons

New Co-based quantum materials with spin-orbit entanglement

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Abstract:

Quantum materials are thriving in a much broader field of quantum information science, and entanglement is the key concept. Arguably, quantum mechanics' rich history is littered with the continuing question about entanglement and its implications, the famous example of the Einstein–Podolsky–Rosen paradox. Materials search has been very active for the last ten years or so. Despite the impressive development of the field over the years, it is still an open question how the spin-orbit entanglement finds itself under the strong correlation effect of large Coulomb U . The natural hunting ground is the 3d transition metal compounds. In this talk, I will present several cases that might host the sought-after phase with spin-orbit entanglement and strong correlation. In the examples, I will highlight several Co-based compounds.

Keywords:

Quantum materials, spin-orbit entanglement, Co-based compounds

Field-Tuned Quantum Effects in a Triangular-Lattice Ising Magnet

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Abstract:

Quantum materials are solids with exotic physical properties that arise not only from the classical properties but also from quantum effects of their electrons. Elucidating the interaction between classical and quantum degrees of freedom quantitatively is not only important to obtain a complete understanding of quantum materials but also provides clues to manipulate quantum states in a controlled manner, which are of great scientific and technological importance.

In this talk, we will present neutron scattering and thermodynamic measurements of the recently discovered triangular lattice antiferromagnet TmMgGaO_4 . We show that TmMgGaO_4 is an Ising magnet with intertwined dipolar and multipolar order, which can be accurately described by a transverse field Ising model. We also use longitudinal magnetic fields to tune the quantum fluctuations and consequently manipulate the quantum states in TmMgGaO_4 . We find that the system exhibits a quasi-plateau state dressed with quantum fluctuations in the intermediate field regime. In this state, all physical properties, including the Néel temperature, static moment, spin gap and quantum excitations, show unconventional non-monotonic behaviors with field and temperature. In the high field regime where the quantum fluctuations are largely suppressed, we observed a disordered state with coherent magnon-like excitations despite the suppression of the spin excitation intensity. Through the combination of quantum and semi-classical analysis, we are able to understand these behaviors quantitatively by considering the subtle competition among quantum fluctuations, classical frustrated Ising interactions, and classical thermal fluctuations.

Keywords:

Neutron scattering, Quantum magnet, Transverse field Ising model

Nontrivial temperature dependence of magnetic anisotropy in multiferroics $\text{Ba}_2\text{MnGe}_2\text{O}_7$

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Abstract:

Spin-driven multiferroics [1] have been extensively studied since the discovery of an enhanced magnetoelectric (ME) effect in TbMnO_3 [2]. Through spin-orbit coupling (SOC), a spin order induces a change of charge distribution, leading to emergence of electric polarization. This time we measured the temperature dependences of the static magnetization and the spin excitation in a square-lattice antiferromagnet $\text{Ba}_2\text{MnGe}_2\text{O}_7$ [3]. An anisotropy gap of the observed low energy mode is scaled by electric polarization rather than a power of sublattice moment. Spin nematic interaction in effective spin Hamiltonian, which is equivalent to interaction of electric polarization, is responsible for the easy-axis anisotropy. The nontrivial behavior of the anisotropy gap can be rationalized as change of the hybridized d - p orbital with temperature, leading to the temperature dependence of the spin nematic interaction. The effect of hyperfine coupling between nuclear and electron spins was also observed in the low temperature region using state of art spectrometer.

[1] Y. Tokura, S. Seki, and N. Nagaosa, Rep. Prog. Phys. **77**, 076501 (2014).

[2] T. Kimura, *et al.*, Nature **426**, 55 (2003).

[3] S. Hasegawa *et al.*, Phys. Rev. Research **3**, L032023 (2021).

Keywords:

multiferroics, spin nematic interaction, square-lattice antiferromagnet

Magnetic Excitations of Honeycomb Iridates studied by Inelastic Neutron Scattering

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Abstract:

The layered honeycomb iridates Na₂IrO₃ [1] and Li₂IrO₃ [2] are probably the first set of proposed Kitaev materials, candidates to display novel magnetic states stabilised by the strong spin-orbit coupling at the 5d Ir ions. This project explores the spin dynamics of these frustrated honeycomb iridate magnets by powder inelastic neutron scattering. However, this is technically challenging due to the large absorption cross-section of neutrons by the Ir nuclei. Using an optimised setup to minimise neutron absorption, we have successfully observed strongly dispersive spin-wave excitations of the Ir moments. Results are compared with predictions for a Kitaev-Heisenberg model and other models, including further neighbour couplings.

[1] Spin waves and revised crystal structure of honeycomb iridate Na₂IrO₃, S. Choi et al., Physical Review Letter 108, 127204 (2012).

[2] Spin dynamics and field-induced magnetic phase transition in the honeycomb Kitaev magnet alpha-Li₂IrO₃, S. Choi et al., Physical Review B 99, 054426 (2019).

Keywords:

Frustrated magnetism, Kitaev physics, honeycomb iridates, inelastic neutron scattering, spin-wave calculation

Energy Band Structure of Cu:PSS/Donor interfaces in photovoltaic device applications

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Abstract:

In Photovoltaic (PV) devices, interfacial properties between the donor phase and hole transport layers (HTLs) are critical factors which govern charge extraction efficiency. Many ionic and polar materials are known to function as effective interfacial layers, however, an understanding of how ionic moieties affect the electronic band structure and characteristics of Photovoltaic (PV) devices is lacking. In this study, we've introduced a new, pH-neutral polyelectrolyte that resolves several problems which are encountered with the commonly used HTL, poly(3,4-ethylenedioxythiophene):polystyrenesulfonate (PEDOT:PSS). We've designed an effective p-type polyelectrolyte dopant, comprising an anionically charged PSS backbone with easily reduced Cu²⁺ counter-ions (Cu:PSS) and analyzed interfacial properties for HTL/donor interfaces by photoelectron spectroscopy. We've quantified the effects of the polyelectrolyte on interfacial energy levels and charge extraction efficiency between the active layer and HTL. Using optimized processing conditions the efficiency can be improved from 8.31 % to 9.28 % in conventional organic solar cells compared to a standard PEDOT:PSS HTL. The energy level alignment at the HTLs/donor interface determined by ultraviolet photoelectron spectroscopy measurements reveals the origin of distinct differences in device performances. The reduced ionization potential (IP) and hole injections barrier (Φ_h) at the HTL/donor interface plays a crucial role in efficient charge extraction in conventional OSCs.

Keywords:

photoelectron spectroscopy (PES), electronic structure

Modulating the Curie temperature and magnetic anisotropy in ultrathin layered ferromagnet Cr₂Te₃

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Abstract:

Ultrathin layered ferromagnets have demonstrated fascinating two-dimensional magnetism down to atomic layers, providing a peculiar playground of spin orders for investigating fundamental physics and spintronic applications. However, a film growth strategy with designed magnetic property is not well established yet. Here, we present a simple method to control both Curie temperature (T_C) and magnetic anisotropy during growth of ultrathin Cr₂Te₃ films. We achieve increase of T_C from 165 K to 310 K in sync with magnetic anisotropy switching from out-of-plane orientation to in-plane one, respectively, via controlling tellurium source flux during film growth, leading to different c-lattice parameters while preserving both stoichiometry and thicknesses. We attributed modulation of magnetic anisotropy to switching of magnetic orbital moment, using x-ray magnetic circular dichroism analysis. We also show that different interlayer distance might be responsible for the magnetic anisotropy change, supported by theoretical predictions. These findings emphasize the ultrathin Cr₂Te₃ films as a promising candidate for developing room-temperature spintronic applications and similar growth strategy might be applicable to other layered chalcogenide compounds

Keywords:

nanoscale-layered-ferromagnets, room-temperature ferromagnetism, magnetic anisotropy, two-dimensional materials, spintronic applications

Orbital-selective observation of Ir 5d in IrO₂ epitaxial thin films using resonant inelastic x-ray scattering

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Abstract:

IrO₂ has been ideal model system in energy conversion material due to activity and stability in *oxygen evolution reaction* (OER). Particularly Ir 5d orbital states in IrO₂ dominantly contribute the OER process because d orbitals constructing electronic states near Fermi level in transition metal oxides catalysis directly interact with adsorbates. But how Ir 5d orbital states of IrO₂ participate in OER is still obscure due to limits of experimental techniques. We introduce Ir L₃-edge resonant inelastic x-ray scattering (RIXS) experiment about IrO₂ epitaxial thin films grown on TiO₂ (100) and (001) substrates. RIXS is an incisive tool to reveal orbital states near Fermi level of specific atom than conventional XAS and XPS. For unveiling the role of Ir 5d orbitals of IrO₂ in OER, we found orbital-selective method of the 5d orbital in IrO₂ by controlling scattering geometries in pristine epitaxial IrO₂ thin films. Concretely, the *5d dx²-y²* orbital in the plane of edge-sharing of octahedra along [001] dominantly contributed to ~ 2eV energy loss signal.

Keywords:

RIXS, IrO₂

Epitaxial growth of ZnTe thin films and Ovonic threshold switching properties for selector device

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Abstract:

Electrical switching materials have attracted renewed attention for next-generation artificial intelligent (A.I.) or neuromorphic computing devices. The A.I. computing devices requires development of highly integrated memory architecture. The Ovonic threshold switching (OTS) selector device serves an essential role to prevent leakage current generated in the high-density memory cells with the cross-point array structure. Chalcogenide materials, such as GeSe, GeTe, and ZnTe, have shown OTS properties with mostly amorphous phases. Microscopic amorphization is considered as main driving mechanism of such threshold switching. Recently, however, polycrystalline ZnTe films also show OTS behavior. However, the effect of crystallinity and stoichiometry on the OTS behavior is not yet thoroughly examined. Here, we demonstrate synthesis of ZnTe thin films with various crystalline states and stoichiometries by using molecular beam epitaxy (MBE). Synchrotron-based high resolution X-ray diffraction (HRXRD) analysis showed that the crystalline states are varied from single-crystalline state to polycrystalline one depending on substrates' crystalline state. X-ray photoemission spectroscopy (XPS) analysis indicated that the chemical composition is largely varied depending on the deposition rate ratio of Te and Zn. We also performed spectroscopic ellipsometry measurements to analyze the optical bandgap. Finally, we analyzed local electrical characteristics by using conductive atomic force microscopy (C-AFM).

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Keywords:

ZnTe, Molecular beam epitaxy, Ovonic threshold switching, selector

Analysis of estimated parameter's probability distribution using machine learning techniques: Application to the x-ray reflectivity data analysis.

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Abstract:

Supervised machine learning 기법을 이용 한 Artificial neural network (ANN) technique은 4차 산업혁명 뿐만 아니라 물리학 전 연구 분야에 많은 영향을 미치며 매우 유용한 도구로써 사용 되고 있다. 많은 data set에 의해 supervised 된 ANN을 활용 한 data 분석 방법은 크게 두가지로 나눌 수 있다. 첫번째는 ANN 으로 하여금 주어진 data가 미리 정해진 그룹 중 어디에 속하는지 판별하게 하는 classification 이고, 두번째는 주어진 data에 대해 특정 parameter를 예측 하는 regression 방법이다. 최근에는 classification 방법을 이용 하여서 X-ray scattering 분야에서도 다양한 x-ray 실험 data 분석을 위해 ANN이 이용 되고 있는데, 전통적인 결정학의 crystal class 구분을 위한 Rietveld refinement로부터, GIWAXS 와 같은 시료의 nano 구조를 분석 하는 문제에 응용 사례가 보고 되고 있다.

한편 Regression 방법을 이용 하는 대표적인 사례로는 X-ray reflectivity (XRR) data 분석을 예로 들 수 있다. XRR을 이용한 박막 시료의 구조 분석은 시료의 laterally averaged 된 electron density profile을 out of plane 방향으로 sub angstrom 단위로 얻을 수 있는 잘 검증 된 tool 이다. XRR data 분석 과정은 시료에 입사 하였다가 거울 반사 되는 X-ray를 incident angle에 따라 측정 하고, 이 data를 simulation과 iteratively 비교 하여 film 각층의 두께, 밀도, 그리고 계면 거칠기 등의 구조를 대표 하는 parameter 를 찾는 과정 으로 요약 가능 하다. 이러한 분석 과정에 드는 시간과 노력을 줄이기 위해 ANN을 이용 한 방법이 연구 되고 있으며, 최근에는 ANN을 이용 한 regression 분석의 정확도를 개선 시키는 방법과, 분석 결과의 신뢰성을 검증 하는 방법에 대한 관심이 특히 커지고 있다.

본 연구에서는 확률론적인 parameter estimation을 가능케 하는ANN인 Mixture density network(MDN)를 XRR data의 curve fitting 에 적용 하여, data로 부터 구조와 관련 된 parameter의 확률 분포를 얻고, 그 분포를 unsupervised learning 방법을 이용 하여 분석 하는 방법에 대해 다룬다. 결론적으로 MDN을 이용 하면 구조 관련 parameter의 에러를 얻는 동시에, X-ray scattering 분야에서 유명한 inverse problem도 해결 할 수 있음을 보인다.

Keywords:

Machine learning, X-ray reflectivity, Neural network, Probabilistic parameter estimation

Surface oxidation in a van der Waals ferromagnet $\text{Fe}_{3-x}\text{GeTe}_2$

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Abstract:

We investigate the surface oxidation in $\text{Fe}_{3-x}\text{GeTe}_2$, a van der Waals ferromagnetic material widely utilized for spintronic applications owing to its high T_C , large perpendicular magnetic anisotropy. While known for its relative air-insensitivity, we find that exposure to air during the handling process (e.g. device or heterostructure fabrication) causes surface oxidation resulting in reduction or disappearance of its magnetic signal. Comparison of x-ray absorption and x-ray magnetic circular dichroism spectra between pristine and air-exposed $\text{Fe}_{3-x}\text{GeTe}_2$ confirm a naturally oxidized surface layer. The surface iron oxide layer has predominantly Fe^{3+} content. X-ray absorption spectroscopy done on micron-sized exfoliated $\text{Fe}_{3-x}\text{GeTe}_2$ flakes show that the change in the surface chemical properties is more prominent for thinner flakes implying that the surface oxide layer has a more-or-less uniform thickness (2~3nm). The presence of a naturally oxidized surface layer on air-exposed $\text{Fe}_{3-x}\text{GeTe}_2$ can significantly alter its surface chemical properties, particularly for thin exfoliated flakes. The surface oxidation of $\text{Fe}_{3-x}\text{GeTe}_2$ is an issue that must be seriously considered in its device fabrication process, and in the characterization of its spintronic properties.

Keywords:

$\text{Fe}_{3-x}\text{GeTe}_2$, surface oxidation, van der Waals ferromagnetic material, x-ray absorption, x-ray magnetic circular dichroism

Resonant interaction in chiral, Eshelby-twisted van der Waals atomic layers

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Abstract:

두 층의 그래핀이 서로 30도 회전하여 적층된 그래핀 준결정 구조는 원자배치와 전자구조에 모두 준결정 질서를 보인다 [1-3]. 이번 발표에서는, 이 그래핀 준결정을 확장하여, 무한히 많은 동일한 원자층들이 서로 특정한 각도 θ 로 적층된 Eshelby-twisted 반데르발스 원자층에서 나타나는 준결정 상태를 소개하고자 한다 [4]. 이 구조들은 브릴루앙 영역의 특정한 위치에서 개개의 원자층의 상태들이 공명을 일으켜, 일반적인 무아레 초격자의 전자 구조와 큰 차이를 나타낸다. 이 공명 상태들은 원자층의 주기와 commute하지 않는 준결정 질서를 보이며, 비공명 상태보다 더 작은 브릴루앙 영역을 갖는다. 또한, 이 상태들은 θ 에 무관하게 보편적인 1차원 사슬 형태의 하밀토니안으로 기술되고, 원형 편광된 빛에 대해 분명한 선택규칙을 보인다.

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Keywords:

그래핀, 준결정, 공명 상태, Eshelby-twisted 반데르발스 원자층

A cascade of integer and fractional quantum Hall transition in a non-magic angle twisted bilayer graphene

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Abstract:

We report on the quantum Hall effect in two stacked graphene layers rotated by 2° . The tunneling strength among the layers can be varied from very weak to strong via the mechanism of magnetic breakdown when tuning the density. Odd-integer quantum Hall physics is not anticipated in the regime of suppressed tunneling for balanced layer densities, yet it is observed. We interpret this as a signature of Coulomb interaction induced interlayer coherence and Bose–Einstein condensation of excitons that form at half filling of each layer. A density imbalance gives rise to reentrant behavior due to a phase transition from the interlayer coherent state to incompressible behavior caused by simultaneous condensation of both layers in different quantum Hall states. With increasing overall density, magnetic breakdown gains the upper hand. As a consequence of the enhanced interlayer tunneling, the interlayer coherent state and the phase transition vanish. In addition, we will discuss recent observations of fractional quantum Hall effect and their phase transition at first excited Landau level in large twist angle device.

Keywords:

quantum Hall, fractional quantum Hall, twisted bilayer graphene

Steady Floquet-Andreev States Probed by Tunnelling Spectroscopy

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Abstract:

Engineering quantum states through light-matter interaction has created a new paradigm in condensed matter physics. A representative example is the Floquet-Bloch state, which is generated by time-periodically driving the Bloch wavefunctions in crystals. Previous attempts to realise such states in condensed matter systems have been limited by the transient nature of the Floquet states produced by optical pulses, which masks the universal properties of non-equilibrium physics. Here, we report the generation of steady Floquet Andreev (F-A) states in graphene Josephson junctions by continuous microwave application and direct measurement of their spectra by superconducting tunnelling spectroscopy. We present quantitative analysis of the spectral characteristics of the F-A states while varying the phase difference of superconductors, temperature, microwave frequency and power. The oscillations of the F-A state spectrum with phase difference agreed with our theoretical calculations. Moreover, we confirmed the steady nature of the F-A states by establishing a sum rule of tunnelling conductance, and analysed the spectral density of Floquet states depending on Floquet interaction strength. This study provides a basis for understanding and engineering non-equilibrium quantum states in nano-devices.

Keywords:

Floquet state, Graphene Josephson junction, Superconducting tunnel spectroscopy

Artificial Phonon Engineering in Atomically-Designed Oxide Heterostructures

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Abstract:

Artificial engineering of phonons, i.e., collective lattice vibrations in crystals, plays an important role in modulating various physical aspects of materials including thermal conductivity, electron-phonon interaction, confinement of lattice vibration, and optical polarization. Most demonstrations of phonon-engineering have been exclusively limited to the high-quality heterostructures of III–V compound semiconductors. Yet, the phonon engineering in materials with useful functionalities, such as complex oxides, will give birth to novel applications of coherent tunable phonons in future quantum acoustic devices. Here, we propose an atomic-scale precision approach for complex oxides to realize the artificial engineering of functional phonons. We demonstrate atomic-scale modulation of phonons using SrRuO₃/SrTiO₃ superlattices [1-7], wherein controllable phonon modes were observed via confocal Raman spectroscopy. In particular, the coherent superlattice structures induced the backfolding of acoustic phonon dispersion, and resultant zone-folded acoustic phonons were created in the THz frequency domain. We could further fine-tune the frequencies (1~2 THz) via atomic-scale precision thickness control. Meanwhile, we also confirmed a polar optical phonon originating from the local inversion symmetry breaking in the artificial oxide superlattices, exhibiting emergent functionality. Our approach of atomic-scale heterostructuring of complex oxides will inspire us to develop material systems for quantum acoustic devices, especially with the capability of functionality integration.

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Keywords:

Synthetic oxide crystal, Phonon engineering, Terahertz acoustic wave, Atomic-scale epitaxy, Confocal Raman spectroscopy

Ultrashort electric pulse-driven polar state in quantum paraelectric SrTiO₃ thin film at room temperature

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Abstract:

Access to hidden metastable phases of matter is a crucial early stage to explore exotic properties. Strontium titanate (SrTiO₃) is a quantum paraelectric in which quantum fluctuations of ionic positions prevent the long-range polar order even at zero kelvin. Application of external bias overcoming the fluctuations has dynamically induced metastable polar states at the cryogenic temperature. However, the existence of these polar states above room temperature has not been proved and explored yet because the magnitude of the electric field required to drive the polar state in SrTiO₃ can be larger than the low-frequency dielectric breakdown field in principle. Using nanosecond electric pulse for which the high field can be applied without the breakdown, we found an ultrafast phase transition into the polar state. We measured the electromechanical response of a 50 nm-thick paraelectric SrTiO₃ epitaxial film grown on the (001) oriented SrRuO₃ electrode and SrTiO₃ substrate as a function of the magnitude of electric field up to 1.5 MV/cm using advanced time-resolved x-ray microdiffraction. At a low field regime, the out-of-plane lattice constant of the film increased quadratically due to the electrostrictive response of the dielectric component. At above 1 MV/cm, SrTiO₃ film exhibited the linear lattice expansion with increasing the electric field, which is consistent with piezoelectric distortion, indicating that the high field induced the transition into polar states.

Keywords:

Metastable phase transition, Quantum paraelectric SrTiO₃, Time resolved x-ray diffraction, Novel phenomena in oxide heterostructure

Revisiting People-Bean Model Using Modern Data Analytics for the Understanding of Epitaxial Strain Relaxation

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Abstract:

Strain relaxation plays a crucial role in thin film systems as it determines the overall structure of the crystalline lattice. The critical thickness h_c is defined as a thickness that the strain starts to relax. Owing to its physical significance, numerous approaches have been proposed to understand the mechanism of strain relaxation and predict h_c . One of the most successful approaches is the phenomenological People-Bean (PB) model, which considers the balance between strain energy density and dislocation energy density. Despite its successful predictability in many instances, predictions for some particular systems have not been as successful. In addition, obtaining the quantitative weight of each physical parameter in determining h_c which would enable a fundamental understanding of the strain relaxation behavior, is inherently difficult for the phenomenological approach. In this study, we use modern data analytics of machine learning accompanied by feature engineering and correlation analyses to quantitatively examine the correlation between h_c and various physical and chemical features. First, Consistent dataset construction is achieved by collecting experimental h_c data of perovskite oxide thin films. Second, Feature engineering for optimum ML training gives high accuracy ($R^2 = \sim 0.87$) among several ML models trained. Third, correlation analyses quantitatively demonstrate that Poisson's ratio ν and lattice mismatch ϵ^E play an important role in determining h_c provided that they are combined with other features. Lastly, the assessment for the fidelity of our ML model is performed by comparing ML predicted h_c and experimental h_c value of the real system, which shows a good agreement. Exploiting this modern data analytics as a useful and expandable platform, one can catch further insights from other effective features.

Keywords:

data analytics, machine learning, correlation analyses, strain relaxation, critical thickness, People-Bean model

Oxygen evolution reaction of BaRuO₃ thin films with crystalline and amorphous structures

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Abstract:

The epitaxial transition metal oxide (TMO) thin films and heterostructures are excellent model system for examining and understanding the activity and stability of electrocatalytic activity. In particular, it has been explicitly shown that the oxygen evolution reaction (OER) and chemical stability of perovskite SrRuO₃ have opposing trend [1]. Because the OER activity and stability are determined by the surface electronic structure of the perovskite Ruthenates, investigation on atomic and electronic structures of the thin film surface provide fundamental insight into the electrocatalytic behavior. Especially, the crystallinity of a material, which can be defined by the degree of translational symmetry of a lattice, should directly influence the OER activity and stability. Whereas the crystalline perovskite Ruthenates have shown high OER activities [2, 3], amorphous structures are more viable in actual applications. In this study, we directly compare the OER activities and stabilities between the crystalline and amorphous BaRuO₃ thin films. We suggest that the cubic crystalline phase (3C) BaRuO₃ thin film has higher OER activity but lower stability than the amorphous BaRuO₃ thin film. The higher OER activity trend in the 3C BaRuO₃ compared to the amorphous BaRuO₃ is principally owing to its higher electric conductivity. In practice, we controlled the growth temperature (T_g) to achieve the crystallinity control. X-ray diffraction confirmed crystalline phase for $T_g = 400\sim 600$ °C and amorphous phase in lower T_g . To show the stoichiometry doesn't change with T_g , we employed the electron dispersive x-ray spectroscopy. Using cyclic voltammetry, we identified that the 3C thin film exhibits higher current density (normalized by electrochemical surface area at 1.4 V vs. RHE) of 340 mA than the amorphous thin film (40 mA) by about an order of magnitude. On the other hand, the amorphous BaRuO₃ thin film show higher chemical stability from chronoamperometry measurements. From transport and optical spectroscopic measurements, we observed enhanced Drude contribution for the 3C thin film compared to the amorphous one, providing the origin of the opposing trend in OER activity and stability.

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Keywords:

Transition metal oxide, Activity, Stability

Non-volatile 180° polarization reversal dynamics of ferroelastic nanodomains in Pb(Zr,Ti)O₃ thin film

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Abstract:

Ferroelectric heterostructures exhibiting non-volatile polarization reversal are promising candidates for next-generation logic devices. However, binary logic from conventional polarization switching (two states) limits the computing capability of the logic devices. To enhance the computing capability, multi-valued logic devices that can store multiple bits of information in a ferroelectric structure should be developed. Controlling the polarization state of ferroelastic nanodomains inside ferroelectric material is one way to induce multiple states through which low power and high information density logic devices can be realized. Due to the strongly coupled polarization vector in the ferroelastic thin film, theoretical studies have predicted that the electric field for the polarization reversal of ferroelectric domains can also induce polarization reversal in the nano-sized ferroelastic domains. The polarization reversal in both ferroelectric and ferroelastic domains is an ultrafast phenomenon, and probing the polarization reversal mechanism is crucial for manipulating the multi-polarization states by external stimuli. Thus, we need an *in-situ* probe to record the ultrafast switching dynamics to explore the multi-polarization states. Here, *in situ* x-ray microdiffraction experiments in the sub-microsecond resolution are carried out to investigate the polarization switching dynamics of ferroelastic nano-sized *a*-domains and ferroelectric *c*-domains in Pb(Zr,Ti)O₃ (PZT) thin films. Our studies reveal that polarization reversal in both *a* and *c*-domains in PZT thin film occurs at the same amplitude of the electric field along [001] direction, and these switched domain states can coexist. The electrostatic potential generated *via* bound charges accumulated at *a/c* domain boundaries causes the polarization reversal even in *a*-domains after ferroelastic switching. The microsecond dynamics of experimental polarization reversal studies and the phase-field simulations reveal that the polarization reversal in *a*-domains occurs faster than *c*-domains. Our experimental identification of the polarization reversal process can provide fundamental insights into the engineering of the ferroelastic domains to realize low-power multi-valued logic devices.

Keywords:

Ferroelectric/ferroelastic domains, Polarization switching dynamics

Pulsed laser growth optimization of SrMoO₃ thin films for magneto-transport property

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Abstract:

SrMoO₃ has been reported to have the lowest room temperature resistivity among perovskite transition metal oxides. Electric resistivity of SrMoO₃ follows the trend of Fermi-liquid with the T^2 -dependence owing to the significant contribution of electron-electron scattering at low temperature. As the temperature is increased above a critical temperature T^* , the resistivity deviates from the T^2 -dependence, and electron-phonon interaction becomes the dominant transport mechanism. In bulk single-crystal SrMoO₃, the T^* was reported to be ~140 K [1], whereas, for epitaxial SrMoO₃ thin films, a lower T^* of ~85 K was reported [2]. On the other hand, a Pauli paramagnetic behavior has also been suggested from temperature-independent magnetic susceptibility measurements [3], implying the importance of spins in transport behavior. Hence, a detailed magneto-transport study would enlighten the correlation between spin ordering and transport behavior in SrMoO₃. It could also provide insight into the dissimilar T^* value between the bulk single crystal and epitaxial thin film.

In this study, we grew epitaxial SrMoO₃ thin films using pulsed laser epitaxy to study the magneto-transport behavior. The growth condition of SrMoO₃ thin films on (110) GdScO₃ substrates was optimized by varying the laser fluences in a high-vacuum condition ($P < 5 \times 10^{-7}$ Torr) at 600 °C. The laser fluences used were varied from 0.19 to 0.57 J/cm² by systematically modifying the laser energy and aperture sizes. Structural characterization done by using x-ray diffraction confirms the growth of high-quality SrMoO₃ thin films. The resistivity data exhibits metallic behavior at all temperatures. The temperature dependence of the resistivity begins to deviate from the T^2 -dependence above the critical temperature $T^* = 111$ K, which is in between the reported value of the thin film and bulk. In addition, magnetoresistance (MR) measurements for the films show a slight change in the resistivity with increasing magnetic field, indicating a small difference in the mean free path of the electron scattering. The positive MR trend increases with decreasing temperature, owing to the electron-electron interactions. Our study provides deeper insights into the magnetic field effect to the electron scattering in understanding the underlying mechanism behind the transport properties of SrMoO₃.

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Keywords:

SrMoO₃, magnetotransport property, electron-phonon interaction, electron-electron scattering

First-principles study on the systematic search of the rotation-induced polar phases in perovskite oxides

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Abstract:

In many perovskite oxides, ferroelectricity is known to be intimately related with octahedron rotation patterns in which the polar distortions can be suppressed or enhanced, depending on the octahedral rotation patterns. Using first-principles density functional theory, we perform a systematic investigation of the relation between octahedron rotation patterns and polar instability in a wide range of perovskite oxides having empty *d*-bands. By identifying the unstable polar distortions for various rotation patterns commonly observed in perovskite oxides, we find switchable polar distortions that can be stabilized by changing octahedral rotation patterns with sizable polarization, which may be stabilized in substrate/thin-film geometry by interfacial coupling. Our work, identifying a new polar phase, provides potential candidate materials useful to design new functional materials utilizing interfacial coupling.

Keywords:

first-principles calculation, ferroelectricity, dielectric properties, perovskite oxides, oxide heterostructures

Advanced power generation performance of PVDF-TrFE films by improving the crystallinity of the Pt bottom electrode

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Abstract:

Piezoelectric power generator, which converts mechanical energy to electrical energy, is researched to enhancing power generating efficiency. Here, we investigated the enhanced ferroelectricity and piezoelectric power characteristics of poly (vinylidene fluoride-co-trifluoroethylene) (PVDF-TrFE) thin films grown on Pt/mica substrates. To improving power characteristics, we studied how Pt bottom electrodes affect the formation of PVDF thin films. The crystallinity of the Pt bottom electrode was improved by reducing the deposition rate. From the results of the x-ray diffraction (XRD) experiments, it was confirmed that the crystallinity of the preferentially (111)-oriented Pt bottom electrode was further improved. It made the β -phase formation of PVDF-TrFE thin films on the Pt bottom electrodes formed well. The flexible Pt/PVDF-TrFE/Pt/mica capacitors showed excellent ferroelectric properties with remanent polarization of about $9 \mu\text{C}/\text{cm}^2$ ($2P_r \sim 18 \mu\text{C}/\text{cm}^2$), and ferroelectric properties did not show a significant change even with 1 mm bending. In the investigation of the piezoelectric power generation characteristics, it was confirmed that the piezoelectric power voltages corresponding to the external force of the PVDF-TrFE piezoelectric power elements showed a tendency to increase in response to the improvement of the ferroelectricity of the PVDF-TrFE thin film.

Keywords:

Piezoelectric power generation, PVDF-TrFE thin film, Pt bottom electrode, Mica substrate

초임 교과교육 교수의 눈으로 바라본 대학 물리교육

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Abstract:

본 발표에서 발표자는 2년차 사범대 물리교육과의 교과교육학 담당 교수로 처음으로 사범대의 여러 교과교육학 과목들을 가르치면서 하게 된 여러 가지 고민들을 함께 나누려고 한다. 발표자는 오랫동안 고등학교 물리 교사로 재직하면서 동시에 물리교육연구자로 연구해 왔으며, 이 과정에서 연구와 교육의 괴리를 느끼고 실천적 물리교육 연구를 위해 노력해 왔다. 이에 대학 강의에서도 예비교사들이 학교 실제 학교 현장에서 가르치는데 도움이 되는 내용을 포함시키려고 고민하였으나, 예비교사들의 임용 시험에 도움이 되는 지식을 가르쳐야 한다는 요구에 의한 어려움도 겪고 있다. 결국 발표자는 이런 어려움의 해결 방안으로 발표자가 연구해 왔던 것을 중심으로 강의를 재조직하고 있다. 본 발표에서 발표자는 개념학습과 지도, 탐구학습과 지도 등 이론과 실천이 융합된 강의의 필요성, 자연대의 교과와 구분되는 강의의 필요성과 함께 미래사회를 대비한 대학 물리교육에 대한 생각을 제안할 예정이다.

Keywords:

초임 교과교육 교수, 개념학습과 지도, 탐구학습과 지도, 이론과 실천의 융합, 사범대 물리교육과정

물리 예비교사의 창의·융합적 교수역량 함양을 위한 교육과정 운영

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Abstract:

물리 교사의 교과교육학지식은 사회의 변화에 따라 유연성 있게 변화해야 할 필요가 있다. 인공지능(AI) 시대를 살아가는 물리 교사도 기존의 교수학습이론 뿐만 아니라 현대 사회에서의 과학기술 변화를 이해하고, 이를 물리 수업에 적극적으로 적용할 수 있는 역량을 갖추어야 할 필요가 있다. 이를 위해, 현재 이화여대 과학교육과(물리전공)에서는 사범대학에서 운영하고 있는 한국과학창의재단 지원 사업으로 교과교육 영역 필수 과목인 '교과교육론', '교재연구및지도법', '교과논리및논술' 과목 내용을 AI 시대의 창의·융합적 미래 세대 양성을 위한 내용으로 전환하고자 하는 노력을 기울이고 있다. 첫째, 교육부의 인공지능 정책에 따라 과학교과 내용과 AI의 연계 방안에 대해 모색하여 반영하고 있다. 예를 들어, 자연과학분야 연구에서 AI(머신러닝)를 적용하고 있는 사례를 제시함으로써 과학탐구방법으로서의 AI의 필요성과 그 원리를 이해하도록 하고 있다. 또한 데이터를 활용한 교수학습 방법을 통해 데이터의 규칙성을 파악하고 시각화하는 등 과학적 발견의 과정을 새롭게 이해하도록 구성하고 있다. 더불어, 최근에 개발된 AI관련 애플리케이션을 활용하여 창의·융합적 교수방법을 운영할 수 있도록 지도하고 있다. 둘째, 창의·융합적 교육을 실행할 수 있도록 하기 위해 통합과학 전공을 연계전공으로 운영하여, 본인의 주전공 이외에 타전공에 대한 교수 역량을 함양하도록 권장하고 있다. 또한 통합과학 관련하여 '과학기술과 사회', '첨단과학기술과 미래사회', '과학사와 융합교육' 등의 교과목을 운영하고 있다. 셋째, 대학차원에서 학생들의 소프트웨어 역량을 높이기 위해 6학점을 필수 학점으로 이수하도록 하고 있다. 현재 사범대학 내에서도 예비 교사들의 AI 융합교육역량을 함양하기 위한 교과목 개발을 수행 중에 있다. 아직까지 물리 내용학 분야에서 AI 내용 도입은 본격적으로 진행되고 있지 않으나, 지속적인 협업을 통해 그 방안을 모색해 나가고자 한다.

Keywords:

물리교육

사범대 물리교육 커리큘럼의 현장 적합성과 이에 관한 연구 활성화에 대한 고찰

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Abstract:

사범대학 물리교육 커리큘럼이 중고등학교 현장에서의 물리 교과 또는 비교과 교육의 요구에 어느 정도 부합되는지에 대한 논쟁은 오래되었지만 여전히 앞으로 나아가지 못하고 있다는 의견에 이견을 제시하기 어려운 것이 현실이다. 이제는 이러한 논쟁 단계를 벗어나 다양한 연구 결과를 기반으로 한 합의와 합의에 따른 실행이 필요한 때이다. 이에 대한 중고등학교 현장의 목소리도 다양하지만 다음과 같은 세 가지 질문에 대해 물리교육 연구자와 예비 교사 그리고 현장 교사 모두 진지한 고민과 해결 방안 모색이 필요하다고 생각한다. 첫째, 학교 현장에서의 물리교육은 어떠한 형태로 이루어지고 있으며 교사에게는 어떤 역량이 요구되는가? 둘째, 사범대 커리큘럼은 어떤 내용과 체계를 갖추고 있으며 앞에서 언급한 학교 현장의 요구를 어느 정도 반영하고 있는가? 또 변화하는 교육과정은 사범대 커리큘럼에 어떠한 영향을 주는가? 셋째, 사범대 커리큘럼과 학교 현장의 물리교육을 연계한 사범대 커리큘럼 개선, 예비교사 교육 등에 관한 연구는 지속적으로 이루어지고 있는가? 이번 발표에서는 위의 질문들에 대한 물리교육자들의 의견과 논의를 토대로 사범대학 물리교육에의 개선 방안에 대해 고민해 보고자 한다.

Keywords:

사범대 커리큘럼, 예비 교사 교육, 교사 역량, 사범대 커리큘럼 연구

물리교육 연구과 물리교육론과의 연결, 그리고 물리교육론과 물리수업 실제와의 연결

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Abstract:

본 발표에서는 먼저, 과거로부터 현재에 이르기까지 이루어져 왔던 많은 물리교육 연구들이 사범대학 물리교육론에 충분히 반영되어 있지 못하다는 측면에서, 예비 물리교사 교육을 위해 물리교육론에서 어떻게 물리교육 연구를 반영할 수 있는지에 대해서 먼저 논의하고자 한다. 그리고 두 번째로, 사범대학 물리교육론에서 배운 내용들이 실제 물리교사들의 수업 실행에 충분히 활용되고 있지 못하다는 측면에서 어떻게 사범대학 물리교육론이 지도될 필요가 있는지에 대한 논의하고자 한다. 첫 번째 논의를 위해, 과학 창의성에 대한 학술적 연구결과를 학교 과학활동에 적용하기 위해 필요한 조건이 무엇인지에 대해 연구한 결과(박종원 등, 미발행)를 간단히 살펴보고, 그로부터 물리교육 연구결과들이 사범대학 물리교육론 수업에 적용될 수 있는 방안을 제안해 보고자 한다. 두 번째 논의를 위해, 경험 귀추적 순환학습을 이용한 물리수업 지도안을 작성하는 과정에서 어려움이 무엇이고, 그러한 어려움이 어떻게 해결될 수 있는지에 대한 연구결과(Lee et al., unpublished)를 간단히 살펴보고, 그로부터 사범대학 물리교육론에서 배우는 내용이 중등학교 물리수업에서 활용되기 위해 물리교육론 수업이 어떻게 수행될 수 있는지에 대해 제안해 보고자 한다. 마지막으로 embodied-PCK(박종원 등, 2021)의 개념을 소개하면서, 사범대학에서 배우는 내용들이 중등학교 수업 실행에 적용되기 위한 조건과 과정을 논의하고자 한다.

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Keywords:

이론과 실제, 물리교육론, 예비 물리교사 교육, embodied PCK

KSTAR 플라즈마에서 불순물 가스 주입 연구

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Abstract:

플라즈마 불순물 및 경계 열속 연구센터에서는 핵융합 플라즈마의 노심에서 플라즈마 경계에 이르는 전영역에서 나타나는 다양한 불순물 관련 난제들을 해결하기 위해 불순물 관련 다양한 최첨단 진단계와 물리 전산해석 코드의 활용 및 주체적인 개발을 통해 연구를 수행하고 있다. 센터의 목표는 세부 그룹 간의 유기적인 연구를 통하여 불순물을 능동적으로 활용하여 플라즈마 경계 영역의 최대 난제 중 하나인 내벽 및 디버터 열속 완화의 실질적 구현을 위한 기초연구이다. 이번 발표에서는 디버터로 향하는 열속과 입자속의 제어를 목적으로 연료개스와 불순물 가스를 KSTAR 장치 내부로 주입하여 경계 플라즈마에서 나타나는 여러 물리적 현상을 진단하고 SOLPS-ITER 등의 최첨단 전산해석 코드를 이용한 모델링 결과에 대해 소개한다. 질소 가스 주입의 경우, RMP 인가 여부 등 여러 플라즈마 조건 하에서도 높은 성공률로 디버터-플라즈마 분리현상이 발생하여 열속의 감소효과를 볼 수 있었으며, 특히 올해 캠페인에서는 질소 주입으로 디버터 분리를 10초이상 유지하는데 KSTAR 최초로 성공하여 플라즈마 운전 및 불순물 주입 조건을 확립하였다. 디버터-플라즈마 분리 현상은 디버터 열속 제어를 위한 핵심적인 해결책으로 연구되고 있는 방법이다. 또한 크립톤 가스 주입 실험을 통하여 이온 내부수송장벽 형성과 디버터 열속 완화를 동시에 달성하였으며 전산모사를 통해 불순물의 영향을 분석 중이다.

Keywords:

불순물 수송 해석, 플라즈마-디버터 분리현상, 디버터 열속 완화, 내부수송장벽

열속 완화 디버터 디자인 연구 개발 현황

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Abstract:

혁신적 디버터 열속 제어 처리 기술 거점 센터 (Center for Innovative Divertor, CID)에서는 디버터의 열속 처리 능력을 획기적으로 향상 시킬 수 있는 디버터의 종합적 디자인 개발을 목표로 크게 1. 전산모사를 통한 열속 감쇄 디버터 구조 연구, 2. 디버터 냉각 채널의 열처리 기술 획기적 증대, 3. 디버터 플라즈마 모사 장치를 이용한 디버터 표면 재료 손상에 대한 연구라는 세 가지 방향으로 연구 개발을 해오고 있다. 전산 모사 디버터 구조 연구에서는 DIII-D에서 처음 제시된 SAS (small-angle-slot) 구조를 변형한 형태를 KSTAR에 성공적으로 적용한 연구를 필두로 ITER 급의 대규모 핵융합로나 에너지 밀도가 높은 소형 핵융합로에서도 SAS-like 구조가 디테치먼트를 효과적으로 유도하는 조건을 발견하였다. 냉각 채널 연구에서는 Hypervaportron 에 핀 구조를 최적화하여 디버터 타겟 밑에서 기존의 원형 채널보다 열속 처리 효율이 크게 향상된 신개념의 냉각 채널 연구를 성공적으로 수행하였으며 높은 수준의 공학적 설계 기준까지 맞춤형으로서 실제 핵융합로에 거의 바로 적용할 수 있는 수준까지의 연구 개발을 수행하였다. 디버터 플라즈마 모사 장치 개발팀에서는 Thruster 장치를 응용하여 Iter급의 열속을 발생시킬 수 있는 플라즈마 발생 장치를 성공적으로 개발하였고 이로부터 플라즈마의 열속과 입자속이 타겟 재료에 미치는 영향을 다각도로 분석하여 향후 디버터 설계에 매우 중요하고 의미 있는 다량의 데이터를 구축하였다. 본 발표에서는 센터의 이러한 성과를 종합적으로 발표하고 향후 새롭게 개발될 핵융합로에 적용 가능성을 논의해보고자 한다.

Keywords:

디버터

핵융합 재료-플라즈마 반응 연구센터 소개 (Center for Interaction of Materials with Plasmas: cimpl)

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Abstract:

핵융합 재료-플라즈마 반응 연구센터는 ITER/KSTAR 와 같은 핵융합로의 벽면(wall) 및 디버터(divertor) 재료와 플라즈마 입자 및 열에 의한 상호작용에서 발생하는 현상에 대한 연구를 수행한다. 벽면 재료에 입사되는 핵융합 플라즈마와 재료 (텅스텐) 표면에서의 반응을 이해하고, 반응 결과 표면 근방의 플라즈마의 변화 및 재료 표면 층에서 재료 물성의 변화를 포함한 상호반응 (plasma-materials interaction) 현상을 연구한다.

1-2차년도 연구 결과로 (1) 장시간 고열속 정상상태 플라즈마에 노출된 텅스텐 표면 변형 (hole, recrystallization) 분석, (2) ELM 모사 천이열속 조건 재료 손상 (erosion, dust, crack) 분석, (3) 고온-고압 환경 텅스텐 수소 동위원소 흡착에 따른 표면 분석, (4) 텅스텐-전자 충돌 단면적 모델 개발, (5) 자화시스 내 이온 거동 해석 및 이온 입사각 측정위한 material probe 개발, (6) 시변동 고열속 인가에 따른 텅스텐 표면 Crack 형성 자료 확보, (7) D, He 이온 인가 조건 표면 형상 변동 (blister, fuzz) 기초 자료 확보, (8) ITER 디버터 구조에 따른 중성자에 의한 표면 손상 (dpa) 도출을 위한 McCARD 코드 구축을 수행하였다.

이를 바탕으로 3차년도 연구로 (1) 정상상태 수소, 헬륨 및 아르곤 플라즈마 ($I_d = 50$ A, $T_e = 5-50$ eV, $n_e = 10^{18-20} m^{-3}$, $q = 0.2-5$ MWm⁻²)에 장시간 노출된 텅스텐 표면의 blister, hole, crack 및 recrystallization의 형성 조건을 분석, (2) 천이열속(ELM 조건 모사: Laser, E&B modulation, e-beam, torch)를 통한 빔에너지, 이온, 전자, 열에너지 소스로부터 발생하는 텅스텐 표면의 erosion, dust 발생 비교, (3) 흡수/취하에 따른 표면 구조 및 중수소 방출 특성 분석 (4) 수소 및 헬륨 배경 플라즈마 속 질소 주입을 통한 경계플라즈마에서의 방사 냉각 효과를 열속 감쇄 길이 통해 검증, (5) 디버터 자화 쉬스 조건 castellation 내 이온 거동 해석 및 표면 입사각 실험적 측정, (6) Crack 형성 및 전파에 따른 방출 dust 크기 증가와 질량 손실 증가 실험적 확인. (7) He 이온 형성 fuzz 에 의한 텅스텐 표면 erosion 증가 및 불순물 W 에 의한 플라즈마 온도, 밀도 변동 해석, (8) 디버터 lifetime 손상 조건 (0.7 dpa) W 에 대한 중수소 총흡착량 실험 측정 및 장기 손상 조건 중수소 흡착 특성 전산 모사 (SPECTER, LAMMPS, KMC) 결과와의 상호 해석을 수행 중이다.

본 발표에서는 (1)센터소개와 함께 (2)1-2차년도 연구결과, (3)3차년도 연구수행 내용 및 성과를 발표한다.

Keywords:

Divertor, Tungsten, Castellation, Magnetic sheath,
Erosion, ELM, Retention, TDS, Transient HHF, Strike point, Crack, ITER, KSTAR

원자-공진기 시스템에서 기준 모드 갈라짐 관측.

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Abstract:

본 연구에서는 87Rb 단일원자를 고휘도 공진기에 결합한 후 기준 모드 갈라짐을 관측하였다. 공진기의 약 4 mm 위에 자기 광 포획을 구현한 후, 포획 포텐셜을 제거함으로써 원자가 자유낙하하게 하였다. 이 냉각된 원자들은 수십 cm/s의 속도로 공진기를 지나가며, 수백 마이크로초 동안 광자와 결맞게 상호작용한다. 공진기 조사광의 주파수를 바꾸며 기준 모드 갈라짐을 관측하였다. 이는 원자-광자 CNOT 양자 게이트의 활용될 수 있다. 단광자 발생, 3차원 쌍극자 포획 등 추후 실험계획을 논의한다.

*김금현과 이도원의 기여도는 동일함.

Keywords:

87Rb, 자기 광 포획, 단광자 발생, 3차원 쌍극자 포획

Rydberg-atom implementation of quantum teleportation and transportation circuits

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Abstract:

We present individual addressing of Rydberg atoms to operate exemplary quantum circuits including quantum teleportation and quantum transportation circuits. Using a Rydberg-atom programmable quantum simulator [1], we perform sequentially and locally addressed switchings in the presence of global Rydberg-atom pumping of N Rydberg-atom qubits in one-dimensional arrangements. Qubit-addressing is operated with two-dimensional acousto-optic deflectors (AOD) in conjunction with a multi-channel arbitrary radio-frequency waveform generator (AWG). Experimental result shows that circuit fidelities are achieved about 75% for N=3 and 40% for N=5 examples, after state-preparation-and-measurement (SPAM) error mitigations. In our implementation of quantum teleportation, the quantum information of Alice atom is delivered with high fidelities to Bob atom, reproducing the equivalent reduced-space unitary operator. Also, quantum transportation of an arbitrary qubit state is successfully delivered from one end of the qubit strings to the other end [2].

[1] Kim, Minhyuk, et al. "Quantum ising hamiltonian programming in trio, quartet, and sextet qubit systems." PRX Quantum 1.2 (2020): 020323.

[2] Ostmann, Maik, et al. "Non-adiabatic quantum state preparation and quantum state transport in chains of Rydberg atoms." New Journal of Physics 19.12 (2017): 123015.

Keywords:

Rydberg atom, Quantum computation

Variational quantum eigensolver optimized by single-shot measurement

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Abstract:

Solving an eigenvalue problem which can find many applications from physics to chemistry, is often intractable on classical computers.

Most quantum variational algorithms for solving this problem have an estimation process of an energy expectation from outcomes of quantum measurements part of Hamiltonian. We propose an efficient variational algorithm for finding eigenstates and eigenvalues by using a single-shot measurement learning method. The algorithm efficiently estimates the energy expectation using a relatively small number of samples and simple measurement settings. We also show single-qubit and two-qubit examples.

Keywords:

VQE, variational algorithm, single-shot, measurement learning

Rydberg quantum tree wires for vertex-spitting in high-degree graphs

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Abstract:

Rydberg-atom quantum simulators have recently drawn significant attentions due to the potentials in quantum computing of NP-hard combinatorial problems. For example, Maximum-Independent-Set (MIS) and Max-Cut problems are being attempted with as many as a few hundreds of Rydberg atoms, which are arranged on vertices of planar graphs or small-scale nonplanar graphs [1]. However, the nature of short-ranged Rydberg-atom interactions inevitably limits the max number of edges (the degree) of each vertex. For example, in Rydberg-atom implementation in three-dimensional space, the max degree is either 4 or 6, depending on the acceptable levels of higher-order interactions. Here, we propose and experimentally demonstrate tree-like structures, termed as Rydberg quantum tree wires, which perform the vertex-splitting operation in graph theory. In a proof-of-principle experiment conducted with a Rydberg-atom programmable simulator, a 6-degree vertex is replaced to a 3-degree vertex at the cost of 7 auxiliary atoms. The many-body ground states of as-constructed Rydberg-atom structures are experimentally measured by the quantum annealing method, resulting in an excellent agreement with the MIS solutions of the target high-degree graph.

[1] M. Kim, K. Kim, et al., "Rydberg quantum wires for maximum-independent-set problems," (in preparation).

Keywords:

Rydberg atom, Quantum Computing, Quantum Wire, Quantum Tree Wire

Geometric Approach to Private Quantum Channels: High-dimensional cases and Regular Polytopes

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Abstract:

As the quantum analog of the classical one-time pad, the private quantum channel (PQC) plays a fundamental role in the construction of the maximally mixed state (from any input quantum state), which is very useful for studying secure quantum communications and quantum channel capacity problems. However, the undoubted existence of a relation between the geometric shape of regular polytopes and private quantum channels in the higher dimension has not yet been reported. Recently, it was shown that a one-to-one correspondence exists between single-qubit PQCs and three-dimensional regular polytopes (i.e., regular polyhedra). In this paper, we highlight these connections by exploiting two strategies known as a generalized Gell-Mann matrix and modified quantum Fourier transform. More precisely, we explore the explicit relationship between PQCs over a qutrit system (i.e., a three-level quantum state) and regular 4-polytope. Finally, we attempt to devise a formula for connections on higher dimensional cases.

Keywords:

Private Quantum Channel, Generalized Gell-Mann matrix, Regular Polytope, Isotropic Measure

Materials design with artificial intelligence

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Abstract:

By simultaneously utilizing artificial intelligence technology and first-principles electronic structure calculation method, we present examples of materials design with thoroughly optimized specific materials properties. We provide materials design examples for semiconducting, superconducting, and topological superconducting materials. In addition, we present frequency-selective metasurface design which can be utilized for high-quality 5G communications. Specifically, we used global optimization and artificial neural networks. As a result, we were able to establish a set of first-principles calculation-based and data-based material exploration/design methodologies. Representation, evaluation, and optimization, the key three elements, as found in machine learning, were persistently utilized for the materials design for a given figure-of-merit. Years of experience have shown that theoretical design is irrelevant to experimental synthesis, but still, the introduction of artificial intelligence technology as a method of material design/exploration is well worthwhile. Nevertheless, in some materials and artificial structures, we were able to verify that our design and exploration were also experimentally valid.

Keywords:

artificial intelligence, materials design, first-principles calculations

소재 개발에서의 데이터기반 연구 : 데이터플랫폼 활용의 예

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Abstract:

2011년 미국의 MGI (Materials Genome Initiative) 발표 이후, 소재물성 데이터베이스의 구축이 활발해지고, 이러한 데이터를 활용하는 연구가 최근 들어 활발해지고 있다. 그러나 공개된 데이터베이스는 대부분 제일원리 기반의 계산 물성 데이터이고, 이러한 계산물성 데이터에 머신러닝을 적용하는 연구가 많이 발표되고 있다.

이번 발표에서는 실제로 소재개발 과정에서 생성되는 실험 데이터를 수집하고 활용하기 위한 데이터 기반 연구 플랫폼의 구축의 예를 제시하고자 한다. (1) 본 연구에서는 특정 열전소재개발을 위해 수행되는 연구 과정의 데이터를 수집하기 위한 웹기반의 열전소재 연구개발 플랫폼인 TEXplorer를 구축하였다. 우선적으로 도핑된 SnSe 기반의 열전소재 개발 과정에서의 합성조건, 특성평가 등에 대한 실험데이터 수집 및 도핑된 SnSe의 제일원리 계산에 의한 전자구조 계산데이터를 플랫폼을 통해 수집하였다. 이렇게 수집된 데이터에 머신러닝을 적용하여 열전 특성을 예측하는 연구를 수행하여 새로운 조성의 열전소재를 제안할 수 있었다. (2) 메탄 직접 전환 촉매 개발에서의 촉매 반응 최적화 연구에 대한 소개를 하고자 한다. 촉매 반응에서의 실험데이터를 수집하여 기계학습 모델을 만들고, 실험의 가상 조건을 메타휴리스틱한 방법으로 적용하여 최적의 반응 조건을 찾아 검증한 예시를 제시하고자 한다.

이번 발표에서는 실제로 소재개발 과정에서 생성되는 데이터를 수집하고 활용한 예를 제시하며, 이러한 데이터기반 연구 플랫폼의 다른 분야로의 확장 가능성에 대해 논의하고자 한다.

Keywords:

데이터, 열전소재, 촉매소재, 기계학습, 플랫폼

Uncovering Rashba Effects Hidden in Two-Dimensional Si₂Bi₂

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Abstract:

We use the first-principles density functional theory and model Hamiltonian calculation to reveal the unusual electronic structure of Si₂Bi₂, one of the two-dimensional (2D) layered materials composed of group IV and V elements, and its physical origin. It intriguingly exhibits Rashba-like bands although its structure possesses inversion symmetry. We find that the observed Rashba-like bands indeed originate from the spin splitting due to strong spin-orbit coupling, but each band is still spin-degenerate guaranteed by inversion symmetry. Such seemingly contradictory band structure can be resolved by considering local inversion symmetry breaking occurred in each sublayer while remaining global inversion symmetry. Local inversion symmetry breaking is responsible for spin splitting resulting in Rashba-like bands, but global inversion symmetry is satisfied by spin-degenerate between one spin from one sublayer and the opposite spin from the other sublayer. In other words, the spin-up (-down) state in one sublayer is degenerate with the spin-down (-up) state in the other sublayer, but the spin-up and -down states in the same sublayer are split. This phenomenon is called spin-layer locking (SLL) or hidden Rashba (R-2) effect. It is also found that such R-2 SLL can be modulated by the sublayer-sublayer interaction that competes with the spin-orbit coupling, which is related to the Rashba strength. In addition, we reveal that the strong R-2 SLL requires an appropriate orbital angular momentum distribution. We verify that the 2D Si₂Bi₂ is an ideal material exhibiting the strong R-2 SLL, whose Rashba strength is evaluated to be 2.16 eVÅ, which is the greatest value ever observed in 2D R-2 materials to the best of our knowledge. Furthermore, we suggest that R-2 states can be spatially farther apart by forming a bilayer or multilayer structure in which the interlayer interaction cancels the opposite spin states located at inner sublayers, expecting a potential application in future spintronics.

Keywords:

Rashba effect, Spin-layer locking, density functional theory, layered material

Electronic Structure of Colloidal Semiconductor Nanocrystals

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Abstract:

Colloidal semiconductor nanocrystals or quantum dots consist of inorganic nanocrystal cores and surface-passivating organic ligands and have recently attracted much attention for large-scale optoelectronic applications such as light-emitting diodes and solar cells. This is mostly because there exist scalable solution-based synthetic routes for colloidal semiconductor nanocrystals, whose size and thus band gap are readily controlled. Different from the well-known quantum confinement effects of nanocrystal cores, the ligand-surface interaction has been less studied although it is very critical for the stability and electronic structure of entire quantum dots. In this talk, I will summarize how we have demonstrated, using electronic structure calculations, that the ligand-surface interaction determines the shape of semiconductor nanocrystals from cube to tetrahedral, cuboctahedral, spherical, and even to tetrapod shapes, and their electronic structures.

Keywords:

quantum dots, semiconductor nanocrystals, colloidal, electronic structure, density functional theory

Effects of senescent cells on the motile patterns of non-senescent cells

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Abstract:

Collective cell migration is one main characteristic of many physiological phenomena, being of importance to a range of biological processes such as embryonic development, wound healing, immune action, and tumor metastasis. Dynamical features of collective migration can depend on several different factors including the types of cell-to-cell interactions (e.g., cell-cell adhesiveness) as well as single-cell properties (e.g., directional persistence in crawling). In addition, various system heterogeneities could play an important role, as biological tissues (or in vitro cell cultures) almost always carry some inhomogeneities. Of particular interest, the spontaneous emergence of cellular senescence renders the population with two distinct cell types (i.e., senescent and non-senescent cells) even in a monoclonal cell-line population. Cellular senescence is a process through which the target cell ceases dividing and enters a permanent growth-arrest state. This process prevents the cell from undergoing apoptosis and expresses diverse new cell properties. Given the unique morphology of senescent cells, some differences in adhesive interactions between cell-to-cell and senescent-cell-to-cell arrangements are expected. In this study, we estimate the adhesion energy between non-senescent and senescent MDA-MB-231 cells by combining the result of the numerical simulations of a cellular Potts model and that of experiments, in comparison to that between normal non-senescent cells. We show that the motility of non-senescent MDA-MB-231 cells is predominated by their own inherent motility mechanism and not so much by the presence of neighboring senescent cells. In other words, the cell motility of a normal cell within a confluent population seems not hindered by the presence of senescent cells, as 1) the cell adhesion to the senescent cells is much weaker than that to the normal cells and 2) the persistence length of normal cells in confluency is comparable to the size (radius) of a typical, enlarged, body of a senescent cell. Therefore, as for the collective motility of MDA-MB-231 cell lines, the senescent cells' biochemical secretions (i.e., senescence-associated secretory phenotypes) may undertake a more important role, serving as a chemo-attractant or repellent as discussed in our earlier paper.

Keywords:

Senescence, cell-motility, contact interaction, Cellular Potts Model

Formation of neuronal superbursts from autonomously developed modular network morphology

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Abstract:

Neural bursts are an important dynamic feature that are relevant not only to many different neurological diseases but also to some latest ideas in neural computations. In this talk, we concentrate on the nature of "superbursts" that are a small (100 ms) temporal packet of several population bursts. A delicate balance of system-wide excitation and inhibition as well as recurrent excitation loops in the network have been suggested to be relevant for the emergence of neuronal population bursts. Nevertheless, the relation between network morphology and (super)burst dynamics has not been investigated rigorously. Here we investigate this issue based on a well-established Izhikevich neural network model. The overall conduction delay has been used as our control parameter for modifying network morphology and its consequent burst dynamics. Interestingly, we found that initially identical neurons self-organize to develop several distinct neuronal subpopulations, which are in turn characterized by different spike firing patterns as well as distinct locations on the in-degree and out-degree plane. Moreover, a few different motifs of superburst have distinct neuronal subpopulations which contribute to their emergence. These superburst-specific neuronal subpopulations comprise different mixture of neuronal subpopulations characterized by different spiking firing patterns. Our analyses suggest that recurring patterns of different superbursts are driven by complex yet organized modular network structures of different subpopulations.

Keywords:

neuronal superbursts, neural network, network modularity

Bayesian model comparison and parameter estimation with noisy discrete-time Lévy walk

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Abstract:

Diffusion dynamics inside complex systems ranging from biological systems to ecosystems show distinct non-Brownian dynamics. It is often tried to classify and quantify those diffusion dynamics with various anomalous diffusion models. However, it is challenging to classify and quantify short and noisy trajectories in an objective way. Following the need for the systematic analysis of the stochastic processes, Bayesian inference for such data has been developed and proved its effectiveness. In this work, we show how to implement Bayesian inference with discrete-time Lévy walk, which is one of the anomalous diffusion models. We emphasize the two points in this work. (i) Calculation of the likelihood function: We calculate the likelihood function of the discrete-time Lévy walk via the hidden Markov model. For this, we show how to decompose the Lévy walk, which is non-Markovian process, via Markov process. (ii) Bayesian inference: With the likelihood function, we carried out Bayesian model comparison and parameter estimation on the artificial trajectories. We show that our method properly calculated the likelihood function and worked well for the Bayesian inference, with the moderate level of inserted noise.

Keywords:

Single Particle Tracking, Bayesian Inference, Anomalous Diffusion, Data Science, Lévy Walk

Force-extension relations of stiff bio-filaments subject to a deflecting force: from theory to simulation

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Abstract:

We study the exact force-extension relation of a stiff polymer subject to a constant external force. Two cases are discussed: (1) a cantilevered force-extension, the one end is tethered to have a fixed orientation and the other end is pulled; (2) a mid-point force-extension, the midpoint of the polymer is pulled. We study an exact theory and also provide a useful interpolation formula for the force-extension relation. Our theory has a flexibility that can be easily extended to the heterogeneous polymer or semi-flexible polymer. We also provide polymer simulation results that show great agreement with the theory. Our results can be useful for interpreting the force-extension experiments on bio-polymers such as microtubules and filopodia.

Keywords:

force-extension, Stiff polymers, Semi-flexible polymers

Free energy analyses of cell penetrating peptides using the weighted ensemble method

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Abstract:

Cell penetrating peptides (CPPs) have been widely used for drug-delivery agents, however, it has not been fully understood how they translocate across cell membranes. The Weighted Ensemble (WE) method, one of powerful and flexible path sampling techniques, can be useful to reveal translocation paths and free energy barriers along those paths. Within the WE approach we show how Arg9s (nona-arginine) and Tat interact with a DOPC:DOPG (4:1) model membrane and we also present free energy profiles (or potential mean of forces, PMFs) of translocation across the membrane. A different composition of lipid molecules was also tried and compared. Our approach can be applied to any CPPs interacting with various model membranes and it will provide useful information regarding the transport mechanisms of CPPs.

Keywords:

weighted ensemble, cell penetrating peptide, free energy, membrane, transport mechanism

CAP 발자취 및 통계 자료

장재원*¹

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Abstract:

물리학회 발행 SCI 학술지인 Current Applied Physics (CAP) 지는 2001년 1월 창간 이후, 다양한 과학, 공학 분야의 응용 물리 관련 연구 논문을 지속적으로 발간 해오고 있습니다. 본 발표에서는 창간 후 20년 동안 CAP 지의 양적, 질적 성장 변화를 다양한 통계 분석을 통하여 알아보겠습니다. 또한 통계 분석 비교를 통하여 CAP 지의 앞으로의 발전 방향에 관해 논의하는 기회를 갖도록 하겠습니다.

Keywords:

CAP

Nanoporous metallic films as electrochemical sensors and catalysts

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Abstract:

Nanoporous metals are sponge-like porous bodies composed of nanometer sized reticulates throughout the body. They have unique characteristics due to their high surface area, high number of active sites, high conductivity, tuneable porosity, and so on. For gold, since its initial preparation by dealloying Ag out of AuAg alloy was known, there have been intensive research activities for improving the preparation methods, investigating the fundamental material properties, and extending the application fields. They range from catalysis, sensors (mechanical/chemical), and materials for energy conversion to bio-related applications. In this presentation, I will first discuss about preparation of nanoporous gold and platinum and examples of their applications as sensors and catalysts. Then I will discuss about limitations of the materials and finally have suggestions for future directions of the research on nanoporous metals.

Keywords:

Nanoporous metal, Electrochemical sensor, Electrocatalysis

Novel Hybrid Molecular Beam Epitaxy for Atomically Precise Growth of Complex Oxide Films

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Abstract:

Conventional molecular beam epitaxy (MBE) approaches have yielded complex oxide films with atomic-level control over film thickness, with low defect densities, and structural perfection, which matches that of the traditional III-V compound semiconductors. However, there remain some key synthesis challenges concerning stoichiometry control, and for metals with low vapor pressure and low oxidation potential (i.e. difficult to oxidize). These challenges often lead to films with large density of point defects and can also yield irreproducible composition. To address this, a novel growth approach using elemental source, reactive oxygen, and metal-organic sources - *hybrid* MBE (*h*MBE) - has been introduced. The advantages of the *h*MBE approach are several folds: (1) it produces complex oxide films with automatic stoichiometry control, (2) it eliminates the issues of difficulty in oxidation and also the low vapor pressure by utilizing metal-organic precursors.

Using this approach, we will present a detailed growth study of SrTiO₃ and RuO₂ combined with their detailed transport and spectroscopy measurements. Films with excellent structural quality was produced with self-regulating cation stoichiometry control. Through intrinsic defect management, we achieved for the first time electron density as low as $3 \times 10^{17} \text{ cm}^{-3}$ in Sr_{1-x}Nd_xTiO₃ films with the corresponding mobility exceeding 42000 cm²/vs at 1.8 K. Similarly, RuO₂ films yielded the lowest residual resistivity attesting to lower disorder in our films. The effect of strain, cation stoichiometry and film thickness on the crystal structure, electronic structure, and transport properties of the SrTiO₃ and RuO₂ films will be discussed.

Keywords:

MBE

RFT-30 사이클로트론 운영 및 이용연구 현황

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Abstract:

RFT-30 사이클로트론은 방사성동위원소(RI)의 생산/응용연구와 재료, 생명 등 분야의 양성자빔 이용연구를 위하여 국내기술로 구축된 30 MeV급 중형 양성자 사이클로트론으로서 2013년부터 이용자 서비스를 제공하고 있다.

RFT-30 사이클로트론을 이용하여 F-18, Zr-89, Ge-68, Cu-67, Co-57 등의 다양한 핵종을 성공적으로 생산하였고, 이를 이용한 다양한 응용연구를 수행하고 있으며 이용자 서비스 또한 제공하고 있다. 효율적인 핵종 생산 및 이용을 위해 생산 공정 최적화에 대한 연구, 농축표적을 이용한 대량생산 연구 등이 진행 중이다.

RI와 더불어 양성자빔 조사 서비스를 제공하고 있으며, 이용분야에는 반도체, 초전도체 등의 재료 물성 개질, 방사선 육종연구, 미생물 사멸 연구 등이 있다. 다양한 빔 이용자들의 요구를 만족하는 서비스를 제공하기 위해서 점진적인 빔라인 개선을 진행 중이며, 가속기 기반 중성자 영상시설 구축 지원, 마이크로빔 조사 환경 구축 등도 병행하여 진행하고 있다.

Keywords:

RFT-30 사이클로트론, 양성자, 방사성동위원소, 빔 이용

Measurement of proton decay from energy levels in ^{21}Na

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Abstract:

The decay protons from $^{24}\text{Mg}(p,\alpha)^{21}\text{Na}^*(p)^{20}\text{Ne}$ reaction were measured at the Holifield Radioactive Ion beam facility (HRIBF) of the Oak Ridge National Laboratory (ORNL). To identify the decay protons from ^{21}Na states, the coincidence between alpha particles from transfer reaction and protons was required. The decay proton from energy levels in ^{21}Na to energy levels in ^{20}Ne were identified. Proton branching ratios of several ^{21}Na levels were extracted for the p0 and p1 decay channels. Details of data analysis will be discussed.

Keywords:

Fusion reaction of a weakly bound nucleus with a deformed target

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Abstract:

We discuss the role of deformation of the target nucleus in the fusion reaction of the $^{15}\text{C}+^{232}\text{Th}$ system at energies around the Coulomb barrier, in which ^{15}C is a well-known one-neutron halo nucleus. To this end, we construct the potential between ^{15}C and ^{232}Th with the double folding procedure, assuming that the projectile nucleus is composed of the core nucleus, ^{14}C , and a valence neutron. In addition, we also take into account the coupling to the one-neutron transfer process to the $^{14}\text{C}+^{233}\text{Th}$ configuration. We show that such calculation simultaneously reproduces the fusion cross sections for the $^{14}\text{C}+^{232}\text{Th}$ and the $^{15}\text{C}+^{232}\text{Th}$ systems, implying an important role of the transfer coupling in fusion of neutron-rich nuclei.

Keywords:

Fusion reaction , weakly bound nucleus , deformed nucleus

Calculation of post-neutron fission fragment mass distribution by using pre-neutron FPY and neutron multiplicity data

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Abstract:

Fission fragment mass distributions are important observables for understanding fission processes. To describe the fission process properly, both pre- and post-neutron emission fission product yields (FPY) need to be investigated. In this work, we use the semi-empirical model to reproduce the FPY of pre-neutron emission. Then the experimental data for the neutron multiplicity of each fission fragment mass are used to calculate the post-neutron FPY. By using a few different assumptions for the neutron multiplicity, we show that the calculated post-neutron emission fission fragment mass distributions reproduce the overall shapes of experimental data.

Keywords:

Nuclear fission, Semi-empirical, Neutron multiplicity, Fission product yield

Nuclear forces with vector mesons within chiral perturbation theory

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Abstract:

In conventional chiral perturbation theory, vector mesons, as well as other massive fields, are integrated out, retaining only nucleons and pions. Such an integration however deteriorates the theory prediction when the momentum scale is non-negligible compared to the masses of those massive fields. The role of vector mesons has been known in terms of the vector meson dominance and the resonance saturation assumptions since a long time ago. In this work, we construct a novel chiral nuclear force with vector mesons as well as pions. Discussions will be made on the consistency with the conventional chiral perturbation theory and the numerical impact of the inclusion of vector mesons.

Keywords:

nuclear force, vector meson, chiral perturbation theory

Study of resonances of elastic p- ^{12}C scattering in cluster effective field theory

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Abstract:

The phenomenological R-matrix theory is an efficient technique for describing nuclear reactions in terms of nuclear resonances. Recent developments of cluster effective field theory suggest an alternative approach to R-matrix without any model dependence at low energies. In the present work, we study the differential cross section for elastic p- ^{12}C scattering in the cluster EFT. The three low-lying resonance states ($1/2+$, $3/2-$ and $5/2+$) of ^{13}N are taken into account as explicit degrees of freedom. The elastic scattering amplitudes are found to be consistent with the effective-range expansion (ERE). We determine the values of the low-energy constants and equivalently the ERE parameters by matching to the experimental data. The resulting theory prediction for the differential cross section is found to be in a good agreement with the experimental data. Our results are also compared with the R-matrix results.

Keywords:

cluster EFT, elastic p- ^{12}C scattering, differential cross section

Elastic α - ^{12}C scattering at low energies with the resonant 2_2^+ and 2_3^+ states of ^{16}O

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Abstract:

The elastic α - ^{12}C scattering for $l = 2$ at low energies is studied in effective Lagrangian approach. We explicitly include two resonant 2_2^+ and 2_3^+ states of ^{16}O in the scattering amplitude and fit the parameters to the phase shift data. We also study three contributions from higher order, the resonant 2_1^+ state of ^{12}C , the resonant 2_4^+ state of ^{16}O , and a vertex correction of the initial and final state interactions of the amplitude for the 2_3^+ state of ^{16}O , by imposing three conditions at the very low energies where the phase shift data are not available, and calculate the asymptotic normalization coefficient (ANC) for the sub-threshold 2_1^+ state of ^{16}O . We find that the previously reported small and large values of the ANC can be reproduced depending on the imposed conditions, but we obtain a large error bar to the large ANC value reported from the α transfer reactions.

Keywords:

d-wave alpha-carbon-12 elastic scattering, asymptotic normalization coefficient, effective Lagrangian approach

Proton production and inelastic cross sections induced by neutron for ^{54}Fe

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Abstract:

New evaluations of neutron-induced nuclear reaction data on $^{54,56,57,58}\text{Fe}$ developed in the framework of the CIELO [1] international collaboration were adopted by the ENDF/B-VIII.0 [2] library, released in 2018. These evaluations were performed by adjusting model inputs to reproduce available experimental data above neutron resonance regions. However, for the high energy range (above 10 MeV) where no experimental data are available, those predictions occasionally fail to reproduce newly measured data. The ENDF/B-VIII.0 evaluation on ^{54}Fe shows such discrepancies with (n, xp) cross sections which were recently measured with the LENZ (Low Energy Neutron-induced Charged-particle (Z) Chamber) instrument at Los Alamos Neutron Science Center (LANSCE), and inelastic cross sections which were measured at the Geel Electron LINear Accelerator facility (GELINA). In this work, we present model parameter adjustments of the Hauser-Feshbach model code, in order to reproduce measurements of (n,xp) and inelastic cross sections on ^{54}Fe .

[1] M. Chadwick, et al., Nucl. Data Sheets 118, 1 (2014)

[2] D. Brown, et al., Nucl. Data Sheets 148, 1 (2018)

Keywords:

Proton production, Nuclear Data, ENDF, LENZ

Active matter physics and eco-evolutionary dynamics in virus-bacteria interactions

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Abstract:

Despite their relevance in natural environments, the spatio-temporal consequences of the interactions between phages and bacteria remain largely unexplored. In the most well-studied setting, i.e. plaque formation, phages infect a uniform background of bacteria, within which the phages spread diffusively, causing the plaque front to grow linearly as a function of time. Here, we investigate the dynamics of the spread of the infection due to a phage-lambda during the range expansion of an E coli colony; strikingly, the phages "surf" the front of the growing bacterial colony. The phages surf the colony edge by hitchhiking on E coli that are advected due to growth of the bacteria in the colony, resulting in an anisotropic spread of the phages -- ballistically in the direction of colony growth and diffusively in the lateral direction (occurring over timescales of many hours and millimetric length scales). We identify microscopic processes -- of the phage release during lysis (occurring on short millisecond timescales at length scales close to that of a single bacterium) and local nematic alignment of the rod-like E coli bacteria (occurring on timescales comparable to the bacterial growth rate and on the length scales of a few bacteria) -- that enhance the advective effects driving the hitchhiking behavior. Altogether, the interplay between the phage infection, cell replication and transport processes -- all involving multiple length and time scales, ranging from diffusion of individual phages to single-cell lysis events to colony-level patterns -- result in a panoply of dynamical patterning phenomena. Combining our experiments with simulations, we explain the multiple spatio-temporal dynamical regimes -- from coexistence of the uninfected bacteria, resistant (lysogenic) cells and phages to fixed points where the entire population turns resistant or remains uninfected. Our work broaches a new frontier in the investigation of a range of eco-evolutionary processes driven by the spatio-temporal interactions between viruses and their hosts and also raises new questions for active matter physics.

Keywords:

active matter

Bacteria in Anisotropic Flatland

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Abstract:

Living liquid crystal is a dispersion of motile bacteria in aqueous liquid crystals and has been of keen interest because it opens up the possibility of controlling bacteria's individual and collective behavior. We observe two-dimensional living liquid crystals with liquid-liquid interfaces, i.e., isotropic-nematic coexistence phase, and study how rod-like bacteria interact with the interface. We propose a force-balance model that explains why bacteria impinging normally upon the interface cross the interface more easily than grazing ones. Understanding the bacteria near the liquid-liquid interfaces would have broad applicability in manipulating and encapsulating cells using aqueous two-phase systems.

Keywords:

Bacteria, Liquid crystal, Interface

Topological defects in cell layers

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Abstract:

Many types of living cells are spontaneously elongated and exhibit long-range orientational order. In this, they are similar to liquid crystals. The alignment of cells can affect their migration patterns and cell-cell communication. When cells grow in 2-dimensional layers, they exhibit topological defects where the order is disrupted. There is increasing evidence that such defects play a role in the organization of the cell layers and in the distribution of forces. We approach this problem from the liquid crystal perspective. We impose and control topological defects in cell layers by patterning the cells' substrate with ridges or grooves and we study the behavior of cells near and far from the defects. This allows us to study defects that do not typically occur in cell monolayers, such as those with topological charge +1 and -1. We analyze the alignment of fibroblasts 3T6 and epithelial cells EpH-4 on the patterns, their dynamics, the cell density distribution and the cell properties at the cores of the defects [1]. We find an unusual behavior of the fibroblasts at the cores of the defects with topological charge +1, where these cells change shape and become round and isotropic. This research will give insight into the role of topological defects in the organization of cell monolayers and will use the framework of liquid crystal physics to interpret the cells' behavior.

[1] K.D. Endresen, M.S. Kim, M. Pittman, Y. Chen, F. Serra, *Soft Matter* 17, 5878 (2021)

Keywords:

liquid crystals, active matter, cell motility, topological defects

Of Microbes, Mechanics and Materials

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Abstract:

Understanding how microbes interface, exchange and communicate with their local surroundings is central to the grand quest for a theory of microbial ecology. From simple to complex fluids, from compliant to rigid surfaces, microbes inhabit plethora of micro-environments spanning vastly different structures, dynamics, and internal energies. Currently we lack a biophysical framework that could explain, generalize, and crucially, predict the if-s, the how-s, and the why-s of the microbe-environment interactions. Research in my lab aims to fill this gap by interfacing soft matter physics and fluid mechanics with microbiology and genetic engineering. In this talk I will discuss that microbes – across individual, species and community scales – are inherently coupled to their micro-environments, and that their behavioural and physiological traits emerge as a consequence of active biophysical feedbacks between the material, information and energy transport processes. Using vignettes from our recent experiments in model gut and aquatic microbial systems, I will demonstrate how microbes and their micro-environments crosstalk via biomechanical coupling, leading to emergence of traits that ultimately translate into ecological and eco-physiological functions. In conclusion, I would like to discuss why our efforts to unpack the microbe-mechanics-materials nexus are central to deciphering microbial fitness, succession, and selection, not least for their emerging prospects in medical diagnostics, biotechnology, and bioremediation during current climatic trends.

Keywords:

microbial active matter, emergent phenomena, topological dynamics, active flows

2015 개정 물리교육과정 구성 경험에서 도출한 물리교육과정 개정에 대한 시사점

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Abstract:

5년마다 수시개정을 하고 있는 국가교육과정개정이 지체가 되어 2022년 개정을 목표로 개정작업 중에 있다. 2015 개정 물리교육과정 팀장으로 겪은 경험을 바탕으로 새 교육과정 개정에 대한 시사점을 도출하고자 한다. 교육과정 개정 논의의 핵심은 개정의 방향이다. 2015 개정의 경우 문이과 통합, 학생참여형 수업을 위한 학습량 적정화가 주요 개정 방향이었다. 문이과 통합은 교과목 분류 체계를 중심으로 학습량의 적정화는 교과 내용 축소 형식으로 반영이 되었다. 따라서 물리학 1은 일반선택과목으로 지정이 되어 일반계 고등학교의 모든 학생들이 선택하여 학습할 수 있는 교과목으로, 물리학 2는 물리학 1을 수강한 후 이공계 진학을 고려하는 학생들이 선택하여 학습하는 진로선택교과목으로 지정이 되었다. 이는 교과간 위계가 없었던 2009 개정의 물리 교과에서 변한 내용이며, 물리학 1이 모든 학생이 이수할 수 있다는 전제는 그 내용 선정에 영향을 주었다. 한편, 학습 적정화 측면에서는 2009 개정 대비 물리학 1, 2의 내용이 대폭 축소가 되었고 이에 대해 일부 현장교사로부터 학생활동이 가능한 수준으로 양이 축소되었다는 긍정적 피드백을 받고 있다. 이러한 개정의 과정에서 교과목 지정은 총론의 문제이고, 학습 적정화의 문제는 각론의 문제로 그 결정 요인이 다르다. 총론의 방향이 결정된 시점에서 물리교육학계가 고민할 사항은 물리 교과 내용 결정에 관련된 주요 요인일 것이다. 총론에서 정의된 교과목 성격을 바탕으로 고등학교 물리 수업에서 학습되어야 할 필수 내용에 대한 논의가 필요하다.

Keywords:

물리교육, 교육과정, 고등학교 물리

고교학점제에 대비한 2022 개정 교육과정의 물리학 영역 선택과목 구성 방안에 대한 교사들의 인식

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Abstract:

본 연구의 목적은 과학과 선택과목 구성에 대한 교사들의 인식을 분석하여 2022 개정 교육과정 물리학 선택과목 구성 방안을 제안하는 것이다. 44명의 고등학교 물리 교사와 148명의 물리 이외의 과학 교사를 대상으로 차기 교육과정에서 선택과목 구성 방안에 대한 설문을 실시하고, 5명의 물리 교사들을 대상으로 면담을 실시하였다. 설문 결과, 교사들은 대체로 차기 교육과정에서도 현 과목 체제를 유지하는 것을 선호했으나 물리 교사들은 상대적으로 체제 변화의 필요성을 많이 느끼는 것으로 나타났다. 체제 유지에 반대하는 이유로 두 집단의 교사들은 공통적으로 'Ⅱ과목이 생활과 과학 등의 교양 과목이 진로선택과목에 함께 묶여 있는 것이 적절하지 않음', '전체적으로 학생들의 과학과 선택과목 기피가 심화', 'Ⅱ과목은 진로선택과목임에도 수능 선택과목으로 포함되어 있어서 교육과정과 수능의 연계성이 떨어짐' 순으로 선택하였다. 일반선택과목의 경우 두 집단 모두 'I, Ⅱ과목을 모두 편성'하는 안을 가장 많이 선택했으나 물리 교사들은 'I 과목 단일 편성'을 상대적으로 선호했다, 진로선택과목의 경우 두 집단 모두 2015 개정 체제 유지를 가장 많이 선택했으나 물리 교사들의 경우 'I, Ⅱ과목 대신 전문교과 I 과목 중 일부와 교양 성격 과목으로 이원 편성'하는 것에 대한 선호도도 상대적으로 높았다. 선택과목 선택률 제고 방안으로 '과학 선택과목을 이수한 학생들에게 대학입시에서 가산점 부여', '이공계 대학 공부에 필요한 과학 선택과목들에 대한 안내 강화' 순으로 응답 비율이 높았으나 물리 교사들은 선택과목 안내 강화에 대한 응답 비율이 상대적으로 낮았다. 면담에서 교사들은 일반선택과목에 물리학 단일 과목을 편성하는 안을 선호했으나 내용 영역 별로 과목을 세분화하는 방안의 장단점도 제시하였다. 교사들은 일반과 진로선택과목에 인문사회 지향 학생들을 위한 융합 및 체험형 과목 개설의 필요성과 부작용에 대해서도 의견을 제시하였다. 진로선택과목을 전문교과 I 과 첨단융합과목으로 편성하는 것의 필요성을 인정하면서도 관련 과목에 대한 교사전문성이 뒷받침되어야 한다고 주장하였다. 연구 결과를 토대로 차기 교육과정 물리학 일반, 진로, 융합선택과목들의 재구조화 방안을 제안하였다.

Keywords:

2022 개정 교육과정 , 고교학점제, 선택과목 재구조화

2022 교육과정에서 물리 교과재구조화 방향과 쟁점

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Abstract:

교육부는 2022 교육과정 개정을 앞두고 총론 및 각 교과별 각론 수준에서 기존 교육과정을 재구조화하는 기초연구를 진행 중이다. 총론 수준에서 교육부가 제시하고 있는 교육과정 재구조화의 기본 방향은 '학교급별 발달단계를 고려하여 수업 시수를 적정화하고, 삶의 기본 역량 함양을 위한 기초소양 및 역량 재구조화'이다. 보다 구체적으로는 초등학교군의 경우 '초등 학년군별 교육과정 연계를 위한 교육과정 재구조화', 중학교군의 경우 '미래 역량함양을 위한 교실수업개선'과 '자유학기 활동을 학교급 전환 준비 프로그램 등과 연계하여 개선', 초중고를 통틀어서 '유·초연계, 초·중연계, 중·고연계 등 고려한 소규모학교, 통합학교 교육과정 운영 모델 개선' 등을 들 수 있다. 특히 고교학점제의 본격 시행에 따라 고등학교급에서 대폭적인 교과목 편제 변화가 예상된다. 이 발표에서는 2022 과학과 교육과정 재구조화 기초연구의 일부로서 초·중고 물리 교육과정의 재구조화 방향 및 내용 초안을 소개한다. 즉 초·중고 공통과목으로 과학 교과에서 물리학 관련 내용 체계 구성안을 소개하고, 고등학교 선택과목군에서의 물리 과목군 편성안을 소개한다. 또한 2022 과학과 교육과정 각론 개발에서 고려해야 할 물리교육 관련 주요 쟁점을 논의한다.

Keywords:

교육과정, 물리교육, 고교학점제

물리 교육과정 개정에서 새로움을 위한 빈 공간을 확보하기

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Abstract:

4차 산업혁명으로 촉발되는 사회변화 속에서 물리학 및 물리교육에 대한 변화 요구도 거세다. 이 과정에서 새로운 물리교육 콘텐츠의 도입의 방향에 대한 여러 논의도 활발히 진행되고 있다. 그런데 기존의 물리교육 콘텐츠를 그대로 두고 새로운 콘텐츠를 더하는 것은 현실적으로 불가능하다. 따라서 새로운 콘텐츠를 추가하기 위해, 기존의 콘텐츠에서 무엇을 뺄 것인지, 그 기준을 무엇으로 할지의 문제가 대두된다. 본 발표에서는 이러한 문제의식에서 기존의 교육과정에서 어떤 기준으로 콘텐츠를 축소할지에 대해 논의하고자 한다. 이를 위해, 핵심 개념(core concept), 나선형 교육과정의 의미를 고찰하고, 현재의 2015 교육과정에서 축소할 부분을 예시적으로 탐색할 것이다.

Keywords:

핵심 개념, 나선형 교육과정

Strong coupling of THz phonon-polariton in lead-halide perovskite film

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Abstract:

Phonon-polaritons based on novel functional materials could provide an efficient quantum level system with extreme light-matter interaction in the far-infrared frequency range. In this work, we explored THz phonon-polariton originating from the strong coupling between THz metamaterial cavities and phonons in lead halide perovskite films and studied the Rabi frequency in conjunction with the crystal domain kinetics. We prepared lead halide perovskite films coated on THz metamaterials, followed by the annealing procedures. When the metamaterial resonance is in tune with the perovskite phonon resonance, the energy splitting (i.e., Rabi splitting) occurs due to the strong coupling between the phonon and the THz waves. Here, the energy splitting between the upper and lower levels depends on the coupling strength, in which case the strong field localization is required in association with the field enhancement. By varying the metamaterial resonance, we obtained phonon-polariton dispersion curve with the clear anti-crossing behavior appearing near the resonance. We also performed an in-situ THz spectroscopy as we annealed the sample at different temperatures; we analyzed the Rabi splitting in conjunction with the crystallinity of the film by varying the annealing temperature (60 °C – 110 °C). We revealed that the Rabi splitting (i.e., the interaction potential) depends not only on the crystallized volume density but also on the local electric field which increases with crystalline domain size. As a result, our work will help to extend the knowledge into the light-matter interaction in the strong coupling regime with material systems having nanoscale crystalline domains.

Keywords:

Phonon polariton, Strong coupling, Metamaterials, Perovskite, THz

금속 할로겐화물 페로브스카이트의 결정 상전이에 따른 폴라리톤 물성 변화

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Abstract:

본 발표에서는 금속 할로겐화물 페로브스카이트 물질 중 하나인 MAPbBr₃의 결정 상전이에 따른 엑시톤-폴라리톤의 강한 결합 세기 변화에 대한 최근 연구 결과를 소개하고자 한다. MAPbBr₃는 온도가 증가함에 따라 orthorhombic, tetragonal, cubic 상의 순서로 상전이를 일으키게 되는데, 이에 따른 엑시톤 특성 변화를 관찰하였고, 더 나아가 MAPbBr₃의 결정 상전이에 따른 엑시톤-폴라리톤의 Rabi splitting 변화를 관찰하였다. 흥미롭게도 엑시톤-폴라리톤의 결합 세기의 지표인 Rabi splitting이 tetragonal 상에서 가장 작은 값을 보임을 관찰하였다. 본 발표에서 이와 같은 페로브스카이트 결정 상전이에 따른 엑시톤-폴라리톤 물성 변화에 대한 물리적 의미에 대해 논의하고자 한다.

Keywords:

금속 할로겐화물 페로브스카이트, 폴라리톤, 상전이

From Hermitian to non-Hermitian photonics via hexagonal microcavity based on semiconductor

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Abstract:

We would like to introduce the strong light-matter interaction in group III-nitride based hexagonal microwire structure in both Hermitian and non-Hermitian regimes described by coupled oscillator model. Group III-nitride material obtains a large exciton binding energy for exciton to survive at room temperature as well as the hexagonal wire structure spontaneously generates cavity photon modes, i.e., triangular- and hexagonal whispering gallery modes, so that it is a favorable platform to investigate the strong light-matter interaction at room temperature. We are going to treat starting from the strong coupling regime between excitons and photons, to the unbroken phase and broken phase in PT symmetry between balanced loss polaritons and gain polaritons.

In the strong coupling regime between excitons and photons, we manipulated the real potential energy of exciton polaritons for ballistic transport of the polariton condensate at room temperature. We focused on the ultralow disorder properties of the cross-section of selectively grown GaN wire reducing disorders in both excitonic perspectives by bent dislocations and photonic perspective by crystallographically defined hexagonal cavities for the manipulation of the polariton potential energy and its landscape. This high-quality wire-on-a-substrate spontaneously generates triangular-whispering gallery modes and allows us to demonstrate the room temperature, whispering polariton condensate with the ballistic propagation through the manipulation of the real potential energy of polaritons via the optical method.

In the unbroken phase and broken phase in PT symmetry between balanced loss polaritons and gain polaritons, we manipulated the imaginary potential energy of exciton polaritons via substrate engineering for unprecedented PT symmetry structure at room temperature. We focused on the unique geometry of the hexagonal cavity to exploit the degeneracy of triangular whispering gallery modes. Although cavity photon energy of upward triangular- and downward triangular whispering gallery modes have degenerated under the condition of regular hexagonal symmetry, both modes cannot interact with each other due to the fundamental property of photons. Exploiting the excitonic components in the polaritons to mediate the interaction, we can obtain the interaction between upward triangular whispering gallery polaritons and downward triangular whispering gallery polaritons. Employing substrate engineering for the loss modulation to individually control both modes, we can demonstrate the unprecedented PT symmetry structure and the transition from unbroken to broken phase in the compact polaritonic system. Contrary to the intuition, the broken phase of PT symmetry, which is the strong loss region for triangular WGMs, reveals the lowest threshold of the polariton condensate owing to the exotic property of the gain branch of imaginary eigenvalues.

Keywords:

Hexagonal microcavity, Exciton polariton, Non-Hermitian, Light-matter interaction

Topological Phase Transitions of the Polariton Condensate

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Abstract:

For the quantum well in an optical microcavity, the interplay of the Coulomb interaction and the electron-photon (e-ph) coupling can lead to the hybridizations of the exciton and the cavity photon known as polaritons, which can form the Bose-Einstein condensate above a threshold density. Additional physics due to the nontrivial Berry phase comes into play when the quantum well consists of the gapped two-dimensional Dirac material such as the transition metal dichalcogenide MoS₂ or WSe₂. Specifically, in forming the polariton, the e-ph coupling from the optical selection rule due to the Berry phase can compete against the Coulomb electron-electron (e-e) interaction. We find that this competition gives rise to a rich phase diagram for the polariton condensate involving both topological and symmetry breaking phase transitions, with the former giving rise to the quantum anomalous Hall and the quantum spin Hall phases.

Keywords:

polariton, BEC, microcavity, transition metal dichalcogenide, electron band topology

Photonic device engineering with non-Hermitian singularities and topological effects

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Abstract:

Photonics have provided a fertile ground for experimental study on non-Hermitian and topological physics because of its powerful capability to construct artificial potential distributions and inter-state coupling configurations. In addition, emergence of the non-Hermitian and topological photonics opens up great possibility to create new device principles characterized by parametric robustness and extra degrees of control freedom in unprecedented ways. In this talk, we provide our recent advances along this line. The topics include broadband optical nonreciprocity, new principle of optical signal modulation, topological guided-mode resonances, and their device applications. We discuss implications of our results, remaining challenges, and future directions.

Keywords:

Photonic

Rapid DNA four-way branch migration with a bulge in the toeholds

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Abstract:

Dynamic DNA nanotechnology enabled the construction of composable molecular reaction circuits made of DNA. The core molecular reaction for dynamic DNA nanotechnology is DNA strand exchange reaction. While most of the current DNA circuits use three-way branch migration, the alternative of four-way branch migration has the advantage of using two input toeholds for double recognition and having less crosstalk from single-stranded species. Such properties have been used to construct molecular walkers, DNA actuators and DNA push-pull systems built with four-way branch migration scheme. Four-way branch migration is also relevant to natural biological systems as the four-armed DNA junction called Holliday junction appear during homologous recombination. However, four-way branch migration is slower than three-way branch migration as the migration of the junction requires simultaneous opening of two base pairs in different arms of the junction while the opening of a single base pair is sufficient in three-way branch migration.

Here, we introduce a bulge at the DNA junction to change the molecular mechanism of four-way branch migration so that the opening of a single base pair is sufficient to induce migration of the branches by a half base pair. We show that the introduction of a bulge accelerates the DNA strand exchange reaction mediated via four-way branch migration. The bulge also increases the concentration of reactants that can be used before the reaction rate saturates. Fitting the data with a two-step reaction mechanism revealed the entire branch migration reaction is 25 times faster in the presence of a bulge. Considering that the number of steps is doubled by adding a bulge, the presence of a bulge decreases the stepping time by 100-fold, making it similar to the stepping time of a three-way branch migration. Therefore, combined with the recently proposed general chemical reaction network scheme using only two stranded complexes, our method opens up the possibility of constructing composable four-way branch migration based DNA circuits that rival the speed of their three-way branch migration counterparts.

Keywords:

DNA nanotechnology, Toehold mediated strand displacement, DNA four-way branch migration

Photoconversion of Cyanine5 to Cyanine3 and its application for high-density single-particle tracking in a living cell

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Abstract:

Cyanine (Cy) dyes are among the most useful organic fluorophores that have found a wide range of applications in single-molecule and super-resolution imaging as well as in other biophysical studies. However, recent observations that blueshifted derivatives of Cy dyes are formed via photoconversion have raised concerns as to the potential artifacts in multicolor imaging. Here, we report the mechanism for the photoconversion of Cy5 to Cy3 that occurs upon photoexcitation during fluorescent imaging. We also show that the deletion of a two methine unit from the polymethine chain, which results in the formation of blueshifted products, commonly occurs in other cyanine dyes, such as Alexa Fluor 647 (AF647). We demonstrate that the potentially deleterious photoconversion, however, can be exploited to develop a new photoactivation method for high-density single-particle tracking in a living cell without using UV illumination and cell-toxic additives.

Keywords:

photoconversion, single particle tracking

Pausing-dependent Stand-by Pathway in Rho-dependent Termination Finely Tunes Riboswitch Control of Termination

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Abstract:

Prokaryotic RNA genesis is terminated by a hexameric helicase Rho. In spite of the important role in the prokaryotic transcription termination, the definite mechanism of Rho-dependent termination still remains elusive. We developed single-molecule assay to observe Rho in high temporal and spatial resolution. Using this assay, we found that the diverse mechanisms suggested for each step co-present with each *Escherichia coli* terminator, but sequentially coupled so that three routes are followed. The catch-up pathway leads first to RNA shearing in recycling, or later to RNAP displacing leading to decomposing. The stand-by pathway accompanies only displacing followed by decomposing. Furthermore, we discovered that stand-by pathway show the pausing-dependence, while catch-up pathway, which thought to require the time for Rho to chase the RNAP, doesn't. In addition, pausing-dependent stand-by pathway showed larger differences in riboswitch-controlled termination efficiency than catch-up pathway. These observations showed that pausing dependence and riboswitch control in Rho-dependent termination is more attributed to stand-by pathway than catch-up pathway.

Keywords:

Single-molecule, Rho, riboswitch, transcription termination, pausing

The effects of the cytosine methylation on the dsDNA bending mechanics

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Abstract:

Cytosine methylation of double-stranded DNA (dsDNA) is commonly found in strongly bent dsDNA structure such as nucleosomal DNA, and is known to play a pivotal role in nucleosome stability and positioning. However, the detailed mechanisms of how the methylation regulates bending properties of dsDNA have remained elusive. To find out the effects of the methylation on the bending properties, we investigated the structural changes of D-shaped DNA nanostructure using single-molecule FRET. The smoothly bent dsDNA shows that bending curvature decreases when it methylated which indicates an increase in the intrinsic stiffness of dsDNA. However, when dsDNA is compressed strongly enough, the methylation seems to have different effects on the bendability depending on the distance between methylation sites and the kink. Our novel results on the relationship between cytosine methylation and dsDNA bending can provide a new insight of the mechanisms of how the methylation distribution over the sequence affects nucleosome stability and positioning.

Keywords:

DNA structure, single-molecule FRET, DNA bending, cytosine methylation, DNA stiffness

Revealing the Formation of IDR (Intrinsically Disordered Region)-mediated PD1 Nanoclusters

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Abstract:

Intrinsically disordered proteins (IDPs) and their phase-separation is an emerging topic in biophysics. Recent studies have revealed the importance of biomolecule condensates that often occurred by phase separation. For instance, some immunological receptors form mesoscale receptor clusters on the membrane, thus dynamically regulating immune responses. Programmed cell death-1 (PD1) also form micrometer-scale clusters at PDL1 binding, inhibiting T cell activation. Yet, the detailed mechanism explaining this condensate formation is limited: whether they go phase-transition or the underlying structural mechanism. Here, we report that the intrinsically disordered nature of the PD1 cytosolic tail can form a nanoscale cluster on the cell membrane. Single-molecule fluorescence imaging combined with theoretical foundations regarding IDP phase separation helped us find out the structural mechanism, accordingly discovering specific residues that are critical for clustering. We also observed the PD1 phase-separation on the supported lipid bilayer as well as on the cell membrane. Our investigation suggests PD1 nano-cluster as a critical initiator component within the PD1:PDL1 interactions in the immunological scene. We expect this unique nature of PD1 self-clustering to help understand other intrinsically disordered signaling molecules and be applied a therapeutic approach targeting the PD1 cytosolic domain.

Keywords:

IDR (Intrinsically disordered region), Membrane protein, Single-molecule imaging, Phase-separation

Korean Neutrino Observatory

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Abstract:

Korean Neutrino Observatory (KNO)는 한국이 독자적으로 추진하는 차세대 중성미자 검출시설 프로젝트이다. KNO의 핵심시설은 중성미자가 물과 반응하면서 방출되는 체렌코프 광을 이용하여 중성미자를 검출하는 거대 중성미자 검출기이다. KNO 검출기는 지하 1000m에 위치한 수십만 톤의 초순수 물로 채워진 거대 수조와 수조 내벽에 설치되는 수만개의 광센서 (PMT)로 구성되어 있다. KNO는 건설이 된다면 세계 최대규모의 지하중성미자 검출시설이 될 것으로 예상되고 있으며 중성미자의 CP 비대칭성 측정, 양성자 붕괴 탐색, 다중신호 천문학 등의 중요한 연구주제에서 세계적인 연구성과를 도출할 수 있을 것으로 기대되고 있다. 2016년에 처음 제안된 KNO프로젝트는 2018년에 KNO 추진단이 조직되면서 본격적으로 추진되고 있으며 물리학, 천문학 분야의 많은 연구자들이 참여하고 있다. 현재 검출기에 대한 기초적인 R&D뿐만 아니라 KNO의 과학적 기대성과에 대한 사전 연구가 활발히 진행되고 있다. 이번 발표에서는 KNO 프로젝트의 추진 경과 및 향후 전망에 대해 보고하고자 한다.

Keywords:

KNO, 중성미자 검출기, 체렌코프광

고자기장 연구시설

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Abstract:

우주에 작용하는 기본 힘에서 자기장은 인류가 가장 오래동안 응용해 왔으며, 현대에도 우리 일상 생활에서 가깝게 이용하고 있다. 물리학에서도 물질의 특성을 알아보는데 자기장을 이용한 연구가 활발하게 이루어지고 있는데, 고자기장을 이용한 실험물리학 연구에서는 극저온, 초고압과 같은 실험 조건에 고자기장을 가하며 극한 연구를 수행하게 되며, 이러한 극한 상황에서 물질내 입자의 거동은 종종 새로운 상태로 변하여 새로운 물리학적 발견을 유도해 왔다. 고자기장 발생장치는 장비 구축과 운영에 많은 인력과 비용이 소요되기 때문에 많은 나라에서 국가 연구시설로 운영하고 있다. 국내 연구자들도 이러한 동향에 맞추어 지난 10년 이상 국가 고자기장 센터 건립에 많은 노력을 기울여 왔지만, 여러가지 이유로 아직 결실을 맺지 못하고 있는 실정이다. 본 발표에서는 해외 고자기장 연구 시설 동향, 국내 국가 고자기장 센터 건립의 타당성과, 최근 국가 고자기장 센터 건립 활동을 조명해 보고자 한다.

Keywords:

고자기장

Korea Spallation Neutron Source (KSNS)

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Abstract:

한국원자력연구원 양성자과학연구단에서는 100 MeV 양성자가속기를 국내 기술로 구축하여 2013년부터 이용자서비스를 해오고 있습니다. 최근 삼성, 하이닉스와 같은 반도체 분야, 우주부품, 의료용 동위원소 생산 등 다양한 응용분야들의 지원으로 빔타인 신청 경쟁율이 3:1이 넘게 급증하는 추세입니다. 하지만 해외 과학선진국 대비 양성자가속기의 저사양으로 반도체, 6세대 이동통신(6G), 미래자동차(자율주행차, 플라잉카, 드론택시 등), 우주부품, 에너지 소재, 극한환경소재, 백신/신약, 등 첨단과학기술분야 국내 이용자들이 해외 양성자/중성자 시설을 (추가로) 이용해야하는 어려움이 발생되고 있으며, 연구용 원자로인 하나로의 7년간의 운영 중단으로 안정적 중성자원을 국내 이용자들에게 공급하지 못하고 있었습니다. 이에 100 MeV 양성자가속기의 성능을 GeV급으로 확장하여 세계 최고 수준의 고해상도 중성자 분석시설이 가능한 파쇄중성자원을 구축하고자합니다. 이 구두 발표에서는 고에너지 중성자와 양성자 공급이 가능한 Korea Spallation Neutron Source (KSNS)의 추진 일정, 사양, 응용분야 등을 다룰 예정입니다.

Keywords:

초고출력 레이저 현황 및 활용

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Abstract:

1960년 Theodore Maiman에 의해 레이저가 최초 개발된 이후 레이저는 기초과학부터 산업 전반에 걸쳐 필수 도구로 광범위하게 사용되고 있다. 따라서 레이저 기술 발달은 곧바로 기초과학은 물론 나노, 바이로, 의료, 국방분야의 신기술 개발과 기술 경쟁력으로 이어진다. 예를 들어 극자외선(EUV) 노광공정 장비는 반도체 산업의 초격차 기술을 좌우하고 있으며 레이저가 핵심광원으로 사용되고 있다. 최근에 레이저 기술 발달은 초고출력의 레이저 발생을 가능하게 하고 있으며 이를 활용하는 극한 과학, 레이저 입자 가속, 아토초 및 펨토초 과학과 같은 새로운 물리 분야의 도래를 예고하고 있다. 따라서 선진 각국에서는 미래의 혁신적인 도구로 활용될 초고출력 레이저 개발에 전략적으로 적극 투자하고 있으며 유럽을 비롯한 영국, 중국, 미국 등지에서 초고출력 대형 레이저 연구시설이 구축 또는 계획되고 있다. 본 발표에서는 초고출력 레이저의 국내외 현황 및 활용을 살펴보고 그 필요성에 대해 논의하고자 한다.

Keywords:

초고출력 레이저, 고에너지 레이저, 극한 과학

Exciton-polaritons in 1D ZnO semiconductor nanocavity

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Abstract:

Excitons, which are Coulomb bound states of electron and hole, are a key element to control the emission efficiency of semiconductor light emitters. Especially, semiconductors with large exciton binding energy, such as GaN, ZnO, lead halide perovskites, are leading to the advancement of semiconductor light sources. In this work, the relevant studies and ideas to realize nanoscale light emitters based on 1D ZnO nanostructure are presented. Importantly, to overcome the limitation of bulk excitons at room temperature, such as thermal dissociation and broadening, the quantum well (QW) excitons were employed to realize the efficient light emitter, especially in nanoscale limit. The nanoscale light emitters were fabricated by utilizing the 1D ZnO nanostructure with MgZnO/ZnO-based radial multiple QWs. The optical properties of 1D nanostructure with radial multiple QWs were widely investigated under electrical pumping and optical pumping. Also, since the QW excitons can interact with the confined photons, dominated by Fabry-Perot mode along the length direction of the 1D nanostructure, the strong light-matter interaction can be observed at room temperature, mainly due to the improved thermal stability of QW excitons. In addition, due to the quantum confinement, such as QWs, the oscillator strength of excitons can be enhanced by increasing the wavefunction overlap of electrons and holes, compared to the bulk excitons. Thus, the polariton devices operating at room temperature can be realized by exploiting the increased oscillator strength from QW excitons. The relevant discussions and studies regarding the exciton-polaritons in the 1D ZnO nanostructure are also presented.

Keywords:

ZnO nanostructure, radial quantum wells, exciton-polaritons, nanoscale light emitter

InGaN/GaN core-shell quantum wells on GaN nanowire for LED application

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Abstract:

We demonstrated the growth of GaN nanowire-based LEDs by MOCVD on an amorphous glass substrate. InGaN/GaN multiple quantum well shells are conformally grown on semipolar (11-22) growth facet of m-axial GaN core nanowires and resulted in reduced quantum confined Stark effect. The PL spectroscopy of the GaN core nanowire-ensemble reveals a very high crystal quality due to the dominant emission from the band-to-band transition and absence of a characteristic yellow luminescence. The QW emission wavelength can be tuned from 460 to 670 nm. Besides, the temperature-dependent PL of the nanowire ensemble exhibits a very high internal quantum efficiency of 76.1%. Therefore, the ultrashort radiative lifetime of the carriers was in the range between 19 ps and 54 ps. The grown semipolar InGaN/GaN QW core-shell nanowires have been successfully fabricated into LEDs, showing the prospect of light emitters grown directly on glass substrates. Growth of high-crystal quality GaN nanowires on amorphous substrates is a promising approach for large scale production and various optical applications such as LEDs, solar cells, and photodetectors.

Keywords:

InGaN/GaN, core-shell, nanowire, light emitting diode

Epitaxy of miniaturized p-n junction semiconductors for light-emitter applications

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Abstract:

Emergence of micro-light-emitting diode (LED) display has motivated to develop miniaturized LEDs by top-down etching from thin film LEDs and bottom-up growth. Currently, the top-down approach is overwhelmingly adopted in fabrication of commercial micro-LED displays. However, for ultrahigh-resolution LED displays, the top-down approach has technological difficulties, such as efficiency drop in miniaturization, sawing edge problem, transfer accuracy limitation for assembly to raster pixel arrays, etc. In this talk, the bottom-up approach for fabricating micro-LED displays is discussed as a competing game player against the top-down technique in micro-LED fabrication. In the first part, the fabrication method and characteristics of miniaturized p-n junction GaN rod arrays by confined (or selective) covalent epitaxy is addressed, whose single emitter diameter is less than 1 micron in a high-density regular array. In the latter part, the releasable epitaxy of GaN microcrystal p-n junction LEDs is discussed for ease of transferring the micro-LED arrays as deployed in the lithography steps. Lastly, this talk will discuss the speaker's personal outlook on epitaxy for future display technology.

Keywords:

Selective epitaxy, remote epitaxy, GaN, micro-light-emitting diode display

Novel optical properties of quantum crescents

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Abstract:

Recently, semiconductor quantum ring structures are considered a new platform of the Aharonov-Bohm effect when the confining rim of carriers is assumed to be a cyclic loop. However, the droplet method gives rise to an anisotropy in the rim height. In this case, carriers are likely localized with a crescent shape, and the separate local structures require an external field to be a connected single loop. Therefore, such a localized state of quantum crescents needs to be investigated first before the idealized loop of quantum ring is realized. In this work, a systematic optical characterization of quantum crescents will be introduced, where time-resolved PL, interferometric correlation, and HBT are utilized. The localized state has been verified through different methods, and we found that the crescent-like localized structure shows a novel selection rule due to the asymmetry. While two crescents become merged, we found the confinement dimensionality can be evaluated as a quasi one dimensiona.

Keywords:

quantum crescent, localized state, quantum ring

Constraints on Quantum Gravity

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Abstract:

Although predictions of quantum gravity are typically at extremely high energy, several non-trivial constraints on its low energy effective theory have been found over the last decade or so. I will start by explaining why the unification of general relativity and quantum mechanics has been difficult. After introducing the holographic principle as our guide to the unification, I will discuss its use in finding constraints on symmetry in quantum gravity. I will also discuss other conjectural constraints on low energy effective theories, collectively called swampland conditions, and their consequences.

Keywords:

Quantum Gravity, unification, constraints

Analyzing High-energy Physics Data through Deep Learning(딥러닝을 이용한 고에너지 입자물리 데이터 분석)

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Abstract:

딥러닝을 이용하여 높은 수준의 인공지능을 구현할 수 있는 성공적인 사례가 소개되고 있다. 고에너지 입자물리 데이터 분석에서도 딥러닝을 적용하였을 때, 고전적인 rule-based 데이터 분석 방법 등에 비해 다양한 측면에서 월등한 성능을 보여준 바 있다. 이에 따라 고에너지 입자물리계에서도 딥러닝을 더욱 공격적으로 적용하려는 시도가 일어나고 있다. 향후 LHC를 비롯한 대형 실험에서의 더 많은 데이터가 확보될 것이며, 이를 빠른 시간 안에 알맞게 처리하기 위해 딥러닝과 빅데이터 분석기술이 전반적으로 활용될 것이다. 본 강연에서는 고에너지 입자물리 데이터 분석에 고속 딥러닝을 적용하기 위한 소개와 함께 실습 및 예시를 통해 진입 장벽을 낮출 수 있는 기회를 제공하고자 한다.

Keywords:

Deep Learning, High-energy

주사 터널링 현미경 (STM/STS)의 기본과 최근 연구 경향

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Abstract:

주사 터널링 현미경은 터널링 전류의 측정으로 응집물질 표면의 전자구조를 분석하는 장비이다. 원자 수준의 공간 분해능과 높은 에너지 분해능으로 국소 전자밀도 측정이 가능하며 응집물질과 나노구조의 전자구조를 이해하는 데 사용되고 있다. 본 튜터리얼 강의에서는 주사 터널링 현미경의 기본 원리 및 측정 신호의 분석 방법을 소개하고, 이를 응용하여 다양한 위상물질과 2차원 물질의 전자구조를 분석하는 방법에 대해 소개하고자 한다.

Keywords:

STM, STS, topological materials, 2D materials

IB DP 물리학 과목 소개

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Abstract:

본 발표에서는 2020년부터 인가를 받아 국내에서 한글로 가르치기 시작한 IB(international Baccalaureate) 교육에 대한 소개와 함께 고등학교 과정(Diploma Programme)에 있는 물리학 과목에 대한 소개를 하는 것을 목적으로 잡았다. 먼저, IB 교육에 대한 소개에서는 IB 교육의 특징, IB 교육내용, IB에서의 수업과 평가 방법, 국내 도입의 의의와 현황을 이야기 하고, 이어지는 DP 물리학 과목에 관해서는 과목의 목표, 교수요목, 평가에 대해 살펴보고 이들 내용을 2015 교육과정의 물리학과 비교해 본 다음에 IB 물리학 과목이 국내에 도입되기 위해 필요한 과제에 대해 논의해 볼 것이다. 이상의 발표를 통해서 참가자들은 IB 교육의 철학, 방향, 교육내용, 국내 도입 가능성에 대해 파악하는 계기가 될 것이다.

Keywords:

물리교육, IB 교육

레이저-플라즈마 물리의 기초와 응용 (Fundamentals of Laser-Plasma Physics and Applications)

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Abstract:

1950년대 초에 Townes 의 연구를 필두로 구현된 레이저 기술은 1980년대 중반 Mourou 교수팀의 CPA (Chirped-Pulse-Amplification) 기술 발명으로 고출력 레이저의 시대로 진입하게 되었다. 역사와트급의 출력까지 발전하고 있는 현대의 고출력 레이저는 자연스럽게 레이저-플라즈마 물리와 응용 분야의 발전을 가져왔는데, 이는 그러한 고출력 레이저에 닿는 물질은 순식간에 이온화 되어 플라즈마 상태로 바뀌기 때문이다. 대표적인 레이저-플라즈마 연구분야는 관성 핵융합, 플라즈마 기반 입자 가속, 플라즈마 기반 고주파 광원 또는 고에너지 광입자원, warm-dense matter 등 다양한데, 본 세션에서는 최근 국내에서 연구가 활발했던 레이저-플라즈마 입자 가속 분야의 기본 원리와 현황에 대해 주로 얘기해보려 한다. 이와 함께, 레이저-플라즈마에서는 상대적으로 아직 마이너한 분야이나 높은 발전 가능성을 가진 블루 오션이라 할 수 있는 플라즈마 옵틱스 (플라즈마를 이용하여 광이나 포톤을 제어한다는 개념) 분야에 대해서도 소개할 것이다. 레이저-플라즈마에서 비중이 매우 높은 몇가지 연구 주제의 기초 원리에 대한 강연을 통해 레이저-플라즈마 연구에 새로 진입하는 대학원생이나 일반 연구자들과 정보를 공유하고 해당 연구 분야 저변 확대에 기여하는 계기를 만들고자 한다.

Keywords:

Laser-Plasma

Rydberg Atoms for Quantum Simulation

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Abstract:

Rydberg atoms refer to neutral atoms in highly excited energy states with principal number $n \gg 1$. A Rydberg atom has a size about a million times larger and about 10^5 times longer lifetime than a hydrogen atom. Such exaggerated properties allow us to utilize the quantum properties of neutral atoms on the macroscopic length and time scales. For example, Rydberg blockade is an essential ingredient to implement quantum gates among neutral atoms via Rydberg-mediated entangled states. This tutorial will briefly introduce experimental techniques for controlling Rydberg atoms, including an array of single-atom dipole traps and Rydberg excitation. The Rydberg atom technologies have recently emerged as a promising candidate for robust quantum computing and sensing.

Keywords:

Rydberg atoms, single-atom trap, Rydberg blockade, entanglement

양자센서기술과 이를 위한 양자방법론 소개

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Abstract:

양자 기술을 방법론적으로 [예: 양자얽힘, 단광자, 단전자등의 발생/제어/측정등] 이용하여 고전적인 물리량 센싱 방법으로 측정한계를 극복하여 높은 민감도의 측정이 가능하게 하는 것을 양자 센싱 기술로 일반적으로 정의한다. [1] 본 발표에서는 다수의 양자 센서중, 산업화에 가까운 양자 관성 센서 [양자 중력 센서, 양자 Compass], 양자 자기장 센서 [양자 MRI], 양자 광학 센서 [양자 Lidar, 양자 현미경]등에 대해서만 좁혀 다룬다. - 양자 관성 센서는 단일개의 trapped된 원자 이온을 이용하여 중력 혹은 회전관성에 따른 변위를 광학적으로 정밀하게 측정하는 것이며, 응용에 따라, 양자 중력 센서, 양자 Compass [양자 각가속도 센서]등으로 분류된다. 양자 중력 센서등은 화산등 자연재해 감지 및 지하 공동구 탐지 응용등에 상용화 위한 연구 진행 중이다. 기존 중력계보다 10배 정밀하며 크기가 1/100이다. 양자 가속도/각가속도 센서는 양자 Compass로 불리고 있다. 이동성 및 환경 민감도 개선 위한 원천기술을 주로 연구하고 있으며, GPS이용이 불가능한, 지하/해수하 장기 이동시, 자신의 위치 추적에 활용된다.

- 양자 자기장 센서는 주로 MRI, 뇌자도와 같이 생체자기 측정 분야에 활용되고 있으며 상용화를 위한 연구개발이 이루어지고 있다. 또한 배터리의 미세 누설전류를 이미지화 하기위한 용도로도 활용될것이다. - 양자 광학 센서는 단일 광자 생성 및 다수 단광자간의 얽힘 제어기술과 광자를 측정하는 기술에 그 기본을 두고 있다. 고성능의 단일 광자 발생기 및 검출기를 개발하기 위해 다이아몬드 NV센터, SNSPD, APD기반 반도체 센서 등을 활용한 개발 진행중이다. 양자 광학 센서중 일부인 양자LIDAR 분야에서는 200Km 거리 측정 시제품을 개발하여 실제 이미지를 구현해 내는 수준이며, 양자 얽힘기술을 이용하는 양자레이더는 스텔스 기술에 대한 대항기술로 사용될것으로 기대된다.

[1] Acin et al., New J. Phys. 20 (2018) 080201

Keywords:

양자센서, 단광자, 이온, 양자기술

Single-molecule diffusion dynamics in living cells: theoretical approach

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Abstract:

Recent advance of single-particle tracking (SPT) technique has significantly elevated the understanding of single-molecule dynamics in living and soft-matter complex systems. Without *in priori* assumption on the underlying dynamics, the SPT tools make it possible to access the information on transport and/or conformational dynamics of individual molecules and, further, to obtain physical observables in a single-molecule level, without ensemble-averaging. In terms of physics, the intracellular environment is understood as viscoelastic and active media, which often results in the so-called "strange kinetics". Currently this field, a.k.a. anomalous diffusion, is rapidly growing at the intersection of biophysics and statistical physics. In this tutorial talk, I introduce this field under the focus of developments & applications of theoretical models that often recurrently emerge in biological systems. It is shown that the information on the stochastic properties of the motion is a fingerprint of identifying the physical origins of the anomalous diffusion as well as the clue for establishing the corresponding dynamic model. Beyond these studies, currently, investigations on the impact of the anomalous diffusion on the cellular dynamics becomes an important topic. A related research problem currently undertaken in my group is shortly explained.

Keywords:

anomalous diffusion, single-particle tracking, intracellular dynamics, target search

Implicit 6D particle in cell simulation of multiscale processes in plasma physics

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Abstract:

6D particle in cell (PIC) methods describe the nonlinear interaction of electrons and ions with the electromagnetic fields they contribute to generate self-consistently. The approach uses a statistical sample of real particles and using interpolation to a grid can represent faithfully the real system. A critical challenge of this approach is the presence of multiple scales in time and in space that requires massive computational resource. The approach we propose to deal with this challenge and make simulations more computationally manageable is a semi-implicit PIC code, known as Energy Conserving semi-implicit model (ECsim). The ECsim keeps the field advance and particle motion coupled within a nonlinear iteration allowing the use of much larger time step and grid size, compared to explicit PIC models. The main advance of ECsim is the use of mass matrix for representation of particle motion for exact energy conservation. Using ECsim, we successfully conducted simulation of turbulent reconnection in the magnetosphere, plasma start-ups in high beta magnetic cusp systems and magnetic mirrors. We also started applying ECsim to tokamak problems. In this talk, we will present some of these results and hope to engage a discussion on the application to spherical tokamaks.

Keywords:

plasma simulation, particle-in-cell method

포스터발표논문

Poster session abstract

Deterministic and Stable single-photon emission in phase-patterned in-plane WSe_2/WO_x quantum wells

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Abstract:

Single photon emitters (SPEs) in solid-state systems are a crucial component for quantum information technologies. The emergence of SPEs in transition metal dichalcogenides (TMDs) provides opportunities to realize a novel quantum structure. Because TMDs have large exciton binding energy, small bandgap to efficient generation of exciton upon optical- or electrical excitation, and the possibility of qubit operation due to the reduced symmetry. Using these exceptional properties, previous studies reported the TMDs based SPEs via the defect creation or creation of strain fields for localized excitons. However, realizing the site-control and integration into the photonic circuit simultaneously has not been reported. To be used for applications, achieving deterministic emitter creation, integration with photonic circuit, and funneling of excitons should be implemented. Here, we demonstrate the novel approach to fabricate site-controlled and band-structure engineered SPEs via on-demand oxidation and monolithic bandgap engineering of TMDs. We introduced the e-beam lithography and oxidation process to fabricate the WO_x/WSe_2 lateral quantum well structure. Through the simple e-beam lithography process, deterministic SPEs could be achieved without artificial structure (e. g., nanopillar), which is a key component for exciton funneling in previous studies. In addition, through the oxidation process and WO_x/WSe_2 heterostructures, extreme funneling of exciton could be realized which comes from additional local strain and lateral quantum well structure. Based on WO_x/WSe_2 lateral quantum well structures, the zero-phonon-line with 284 μeV linewidth at 4 K, and accordingly the estimated value of $g^{(2)}(0) = 0.244$ were observed. In addition, by examining the stability of WO_x/WSe_2 , we found that spectral wandering and blinking were not exhibited in the 150s scale. This work paves the way toward site-controllable and integrable with the photonic circuit of 2D SPEs for novel quantum information technologies.

Keywords:

Two-dimensional materials, In-plane quantum well, Quantum emitter

Molecular-Dipole-assisted Fermi-level Engineering of *vdW* Schottky Junctions for 2D Semiconductor Photovoltaics

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Abstract:

Two-dimensional (2D) semiconductors have attracted much attention for ultrathin optoelectronics due to their exceptional optical properties and the ability to build artificial heterostructures. Nevertheless, the Fermi-level (E_F) pinning at the metal-semiconductor interface still impedes the realization of high-performance optoelectronic devices. In this regard, it is highly demanding to develop the appropriate strategies to control the Schottky barrier in a predicted manner according to the ideal Schottky-Mott rule. However, in the case of van der Waals (*vdW*) transfer methods previously reported, the use of different metals is necessary to control the work function and corresponding energy barrier. Here, we report a facile approach to modify the work function of metals and the associated built-in potential in *vdW* Schottky junctions utilizing interface molecular dipoles. The dipole field induced by self-assembled monolayers (SAMs) on the metal surface leads to the work function difference and the built-in potential across the *vdW* metal-semiconductor junction. As a result, when the SAMs interlayer was introduced at the interface, the photovoltaic characteristics such as the short-circuit current and open-circuit voltage were tuned depending on differently polarized molecules. Furthermore, the photoresponsivity can be substantially enhanced by creating a strong built-in field via interface dipole control. Our work suggests a new route to achieve molecular band engineering in *vdW* heterostructures toward realizing high-performance 2D optoelectronics.

Keywords:

2D semiconductor, Photovoltaics, Interface Engineering

Hole Charge Carrier Increment of 2D Materials driven by Surface Oxidation

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Abstract:

Transition metal dichalcogenide (TMDC) based two dimensional (2D) materials have attracted significant attention to be used in both high performance and low power electronics due to their superior properties such as enhanced electrostatic control and high charge carrier mobility. **[1]** However, there are several bottlenecks that deter the replacement of current silicon-based CMOS technology with 2D semiconducting materials. **[2]** A significant challenge for MoS₂ based field-effect transistors (FETs) is the difficulty to fabricate both electron and hole charge-carrier controlled FETs from the same material due to the lack of ambipolar transport. The previous results from other groups are ambipolarity demonstration with an electric double layer transistor using ionic gel gating materials. **[3, 4]** However, this method has a difficulty to modulate the current with a poor on-off current ratio. Another method is fabrication of MoS₂ FETs on polymethyl methacrylate dielectric substrate **[5]**, which is not compatible to CMOS circuit. So, in this work, we used comfortable UV light treatment for MoS₂ surfaces in air with the various exposure times to oxidate the TMDC surface for a p-type doping. To support our results, we measured thicknesses of 2D semiconducting material flakes using AFM and Raman spectra systems. And the relative degree of oxygen doping was also analyzed by Raman measurement. As a result, this method could regulate the oxygen doping degrees with UV exposure times efficiently without any unrequired residues in 2D materials-based FETs.

Acknowledgments This work was supported by BK21 Plus program, and National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (Grant No. 2019R1A2C1002787) and by Basic Science Research Program (NRF-2019R1A6A3A01096367, and NRF-2020R1A6A1A03047771) through the Ministry of Education.

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Keywords:

2D material, field-effect transistor, ambipolarity, UV irradiation, p-type doping

Polarization-dependent resonance energy transfer between MoS₂ / plasmonic asymmetric Au nanoparticles

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Abstract:

Low-dimensional materials such as graphene, nano-wires, transition metal dichalcogenides (TMDCs) monolayer, are important to the optical absorption and emission for optoelectronic devices. Plasmonic metal nanoparticles applicant to the low dimensional materials have improved to the optical properties resulted from the localized surface plasmon resonance (LSPR). However, the mechanism for the plasmon hot electron transfer from the metal conduction electron to the target optical materials was not clearly defined by the experiment. In this paper, we used the asymmetric Au split ring structures for plasmon enhancement particles under the MoS₂ monolayer. It has polarization dependence on the electromagnetic field confinement of the plasmonic particles. The resonance frequency of the absorption and emission spectra is measured by the absorption hyperspectral images. Thus, the excitation laser wavelength is selected by the resonance frequency region (633 nm, He-Ne laser) and un-resonance frequency region (532 nm).

The result of the polarization depends on the photoluminescence on the plasmonic structures is enhanced about a few 100 magnification intensities. It is controlled by the incident angle of the laser polarization. And then, the surface potential was changed to ~ 50 meV measured by Kelvin probe force microscopy (KPFM). The reason for the coupling between metal conduction electron and MoS₂ exciton is the resonance energy contribution of the absorption process and emission process. The plasmonic resonance on the Au particles is separated by plasmonic hybridization. Then the higher energy resonance region of frequency is matched the MoS₂ absorption band. Also, the photoluminescence is redshift affected by the hot electron transfer from the metal conduction electron. the evidence of the electron transfer is the trion exciton peak intensity boosted.

Keywords:

hot-electron transfer, 2D material, optical measurement, Kelvin probe force microscopy

Controlling nucleation and growth parameters of AgCN microwires on two-dimensional crystals

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Abstract:

Various mixed dimensional van der Waals heterostructures have gathered intense research interest owing to their emerging new physical and electrical properties from coherent interaction between components. In particular, one-dimensional (1D) nanowires or microwires assembled on two-dimensional (2D) crystals can serve as model systems for investigation of van der Waals assembly on 2D crystals and are potentially useful for various electrical device applications. We previously confirmed that the assembly of 1D AgCN microwires exhibits the well-oriented assembly on various 2D crystals and reflects the symmetry of underlying substrates. Here, we investigate in detail the growth and assembly mechanisms of 1D AgCN wires on 2D crystals. We find that the surface treatment of 2D substrate dramatically change the nucleation density, length and width of AgCN microwires. The growth behavior of 1D chains is also modeled using Monte Carlo simulation with varying growth parameters including nucleation and growth rates. The demonstrated control of 1D wire assembly on 2D will be useful for controlling the electrical and optical properties of 1D/2D van der Waals heterostructures.

Keywords:

2D materials, 1D AgCN Microwire, Monte Carlo simulation, Epitaxy growth control

Direct growth of GaN layer on hexagonal boron nitride

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Abstract:

질화갈륨 (GaN) 기반 발광 다이오드 (LED) 는 단색광, 백색광, 디스플레이, 조명, 액정 백라이트와 같은 응용 분야에서 상당한 연구가 되는 물질이다. 상업적 사용을 위해서는 저전력 LED를 위한 고품질 GaN 에피층의 개발이 필수적이다. 일반적으로 GaN 박막은 단결정 사파이어 기판 위에 합성이 되는데, GaN 층과 사파이어 기판 사이의 격자상수 불일치 및 열팽창 계수의 차이에 의해 높은 밀도의 선결함 (threading dislocation)을 발생시키며, 고 전류 주입시 열이 발생하게 된다. 이는 발광소자의 효율 및 성능을 저하시키는 주요인이다. LED의 신뢰성과 성능을 향상시키기 위하여 현재 대부분의 연구는 선결함을 감소시키고 열 발산을 향상시키는 두가지 주요 문제에 중점을 둔다.

보론 원자와 질소 원자가 육각형 형태로 공유결합을 한 hexagonal-boron nitride (h-BN) 는 부도체이며 유연하고 높은 전기적-화학적-물리적 내구도를 가지는 특성을 가지는 2차원 박막 물질이다. 본 연구에서는 GaN 박막 성장시 사파이어와 GaN 박막 사이에 h-BN 박막을 삽입한 구조를 사용함으로써 성장된 GaN 박막의 품질을 향상시키고자 한다. 일반적으로 성장된 GaN 박막, 사파이어 위 h-BN 박막에 성장한 GaN 박막, 사파이어 위 패터닝된 h-BN 박막에 성장된 GaN 박막을 비교하여 기존 GaN 박막에 비해 향상된 특성을 비교하고자 한다.

Keywords:

GaN, h-BN

Probing interlayer interactions of stacked WS₂ by Raman spectroscopy

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Abstract:

We have investigated the vibrational properties of artificially stacked WS₂. Twisted van der Waals systems exhibit exotic properties such as correlated insulating phase and unconventional superconductivity. [1, 2] When monolayer crystals were overlaid, the new periodicity (moiré periodicity) has been observed. Due to this moiré pattern, zone-folded acoustic phonons by the moiré period (so-called moiré phonons) in the twisted van der Waals system have been reported. [3] We carefully examined the effect of interlayer interaction and moiré patterns on the phonons of artificially stacked WS₂ by using Raman spectroscopy. The twist angle dependence of the Raman spectra will be reported.

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Keywords:

Interlayer interaction, Raman spectroscopy, Stacked WS₂

Effect of engineering the electronic structure of 2D materials via exposure to high gas pressure

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Abstract:

Two-dimensional materials such as graphene and transition metal dichalcogenides (TMDC) have been focused on due to their interesting properties. Graphene, which is an ideal monolayer honeycomb lattice carbon, has unique physical and electrical properties like linear energy dispersion, zero band-gap at Dirac point, high electron mobility, and tensile strength, etc. In the case of TMDC materials, a quasi-two-dimensional honeycomb lattice that transition metal and chalcogen are stacked layer by layer, also have unique properties. For example, since the molybdenum disulfide has a proper band-gap and high thermoelectric power factor, it is considered as the next generation material to alternate silicon. However, the electronic structure of 2D materials is inevitably modified to apply for various fields. Here we demonstrate the change of structure and electronic properties of graphene and MoS₂ using exposure to high H₂ and O₂ gas pressures. On H₂ exposure, the change of graphene and MoS₂ is attributed to dissociative adsorption, and hydrodesulfurization, respectively. For high O₂ gas, the changes occur from the creation of oxygen species in graphene and transition of structure into MoO₃ for MoS₂. The structural changes were investigated with Raman spectroscopy, x-ray diffraction patterns, and x-ray photoelectron spectroscopy. The gate voltage-dependent conductance and current-voltage characteristics as a function of gas pressure and exposure time were performed to show the change in electrical properties.

Keywords:

Molybdenum disulfide, Graphene, High Gas Pressure, Electronic Structure Modulation

Optical Heterogeneity of MOCVD Grown Tungsten Disulfide

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Abstract:

We have performed a systematic investigation of the optical heterogeneity of tungsten disulfide. The monolayer flakes of the tungsten disulfide have been grown by metal-organic chemical vapor deposition (MOCVD). The synthesized monolayer tungsten disulfide shows optical heterogeneity even within a single domain. The amount of injected precursors can be fine-controlled which affects the optical properties of crystal significantly. We have performed a systematic investigation of samples grown at different conditions by using Raman and photoluminescence spectroscopy. This work can pave the way to synthesize high optical quality monolayer crystals using MOCVD.

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Keywords:

MOCVD, photoluminescence, WS₂, Raman spectroscopy

Atomic force microscopy study of Moiré superlattices in twisted bilayer WSe₂

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Abstract:

Moiré superlattices in van der Waals heterostructures have attracted tremendous attention for their emergent phenomena that the individual layers themselves do not exhibit, such as superconductivity, magnetism, and topological edge states. It is known that rearrangement of atoms within the individual layers occurs for small twist angles, yielding the domain structures with different stacking sequence. Such domain size typically ranges from tens of nanometer to a few micrometer depending on the twist angle. Therefore, atomic force microscope-based techniques can be a powerful tool to characterize the physical properties of Moiré superlattices. In this study, we investigated various physical properties of nanoscale reconstructed domains in twisted bilayer WSe₂ using vector piezoresponse force microscopy (vector PFM) and conductive-atomic force microscopy (c-AFM). Using vector PFM, we studied lateral and vertical surface deformation of Moiré superlattices. We discuss the relationship between domain size and twist angle and further examine the dynamics of domains, i.e., domain wall motion. Moreover, electrical properties of domain measured by c-AFM is discussed.

Keywords:

In-situ microscopy studies of electromechanical responses of ZnO microwires

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Abstract:

In this study, we observed electromechanical responses of individual ZnO microwires using optical and electron microscopes. ZnO microwires were transferred from their growth substrate to an electrical lead attached to homemade micromanipulators. A simple method for making electrical connections to ZnO microwires is reported. The electrical properties of the ZnO microwire during mechanical manipulation under microscope observation are investigated. The experimental set-up and future plan for in-situ electromechanical measurements based on our result will be presented.

Keywords:

ZnO microwire, In-situ measurement, Electromechanical response

Raman study on MoS₂-ReS₂ heterostructures

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Abstract:

Heterostructures stacked with two different monolayer transition metal dichalcogenides result in moiré superlattices due to the lattice mismatch or rotational misalignment [1]. Although, there are many Raman studies on the heterostructure of transition metal dichalcogenide materials, there is a lack of Raman studies on the isotropic-anisotropic heterostructure. Therefore, I conducted a study on the heterostructures of MoS₂ which is an isotropic transition metal dichalcogenide material and ReS₂ which is an anisotropic transition metal dichalcogenide material.

MoS₂ and ReS₂ monolayers were fabricated using the mechanical exfoliation method, and heterostructures were fabricated using the dry-transfer method. MoS₂ has a honeycomb structure and it is consisting of stacks of S-Mo-S sandwiches held together by van der Waals interactions [2]. ReS₂ has an anisotropic structure, 1T', because Re has one more electron that makes a Re-chain [3]. The twist angle of the heterostructure was determined by using polarization-dependent second harmonic generation for MoS₂ and polarization-dependent Raman for ReS₂. By observing interlayer interaction by low frequency Raman, it was confirmed that the two layers are interacting. It was found that the maximum intensity polarization of the mode 5 of ReS₂ varies depending on the twist angle of the heterostructure. Also, new peaks were discovered in the high frequency range of the Raman spectrum which are attributed to moiré phonons.

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Keywords:

Raman, 2D materials, TMDs, MoS₂, ReS₂, Moiré, phonon

Photocurrent characteristics of multilayer WSe₂

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Abstract:

The optoelectronic response of layered materials has been widely studied due to very interesting subjects such as next-generation photodetectors, spectroscopic analysis of exciton properties, memory devices, and understanding of 2D spintronic properties. Therefore, it is necessary to investigate the sample fabrication to measure photoelectric response and the experimental setup for the photoinduced response depending on the light source characteristics.

In this study, we fabricated exfoliated multilayer WSe₂ on bottom-hBN flake(b-hBN) on a Si/SiO₂ substrate with two gold electrodes. The b-hBN flake and multilayer WSe₂ is exfoliated on a PDMS and transferred to the Si/SiO₂ substrate by the typical dry transfer method using the PDMS. The two gold electrodes are deposited using the electron beam evaporator after patterning of the 5 μm gap with photolithography. The drain-source IV(I_{ds}-V_{ds}) curves show linear and symmetric for small bias voltages, implying an ohmic-like contact. The I_{ds}-V_{ds} shows an increase of drain current by an order of magnitude as 532 nm laser illuminates the WSe₂ flakes.

Keywords:

Photocurrent, TMDCs, WSe₂, photolithography

Electrical properties of Two-Dimensional Tellurene as PMOS materials for an inverter.

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Abstract:

Two-dimensional tellurene (Te) is widely used for practical applications such as field-effect transistor and photodetector as semiconductor materials with high carrier mobility, tunable bandgap energies, environmental stability and photoconductivity. However, logic gates such as inverters has not been reported much so far. Here, we fabricated field-effect transistors with chemical-grown large area two-dimensional tellurene to measure electrical properties as a PMOS materials for inverter. Tellurene field-effect transistors showed the typical p-type semiconductor properties with hole carrier mobility $250\sim 300\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ and on/off ratio 10^5 , it is confirmed that two-dimensional tellurene can be operated well as PMOS materials for an inverter.

Keywords:

Tellurene, P-type semiconductor, Field-effect transistor, 2D materials, Inverter

계면 처리가 GIS (Graphene-Insulator-thin Silicon) 광 검출 소자의 파장 의존성 및 광 반응도에 끼치는 영향

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Abstract:

Graphene-silicon heterojunction은 Graphene의 훌륭한 전기, 광학적 특성으로 인해 광 검출 소자 연구에 적극적으로 이용될 수 있다. Graphene은 높은 투과율을 보여 투명 전극으로 이용할 수 있고, 반도체를 absorbing layer로서 이용하여 반도체에서의 높은 흡수율을 유도한다. 그러나, 실리콘 표면에 형성되는 native oxide layer는 heterojunction 광 검출기의 성능을 악화시킨다. 본 연구에서는 계면 처리를 통해, defect states가 존재하는 native oxide layer를 최소한의 defect states와 적절한 두께를 갖는 얇은 insulating layer로 대체, 또 매우 얇은 실리콘을 device layer로 사용하여 다수인자 기반 Graphene-Insulator-SOI (Silicon-On-Insulator) back-to-back 광 검출기를 개발하였다. G-SOI 광 검출기는 뚜렷한 파장 의존적 광반응도 뿐만 아니라 매우 높은 광반응도를 보인다. 높은 광반응도는 계면 최적화에 의한 것인 반면 뚜렷한 파장 의존적 현상들은 SOI의 device layer의 유한한 두께로부터 발생한다. 이를 통해, thin silicon layer를 도입하여 계면 특성을 높일 수 있음을 증명한다.

Keywords:

Graphene, GIS, SOI, Schottky barrier, Interface optimization

Interlayer Interactions in Bilayer-Monolayer MoS₂/WSe₂ Heterostructure

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Abstract:

Two-dimensional-material-based heterostructures produce novel phenomena due to distinctive interactions between the stacked layers. For MoS₂ and WSe₂, several studies have been done for their monolayer-monolayer heterostructures [1]. However, there are only few studies on monolayer-multilayer or multilayer-multilayer structures. As a first step, we tried to investigate bilayer-monolayer heterostructure.

We fabricated bilayer-monolayer MoS₂/WSe₂ heterostructure using the dry-transfer method [2]. The twist angles of these heterostructures were determined using polarization dependent second harmonic generation. When the interlayer interaction between the constituent layers existed, we found that new low-frequency Raman modes appeared in addition to the breathing and shear modes of bilayer MoS₂. Using circularly polarized Raman spectroscopy, we assigned the peaks as breathing- and shear-like interlayer vibrational modes. For breathing-like modes, 3 or more peaks were observed only in the samples with relatively smaller twisted angles (< 9 °), although only 2 normal modes can exist in a material with 3 layers. Additional peaks also appeared as shear-like modes. We observed that these new modes vary with the twist angle of the samples. We calculated the Moiré reciprocal lattice considering the lattice mismatch between MoS₂ and WSe₂ and the twist angle in the heterostructure [3]. With the Moiré reciprocal lattice constant, we found the position of twist-angle-dependent zone-folded phonons from phonon dispersion of bilayer MoS₂ and monolayer WSe₂.

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Keywords:

Raman Spectroscopy, MoS₂, WSe₂, Van der Waals Heterostructure, Heterostructure

Optical birefringence of ReS₂

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Abstract:

Rhenium disulfide (ReS₂), one of the transition metal dichalcogenides (TMDs), is a semiconducting material which has a direct bandgap from monolayer to bulk. ReS₂ has an anisotropic crystal structure (1T', distorted tetragonal) unlike hexagonal MoS₂ or WS₂ because Re has one more electron, which makes a Re-chain. Furthermore, opposite vertical orientations of ReS₂ are not equivalent. Due to the in-plane anisotropic structure, its physical properties such as electrical transport and optical response are anisotropic [1]. The direction of the Re-chain and the direction of the c-axis of ReS₂ can be determined by polarized Raman spectroscopy [2, 3].

We made ReS₂ samples by mechanical exfoliation and found that some samples have several domains in a flake. Polarized Raman spectroscopy is used to identify opposite vertical orientations [3, 4]. The direction of the Re-chain in each domain is also determined by polarization dependence of the Raman mode at 212 cm⁻¹ [2, 3] and selected area electron diffraction (SAED) patterns. The high-resolution scanning transmission electron microscopy (HR-STEM) image shows the atomic structure in the grain boundary between the two domains. Furthermore, the grain boundary can be observed by Raman mapping, the dark-field images of TEM, and the angle-resolved polarized optical microscopy (ARPOM) [5]. We found that the directions of the Re-chain in neighboring domains are exactly aligned, though the ARPOM images shows different optical contrast of the two domains. Moreover, we studied the birefringence in the ReS₂ samples with several domains by the angular dependence of the optical contrast with the cross-polarized optical images [6] and the reflectance in the cross-polarization configuration. We found that the optical axis is not exactly aligned with the Re-chain of the ReS₂ samples.

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Keywords:

ReS₂, birefringence, optical axis, domain structure

Fabrication and Characterizations of MoS₂ Monolayers on Au-coated Nanopillar Arrays

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Abstract:

Transition metal dichalcogenides (TMDs) have been intensively studied due to their interesting electrical and optical characteristics. As TMDs have very large optical absorption coefficients, enabling high absorption per unit thickness. Monolayers of TMD are characterized by strong in-plane covalent bonding similar to graphene and other van der Waals solids and possess direct bandgap which can be tuned by an external field or mechanical strain. In TMD/metal hybrid systems, excitation of surface plasmons can give rise to enhanced light-matter interactions and tuning of the spectral responses of the TMD materials. In this work, chemical vapor deposited MoS₂ monolayers were dry-transferred on Au-coated SiO₂ nanopillar (NP) arrays (diameter: 250 nm, height: 50 nm, and period: 500 nm). The NP arrays were fabricated by electron-beam lithography and dry etching processes. We investigated reflectance and photoluminescence spectra of MoS₂ monolayers on the Au-coated NP arrays. Optical characteristics of the MoS₂ monolayers on the NP arrays were compared with those on the flat Au surfaces based on experiments and calculation results. This work will help us to propose novel TMD-based optoelectronic devices for various applications, including catalysis, sensing, light emitting devices, and photovoltaics.

Keywords:

MoS₂, Nanopillar, photoluminescence

Raman study of ReSe₂/MoSe₂ heterostructures

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Abstract:

Two-dimensional-material-based heterostructures produce novel phenomena due to distinctive interactions between the stacked layers. In the study of transition metal dichalcogenides (TMDs), there are several studies on isotropic/isotropic heterostructure. However, there is a lack of research on anisotropic/isotropic heterostructure.

ReSe₂, one of the TMDs, is a semiconducting material which has a indirect (nearly direct) bandgap from monolayer to bulk [1]. ReSe₂ has an anisotropic crystal structure (1T', distorted tetragonal) unlike hexagonal MoSe₂ or WSe₂ because Re has one more electron, which makes a Re-chain [1]. MoSe₂ is an isotropic material with a hexagonal structure [2]. It has a direct bandgap only for the monolayer case [1-3].

We made ReSe₂/MoSe₂ heterostructures by using mechanical exfoliation and dry-transfer. The directions of the Re-chain and the c-axis of ReSe₂ were determined by using polarized Raman spectroscopy [1, 4, 5]. The armchair direction of MoSe₂ is measured by the second harmonic generation [6]. We studied Raman modes in ReSe₂/MoSe₂ heterostructure with different twisted angles. When the interlayer interaction between the constituent layers existed, we found that new low-frequency and high-frequency Raman modes appeared.

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Keywords:

Polarized Raman spectroscopy, ReSe₂, MoSe₂, Anisotropy/isotropy heterostructure, Twisted angle

Photodetector characteristics of MoS₂/Si quantum dot heterostructures

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Abstract:

Molybdenum disulfide (MoS₂) has great potential for optoelectronic applications due to its optical and electrical properties such as tunable bandgap and high mobility. However, a few nanometer channel thickness limits the photon absorption. Recently, a hybrid structure of 2d material and 0d quantum dots has been studied to overcome the low light absorption in the channel area. In this study, the hybrid structure of few-layer MoS₂ and silicon quantum dots (SiQDs) is studied for photodetector. MoS₂ was prepared using mechanical exfoliation with tape. SiQDs were synthesized using HSQ powder. The SiQDs powder was etched in the HF followed by solvent extraction in toluene:ethanol = 3:1 solvent. The SiQDs were spin-coated on the MoS₂ device to make the MoS₂-SiQDs hybrid structure. Photodetectors were characterized under focused illumination of monochromated light. The wavelength dependence of photoresponsivity and time-resolved photoresponse were examined. The photoresponsivity was enhanced in the hybrid structure compared to the MoS₂-only device. The hybrid structure of MoS₂ and SiQDs will be a new candidate for optoelectronic application.

Acknowledgement: NRF-2020R1F1A1048651

Keywords:

2d-0d hybrid, photodetector, MoS₂, Silicon quantum dots

Tunneling Transport through the Single-Layer Graphene Electrode Monolayer Junctions

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Abstract:

In this study, we present tunneling transport characteristics of chemically grafting aryl alkane monolayers onto single-layer graphene (SLG) electrodes. The molecular monolayers were sandwiched two SLG electrodes, creating a vertical tunnel junction. Raman spectroscopic study demonstrates that the aryl alkane molecules were successfully incorporated as an effective tunneling barrier between the SLG electrodes. The temperature-variable and length-dependent transport measurements, and transition voltage spectroscopy characterization consistently demonstrate that tunneling is intrinsic transport properties of the SLG/monolayer/SLG junctions.

Keywords:

Tunneling, Molecular electronics, Graphene Electrode

그래핀/질화 붕소/다공성 Si태양전지의 전기적 및 광학적 특성 연구

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Abstract:

다공성 Si (porous Si, P_{Si})를 제작하기 위해 Au 나노 입자를 Si 표면위에 5초간 증착시킨 후 일반적으로 잘 알려진 식각 방법을 통해 샘플을 제작하였다. 주사 현미경 이미지를 통해 나노구조 Si에 잘 형성되었음을 확인하였다. Bulk Si와 P_{Si}의 반사율 측정 결과, P_{Si}는 bulk Si보다 반사도가 최대 50% 정도 감소하였다. 화학 기상 증착법에 의해 단층 그래핀 및 다층 질화붕소 (hexagonal boron nitride, h-BN) 박막을 제작하였다. P_{Si} 위에 hBN 및 그래핀이 차례대로 전사되었으며, 광학현미경 이미지를 통해 h-BN 위에 그래핀이 잘 전사되었음을 알 수 있었다. 532 nm 파장의 레이저를 이용하여 라만 스펙트럼을 측정한 결과, h-BN의 라만 스펙트럼에서 1369 cm⁻¹ 부근의 E_{2g} 진동모드와 관련된 라만 피크가 관찰되었으며, 이질 접합 구조의 경우 1,580 cm⁻¹ 부근의 G 밴드와 2,700 cm⁻¹ 부근의 2D 피크가 관찰되었으며 이는 그래핀이 h-BN에 잘 전사되었음을 의미한다. 그래핀/hBN/P_{Si} 구조의 태양전지를 제작하였으며, 최대 12.1%의 광전효율을 나타냈으며, hBN이 존재하지 않은 소자에서는 최대 8.7 %의 효율을 보였다. 이는 그래핀의 높은 전도도와 h-BN 절연층 삽입으로 캐리어 재결합을 차단한 결과로 해석된다. 본 연구에서는 hBN의 존재 여부에 따른 태양전지의 파라미터의 메커니즘을 분석하고자 한다.

Keywords:

그래핀, 질화붕소, 다공성 실리콘, 태양전지

Fabrication of copper-oxide nanowires based micro sensor by laser induced hydrothermal growth

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Abstract:

Among the various metal oxide nanomaterials, copper II oxide is very attractive due to cheapness, easy synthesis, and its various advantages. Copper II oxide is a p-type semiconductor with 1.21 to 1.55 eV narrow direct band gap. Thus, copper II oxide nanostructure is used as an optoelectronic application such as solar cell, battery, supercapacitor, biosensor, and photodetector.

In our study, we synthesized successfully copper II oxide nanowires (NWs) by laser induced hydrothermal growth (LIHG). Since, compared to conventional NWs growth methods including Chemical Vapor Deposition (CVD), LIHG process is rapid and digital synthesis method, copper II oxide NWs are selectively grown on desired position of micro metal pattern. Finally, through LIHG process, we fabricated copper II oxide NWs based micro sensor.

Keywords:

laser, hydrothermal, metal oxide, sensor

Vapor-liquid-solid growth of γ -GeSe crystals

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Abstract:

The family of group IV–VI monochalcogenides has an atomically puckered layered structure, and their atomic bond configuration suggests the possibility for the realization of various polymorphs. We recently reported the synthesis of the first hexagonal polymorph, so-called γ -phase GeSe, from the family of group IV–VI monochalcogenides. γ -GeSe was synthesized by chemical vapor deposition (CVD) method on a gold-coated substrate and it was attributed that Au nanoparticles serve as vapor-liquid-solid (VLS) catalyst for γ -GeSe growth. Here we study in detail the growth mechanism of γ -GeSe by controlling the size and density of Au nanoparticle catalyst, growth temperatures and growth time. We present the optimal process of Au catalyst preparation for reliable growth of γ -GeSe crystals.

Keywords:

Vapor-liquid-solid, VLS, GeSe, Germanium Selenide, CVD

리튬 이온 전지를 위한 실리콘 산화물 음극의 전기적 특성 변화 연구 (Electrical Degradation of SiO_x Anodes for Lithium Ion Batteries)

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Abstract:

리튬 이온 전지 (lithium ion battery, LIB)를 위한 실리콘계 음극은 높은 이론 용량에도 불구하고 충/방전 과정에서 일어나는 실리콘의 과도한 부피 변화 및 불안정한 고체 전해질 계면상 (Solid electrolyte interphase, SEI) 형성으로 인해 발생하는 수명 감소 등의 문제가 있다. 실리콘 산화물 (SiO_x) 전극은 순수 실리콘 전극보다 용량은 낮지만, 수명이 긴 장점으로 인해 많은 연구가 진행되고 있다. 본 연구에서는, 원자현미경 (atomic force microscopy, AFM) 기반의 주사 확산저항 현미경 (scanning spreading resistance microscopy, SSRM) 및 켈빈 탐침 현미경 (Kelvin probe force microscopy, KPFM) 방법을 이용하여 충/방전 사이클에 따른 실리콘 산화물 전극의 열화 (degradation) 특성을 분석하였으며, 반복적인 충/방전에 의한 열화가 진행됨에 따라 실리콘 산화물 전극의 일함수 및 저항 특성 변화 양상을 확인할 수 있었다.

Keywords:

Effect of Nano – ZrO₂ and PEG on Planarization of SOC-Film Removal rate and Surface Topography

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Abstract:

As the design rule of semiconductor devices is scaled down, chemical mechanical planarization (CMP) process has become an essential part in realizing the global planarization. Lithography process is applied in the order of KrF, ArF dry, and ArF immersion, which have been used recently for exposure wavelengths. In particular, in the case of ArF immersion applying a 193 nm wavelength, when the size of the device pattern is to be made less than 10 nanometers, the thickness of the photoresist becomes thinner to prevent the pattern from collapsing. A phenomenon in which the etched layer cannot be etched occurs. To solve this problem, a hard mask with strong etch resistance was introduced between the photoresist and the layer to be etched. In particular, the carbon hard mask using CVD was recently used for the hard mask, but due to the void issue due to pattern miniaturization, it is planned to be replaced with a SOC (Spin of carbon) layer. But, long wavelength topography occurs when depositing by spin-coating method on an existing SOC pattern as a hard mask. Therefore, SOC CMP process is essential to improve topography of long wavelengths. In this study, we used Zirconia (ZrO₂) particles with a higher polishing rate than colloidal silica (SiO₂) and improvement of dishing and erosion ^[1] and polyethylene Glycol (PEG) to improve the stability of the slurry particles. We investigated with SOC polishing rate and roughness by pH effect that is increased from 2.0 to 7.0.

Keywords:

Chemical mechanical polishing, Zirconia particle, Hard mask, Spin on Carbon

Modulation Doping of MoS₂ by Defective TiO_x Overlayer

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Abstract:

Modulation doping of 2D layered materials by transition metal sub-oxides are getting interests due to its nondestructive nature and industrial compatibility[1, 2]. In this work, we investigate how the excess free electrons from TiO_x oxygen vacancies are transferred to MoS₂ by constructing TiO_x/MoS₂ heterostructure.

We fabricated exfoliated MoS₂ field-effect transistors by photolithography and deposited TiO_x on the MoS₂ channel by reactive DC magnetron sputtering. We controlled the TiO_x stoichiometry by differing oxygen flow rates, which was characterized by UV-vis and X-ray photoelectron spectroscopy. I-V measurements confirmed the n-type doping effects on MoS₂ flake, especially for threshold voltage and field-effect mobility. Furthermore, we performed XPS spectroscopy to analyze charge transfer at the TiO_x/MoS₂ interface. Finally, we construct the energy band alignment of TiO_x/MoS₂ to study the doping mechanism. Through this work, we performed the modulation doping of MoS₂, which could be utilized in electronics and optoelectronics such as contact doping and photodetector.

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Keywords:

MoS₂, TiO_x, I-V measurement, UV-vis, XPS

Directly Fabricated Carbon Nanomaterials using Pulsed Laser on Cu-Polyimide Composites for Gas Sensor

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Abstract:

Carbon nanomaterials have excellent chemical and physical properties, and their molecular adsorption behavior resulting from high surface area and conductivity enables their application in gas sensors. But preparing carbon nanomaterials using a thermal based furnace accompanied by high-temperature heat treatment is time-consuming and expensive, in contrast, the laser-scribing method enables the synthesis with a shorter processing time and carbonization in a desired pattern.

In this study, we synthesized a carbon nanomaterial using local laser-scribing method following spin-coating on a quartz substrate with a copper-embedded polyimide (PI) thin film to reduce the processing time and costs. In contrast to the PI film without copper, the laser absorption of the copper-embedded PI (Cu@PI) had extremely improved. The synthesized laser-scribed carbon nanomaterial from Cu@PI had a stereoscopic 3D-structure that was advantageous for reaction with gas molecules, and when exposed to NO₂ and NH₃, its electrical resistance responses were detected by -0.79 and +0.33 %, respectively. In addition, laser-scribed carbonization on quartz substrates with high thermal stability may ensure a gas sensor that can operate under extreme environmental conditions, such as fires and other disasters.

Keywords:

carbon nanomaterials, laser scribing, polyimide, copper particle, gas sensor

Mg K-edge XANES spectra in Mg alloy by surface treatments

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Abstract:

Magnesium (Mg) alloys are commonly used in various industries such as automotive, aerospace and portable electronics etc., because of low cost, ease of handling, good strength and ductility, etc. However, since Mg alloys are electrochemically too active to be used without surface treatment in corrosive environments, their practical applications have been limited.

In order to investigate the structural role of Mg in Mg alloy by surface treatments, XANES spectroscopy was employed at the Mg K-edge. It was known that X-ray absorption near-edge structure (XANES) is one of the best techniques for the determination of the chemical environment of matter, since it is a molecular-scale analytical technique that yields electronic and structural information about an element of interest. Especially, the Mg K-edge XANES provides information about the local structures of magnesium in Mg alloy, which is otherwise difficult to study with other methods.

In this study, AZ31 sheet [Mg of 95.99 wt.% with 2.9% Al, 0.75% Zn, 0.33% Mn, 0.03% Si (wt.%) : rolled to thickness of 2.0 mm by POSCO] as Mg alloy, was used as matrix material. The surface change of the Mg alloy by surface treatments was compared and analyzed by X-ray photoelectron spectroscopy (XPS, PHI 5000 VersaProbe at BinGee Surface Analysis Co., Korea) using an Al K α source, and XANES spectra. Mg K-edge X-ray absorption spectra were measured by using synchrotron light at the 10D XAS KIST beam lines of the Pohang Light Source (PLS) by total electron yield (TEY) mode.

Keywords:

Mg K-edge, surface treatments

High-throughput fabrication of TERS probes using DC bias

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Abstract:

Tip-enhanced Raman spectroscopy (TERS) has gained great attentions for sensitive characterization and superresolution chemical imaging of various materials. The performance of TERS is mainly affected by the probe geometry, such as the diameter of the tip apex, surface roughness, etc. In this regard, the fabrication of a sharp apex from metal wire is the one of the most important factor for TERS experiments. Conventionally, the electrochemical etching is commonly used technique for fabricating those metallic probes. To avoid the surface defects, the pulsed bias was commonly employed in the electrochemical etching process. However, it would make the fabrication system to be complex and sophisticated. Here, we report an simple automated electrochemical etching systems using DC bias for the efficient fabrication of TERS probes. With our optimized condition for DC electrochemical etching, gold probes with a clean surface and a radius of curvature below 200 nm can be obtained with yield of 85%. The fabricated metallic probe is used to detect the brilliant cresyl blue (BCB) molecules on the gold film, and it is confirmed that the enhancement factor is about 3,400.

Keywords:

Tip-enhanced Raman spectroscopy, Electrochemical etching, Automatic system

Horizontal and Vertical Near-field Imaging of Gold Nano Slit Arrays Using Scanning Thermal Microscopy

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Abstract:

Near-field scanning optical microscopy (NSOM) is a technique that can measure the structural and optical information of nanostructures by performing sub-wavelength near-field optical imaging. As an alternative technique, photothermal microspectroscopy (PTMS) has been studied, which measures the photo-thermal energy conversion at the tip as a temperature. Since the probe acts as a detector, there is an advantage that a photodetector and advance optical alignment are not required. In this study, sub-wavelength near-field optical imaging in the plasmonic grating coupler was performed using scanning thermal microscopy (SThM). The near-field distribution image in the sample depending on the polarization of the incident light was obtained as a temperature image and the structure-dependent light distribution could be analysed. Spatial resolution of the temperature image measured by SThM was calculated to be ~40 nm, which is equivalent to 1/20 of the wavelength of the incident light. In addition, vertical near-field imaging was performed by measuring the temperature line profile while varying the distance between the probe and the sample, which showed the decay property of near-field.

Keywords:

Photothermal Micro-spectroscopy, Scanning Thermal Microscopy, Near-field Scanning Optical Microscopy, Photothermal effect, Surface Plasmon

High-Precision White Light Interferometry Based on Color CCD and Peak Matching Algorithm

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Abstract:

In industry, attempts have been being made to find defects by measuring height difference of semiconductor devices over a large area and with high resolution. White light interferometric microscopy, in which the algorithms for analysis have been intensively studied, is suitable for this purpose since incoherent light source. However, the large step height of adjacent pixels causes multi peak problem due to CCD pixel resolution. Here, we used 3-color CCD to obtain separated Red, Green, and Blue fringes to find absolute peak positions of each envelope. We overcame the ambiguity by finding position has peaks which have minimum deviation for fringe of RGB data was obtained from 3-color CCD. It is expected that our results could be applied to measuring topography in various fields.

Keywords:

White Light interferometry, topography, 3-color-CCD, peak-matching-algorithm

Neutron endurance of the Al₂O₃ on the reduced-activation ferritic/martensitic steel

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Abstract:

국제핵융합실험로 (International Thermonuclear Experimental Reactor)를 구성하는 요소들은 중성자 조사와 수소 동위원소 투과에 의해 결함이 발생한다. 중수소(²H)와 삼중수소(³H)는 핵융합발전에 필요한 연료이며, 삼중수소를 재생산하기 위해 ⁶Li(n,α)³H 반응을 일으키기 위한 TBM(Test Blanket Module)이 개발되었다. 이러한 이유로 TBM 구성요소들은 중성자에 노출되기 때문에, 저방사화를 위해 개발된 RAFM (Reduced-Activation Ferritic/Martensitic) 강으로 구성되며, 이는 또한 수소동위원소 투과에도 노출되어 있다.

Al₂O₃은 압축의 강도, 내마모성, 화학적 안정성, 그리고 수소에 대한 낮은 용해도를 갖기 때문에 수소동위원소 투과도를 낮추기 위한 투과방지막 소재로서 적합하다. 최근에는, Al₂O₃에 점결함이 발생할 경우, PRF (Permeation Reduction Factor)를 변화시킬 수 있음이 DFT 계산결과로 보고되었다.

따라서, 중성자 조사에 따른 Al₂O₃의 결함발생과 수소동위원소 투과도의 상관관계를 분석하는 것이 필요하다. 본 연구에서는 Al₂O₃의 중성자조사결함과 충돌열에 의한 Al₂O₃/RAFM의 열변형률을 계산하였다.

Keywords:

RAFM, 중성자

Influence of Etidronic acid on Tungsten (W) and Silicon dioxide (SiO₂) films for the W Chemical Mechanical Planarization (CMP) process

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Abstract:

The Chemical-Mechanical-Planarization (CMP) process is an important process in fabricating a device with a 'multi-level metallization and incorporation of gate and channel materials' structure. CMP in IC manufacturing consists of three main steps; the process to configure the transistor (front-end-of-line, FEOL), the process of forming electrical connection between transistors (middle-of-line, MOL), and the process of interconnection of the structure (back-end-of-line, BEOL). In the MOL stage, W and Co are materials that are attracting attention in terms of stability and electrical conductivity. But, CMP process is necessary after the metallization process to use W and Co.

In general, colloidal silica (SiO₂) has been applied as the abrasive in W CMP slurry. However, it has been reported that dishing and erosion of wiring generated from CMP process induce the fatal problems such as the increase of resistance and heat generation. Erosion and dishing can be reduced by adding chemical additives or controlling Material Removal Rate (MRR), which is related to selectivity, of W and SiO₂ films. We investigated influence of the planarization of the W and SiO₂ films according to the phosphate group chemicals concentration and source type of phosphate ion. We propose a novel W-film CMP slurry based on etidronic acid having two phosphate groups in one compound. And ZrO₂ abrasives with 40-nm-diameter to replace colloidal silica, and a ferric based catalyst, corrosion inhibitor and pH titrator used for general W slurry were used under the same conditions. We investigated the effect with concentration of etidronic acid from 0 wt% to 0.25 wt%. In terms of MRR of W, it shows a linear decrease as the concentration of etidronic acid increases. This seems to be related to the rate of radical decomposition of H₂O₂ used as an oxidizing agent. However, in terms of MRR of SiO₂, it increases in the range of 0 - 0.10wt% and decreases in the range of 0.1 - 0.25wt%. In our presentation, we will review the detailed mechanism which CMP performances in W film and SiO₂ films CMP using the slurry which containing etidronic acid.

Keywords:

Chemical-mechanical-planarization, Etidronic acid, Silicon dioxide, Tungsten

블록공중합체의 자기조립을 통한 내부망상구조를 갖는 다공성 박막 제조

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Abstract:

내부에 망상구조를 갖는 다공성 박막은 높은 표면적을 가지고 있으며 연결된 망상 구조를 이용하여 여과, 크로마토그래피, 약물전달, 촉매, 주형 등 여러 분야에 응용 가능한 소재이다. 다공성 박막 중 블록공중합체(block copolymer)는 자기조립을 통해 다양한 구조체를 형성하는 소재로써 블록간 비율과 자기조립 조건에 따라 라멜라, 육방구조체 외에도 이중 자이로이드, 이중 다이아몬드와 같은 복연속적(bicontinuous) 망상 구조를 형성할 수 있다.

본 연구에서는 두 가지 자기조립 방법으로 다공성 박막을 제조하였다. 먼저 Polyisoprene-*b*-Polystyrene (PI-*b*-PS) 선형 블록공중합체를 벌크상으로 자기조립 후 PI 블록을 선택적으로 에칭하여 PS 기반의 다공성 박막을 구현하였다. 다른 제조 방법으로는 친수성인 Polyethylene glycol (PEG) 블록을 PS에 가지형태로 연결한 양친성 블록공중합체를 용액상으로 자기조립하여 후처리 공정 없이 구조표면에 친수성 블록이 배열된 다공성 박막을 구현하였다. 두 가지 제조법은 기공의 크기는 다르나 내부에 규칙적인 망상구조를 가지며 각각 이중 자이로이드, 이중 다이아몬드의 결정성 내부망상 구조를 나타내는 것을 SEM 및 X-ray를 통해 확인하였다.

Keywords:

블록공중합체, 다공성, 자기조립

이중층 마이크로캔틸레버 구조상에서의 질량 및 강성에 따른 공진 주파수 변화

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Abstract:

이중층 구조 마이크로캔틸레버의 경우 각 층의 질량과 강성은 역학적 움직임에 영향을 미치므로 이에 대한 연구를 시도하였다. 실험적으로, 니켈 박막이 증착된 실리콘 마이크로캔틸레버의 공진주파수가 니켈 박막 두께에 따라 달라지는 것을 관측하였다. 실험된 결과는 이중층 구조 캔틸레버 모델을 이용하여 분석할 수 있으며 이를 통해 캔틸레버 상부층과 하부층의 질량비와 영률비, 그리고 두께의 비율에 의한 동역학적 거동 변화를 확인할 수 있었다. 강성 또는 질량만의 단일 효과에 의한 공진 주파수 변화는 선형적이거나 두께에 따른 질량과 강성 변화를 동시에 고려할 경우 공진 주파수 변화는 비선형적으로 나타난다. 이러한 결과는 마이크로캔틸레버 기반 센서 응용시 캔틸레버 표면으로의 흡착에 따른 질량 및 강성 변화의 영향과 이에 따른 유효 감지 범위를 식별하는 데 도움이 될 것이다.

Keywords:

bi-layer microcantilever, mass loading effect, beam stiffness effect

Gating mechanism of the voltage-gated proton channel (Hv1) studied by molecular dynamics simulations

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Abstract:

The voltage-gated proton channel (Hv1) has an important role in proton extrusion, pH homeostasis, sperm motility, cancer progression. The Hv1 channel is also found to be highly expressed in cell lines and tissue samples from patients with breast cancer. The closed-state structure of mouse Hv1 chimera channel (mHv1cc) solved by X-ray crystallography was reported. The open-state structure of Hv1 was proposed by some simulation studies. However, the gating mechanism of Hv1 under the effect of electric field and pH condition have been not deeply studied yet. Herein, the closed-state structure of mHv1cc was used to run the molecular dynamics (MD) simulations with the electric field and pH condition to investigate the mechanism of proton transfer in Hv1. We observed a continuous hydrogen-bonded chain of water molecules called water-wire that goes through the channel when the channel is fully opened by the moving downward of the S2 helix and the moving upward of the S4 helix. Due to the movement of S2 and S4 helices, the internal salt-bridge network was changed and the hydrophobic layers were destructed. The open channel allows water molecules to pass through the channel but excludes other ions. This indicated that the Hv1 channel is highly selective for protons. In the line with the previous experimental and simulation observations, our simulation results made us conclusion that the protons were transferred through an internal water-wire and the opening of the Hv1 channel is voltage-and pH-gradient sensing.

Keywords:

gating mechanism, Hv1 proton channel, water-wire, molecular dynamics simulations

Comparison of dissociative and non-dissociative search mechanism in DNA mismatch repair system using Monte Carlo simulation

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Abstract:

The search mechanism of the mismatch repair system has been explored with various single-molecule experiments, explaining individual proteins' dynamics and interactions on DNA. Our Monte Carlo simulation adapts experimentally determined parameters, such as diffusion constant of repair proteins, binding time, and binding dynamics, to suggest reasonable comparisons of different repair models. Interactions of the MutS, MutL, MutH proteins in E.coli significantly impact the overall repair mechanism. We designed unknown parameters of the repair system as inputs of simulations and examined the potential advantage of different possible models. Furthermore, investigation of various outputs such as arrival time, number of collisions, and number of binding proteins for each model provides dominant variables for the efficiency of the repair system.

Keywords:

Monte Carlo simulation, DNA mismatch repair

Modulation of $1/f^{\alpha}$ scaling behavior in a biological signal using self-replication and death balance control

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Abstract:

This study presents a novel model of artificial biological signal generation. We employed a cellular automata (CA) system that comprises self-replicating and mutually competing loops. The complex self-replicating CA loops were developed using a construction scheme in which we introduce a unique measure of the CA to quantify the activity of the loops. By summing the loop activities globally and observing the time evolution of the sum, we obtain an artificial biological signal. The power spectrum of the resulting time series exhibits $1/f^{\alpha}$ scaling behavior ($\alpha \sim 1.5$). Constraints on loop dynamics, leading to larger-scale death in the loop colonies, are implemented in our CA. With the application of the constraints, the value of α is lowered to nearly 1. The results show that self-replication and death in the CA space play the roles of excitatory and inhibitory synaptic functions, respectively, in a neuronal network. The self-replication/death balance control in our study could modulate the scaling exponent α in the power spectrum, similar to the activation/inhibition balance control in neural networks (Chaos 27, 047402) and local field potential (LFP) simulations (NeuroImage 158, 70-78) in recent studies. This work was recently published in JKPS. (JKPS 79:4, 412-427)

Keywords:

$1/f^{\alpha}$, biological signal, cellular automata, activation/inhibition balance control

Elucidating the diffusion dynamics of XPC proteins along DNA: single-trajectory analysis

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Abstract:

The XPC is one of the DNA repair proteins that repair DNA damage caused by various causes such as UV light exposure, chemical exposure, replication error, etc. The study of the diffusion dynamics, where XPC finds DNA damage for repair, is the basis for studying diseases caused by DNA damage, such as cancer. In this work, we investigate the diffusion dynamics of XPC proteins along with DNA. For this, we obtain the time series of diffusing XPCs on the λ -DNA using the single-molecule DNA curtain assay. Using state-of-the-art trajectory analysis, we find that XPC diffusion dynamics are temporally heterogeneous and there are multiple dynamic states. We scrutinize the diffusion characteristics of each dynamic state in terms of dynamic quantities such as the mean-squared displacement, diffusivity, van-Hove correlation functions, etc. Based on this, we identify the stochastic model for each dynamic state. We also shortly discuss the transition between the dynamic states.

Keywords:

DNA binding protein, XPC, anomalous diffusion

A model study on protein stabilization: cation-p interaction investigated by sum-frequency vibrational spectroscopy

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Abstract:

Cation-p interaction is an interaction between a positively charged cation (a monopole) and negatively charged electrons in an aromatic group of a molecule (a quadrupole). Its key role in stabilizing the protein structure is well accepted from the statistical tendency of 'amino-aromatic' interaction, owing to the interaction between cationic amino acids with other nearby amino acids having p moieties such as phenylalanine (Phe), tyrosine (Tyr), and tryptophan (Trp). In this report, sum-frequency vibrational spectroscopy investigated the interaction between a surfactant molecule (octadecylguanidine hydrochloride, ODG) having guanidine headgroup resembling an arginine (Arg) amino acid and p molecules (phenol or indole). Due to its charge in the headgroup, ODG was unstable and did not form a neat monolayer on water surface at neutral pH. However, after adding p molecules into the subphase water, the ODG molecule became more stable against dissolution and appeared at the interface, as evidenced by the appearance of its CH_x peaks in the sum-frequency spectrum, together with a CH peak of the aromatic ring of the adsorbed p molecules. The indole molecules interacted more strongly with the guanidine headgroup than the phenol and were seen to penetrate even between the alkyl chains in the monolayer.

Keywords:

cation, amino acid, sum-frequency generation, molecular monolayer, protein

Single-molecule studies on co-transcriptional R-loop formation near DNA damages and its effect on the next-round transcription

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Abstract:

R-loop, a non-canonical nucleic acids structure, consists of a DNA:RNA hybrid and a non-template single-stranded DNA. In some cases, a template strand can form DNA:RNA hybrid with a nascent transcript rather than returning to a double helical structure with a non template strand after transcription. This abnormal structure has been considered as a putative source causing genomic instability although it can play roles in gene regulation. Recent studies, however, suggest that R-loop may also have crucial roles in maintenance of genome stability showing its formation is one of the key steps at transcription-coupled homologous recombination repair. Here, in light of emerging roles of R-loop in DNA repair processes, we systemically identify the degree of R-loop formation near various DNA damages using single-molecule FRET technique. Futhermore, elongation and propagation of R-loop was monitored in real-time and the effect of R-loop on the next-round transcription was also studied. We surmise that co-transcriptional R-loop formation may serve as potential DNA damage response.

Keywords:

R-loop, single-molecule, FRET, DNA damage, DNA repair

Accelerated quantification of miRNAs using FRET-PAINT

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Abstract:

MicroRNAs are short non-coding RNAs that suppress the expression of protein coding genes at the post-transcriptional level. Differential expression profiles of miRNAs across a range of diseases have emerged as powerful biomarkers. However, detection of miRNAs is challenging because their size is small (~22nt) and there are many highly homologous miRNAs which differ only in a single nucleotide. These points make current conventional miRNA detection methods vulnerable. Previously developed Ago-FISH enables single-nucleotide specific amplification-free miRNA profiling with high sensitivity. But there is a limit increasing probe concentration to enhance probe binding frequency while maintaining signal to noise ratio (SNR) for analysis of trace dynamics. Using FRET-PAINT, we introduce SNR enhancing method that enables increasing probe concentration.

Keywords:

single-molecule , FRET-PAINT, miRNA

Monitoring DNA mismatch removal and resynthesis by single molecule fluorescence imaging

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Abstract:

DNA mismatch repair (MMR) has a fundamental role in maintaining the genomic stability of cells by correcting the mismatched base mainly generated during DNA replication. During DNA mismatch repair (MMR), the removal of mis-incorporated base pairs is carefully controlled but the details are still ambiguous. It was reported that MutL and its homologs have endonuclease activity in DNA mismatch repair. We propose a model that polymerase delta removes mismatched DNA strands by its strand displacement activity. Using a novel DNA skybridge, we visualize DNA synthesis by DNA polymerase delta. When double-strand DNA is denatured then polymerized from the nick, the fluorescence-labeled dNTPs are incorporated. We compared the spatial distribution of polymerization on lambda DNA with MMR proteins and without MMR proteins. We also observed PCNA interacting with polymerase delta during DNA polymerization, which displaced DNA strand with RPA-mRubby2 which binds to single-stranded DNA in real-time. Our study suggests the mechanism of how an exonuclease independent pathway in MMR is operated.

Keywords:

Single-molecule physics, DNA mismatch repair, polymerase delta, Real-time, Single-molecule fluorescence imaging

Single Molecule detection of miRNA biomarkers

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Abstract:

MicroRNAs are short RNAs (~22nt) that regulate the gene expression at the post-transcriptional level. Many miRNAs are found to play a crucial role in disease development, and thus they are emerging as promising diagnostic biomarkers. However, detection of miRNAs is difficult because their size is small and there are many highly homologous miRNAs which differ only in a single-nucleotide. Ago-FISH is a highly accurate single-molecule detection technique for amplification-free miRNA counting. We are going to detect three miRNAs from human blood RNA and three miRNAs from virus RNA. These miRNAs are related to allergic inflammation and cancer metastasis. Our plan is verifying this technique is sufficient to be used as a biomarker detection technique.

Keywords:

miRNA, biomarker, single molecule experiment

Direct observation of the strength of protein-protein interactions by live-cell FRET imaging

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Abstract:

Protein-protein interactions (PPIs) take place in almost every biological process including gene expression, DNA replication and repair, signal transduction, cellular metabolism. There are lots of ways to characterize the PPIs and dissociation constant (K_D), which quantifies the binding affinity of proteins, is one of the most important parameters.

Measurement of K_D *in vitro* is relatively feasible since the concentration of proteins and their environment can be easily manipulated. On the other hand, it is demanding to quantify PPIs within living cells due to cellular complexity and difficulties of determining the precise intracellular protein concentration. Despite the challenges, the relevance of investigating PPIs *in vivo* is increasing due to the vast differences between the two environments.

Here, we established three-channel fluorescence resonance energy transfer (FRET) imaging system and directly measured K_D of PPIs in single living bacterial cells, which was previously thought to be a challenging task. The identification of the PPIs in living cells can provide us with a better understanding of the intracellular environment.

Keywords:

Protein-protein interaction, Dissociation constant, Fluorescence resonance energy transfer, Cell imaging

Conformational rearrangements of Cas12a R-loop complex requires Mg²⁺ ion for complete double-stranded target DNA cleavage

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Abstract:

CRISPR-Cas12a is an RNA-guided double-stranded DNA targeting endonuclease that has been widely utilized for genome editing and nucleic acid detection. The molecular mechanism governing cleavage in target DNA employed for the applications is that the two strands are sequentially cleaved by a single catalytic site in RuvC domain of Cas12a. However, the mechanistic details of complete double-strand breaks are still remained to be explored in depth. Here, we identified two consecutive conformational intermediates before target-strand cleavage following non-target strand cleavage using single-molecule FRET assay. Specifically, we revealed that the two conformations represent additional unwinding of target DNA in the PAM-distal region containing target-strand cleavage site and subsequent loading of the target strand at the catalytic site, respectively. Particularly, the intermediate that is unwound conformation of PAM-distal region of target DNA was highly stabilized by Mg²⁺ ions, thereby substantially promoting the cleavage of the target strand. These findings provide a Mg²⁺-dependent kinetic model for target strand cleavage by Cas12a, highlighting the prerequisite conformational rearrangements for the complete double-strand breaks in target DNA

Keywords:

CRISPR-Cas12a, single-molecule FRET

Dynamic nature of divalent metal ions involved in DNA cleavage by CRISPR-Cas12a using Single-molecule FRET

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Abstract:

CRISPR-Cas12a, an RNA-guided DNA endonuclease, has been widely used in genome editing and nucleic acid detection. In both of these applications, Cas12a cleaves target DNA in a divalent metal ion-dependent manner. However, when and how metal ions involve in the cleavage reaction mediated by Cas12a is unclear. Here, using a single-molecule FRET assay, we reveal that divalent metal ions are necessary for stabilizing cleavage-competent conformations and that they are easily exchangeable, indicating that these ions are dynamically coordinated.

Keywords:

singlemolecule FRET, CRISPR-Cas12a

Effects of transcription-dependent physical perturbations on the chromatin dynamics in living cells

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Abstract:

Recent studies using single-particle tracking have revealed that chromatin dynamics are directly affected by transcription activity. However, how movements of chromatin are altered by transcription activity in consequence of changes in physical properties of the chromatin fiber has not been elucidated. Here, we measured diffusion characteristics of chromatin by CRISPR-labeling targeting telomeric DNA repeats, which allows us multiplexed single-locus tracking in a living cell nucleus. Upon transcription inhibition by drug treatments, we found mobility of chromatin is globally increased with most transcription inhibitors, while an inhibitor that blocks transcription by DNA intercalating showed an opposite effect. We hypothesized that the increased mobility of chromatin by transcription inhibitions is due to the dissolution of transcription condensates that induce physical constraints on the chromatin, and the opposite effect by the DNA intercalating transcription inhibitor is due to the increase of chromatin fiber rigidity, which we confirmed with other DNA intercalates. On the contrary to our hypothesis, however, upon treatment with a drug that dissolves the transcription condensates, we observed a decrease in chromatin mobility. By overexpression of DNA binding proteins, we found the mobility of chromatin is decreased. Taken together, we concluded that the increased chromatin mobility by transcription inhibition may not be due to transcriptional condensate induced constraints on chromatin fibers, but because of the disassociation of DNA binding proteins from chromatin fiber.

Keywords:

Chromatin dynamics, CRISPR labeling, Telomere, Single-particle tracking, Transcription, Gene expression regulation, Epigenetic modulation, Fluorescence microscopy, Biophysics

Single-molecule cryo-blinking microscopy

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Abstract:

Under cryogenic conditions, the brightness of most fluorophores increases, and native ultrastructure is preserved much better than chemical fixation. In addition, continuous blinking of fluorescent proteins is observed when some fluorescent proteins, such as EGFP and mEmerald, are illuminated by high intensity laser ($\sim 1-10\text{kW/cm}^2$). Based on these characteristics that appear under cryogenic conditions, we analyzed the blinking kinetics of EGFP and confirmed blinking capable of super-resolution imaging to implement super-resolution imaging with blinking fluorescent proteins. Furthermore, a solid immersion lens was used to implement high NA system ($\text{NA}=1.8$) for single molecule imaging. We will present single-molecule cryo-blinking microscopy using a solid immersion lens and EGFP blinking kinetics in cryo-immobilized mammalian cells under the cryogenic conditions.

Keywords:

Single molecule imaging, Solid immersion lens, the blinking kinetics of EGFP, Cryo-blinking microscopy

Nucleus-cytoskeletal Connections Determine the Alteration of Intracellular Polarization

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Abstract:

Cell polarization plays a crucial role in dynamic cellular events, such as cell proliferation, differentiation, and directional migration in response to diverse extracellular and intracellular signals. Although it is well known that cell polarization entails highly orchestrated intracellular molecular reorganization, the underlying mechanism of repositioning by intracellular organelles in the presence of multiple stimuli is still unclear. Here, we show that front-rear cell polarization based on the relative positions of nucleus and microtubule organizing center is precisely controlled by mechanical interactions including cellular adhesion to extracellular matrix and nucleus-cytoskeletal connections. By modulating the size and distribution of fibronectin-coated adhesive spots located in the polarized cell shape mimicking micropatterns, we monitored the alterations in cell polarity. We found that the localization of individual adhesive spots is more dominant than the cell shape itself to induce intracellular polarization. Further, the degree of cell polarization was diminished significantly by disrupting nuclear lamin A/C. We further confirm that geometrical cue-guided intracellular polarization determines directional cell migration via local activation of Cdc42. These findings provide novel insights into the role of nucleus-cytoskeletal connections in single-cell polarization under a combination of physical, molecular, and genetic cues, where lamin A/C acts as a critical molecular mediator in ECM sensing and signal transduction via nucleus-cytoskeletal connection.

Keywords:

Cell polarity, Lamin A/C, Microcontact printing, Cell adhesion, Nucleus positioning

Novel surface-free/multiplexed single-molecule blotting platform

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Abstract:

It is necessary to passivate the surface for detection of target molecules in all blotting techniques. Especially, non-specific binding events make the analysis of target molecules difficult. Therefore, highly sensitive single-molecule detection requires super-clean surface. To solve the problems, we fabricated a new single-molecule blotting platform that is a surface-condition independent and high-throughput single-molecule optical imaging assay. We also show that the imaging method has an ability to reduce background signal from a quartz surface. We successfully imaged interaction between poly-(A) binding protein and poly-(A) RNA using the single-molecule platform.

Keywords:

Biophysics, Single molecule blotting, Beam sheet

C. elegans under pressure in a microfluidic environment

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Abstract:

C. elegans is a model organism which is widely used to study various biological questions. Recently, the application of microfluidics in the *C. elegans* research allowed many opportunities such as easy and precise control of the environment and live imaging of the behaviors and gene expressions of the worms. However, worms in a microfluidic device can experience unusually high or low pressure compared to those cultured on solid media and their body sizes change according to the pressure. As these high or low pressure could induce unwanted problems in the experiments, we monitored the worms under pressure in a microfluidic environment to find the suitable pressure range which would not cause any artifacts in the experiment. We tested the constant loading rate for positive and negative pressure, and also checked the response under a constant pressure. We find that 10~20 mbar is enough pressure to maintain high enough flow rate while not disturbing the animals.

Keywords:

C. elegans, Microfluidics

생리식염수 및 혈관 내 COVID-19 면역치료 항체 포탈루맵과 자성나노입자 접합의 흐름 특성

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Abstract:

이제까지는 정맥으로 전달된 항-CD3 항체가 부작용을 나타내 면역치료제로 이용하는데 부정적인 특성이 있음이 알려져 있다. 최적의 COVID-19 면역치료제 액상제조를 위한 실험 조건으로 항-CD3 포탈루맵 단클론항체(Ab)와 자성나노입자(MNP)의 Fc-유도 접합이 필요하다. 항-CD3 항체가 SiteClick 항체 라벨링 키트를 사용하여 MNP와의 접합을 위해 준비되었다. Ab-MNP의 성공적인 접합은 TEM 이미지 및 EDS 분석을 사용하여 확인되었다. 생리식염수(PBS)에서 브라운운동(Brown motion)을 하는 MNP 및 Ab-MNP의 이동 속도의 평균값은 x축에서 각각 +3.16 pix/frame 및 +6.70 pix/frame이었다. 이것은 MNP의 표면에 부착된 생체적합성 리간드 작용기를 갖는 CD3 항체가 PBS에서 더 빠른 유동성을 갖는다는 것을 보였다. 이후, 혈관 주사를 통한 직접 접합체 전달 효과를 관찰하기 위해 혈관 내 Ab-MNPs의 유동 특성에 대한 비임상 동물 실험을 수행하였다. 혈액내에서 Ab-MNPs는 MNPs 보다 항체가 갖는 생체적합성에 의해 흐름의 유동성이 향상되었다.

Keywords:

항-CD3 단클론항체, 포탈루맵, 자성나노입자, 접합, 브라운운동

Application of hierarchical model to the feeding dynamics of *C. elegans* under constant food availability

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Abstract:

The soil nematode *C. elegans* feeds on bacteria suspended in liquid, and its feeding dynamics can be monitored by tracking this pumping behavior. We recorded this pumping behavior of individual worms at 50Hz, and analyzed the video to produce time series of pumping pulses. As the pulses are more frequent when the worms eat more often and vice versa, understanding these time series could provide how animals adjust their behaviors to the environment. As a first step toward understanding it, we applied a state space model to this dynamics. Simple state model failed due to durable fast pumping and long pauses. To explain these two extremes, hierarchical structure is required.

Keywords:

C. elegans, Model Organism, Feeding

The domain-wall motion driven by a rotating field in a ferrimagnet

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Abstract:

A magnetic domain wall is a topological defect between two uniform states, which is stable against local perturbations due to the topological nature. For this robustness, a domain wall has been proposed as central units in spintronic devices such as magnetic domain-wall racetrack memory and domain-wall logic devices [1,2]. Due to this utility, it is important to find efficient means to drive a domain wall. For example, it has been recently reported that a domain-wall in a ferromagnet can be driven by an AC-field and AC-current and a domain wall in a ferrimagnet can be driven by spin-transfer-torque [3,4]. Here, we theoretically and numerically study a domain-wall motion in a ferrimagnet by a rotating field. Depending on the magnitude and the frequency of the rotating field, the dynamics of a ferrimagnetic domain wall can be classified into two regimes [5]. First, the stationary solution corresponding to the low frequency can be interpreted to belong to a phase-locking regime, where a domain-wall angle rotates in-phase with an external field. Second, the non-linear solution corresponding to the high frequency can be interpreted as a phase-unlocking regime, where a domain-wall angle is not synchronous with the applied field. In the phase locking regime, the domain-wall velocity is proportional to the field frequency, which implies that the velocity of the domain wall can be controlled by the rotating-field frequency. Once the frequency is over the critical frequency (set by the field magnitude), the domain-wall dynamics enters the phase-unlocking regime where the domain wall velocity decreases due to the incoherent precessional motion of a domain wall. Moreover, the sign of the domain-wall velocity is flipped across the angular compensation point where the net spin density of the ferromagnets changes its sign. Considering that there have been experimental demonstrations of the effect of rotating magnetic field on the dynamics of a magnetic vortex domain-wall chirality reversal [6], we believe that our setup is experimentally feasible. Our work reports not only the novel critical phenomenon associated with the dynamics of a ferrimagnetic domain-wall by a rotating field, but also a new way to detect the angular momentum compensation point of ferrimagnets

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Keywords:

Spintronics, Domain wall, Ferrimagnets, Angular compensation point, Rotating field

Multiferroic exciton of 2-dimensional van der Waals material NiI₂

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Abstract:

NiI₂ is a 2-dimensional antiferromagnetic van der Waals material, which has two successive phase transitions at $T_{N2}=78$ K and $T_{N1}=59.5$ K. NiI₂ has been reported to possess a proper-screw (spiral) magnetic order and a multiferroic phase below $T_{N1}=59.5$ K. Using IR-visible spectroscopy, we measured the optical absorption of NiI₂ and found a sharp absorption peak at 1.384 eV below 60 K where NiI₂ has a multiferroic ground state. The position, linewidth, and spectral weight of the exciton peak was studied as a function of temperature, which suggest a close connection to the underlying multiferroic order.

Keywords:

Multiferroicity, Spectroscopy, van der Waals, NiI₂, Exciton

(100) NiCo₂O₄ 에피택시 박막의 결정구조와 자기적 특성

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Abstract:

준 강자성 NiCo₂O₄는 역스피넬 구조이고 전도성을 띠는 산화물로서 슈터 캐패시터 전극, MTJ소자 등에 활용될 수 있어 많은 주목을 받고 있다. 펄스 레이저 증착법 (PLD)을 이용하여 250 ~ 380°C 사이의 온도에서 (100) MgAl₂O₄ 기판 위에 에피택시 (100) NiCo₂O₄ 박막을 증착하였다. 약 50 nm 두께에서 (100) NiCo₂O₄ 에피택시 박막의 표면특성, 결정성, 수직 자기이방성, 임계온도를 분석하였다. X-선 회절 측정법으로 증착온도를 높일 수록 박막의 격자상수가 증가함을 관찰하였다. 자기 광 커 효과(MOKE) 방법을 이용하여 측정한 수직 자기이방성은 증착온도가 높을수록 임계온도가 낮아졌으며, 보자력은 증착온도 320도 부근까지 증가하며 335도 이후 급격하게 감소하였다.

Keywords:

PMA, Oxide

Home-built one-Kelvin scanning tunneling microscope combined with electron spin resonance

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Abstract:

Electron spin resonance (ESR) combined with scanning tunneling microscope (STM) allows us to achieve the single spin sensitivity with atomic resolution. ESR measurement in STM requires semi-rigid coaxial cables for high frequency electric fields transmission. Adding high-frequency cables or replacing the existing cables by high-frequency cables is not trivial due to the unwanted creation of vibration and heat transmissions to the STM junction. Furthermore, to obtain measurable ESR signals of a single atom/molecule, it is important to polarize the spin state to the ground state by increasing the energy difference between two spin states, which requires higher frequency power at the STM junction. In this work, we compared several different approaches to apply RF signals to the STM junction without requiring extensive modification of the existing STM systems. We demonstrate that an additional high frequency cable near the STM junction (the junction between the sample and STM tip) enables for applying high frequency powers up to 40 GHz without a direct contact with any part of the STM. This integration of high-frequency cables will allow many STM groups to modify the existing system more easily and apply high frequency powers to the STM junction.

Keywords:

Electron spin resonance, Scanning tunneling microscope, Scanning tunneling spectroscopy, Construction

Study of Lanthanide Atoms Adsorbed on MgO/Ag(100) as Potential Qubits in ESR-STM

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Abstract:

Lanthanide atoms are characterized by unpaired electrons in the spatially localized $4f$ orbitals that are shielded by the outer filled orbitals ($5s$, $5p$ and $6s$). This property allows long coherence time of the spin states[1] and thus, large number of attainable quantum coherent operations, a key feature in their potential use as building blocks for quantum computation (qubit). Coherent control of their quantum states is possible using electron spin resonance (ESR). This technique can be operated down to the atomic level when combined with scanning tunnelling microscopy (STM) [2]. So far, this technique has been tested on a few systems showing relatively short coherence time. Therefore, identifying novel atomic qubits with more robust quantum properties will allow further developments in quantum logic operation sequences at the single atom level.

In this work we present two possible candidates as spin qubits characterized by long coherence times. Specifically, we studied thulium (Tm) and erbium (Er) deposited on MgO/Ag(100) by means of x-ray magnetic circular dichroism (XMCD), multiplet calculations and STM, characterizing the electronic and magnetic properties of the systems. We found their ground state to potentially allow quantum coherent operations, hence they represent an alternative to the commonly adopted transition metal atoms for their use as qubits in ESR-STM experiments.

[1] M. Shiddiq et al., Nature 531, 348-351 (2016).

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Keywords:

Single atom qubits, Electron spin resonance, X-ray magnetic circular dichroism, Coherent control, Quantum states

Volume Dependence of Anomalous Hall and Nernst Effect in compensated ferrimagnet Mn_3Al

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Abstract:

Recent studies shows that anomalous Hall effect (AHE) can exist even with zero magnetization using symmetry analysis [1-3]. In this context, anomalous Hall conductivity (AHC) of a compensated ferrimagnet Mn_3Al has been investigated using *ab initio* calculations. Uniform volume change is considered to not change any symmetries, but only volume. With volume change, bands near Fermi level are affected. Occupancy of conduction bands changes and valence bands upper shift. Furthermore, anomalous Nernst conductivity (ANC) is also calculated. Van Hove singularity is found in specific energy range around L point, where AHC and ANC peak is located.

Keywords:

DFT, Spintronics, Magnetism, Transport

Comparison of electrical properties for Ni, Fe doped CoS₂ single crystals

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Abstract:

Itinerant ferromagnet CoS₂ shows a crossover behavior between extrinsic skew type scattering and intrinsic Berry curvature origin of anomalous Hall effect (AHE). Below the crossover temperature ($T_{\text{cross}} \approx 20 \text{ K}$), there appears linear positive magnetoresistance (MR) and positive AHE contribution which has rapidly increasing anomalous Hall conductivity (σ_{AHE}) as longitudinal conductivity (σ_{xx}) increasing. In contrast to the extrinsic regime, MR and AHE at $T_{\text{cross}} < T < T_{\text{C}}$ have opposite signs with sign reversal occurred around T_{cross} . Interestingly, the crossover behavior doesn't appear by even a small amount of Ni or Fe doping and most of the doped samples show large anomalous Hall conductivity than that of CoS₂.

Keywords:

Anomalous Hall effect, Magnetoresistance

Vacancy-induced topological semimetallic response in hexagonal ferromagnet

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Abstract:

Hexagonal ferromagnet Fe₅Sn₃ has been reported to exhibit 3 times higher intrinsic anomalous Hall conductivity than Fe₃Sn₂ and topological Hall effect arises due to the scalar spin chirality. However, neither the magnetic response nor the structure of Fe₅Sn₃ are not consistently reported. We found such discrepancies are derived from occupancy of Fe(II) site and structure deformation. We further observed that Fe₅Sn₃ which possesses higher Fe occupancy guarantees higher residual resistivity ratio, whence enhanced anomalous Hall conductivity and magnetoresistance follow. In aspect of magnetoresistance and mobility at 5 K reaching ~5000 % at 14 T and $1.3 \times 10^5 \text{ cm}^2 / \text{V s}$ respectively, Fe₅Sn₃ with higher Fe proportion could become one prominent candidate for topological semimetal. Moreover, anomalous Hall response moves from intrinsic-dominant to skew scattering-dominant, and eventually extremely large peak appears where topological Hall effect arises.

Keywords:

anomalous Hall effect, Ferromagnet, Fe vacancy, topological semimetal, skew scattering

In-situ sample preparation and electron spin resonance measurement of unpaired electrons in organic molecular spin films

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Abstract:

Electron spin resonance (ESR), also known as electron paramagnetic resonance (EPR), is an important spectroscopic technique for the study of molecules and ions containing unpaired electrons [1]. Developing atomic- and molecular-scale quantum devices requires the spins to be integrated on a solid-state support. However, it is challenging to use this technique to characterize surface-adsorbed spins, due to the very small amount of magnetic materials arranged in a 2D structure.

In order to perform ESR on these systems, we develop several surface-type microwave resonators that maximize the sensitivity to surface-adsorbed spins. Using electron spins in organic radicals such as α,γ -Bisdiphenylene- β -phenylallyl (BDPA) and 2,2-Diphenyl-1-picrylhydrazyl (DPPH) as test samples, we characterize the sensitivity of our instrument, demonstrating that we can detect one single layer of molecules. Combining surface-type resonators with an in-situ sample preparation setup will allow us to measure the anisotropy and optical excitation of molecular spins on clean surfaces that are prepared and measured without breaking the vacuum.

Reference

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Keywords:

Electron spin resonance, Surface-adsorbed spins, Surface-type microwave resonator, In-situ sample preparation, Molecular spins

Study of VOPc/TiOPc layers on Ag(100) using X-ray absorption spectroscopy.

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Abstract:

VOPc is a transition metal-based phthalocyanine that has spin 1/2, and long coherence time of almost 1 microsecond up to room temperature [M. Atzori et al., J. Am. Chem. Soc. **138**, 2154 (2016).], so it is a promising molecular spin qubit. In order to obtain this long coherence time, one needs to dilute VOPc in diamagnetic isostructural TiOPc. In order to integrate magnetically diluted molecular films of VOPc/TiOPc in quantum computing devices, it is important to understand the interactions between the molecular spin and the supporting substrate [I. Cimatti et al., Nanoscale Horiz. **4**, 1202 (2019).]. In our work, we realize molecular films of VOPc on TiOPc grown on Ag(100), using the TiOPc to decouple the V spins from the conduction electrons of Ag substrate. By using X-ray magnetic circular dichroism (XMCD) we investigate the magnetic properties of the V spin center and the decoupling effect of the TiOPc layer. In all cases, VOPc molecules preserves a spin 1/2. Depending on the presence and thickness of the TiOPc decoupling layer, we observe changes in the shape of the XMCD. This reveals differences in the orbital structure of V induced by the proximity of the Ag(100) substrate. Annealing up to 450 K can modify the molecular absorption configuration, however, the orbital structure of VOPc remains unchanged when adsorbed on TiOPc. Our work shows the possibility to realize robust molecular spin films on surfaces with potential use in quantum computing technology.

Keywords:

Molecular Spin Qubit, X-ray Magnetic Circular Dichroism, X-ray Linear Dichroism, Molecular Thin Films

Role of strain on magnetism in atomically thin Fe₃GeTe₂

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Abstract:

Among recently discovered two-dimensional magnetic materials [1-4], Fe_xGeTe₂ family (x=3, 4, and 5) has received attention due to relatively high Curie temperature larger than 130 K [5]. In this study, strain tunable magnetism of Fe₃GeTe₂ (FGT) are investigated using density functional theory. FGT structure has two inequivalent Fe site, where Fe(I) sandwiches Fe(II)-Ge plane. In monolayer, by strain (-5 % ≤ η ≤ +5 %), Fe(I) moment ranges from 1.53 to 2.37 μB, while Fe(II) change little. Besides, under strain, magneto-crystalline anisotropy varies from 0.85 to 4.15 meV/cell. To analyze these, strain dependent occupation of bands of Fe(I) and Fe(II) are investigated. In bilayer, without strain, each ferromagnetic monolayer couples antiferromagnetically. With strain, antiferromagnetic coupling is retained until η = +4.17 %, where transition to ferromagnetic coupling occurs. This layer-by-layer magnetism is further studied by the interlayer exchange coefficient.

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Keywords:

2D magnetic material, Density functional theory, Magneto-crystalline anisotropy, Strain

Multiple Magnetic Domain Wall Injector

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Abstract:

magnetic domain을 활용한 magnetic memory는 domain의 magnetization을 사용하여 정보를 기록하고 spin-transfer torque(STT)와 spin-orbit torque(SOT)에 의한 domain wall (DW) 운동을 통한 시프트 레지스터 형태의 DW memory를 만들 수 있다. DW memory를 만들기 위해선 자성 정보 기록 해당하는 DW 쓰기가 제어된 방식으로 작동해야 한다. 일반적으로 DW 쓰기는 자성 트랙에 가로질러 지나가는 전극에서 발생하는 에르스텝(Oersted) 자기장을 이용해 왔다. 그러나 이 경우 DW 쓰기를 위한 단자가 2개 더 추가되어야 하므로 소형화에 걸림돌이 된다. 본 연구에서는 OOMMF 시뮬레이션을 통해 자성 트랙의 한쪽 경계에 magnetic anisotropy의 기울기가 존재하는 영역을 준비하고 이러한 시스템에서 SOT에 의한 DW injection 여부를 조사했다, magnetic anisotropy가 수평-수직으로 연속적으로 바뀌게 됨에 따라 전류 방향의 자화 성분이 생겨 SOT에 의한 DW injection이 수월하게 일어남을 확인했다. 이를 기반으로 Dzyaloshinskii-Moriya 상호작용의 크기, anisotropy 기울기, 그리고 구동 메커니즘에 따른 DW injection을 일으키는 전류의 의존성에 대해 논의하고자 한다.

Keywords:

Domain wall motion, magnetic anisotropy, domain wall injection, spin current injection

Magnetic anisotropy of Pd/Co/Pd ultrathin film: Interface vacancy defect and O diffusion effect

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Abstract:

Magnetic anisotropy represents one of the most important properties in magnetic systems and it is largely sensitive to its environment. Using the first principles calculation, we investigated the magnetic anisotropy of Pd/Co/Pd ultrathin film. Here, we explored the magnetic anisotropy of pristine Pd/Co/Pd ultrathin film and also interface vacancy defect (Pd or Co) structure. Besides, we considered the oxygen diffusion into the Pd/Co/Pd ultrathin film. In the pristine structure, the Co had a magnetic moment of $1.71 \mu_B$ at the central layer whereas the interface Co had a magnetic moment of $1.85 \mu_B$. Meantime, we obtained an induced magnetic moment of $0.33 \mu_B$ in the interface Pd atom. Nonetheless, no substantial change in the magnetic moment was found in the vacancy defect and also in the O diffusion structure. We found that the pristine Pd/Co/Pd system had a perpendicular magnetic anisotropy of $1.37 \text{ meV/unit cell}$. By considering the Pd-vacancies defect, the magnetic anisotropy of the Pd/Co/Pd ultrathin film has decreased to $0.46 \text{ meV/unit cell}$, while the magnitude of the anisotropy was decreased to the $0.56 \text{ meV/unit cell}$ with Co interface vacancy defect. However, we obtained that the magnetic anisotropy of the Pd/Co/Pd ultrathin film was suppressed with the O adatom to a magnitude of $0.52 \text{ meV/unit cell}$. Thus, we found the magnetic anisotropy of the Pd/Co/Pd ultrathin film was largely sensitive to the effect of interface vacancies and O diffusion defects

Keywords:

magnetic anisotropy, Pd/Co/Pd thin film

Orbital angular momentum of a domain wall and geometrically twisted magnons

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Abstract:

We theoretically study the dynamics of a domain wall in a ferromagnetic nanotube driven by electrons and magnons by investigating the electron-domain-wall and magnon-domain-wall interactions. Due to the geometry of the sample, domain walls are classified by the Skymion charge which counts the winding number of magnetic textures on the domain wall [1]. The domain wall with a non-zero Skymion charge generates an emergent magnetic field for interacting particles, which exerts the Lorentz force on moving electrons and magnons and thereby deflects their trajectories. This deflection is manifested as the generation of the finite orbital angular momenta of the electrons and magnons that traverse the domain wall [2,3]. For the case of electrons, we can interpret the exchange of orbital angular momenta between electrons and the domain wall as a current-induced torque. From this peculiar torque, the domain wall with the non-zero Skymion charge can be driven by an arbitrary small current without the Walker breakdown. For the case of magnons, we obtain the exact solution for the magnon on the Skymion-textured domain wall and also their scattering properties with the domain wall with the aid of supersymmetric quantum mechanics (SUSY QM). We also show that there is a critical wavenumber for the total reflection and it is discretized by the Skymion charge of the domain wall. Our results show that the orbital angular momenta of magnetic systems and quasi-particles can be intertwined in a curved geometry.

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Keywords:

Magnon, Domain wall, Orbital angular momentum

Magnetic-field-resilient superconducting coplanar-waveguide resonators

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Abstract:

High-quality superconducting coplanar waveguide (SCPW) resonators are crucial for developing superconducting quantum information devices and sensors. Especially, operation of SCPW resonators under strong magnetic fields is required for developing spin-ensemble sensors or topological superconducting qubits. Magnetic fields, however, degrade the quality factor of SCPW by creating vortices, which induce resistive losses, and suppressing the superconductivity itself. Here, we fabricated and characterized various SCPW resonators with varying superconducting materials (Nb, NbN, and NbTi) and the film thicknesses (20 ~ 150 nm). At $T = 1.8$ K, the internal quality factor, Q_i , ranges between 10^3 and 10^5 at zero magnetic field, but decreases rapidly with the magnetic field. When we compare the characteristic magnetic field B^* , which is defined as $Q_i(B^*) = Q_i(B=0)/2$, B^* varied from 0.05 to 0.75 T, depending on the superconducting materials and their thicknesses. We will discuss about the optimal conditions for the magnetic-field-resilient SCPW resonators.

Keywords:

coplanar waveguide resonators, circuit quantum electrodynamics

A Detailed Computational Study of High- T_c Superconductivity Phase Diagrams Based on U(1) and SU(2) Slave-Boson Representation of the t - J Model Hamiltonian

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Abstract:

The phase diagrams of high- T_c superconductors display a monotonously decreasing pseudogap temperature and a dome-shaped superconducting transition temperature in the plane of temperature vs. hole concentration. One of the major theoretical challenges in high- T_c superconductivity is to reproduce the observed phase diagrams. Earlier Lee and Salk [Phys. Rev. B **64**, 052501 (2001); *ibid.* **71**, 134518 (2005)] reproduced successfully the phase diagrams by applying a feasible slave-boson representation to the Heisenberg exchange interaction term in the t - J model Hamiltonian. Recently, Shin *et al.* [J. Supercond. Nov. Magn. **23**, 637 (2010)] reported both the temperature and the doping dependencies of magnetic susceptibility and spin pairing correlations involved with spin dynamics in high-temperature superconductivity. More recently, Salk [Quantum Studies: Mathematics and Foundations **5**, 149 (2018)] presented a detailed study with emphasis on the physics of high- T_c superconductors. In addition, highly reasonable room temperature superconductivity was proposed by demonstrating that the higher, the antiferromagnetic coupling strength J , the higher, the superconducting transition temperature T_c . Most recently, Ahn *et al.* [J. Korean Phys. Soc. **76**, 1020 (2020)] discussed hitherto-less-reported detailed computational study of the phase diagrams by varying the values of J based on the U(1) slave-boson representation of the t - J model Hamiltonian. Here we present a detailed computational study of the phase diagrams, specially focusing on the comparison of the U(1) slave-boson representation with the SU(2) slave-boson representation of the t - J model Hamiltonian.

Keywords:

Computational Study, High- T_c Superconductivity, Phase Diagram, U(1)/SU(2) Slave-Boson Representation, t - J Model Hamiltonian

Anomalies in highly overdoped region of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ phase diagram

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Abstract:

Intriguing anomalies have been observed in the highly overdoped region of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ (Bi-2212) the phase diagram of hole-doped cuprates. These anomalies in the highly overdoped region of Bi-2212 may be related to the disappearance of the optical coherence mode. Here, we investigate single crystals of Bi-2212 in a wide doping range from the optimally doped to highly overdoped region using optical spectroscopy. An optimally doped sample with the superconducting transition temperature, $T_c = 91$ K and five overdoped ones with $T_c = 82, 70, 64, 58,$ and 52 K are investigated. We obtain optical conductivity spectra from measured reflectance spectra using a Kramers-Kronig analysis. We also obtain the optical self-energy using the extended Drude model. We observe a systematic change of the optical coherence mode with the doping. We also observe strange fluctuations in the optical spectra, which we do not understand yet. We speculate that the fluctuations are related to the nematic fluctuations because they take place in a similar doping region.

Keywords:

High T_c superconductor, Overdoped, Optical spectroscopy

Al-AIO_x-Al Josephson junction and SQUID using shadow evaporation technique

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Abstract:

Aluminum-based Josephson junction (Al-AIO_x-Al JJ), which is a nonlinear superconducting element, provides an essential building block for developing superconducting qubits and various quantum electronic devices. In this work, we fabricated Al-AIO_x-Al JJs by using shadow evaporation technique, where a bilayer of copolymer and PMMA was used to form a Dolan bridge after the electron beam lithography. After completing the device fabrication, the lateral area and the normal-state resistance of the JJ turned out to be $A = 400 \times 450 \text{ nm}^2$ and $R_n = 2.4 \text{ kW}$, respectively. At $T = 0.3 \text{ K}$, the critical current of the JJ was obtained to be $I_c = 10 \text{ nA}$ and the superconducting gap energy of Al was $D_{Al} = 0.23 \text{ meV}$. The Al-AIO_x-Al SQUID, which was fabricated with the same method, exhibited $I_c = 115 \text{ nA}$ at the base temperature. As we applied external magnetic field perpendicularly to the substrate, we observed a periodic modulation of I_c of the SQUID with a period of $B_{\text{period}} = 85 \text{ mT}$, corresponding to a magnetic flux quantum of $F_0 = h/2e$ through the inner area of the SQUID, where h is the Planck constant and e is the elementary charge. Our observations indicate that the shadow evaporation technique would be very useful to develop superconducting quantum electronic devices for qubits and quantum sensors.

Keywords:

Josephson junction, Aluminum tunneling junction, SQUID, Shadow evaporation technique

Enhanced Superconductivity in the Ruddlesden-Popper Oxide $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$ thin films Using Single-Terminated LaSrAlO_4 Substrate Surfaces

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Abstract:

Over the past decades, Ruddlesden-Popper (RP) oxides ($A_{n+1}B_nO_{3n+1}$, $n = 1, 2, \dots$) have been investigated extensively with advantageous physical properties such as high-temperature superconductivity and colossal magnetoresistance. [1,2] These emergent phenomena provide a platform for novel oxide-based electronic devices. However, high-quality RP thin film growth has been disturbed by extended structural defects, so-called out-of-phase boundaries (OPBs). [3] Since OPB formation hampers the physical properties of RP thin films, the suppression of the structural defects is highly required to carry out high-performance RP-based functional devices. [4]

In this study, we suppressed OPBs in RP thin films by using single-terminated LaSrAlO_4 substrate ($n = 1$ RP phase, $a = b = 3.756 \text{ \AA}$ and $c = 12.636 \text{ \AA}$). As a model system, the high- T_c cuprates superconductor $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$ thin film ($n = 1$ RP phase, $a = b = 3.777 \text{ \AA}$ and $c = 13.226 \text{ \AA}$) was employed. Despite the structural similarities between films and substrates, the $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$ films exhibited huge OPB formations when deposited on mixed-terminated LaSrAlO_4 substrate. In contrast, when the $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$ films were deposited on single-terminated LaSrAlO_4 substrates, the OPBs were significantly suppressed in the film structure. Notably, these OPB-free $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$ films exhibited highly enhanced superconductivity ($T_c^{\text{zero}} \sim 30 \text{ K}$) than the film with huge OPB formation ($T_c^{\text{zero}} \sim 5 \text{ K}$) under the same thickness ($\sim 6.5 \text{ nm}$). Our study suggests a comprehensive method to suppress OPB formation in RP thin films, enabling superconducting spintronics devices based on RP high- T_c superconductors. [5]

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Keywords:

Ruddlesden-Popper oxides, oxide thin films, superconductivity

Growth phase diagram of cobalt oxide thin films with control of oxygen vacancy

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Abstract:

AB_2O_4 spinel oxides have various functionalities originated from their tetrahedral crystal field and spin configuration. The physical properties of these materials are diverse, for example, ferromagnetism, antiferromagnetism, spin-glass, and even superconductivity. Recently, the two-dimensional topological superconductivity has also been predicted at the antiferromagnetic/superconducting interface of spinel oxide structure [1]. However, a realization of this exotic phase requires a stable antiferromagnetic state, which is a hardship due to the subtle electronic structure and intrinsic geometrical spin frustration of spinel oxides [2]. The magnetic properties of these systems are governed by crystal field splitting with oxygen bonding; thus, the formation of oxygen vacancy (V_O) plays an important role to utilize the physical properties of spinel oxides.

Control of V_O in this system is also important for the application. Among the spinel oxides, cobalt oxides have recently got much attention with their catalytic behavior for oxygen evolution/reduction reaction [3]. Since cobalt ion has multiple oxidization states, cobalt oxides can be rock-salt CoO and spinel Co_3O_4 . The reduction/oxidization of cobalt oxides are very sensitive to temperature and pressure. This sensitivity makes cobalt oxides highly reactive. There have been extensive studies on the oxidization process in cobalt oxides from the bulk, nanoparticles, and thin films. Previous works have reported that the oxygen pressure is a key parameter to control the oxidization state of cobalt oxides thin films [4], while overlooking the possibility of V_O formation with their growth temperature. Therefore, a comprehensive understanding of growth conditions including temperature and V_O formation in cobalt oxides is still required, particularly on thin films.

Here we provide a detailed growth diagram of cobalt oxide thin films with V_O formation. We grew several cobalt oxide thin films on $MgAl_2O_4$ (111) [MAO(111)] substrate by pulsed laser deposition (PLD) technique. MAO single crystal was used for the epitaxial growth since it has a similar lattice constant and spinel structure with Co_3O_4 . Growth temperature and oxygen partial pressure [$P(O_2)$] were the main variables. To distinguish the various oxidation states and V_O formation of cobalt oxide thin films, we performed X-ray diffraction (XRD) for the lattice structural characterization, and X-ray photoemission spectroscopy (XPS) for the core-level electronic characterization. We also conducted spectroscopic ellipsometry for the optical properties. Combining the experimental results, we obtained a comprehensive growth phase diagram. Even we used a single CoO compound as a target for PLD, we could obtain various oxidized phases of cobalt oxides. As a result, we could suggest a criterion for the growth and analysis of cobalt oxide thin films.

Keywords:

Spinel Oxides, Cobalt Oxides, Co_3O_4 , Oxygen vacancy, Growth phase diagram

Ferroelectric domain structures of an epitaxial Bi_2WO_6 thin film

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Abstract:

We grow an epitaxial bismuth tungsten oxide (Bi_2WO_6) thin film on SrTiO_3 (001) substrate using the pulsed laser deposition method. By using angle-resolved piezoresponse force microscopy [1,2], we have discovered a ferroelectric state of $\langle 100 \rangle$ -oriented polarization between the known 4-variant $\langle 110 \rangle$ polarization domains [3,4]. Since the mixture of competing phases and the emergence of charged domains walls are expected to enhance the photovoltaic effect [5] as well as conductivity, we are investigating the photocurrent by applying a laser diode and searching domain-switching properties of this material. Our finding of an in-plane polarization system will offer useful information for various domain-related phenomena in the ferroelectric material.

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Keywords:

Ferroelectrics, oxide thin films, bismuth tungsten oxide, piezoresponse force microscopy, photovoltaic effect

Dielectric Properties of Eu_2O_3 -doped Potassium Sodium Niobates Ceramics with varying K/Na Ratio

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Abstract:

We have investigated temperature and frequency dependencies of complex dielectric constants of Eu_2O_3 5.0 mol.% doped potassium sodium niobates $\text{K}_{1-x}\text{Na}_x\text{NbO}_3$ (EuKNN, $x = 0.40 \sim 0.60$) lead-free piezoelectric ceramics in the temperatures ranging from room temperature (RT) to 600°C and the frequency range of $0.01 \text{ Hz} \sim 1 \text{ MHz}$. The EuKNN ceramic specimens were prepared by using the conventional ceramics process at the same sintering temperature of 1160°C in air atmosphere. All the EuKNN ceramic specimens showed two dielectric anomalies at the structural phase transition temperatures of cubic-tetragonal (T_C) of 370°C and tetragonal-orthorhombic (T_{TO}) of 140°C on cooling cycle, respectively. The dielectric constant maxima of the Eu-doping in EuKNN ceramics became broader than that of a $\text{K}_{0.5}\text{Na}_{0.5}\text{NbO}_3$ ceramic at T_C . The two phase transitions on cooling were observed at temperatures below 6°C than at temperatures on heating, respectively. The EuKNN ceramics showed strong low frequency dispersions (LFDs) at the temperatures above 200°C . The strong LFDs were characterized as of two weaken frequency-dependencies of the real dielectric constants and two broaden peaks in the dielectric loss tangents in the temperature range above T_C , which were considered to be related with the two impedance relaxations due to the grain and the grain boundary phases as a Maxwell-Wagner type. It is invoked that the volume LFD is not influenced by an Eu-doping in KNN grain phases but the interfacial LFD and/or surface conduction are contributed by a semi-conductive nature due to a secondary phase of $\text{Eu}_{1-y}\text{NbO}_3$ ($0 < y < 1$) in the grain boundary. We are further studying on structural and optical properties of the EuKNN ceramics, which were characterized by using the scanning electron microscopy, the X-ray diffraction, the Raman spectroscopy, and the diffused reflectance spectroscopy at RT.

Keywords:

Low frequency dispersion (LFD), Volume LFD, Interfacial LFD

Lattice instabilities and pressure effects on the electrical properties of CuCrP_2S_6

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Abstract:

In recent years, van-der-Waals (vdW) materials have garnered enormous interest due to their relevance to the next generation of electronic devices. CuCrP_2S_6 is a vdW multiferroic compound, in which the Cu^+ and Cr^{3+} cations bring about antiferroelectric and antiferromagnetic ordering at $T_C \sim 145$ K and $T_N \sim 30$ K, respectively. Our Raman scattering measurements unveil intriguing phonon anomalies as a function of temperature. New phonon modes appear through a two-step process, evidencing multiple phase transitions. The lattice anomalies at $T=190$ K and 140 K are inextricably associated with glassy and long-range antipolar states, respectively. Besides, we identify the phonon anomalies in their intensity between T_C and T_N , indicating the competing antiferroelectric and antiferromagnetic states. Further, our preliminary transport data showcase a pressure-induced insulator-to-metal transition on the application of quasi-hydrostatic pressure at ca. 18 GPa, which is commonly reported in the MPS_3 family (M=transition metals).

Keywords:

van der Waals material, antipolar order, insulator-to -metal transition

Microscopic observation of flexoelectric polarization around crack in SrRuO₃ thin film

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Abstract:

In a periodic lattice, symmetry breaking due to structural discontinuity induces natural flexoelectricity and can be a promising route to stabilize interesting structural properties. Here, we demonstrate strain gradient stabilizing polar metal phase around a crack in SrRuO₃ thin films. By changing film thickness, we control the population and morphology of cracks on the film surface, which influence the strain gradient. Microscopic structural analysis by adopting scanning transmission electron microscopy (STEM) reveals that the morphology of crack determines strain gradient and flexoelectric polarization. Our results help to comprehend the properties of plastic deformation in well-grown oxide thin films and suggest that we can utilize crack as a new strain source to realize multifunctionality.

Keywords:

flexoelectricity, polar metal, crack, SrRuO₃

Study of gate voltage dependent hysteresis in temperature dependence of resistance

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Abstract:

We investigated the temperature dependence of resistance($R(T)$) for cool-down and warm-up in LaAlO₃/SrTiO₃ heterostructure grown by Pulsed Laser Deposition when back-gate voltage was applied. For four-probe measurement, hall bar geometry was fabricated via photolithography and Ar-ion milling. After fabrication, $R(T)$ was measured while temperature was swept from 300 K to 4 K and then to 300 K. It was observed that $R(T)$ showed an irreversible path when sweeping the temperature, and the irreversible magnitude of $R(T)$ became larger with increasing back-gate voltage. To explain the irreversible path of $R(T)$, we present a model that includes the occurrence of electron trapping by the back-gate and the increase in dielectric constant of SrTiO₃ with decreasing temperature.

Keywords:

Hysteresis, Heterostructure, LaAlO₃/SrTiO₃, back-gate

Local structural changes and improvement of ferroelectric properties in BNT-based relaxor ferroelectrics

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Abstract:

Relaxor ferroelectrics have attracted much attention due to their large piezoelectric properties and excellent dielectric properties. However, the origin of these excellent electrical properties is still unclear. In stark contrast to typical ferroelectric, relaxor ferroelectrics show unusually large dielectric constant over a large temperature range. This large dielectric response is highly frequency dependent, and unlike the dielectric anomalies associated with a ferroelectric phase transition, the maximum of dielectric response in relaxor does not indicate the occurrence of a ferroelectric phase transition. Thus, this huge dielectric response suggests that local polarization may occur in the crystal. The local polarization is suggested to occur in a nano-region, and is generally called as polar nano-region (PNR). In this regard, the most popular model to describe the mesoscale polar structure is the "PNRs + nonpolar matrix" model. Nevertheless, this model is not completely acceptable for relaxor ferroelectrics. We fabricated $0.8(\text{Bi}_{0.5}\text{Na}_{0.5}\text{TiO}_3)-0.2(\text{Bi}_{0.5}\text{K}_{0.5}\text{TiO}_3)$ (BNKT) ceramics, one of relaxor ferroelectrics. Characteristically, when the external electric field is removed near this composition, the residual polarization shows a value close to zero (i.e., the ferroelectricity disappears). These results indirectly support the existence of nonpolar matrix. However, in a subsequent study, the ferroelectric properties including residual strain were improved by adding orthorhombic CaTiO_3 (CT) to the above composition. This phenomenon is difficult to explain with the "PNRs + nonpolar matrix" model. In particular, CT is a typical linear dielectric material. Therefore, the improvement of ferroelectric properties according to the addition of CT is a very unusual phenomenon. Therefore, we will discuss in detail the microstructure changes according to the amount of CT added through Raman and transmission electron microscopy (TEM) analysis.

Keywords:

relaxor, Ferroelectrics, Polarization

양극산화 TiO₂ nanotube를 이용한 저온에서 PbTiO₃ nanotube 열수 합성을 통한 구조적 변화 연구

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Abstract:

PbTiO₃는 perovskite의 구조를 가지고 있는 높은 유전율을 보이는 강유전체로 널리 알려져 있다. 이러한 PbTiO₃를 제작하는 대표적인 방법들 중, 양극산화를 통해 TiO₂를 나노 튜브 형태로 제작한 다음, 이를 열수 합성법이라는 저온에서의 합성 공정을 통해 PbTiO₃를 나노 튜브의 형태로 합성한 연구들이 보고 되었다[1, 2]. TiO₂ 나노 튜브의 경우, 비정질 구조의 나노 튜브는 물 속에서 자가 분해와 재결정화를 반복하면서 아나타제 구조로 변환된다. 그 과정에서 acetate와 금속(M) 이온이 결합된 물질을 첨가하고 열수 합성을 진행하게 되면, TiO₂ 나노 튜브가 재결정화를 거치기 전 M⁺와 결합하여 MTiO₃ 나노 튜브가 합성되는 메커니즘이 보고되었다[3]. 본 연구에서는 양극산화를 통해 제작한 TiO₂ 나노 튜브와 lead acetate를 출발물질로 사용하여 위의 제시된 메커니즘을 바탕으로 열수 합성법을 통하여 PbTiO₃를 합성하는 연구를 진행하였다. 그 결과, PbTiO₃가 합성되는 과정에서 온도와 시간을 변수로 적용하여 PbTiO₃가 합성되는 기준점을 분석하였고 이를 통해 특정 온도와 시간을 기점으로 PbTiO₃가 perovskite의 형태로 저온에서 합성되고 결정성이 변화되는 것을 XRD를 통해 분석하였다. 또한 lead acetate의 농도와 TiO₂의 구조를 추가적인 변수로 적용하여 이에 따라 합성된 PbTiO₃의 형태와 구조에 영향을 미치는 것을 XRD를 통해 분석하였고 이러한 형태를 FE-SEM을 통하여 관찰하였다. 결과적으로, 열수 합성법이라는 저온 합성 공정을 통해 원하는 구조와 형태의 강유전체를 여러 변수를 매개로 최적화 하여 각각의 변수들이 어떠한 영향을 미치는 지에 대해 분석되었다.

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Keywords:

강유전체, PbTiO₃, 나노 튜브

BaBi₂Nb₂O₉ 첨가에 따른 릴랙서 강유전체 0.8BNT-0.2BKT 세라믹의 에너지 저장 성능 분석

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Abstract:

유전체 커패시터는 높은 충방전 속도와 전력 밀도를 가져 친환경 에너지를 위한 에너지 저장 장치로서 주목받고 있다. 그 중에서도 릴랙서 강유전체 커패시터는 상대적으로 높은 분극과 낮은 잔류 분극을 지니고 있어 높은 에너지 밀도와 에너지 저장 효율을 얻을 수 있으리라 생각된다. xBNT-(1-x)BKT (이하 BNKT) 세라믹은 릴랙서 강유전체면서 납과 같은 인체에 유해한 물질을 포함하고 있지 않기 때문에 연구가 활발히 진행 중이다. 최근 일부 릴랙서 강유전체를 BNT 기반 세라믹스에 도입하였을 때 완화형 거동이 향상되고 결정립 크기가 줄어들면서 잔류 분극이 작아지고 절연파괴강도가 향상되는 것이 보고되었다.[1] 비스무스 층간 구조의 강유전체인 BaBi₂Nb₂O₉ (이하 BBN)은 릴랙서 강유전체 특성이 보고된 바 있다[2]. BBN은 최대 분극은 낮은 편이지만 잔류 분극이 낮고 절연파괴강도가 뛰어나기 때문에 높은 잔류 분극을 지니고 절연파괴강도가 낮은 BNKT에 첨가하여 특성을 보완해줄 수 있을 것으로 기대된다. 본 실험에서 (1-x)(0.8BNT-0.2BKT)-x(BaBi₂Nb₂O₉) 세라믹은 고상 반응법으로 제작되었다. 배합된 원료들은 HDPE 용기에서 지르코니아 볼과 함께 20시간 볼 밀링하였다. 하소와 소결 공정은 각각 800 – 850 °C, 1050 – 1150 °C로 2시간 동안 진행되었다. 제작한 시료는 XRD를 통해 조성을 확인하고 전극을 씌워 PL & DB Test System에서 전기장-분극 특성을 확인하였다.

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Keywords:

강유전체, Relaxor, 0.8BNT-0.2BKT 세라믹

다양한 플라즈마 후열처리를 통한 비정질 기판위에 성장된 VO_x 박막의 특성 연구

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Abstract:

다양한 플라즈마 후열처리를 통한 비정질 기판위에 성장된 VO_x 박막의 특성 연구

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초록

Vanadium dioxide(VO₂)는 절연체-금속전이(IMT: Insulator-Metal transition)을 하는 물질 중에 하나로써 상전이 메커니즘을 이해하려는 다양한 연구가 진행되었다. 지금까지 다양한 연구에도 불구하고, 바나듐은 다양한 산화가를 가질 수 있기 때문에 안정적인 VO₂ 상으로 물질을 구현하는 것에는 많은 어려움이 있었다. 그러나 시료 내에서 일정한 비율의 VO₂ 상을 가지게 된다면, 상온 근처에서 상전이가 구현될 수 있다는 것이 확인되었다. 따라서 높은 결정성이나 단일 상을 가지지 않더라도, 일정한 크기의 상전이(저항변화)가 구현되며, 상대적으로 쉽게 증착할 방법에 관한 연구는 VO₂ 상전이 특성을 활용한 다양한 응용소재 연구에 유용할 수 있다.

본 연구에서는 RF magnetron sputtering을 이용하여 600 °C에서 비정질 유리 기판 위에 VO_x 박막을 제작하고, Ar과 O₂를 혼합한 플라즈마를 이용해 상기 박막을 10 분간 같은 온도에서 후열처리 하였다. X-선 회절과 X-선 광전자 분광 측정을 통해 각 샘플이 후열처리 시 산소가스의 비율에 따라 Stoichiometry가 V³⁺ → V⁴⁺ → V⁵⁺ 순으로 바뀌는 것을 확인하였다. 위 측정들과 함께 온도에 따른 비저항 측정을 통해서 VO₂의 상전이 특성이 가장 잘 일어나는 박막을 제작하는 조건이 Ar : O₂ = 9 : 1 환경임을 찾아냈다. 또한, 이 결과로부터 기판의 결정성에 무관하게 산화바나듐의 Stoichiometry를 산소가 함유된 플라즈마를 이용해 손쉽게 바꿀 수 있음을 확인하였다.

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Keywords:

VO₂, Plasma, Insulator-Metal transition

Nd_{0.8}Sr_{0.2}NiO₃ film oxygen vacancy through pulsed laser deposition

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Abstract:

Nd_{0.8}Sr_{0.2}NiO₃ is an intermediate step to the infinite-layer superconductor Nd_{0.8}Sr_{0.2}NiO₂. When Nd_{0.8}Sr_{0.2}NiO₃ thin film undergoes an oxygen reduction by exposure to CaH₂ gas, the composition of the film changes to Nd_{0.8}Sr_{0.2}NiO₂ with superconductivity accompanying the structural transition. However, Nd_{0.8}Sr_{0.2}NiO₂ and Nd_{0.8}Sr_{0.2}NiO₃ are vulnerable to oxidation and reduction when placed in air. This is due to the nature of Ni, so controlling this reaction in the two materials is important for understanding nickelate and in future research. The conventional reduction method for Nd_{0.8}Sr_{0.2}NiO₃ and NdNiO₃ is mainly carried out by annealing with different oxygen pressures. Our work induces Nd_{0.8}Sr_{0.2}NiO₃ reduction (oxygen vacancy) through pulsed laser deposition (PLD). Nd_{0.8}Sr_{0.2}NiO₃ was deposited on a SrTiO₃ substrate using PLD, and then another SrTiO₃ film was deposited on it using the same PLD method. At this time, during SrTiO₃ growth, PLD under certain conditions changes the resistivity of the Nd_{0.8}Sr_{0.2}NiO₃ thin film. The resistivity, which used to be like a metal, increases and becomes insulator-like. This is assumed to be due to oxygen vacancy of Nd_{0.8}Sr_{0.2}NiO₃. To confirm this, We measured XRD and XPS.

Keywords:

oxygen vacancy, Nd_{0.8}Sr_{0.2}NiO₃, nickelate, pulsed laser deposition, pld

Realization topological states in bilayer LaNiO₃ buckled honeycomb lattice

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Abstract:

[111] Oriented-transition metal oxide thin films and heterostructures have attracted great interests for their exotic topological states which are not shown in [001] direction. However, there are less experimental studies on these [111] oriented transition metal oxide thin film systems because of their growth and band characterizing difficulties. In this study, we sincerely optimized [111] oriented LaNiO₃ thin film growth condition to get high quality bilayer LaNiO₃. Also, we adopt LaNiO₃/LaAlO₃/LaNiO₃/LaAlO₃ heterostructure to conduct ultra-thin film angle resolved photo emission spectroscopy (ARPES) measurements. It is theoretically predicted that there is quadratic band crossing gamma point where fermi level lies. And strong correlation is anticipated to open topological band gap realizing topological insulator in bilayer LaNiO₃ combined with coulomb interaction. This study will be the first experimental research which realizes topological states in [111] oriented bilayer honeycomb transition metal oxide.

Keywords:

ARPES, Honeycomb lattice, Topological phenomena, transition metal oxide

Growth optimization and atomic polarization mapping of ferroelectric Bi₂WO₆ thin film

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Abstract:

Bi₂WO₆ (BWO) sparked the interest in Aurivillius phase by its simplest structure among Aurivillius phases, with each Bi₂O₂ layers are sandwiched by WO₆ octahedron layers, and robust ferroelectric properties such as high Curie temperature ($T_C \sim 950$ °C) and strong spontaneous polarization (~ 50 $\mu\text{C}/\text{cm}^2$). Most interesting property is that its ferroelectric domains are aligned along only the in-plane (IP) direction, forming 90° degree in total 4 directions. Moreover, ferroelectric domains of BWO can be switched with low energy cost than other conventional ferroelectrics like PbTiO₃, which is essential for realizing electric device applications with low energy demand. Although BWO has these advantages, a systematic study focusing on the growth condition optimization of BWO thin films, and experimental proof of ferroelectric origin is still missing.

Here, we have grown epitaxial BWO thin films on (001)-oriented SrTiO₃ substrates and got growth window using the pulsed laser deposition (PLD), tuning the two most important parameters, oxygen pressure and substrate temperature. Quality of crystal structure and surface of BWO films is confirmed by X-ray diffraction, atomic force microscopy and transmission electron microscopy. Finally, we proved the ferroelectric properties and its origin in our BWO films using piezoresponse force microscopy and scanning transmission electron microscopy. Based on our optimization, we suggest the phase diagram of BWO film growth and W cations dislocation cause ferroelectricity. Our study would contribute to the realization of BWO-based low-energy switching device.

Keywords:

Ferroelectricity, Scanning Transmission Electron Microscopy, Bi₂WO₆, Pulsed Laser Deposition, Piezoresponse Force Microscopy

Angle-resolved photoemission spectroscopy study of a van der Waals triangular antiferromagnetic metal $\text{Co}_{1/3}\text{TaS}_2$

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Abstract:

Layered transition-metal dichalcogenides (TMDs) are well known for rich physical phenomena such as superconductivity, Mott insulating phase, and charge density wave. For some TMDs, more interesting phases can be induced. For example, 3d transition metal ions can intercalate into the gap regions of the layered TMDs to form an ordered structure, inducing a new magnetic/nonmagnetic phase. Recently, a theoretical analysis has been provided that those ordered structures can also induce a magnetic/nonmagnetic topological Weyl semimetallic phase in hexagonal materials. In order to make an experimental example to the proposal, we performed an ARPES study on a vdW triangular antiferromagnetic metal $\text{Co}_{1/3}\text{TaS}_2$. Even though a direct observation of the expected Weyl points in this system was not successful, a relevant electronic structural change in comparison to that of 2H-TaS_2 was measured.

Keywords:

$\text{Co}_{1/3}\text{TaS}_2$, magnetic Weyl semimetal, ARPES

Epitaxial growth and band structure of 2D CoSe

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Abstract:

Two-dimensional (2D) magnetic materials attract escalated attention for their fundamental properties and spintronics applications. Among various 2D magnetic material candidates, such as CrI₃, Fe₃GeTe₂, Cr₂Ge₂Te₆, VSe₂, Cr₂Se₃, and CrTe_x, cobalt selenides (CoSe_x) show several competing phases with various possible magnetic ground states. Tetragonal CoSe phase with anti-PbO structure has been grown on SrTiO₃, in which non-magnetic band structure was understood as a result of substrate-induced strain. It is necessary to prepare the layer on non-interacting substrates in order to confirm the magnetic and electronic phases in the freestanding tetragonal form. On the other hand, hexagonal CoSe phase with NiAs structure has only been theoretically investigated and is expected to have spin-density wave in 2D. However, experimental band structure verification is limitedly available for the freestanding CoSe layers. Here, we prepare freestanding CoSe_x layers on bilayer graphene substrates by using molecular beam epitaxy (MBE) and investigated their band structures by using angle-resolved photoemission spectroscopy (ARPES). We discuss two types of band structures present in the monolayer CoSe_x films depending on the growth parameters.

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Keywords:

Cobalt selenide, ferromagnetism, antiferromagnetism, Molecular beam epitaxy, Angle-Resolved photoemission spectroscopy

strange metamagnetic transition of Weyl semimetal candidate NdAlGe

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Abstract:

Sophisticated form of magnetocaloric effect(MCE) of NdAlGe, affected from the strong and unique magnetic anisotropy and metamagnetic transition in itself was measured.

First synthesis of single crystal of NdAlGe was done successfully, showing concrete tetragonal I4₁md that has inversion symmetry breaking(IS breaking), slightly different from I4₁/amd.

Magnetic property of single crystal NdAlGe has ferromagnetism(FM) with metamagnetic transition of FM to FM along the c axis and stubborn antiferromagnetism(AFM) along the a axis, displaying clear anisotropy of intrinsic magnetism.

In addition, calculation of entropy change(ΔS) shows -13.80 J/kgK at 7 K, induced magnetic field 50 kOe along the c and 2.64 J/kgK at 5 K, 50 kOe along the a axis, proposing clear anisotropy between conventional MCE(CMCE) and inverse MCE(IMCE) with chance of utilization of NdAlGe as a candidate of rotating MCE(RMCE).

Lastly, CMCE from FM shows complex change of order of magnetic transition from anisotropic metamagnetic transition, different with former reported PrAlGe.

Keywords:

Weyl semimetal, RAlGe, NdAlGe, metamagnetic transition

Temperature dependent Raman spectroscopic study of Methylammonium Lead Bromide (MAPbBr₃)

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Abstract:

Organic-inorganic halide perovskites (OIHP) have emerged as a fascinating material for photovoltaic applications [1], [2]. Over the last decade, a remarkable increase has been seen in the solar cell efficiency of the perovskite based solar cells up to 25.5% as of early 2021 [3]. OIHPs have a low-cost synthesis route, high charge carrier lifetime and tunable bandgaps which makes them an attractive material for photovoltaic applications [4], [5]. In this study, single crystals of OIHPs MAPbBr₃ were synthesized and investigated by Raman spectroscopy. The laser wavelength used was 633nm to avoid any degradation effect and the frequency range was 200-3500 cm⁻¹. Raman spectra were recorded in a wide temperature range from room temperature to -190°C. The Raman shifts were plotted as a function of temperature in the intensity plot as shown in figure 1. MAPbBr₃ undergoes three phase transitions that are from cubic to tetragonal I at -37°C, tetragonal I to tetragonal II at -119°C and tetragonal II to orthorhombic at -125°C. In our results, noticeable anomalies were seen only for the tetragonal II to orthorhombic transition. The tetragonal phase needs to be investigated in more detail as it was stable for a short temperature range.

Keywords:

raman, perovskite, spectroscopy

Phase transitions of APbBr₃ (A=Cs, MA, FA) probed through temperature-dependent Raman spectroscopy

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Abstract:

Halide perovskites have emerged as a star material in the photovoltaic industry due to their intriguing features, especially in solar cells, where a ~25.5% power conversion efficiency has been achieved [1]. Halide perovskites have become a widely researched area due to their high photovoltaic efficiency and ease of fabrication. They consist of ABX₃ common structure where MA, FA, or Cs occupy a site; B site is occupied by Pb, and X site by halogens such as Cl, Br, and I. Owing to the fact that halide perovskites have high compositional flexibility, several compositions of these materials are being explored [2]. They appear in different phases at room temperature, and the phase transitions are affected by the change of A site or X site ions. In this study, we synthesized three halide perovskites, CsPbBr₃, FAPbBr₃, and MAPbBr₃, with different A-site cations and a fixed X site Br anion. We employed Raman spectroscopy to study the phase transitions behaviors in these materials. FAPbBr₃ and CsPbBr₃ exist in three phases cubic, tetragonal, and orthorhombic, while in MAPbBr₃, other than cubic and orthorhombic phase, two tetragonal phases I and II exist. Raman spectra of all materials show a significant change in the orthorhombic phase and number of resolved mode also increase due to symmetry breaking. Further fitting analysis of all Raman spectra will reveal more details about the exact phase transitions temperatures.

Keywords:

perovskite, Raman spectroscopy, Phase transitions

Ultrafast resonant X-ray scattering investigation of non-thermal melting using XFELs

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Abstract:

Ultrafast melting transitions in noble metals and semiconductors irradiated by femtosecond IR laser have been reported with signatures of lattice disorder in less than a picosecond timescale, which is faster than electron-phonon energy transfer rates. With this mysteriously fast reaction of crystal lattice, the interest in unveiling the fundamental energy transfer mechanism has been intense with extensive research effort using ultrafast electron diffraction, time resolved X-ray diffraction, etc. By employing time-resolved resonant X-ray scattering, we have investigated the ultrafast lattice melting with femtosecond IR laser irradiation synchronized to the X-ray laser pulses from PAL-XFEL. Experimental evidence on the electron transition driven lattice disorder has been obtained, supporting the bond softening explanation on the nonthermal melting in covalent bonding crystals. IR laser fluence dependence of the melting time and MD calculations suggest essential role of electrons in bonding orbitals in causing the crystal melting and from thermal to nonthermal melting transition and interesting perspective on ultrafast disordering phenomena.

Keywords:

Ultrafast melting, Resonant X-ray Scattering, X-ray Free Electron Laser

Calculations using Monte Carlo simulations of the beam quality correction factor in the plateau region of single-energy proton beams.

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Abstract:

In proton radiotherapy, k_Q is a factor which corrects for the difference in physical properties between the reference beam quality, ^{60}Co gamma radiation, used for the calibration of the ionization chamber, and the user beam quality used for patient treatment. The k_Q factor for a proton beam as suggested in the current dosimetry protocol was calculated on the premise that it is applied to the SOBP (Spread Out Bragg Peak). Thus, it cannot be applied to the plateau region of a proton beam. In this study, the beam quality correction factor was calculated in the plateau region of a single-energy proton beam by using Monte Carlo simulations. We used TOPAS to perform simulations of a beam nozzle from the NCC (National Cancer Center) to irradiate a water phantom with a proton beam with a range of 28 g cm^{-2} . By simulating the dose absorbed by water and the measurement value of the ionization chamber, the beam quality correction factor was calculated at various locations in the plateau region.

Keywords:

Proton Radiotherapy, Monte Carlo simulations, k_Q factor

Synthesis of Ce^{3+} -ions doped Lithium Phosphate Glass for Radiation Scintillation

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Abstract:

The application of glasses for radiation detection is in search for a long due to its sustainability, rigidness in harsh weather along with cost-effective fabrication process. However, it is always a difficult venture to apply such compound for radiation detection due to its low luminescence ability and non-homogeneous structure. However, Ce^{3+} doped phosphate glasses have widely been studied so far that efforts reasonable luminescence ability. In present experiment we have fabricated $32Li_2O:(48-x)P_2O_5:10GdI_3:5Ca_2CO_3:5Al_2O_3:xCeBr_3$ ($x = 1, 2, 3$) glasses with conventional melt quenching technique. The luminescence of sample glasses has been characterized by X-ray and UV excitations. The glass samples have been applied for α -particles and γ -ray detection experiments under ^{241}Am , ^{22}Na , and ^{137}Cs sources. The complete report will be presented in the presentation.

Keywords:

Glass, Scintillation, Phosphate, Radiation, Luminescence

Gamma energy spectrum measurement using silicon photomultiplier with $\text{Ti}_2\text{LaCl}_5:\text{Ce}^{3+}$ scintillator

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Abstract:

Silicon photomultiplier (SiPM) is a single photon detector from operation in Geiger mode and also have multiplication factor of 10^5 to 10^6 . In a radiation detection, it is important to measure the incident radiation energy quantitatively and SiPM can be used for energy calibration from single photon energy measurement.

In this study, we measure the gamma energy spectrum of various radioactive sources by using SiPM with a new crystal $\text{Ti}_2\text{LaCl}_5:\text{Ce}^{3+}$ which has high detection efficiency for gamma energy. We report our experiment results and discuss a possibility of utilizing SiPM compared with $\text{Ti}_2\text{LaCl}_5:\text{Ce}^{3+}$ crystal for radiation monitoring.

Keywords:

SiPM, Energy Spectrum, Scintillator, $\text{Ti}_2\text{LaCl}_5:\text{Ce}^{3+}$

Characterization of silicon-based alpha detectors for mono-energy neutron fields

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Abstract:

Accelerator-based deuterium-deuterium (DD) and deuterium-tritium (DT) neutron generators are well-known mono-energy neutron sources. Both reactions produce alpha particles and neutrons, satisfying two-body kinematics and conservation of energy and momentum. Therefore, measurement of produced alpha particles is an important technique to confirm the generation of mono-energy neutrons and to achieve accurate neutron energy and fluence measurements. Silicon pin diode and silicon surface barrier detectors (SSD) are silicon-based detectors with high efficiency for alpha particles. In this study, the characteristics of two silicon-based detectors were comparatively analyzed and optimization studies were performed. This result will be utilized for monitoring mono-energy neutron fields and various development studies.

Keywords:

neutron, silicon surface barrier detector, silicon pin diode

Fast neutron imaging for air cargo inspection

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Abstract:

Korea Atomic Research Institute (KAERI) has been developed the fast neutron imaging system for air cargo inspection. This system is consist of D-T generator, fast neutron detector array modules, and air cargo moving transfer. The D-T generator emitted the fast neutrons with 14.1 MeV in energy and 2×10^9 n/s. The fast neutron detector modules are the plastic scintillator based photon counter circuits. They are installed vertically to image the container box in size of about $1.5 \times 1.5 \times 1.5$ m³. The neutron signals are analyzed with pulse shape discrimination algorithm. The neutron image is reconstructed from the data processing. The neutron imaging experiments collected the neutron transmission intensities for various materials to distinguish inspecting package in air cargo container. In this study, we report the fast neutron imaging system for the security inspector providing the material discrimination.

Keywords:

neutron, D-T generator, neutron imaging, air cargo inspection, material discrimination

Development of the Bi-Alkali Photocathode

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Abstract:

Among today's modern photosensitive devices, the photomultiplier tube (PMT) is a versatile device with low noise, ultra-fast response, and high sensitivity. It has the ability to detect photons at an extremely low light level, such as single photon counting. The photocathode's quantum efficiency (QE) is one of the most significant features of the PMT. Among all other photocathodes, a bi-alkali photocathode is one of the most frequent types of photocathode that is widely employed in particle physics experiments because of its higher sensitivity and lower dark current than other types of photocathodes. By controlling the photocathode activation time, the QE reaches as high as 43% at peak wavelength and it was named Ultra Bi-Alkali and was incorporated in the PMTs successfully. Therefore, they are ideal for photodetectors such as PMT, hybrid PMTs, and image intensifier tubes. Moreover, these vacuum-tube types of photocathode required vacuum-tight seals for both vacuum and electrical connection for the fabrication of bi-alkali photocathode. To create the Ultra-High Vacuum (UHV), the vacuum tube which houses the internal structure (equipped with an anode, ground, Alkali Metal Dispensers (AMD), and antimony beads) for photocathode deposition is further connected to the UHV pump system. Hereby, we will present the prototype of the vacuum type of photocathode with the internal structure, Glass Metal seals for electrical connection to the various electrical sources, and vacuum connection to the UHV pump system.

Keywords:

Bi-Alkali Photocathode, Internal structure, Glass Metal seal, Vacuum & electrical connection, UHV system

Study of the temperature dependence of $\text{Cs}_3\text{Cu}_2\text{I}_5$ scintillation properties

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Abstract:

A $\text{Cs}_3\text{Cu}_2\text{I}_5$ crystal shows good performance of scintillation properties at room temperature. At room temperature, the $\text{Cs}_3\text{Cu}_2\text{I}_5$ scintillator has the high light yield and good pulse shape discrimination. Besides this crystal can be grown in bulk size with the reasonable cost from compound of CsI - CuI powders. These suggest that this crystal can be applied not only for the radiation measurement, but also for the study of nuclear and ion beam physics. The $\text{Cs}_3\text{Cu}_2\text{I}_5$ crystal can also be candidate for the search of dark matter. With the development of cryogenic detector, it provides strong motivation for study and optimization of this crystal at low temperature. In this work, the performance of $\text{Cs}_3\text{Cu}_2\text{I}_5$ scintillation crystal will be investigated over the 10-300 K temperature range. The temperature dependence of light output and decay time will be reported. For the measurement, the crystal was synthesized and grown by using a Bridgman technique. The pulse signals were recorded by the Photonis XP2260 coupled to the 500-MHz NKFADC Notice Korea.

Keywords:

$\text{Cs}_3\text{Cu}_2\text{I}_5$ crystal, low temperature, scintillation, Bridgman crystal growth

Fabrication of Silver Metal Photocathode and Measurement of DC & Pulsed Photocurrents

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Abstract:

A photocathode is an electrode kept at a negative voltage that emits electrons when activated by light or other radiation. The photocathode is an essential element of all vacuum-tube-type photodetectors such as photomultiplier tubes and hybrid photo-diodes. Photocathodes are used in a photo-injector to generate high-brightness electron beams, which are vital in accelerator physics as well as in a free-electron laser accelerator (FEL), where electron source is one of the key components. Photocathode materials are either metals or compound semiconductors. Metal photocathodes are very robust and have a fast response time. They are easy to fabricate and are stable in air for a short period of time, but their quantum efficiency is extremely low like 10^{-6} or 10^{-7} . On the other hand, the compound semiconductor photocathodes like bi-alkali or multi-alkali photocathodes have very good quantum efficiency. However, the fabrication of these photocathodes is difficult, and it needs an ultra-high vacuum. This poster presentation will focus on the fabrication of the silver metal photocathode and its characterization. We will present the photocurrent measurement in dc mode using a pico-ammeter with high power 250 nm LED and the quantum efficiency calculation in dc mode. In addition, we will also present a technique to measure the pulsed photocurrent using a pulse laser

Keywords:

photocathode, quantum efficiency, dc photocurrent, pulsed photocurrent

Noise characterization of a photodiode and an avalanche photodiode for absolute light yield measurement of perovskite crystal at low temperature

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Abstract:

It is important to reduce the thermal noise which can significantly impact the detection of relatively low-intensity light of scintillators in direct dark matter searches. We need high number of scintillation photons per unit energy deposited at low temperature for this purpose, but established scintillators do not exhibit dramatically improved performance with decreased temperature. Since perovskite crystal has excellent scintillation properties in terms of signal output and fast response, it is considered as a good candidate for dark matter searches. There have been many scintillation characterization experiments of perovskite at low temperature, but the absolute light yield measurement of perovskite crystal using a semiconductor detector has not been studied. We study the dependence on the dark current and noise characteristic on temperature of a photodiode and an avalanche photodiode by varying the temperature from 4 K to 300 K in the cryostat. The thermal noise of semiconductors and the electron mobility are decreased as temperature. We investigate at which temperature the electrical characterization of detectors has the best performance. We report our test results and discuss the feasibility of utilizing low temperature semiconductor detectors in combination with perovskite crystal.

Keywords:

Photodiode, Avalanche photodiode, Noise characterization, Low temperature

Ac228 isomers measurement by using GAGG:Ce crystal

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Abstract:

Recently the COISNE-100 experiment observed new isomers in Ac228 at 6.28keV and 20.19keV. In this study, we measure these isomers in Ac228 by using two GAGG:Ce (Cerium doped Gadolinium Aluminum gallium garnet) crystal scintillators with a coincidence method. The Ac228 is produced by beta decay of Ra228. Due to all beta decays from Ra228 to Ac228, gamma rays are always come out with beta particles. So, we use coincidence measurement. For this measurement, we cut TPS GAGG in 1.5cm x 1.5cm x 0.3cm size and polish them well to make 2 pieces. We deposited the Ra228 source on only one of the two, put a thin reflector in between, and glued the wide sides together. And then it was measured by combining two R6231-100 PMTs (PhotoMultiplier Tubes) on both sides, respectively. I will present a preliminary measurement of Ac228 isomer decay.

Keywords:

Scintillator, GAGG:Ce, Ra228, Ac228

The effect of varying Gd on phosphate-lithium-gadolinium-aluminium-cerium doped glasses for scintillation purpose

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Abstract:

A glass samples of the formula $62\text{P}_2\text{O}_5: 20\text{Li}_2\text{CO}_3: 10\text{X}: 5\text{Al}_2\text{O}_3: 3\text{CeBr}_3$ where X is the varying Gd effect of Gd_2O_3 , GdF_3 , GdCl_3 , GdBr_3 and GdI_3 were fabricated by adopting the conventional melt quenching technique. The amorphous structure of the glass samples was studied by using PXRD measurements. The emission spectra of these glass samples were obtained from X-ray and UV-Vis excitation sources. The decay time was measured under UV, ^{241}Am and ^{137}Cs excitation sources. The scintillation property was studied with ^{241}Am , and clear alpha peak was observed. The transmittance, density, and refractive index of the fabricated glass samples were also measured. We will report the results of the prepared glass samples in this meeting

Keywords:

Phosphate Glass, Gadolinium, Luminescence, Scintillation, Decay time

Neutron shields for AMoRE-II

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Abstract:

The second phase of Advanced Molybdenum-based Rare process Experiment (AMoRE-II) is a final experimental setup for the research of neutrino less double beta decay of ^{100}Mo in Center for Underground Physics (CUP). Because it is a rare decay process, low background level in the region of interest around 3034 keV is required as 10^{-5} count/kg/keV/year. Neutron is one of the background source candidates due to its reaction with the experimental materials in the AMoRE-II detector, such as copper and iron. The reaction can generate gamma having high energy up to 7.9 MeV. To prevent the reaction, neutron shields will be installed in the AMoRE-II detector setup. In this poster, the production of neutron shields and their performance for shielding efficiency will be presented.

Keywords:

Neutron shields, Neutrinoless double beta decay, Rare decay experiments

Characteristics Study of Radiation Detector Using Perovskite Nanocrystals

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Abstract:

Nanocrystals have attracted attention as radiation detectors with tunable emission spectra, large stock-shift, and high atomic numbers. Recently, various studies have been carried out with radiation detectors using perovskite single crystal as well as perovskite nanocrystals. In contrast to conventional single crystals, perovskite nanocrystals are powder type. Therefore, an additional process is required to use it as a scintillator. In this study, a research method for synthesizing MAPbBr₃ nanocrystals in a polymer at a high concentration is presented. We show the results of luminescence characteristics, XRD, absorbance, etc. as a basic characterization analysis, and further show the results of x-ray induced photoluminescence for characterization as a radiation detector. These results suggest the possibility of application as a radiation detector using perovskite nanocrystals.

This research was supported by Nano-Material Technology Development Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and Future Planning. (2020R1A6A3A01099805 and 2009-0082580)

Keywords:

Perovskite, Radiation detector, Nanocrystals

Geant4 simulation for the design of KAPAE phase II detector

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Abstract:

KNU Advanced Positronium Annihilation Experiment (KAPAE) aims to detect visible rare positronium decay and search for invisible decay such as milli-charged particle, mirror world, new light X-boson, and Extra dimensions. The KAPAE phase 1 is designed with $7.5 \times 7.5 \times 150 \text{ mm}^3$ 196 BGO crystals by 14×14 arrays and has a high angular resolution for detecting visible decay from CPT violation. The aim of the KAPAE phase II will be designed to increase the sensitivity of invisible decay. The detector size will be increased, and the dead area will be minimized to observe the invisible decay by comprising of 38 BGO crystals which are hexagonal prisms of an internal diameter of 5.4 cm and a height of 30 cm. In this study, we investigate the invisible decay by selecting the background event which is not fully deposited to the BGO crystal. The detector configuration is simulated by the Geant4 simulation toolkit. We will report the upper limit of invisible para-positronium decay sensitivity of 90% confidence level from the simulation result.

Keywords:

positronium, annihilation, KAPAE, BGO

Proton response of a 1.5-inch EJ-276 plastic scintillator

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Abstract:

EJ-276 plastic scintillator has been using for neutron detection due to the good neutron-gamma pulse shape discrimination and several advantages such as robustness, non-toxicity and non-flammability. In this hydrogenous material, neutrons are detected through elastic scattering and therefore, unfolding are usually required to obtain the energy distribution of incident neutrons. The unfolding of neutron spectrum requires prior understanding of detector characterization, particularly the proton response of the detector. In this study, we measured the proton response of a 1.5-inch EJ-276 plastic scintillator. The experiment was performed at Korea Institute of Radiological and Medical Sciences (KIRAMS) using 45 MeV proton beams. Different thickness Aluminum degraders were used to achieve various beam energy levels. The results were calibrated with gamma source for different energy response of EJ-276.

Keywords:

EJ-276 plastic scintillator, proton beam, response function, proton quenching

The Dose Distribution of 6He Ion Beam

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Abstract:

In this study, we evaluated the dose distribution of 6He ion beam with the comparison of 4He ion beam under the same irradiation condition by using the Monte Carlo method. For details, we defined a water phantom that includes three normal volumes and one target volume, as well as 6He and 4He ion beams. Then the dose depositions and tracks of the ion beams and secondary radiations are calculated. Through comparing the dose distributions of 6He and 4He ion beams. It can be found that the dose distribution of 6He ion beam is similar with that of 4He. However, considering the decay and the relatively biological effect, the 6He ion has its advantages in some conditions.

Keywords:

Dose Distribution, 6He Ion Beam, Simulation

The radiative proton capture on ^{15}N with effective field theory

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Abstract:

The CNO cycle is one of the hydrogen-burning processes whose end product is ^4He , the source of the triple- α process. The radiative proton capture on ^{15}N reaction, $^{15}\text{N}(p, \gamma)^{16}\text{O}$, is the leading process that gives a path from the CN cycle to the NO cycle and, therefore, further types of the CNO cycle. In the present work, we study the $^{15}\text{N}(p, \gamma)^{16}\text{O}$ reaction in effective field theory. We construct the effective Lagrangian appropriate for this reaction at stellar energies and calculate the astrophysical S-factor. Furthermore, we determine the low-energy constants, resonance energies, and widths by fitting the empirical data of the S-factor at the range of $338 \text{ keV} < E_p < 1028 \text{ keV}$. Based on the obtained values of the parameters, we report an S-factor value for this reaction at extremely low energy, $S(E=0)$, and compare the results with that of the previous studies.

Keywords:

Nuclear reaction, Effective field theory, Astrophysical S-factor

Calculation of the energy spectra and electromagnetic transitions of radon's progeny using the IBM

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Abstract:

In order to understand the lung cancer-causing mechanism of radon progeny, research on the chemical properties of radon and its progeny must be conducted simultaneously. Therefore, this study aims to calculate the nuclear structure and properties of radon progeny produced during the decay of uranium and thorium present in nature. To this end, the basis state and matrix element calculations of radon and progeny should be made using a suitable nuclear model, which will calculate the energy spectra and electromagnetic transitions of radon and its progeny. This is because exploiting this physical measurable amount is theoretically the best way to identify radon's nuclear structure. Collective low-lying states are described in radon's progeny within the framework of the model proposed by Iachello, whose symmetries are $U(5)$, $SU(3)$ and $O(6)$. The predicted theoretical results for energy spectra and $B(E2)$ values of low-lying states of the radon's progeny are compared with experimental data.

Keywords:

radon, radon'progeny, IBM, IBM-2

Describe the Ridge structure in high-multiplicity pp collision at $\sqrt{s_{NN}}=13$ TeV in ALICE via Momentum-Kick model

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Abstract:

The momentum-kick model is a phenomenological model that explicates ridge structure in high-multiplicity pp collision. The momentum-kick model assumes the state in which the leading jets kick the momentum of partons in the medium. This model can be applied not only to heavy ion collisions, but also to relatively small systems such as proton-proton collisions. Momentum transfer is a suitable concept for explaining the appearance of ridge structures in high-multiplicity pp collisions. In this study, the model applied to Au-Au $\sqrt{s_{NN}}=0.2$ TeV data of STAR at RHIC was extended to recent data of high-multiplicity pp $\sqrt{s_{NN}}=13$ TeV of ALICE and CMS at LHC. And using the parameters that reproduce the p_T distribution and $\Delta\eta$ - $\Delta\phi$ correlation, we can examine the state of the medium.

Keywords:

Near- and far-field analysis in metallic nano-structures induced by femtosecond laser pulses

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Abstract:

Interaction of metallic nano-structures with a laser field induces the generation of surface plasmon, modifying the shape of the electric near-field and spectral absorption spectra in the far-field. In this work, the Maxwell's equation was numerically solved using finite-difference-in-time-domain method in an array of gold nano-structures. The near- and far-field spectra are compared and analyzed using a simple theoretical spring-mass model.

Keywords:

surface plasmon, femtosecond laser, resonance, non-linear optics, ultrafast optics

Chiral Emission of Classical Rays in an Asymmetric Microcavity

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Abstract:

In a microcavity, chiral resonance modes have attracted much attention in relation with exceptional points (EPs). The chiral EP mode can be found when a mirror-symmetric microcavity is perturbed to induce non-Hermitian coupling of two modes (an even and an odd mode)[1,2,3]. However, even when an external perturbation is applied, chiral emission of classical rays can not be found in a symmetric cavity. In an asymmetric microcavity such as a spiral shape, classical rays exhibit chiral emission due to its typical shape having a notch[4,5]. However, when the boundary is smoothly connected to satisfy $C(1)$ continuity, it is hard to find highly chiral emissions in classical rays even in an asymmetric cavity. To study the classical chiral emission in an asymmetric microcavity, we consider a microcavity comprised of one half-ellipse and two quarter-ellipses, whose shape satisfies $C(1)$ continuity. By controlling the aspect ratios of the three different ellipses, classical chirality is investigated. According to the deformation parameters, highly chiral CW and CCW emissions are found. The phenomenon of chiral emission is analyzed in the phase space of Birkhoff coordinate.

References

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Keywords:

Chirality, Asymmetric Microcavity, Ray Dynamics

A development of Confocal photoluminescence spectroscopy imaging system for observing local luminescent characteristics of Perovskite materials

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Abstract:

Perovskite is a material that attracts attention in various photoelectric elements and solar cells. This material is composed by organic molecules, metals and halogen elements and has the characteristic of converting energy into light energy. It is a material that can also be used as an LED light emitter with high luminous efficiency. The challenge using perovskite to those light harvesting or lighting is to ensure the homogeneity of the material, because the current fabrication techniques only available to grow small scale structure [ref]. Hence, inspecting such inhomogeneity, those methods which can resolve the local energetic or structural variations.

PL spectroscopy (Photo Luminescence Spectroscopy) is widely applied to examine the characteristics, especially the internal energetic structure, of the perovskite materials. However, the conventional PL methods are unable to supply spatially resolved information, it is required to adapt confocal microscopic techniques. By doing this, it is available to obtain PL image with high spatial resolution, which helps us to examine the inhomogeneity of the perovskite samples and may provide an idea to develop an improved synthesis process to obtain higher uniformity.

We demonstrate in this research how to construct the PL imaging system based on the home-made confocal microscope system. Additionally, we also provide PL imaging and correspond spectra for representative perovskite material of MAPbCl₃. position.

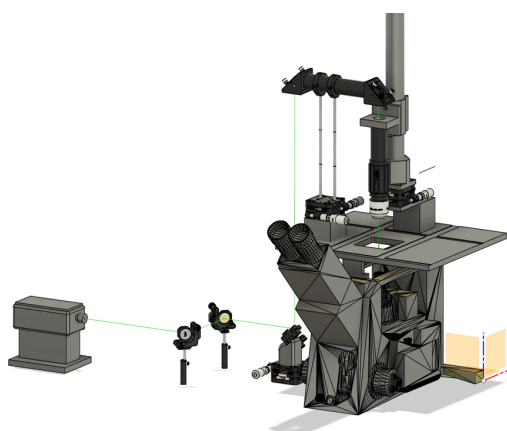


fig1. Confocal photoluminescence spectroscopy design image

Keywords:

confocal microscopy, perovskite, photoluminescence, imaging

Analysis of the Terahertz Response of Red Lead Pigment by Terahertz Spectroscopy

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Abstract:

Terahertz spectroscopy is a useful tool as a non-destructive analysis method for pigments in paintings. For identification of various pigments, we need their terahertz spectral features. Red Lead (Minium, Pb_3O_4) is one of the earliest red color pigments that have been widely used in traditional painting not only in Korea but also in other Asian countries. We measured the spectra of Red Lead pigment in polyethylene-mixed form and in oil color free-standing form by using terahertz time-domain spectroscopy. Four peaks were found in the frequency range of 50 to 90 cm^{-1} . These results can be employed to analyze red pigments in actual paintings.

Keywords:

Terahertz spectroscopy, Pigment, Red lead, Minium

Terahertz Time-domain Spectroscopy of Vermilion Pigments

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Abstract:

Terahertz time-domain spectroscopy is a well-established analytic technique for studying artworks. We conduct a terahertz study on vermilion pigments in free-standing oil-paint form at room temperature to analyze its terahertz spectroscopic characteristics. We also performed low-temperature measurements on vermilion pigments mixed with polyethylene powder in order to identify the existence of the much-disputed low-frequency double peaks. As the temperature increases, the three major absorption peaks of vermilion redshift monotonically [1]. Our results will be useful to non-destructive, non-contact analysis of cultural heritage materials.

Reference

[1] J. E. Lee, et al. ACS Omega 6(21), 13802 (2021)

Keywords:

vermilion, terahertz spectroscopy, pigments

Spectroscopic investigation of electrical conductivity of biochar

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Abstract:

Conducting characteristics of biochar derived from the pyrolysis of paper has been studied by terahertz time-domain spectroscopy (THz-TDS), energy-dispersive X-ray spectroscopy (EDS), Fourier-transform infrared spectroscopy (FT-IR), Raman spectroscopy, X-ray diffraction (XRD), and X-ray photoelectron spectroscopy (XPS).

The terahertz electrical conductivity of biochar was obtained by THz-TDS with numerical calculation. The terahertz conductivity increased exponentially with increasing annealing temperature. The electrical conductivity increased significantly to the order of 10^2 S/m as the annealing temperature increased up to 800 °C.

By harnessing structural analysis, the origin of the conductivity enhancement was revealed. It was confirmed that more graphitic biochars were produced at higher temperatures. Therefore, our results showed that the pyrolysis of celluloses and the crystallization of carbon elements were the origins of the conductivity enhancement.

Keywords:

biochar, terahertz time-domain spectroscopy

Active THz transmission modulators using organic/metamaterial/silicon hybrid structures

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Abstract:

In this study, we demonstrate frequency-selective terahertz (THz) filters that can be actively controlled by an optical method, by employing the three-layer structure consisting of phenyl-C61-Butyric acid methyl ester (PCBM), metamaterials, and silicon. Here, the metamaterial, fabricated based on split-ring metal resonators, gives frequency-selective features and the PCBM/silicon bilayer structure enables active control of THz wave transmission by optical laser beams that generate photo-excited carriers on the silicon substrate. The photo-excited electrons and holes are transported and separated at the interface of the PCBM and silicon, making the organic layer more metallic. In addition, the change in charge carrier density due to the charge separation was quantitatively analyzed through simulations using Comsol Multiphysics program based on finite element method (FEM) for solving Maxwell's equations. The findings may be useful for achieving actively controllable THz multifunctional devices or for studying the real-time charge carrier properties in organic-based multilayer structures.

Keywords:

Terahertz spectroscopy, Metamaterials, Modulators, Active optics

Optimal conditions for maximizing fluorescence and photothermal effects of indocyanine green

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Abstract:

Indocyanine Green(ICG) is a cyanine dye used primarily in angiography based on fluorescence effects. In addition, it can damage human cells and tissues with photothermal effects, which is highly utilized for medical diagnostics and medical therapy. ICG is harmless to the human body and is approved by the FDA, but high concentrations and precipitate can have a bad effect on the human body. This study sought to systematically understand the photothermal effect and fluorescence properties of ICG at lower concentrations than previously used standards. We simultaneously measured the intensity properties of fluorescence and the temperature changes caused by the photothermal effect by varying various conditions such as laser power density, laser irradiation wavelength, exposure time of laser irradiation, and concentration of ICG solutions. The optimal conditions for maximizing fluorescence and photothermal effects are ICG concentration of 50 $\mu\text{m}/\text{ml}$ and laser power density of 1.5 W/cm^2 . Optimal conditions mean that stable, high-intensity fluorescence lasts a long time and the temperature induced by the photothermal effect is sufficient to damage human cells and tissues. The results of this study provide basic data to enable real-time treatment monitoring based on angiography.

Keywords:

Indocyanine green, ICG, Fluorescence, Photothermal

Design of a Cylindrical Telecentric f - θ Lens for Optical Pulse Shapers with 20 GHz Resolution

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Abstract:

We present a design of a cylindrical telecentric f - θ lens that improves a field curvature and a distortion to mitigate a channel cross talk for an optical pulse shaper, which can resolve 20 GHz at C -band.

Keywords:

pulse shaper, telecentric f - θ lens, lens design

SESAM Modelocked pulse laser generation with diode-pumped Yb:KGW crystal

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Abstract:

In prior work, we fabricated a CW laser system using Yb:KGW as a gain media. The gain crystal is ytterbium doped potassium gadolinium tungstate(Yb:KGW) at 1.5% doping rate, and it was cut in 1.2x1.5x8 mm cuboid structure at Ng,Np,Nm axis, respectively. Pumping diode laser made CW light which delivered into the cavity via an optical fiber with output-power up to 27 W and wavelength centered at 976 nm. After then, We had studied and fabricated a passive modelocking system using semiconductor saturable absorber mirror (SESAM) in this work. SESAM-modelocked lasers are well known for its convinient property of self-starting pulse generation.

Keywords:

Pulse-laser, Modelock, SESAM, Yb:KGW

대구경 Fresnel Lens 설계에 관한 연구 (Design of large-diameter Fresnel Lens)

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Abstract:

대구경 Fresnel lens는 초기에 등대등으로 개발되었으나 금형 가공 및 사출 기술의 발달에 따라 다양한 용도와 형태로 사용되고 있다. 일반적으로 Fresnel lens 광학계는 광원에서 발산하는 광속을 시준하여 최대한 멀리 전달하는 목적으로 사용하고, 광학계의 부피를 줄이기 위하여 광학재질, 초점거리, groove 개수 (zone 개수) 및 기울기 등의 여러 광학요소들에 의해 성능이 좌우되는 특수한 용도의 조명용 광학계이다. 이와같이 대구경 Fresnel 광학계의 설계는 근축광학 이론을 이용하여 해석적인 방법으로 각 sag별 광학적 요소를 독립적인 단일 렌즈의 일부분으로 설정하여 각각의 구속조건을 만족하도록 설계변수를 결정하고, 광원의 중심에 대하여 전체가 시준 빔(collimation beam)이 되도록 최적화 설계를 한다.

Keywords:

Lens Design, Fresnel lens, 대구경 광학계

시뮬레이션을 통한 UV LED 광원의 살균효과 분석 (Analysis of sterilization effect of UV LED light source)

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Abstract:

최근들어 COVID-19로 인하여 UV LED(Ultra Violet Light Emitting Diode) 광원을 이용한 응용 연구가 급속히 진행되고 있다. UV광원이 갖는 양자 효율과 세포분열의 비 활성화 효과로 인한 유해균에 대한 살균력을 공간적인 분포와 시간적인 관계성을 simulation을 통하여 알아보고 최적의 조건을 도출하였다.

Keywords:

UV LED, 살균효과, 시뮬레이션

디스퍼시오렌지 3 색소가 첨가된 PMMA에서의 위상공액파 발생 특성

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Abstract:

디스퍼시오렌지 3색소가 첨가된 PMMA부피시료와 박막에 선편광된 광을 쪼여 축퇴4광파혼합에 의한 위상공액파를 생성하였다. 비공명흡수대의 파장633 nm에서 위상공액파는 최고 반사율 1.8%로 측정되었고, 광여기에 의한 각재분포(angular redistribution)에 따르는 굴절률 변조가 위상공액파의 시간적 거동을 주도하였고 홀로그램 기록에 의한 효과가 중첩되어 나타났다. 공명흡수대의 파장 476 nm에서 위상공액파는 최고 반사율 0.03%로 측정되었고, 광흡수 변조가 위상공액파의 시간적 거동을 주도하였다. 공명흡수대 476 nm에서는 위상공액파의 세기가 탐사광의 편광각과 펄스광의 편광각에 대하여 사인제곱함수로 측정되어 각홀버닝(angular hole burning) 효과를 확인하였다.

Keywords:

위상공액파, 디스퍼시오렌지 3, 각재분포, 각홀버닝

Enhancing noise-robustness of single-pixel imaging with pulsed illumination

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Abstract:

Quantum imaging employs non-classical properties of light to obtain an image with a higher resolution and signal-to-noise ratio. In this work, we imitate the concept of noise rejection in quantum imaging and experimentally demonstrate a noise-robust imaging method, which is classically achievable with a simple implementation. In noisy environments where the noise intensity is up to 120 times brighter than the signal intensity, we compare target images obtained by three different imaging methods: classical, quantum, and classically enhanced imaging. We demonstrate that the proposed classically enhanced imaging scheme shows a remarkable noise-robustness which is comparable to quantum imaging under a stationary noise condition. This work provides more efficient imaging strategies to various real-world scenarios.

Keywords:

single-pixel imaging, quantum imaging, correlation-based enhancement

Synthesis and luminescence characterization of rare earth ions Tb^{3+} doped in $Sr_9La_{1-x}(PO_4)_7$ phosphors

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Abstract:

The synthesized samples of $Sr_9La(PO_4)_7: xTb^{3+}$ were obtained by the substitution of Tb for La in the $Sr_9La(PO_4)_7$ host. From the XRD pattern analysis, it was confirmed that these obtained samples changed from the rhombohedral (space group $R\bar{3}m$) to the monoclinic (space group $I2/a$) with an increase of the x value. To obtain changed crystal structure information, the Rietveld refinement and high-resolution transmission electron microscope (HRTEM) of $Sr_9La(PO_4)_7: xTb^{3+}$ ($x= 0, 1$) were performed. It was found that $Sr_9La_{1-x}(PO_4)_7: xTb^{3+}$ phosphors have a broad excitation band at the 200–300 nm region due to the $4f^8 \rightarrow 4f^7 5d^1$ transitions of Tb^{3+} ions. Under the excitation of 376 nm, Tb^{3+} -doped $Sr_9La(PO_4)_7$ shows green emission with a main peak at 542 nm. The optimum concentration of Tb^{3+} -doped in $Sr_9La(PO_4)_7$ reaches 100 mol%. It demonstrates that concentration quenching did not occur, and the decay time of the $Sr_9La(PO_4)_7: Tb^{3+}$ phosphor increased from 2204 to 4062 μs . It indicates that $Sr_9La(PO_4)_7: Tb^{3+}$ could be a potential candidate as a green-emitting phosphor.

Keywords:

phosphors, luminescence

Knife-edge 효과를 이용한 미세 변위 측정기법에 대한 유한요소 분석

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Abstract:

최근 다양한 광학적 기법들이 소형 역학 공진기의 거동 측정을 위해 개발되어 왔다. 이들 중, 광학적 knife-edge 효과를 이용할 경우 정밀한 미세 변위 측정이 가능하며 특히 소자와 광검출기를 동일 광 경로 상에 위치시킴으로써 측정 방식의 단순화를 시도해 볼 수 있다. 본 연구에서는 마이크로 캔틸레버 구조를 대상으로 knife-edge 효과를 이용하였을 때 나타나는 광학적 측정 민감도를 콤솔 프로그램을 사용하여 유한요소분석을 시도하였다. 유한요소 계산을 통해, 실험적으로 관찰된 knife-edge효과 기반 측정기법의 민감도를 확인할 수 있었으며, 이에 더 나아가 다양한 광학적 조건들이 변위 측정에 미치는 영향을 살펴보았다. 구체적으로는 소자와 입사된 광점의 크기 비율, 광검출기와 소자사이의 거리, 광초점과 소자사이의 간격과 같은 조건에 따른 측정기법의 민감도 변화를 계산 및 분석하였다. 이러한 시도를 통해 knife-edge 효과가 소형 역학 공진기의 거동 측정에 충분히 활용될 수 있음을 보여주며, 측정 기법의 최적화에 필요한 광학적 조건들을 제시할 수 있다.

Keywords:

displacement detection, optical knife-edge effect, finite element analysis

Slowcontrol System management for Belle II Detector Operation.

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Abstract:

Belle II experiment is a high-energy physics experiment at the SuperKEKB electro-positron collider. With high-luminosity, we can make high precision measurement of rare decays and CP-violation in hadrons and leptons to probe new physics beyond standard model. In this presentation, we present DAQ and Slowcontrol system management to make stable detector operation, including slowcontrol, monitoring system, and so on.

Keywords:

Belle II, DAQ, Slow Control

의학 물리 기기 활용 다양한 용매를 기반으로 한 액체섬광검출용액 특성 비교

Comparison of characteristics of liquid scintillator based on various solvents using medical physics instruments

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Abstract:

본 포스터는 여러 가지 용매를 사용하여 액체섬광검출용액의 의료용 장비를 이용하여 측정에 대해 간략히 기술하였다. 기존 중성미자 실험에 사용한 액체섬광용액(LS)는 기름과 물을 혼합하여 섬광체를 녹였지만, 최근에 본 연구팀에서는 알코올을 이용한 액체섬광용액(AbLS)를 개발하였다. 이러한 알코올을 이용한 액체섬광용액의 가장 큰 장점은 계면활성제를 이용하지 않고 섬광체를 녹일 수 있다. 이러한 실험들을 바탕으로 아세톤(알드리치 시그마사)을 용매로 사용해 물과 혼합한 새로운 형태의 액체섬광검출용액을 제조하여 알코올 기반 액체섬광용액과 특성에 대한 비교 분석을 하였다. 특히, 그중에 하나의 응용으로 여러 방면에서 사용하는 의료용 장비인 CT Image와 몬테카를로 시뮬레이션을 이용하여 비교 분석을 하였으며, DAQ를 이용한 빛의 방출량과 투명도에 대한 실험을 비교 분석하였다. 아세톤 기반 액체섬광검출용액과 알코올을 이용한 액체섬광검출용액을 비교 분석하여 향후 액체섬광검출용액의 섬광체를 녹일 수 있는 용매로서 다양한 실험을 연구할 수 있으며, 이러한 결과로 좋은 품질의 액체섬광검출용액을 생산할 뿐만 아니라 여러 액체섬광검출용액에 대한 연구를 기여할 수 있을 것이다.

Keywords:

AbLS, CT image, Acetone

Photo Image Analysis of Water-based Liquid Scintillator Using CMOS Sensors for the Next Generation Neutrino Detector

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Abstract:

현재의 액체섬광검출용액 (Liquid Scintillator, LS) 는 유기 용매에 flour를 용해하여 빛을 낸다. 액체섬광검출용액은 외부의 에너지원으로부터 에너지를 받으면 빛을 방출한다. 액체에 PPO를 녹이고, UV light 영역의 에너지를 주면, ~380nm의 빛이 방출한다. PPO가 녹은 액체에 POPOP, bis-MSB 등 2차 shifter인 flour를 녹이면, PPO에서 방출된 ~380nm의 빛을 받아 ~410nm, ~420nm의 빛을 방출한다. 이 포스터에서는 유기용매가 아닌 물을 기반으로 한 액체섬광검출용액을 개발하여 분석하였다. 현재 사용하고 있는 spectrometer로 파장을 분석하는 방법 이외에 Complementary Metal Oxide Semiconductor (CMOS) 를 기반으로 한 이미지 센서를 Bayer color filter array (CFA) 기법과 demosaicing 과정을 통해 디지털 카메라를 이용하여, 물 기반 액체섬광검출용액을 분석하였다.

Keywords:

Liquid Scintillator, flour, Hue, Wavelength, CMOS

A simulation of dark photon (A') at e^+e^- colliders with $e^+e^- \rightarrow \mu^+\mu^-A'$

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Abstract:

We studied MC simulation of dark photon (A') which decays into dimuon [1] at the center of mass energy of present/future e^+e^- colliders of Belle II, FCC-ee, CEPC and ILC. The signal process is $e^+e^- \rightarrow \mu^+\mu^-A'$ where A' decays into dimuon. We generated signal MC using MadGraph5 with simplified model [2]. Using the stand-alone code of KISTI-5 supercomputer, we did fast detector simulation (Delphes) of each collider experiment [3]. We compared various physics variables between generation level and reconstruction level. Then, we got detector acceptance of each experiment. Especially, at the center of mass energy of Belle II experiment, we compared the results between fast Delphes simulation and full Geant4 simulation.

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- [3] <https://cp3.irmp.ucl.ac.be/projects/delphes/browser/git/cards>

Keywords:

Dark matter, Dark photon, Electron-positron collider, MadGraph5, Delphes

Searches for the B meson rare decay modes at Belle experiment

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Abstract:

In this presentation, we report recent updates and newly started topics of B meson rare decay analysis done by Yonsei HEP group.

we are going to present signal extraction procedure.

We used 10 stream of BB, 6 stream of qq 50 stream of rareB and 20 stream of ulna to evaluate this result. Each stream is corresponds to 711fb^{-1} full $Y(4S)$ Belle Montecarlo samples that equivalent to 772M BB pairs.

Keywords:

Belle , B Meson

In-situ Beam Profile Monitoring and Quality Assurance Using Scintillation Screen and TE-cooled CMOS Camera

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Abstract:

The Korea Multi-Purpose Accelerator Complex (KOMAC) has been operating a 100 MeV linac proton accelerator and providing proton beam to users since 2013. Proton beam profile quality assurance is implemented to adjust and confirm the uniformity of the proton beam profile irradiated to the users' samples less than $\pm 15\%$. In the case of TR103 proton irradiation facility, a 100 MeV high-flux irradiation facility, a radio-chromic film has been used to measure the beam profile. Recently, For in-situ beam profile monitoring, P43 scintillation screen and TE-cooled CMOS camera were introduced. P43 scintillation screen is characterized by high light yield and fast decay. TE-cooled CMOS camera has sufficient radiation resistance for experiments in high-radiation environments. To confirm performance, beam profile measurement experiment and data post-processing was conducted. A background subtraction was used to remove the noise. Correction for geometrical deformation due to tilting of the screen was performed. Using a Matlab, X, Y coordinates were set by calculating mm/pixel and uniformity within 30 mm- Φ was calculated. As compared with the measurement results of screen and HD-V2 film, The uniformity was 6.8% and 6.2% respectively showing a difference about 10%. In the future, it is expected to increase the accuracy of proton beam profile measurement by synchronizing the camera exposure with the accelerator timing system.

Keywords:

LINAC, Proton, Beam profile

a few MeV photon detector made of LYSO crystal

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Abstract:

Our motivation for this study is to detect 1 MeV to 10 MeV photons by scintillator crystal for detecting cosmic rays. The one cell of detector is 5*5*55 mm³, and the total detector is 30 by 30 cells. The detector consists of LYSO(Lu_{1.9}Y_{0.1}SiO₅(Ce 0.5mol%)) and each cell is lapped by aluminum foil. With a light yield signal, the detector measures the energy & position of the photon. In this poster, we present the performance of our detector designed using the GEANT4 simulation.

Keywords:

LYSO crystal, Scintillator, Geant4

PSD capability with likelihood method in JSNS²

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Abstract:

JSNS² (J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source, E56) experiment has been taking first data during 10 days on June 2020, and detector was confirmed to work well. In 2021, 2nd data taking with 620~740 kW of beam power was completed from January to end of June. JSNS² detector has a lot of cosmic induced fast neutron background due to set above ground. Therefore, the neutron reduction by PSD (Pulse Shape Discrimination) is the most important for the sterile neutrino search. The JSNS² experiment decided to dissolve the Di-isopropyl naphthalene (DIN), and dissolved the DIN into 17 tons of GdLS on 2020-Dec. This is the first trial in the world, and succeeded to have drastically improved. To improve the PSD capability further, we have developed the PSD algorithm with the likelihood using the full waveform information. In this poster, we will report the preliminary results of PSD capability with likelihood method in JSNS².

Keywords:

JSNS2, PSD, neutrino

Study of WZGamma production in fully leptonic final state at High-Luminosity LHC using Machine Learning Method

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Abstract:

The High-Luminosity LHC (HL-LHC) will be operated at the center-of-mass energy of 14 TeV with the largest integrated luminosity ever, 3000 fb^{-1} . It allows a significant improvement in sensitivity to isolate and observe the interesting process that is rarely expected in the Standard Model. The triple vector boson production processes are typical channels due to a very small cross-section. Among them, we report the potential for the observation of the WZGamma process at the HL-LHC environment. We use the fully leptonic decay channel of the WZGamma production in the final states containing three leptons, a neutrino, and a photon. The sample has been generated and simulated using Madgraph5, Pythia8, and Delphes3. The machine learning method was implemented for the classification of signal and background events.

Keywords:

HL-LHC, Triple Vector Boson Production, Machine Learning

Pulse Shape Discrimination with Machine learning at JSNS²

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Abstract:

The JSNS² (J-PARC Sterile Neutrino Search at the J-PARC Spallation Neutron Source) experiment searches for neutrino oscillations at 24m baseline from the J-PARC's 3 GeV 1 MW proton beam incident on a mercury target at the MLF. The particles from the mercury target are detected at the JSNS² detector which is filled with the gadolinium (Gd) -loaded Liquid Scintillator (LS). The Fast Neutron (FN) is one of the important backgrounds in this experiment. Discrimination of Michel Electron (ME) and FN is an important topic in the LS-based neutrino experiments. In the JSNS² experiment, a Pulse Shape Discrimination (PSD) algorithm based on the charge fraction at the tail of the overall pulse shape has been used to discriminate ME and FN. In this presentation, we will show new methods based on Machine Learning (ML) techniques. Especially, we focus on the Convolutional Neural Network (CNN) algorithm which is one of the Deep Neural Network (DNN) methods.

Keywords:

JSNS2, CNN, PSD

Performance study of dual-readout calorimeter with Higgs decaying into Z and gamma process

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Abstract:

The dual-readout calorimeter (DRC) is one of the future collider calorimeter candidate for FCC-ee and CEPC. Using both Cerenkov and Scintillation fibers, it shows excellent performance with measuring both EM and hadronic processes. With DD4HEP framework implemented with GEANT4 to describe DRC detector geometry, we present the study of the detector performance using Higgs decaying into Z and gamma process.

Keywords:

dual-readout calorimeter, future collider, Higgs, detector simulation

The process of assembly for the module of the dual-readout calorimeter

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Abstract:

The dual-readout calorimeter (DRC), consisting of scintillating and čerenkov fibers, is one of the calorimeter candidates in future e+e- colliders. We are building a module that has four towers that are made up of čerenkov fibers and different cladding types of scintillating fibers. As the first step, we will present the process to assemble the modules in this talk. Module assembly can be divided into 3 steps. The first step is inserting fibers on copper plates. The second is čerenkov holder step that can be separated as the combination of holder and fibers, polishing the endpoint of čerenkov fibers and attaching an aluminum-based reflector. The last step is the connection with the readout system.

Keywords:

dual-readout calorimeter, future collider, prototype

The Optical fiber treatment used in the module of the dual-readout calorimeter.

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Abstract:

The dual-readout calorimeter(DRC) has been proposed in the IDEA detector concept for future e+e-collider. The DRC is implemented by two different types of optical fibers, Cerenkov and scintillation fibers, allowing simultaneous measurement of electromagnetic and hadronic particles. Scintillation fiber has two different shapes(square, round), & two cladding types (double cladding, single cladding). Cerenkov fiber has only round shape and single cladding. Since optical fiber is very sensitive and needs careful treatment, we performed various tests. We present the progress of optical fibers treatment and various tests of optical fibers in this talk.

Keywords:

dual-readout calorimeter, future colider, prototype module

Event Reconstruction in JSNS2

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Abstract:

The JSNS2 experiment aims to search for the existence of sterile neutrinos at J-PARC. A 1 MW beam of 3 GeV protons incident on a spallation neutron target produces an intense neutrino beam from muon decay at rest. The experiment will search for muon anti-neutrino to electron anti-neutrino oscillations which are detected by the inverse beta decay interaction, followed by gammas from neutron capture on Gd. A software tool named JADE was adopted to reconstruct energy and vertex of events with a charge likelihood method from the JSNS2 data. In this slide, details for the event reconstruction are shown.

Keywords:

JSNS2, sterile neutrino, neutrino oscillation, J-PARC

Preliminary Test of In-air AC Current Transformer for Low Current Proton Beam Measurement at KOMAC

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Abstract:

In Korea Multi-purpose Accelerator Complex (KOMAC) of Korea Atomic Energy Research Institute (KAERI), a proton LINAC for 20 MeV and 100 MeV is in operation and provides the proton beam for various applications since 2013. A new beamline for low-flux applications was developed and started beam service to users in 2018. Recently, this low-flux beamline has been most actively used for the radiation effect test of semiconductors, such as single event effects (SEE). A proton beam accelerated by the LINAC passes through a collimator to reduce the beam current to at least 10^{-4} , and then uses octupole magnets to provide a uniform and wide-area beam. However, the beam current reaching the in-air final sample position is too low to measure using a conventional Faraday cup. To measure low current proton beam in the air at sample position in real-time, therefore, we used an in-air AC current transformer (ACCT) and performed preliminary experiments under various beam conditions. The ACCT is a non-destructive particle beam diagnostic method without perturbation of the proton beam. Also, it has the advantage of having a fast response characteristic.

In this presentation, the details on the test result of the in-air ACCT in the low-flux proton irradiation room will be presented.

Acknowledgements: This work has been supported through KOMAC (Korea Multi-purpose Accelerator Complex) operation fund of KAERI by MSIT (Ministry of Science and ICT) and by the "Development of the Evaluation Technology for Space Parts" project through the National Research Foundation of Korea

Keywords:

Low-current Proton beam, Proton Beam Diagnostics, AC Current Transformer, in-situ beam current measurement

The status of a plastic scintillator array prototype for the Deep Underground Neutrino Experiment (DUNE)

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Abstract:

DUNE aims to measure Charge-Parity Violation via neutrino oscillations using a Fermilab accelerator beam. To reduce systematic errors, we use a plastic scintillator cube array for studying neutrino interactions at the near detector facility. The 3D array will consist of several millions of $1.5 \times 1.5 \times 1.5 \text{ cm}^3$ cubes connected/coupled by wavelength shifting fibers with SiPM readouts. Chung-Ang University is responsible for constructing a prototype system which is currently built as a $4 \times 4 \times 4$ cube array and grows every year. We report the status of the prototyping.

Keywords:

DUNE, neutrino, scintillator

Physics with neutrinos from charged kaon decay-at-rest in JSNS2

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CHEOUN M. G. ⁹, LEE C. Y. ⁹, JEON H. ¹⁰, JEON S. ¹⁰, JUNG D. E. ¹⁰, KIM S. B. ¹⁰, ROTT C. ¹⁰, YU I. ¹⁰

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Abstract:

JSNS2 (J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source) has the unique ability to precisely measure monoenergetic 236 MeV neutrinos from charged kaon decay-at-rest (KDAR). This KDAR neutrino gives the optimal data for studying the neutrino-nucleus interaction, energy reconstruction, and cross sections in the hundreds of MeV energy region. The J-PARC MLF (Materials and Life science experimental Facility) 3 GeV primary proton energy is sufficient to produce kaons efficiently and, also in consideration of the facility's beam intensity (eventually 1 MW), it represents the best facility in the world to accomplish this physics. In this presentation, the prospect and research status with Monte Carlo for this study will be reported.

Keywords:

KDAR , neutrino-nucleus interaction , energy reconstruction , J-PARC MLF

Search of $B^0 \rightarrow l^{+-} \tau^{-+}$ decays at Belle experiment

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Abstract:

We study the rare leptonic decays $B^0 \rightarrow l \tau$ where τ to one lepton and 2 neutrinos, using Monte Carlo based simulation data from Belle detector at KEKB e^+e^- collider. One of the B meson from $\Upsilon(4S) \rightarrow B^0 \bar{B}^0$ is fully reconstructed by semi-leptonic full event interpretation (FEI) of Belle II, while remaining particles are from signal B decay. The Toolkit for Multivariate Data Analysis with ROOT(TMVA) is used to improve signal purity, with 3 variables. The multi-layer perceptron method is selected to optimize the figure of merit between signal and background MC samples.

The momentum of primary lepton on center-of-mass frame(p_l^*) in semileptonic tagged sample is selected. The signal and background PDF are constructed by their MC distribution of p_l^* , and the PDFs are tested with 3 sets of Belle generic MC distributions for validation of fit. Finally, expected upper limit is calculated from the yield of signal in signal region by the fit result of PDFs of background MC distributions.

Keywords:

Belle, KEKB, B meson, missing particles, MLP

Impact of Strong Coupling Effect on Free-free Opacity of Dense Plasma Using FLYCHK Code

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Abstract:

Opacity, which is a measure of the tendency of a material to absorb and scatter radiation, is essential information to understand the fundamental properties of dense plasmas. In particular, the free-free opacity is of increasing interest since it is an important factor in various fields such as fusion research and astrophysics. In this poster, we analyze the free-free opacity of aluminum using the collisional radiative code FLYCHK in a wide range of temperatures and densities. It shows that strong coupling effects, such as plasma screening and electron degeneracy, have a huge impact on the free-free opacities of dense plasmas at low photon energies. For validity, the FLYCHK aluminum opacities are compared to those obtained by the Los Alamos opacity code ATOMIC.

This work was supported by the NRF of Korea (No. NRF-2019R1A2C2002864 and NRF-2015R1A5A1009962) and the Defense Research Laboratory Program of the Defense Acquisition Program Administration and the Agency for Defense Development of the Republic of Korea.

Keywords:

opacity, free-free opacity, strong coupling effect, dense plasma, FLYCHK

Investigation of He atmospheric pressure plasma jets' interaction with optical diagnostics

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Abstract:

기존 산업에서 많이 쓰여져 오고 있는 저압 플라즈마에 비해 여러가지 장점을 지닌 대기압 플라즈마는 수년 전부터 폭넓은 응용분야에 적용하고자 주변환경과 상호작용에 대해 활발히 연구 및 응용이 되고 있다. 본 연구에서는 헬륨 가스를 이용한 대기압 저온 플라즈마 젯 장치 두개를 사용하였을 때 서로 어떠한 영향을 미치는지 확인해 보았다. 구체적으로 보기 위해 광신호를 검출하여 정보를 가진 전기적 신호를 증폭하여 검출하는 ICCD (Intensified Charge-Coupled Device) system과 빛의 굴절을 이용하여 빛을 선택적으로 통과시켜 물체를 구별하는 Schlieren method를 이용하여 plasma discharge 에 영향을 미치는 Amp circuit 구조 2가지를 광학진단을 통해 분석하였다.

Keywords:

plasma discharge, ICCD, Schlieren method

Data-driven 비정상 전자 충돌주파수를 활용한 홀추력기 플라즈마의 전산해석 연구

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Abstract:

홀추력기는 축 방향 전기장과 반경 방향 자기장이 서로 직교하는 E×B장치로, 공급되는 중성기체를 이온화하고 전기장을 통한 가속으로 우주 공간에서 추력을 얻는 전기추력기의 일종이다. 특히, 최근 증가하고 있는 전기추력기 활용에 따라 고효율 홀추력기 개발이 중요해지고 있으며, 이를 위한 추력기 방전채널 내부의 플라즈마 특성 분석은 필수적이다. 하지만 방위각 방향의 플라즈마의 비대칭성과 난류에 의한 전자의 축방향으로의 비정상 수송 (electron anomalous transport)은 홀추력기 플라즈마 전산해석의 난제로 남아 있다. 이를 본 축방향 전산해석에서 고려하기 위해서는 추력, 방전전류 및 플라즈마 전위들과 같은 실험 측정값들을 활용한 비정상 전자 충돌주파수 도출이 필수적이다. 그러나 상기한 충돌주파수를 얻기 위해서는 수십번 이상의 반복계산을 통한 시행 착오 방법을 거쳐야 하므로, 시간 단축을 위한 즉각적인 비정상 충돌주파수 획득 기법이 필요하다. 따라서 본 연구는 일차원 하이브리드 Particle-In-Cell (PIC) 기법을 통해 얻어진 결과들을 통해 예측된 data-driven 비정상 전자 충돌주파수를 새로운 전산해석에 적용하여 반복계산이 불필요한 새로운 예측 기법을 제안한다. 개발된 기법에 사용된 학습 데이터는 50 W, 300 W, 그리고 6 kW급 홀추력기를 기반으로 반복계산을 통해 얻어진 비정상 전자 충돌주파수 결과값 들이다. 특히 300 W급 홀추력기는 고정된 양극 유량에서 양극전압을 200, 250, 그리고 300 V로 조절하며 넓은 작동환경에서의 비정상 충돌주파수를 획득했다. 이때 100개의 독립적인 인공신경망들을 앙상블하여 홀추력기의 반경방향 자기장 분포, 축방향 플라즈마 전위 및 전기장 분포, 양극유량, 그리고 평균 방전채널 직경 값들을 입력 변수로 사용해 전자의 비정상 충돌 주파수를 출력한다. 학습된 모델을 검증하기 위해 학습데이터에 포함되지 않은 자기장이 제어된 50 W 급 홀추력기의 실험 측정 플라즈마 전위 및 전기장을 적용하여 data-driven 전자 비정상 충돌 주파수를 획득했다. 예측된 충돌주파수를 일차원 하이브리드 PIC 전산해석에 적용해 얻어진 추력 및 방전전류는 3.7 mN 및 0.32 A으로, 실험 측정값인 추력 3.8 mN 및 방전전류 0.30 A에 비해 각각 3% 및 7% 이내의 정확도로 계산되었다. 본 발표에서는 자세한 data-driven 기법 및 이를 적용한 전산해석 결과에 관해 논의하고자 한다.

Keywords:

홀추력기(Hall Thruster), 인공신경망(Neural Network), 플라즈마 모델링(Plasma Modeling)

원통형 홀추력기 플룸의 저에너지 이온 및 각도에 따른 다중이온 비율 분석

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Abstract:

홀추력기는 플라즈마 내 가속된 이온으로 추력을 얻는 전기추력기의 일종으로, 높은 추력밀도(>50 mN/kW)와 높은 연료 효율을 기반으로 인공위성의 궤도 천이 및 궤도 수정과 심우주탐사 등에 사용된다. 특히 홀추력기의 일종인 원통형 홀추력기는 플라즈마의 부피 대비 표면적을 낮춰 방전채널로의 열 및 입자 손실을 줄인 추력기이다. 본 연구에서는 원통형 홀추력기 플라즈마에서의 저에너지 이온과 그에 따른 다중이온 생성에 대해 조사하였다. 레이저유도형광 진단(LIF)에 따른 300 V, 7 sccm의 원통형 홀추력기 제논 플라즈마의 축방향 이온속도분포 측정 결과, 홀추력기 방전채널 바깥 영역(축부터의 방사방향 위치 $r > 21$ mm, 방전채널로부터 축방향 위치 $z = 10 - 20$ mm)에서 방사방향 속도 $V_r \sim 2 - 10$ km/s 보다 작은 축방향 속도 $V_z \sim 1$ km/s 를 가진 저에너지 1가이온(Xe II) 발생이 확인되었다. 이때 저에너지 1가이온 발생 영역에서 체류시간 증가로 인한 단계적 이온화를 가정, 해당 영역에서 기인한 다중이온(Xe III, Xe IV) 측정을 위하여 추력기 방전채널로부터 76 cm거리에서 추력기 축 대비 각도($0.0 - 75.0^\circ$)에 따른 ExB 진단을 진행하였다. 이때 ExB 탐침 측정 결과 $0.0 - 30.0^\circ$ 까지의 Xe III 비율은 28.0%에서 19.0%로 감소하였으나, 30.0° 이상부터 증가하여 52.5° 에서 최대 38.0%까지의 증가가 확인되었다. 그 후 65.0° 이상에서는 각도 증가에 따라 Xe III 비율이 감소하는 경향을 보였다. 또한, 62.5° 부터 75.0° 까지의 ExB 탐침 스펙트럼에서는 최대 66 eV의 Xe II 및 Xe III 최빈값 분리 현상이 확인되었다. 이는 채널내부에서 이온화되어 양극 근처의 높은 전위 차이에 의해 가속된 고에너지 1가 및 2가이온, 그리고 채널 밖에서 이온화되어 상대적으로 낮은 전위 차이에 의해 가속된 저에너지 1가 및 2가이온의 분포로 사료된다. 따라서 각도에 따른 ExB 탐침 측정 결과, 축 대비 큰 각도로 가속된 다중이온이 발견되었다. 본 발표에서는 원통형 홀추력기에서 발견된 저에너지 이온에 기인한 것으로 예상되는 다중이온 비율 측정 상세 결과 및 홀추력기 방전채널 밖에서의 저에너지 이온 발생원인에 대해 논의하고자 한다.

Keywords:

홀추력기, 다중이온, 저에너지 이온, 플라즈마 진단, 레이저유도형광

Emittance Measurement methods using Wire Scanner in Injector of RAON

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Abstract:

The goal of RAON is to accelerate uranium beams up to 200 MeV/u, with a maximum beam currents of 8.3 μA . RAON Injector consists of 14.5GHz ECR ion source, LEBT, RFQ, MEBT and several diagnostics devices. Diagnostics devices such as 8 Wire Scanner, 5 Faraday Cup, 3 ACCT, 3 Beam Viewer, 6 BPM was constructed for Injector beam line. Emittance would be measured by Allison Scanner in LEBT. We can also measured the emittance using wire scanner and quadropole with quadropole scan and multi-wire methods. This poster describes mathematical analysis of emittance measurement method using wire scanner and quadropole.

Keywords:

Diagnositcs, Emittance, Wire Scanner

대형 리본형 이온빔의 최적 수송을 위한 이온빔 수송 라인 전자석 설계에 대한 기초 개념 연구

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Abstract:

경제적인 디스플레이 패널 제조를 위해 인출빔의 길이가 1 m 이상인 리본형 이온원을 설치한 대형 이온 주입기가 개발되고 있다. 이 대형 이온원으로부터 이온 주입 공정을 위한 붕소 또는 인 이온을 인출하는 과정에서 불필요한 이온종도 같이 나오게 되므로, 이를 걸러내기 위한 분석 이극 전자석이 필요하게 된다. 이 전자석을 지나 대형 디스플레이 패널 기판에 수 % 이내의 균일도로 원하는 이온종을 조사하기 위해서는 이온원 출구에서 조사 기판까지 이극 분석 전자석을 포함하여 가급적 짧은 최적화된 빔 수송 라인이 요구된다. 빔 수송 라인의 전자석은 큰 갭의 이극 분석 전자석에서 발생하는 육극 자기장을 보정하기 위한 육극 보정 전자석, 빔 집속을 위한 사극 집속 전자석, 빔 방향 조절을 위한 이극 스티어링 전자석, 이온원 그리드 오차를 보정하기 위한 사극 보정 전자석 등으로 이루어진다. 본 발표에서는 이온원에서 인출되는 빔 및 이온빔 수송 라인 자체에서 발생하는 여러 오차 요인을 검토하고, 이에 의한 영향을 최소화할 수 있는 최적화된 이온빔 수송 라인 전자석을 설계하기 위한 기초 개념을 제시하고자 한다.

Keywords:

리본형 이온빔, 이온주입기, 전자석

1 MeV/n RFQ 초기 고주파 컨디셔닝

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Abstract:

한국원자력연구원에서는 멤브레인 제작, 반도체 조사 등을 포함하는 SHI (Swift heavy ion) 응용기술 및 소형 중성자원 개발을 목적으로 1 MeV/n의 가속에너지를 가지는 고주파 사중극 가속장치 (Radio-Frequency Quadrupole, RFQ)을 개발 중에 있다. 공진주파수 200 MHz를 가지는 가속관의 제작 및 고주파 튜닝을 완료한 후 초기 고주파 컨디셔닝을 수행하였다. 고주파 시스템은 non-IQ 방식의 디지털 저출력 고주파 시스템, 240 kW 첨두 전력을 가지는 solid state amplifier, 써큘레이터 및 방향성 결합기를 포함하는 3-1/8" 동축선 기반의 고주파 전송시스템으로 구성된다. 펄스폭 50 us, 반복율 1 Hz로 초기 고주파 컨디셔닝을 수행하였으며 고주파 인가 후 2 시간 이내에 50 kW까지 안정적으로 인가하였다. 설계 고주파 전력은 펄스폭 1 ms, 반복율 100 HZ, 첨두 고주파 전력 200 kW 이다. 본 발표에서는 개발 중 RFQ의 현황에 대해 고주파 시스템 구성 및 초기 고주파 컨디셔닝을 중심으로 논한다.

본 연구는 과학기술정보통신부의 연구비 지원을 받았음

Keywords:

RFQ, RF conditioning, RF system, KOMAC

Transverse Beam Characterization at KOMAC Beamlines via Thick Lens Model Fitting Quad Scan

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Abstract:

The characterization of the transverse phase space of beams is a basic requirement for particle accelerators. The quad scan technique is a simple and useful method for the transverse beam characterization. We set the quad scan using a set of a quadrupole magnet and a wire scanner at several locations in the KOMAC (Korea Multipurpose Accelerator Complex) beamlines. In this technique, larger drift distance between the quadrupole magnet and the wire scanner is preferred because it gives better thin lens approximation. However in reality, the drift distance is not long enough for the approximation. Therefore, instead, we generally use the thick lens model directly. In thick lens model, the three sigma beam matrix elements (beam parameters) are solved by applying a least-squares fit for one set of measurements. To extract the emittance and Twiss parameters from all the accumulated quad scan measurements, we implement the error-weighted fitting of parabolic equations from the transfer matrix elements. We shall describe the measurement at KOMAC beamlines and discuss the result.

Acknowledgments

This work has been supported through KOMAC operation fund of KAERI by the Korea government (MSIT).

Keywords:

Proton linear accelerator, Beam diagnostics, Quad Scan

Preliminary Design study of Injector System for Synchrotron Light Source

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Abstract:

This work presents a design study of an electron linac as an injector system for the 4th generation synchrotron radiation facility. The linac consists of an electron gun, a series of bunchers, and accelerating structures. The Buncher system has three components: a sub-harmonic buncher at 500 MHz, a pre-buncher at 3 GHz, and a buncher at 3 GHz. In this study, we will show the preliminary design work of the linac including electron gun and buncher system. The gun consists of a hot cathode that generates electrons, an anode that accelerates the electron beam, and a focusing electrode that focuses the electrons during emission. Using the CST Code Suite, the geometry of the electron gun was optimized to generate and deliver a high current, low emittance electron beam with the designed beam energy. The EM fields of the buncher system were calculated by using the Superfish code, and then beam dynamics simulations were performed to optimize the linac lattice configuration from the electron gun to the Buncher system.

Keywords:

electron linac, injector system, electron gun, buncher

100 MeV 양성자가속기 기반 우주부품검증 시험환경 개선연구

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Abstract:

한국원자력연구원에서는 100 MeV 양성자가속기 기반 우주부품검증지원기술개발에 대한 연구를 수행하고 있다. 이 가운데 우주부품검증 시험을 위한 시험환경개선 연구가 포함되어 있으며, 이에는 빔 균일도 향상, 빔 진단계통 성능향상의 내용에 대한 연구가 있다. 빔 균일도는 10%의 균일도를 갖는 영역을 기존의 100 mm X 100 mm 에서 최종적으로는 150 mm X 150 mm 까지 향상시키는 목표를 갖고 있고, 빔 진단계통은 실시간 측정영역을 확장함과 동시에 가속기 제어계통과의 연동을 통하여 이용자 중심의 빔 서비스를 할 수 있는 체계를 갖추하고자 한다. 본 발표에서는 100 MeV 양성자가속기에 기반한 우주부품검증 지원기술개발 현황을 시험환경개선 연구를 중심으로 논한다.

본 연구는 과학기술정보통신부의 원자력융복합기술개발사업의 연구비 지원을 받았음

Keywords:

양성자가속기, 우주부품검증

고에너지 양성자가속기 기반 우주방사선 모사장치에서의 낮은 플럭스 측정

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Abstract:

한국원자력연구원 양성자과학연구단에서는 우주부품에 대한 내방사선 시험을 위해 100 MeV 고에너지 양성자가속기 기반의 우주방사선 모사장치의 개발을 수행 중이다. 양성자가속기의 빔라인 중 하나인 저선량 빔라인 (TR102) 에서는 우주 및 생명공학 분야 이용자들을 위해 플럭스 범위 $1E+6 \sim 1E+8$ /cm²-sec 를 가지는 양성자빔을 제공하고 있다. 이 빔라인에서 메모리 소자, 광센서, 태양전지 등 다양한 소자에 대한 내방사선 실험이 이루어지고 있다. 한편 일부 이용자들은 방사선에 민감한 소자의 시험을 목적으로 더 낮은 플럭스의 양성자빔 조사 서비스의 제공을 꾸준히 요청해왔다. 이러한 이용자들의 요구를 반영하기 위하여 $1E+5$ /cm²-sec 까지 선량범위를 낮추는 방법을 검토 중이며 이를 위해 기초적인 플럭스 조절 및 측정 실험을 수행하였다. 본 논문에서는 응답 특성이 다른 두 종류의 이온챔버를 이용한 실험결과와 가속기 운전조건 변경에 따른 플럭스 변화 측정 결과에 대해 설명하고 향후 이를 이용한 제공가능 플럭스 범위에 대해 논하고자 한다. 사용된 이온챔버는 PTW사의 Farmer Ionization Chamber (Model : 30013)와 Bragg Peak Ionization Chamber (Model : 34073)이다. 두 이온챔버들의 응답신호크기는 각각 20 nC/Gy와 78 nG/Gy로서 동일한 흡수선량값에 대해 Bragg Peak 이온챔버의 신호크기가 Farmer 이온챔버에 비해 3배 이상 더 크다. 플럭스는 흡수선량값으로부터 계산을 통해 얻을 수 있었으며 동일한 플럭스에 대한 이온챔버 신호의 크기를 비교하였다. 가속기 운전 조건을 변경하면서 플럭스 변화에 따른 이온챔버 신호의 선형성과 노이즈의 영향 등을 조사하여 측정가능한 플럭스 범위에 대해 검토하였다. 가속기 운전 조건 변경에 따른 플럭스 변화를 측정하여 향후 제공가능한 양성자빔 조사 조건을 확보하였다.

Keywords:

우주방사선, 양성자가속기, 이온챔버, 내방사선 시험

다목적방사광가속기를 위한 3차 조화 가속관의 기초 설계 및 분석

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Abstract:

4세대 방사광 가속기의 대표적인 특징은 높은 휘도이다. 빔의 휘도를 높이기 위해선 설계 단계에서 에미턴스를 최소화하고 빔 전류를 높인다. 하지만, 낮아진 에미턴스와 높아진 빔 전류로 인해 짧은 길이의 빔 번치 내 충돌 횟수가 증가한다. 따라서, 빔 안정도와 Touchek 생존 시간을 높이기 위해 전자간의 거리를 늘이기 위해 3차 조화 가속관을 이용하여 빔 번치 길이의 증가가 필요하다. 본 포스터에선 빔 번치 길이 증가를 위한 3차 조화 가속관의 기초 설계 및 분석에 대해 발표한다.

Keywords:

초전도 가속관, SRF, 방사광가속기

100 MeV 양성자빔 진단용 Cooled CMOS Camera의 내방사선 특성 시험

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Abstract:

양성자과학연구단은 100 MeV의 선형 양성자 가속장치와 100 MeV 양성자빔을 활용한 방사선 영향 시험 시설을 운영하고 있다.

카메라와 Scintillation Screen에 의한 빔 이미지 측정은 입자빔의 위치 및 빔 프로파일을 직관적으로 정확하게 측정할 수 있어 널리 활용되는 빔진단 방법 중에 하나이다. 그러나 고에너지 양성자빔의 경우 카메라의 이미지 센서가 양성자빔에 의한 2차 방사선에 의해 쉽게 손상되어 100 MeV 양성자빔의 진단에 활용되기 어려웠다.

카메라 이미지 센서를 -20°C 로 생각하는 Cooled 카메라의 경우 방사선에 의한 손상이 적어 고품질의 빔 이미지를 획득할 수 있고 일반 카메라에 비하여 장기간의 수명을 가지는 것으로 보고되고 있다*. 그러므로 냉각이 가능한 Cooled CMOS Camera를 100 MeV 양성자빔 진단에 활용하기 위하여 내방사선 특성을 시험하였다. 시험에 사용된 Cooled CMOS Camera는 천체 사진 촬영 목적의 ASI183MC Pro (ZWO) 모델을 사용하였다.

Cooled CMOS Camera에 누적된 방사선량을 측정하고 방사선량에 따른 Dark image, White image의 Dead & Hot Pixel 수의 변화를 통해 Cooled CMOS Camera의 내방사선 특성을 시험하였으며 그 시험 결과에 대하여 보고 및 논의하고자 한다.

* Reference : Fusion Engineerind and Design

Acknowledgment

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Keywords:

Cooled CMOS Camera, 내방사선 카메라, 내방사선 특성

Finding Optimal Conditions for Stable Operation of Laser Wakefield Accelerator Using The 20 TW/30 fs Ti:Sapphire Laser System.

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Abstract:

Laser wakefield acceleration (LWFA) is an innovative idea for particle acceleration, and it has been studied intensively in the accelerator physics community over the past three decades. One of the issues making realization of LWFA for practical use hard is that the LWFA is very sensitive to the experimental conditions. For example, laser parameters can be easily altered during the experiment owing to the lab environment, weather, thermal effects, etc. Such latent uncertainties can be critical especially for a lab with a laser system that marginally meets the threshold condition for LWFA, thus resulting in lower reproducibility. In this point of view, it is important to obtain and characterize LWFA results from as many different conditions as possible. Additionally, finding an easier way to get electron beams is important. In this presentation we present a full characterization of the experimental conditions and the LWFA results from different conditions.

Keywords:

Laser, Laser-plasma, Laser wakefield acceleration (LWFA), Gas jet

Interaction between laser induced plasma and guided streamer of helium atmospheric pressure plasma jet

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Abstract:

Atmospheric pressure plasma jet (APPJ) combined with high power pulse laser was configured to investigate the interaction between laser induced plasma (LIP) and guided streamer in APPJ. The guided streamer was produced in a helium APPJ obtained from a quartz tube with single electrode configuration. Atmospheric pressure plasma was generated by applying a square pulse with the frequency of 5 kHz, the amplitude of 10 kV_{p,p} and the duty cycle of 35 % to the electrode. A nanosecond pulse Nd:YAG laser with the wavelength of 1064 nm was focused on center of the guided streamer. A delay generator was used to control the interval between the streamer and the laser pulse. Respective emission lights from the guided streamer, the LIP, and the LIP-streamer interaction were collected by a lens system and an optical fiber, and the spectra were measured by a portable spectrometer. Optical emission spectra for the interaction were analyzed with the change of the delay time between the streamer and the laser pulse. Mechanism for the interaction between the streamer and the laser pulse was discussed.

Keywords:

Laser-induced plasma, guided streamer, atmospheric pressure plasma jet

Development and experimental investigation of 1 mm diameter capillary gas cell for laser wakefield acceleration

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Abstract:

We developed one body cylindrical capillary gas cell with 1 mm diameter for laser wakefield acceleration (LWFA). The capillary has the advantage of being relatively large in diameter, making it easy to manufacture and easy to align with lasers. The gas density inside the capillary was diagnosed using a longitudinal Mach-Zehnder interferometry and CFD simulation results were used to increase the accuracy of the density analysis. In order to investigate the application of capillary gas cell with large diameter in LWFA, an electron acceleration experiment was conducted using 100 TW laser system in the IBS at GIST. PIC simulations were performed to verify the experimental results. The detailed of experimental and simulation results will be reported in this presentation.

Keywords:

capillary gas cell

라디에이션 리액션으로 인한 하전 입자의 유효질량 상승

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Abstract:

Larmor formula에 따르면 가속하는 하전 입자는 언제나 광자를 방출한다. 각각의 광자는 운동량을 가지고 있기 때문에 결과적으로 입자는 운동량을 조금씩 잃게 되는데, 이 과정에서 입자가 느끼는 힘을 라디에이션 리액션이라고 부른다. 입자의 크기가 점일 경우에 한해서 이 힘은 디랙에 의해 정확히 계산되었으며, 따라서 이 힘은 Lorentz-Abraham-Dirac force라고도 불린다. 그러나 입자를 점으로 가정하면서 몇 가지 예상치 못한 문제들이 발생했는데, 대표적으로 질량 재규격화 문제, 인과율이 붕괴되는 문제, 그리고 등가속운동에서 리액션이 없어지는 문제 등이 있었다. 그러나 최근 연구에서, 우리는 입자의 크기가 유한하면 등가속운동에서의 라디에이션 리액션이 간단히 설명될 수 있음을 알아냈다(단, 입자는 단순히 크기가 유한할 뿐만 아니라, 외부에서 관측되었을 때 완벽히 점전하처럼 보여야 한다는 조건이 붙는다.) [Phys. Lett. A 407 (2021) 127445]. 흥미롭게도, 이런 식으로 정의된 (유한한 크기의) 입자는, 가속되는 상황일 때 거의 항상 자신의 유효질량을 증가시키는 특징이 있었다. 이는 입자를 점으로 가정했던 기존의 이론들에선 볼 수 없었던 현상이다. 따라서 이 발표에서는 새 입자 모델의 질량 증가 현상이 자세히 소개될 것이다. 등가속운동 뿐만 아니라, 등속원운동에서의 질량 증가 계산 결과가 새롭게 제시된다. 또한 어째서 유한한 크기를 가정했더니 입자의 유효질량이 증가하는지에 대해 논의해본다. 마지막으로, 입자 크기에 대한 한계값을 구해보고, 이 한계와 Schwinger limit의 관련성을 제시할 것이다.

Keywords:

radiation reaction, electrodynamics, Schwinger limit

Radiation emission of magnetized Plasma Dipole Oscillation

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Abstract:

Plasma dipole oscillation (PDO) investigations have demonstrated that magnetic fields do not disturb the coherent oscillation but rather circulate PDO since the discovery of PDO, which is a coherently oscillating plasma bunch. Particle trajectories are computed using a two-dimensional particle in cell code, and its spectra contain peaks at the right circular (R), left circular (L), and upper hybrid modes. PDO radiation is p-polarized and features two spectral peaks. Except for the upper hybrid mode, the radiation spectra are identical to the source spectra. The intensity curve of transverse radiation shows dipole. Upper hybrid mode is a resonance point that causes the spectral discrepancy between the radiation and source spectra.

Keywords:

Plasma dipole oscillation (PDO), right circular (R), left circular (L), and upper hybrid modes

Optimization of the laser wake-field acceleration using a helium or aluminum plasma target

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Abstract:

오늘날 입자/방사광 가속기에 관한 연구는 반도체, 바이오 신약, 신소재 개발 등과 같은 다양한 분야에 있어서 폭넓게 활용되어오고 있다. 한편, 일반적인 입자 및 방사광 가속기와는 달리 레이저-플라즈마 상호작용을 이용한 레이저-유도 가속기의 경우 GeV/cm급의 가속 길이 대비 높은 가속 효율을 얻을 수 있어 소형가속기 개발에 각광받아 오고 있다.

대표적인 레이저-유도 전자빔 및 방사광 가속기 원리인 레이저 웨이크 필드 가속(Laser wake-field acceleration; LWFA)의 경우, 기존에는 헬륨과 같은 중성기체-제트 표적을 활용해왔는데, 이러한 기체-제트 표적을 사용하는 LWFA 방식(GT-LWFA)은 고진공 유지가 힘들고 반복효율이 낮다는 단점을 가지고 있다. 이러한 GT-LWFA 방식의 단점을 극복하기 위해 최근에는 고체표적을 프리-펄스 레이저를 통해 레이저-용삭시켜 만든 플라즈마 깃털을 활용하는 LWFA 방법(ST-LWFA)이 제안 및 연구되어 오고 있다. 이러한 ST-LWFA의 경우 기존의 GT-LWFA에 비해 이온화 효과가 주요하게 작용함으로써 기존에 알려졌던 최적화 조건과는 또 다른 최적화 조건을 가지게 된다.

본 연구에서는 2D/3D Particle-In-Cell 시뮬레이션을 통한 반복 매개변수 연구를 통해서 각각 GT-LWFA와 ST-LWFA를 대표하는 헬륨 및 알루미늄 플라즈마를 이용한 LWFA에서의 최적화 조건에 대해 연구하였다.

Keywords:

Laser Wakefield Acceleration, Laser-Plasma Interaction, Particle-In-Cell(PIC) Simulation

Compact Soft X-ray Free Electron Laser by Laser-Plasma Accelerator Using External Injection From Photocathode RF GUN

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Abstract:

X-ray free electron lasers (XFELs) provide a revolutionized tool for studying atomic, molecular, chemical, and biological systems in femtosecond scales. The generation of X-ray pulses from soft X-ray to hard X-ray FELs relied on the electron beam with energy of GeV scale, high brightness, and good stability from conventional RF Linac. The PAL-XFEL also uses S-band LINAC, which accelerates the electron beam energy up to 10 GeV over 700 m in length. In contrast, the GeV scale electron beam can be produced in few centimeters if the laser-plasma accelerator is used due to an almost 1000 times stronger gradient in the plasma wakefield. Therefore, if this LINAC can be replaced with the laser-plasma accelerator, the XFEL facility may significantly reduce its size and construction costs.

However, the electron beam quality of the laser-plasma accelerator is reported as poor of a few percent of energy spread, low stability, and low reproducibility, which does not satisfy the demanding criteria for the XFEL. In order to overcome this limitation, one of the most promising ways is to use the electron beam of good quality from the RF photocathode as a seed beam for laser-plasma accelerators. PAL-ITF GUN-II beamline of RF photocathode can produce the beam energy of 70 MeV, an energy spread of 10^{-3} , few tens femtoseconds jitter, and low emittance of 0.2 mmrad, which can be the excellent seed for the LWFA. For the compact soft X-ray free electron lasers, we used this external injection technique with an electron beam of 70 MeV, a few tens fs duration, and lower emittance from the Pohang Accelerator Laboratory Injector Test Facility (PAL-ITF). In this presentation, we show the simulation results on the generation of soft X-ray free electron laser pulses by LWFA-based electron beam using the external injection.

Keywords:

Laser-plasma accelerator , X-ray Free Electron Laser, Laser wakefield acceleration

표면 유전장벽 방전의 플라즈마 특성과 전기풍 발생 연구

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Abstract:

전기풍은 중성 기체 입자가 전기장에 의해 가속되는 하전입자와의 운동량 교환을 통해 전기유체역학적 (Electrohydrodynamic: EHD) 힘을 받아 발생하는 기체의 흐름이다. 이러한 전기풍은 전기 에너지를 기계적인 부분을 거치지 않고 기체의 유동으로 전환할 수 있다는 특성으로 인해 유체 제어에 활용하기 위한 연구가 진행되어 왔다. 이러한 연구들에서 표면 유전장벽 방전(Surface Dielectric Barrier Discharge: sDBD)은 표면을 따라 흐르는 유체 제어에 용이한 구조적 특성으로 인해 전기풍 발생원으로 주로 사용되었다. 본 연구에서는 이러한 sDBD에서 발생하는 플라즈마와 전기풍의 특성을 분석하고자 2차원 전산모사를 진행하였다. 15kVpp, 2.5kHz의 AC 전압을 전극에 인가했을 때 각 하전입자종의 밀도와 그에 따른 전기장의 분포를 계산하였고, 이를 기반으로 중성기체 입자에 가해지는 EHD 힘과 이로 인한 전기풍의 유속분포를 계산하였다. 중성기체로 질소만 있는 조건과 질소와 산소를 함께 고려한 조건에서 플라즈마의 시공간적 변화를 각각 계산함으로써 각 이온들의 전기풍의 특성에 대한 기여를 정량적으로 분석하였고, 전산모사와 동일한 실험 조건에서 전기풍의 유속을 측정하고 계산결과와 비교하였다. 그 결과, 측정 결과와 전산모사 결과는 각각 최대 1m/s와 1.3m/s로 차이를 보였으며, 이러한 전산모사와 실험의 차이를 줄이기 위해서는 방전 시작 후 플라즈마가 안정되고 전하가 축적되는 시간까지 전산모사를 진행해야 할 것으로 예상된다. 본 연구를 통해 시간에 따라 변화하는 sDBD의 하전입자종 밀도와 전기장 분포, 그에 따른 전기풍의 유속분포를 계산할 수 있는 전산모델을 개발하였으며 차후 여러 입력전압 주기 계산과 전산모델 개선을 통해 sDBD 유전체의 종류, 구조, 인가되는 전압 등의 조건에 따라 발생하는 플라즈마 변수와 전기풍의 특성을 예측하는데 사용될 수 있을 것으로 기대된다.

Keywords:

Atmospheric-pressure plasma, Surface dielectric barrier discharge, Electrohydrodynamic force, Electric wind

충돌-방사 모델 기반 베이지안 기계학습 기법을 이용한 아르곤 플라즈마의 전자 온도와 밀도 예측

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Abstract:

플라즈마의 방출광 분광법 및 충돌-방사 모델을 통한 전자 온도 및 밀도의 예측은 상대적으로 간단한 측정 시스템을 기반으로 물리적 특성 분석을 수행하는 장점을 지닌다. 그러나, 측정된 두 쌍의 파장 세기의 비율을 충돌-방사 모델에 활용하여 전자 온도와 밀도를 도출하는 일반적인 방법은 다양한 범위의 실험조건에 따라 서로 다른 파장 쌍을 선택해야 하는 모호함이 존재한다. 또한 방출광의 모든 스펙트럼 세기가 아닌 오직 네 개의 파장에 의한 진단결과 이므로 충분한 데이터가 활용되지 않는다는 한계가 있다. 본 연구에서는 이를 해결하기 위하여 기계학습 기법을 적용하여 예측하는 새로운 방법을 제시한다. 기존의 충돌-방사 모델에서 도출한 총 12개의 저온 아르곤 플라즈마 내 중성입자 방출광 세기를 다층 퍼셉트론 모델의 입력으로, 전자 온도 및 밀도를 출력으로 학습시켜 90% 이상의 예측 정확도를 확보하였다. 또한 베이지안 기계학습의 일종인 딥 앙상블 뉴럴 네트워크를 적용하여 예측 결과와 함께 오차를 계산할 수 있도록 하였다. 서로 다른 30개의 뉴럴 네트워크 모델을 학습시켜, 결과들의 평균을 예측값으로, 분산을 예측 오차로 추정하여 계산하였다. 본 모델의 유효성 입증을 위해, 5-20 W의 아르곤 축전결합 플라즈마와 150-200 W의 유도결합 플라즈마 실험을 활용하였으며, 개발된 머신러닝 모델로 예측한 값과, 램뮤어 탐침 기반 측정 데이터를 비교 및 분석하였다. 그 결과, 중성 기체온도 300 K, 기체압력 600 mTorr, 방전세기 20 W 축전결합 플라즈마에서의 전자온도는 머신러닝을 통해 1.50 eV, 램뮤어 프로브를 통해 1.33 eV로 계산되어 13%의 오차로 예측함을 확인하여 머신러닝의 유효성을 검증하였다.

Keywords:

Collisional-Radiative model, Bayesian machine learning, Plasma diagnostics

단층촬영 재구성 기법 및 충돌-방사모델을 활용한 홀추력기 플라즈마의 전자 온도 및 밀도 분포 특성 분석

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Abstract:

홀추력기는 이온가속을 통해 추력을 생성하는 전기추력기의 일종으로, 축방향 전기장과 방사방향 자기장이 교차하여 축 및 방위방향으로의 전자 및 이온요동, 다중전하 이온 생성 등과 같은 풍부한 물리현상이 관찰된다. 특히, 홀추력기의 채널 끝단의 근 자기장 플룸(near-field plume) 지역은 많은 양의 이온 생성과 가속이 발생하는 지역으로, 이 영역에서의 전자 온도와 밀도 진단은 홀추력기의 가속 및 이온화 특성과 추력성능을 분석하기 위해 필수적이다. 그러나, 일반적으로 근 자기장 플룸지역 내 플라즈마는 외부 음극과의 전류경로를 형성하므로 본 지역에서의 탐침과 같은 침습식 진단은 플라즈마 섭동을 크게 야기하여 전자 특성 진단이 제한적이다. 본 연구에서는, 단층촬영 재구성 기법을 통해 200 W급 저전력 홀추력기 아르곤 플라즈마 방출광의 공간분포를 도출하고, 충돌-방사(Collisional Radiative) 모델을 활용하여 채널 끝단부터 2, 6 mm지역에서의 전자 온도 및 밀도 분포의 국소분포를 계산하였다. 특히, 회전 및 선형 스테이지를 활용하여 홀추력기를 회전(0 – 180°, 10° 간격) 및 이동(0 – 64 mm, 0.8 mm 간격)함으로써 총 1,458개의 광섬유 시선정보를 측정하였으며, 라돈 변환 기법을 기반으로 17개의 아르곤 중성입자 방출광 국소 세기분포를 재구성하였다. 측정된 방출광 분포를 총 31개의 전이를 고려하는 아르곤 중성입자 충돌-방사 모델을 적용하여 전자 온도 및 밀도의 이차원 국소분포를 도출하였다. 결과적으로 양극전압 250 V 및 양극유량 1.1 mg/s 방전의 축방향 거리 2 mm에서 방위방향에 대해 평균적으로 전자온도 약 14 eV 및 전자밀도 $4.0 \times 10^{17} \text{ m}^{-3}$ 가 획득되었다. 본 발표에서 보다 상세한 국소분포 계산 결과 및 탐침 측정과의 비교, 분석이 소개될 예정이다.

Keywords:

전기 추력기, 홀추력기 플라즈마, 라돈변환, 단층촬영 재구성

아르곤-헬륨 플라즈마 내의 아르곤 준안정 준위 밀도 측정

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Abstract:

레이저는 통신, 국방, 정보처리, 가공, 계측, 의료, 생활기기 등 다양한 분야에서 활용되고 있으며, 특히 국방과 재료 가공 분야에의 응용을 위해서는 고빔품질의 고효율, 고출력 레이저가 요구되고 있다. 차세대 고출력 레이저 기술로 연속발진 다이오드 펌핑 불활성기체 레이저(diode pumped rare gas laser, DPRGL)가 제안되었다. DPRGL은 헬륨가스를 완충기체로 사용하여 네온, 아르곤, 크립톤, 제논 등의 불활성 원소를 이용한 플라즈마를 이득매질로 사용하는 방식이다. 따라서 이득 매질로 사용하는 에너지 준위의 밀도를 일정 수준 이상으로 유지해야한다. 아르곤의 경우 10^{12}cm^{-3} 이상의 아르곤 $1s_5$ 준안정 준위 밀도가 요구된다고 알려져 있다. 본 연구에서는 펄스방전 플라즈마에서 레이저 흡수 분광법을 이용하여 아르곤 $1s_5$ 준안정 준위 밀도를 측정하였으며, 아르곤-헬륨 혼합비를 조절하여 다양한 조건의 플라즈마에서 아르곤 $1s_5$ 준안정 준위 밀도를 측정, 분석하였다.

Keywords:

Metastable state, Laser absorption spectroscopy, High power laser, Pulse discharge, He/Ar plasma

ICP와 CCP가 결합된 플라즈마 식각 장비의 Particle-In-Cell 전산모사: 주파수 별 인가 전압 변화에 따른 이온에너지각도분포 비교

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Abstract:

반도체 식각 공정에서 이온에너지를 높이기 위해 저압 공정을 유지하면서도 플라즈마 밀도와 균일성을 확보하기 위해서 유도 결합 플라즈마(ICP)와 용량성 결합 플라즈마(CCP)가 혼합된 장비가 널리 사용된다. 일반적으로 ICP는 고밀도 플라즈마를 유지하는데 장점이 있고, CCP는 이온 에너지의 조절과 플라즈마 균일도를 확보하는데 장점이 있다. 특히 CCP에 인가되는 이중 주파수는 이온 플라즈마 진동수와 비교하여 고주파(HF)와 저주파(LF)로 나뉠 수 있는데, 고주파는 고밀도 플라즈마 생성에 기여하고 저주파는 웨이퍼에 입사되는 이온의 에너지를 조절하여 식각 공정의 정밀도를 높일 수 있다. 본 연구에서는 GPU로 병렬화된 2차원 Particle-In-Cell 시뮬레이션을 이용하여 CCP 장비에 ICP 효과를 추가하여 혼합 장비를 계산하였다. 웨이퍼 전극에 20MHz와 1MHz의 이중 주파수 RF 전력을 인가하여 고주파와 저주파의 전압비에 따른 입사 이온의 에너지 및 각도 분포를 비교하였다. 고주파 전압이 저주파 전압보다 높은 경우에는 위상에 따른 이온의 에너지 분포 변화가 크지 않지만 저주파전압이 고주파 전압보다 큰 경우 위상에 따른 이온의 에너지 분포 변화가 관찰되었다.

Keywords:

ICP, CCP, Dual-frequency, Ion Angle Energy Distribution

Optimization of 2.45 GHz Microwave Coupling and Recent Progress on Long Pulse Operation in Electron Cyclotron Resonance Ion Source (ECRIS)

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Abstract:

The optimization of 2.45 GHz microwave coupling in electron cyclotron resonance ion source (ECRIS) is investigated through experiments and full wave simulation studies in order to operate high density ion source. Previous researches on the 2.45 GHz ECRIS have shown that beam current density increases when the two ECR zones are located in the plasma chamber and when the first ECR zone is close to the RF entrance. A coupling study with various magnetic field profiles finds that the gap distance between the RF window and first ECR zone and the effective ECR zone width determine the coupling efficiency. Optimum power coupling is obtained under the condition of an appropriately slight gap distance comparable to the half width of the effective ECR zone. This explains the empirical observations which showed that the magnetic field strength at the microwave entrance should be close to B_{ECR} rather than an obviously higher magnetic field strength than B_{ECR} for efficient power coupling. With the optimized microwave coupling in ECRIS, long pulse operations (~ 1 hour) have been attempted. Recent progress on the long pulse operations with intensive conditioning is presented.

Keywords:

2.45 GHz electron cyclotron resonance (ECR) ion source, microwave coupling, axial magnetic field profile, gap distance, effective ECR zone width

Effect of photon intensity in ZnSe/GaAs grown by photo-assisted molecular beam epitaxy

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Abstract:

Resistive heating at the back of the substrate during epitaxy is a well-known method to control adatom incorporation processes at the growth front and form high quality semiconductor epilayers. However, heating through the entire sample thickness can introduce additional challenges associated with continued heating of buried epilayers in multilayer stacks. Photon irradiation of the growth surface, on the other hand, provides an alternative method to control growth processes and can permit the use of lower substrate temperatures. In this work, we investigate the role of intense, above-bandgap laser light in the growth of multiple layers, using ZnSe/GaAs as a model system. A 248 nm KrF excimer laser is used to supply above-bandgap photons during growth. We found that there are lower and higher limits of photon power to obtain high epitaxial quality.

The authors also would like to acknowledge support from National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF-2020R1F1A1070471) and System Semiconductor Development Program funded by Gyeonggi-do.

Keywords:

Optical and electrical properties of transparent polytetrafluoroethylene and (Ga, Ti)-codoped In₂O₃ composite films

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Abstract:

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Amorphous transparent conducting oxides can be used as transparent electrodes in flexible displays. Using a mixture of polytetrafluoroethylene (PTFE) and (Ga, Ti)-codoped In₂O₃ (GTiIO), amorphous thin films that are both conducting and transparent were fabricated. The percolation threshold for conductivity was found at a GTiIO volume percent between 53.35% and 68.54%. The transmittance of GTiIO films improved with the addition of PTFE. Using Bruggeman effective approximation to the dielectric functions of PTFE-GTiIO composite films, the volume fractions of PTFE and GTiIO components were determined. The dielectric functions of the PTFE films were determined using spectroscopic ellipsometry. Using the X-ray photoemission spectra, the coordination number of carbon atoms and F/C ratio of the PTFE films were estimated.

Keywords:

Semiconductor

Si 기판 위의 Ga₂O₃ 박막 성장 및 열처리 온도에 따른 결정 상의 변화 (Growth of Ga₂O₃ thin films on Si substrates and transformation of crystal phase by thermal treatment)

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Abstract:

산화물 반도체의 일종인 β-Ga₂O₃는 단사정계 (monoclinic) 구조로 상온에서 약 4.9 eV의 넓은 에너지 밴드갭을 가지는 반도체 재료로서 전력반도체용 소자 응용을 위해 연구가 활발하게 진행 중이다[1,2]. 다양한 형태의 고기능의 소자를 제작하기 위해서는 homo-epitaxy 이외에도 hetero-epitaxy 성장이 매우 유용한 기술이 될 수 있다. 본 연구에서는 Si 반도체의 높은 기술의 완성도와 Ga₂O₃ 박막의 우수한 물질적 특성을 활용할 수 있는 hetero-epitaxy 성장을 시도하였다. β-Ga₂O₃ 성장을 위한 기판으로 Si (111)를 사용하였다. Ga₂O₃ 박막 성장을 위해서 자체 제작한 수평형 metal organic chemical vapor deposition (MOCVD) 장비를 사용하였다. Ga 원자의 공급원으로는 trimethylgallium (TMGa), 산소 원자의 공급을 위해서는 DI water를 각각 사용하였으며, 분위기 가스 및 캐리어 가스로는 N₂ 가스를 사용하였다. Ga₂O₃ 박막 성장 시 TMGa와 H₂O의 유량은 각각 7 sccm과 450 sccm으로 고정하였다. 지금까지 Ga₂O₃ 박막을 600 °C 이상에서 열처리를 실시하면 ε-Ga₂O₃ 박막으로 결정상이 변화한다는 사실은 잘 알려져 있지만, Si (111) 기판 위에 성장된 ε-Ga₂O₃ 박막의 온도 변화에 따른 결정상의 변화 과정을 체계적으로 연구한 결과는 많지 않다. 따라서 본 연구에서는 성장 조건 변화에 따른 ε-Ga₂O₃ 박막의 결정질을 평가하는 한편, ε-Ga₂O₃ 박막을 500 °C, 550 °C, 600 °C, 650 °C, 700 °C에서 각각 성장시킨 후, 900 °C에서 10분씩 열처리를 실시한 후에 결정상이 전이된 β-Ga₂O₃ 박막의 결정학적 특성에 대해 평가를 진행하였다. 한편, Schottky diode 제작을 위해 열처리에 의해 결정 상이 변화된 β-Ga₂O₃ 박막들 위에 Ti/Au를 증착하여 Schottky contact을 형성하고, Si 기판 뒷면에는 Al을 증착하여 ohmic contact을 형성하였다. SEM, XRD 측정을 통해 표면 상태 및 결정 구조를 평가하였고, 수직형 Schottky diode의 전기적 특성 분석을 위해 I-V 측정을 시행하였다.

이 연구는 2021년도 정부(산업통상자원부)의 재원으로 한국산업기술진흥원의 지원을 받아 수행된 연구임
[1] M. Orita, H. Ohta and M. Hirano, "Deep-ultraviolet transparent conductive β-Ga₂O₃ thin films", Appl. Phys. Lett. 77 (2000) 4166.
[2] M. Higashiwaki, K. Sasaki, A. Kuramata, T. Masui and S. Yamakoshi, "Development of gallium oxide power devices", Phys. Stat. Soli. (a) 211 (2014) 21.

Keywords:

MOCVD, Ga₂O₃, homoepitaxy, n-si(111), Schottky diode

Uncertainty in the mutual calibration method for the traceable thickness measurement of ultra-thin oxide films

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Abstract:

Mutual calibration by a combination of a zero-offset method and a length-unit traceable method has been suggested as a promising approach to determine the traceable thickness of ultra-thin oxide films. However, the measurement uncertainty is somewhat complicated to calculate because the standard uncertainties from the two measurement methods and the linear regression process should be combined. In this study, the mutual calibration method to evaluate the film thickness and uncertainty of ultra-thin oxide films was investigated. The algorithm of the linear regression equation in the mutual calibration method was studied and the uncertainty calculation program for the thickness measurement by mutual calibration was developed. The result will provide an effective and useful guideline to certify the thickness of the ultra-thin oxide film on Si(100) substrate which is used as the gate oxide in the semiconductor devices. The magnitude of the relative expanded uncertainty in the thickness measurement by mutual calibration is in the range from 8.6% to 9.3%.

Keywords:

thickness measurement, uncertainty

Extension of Density-functional-based Tight-Binding Parameters for Indium Compound Semiconductors

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Abstract:

The new material parameter files for density-functional-based tight-binding (DFTB) calculation method have been generated and validated. The DFTB method has been reported as a successful and effective approximation of the quantum mechanical calculations for atomistic structure and also electronic structures of semiconductors, surfaces, and nanostructures. The bottleneck of the wide usage of the DFTB method has been the limited number of material parameter files, i.e. Slater-Koster (SK) set. In this presentation, the extension of the new parameter files from the pre-existing SK set will be shown. The new parameter for Indium has been developed by extending the Mio set. This In-mio set enables us to investigate the group III-V compound semiconductor InP with the DFTB method. The comparative benchmark calculations by DFTB and density functional theory (DFT) methods will show the validity of the new materials parameter files of In-mio set for DFTB method.

Keywords:

DFTB, parameter

Growth and characterization of copper oxide thin films with different oxygen flow during RF magnetron sputtering

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Abstract:

Oxide semiconductors are attracting a lot of attention as an alternative to conventional a-Si due to their reasonable electrical and optical properties. Although most of oxide semiconductors exhibit intrinsic n-type characteristics due to oxygen vacancy, there are some materials with intrinsic p-type properties, such as Cu₂O, CoO, and NiO. Among them, copper oxides are considered a good candidate because of their low cost, non-toxicity, and high electrical and optical properties. In most oxide semiconductors, electrons are generated by oxygen vacancies (V_O) from weak bonds between oxygen and metal atoms, and holes are generated by metal vacancies (V_M) from strong bonds between metals. Accordingly, the electrical characteristics of the p-type oxide semiconductor having many holes are disadvantageous compared to the n-type oxide semiconductor having many electrons. Therefore, to improve the performance of the p-type characteristic, it is necessary to deposit Cu₂O without increasing V_O .

In this work, we deposited the copper oxide films under various rates of oxygen gas flow during RF magnetron sputtering. Here, the oxygen gas ratio in mixed gas with argon are ranging from 0 to 10%. These films were deposited on quartz substrates by RF sputtering using a Cu₂O target at 50 W for 30 min. The post-deposition annealing process was performed for 1h at a temperature of 300 °C under O₂ ambient. As the results of XRD and UV-vis absorption spectroscopy, it was confirmed that the physical properties changed from Cu₂O to CuO as the oxygen ratio increased. From the Hall-effect measurement, the hole concentration was increased from $1.0 \times 10^{13} \text{ cm}^{-3}$ to $4.68 \times 10^{17} \text{ cm}^{-3}$ as increasing the oxygen gas ratio from 0 to 10%. The effect of oxygen on electrical and optical properties in Cu₂O films will be discussed.

Keywords:

copper oxide, p-type oxide semiconductor

Optical characteristics of Ga₂O₃ thin films by oxygen plasma-assisted pulsed laser deposition

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Abstract:

In recently, deep ultraviolet (DUV) photodetectors that have detection ranges from 200 nm to 280 nm wavelengths are in high demand because of their potential applications in various areas. Such as missile tracking, fire detection, ozone holes monitoring, chemical or biological molecules analysis, and space-to-space communication. Recently, wide-bandgap semiconductors such as AlGa₂N, MgZnO, diamond, and β-Ga₂O₃ were mentioned as candidates for solar-blind photodetectors. In β-Ga₂O₃ photodetectors with a direct bandgap of ~4.9 eV, the oxygen vacancy control is an important issue because the vacancies act as not only donors but also causing structural defects. However, it is difficult to control the appropriate amount of oxygen vacancies for practical application.

In this work, we fabricated β-Ga₂O₃ photodetectors under oxygen plasma conditions to optimize the oxygen vacancies. The β-Ga₂O₃ films were grown on quartz substrates by plasma-assisted pulsed laser deposition (PAPLD) technology using a β-Ga₂O₃ target (99.99 % purity). A pulsed (10 Hz) neodymium-doped yttrium aluminum garnet (Nd: YAG) laser was operated at a wavelength of 266 nm and a density of energy of ~90 mJ/cm². After growth at the temperature of a substrate of 250 °C for 15 minutes, the film thickness obtained about 120 nm. The transmittance shows a sharp cut-off at 280 nm of the DUV region. From the Tauc-plots, the bandgap was calculated to shifting from 4.9 eV to 5.1 eV in the presence of oxygen plasma. The effect of the oxygen plasma will be discussed with these results.

Keywords:

β-Ga₂O₃ , Pulsed laser deposition, Deep ultraviolet, Photodetector

Excited-state absorption in perovskite MA_{0.2}FA_{0.8}PbI₃ single crystal

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Abstract:

Recently, organic-inorganic hybrid halide perovskites have gained much attention on their excellent optoelectronic properties for various applications such as solar cells, light-emitting diodes, gamma-ray detectors, lasers, and nonlinear optics. Also, one can readily tune the bandgap of this material by modulating the halide composition ratio. In this work, we have prepared an MA_{0.2}FA_{0.8}PbI₃ single crystal by inverse temperature crystallization, which has an ideal bandgap for the performance of a solar cell, 1.5 eV. Interestingly, this bulk perovskite exhibits unusual multi-photon absorption (PA), in which the order of the PL varies with the excitation wavelength. We employed fine-scale PL excitation (PLE) spectroscopy along with temperature dependence, in order to clarify the origin of this unusual behavior in our perovskite under one, two and three PA. Based on the excitation power dependence across the 2PA and 3PA edges, we found an evidence for excited-state absorption. Also, 2PA and 3PA coefficients and the corresponding damage thresholds were precisely determined.

Keywords:

FAMAPbI₃, Excited state absorption, Perovskite

습도 환경에서 MAPbBr₃의 공간 및 에너지 트랩 분포

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Abstract:

개요: 유기-무기 할로겐화 납 페로브스카이트 태양 전지(PSC)는 광대역 클리어런스 투명도, 잠재적 유연성 및 더 빠른 연속 롤투를 제조를 통해 결정질 실리콘 PV보다 현재 유리한 새로운 박막 광전지 기술로 독특한 틈새 응용성을 보여줍니다. . 그러나 PSC는 물에 잘 녹기 때문에 습기를 피하기 위해 일반적으로 글로벌 박스 내부에서 제조 공정을 수행합니다. 이 연구에서 우리는 PSC의 제조 환경 습도에 따라 트랩 상태의 밀도와 트랩 에너지 분포 프로파일이 관찰되었음을 보고합니다. 제조 환경에 따라 트랩 밀도는 dry N₂, RH25, RH50, RH80에서 5~1000배, 최소값은 $3.7 \times 10^{14}/\text{cm}^3$ 로 측정되었습니다. 대부분의 트랩 밀도는 인터페이스에 있습니다. 놀랍게도, 25% RH에서 제작된 MAPbBr₃(CH₃NH₃PbBr₃) 태양 전지는 습기가 없는 건조한 N₂ 환경보다 더 낮은 트랩 밀도와 더 높은 장치 성능을 보여주었습니다.

Keywords:

moistureMAPbBr₃ (CH₃NH₃PbBr₃) trap density

Structural and optical properties of perovskite films by antisolvent application speed

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Abstract:

Among various synthesis methods of perovskite films, one-step antisolvent treatment method has been used in much research because of its efficient and simple process. To form a high-quality perovskite film, an antisolvent treatment method is used that induces perovskite crystallization by extracting the solvent from the perovskite precursor solution. However, the faster the speed of dripping the antisolvent, the damage to the surface of the film, and the slower the speed, the greater the interaction due to the difference in solubility between the antisolvent, solvent, and precursor material, which affects the microstructure of the formed perovskite film. We synthesized perovskite films using different dripping speeds of the antisolvent in the ambient atmosphere for comparative analysis. The structural and optical properties of the perovskite films were investigated using X-ray diffraction, scanning electron microscopy, photoluminescence (PL), and time-resolved PL measurements. These results can be a milestone for the synthesis of high-quality perovskite films following the application of various antisolvents.

Keywords:

perovskite, antisolvent, dripping speed

Towards to strong light-matter interaction in AlGaAs based microcavity by using metal organic chemical vapor deposition

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Abstract:

Strong coupling of light-matter interactions in microcavity shows Rabi splitting behavior and exciton-polaritons. Most researches about the strong coupling in AlGaAs based microcavities with quantum wells (QWs) and distributed Bragg reflectors (DBRs) have been usually assisted by molecular-beam epitaxy, which can fabricate very high-quality epitaxial structures and shows rich optical properties. On the other hands, the metal organic chemical vapor deposition (MOCVD) has advantages in fast growth rate and large-scale production for application. However, the above-mentioned microcavity research using MOCVD have been rarely investigated probably due to relatively less precision control in epitaxial growth, causing a relatively broader linewidth of QW emission that prevents the strong coupling condition even at low temperature. Here, we fabricated AlGaAs based microcavity, which consists of 32 top & 50 bottom DBRs and multiple QWs using MOCVD and measured optical properties of photoluminescence at low temperature. Although the microcavity has a high Q factor of cavity mode, it is still in weak coupling regime and shows just photonic lasing behavior because of a relatively large linewidth broadening of QW. To achieve strong coupling condition, it is necessary to narrow the linewidth of QW emission further and to fabricate higher quality of QW structures. Although MOCVD mainly focused a vertical-cavity surface-emitting laser that operating at room temperature so far, this study will be able to increase the accessibility to exciton-polariton research through MOCVD growth in the near future.

Keywords:

MOCVD, Exciton-polariton, light-matter interaction, VCSEL

Optical investigation of coupling between exciton and superscar mode in GaN prism structure grown by metal organic chemical vapor deposition

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Abstract:

Wide bandgap semiconductor GaN has large exciton binding energy and high oscillator strength, which offers a good platform for investigating room temperature exciton-polaritons. Room temperature polaritons have been reported previously in whispering gallery mode (WG) mode cavities of GaN microrod structure. However, a lower quality factor of WG mode is the main challenge to utilize room temperature polariton device. Here, we demonstrate a superscar mode polariton in triangular GaN prism structure fabricated by bottom-up approach via metal organic chemical vapor deposition. Superscar mode, which has a longer optical path than WG mode cavity, resulting relatively higher Q factor. We carried out wavelength- and angle-resolved photoluminescence, showing signature of coupling of exciton and superscar mode, which was also compared with calculation results.

Keywords:

Exciton-polariton, superscar mode, prism structure, photoluminescence measurement

전력반도체 신소재를 위한 육각형태 Si 결정의 성장과 특성

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Abstract:

에너지 저장장치, 전기차, 재생에너지의 발전으로 전력반도체 산업이 빠르게 성장하고 있다. 대부분의 전력반도체는 Si 웨이퍼를 기초 소재로 사용해왔다. 하지만 Si이 가진 특성은 점차 발전하는 고성능 전력반도체의 요구를 만족시킬 수 없는 물리적 한계에 도달했다. Si은 표준 조건에서 일반적으로 다이아몬드 입방 구조를 가지나 물질을 구성하는 원자의 배열을 다르게 하면 물질이 가지는 특성을 변화시킬 수 있다. 본 연구에서는 혼합 소스 수소화물 기상 증착법(HVPE)을 이용하여 육각 형태 Si 결정을 성장시켰다. Al, Ga, Si 소스와 HCl 가스를 사용하여 금속-염화물 가스를 생성한 후 Si 기판 위에 육각 형태 Si 결정을 얻었다. 성장 시간은 100분이며 HCl 가스는 성장 시간 전반에 걸쳐 지속하여 공급하였다. 결과적으로 직경 약 50 μ m, 최대 길이 3000 μ m, 중형비 1:200 이상을 가지는 육각 형태 Si 결정을 성장시켰다. 육각 형태 Si 결정은 전계방사형 주사전자현미경(FE-SEM)을 통한 표면 관찰, 에너지 분산 X-선 분광법(EDS)과 X-선 광전자 분광법(XPS)을 통한 정성 및 정량 분석, 고분해능 X-선 회절분석기(XRD)와 라만 분광기를 통한 구조적인 분석을 진행했다. 그 결과 혼합소스 HVPE 방법으로 성장한 육각 형태 Si 결정은 기존의 Cubic Si과 다른 구조의 Si으로 고성능 전력반도체 소자 제작을 위한 신소재로서의 가능성이 기대된다.

Keywords:

MS-HVPE, Hexagonal Si, Si allotrope

Simultaneous Implementation of Artificial Neurons and Artificial Synapses Characteristics using CuTe/GeS₂-based Memristor

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Abstract:

Recently, with the advent of the artificial intelligence (AI) era, artificial neural network (ANN) which mimics the human brain using hardware has attracted great attention. The neural network structure consists of artificial neurons that act as nerve cells in the brain and artificial synapses that connect pre-synaptic and post-synaptic neurons. In general, since the electrical characteristics corresponding to the roles of the artificial synapse and the artificial neuron are different, different devices are required to implement each characteristic.

In this study, we developed a CuTe/GeS₂-based memristor that simultaneously implements both artificial synapse and neuron characteristics by varying the current density. The schematic device structure and cross-sectional transmission electron microscopy (TEM) image was demonstrated. The CuTe/GeS₂-based memristor cell has a structure of the bottom Ti electrode, 10-nm thick GeS₂ switching layer, 10-nm thick CuTe source layer, and top Ti electrode. The CuTe/GeS₂-based memristor demonstrated volatile electrical characteristic when the current density was less than 400 A/cm². It exhibited a set voltage of 1.10 V and selectivity of 2.39×10^4 . In addition, CuTe/GeS₂-based memristor demonstrated non-volatile electrical characteristic when the current density was higher than 2000 A/cm². It exhibited a forming voltage of 2.24 V, a set voltage of 1.25 V, reset voltage of 1.1 V and I_{on}/I_{off} ratio of 2.71×10^1 .

In this presentation, we implemented artificial neuron and synapse characteristics using volatile and non-volatile characteristics of memristor by varying the current density. The characteristics of artificial neuron, integrate characteristics, was confirmed using volatile characteristics. In addition, the characteristics of artificial synapse, long-term potentiation/long-term depression (LTP/LTD) and paired-pulse facilitation (PPF), was confirmed using non-volatile characteristics.

Acknowledgement

This research was supported by the MOTIE (Ministry of Trade, Industry & Energy) (10068055) and KSRC (Korea Semiconductor Research Consortium) support program for the development of the future semiconductor device.

Keywords:

Artificial Neurons, Artificial Synapses, CuTe/GeS₂-based Memristor, Simultaneous Implementation

AlGaInP 적색 micro-LED의 칩 크기 및 p-GaP층 두께에 따른 에피-칩 발광 특성에 대한 연구

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Abstract:

AlGaInP 물질은 원소의 조성비에 따라 고휘도의 적색 영역에서 노란색 영역의 범위에 이르며 LED에 응용된다. 적색 micro-LED의 경우, 칩 크기가 50 μ m 이하로 줄어들어 따라서 표면 재결합이 급격히 증가하여 내부양자효율이 크기에 따라 급격히 변하는 현상이 발생한다. 본 연구에서는 적색 계열의 AlGaInP로 구성된 epi structure 개선에 따른 동작전류 영역에서 내부양자효율(IQE)의 향상 가능성에 대해 중점을 두고, 온도에 따른 PL spectrum의 분석을 통해 활성층에서 결함분포의 차이와 excitation power에 따른 내부양자효율의 결정을 통해 최적의 효율을 내는 carrier density의 정도를 파악하였다. 다음으로 micro-LED의 칩 크기(직경 20, 10, 5, 3 μ m)에 따라 나타나는 LED의 발광 특성을 알아보기 위해 PL spectrum을 분석하여 size effect를 파악하였고 micro-chip의 center와 sidewall의 PL spectrum의 경향성을 통해 활성층의 재결합속도에 미치는 영향을 파악하였다. 이러한 분석을 통해 PL 특성이 칩 크기 및 활성층의 특성에 크게 의존하여 변하는 현상을 관측하였다.

Keywords:

내부양자효율, 활성층, 칩 크기, 결함

A reason for the PL reduction analyzed by machine learning approaches

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Abstract:

Various quasi- and single particles are closely linked to each other in terms of physical coupling and collisions. These correlations enable to indirectly estimate the optical or electrical properties, which have difficulty on direct observation. Thus, this correlation has been widely studied and reported so far.

Herein, we introduce machine learning-based approaches which indirectly estimate the photoluminescence efficiency of MoS₂ by phonon property measured by Raman. From the results, we derive the generalized answer why photoluminescence is reduced and influencing defects via tracking the nodes. Each node in the hidden layer featured the defects appearing as ripple points, grain boundaries, ripple-near locations, interstitial defects, and edge sides. In complexly combined quantum physics, there is no mathematical answer. And we merely argue a generalized answer suggested by machine learning which may or may not be correct.

Keywords:

MoS₂, Raman, Photoluminescence, machine learning

Instability of Image Scoring in the continuous model of indirect reciprocity

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Abstract:

A key issue of indirect reciprocity is how to store, transmit, and retrieve information on each other's past action in a distributed manner. A recent study shows that the problem of private, noisy, and incomplete information can be handled analytically by regarding reputation and cooperation as continuous variables, as long as mutant norms are close to the existing one. In this way, the linear-order perturbative analysis suggests that it suffices to judge someone solely based on his or her action to another person regardless of their reputations, which is known as Image Scoring. However, this argument goes against our intuition because such a norm would not justify punishing defectors. In this work, we analyze the instability in more detail and conclude that if one cannot refer to previous reputations for assessment, the only stable fixed point is the complete breakdown of cooperation. The speed of this dynamics can nevertheless be slow because it is proportional to the fraction of mutants.

Keywords:

indirect reciprocity, Image Scoring

Finding different regimes of Korean stock market and Seoul-si housing market via record statistics with drift

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Abstract:

본 연구에서는 record statistics를 바탕으로 한국 주식 시장과 주택 시장의 거동을 이해하고자 한다. 이를 위해 우리는 inter-record 분포를 연구하였다. 주식시장과 주택시장에서 구한 inter-record 분포와 first-passage 분포 사이의 연관성을 논의한다. 이로부터 inter-record 분포가 record 발생 비율 및 record 발생 횟수인 record number에 미치는 영향에 대해 논의한다. 추가적으로 record statistics에서 주요 관심사가 되는 record number의 기댓값과 record number의 분산, record 발생 비율의 다른 두 시점에서 연결된 상관관계인 connected correlation에 대해 논의한다.

Keywords:

Extreme Statistics , EconoPhysics, Complex System

Phase transition of Laplacian roughening model on two-dimensional lattices

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Abstract:

Phase transition of the discrete Laplacian roughening model is investigated on a triangular and a square lattice.

By using the Wang-Landau method, we obtain the density of states, by which the internal energy and specific heat are calculated as a function of temperature.

A single transition is observed on both lattices and critical exponents on both lattices are in good agreement with each other.

The finite-size scaling analysis of the partition function zeros confirms the exponents independently.

Keywords:

Laplacian roughening model, Wang-Landau Monte Carlo simulation, partition function zeros

Exact Density of States for the Square-Lattice Ising Model with a Ratio of 2:1 between the Nearest-Neighbor and the Next Nearest-Neighbor Interactions

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Abstract:

The exact integer values for the density of states of the square-lattice Ising model with a ratio 2:1 between the nearest-neighbor interaction and the next nearest-neighbor interaction (J_2) are evaluated on $L \times 2L$ square lattices with free boundary conditions in the L -direction and periodic boundary conditions in the $2L$ -direction up to $L=12$. The total number of spin configurations is $2^{288} = 5 \times 10^{86}$ for $L=12$, and counting all 2^{288} spin configurations requires enormous computational work. For $J_2 < 0$, the number of the ground states of the square-lattice Ising model with a ratio 2:1 between the nearest-neighbor interaction and the next nearest-neighbor interaction increases as 2^L , as the system size L increases. In the thermodynamic limit, the number of the ground states becomes infinite for $J_2 < 0$. Therefore, it is very difficult to understand the properties of the square-lattice Ising model with a ratio 2:1 between the nearest-neighbor interaction and the next nearest-neighbor interaction for $J_2 < 0$.

Keywords:

Exact density of states

The Rouse-like out-of-equilibrium dynamics for active Brownian particle on stiff polymer network

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Abstract:

Self-propelled particles can perform directed motion using internal chemical energy or energy from the environment. Their out-of-equilibrium nature is the origin of intriguing structural and dynamical properties within biological polymer networks. As a minimal model, we investigate the dynamics of active particle-polymer composite system where the active Brownian particle (ABP) having self-propelled motion cross-links star-shaped stiff $l_p \gg b$ worm-like chains (WLC). We perform the Langevin dynamics simulation on this system at various conditions. We found that the ABP cross-linker shows an active but subdiffusive motion with the scaling $\langle \Delta R^2(t) \rangle \sim t^\alpha$ with $1/2 \leq \alpha \leq 3/4$; $\alpha = 3/4$ is for the monomer dynamics of the passive WLC. As self-propulsion velocity v_p of ABP increases, the apparent anomaly exponent α surprisingly approaches towards $1/2$ which is observed in the monomer dynamics of the ideal chain called Rouse dynamics. Measuring non-Gaussian parameter, we found the difference that the motion of ABP on stiff chain is non-Gaussian while ideal chain has Gaussian process. Our results suggest a new interpretation of the existing results observed as Rouse-like dynamics $\langle \Delta R^2(t) \rangle \sim t^{1/2}$ [1-2]. This study is an extension of our previous work using flexible chain polymer [3].

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Keywords:

Active Brownian particle, Wormlike chain, Viscoelastic feedback, Anomalous dynamics

Solving a generalized Langevin equation violating the fluctuation-dissipation theorem under an asymmetric ratchet potential

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Abstract:

A viscoelastic system is governed by a generalized Langevin equation, where viscoelastic interactions are described by a memory kernel $K(t-t') \sim |t-t'|^{-\alpha}$, and the particle has an effective noise $\zeta(t)$ governed by the autocorrelation $\langle \zeta(t)\zeta(t') \rangle \sim |t-t'|^{-\beta}$. Using the GLE, we study active particle moving through a periodic potential in a viscoelastic environment where the active particle's motion violates the fluctuation-dissipation theorem (FDT). We numerically solve the GLE for several types of the memory kernel and effective noise under an asymmetric ratchet potential. Both exponents of memory kernel and correlation of effective noise determine the dynamics of particle in active viscoelastic system. We investigate ergodicity breaking of active viscoelastic systems violating the FDT. Our results can give an insight into related problems such as dynamics of ATP-consuming proteins on a DNA.

Keywords:

Generalized Langevin equation, Viscoelastic system, Anomalous diffusion, Ergodicity breaking

Homoepitaxial growth of polymer films on liquid surface

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Abstract:

화학 기상 증착법을 통해 액체기판위에서 기른 선형체인폴리머 패럴린-C의 초기 성장 영역을 AFM으로 스캔하고 계면의 특성을 동력학적 스케일링 이론을 적용하여 논의할 것이다. 일반적으로 박막을 증착함에 있어서 기판과 증착 물질이 같은 경우 호모 에피택시(Homoepitaxy), 기판과 증착 물질이 다른 경우를 헤테로 에피택시(Heteroepitaxy)라 한다. 액체 표면위에서 패럴린을 증착하는 경우 초기 성장영역에서 거의 원자 단위의 평평한 막의 형성과 함께 마치 호모 에피택시 특성의 초기 성장 패턴을 얻을 수 있었다. 평평한 막 위에 자연스럽게 가로방향으로 연결된 모노머 체인은 증착이 진행됨에 따라 네트워크 형태로 자라면서 점차 표면을 채우며 성장하게 된다. 이는 일반적인 고체 위에서 성장한 폴리머 박막과는 그 양상이 매우 다르다. 오히려 액체 표면에서 만들어진 폴리머 막 위에서의 성장은 실질적으로 호모 에피택시에 해당된다. 이는 표면에 입사된 모노머가 폴리머체인을 형성하면서 형성된 체인 사이에 작용하는 강한 상호작용(응집력)이 폴리머막과의 상호작용에 의해 억제되었기 때문이다. 그럼에도 폴리머 필름을 200nm 이상 충분히 성장시켰을 때 표면의 성장계수 $\beta = 0.25 \pm 0.01$, 동적계수 $1/z = 0.18 \pm 0.02$, 로컬 거침계수 $\alpha_{loc} = 0.74 \pm 0.01$, 스펙트럼 거침계수 $\alpha_s = 1 \pm 0.05$ 를 얻었으며 이는 고체표면에서 성장한 박막의 특성과 동일하다.

Keywords:

AFM, Dynamic scaling theory, linear chain polymer

Heterogeneous diffusion described by Telegrapher's equation

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Abstract:

We study persistent random walks described by Telegrapher's equation in a heterogeneous environment. We consider a set of random walkers with individually distinct directional persistencies (relaxation rates) and examine dynamic observables obtained from the superstatistics. In particular, we analytically derive the velocity autocorrelation function and the flight-time distribution. Our heterogeneous persistent random walk shows various anomalous diffusion according to the distribution of the walker's relaxation rate.

Keywords:

Telegrapher's equation, Persistent random walk, Heterogeneity, Anomalous diffusion, Superstatistics

Correlation between concurrence and mutual information

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Abstract:

We investigate how entanglement in a two-qubit system relates to mutual information, a classical residue after performing the local projective measurement on the system. For a given ensemble of random pure states, we calculate the joint probability of concurrence and mutual information. It turns out that mutual information coincides with concurrence for some localized cases although mutual information generally has no lower bound due to the information loss caused by the measurement. We also discuss the effect of phase difference on the correlation between the quantum and classical information measures.

Keywords:

entanglement, concurrence, mutual information

Tracking and modeling of living particles using deep learning and active Brownian dynamics

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Abstract:

Bacterial system is usually categorized as active matter because of constituent particle's self-propulsion. In opposite to passive particles, it is not straightforward to explain the process that living organism perceives its surroundings and decides its next motion. Furthermore, equilibrium statistical mechanics is not applicable for living system due to the existence of energy dissipation. There have been many attempts to describe the motion of living particles with non-equilibrium statistical mechanics adopting stochasticity.

In this work, we observe non-pathogenic bacteria, *B. Subtilis*, to study living active matter. After obtaining video data from bacterial system confined in 2-dimensional world, we extracted their quantitative trajectory data using object tracking method adopting deep learning. In order to understand the motion of bacteria, we compare our trajectory data with that of known phenomenological active particle models based on Brownian motion such as run-and-tumble model and rotational diffusion model.

Interestingly, the two models are analytically identical in terms of mean squared displacement and average displacement, but show a difference in their velocity change distribution. Using this measure, we compare experimental data with each model.

Keywords:

active matter, object tracking, deep learning, run-and-tumble model, rotational diffusion model

Charge sequence influence on polyampholyte translocation: Exact enumeration study

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Abstract:

We investigate the role of the charged sequences on the translocation behavior of polyampholyte chains through a pore. By means of Monte Carlo simulations incorporating a realistic translocation potential profile along the pore, the translocation behavior (translocation vs. rejection) is recorded for all 2^{20} sequences comprised of $N = 20$ charged monomers. The results are compared with those for 10^7 random sequences of $N = 40$ to better demonstrate asymptotic laws. The distributions of translocation times and rejection times are measured. Rejection and short sequence ($N = 20$) translocation are mainly controlled by the head-sequences at short times, but late translocation/rejection is governed by the escape from a trapped state over an antagonistic barrier sequence. The probability distribution of translocation times from all successful attempts reveals a power-law tail decaying $\propto t^{-(1+\mu)}$ where the exponent increases with the number of favorable net charges ($\mu < 1$, except close to the limit where all charges are agonistic). We provide operational criteria for the translocation behavior of the sequences.

Keywords:

Polyampholytes, translocation

Partially globular conformations from random sequences: when nature does not cut even shares

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Abstract:

Overall charged polymers with quenched charge sequences often adopt partially globular structures. Simple energetic considerations show that structures with alike (equal-size–equal-charge) globules are not favourable. We predict the globule distributions with the lowest energies in the size–charge space, they comprise large (undercharged) and small (overcharged) globules. We also perform large scale numerical simulations on random quenched +/- sequences (polyampholytes). It is shown that the simulated sequences preferentially visit the predicted low energy structures despite their quenched charge distribution. Implications for polyampholytes, polyelectrolytes and intrinsically disordered proteins are discussed.

Keywords:

Randomly charged polymer, Simplex, Rayleigh instability, Polyampholyte, Polyelectrolyte

Diffusion properties of active particles in an interacting polymer network

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Abstract:

The active self-propelled particles consume energy from the environment. Examples are swimming E. coli or motor protein that consumes ATPs. Viscoelastic environments like polymer networks can change particle diffusion dynamics drastically, and understanding the diffusion of self-propelled particles in such environments is a challenging problem. Self-propelled particles are in a nonequilibrium state, constantly driving the system away from equilibrium. We construct a computational model of polymer networks and perform the Langevin dynamics simulation for the active self-propelled particles therein. We systematically investigate the dependence of the long-time diffusivity of the self-propelled particle on the particle-network interaction strength and the Péclet number. This result may give an insight into the transport dynamics of motor proteins interacting with a biological network or the drug delivery via active particles in the polymer networks.

Keywords:

active particle, polymer network, diffusion dynamics, transport dynamics, self-propelled particle

Order-to-disorder Transition of Discrete Polymer Chain Model: Analytic Calculation Using Random Phase Approximation

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Abstract:

Random Phase Approximation (RPA) is an approximation method adopted in polymer physics for the system under weakly inhomogeneous field. During the RPA calculation, the effects of polymer chains in the system are represented by self-consistent mean field. The total field contribution is averaged out while contribution from perturbing parts of the field in Fourier space survives. Because RPA calculation allows us to analytically calculate the structure factor of the polymer chain in disordered state, the RPA is one of the useful methods to study order-to-disorder transition (ODT).

The RPA is well known for finding the ODT point of AB block copolymer melts in continuous chain model, $(\chi N)_{\text{ODT}}=10.495$, but RPA calculation of discrete chain models is a relatively new subject. The result for the RPA calculation for discrete chain can be diverse depending on the discretization method of chain model. In our study, we solve integral equation of partition function of the discrete chains instead of solving differential equation of continuous chains. Using this integral equation method, we calculate structure factor of AB binary homopolymer mixture and AB block copolymer melts to find ODT point for various chain length and discretization method and compare the result with the continuous chain model.

Keywords:

polymer physics, Random phase approximation, self-consistent field

Magnetic colloidal crystals under active noise

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Abstract:

A colloidal particle at equilibrium exhibits the Brownian motion by thermal noise. When this particle is under a potential or experiences active noise at a non-equilibrium state, the particle's motion deviates from the free diffusion. As a model system of such particles, we experimentally observe a system of particles, i.e., the quasi-two-dimensional colloidal crystal formed by super-paramagnetic beads under a vertical magnetic field. Each particle is trapped in a potential by magnetic dipole-dipole interaction, and the repulsion between each particle results in a hexagonal pattern. We may add active noise to the system by placing the 2D colloidal crystal in a bacterial bath. We investigate how the potential and active noise affect the particles' motion by tracking their trajectories.

Keywords:

colloidal particle, non-equilibrium, active noise, trapped particle

Microbes crossing liquid-liquid interfaces

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Abstract:

Some microbes swim by rotating their flagella bundles in the viscous liquid, balancing the propulsion force with the viscous drag force at a low Reynolds number environment. Dispersing rod-like and swimming *Bacillus subtilis* into a quasi-two-dimensional environment with liquid-liquid interfaces such as isotropic-nematic coexistence phases of aqueous liquid crystals, we observe how they interact with the interfaces. Our experimental observations indicate that bacteria with a lower incident angle, i.e., more normal to the interface, have a higher probability of crossing the interface. We observe no strong correlation between the crossing probability and the incident speed and body length. Hypothesizing the interfacial deformation by the rod-like bacteria, we propose a force-balance model where the propulsion force, viscous drag force, and interfacial tension are intertwined. The crossing criterion from the model indeed supports that the incident angle may play a vital role in the crossing behavior.

Keywords:

liquid-liquid interface, microbes, low Reynolds number

Effect of point defects on electronic structure of monolayer GeS

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Abstract:

Two dimensional (2D) materials have recently attracted great attention in the fields of electronic devices due to their unique electrical and optical properties. Among 2D materials, graphene, black phosphorus (BP), and transition metal dichalcogenides (TMDs) have been actively studied in various ways. Along with such attention, germanium sulfide (GeS) has also received attention as it has a similar structure to BP. Furthermore, it is worthwhile to note that defects in 2D materials play a fundamental role in variation of their electronic properties because they can be donor or acceptor. In this study, the effects of vacancies and substitutional atoms in monolayer GeS are investigated using density functional theory calculations. We choose group IV or chalcogen atoms as substitutional ones which substitute for Ge or S in GeS. It is found that the bandgap of GeS with substitutional atoms is close to that of pristine GeS, while the bandgap of GeS with Ge or S vacancies is smaller than that of pristine GeS. In terms of formation energy, monolayer GeS with Ge vacancies is more stable than that with S vacancies. Moreover, any kinds of defects do not make significant changes in piezoelectric properties. Details are analyzed using the partial density of states.

Keywords:

defects, GeS, piezoelectric property, DFT

Computational studies of electronic properties of Cr₂Ge₂Te₆

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Abstract:

Until now, a wide range of two-dimensional (2D) materials has been extensively studied for various applications based on their superior properties with atomically thin layers. Since the discovery of Cr₂Ge₂Te₆ (CGT) as a 2D intrinsic ferromagnetic material, CGT has received a lot of attention from scientific community. In addition to its layered structure, ferromagnetic properties of CGT have recently shown the possibility of applications for spintronics. The inverse resistance change of CGT also suggests huge potential to reduce operational energy and scale down. However, there are few computational studies of electrical and thermal properties of CGT due to the difficulty of large-scale simulations and its ferromagnetic properties. In this study, we study electronic structures of CGT by using density functional theory calculations and investigate behaviors and characteristics of CGT during melting and crystallization process. Especially, we use neural network potentials (NNPs) to do molecular dynamics simulations. Further, the atomic-scale evolution of CGT depending on temperature and surface interaction with various molecules is examined to study its thermal stability and related electrical properties.

Keywords:

MD simulation, Neural network potentials, Cr₂Ge₂Te₆, Thermal properties

MoS₂ device 기반 활성화 함수 제안 및 이를 이용한 패턴인식과 기계 학습

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Abstract:

기존의 컴퓨터는 중앙처리장치와 기억장치가 분리되어 0과 1을 바탕으로 순차적인 연산을 하는 Von Neumann Architecture를 따르고 있다. 21세기에는 기술의 발전으로 빅데이터를 활용한 인공지능이 비약적으로 성장하였으나, 중앙처리장치와 데이터 저장장치의 데이터 병목 현상이 큰 문제로 대두되었다. 이를 해결하기 위해 인간의 두뇌를 모사하는 뉴로모픽 컴퓨팅이 주목받고 있다.

인공 시냅스 소자에서는 입력 값과 출력 값은 간단하게 입력 전압과 출력 전류로 얻어진다. 본 연구는 MoS₂ 시냅스 소자를 제작하여 전기적 특성 측정을 통해 얻은 데이터를 바탕으로 시냅스 소자에서 사용 가능한 활성화 함수를 직접 설계하여 학습의 기본인 패턴인식을 구현하였고, 채택된 활성화 함수들이 기존의 기계학습에 사용되었던 함수들과 인식 정확도를 비교하였을 때 경쟁력이 있음을 확인할 수 있었다.

Keywords:

MoS₂, 시냅스 소자, 인공지능, 패턴인식

Electromagnons in GdMn₂O₅ Studied by Terahertz Spectroscopy

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Abstract:

Multiferroic materials with electronic and magnetic orderings show unique magnetoelectric phenomena. In particular, electromagnons are excited by the electric field of light. The interpretation of the unique behavior of electromagnons can help understand the interaction between ferroelectricity and ferromagnetism. We studied the electromagnons in GdMn₂O₅ by using terahertz spectroscopy including their dynamics under an external magnetic field. Our results show that the spin reorientation of the Gd³⁺ ions induces the reorientation of the Mn sublattice as well. We expect that this unique effect can help elucidate the role of the rare-earth ions in RMn₂O₅.

Keywords:

electromagnon, terahertz

Parametric spin waves controlled by dc Oersted field in NiFe nano-wire

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Abstract:

Parallel parametric pumping is a nonlinear wave phenomenon and a promising technique for electronic devices based on spin wave, so-called "magnonics". Using a dc Oersted field generated by electric current, parametric spin wave mode transition was implemented in NiFe nano-wire. An Oersted field is used for modulating a static magnetic field in the experimental magnetic system of 650 nm-width NiFe wire structure. The threshold characteristics and width mode profiles of parallel parametric pumping, obtained by micro-Brillouin light scattering, explicitly show a mode transition depending on the total magnetic field which is sum of static magnetic field (= 700 Oe) and Oersted field. These Oersted field-controlled parametric process is well described in conjugated with change of dispersion relation according to the magnitude of applied magnetic field. The results about applicable of dc electric current to parallel parametric pumping show a potential of parametric process in magnonic applications

Keywords:

Parallel parametric pumping, Parametric spin waves, micro-Brillouin light scattering, dc Oersted field

Magnetic ordering of NiPS₃ studied by low-frequency Raman spectroscopy

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Abstract:

Magnetic van der Waals materials are actively studied by researchers in various fields recently. Transition-metal thiophosphate (MPS₃, M=Fe, Ni, and Mn) is one of the magnetic van der Waals materials, which shows antiferromagnetic ordering in bulk below its Néel temperature [1-2]. NiPS₃ is an XXZ-type magnetic material showing antiferromagnetic ordering below the Néel temperature, which changes depending on the thickness of the material [2]. After the magnetic ordering of NiPS₃ in the 2D limit is reported, many interesting properties of 2D magnetic materials are studied. We conducted temperature-dependent polarized Raman spectroscopy of exfoliated NiPS₃ samples. We measured the Raman spectra of samples from 3.5K to room temperature and analyzed the changes of the peak positions and intensities of Raman modes as the temperature increases. From a bulk crystal sample, a low-frequency peak is observed at 10 cm⁻¹, which is not due to an interlayer vibration mode. The intensity of this peak seems to correlate with the magnetic transition. The dependence of this peak as the thickness of the sample will be presented.

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Keywords:

2D magnetic material, Low-frequency Raman spectroscopy, NiPS₃, Magnetic van der Waals material

Temperature dependence of Raman spectrum of few-layer anti-ferromagnetic CrPS₄

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Abstract:

Van der Waals materials are attractive to investigate because they exhibit diverse and unique physical properties that depend on their compositions and structures. Recently, magnetic semiconductor CrPS₄ is attracting interest since the first report in 1977 [1]. CrPS₄ is an Ising-type antiferromagnet with the Néel temperature of 36 K in bulk [2,3]. In this work, the temperature dependence of the Raman spectrum of exfoliated CrPS₄ samples were investigated by polarized Raman spectroscopy with the 514.4 nm excitation source between 3.6 K and room temperature. The peak positions and the polarization dependences of observed Raman modes are consistent with the previous report at room temperature [4]. However, at low temperature, there are some critical changes in Raman spectra. The polarization dependence of the mode at 308 cm⁻¹ change in parallel configuration, meanwhile, new modes appeared.

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Keywords:

CrPS₄, Raman spectroscopy, antiferromagnetic, Low Temperature

Paper-based Triboelectric Nanogenerator for High Durability and efficiency Mechanical Energy Harvesting

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Abstract:

Sliding mode triboelectric nanogenerator(S-TENG) among various triboelectric nanogenerator modes can harvest the most energy from rotational motion, but have the issue of low durability due to friction. Several methods are being studied to solve friction problems [1-3]. We fabricated a paper-based energy harvesting device for high efficiency and high durability three-dimensional structure. The rotation-folding(R-F) TENG has a 3D structure consisting of paper, aluminum film (Al), and PTFE film, and the organic movement of each side converts the rotational motion into folding-unfolding vibration. The R-F TENG generated an open-circuit voltage of 31 V, a short-circuit current of 0.67 μ A and an instantaneous power (power density) of 1.2 μ W (0.13 μ W/cm²) at 200 rpm, which was sufficient to turn on 25 light-emitting diodes and a thermo-hygrometer. The triboelectric outputs of the R-F TENG were decreased very slightly even after 288,000 continuous rotations, i.e., the output of 86% of initial value was maintained. This work shows that an R-F TENG could efficiently harvest energy from various forms of rotational motion with a long-term durability.

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Keywords:

Energy harvesting, Triboelectric nanogenerator, Three-dimensional structure, Rotational motion

Promoting selective nitrogen reduction with a Fe-confined MoS₂ catalyst inspired by nitrogenase

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Abstract:

Electrochemical reactions involving multiple steps, such as nitrogen reduction reaction (NRR), often suffer from low catalytic efficiency due to competition with other simple reactions. Hence, developing an electrocatalyst that can promote the selective activation of such a multistep reaction is vital. Here, we propose a highly selective electrocatalyst for NRR comprising molybdenum disulfide (MoS₂) with the iron (Fe) confined in van der Waals (vdW) gaps, which is inspired by Nitrogenase capable of nitrogen fixation in atmospheric conditions. This bio-inspired structure is achieved by sequential intercalation of lithium and Fe ions followed by Fe reduction in vdW-layered MoS₂, whose design is confirmed by structural analyses. We found that the metallic Fe-confined MoS₂ structure offers a favorable active site for boosting selective NRR. As a result, the Faradic efficiency and yield rate of the ammonia production are obtained as high as 30.2 % and 1.2 $\mu\text{mol}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$, respectively. Such improved catalytic performances can be attributed to the change of the *d*-band center of MoS₂ by Fe intercalation, strengthening the binding strength of nitrogen and lowering the potential barrier of NRR. Our demonstration offers new insight into designing novel catalysts to enhance selectivity and activity in complex catalytic reactions.

Keywords:

NRR, Electrochemical, Renewable energy

The Strategy of Enhancing Performance of Sulfur Copolymers via Fluorine-Rich Additives

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Abstract:

Recently, halogen elements have been drawing attention in the research fields of Triboelectric Nanogenerator (TENG) as for high performance applications. In here, we present the fabrication of extreme negative polymer film synthesized with fluorine elements. As for additive of fluorine atoms poly(2,3,4,5,6-pentafluorostyrene) (PPFS) were employed. In our study the spatial distribution of fluorine on the film surface was maximized at the 7.5 wt% PPFS-blend film, and the similar tendency was appeared in the result of electrical outputs of TENG based on PPFS blends. We also fabricated a 4 inch-diameter(81.1cm²) TENG device based on 7.5 wt% PPFS-blend film which exhibited an open-circuit voltage (V_{pp}) and a short-circuit current (I_{pp}) of 1360 V and 25 μ A, respectively. It was sufficient to light up 400 series-connected blue LEDs, suggesting possibilities of various developments in the field of high-performance TENGs.

Keywords:

triboelectric nanogenerator, sulfur copolymer, polymer blending, phase separation, fluorine-rich polymers

Introduction to Earth Transfer Technology of Space-based Solar Energy through Wireless Power Transmission

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Abstract:

Since the ever-increasing world-wide energy demand and the need for a clean energy resource, the solar power satellite (SPS) concept has been explored by some scientists and engineers in the US, Japan, EU, and China. An SPS constitutes a method of generating electricity from solar energy by using satellites and transporting it to the ground through a shape of electromagnetic (EM) waves. Several candidate systems have been proposed in some countries. However, no system has been, until this time, either constructed or tested in space, and it is currently unknown when one might be. In a typical SPS system, solar energy is collected in space by a satellite in a geostationary orbit. The solar energy is converted to direct current (DC) by solar cells (and/or solar heat), and then the DC is used to power microwave (and/or laser) generators in the microwave frequency range. The generators feed a highly directive satellite-borne antenna beaming the energy to the Earth. On the ground, a rectifying antenna (rectenna) converts the microwave (and/or laser) energy from the satellite into the DC, which, after suitable processing, is fed to the terrestrial power grids. Two critical aspects that have motivated research into SPS systems are the lack of attenuation of the solar flux by the Earth's atmosphere and the twenty-four-hour availability of the energy, except around midnight during the equinox periods. The status of SPS research in the technically advanced countries (as US, Japan, EU, and China) is introduced, and the development strategy of SPS technology in Korea is suggested.

Keywords:

solar energy, solar power satellite, wireless power transmission, microwave generator, rectenna

Intriguing triboelectrification behavior of identical P(VDF-TrFE) polymers

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Abstract:

With the increasing demand for charging portable and wearable electronic devices, energy harvests from wasted machine vibrations in everyday life have attracted considerable attention. But we still don't quite understand the fundamental mechanism of triboelectrification [1–4]. One of the most puzzling issues is triboelectrification between identical materials. To identify the triboelectrification between the same materials, we prepared PVDF-TrFE materials by cooling (C-) and annealing (A-). The C-P(VDF-TrFE) had sparse grains and small elastic modulus and surface charge density, while, the A-P(VDF-TrFE) had dense grains and large elastic modulus and surface charge density. When the polymers contacted ITO electrodes, the triboelectric outputs of C-(PVDF-TrFE) were larger than those of A-P(VDF-TrFE). When the polymers contacted each other, the triboelectric outputs of different P(VDF-TrFE) films were significantly larger than those of similar P(VDF-TrFE) films. Based on detailed X-ray photoemission spectroscopy results, we suggested that roughness-induced frictional heat and elastic modulus differences may play an important role in minute material and/or ion transfer during the triboelectrification of identical P(VDF-TrFE) polymers.

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Keywords:

P(VDF-TrFE), Triboelectrification, Identical polymers, Frictional heat, Elastic modulus

Interlayer corona discharging on laminating structure for improvement of surface charge retention.

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Abstract:

Surface corona discharge method (s-CDM) is a surface treatment technique in which electrons and ions are injected into the target surface by high electric field. Such treatment enhances the performance of TENG devices by largely injected surface charges. Herein, we report an interlayer corona discharge method (i-CDM) in which charges are injected inside of laminating structure. We found that a laminating structure treated by i-CDM exhibited improved charge retention compared to the film treated by typical s-CDM. It also maintained outstanding performance of triboelectric nanogenerator even in the harsh environments such as high humidity or underwater conditions

Keywords:

Triboelectric nanogenerator, interlayer corona discharge treatment, surface corona discharge treatment

친환경 소재를 활용한 정전형 나노발전기의 에너지발전 특성 및 모션 센서 동작에 대한 연구

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Abstract:

최근 환경에 대한 관심이 증가하면서 화석에너지를 이용한 발전이 가진 탄소배출 및 환경파괴 문제를 해소하기 위해 지속가능한 친환경에너지를 이용한 발전은 최근 크게 주목을 받으며 발전하고 있다. 그 중 정전형 나노발전기 기반 발전기술은 운동에너지나 마찰에너지를 통해 전기를 발생시키는 친환경에너지 발전기술이며, 높은 에너지 전환 효율, 낮은 제조 단가, 및 지속가능성의 장점을 가진다. 또한, 단위소자의 구조가 간단하여 배열구조로 제작될 수 있으며 flexible한 소자로 제작 가능하다는 점에서 활발한 연구가 이루어지고 있다.

본 연구는 친환경 기판을 이용한 나노발전기를 이용한 에너지 발전소자를 제작하여 에너지 발전 원리를 분석하여 에너지 발전효율을 높이고 이를 활용한 친환경 모션 센서를 구현한다. 용액공정을 이용해 나노발전기에 전극을 제조하고 나무 소재의 기판을 압축하여 소자를 제작한다. 이 때, 용액공정으로 나무 기판의 한 쪽면에만 전극을 도포하기 위해 나무 기판의 부력을 이용하여 전도성 고분자물질을 포함하는 용액에 띄워 나무 기판의 단일면에만 전도성 고분자물질을 도포한다. 전도성 고분자용액 처리의 시간에 따라 전극의 면저항을 측정하여 공정조건을 최적화하고 원리를 주사전자현미경 (Scanning electron microscope, SEM)을 통해 분석한다. 친환경 정전형 나노발전기의 에너지 발전효율을 분석하기 위해 접촉-분리 모드 (contact-separation mode)로 발전 전압과 전류를 측정하였다. 모션 센서로 활용하기 위해 인체 또는 정전기를 가지는 물질의 터치에 따라 발생하는 전기신호를 측정하기 위해 단일 전극 모드 (single electrode mode)로 손가락의 터치에 따른 전기신호의 변화를 관찰하였다.

본 연구결과는 친환경 기판을 활용한 지속가능한 발전 기술 및 모션 센서의 기초자료로 활용할 수 있다.

Keywords:

에너지 하베스팅, 나노발전기

Flexible Solid Oxide Fuel Cells with Highly Thermomechanical Stability

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Abstract:

고체산화물 연료전지(SOFC)는 고온에서 구동되어 화학 에너지를 이용하여 높은 에너지 효율로 전기 에너지로 변환한다. 하지만 고온 환경에서 장기 구동 시 전극에 반복되는 산화 환원에 의해 기계적 변형 또는 균열이 형성되게 된다.

본 연구에서는 이를 해결하기 위해 유연성 전해질 소재를 이용하여 SOFC를 얇게 제조하여 열기계적 내성을 강화하여 구동 시 형성되는 스트레스를 완화하고 장기 구동을 가능하게 하였다. 이트리아 안정화 지르코니아(YSZ) 전해질 소재의 Y 도핑 조성에 따른 상전이, 입자 크기 및 표면 거칠기에 의해 필름의 유연성이 제어된다. 또한 이를 이용한 SOFC는 테이프 캐스팅, 스크린 프린팅 등의 간단한 저비용 대용량 공정을 통해 제조되었다. 제조된 SOFC를 400 °C에서 800 °C까지 승온 및 냉각을 일정 시간동안 진행하였으며 이러한 가혹한 조건에서 500시간의 장기간 동안 on-off 사이클에서 0에 가까운 열화율을 달성하였다. 제조된 고내구성 유연성 SOFC 연구는 열적 충격 저항을 갖는 차세대 플렉서블 SOFC 연구를 위한 기반을 마련하였으며 이 외에도 태양광, 플렉서블 전자, 센서 등 다양한 연구 분야에 적용될 수 있다.

Keywords:

SOFC, 에너지소자, 고체산화물

Phase transition and crystal structure of epitaxial perovskite ruthenates (ARuO₃, A = Ca, Sr, and Ba)

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Abstract:

Perovskite ruthenate thin films have been extensively investigated for oxide electronics due to various interesting physical properties, such as conductive oxide, ferromagnetism, and superconductivity. Among them, CaRuO₃ (CRO) and SrRuO₃ (SRO), which has been widely reported as epitaxial thin films, have the same orthorhombic structure (*Pbnm*, 62) including RuO₆ octahedral distortion, and can be considered as pseudo-cubic with the lattice constant of 3.84 and 3.93 Å, respectively. On the other hand, in bulk, BaRuO₃ (BRO) has four polymorph phases with different physical properties. However, temperature dependence of structural characteristics for CRO and BRO has not been studied. We investigated phase transition and crystal structure of the ruthenate thin films to understand the structural fundamentals affecting physical properties of these films. Structural phases of the epitaxially grown ruthenate thin films, such as tetragonal structure for CRO and 3C-BRO and orthorhombic SRO at room temperature, were clearly identified by X-ray diffraction. To determine temperature dependence and phase transition, in-plane and out-of-plane ω - 2θ scans of ruthenate thin films were analyzed with varying temperatures under atmospheric and vacuum conditions. We observed that structural phase transition is consistent for SRO regardless of atmospheric and vacuum condition. However, CRO film only showed the behavior of phase transition at vacuum condition.

Keywords:

phase transition, crystal structure, ARuO₃, thin film

Synthesis of tungsten-doped vanadium dioxides thin films applicable for temperature sensors by controlling doping profile

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Abstract:

Vanadium dioxide (VO₂) is a well-known material for metal-insulator transition (MIT) phenomena occurred at the MIT temperature, T_{MIT}, of ~67°C. The MIT-driven switching functionality of VO₂ can be exploited for various applications. However, the T_{MIT} of VO₂ quite higher than room temperature limits the scope of VO₂-based applications. Therefore, to enhance the applicability of VO₂, diverse approaches for modulating T_{MIT} are undergoing: substitutional doping, irradiation, mechanical engineering, and so on. Above all, cation substitutional doping with W⁶⁺ enables efficient reduction of T_{MIT} throughout the entire doped regions stably and delicately.

Recently, we have developed a novel two-step process using sputtering technique followed by thermal annealing treatment for synthesizing high-quality VO₂ thin films with gradual W-doping profiles in the direction perpendicular to the film surfaces. Widening their phase transition regimes substantially by the spatially gradual doping inside thin film structures probably leads to achieving the temperature resistance coefficients (TCRs) superior to those of conventional pure and uniformly W-doped VO₂ thin films. Further, we have grown W-doped thin films where the W doping concentration changes in a direction parallel to thin film surface by reactive co-sputtering using both on-axis and off-axis sputtering sources simultaneously. These two different nanoscale compositionally graded VO₂ thin film structures may be closely relevant to developing novel temperature and heat sensors.

Keywords:

vanadium dioxide (VO₂), metal-insulator transition (MIT), doping effects, temperature resistance coefficient (TCR)

Characteristic of Time-Dependent Humidity Sensing Property of $K_{0.5}Na_{0.5}NbO_3$ Film Fabricated by Pulsed Layer Deposition

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Abstract:

Recently, measurement and controlling of humidity are state of art research field for many industries such as food, agriculture, meteorology, and human activity etc. Many researchers are studying on exploitation of new materials to acquire humidity sensors with great properties such as linear response, higher sensitivity, wider humidity detection range and fast response speed [1]. Among them, $K_{0.5}Na_{0.5}NbO_3$ (KNN) is receiving attention because the A-site ions (K or Na) in KNN can be combined to the water molecules so that KNN material is easily affected and changed its properties by the ambient humidity. Also, KNN is a ferroelectric material with perovskite ABO_3 -type complex metal oxides and is one of candidates for eco-friendly materials representative lead-based materials. Its high electrical properties and temperature stability are the important factor to make a device. In this research, we fabricate KNN film which was deposited by Pulsed Laser Deposition (PLD). We measured and compare the structural and electrical properties as time passes in air. X-ray diffraction (XRD) was done to analysis the structural difference. In XRD, there is no specific change to be considered. However, the dielectric constant decreases 140 to 100 at 10^5 Hz. The P-E hysteresis loop also changed that the shape had a sharp with $30 \mu C/cm^2$ for $2P_r$ value and lower coercive field, but after few days in the air, it looks broad with lower $2P_r$ and larger coercive field. In addition, we will discuss the effect being able to affect (or recover) its properties when it is thermally annealed.

[1] Mengjian Yuan *et al.*, Humidity sensing properties of $K_{0.5}Na_{0.5}NbO_3$ powder synthesized by metal organic decomposition, *Sens. Actuator B-Chem.* **209**, 252 (2015).

Keywords:

Ferroelectrics, $K_{0.5}Na_{0.5}NbO_3$ (KNN)

Systematical Analysis Resonant Tunneling Current in a SrRuO₃/SrTiO₃ Superlattices Structure by Pulse Measurement

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Abstract:

Resonant tunneling[RT] which is a quantum mechanical process has been attracting both scientific and technological attention because of its interesting physics and application for electronics. This phenomenon accompanies negative differential resistance[NDR] in current-voltage characteristics and has various physical properties that are used in many electronic circuits. But oxide-based NDR study encounters difficulty because of crystal quality, sample instability, and lack of evidence for a mechanism.

Here we show NDR by applying voltage and measuring current passing through the SRO/STO SL system. we deliberately designed SrRuO₃/SrTiO₃[SRO/STO] superlattice[SL]. Using the pulsed-laser deposition, we can control SRO/STO SL with an atomic-scale precision which results in a quantized state of SRO between the STO barrier. Due to the discrete state of the SRO, SRO/STO SLs system show [NDR] when Fermi level match with the SRO discrete state. Specifically, we changed the thicknesses of STO from 2 to 8-unit cell and period of SRO/STO quantum well while that of SRO is fixed to check the evolution of RT. I did pulse I-V sweep measurement for removing joule heating and systematical measurement. We expect this study opens a possibility of new applications based on the epitaxial thin film oxide.

Keywords:

Superlattice, Oxide films, Resonant tunneling

Investigation of correlation between defective structure and electronic structure dependent on the amount of oxygen vacancies

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Abstract:

Tantalum oxide-based memristor has been studied extensively as a memory device¹ and has recently emerged as an artificial synaptic device in neuromorphic computing systems.² In these devices, oxygen vacancies (V_o) play an essential role, where the migration of V_o dictates the formation and rupture of filament, making resistive switching. It is also important to understand the ground electronic structure of the defective TaOx as it determines the behavior of the electrons under applied bias. Therefore, several studies have been tried to observe the electronic structure of TaOx by an experimental method such as XAS, XPS, and EELS³, and by theoretical DOS calculation⁴. However, there is still a lack of correlation between the electronic structure and unit cell structure, when the properties of V_o such as number, location, and oxidation state vary. In this study, we investigated the electronic structure of two defect TaOx which has different stoichiometry by using RIXS (resonant inelastic x-ray scattering) measurements. As the increasing concentration of V_o , the distance extension and number decreasing of Ta-O was measured by EXAFS. Moreover, we constructed various configurations of TaOx dependent on properties of V_o by the VASP program and compared the calculated dielectric function and RIXS spectrum. Through this comparison, we could find preference configuration at each stoichiometry, and provide formation mechanism and structural modulation when the additional V_o is made. We expect that these results could support the advancement of tantalum oxide-based neuromorphic computing at the atomic level.

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2 Hwang, H. G. *et al.* Synaptic plasticity and preliminary-spike-enhanced plasticity in a CMOS-compatible Ta₂O₅ memristor. *Materials & Design* **187**, doi:10.1016/j.matdes.2019.108400 (2020).

3 Tsuchiya, T. *et al.* X-Ray absorption, photoemission spectroscopy, and Raman scattering analysis of amorphous tantalum oxide with a large extent of oxygen nonstoichiometry. *Phys. Chem. Chem. Phys.* **13**, 17013-17018, doi:10.1039/c1cp21310e (2011).

4 Perevalov, T. & Shaposhnikov, A. Ab initio simulation of the electronic structure of Ta₂O₅ crystal modifications. *Journal of Experimental and Theoretical Physics* **116**, 995-1001 (2013).

Keywords:

Defect tantalum oxide films, Memristor, ReRAM, Neuromorphic computing, RIXS

Lead-free $\text{Bi}_{0.5}(\text{Na}_{1-x}\text{K}_x)_{0.5}\text{TiO}_3$ relaxor ferroelectric ceramics for a wearable energy harvester

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Abstract:

Piezoelectric ceramics have been applied to sensors, actuators, transducers, etc. In particular, they have received a lot of interest in relation to energy harvesting. The lead-free piezoelectric material, $\text{Bi}_{0.5}(\text{Na}_{1-x}\text{K}_x)_{0.5}\text{TiO}_3$ (BNKT) has a perovskite structure and is a binary system comprising $\text{Bi}_{0.5}\text{Na}_{0.5}\text{TiO}_3$ (BNT) and $\text{Bi}_{0.5}\text{K}_{0.5}\text{TiO}_3$ (BKT). It was recently reported that a large strain response can result from electric field induced phase transitions induced by changes in the composition and ion substitution. Interestingly, this phenomenon exhibits pinched-type polarization-electric field (P - E) loops (i.e., lower hysteresis), which reduces the piezoelectric coefficient, and thus can be disadvantageous for energy harvesting using a piezoelectric generator. The reason is that a material with a high piezoelectric coefficient has a larger electric displacement under the same stress, which generate more charges and electric currents. Accordingly, research has focused on piezoelectric ceramics with high piezoelectric coefficients for achieving piezoelectric generators with high electric output performance. However, when bending and stretching occur through human body movement, it is different from the ideal situation where the applied pressure is in the same direction as the polarization axis of the piezoelectric material. Interestingly, relaxor ferroelectrics in which large strains occur, can be advantageous for energy conversion in these situations. In order to investigate this, BNKT relaxor ferroelectrics of various compositions that transition from the non-ergodic state ($x = 0.16$) to the ergodic state ($x = 0.18 - 0.24$) were prepared, and the electrical properties and electric output performance were compared. It was found that the BNKT relaxor ferroelectric composition corresponding to $x = 0.20$, which had the largest inverse piezoelectric coefficient d_{33}^* , exhibited the best output performance, and thus should be suitable for application in wearable energy harvesters.

Keywords:

Piezoelectrics, Generators, Relaxor

"Effect of insulator layers and substrate dopant types on HfO₂-based metal-ferroelectric-insulator-silicon capacitors"

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Abstract:

Since the discovery of unexpected ferroelectricity in doped-HfO₂ thin films in 2011, doped HfO₂ have attracted a great of attention in the fields of ferroelectricity and nonvolatile memories. The main reason is that doped-HfO₂ can be easily integrated with current semiconductor technologies without other material compatibility issues faced by conventional ferroelectrics. Recently, there has been much interest in ferroelectricity in metal-ferroelectric-insulator-semiconductor (MFIS) structures, since it can be directly utilized for one transistor-based memory devices. Here, we present our recent efforts to study ferroelectric properties of Si-doped HfO₂-based MFIS capacitors. To investigate the effect of insulator layer and the dopant type of silicon substrate on ferroelectric properties, we used two different insulator layers, i.e., SiO₂ and SiON and two different Si substrates, i.e., p-type and n-type, resulting in total four distinct MFIS capacitors. We discuss their ferroelectric properties and domain switching behaviors from various experimental results, such as polarization-voltage hysteresis loops, transient switching current measurement data, and piezoresponse force microscopy images.

Keywords:

ferroelectirc, MFIS, HfO₂, PFM

Kinetic roughening of the oxidized phase expansion in a Ca-doped BiFeO₃

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Abstract:

Surface roughness in kinetic growth with diffusion has been quite actively studied in various systems of ferroic domain walls or fluid invasion in porous media.[1,2] However, studies of kinetic roughening are lacking in the areas of electrochemical topotactic transition and electrocoloration in spite of the technological importance. Our model material, a Bi_{0.7}Ca_{0.3}FeO_{3- δ} thin film, is an ionic conductor with electrochromism, and shows color change according to oxygen stoichiometry (3- δ).[3] We induce sequential topotactic transitions from the as-grown phase ($\delta = 0.15$) to the oxygen-vacancy-poor phases ($\delta = 0$ or less than 0.15) by applying a voltage between coplanar electrodes.[4,5] Here, we observe kinetic roughening of the boundary between two lightly and heavily oxidized phases with optical microscopy. The boundary widths are analyzed as a function of spatial position and elapsed time at selected applied voltages and temperatures. Our finding of the spatial and temporal behaviors provides useful insights into redox reaction and oxygen diffusion process in oxide electrolytes.

[1] J. Y. Jo et al., *Physical Review Letters* **102**, 045701 (2009)

[2] H. S. Rabbani et al., *PNAS* **115**, 19 (2018)

[3] J. Seidel et al., *Nature Communications* **3**, 799 (2012)

[4] J. S. Lim et al., *NPG Asia Materials* **10**, 943 (2018)

[5] H.-S. Park et al., *Applied Physics Letter* **115**, 183901 (2019)

Keywords:

Ionic conduction, Kinetic roughening, Solid electrolyte, BiFeO₃

Large-area molecular junction via direct probe of giant metal nanosheets on self-assembled monolayer

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Abstract:

In order to process massive information such as letter, voice and video, it is still necessary to develop high speed and ultra-high-density semiconductor devices. Among a lot of emerging electronic devices, molecular electronics have been considered as one of the potential candidates as the miniaturized electronic devices which employ various functional molecules as nanoscale building blocks due to the merits such as low cost, high-density capability and less heat problems. Previous researches on molecular electronics have been focused to understand charge transport self-assembled monolayer (SAM) in the metal-molecule-metal (MMM) junction. However, the device yield of the molecular electronics with MMM junction exhibited extremely low due to the electrical shorts caused by the penetration of top electrode through the molecular layer and contacting the bottom electrode. To overcome this issue and form large scale molecular junctions, conductive protecting layers such as conductive polymer, graphene have been introduced in between SAM and top electrode. However, to study pure charge transport through SAM, the large-area MMM junction is still required without any protective internal layers. In this study, we introduce giant metal nanosheet large-area, sheet-shaped metallic fillers with micron-sized edge length and nanometer-scale thicknesses as a top electrode and directly probe the metal sheets on the SAM at the Au bottom electrode surface. Our metal nanosheet-molecule-metal junction exhibited almost 100% of device yield and excellent length dependent charge transport characteristics on various alkanethiol ($\text{CH}_3(\text{CH}_2)_{n-1}\text{SH}$) self-assembled monolayers (octanethiol (C8), dodecanethiol (C12) and hexadecanethiol (C16)).

Keywords:

Molecular electronics, large-area junction, metal-molecule-metal junction, metal nanosheets

High-quality perovskite film obtained via pressure-applied annealing strategy for efficient solar cell

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Abstract:

Organic-inorganic hybrid perovskite solar cells have been rapidly improved in device power conversion efficiency(PCE) and are in the spotlight as a next-generation eco-friendly energy source. Achieving a high-quality photo-active layer that has a lot of ways to be influenced by processing parameters is critical to the device performance of organic-inorganic hybrid perovskite solar cells. In this work, a pressure-applied annealing process(PA method) was developed to control the evaporation speed of the solvent inside the perovskite layer. By applying pressure during the annealing process for crystallization of the methylammonium Lead Iodide (MAPbI₃), which leads to control the evaporation speed of solvent to promote high-quality crystal growth of MAPbI₃. As a result, the PA device exhibited a high PCE of ~17.3% with a significantly enhanced short-circuit current of ~24.4 mA cm⁻², an open-circuit voltage of 0.96 V, and a fill factor of 0.75.

Keywords:

perovskite solar c, grain growth, crystallinity, pressure, current density

Optimizing organic ternary inverters by output node engineering

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Abstract:

We report a direct and significant impact of output electrode on the performance of thin-film heterojunction ternary inverters. Taking an organic-semiconductor-based inverter as a model system, two-dimensional drift-diffusion simulation is carried out aimed at its functional improvement. Despite an electrically floating and non-polarized nature of output node, its junction-relative position and energy is found to be critical to multi-valued logic processing, revealing a near-ideal ternary characteristic achievable by optimum material and layout selection. We demonstrate that output-electrode engineering is an original and highly promising approach to ternary inverter optimization. Two-dimensional finite-element simulation based on a drift-diffusion framework is used as a strategic computational tool, since it effectively predicts and rationalizes practical device characteristics as an outcome of various materials and interface parameters. It is found that placing the output node with a controllably low work function in close proximity to the heterojunction interface greatly improves the overall ternary logic performances. Our predictive simulation show that nearly ideal output swing and ternary ratio levels can be obtained by positional and energetic optimization of the floating electrode. The attraction of diffusive holes and the bipolar charge build-up induced by the output metal are found to be the major microscopic origins behind the macroscopic voltage-transfer curve modulation. These results are expected to stimulate various future activities aimed at unconventional approaches to next-generation multi-valued logic technologies.

Keywords:

Organic semiconductors, Organic field-effect transistors, Multi-valued logic circuits

Defect passivation using small lewis-base molecule in perovskite solar cells

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Abstract:

Abstract: Surface defects are major obstacles that has been preventing researchers from obtaining high-efficiency organic-inorganic hybrid perovskite solar cells. Because of the ionic nature, the perovskite structure has many kinds of defects such as anti-sites, vacancies and undercoordinated ions. Herein, we explored the effect of adding the variety of small Lewis-base molecules, which react with undercoordinated Pb ions and thereby suppress the surface defects. After adding these molecules, we found that they can improve the current density and fill factor. This demonstrates that adding typical Lewis-base molecules may be an effective method to suppress native defects, improving charge carrier transport.

Keywords:

small molecules, passivation, Lewis adduct, High-current

Self-healable optoelectronic skins

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Abstract:

Numerous materials are utilized to fabricate electronic skins (OE-skin) which are of pivotal importance in robotics and human-machine communications. Here we present an implementation of optoelectronic skin (OE-skin) using silk protein and melanin nanoparticles that possessed functionalities of the human skin along with the photo-responsive characteristics. The OE-skin offered abilities of stretchable, conductive, photo-responsive, and self-healable. Free radicals present in the melanin nanoparticle activated at high humidity ultimately increase the photoconductivity of OE-skin. On the other hand, Ca^{2+} ions capture water molecules from the environment that cause stretchability and self-healing in silk/melanin hydrogel layers. OE-skin exhibited an enhanced electrical conductivity upon increasing the humidity and under laser light illumination. These sensing capabilities of OE-skin have been employed to realize multiple sensors such as strain sensor, humidity sensor, and photoconductive sensors. The study suggested that our OE-skin provides a new outlook to the field of prosthetics and skin-attachable devices.

Keywords:

Opto-electronic skin, Silk protein, Melanin, Photoresponse

Fabrication of Flexible conducting film by mixing cellulose nanocrystals and graphene dispersion

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Abstract:

Flexible conducting materials for wearable healthcare devices must have good biocompatibility. In this regard, cellulose nanocrystals (CNCs), which are extractable from natural materials, are a promising candidate for such uses. However, because the CNCs are insulating, their conductivity should be modified. For this, mixing CNC with other functional materials can be an efficient strategy.

In this study, we fabricated conducting flexible film using CNC and graphene dispersion. The conductivity of the flexible CNC film was controlled by the mixing ratio of graphene dispersion. To understand the changes in conductivity, the structural property and electron structure of CNC-graphene film were analyzed using scanning electron microscopy and X-ray photoelectron spectroscopy. Through these results, we suggest the underlying mechanism of conductivity change in the CNC-graphene hybrid film.

Keywords:

cellulose nanocrystal, graphene dispersion, electronic structure, conductivity

Research on crystal properties by controlling the deposition temperature of organic semiconductors

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Abstract:

The driving carrier mechanism of the organic devices is very complicated due to the dielectric nature of active organic semiconductor layers, the complexity of interfaces, the trapping effect by stress biasing, and others. These are still not sufficient for the use of organic semiconductor materials in actual organic devices. In this study, we controlled crystals by varying the temperature during the deposition of the organic semiconductor devices. Through electrical measurements such as I-V, C-V, C-F measurements, the characteristics of the organic device were analyzed. It was possible to control the crystal structure according to the deposition temperature of the organic semiconductor, and through this analysis, it was possible to analyze the factors affecting the stability and performance of the device.

Keywords:

Organic field effect transistors(OFETs), Crystallinity of TIPS-Pentacene layer, Maxwell-Wagner model

Sol-gel preparation and red emission properties of Eu^{3+} in double perovskite $\text{La}_2\text{ZnTiO}_6$

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Abstract:

In recent years, the solid state white-light emitting diodes (WLEDs) have more advantages than the traditional incandescent or fluorescent lamps, because several reports suggested that the WLEDs would reduce global electricity consumption by about 50% by taking advantage of the conversion from direct electricity to light rather than the processes in which light is the by-product of another conversion, as with traditional lamps. It is well known that rare earth (RE) ions activated phosphors have found excellent luminescent materials because of their marked improvements in lumen output, color rendering index, energy efficiency and greater radiation stability. The RE ions are characterized by a partially filled 4f shell that is shielded by $5s^2$ and $5p^6$ electrons.

Double-perovskite compounds $\text{A}_2\text{BB}'\text{O}_6$ possess many advanced physical properties, such as thermal, electrical, and magnetic stability. The crystal environment of A site contains eight to 12 coordinates and can be modulated with various elements. B-site and B'-site are coordinated by six oxygen atoms to form octahedrons. The BO_6 and $\text{B}'\text{O}_6$ octahedra in the crystal are alternatively connected with one another by sharing the same site to form octahedral chains. $\text{La}_2\text{ZnTiO}_6$ belongs to double-perovskite compounds and has a potential to be a luminescence host.

Here, we report on the synthesis and characterizations of $\text{La}_2\text{ZnTiO}_6:\text{Eu}^{3+}$ phosphor phosphors for solid state lighting application, and a systematic study on the structural and luminescent properties of these phosphors has been carried out in detail.

Keywords:

phosphor, perovskite

Size-dependent electrical and optical characteristics of InGaN/GaN based blue light emitting diodes

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Abstract:

Group III-nitride semiconductor based micro light-emitting diodes (mLEDs) having lateral dimensions less than 100 X 100 μm^2 have attracted much interests due to their high efficiency, long device lifetime, etc. There have been many reports realizing high resolution mLED arrays from monochromatic to full-color [1, 2]. However, it has been known that reducing lateral dimension of mLEDs via top-down approach often accompanies degradation of efficiency [3]. The main cause of the efficiency degradation is increased non-radiative recombination rate due to additionally generated non-radiative centers during tough dry etching process. However, a detail mechanism of efficiency degradation and correlation with bare wafer properties are not clearly studied. In this study, we investigated the size-dependent electrical and optical characteristics of InGaN/GaN based blue mLEDs and the detail mechanism of the size dependency. Photoluminescence (PL) and time-resolved PL measurements were performed on various size of micro-disk structures to investigate PL efficiencies and carrier lifetime. For electroluminescence experiments, circular mLEDs of which diameter range from 10 to 300 μm were realized by conventional lateral LED fabrication conditions. Basic electroluminescence properties were investigated using semiconductor parameter analyzer and integrating sphere system.

[1] IEEE Trans. Electron. Dev. **62**, 1918 (2015)

[2] J. Soc. Inf. Display **27**, 347 (2019)

[3] Phys. Status Solidi A **215**, 1700508 (2018)

Keywords:

Group III-nitride semiconductor, Micro light-emitting diodes

Self-powered Solar-blind Ultraviolet Photodetectors based on SnO₂ Nanowires

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Abstract:

We report the performance of self-powered solar-blind photodetectors based on the SnO₂ nanowires (NWs). SnO₂ NWs with a length of several hundred micrometers can be synthesized by thermal chemical vapor deposition using SnO powder as a source material. The initial in-plane growth of NWs via the Au-catalyzed vapor-liquid-solid mechanism evolves into vertical growth of NWs forming NW bundles. Metal-SnO₂ NWs-metal photodetectors were fabricated, and their photo-responsivity to the ultraviolet (UV) light with a wavelength of 254 nm was investigated. The device exhibited good photo-sensitivity, and the photocurrent gain was estimated to be 10⁴ times. The raise and decay time scales were ~0.6 s and ~1.8 s, respectively. In particular, the self-powered photocurrent gain at 0 V was ~0.78 nA under 254 nm UV illumination of 36 mW/cm². Our results demonstrate that the SnO₂ NWs are promising candidates for self-powered solar-blind photodetectors and that thermal CVD using SnO power is suitable for growing the SnO₂ NWs at temperatures as low as 800 °C.

Keywords:

SnO₂ nanowires, Self-powered photodetectors, Solar-blind ultraviolet, SnO powder, Metal-semiconductor-metal devices

Blue emitting carbon dots using wasted styrofoam

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Abstract:

The researches on recycling of wastes (paper, plastic, coffee residue, and mask, etc.) have been conducted because of global environmental problems. In particular, the use of styrofoam is increasing for fresh storage of food and safe management of items. Therefore, the amount of discarded styrofoam increases. It causes the disposal cost and global environmental problem. To solve this problem, the development of applications for recycling wasted styrofoam has been needed. Therefore, we research the carbon dots through recycling wasted styrofoams. These carbon dots have been researched because of their good optical properties and facile synthesis process. Therefore, carbon dots have been widely used for light emitting diode, sensing, bioimaging, and catalysis, etc. In this work, we synthesized carbon dots with using wasted fine dust in HEPA filters by solvothermal method according to various solvents such as DI-water, EtOH, and 2-ProH. Their structures, luminescence, and morphology characterization synthesized carbon dots were investigated by using X-ray photoelectron spectroscopy (XPS), raman spectroscopy, Fourier-transform infrared spectroscopy (FT-IR), photoluminescence (PL) and high-resolution transmission electron microscopy (HR-TEM), respectively.

Keywords:

Carbon dot, styrofoam

Orientation of methylammonium cations on methylammonium lead chloride single crystals studied by polarization dependent Raman scattering spectroscopy

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Abstract:

Hybrid organic-inorganic perovskites (HOIPs) are interesting material to many researchers as an absorber in solar cell devices. HOIPs have a high potential for applications, because the efficiency of perovskite solar cells has been rapidly increasing compared with that of other material-based devices. We measured polarization dependence of Raman response of methylammonium lead chloride (MAPbCl₃) single crystals where successive structural phase transitions occur from cubic to tetragonal structure at ~179 K and from tetragonal to orthorhombic structure at ~172 K. We observed anomalous polarization dependence especially in the low temperature orthorhombic phase that can be associated with orientation of methylammonium (MA) cations. We developed a systematic way to analyze the polarization dependence from which we could determine the MA orientation. Our results show that the MA ions are oriented towards a specific direction in the low temperature phase. We also claim that Raman scattering spectroscopy is very useful in monitoring unusual structural properties in HOIPs.

Keywords:

Perovskite, HOIPs, MA orientation, Polarization dependent Raman, Solar cell

Enhancement of Silicon Nanostructure Hybrid Solar Cell Performance by Silicon Quantum Dots.

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Abstract:

Many of the studies in silicon solar cells have been investigated through conducting polymer poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate)(PEDOT:PSS) films. Recently, solar cells with quantum dots have come into new generation photovoltaics. In this study, size-dependent silicon quantum dots (Si QDs) have been investigated to increase hybrid heterojunction solar cell performance. Si QD's optical and electrical properties can enhance photovoltaic effects. They absorb UV light to shift visible light as 700nm which contains a solar spectrum, called Down-shifting effect. On the other hand, Si QDs help energy transfer between hole-electron generation layers using dipole-dipole interaction. We made silicon nanoholes (Si NHs) on the n-type crystalline silicon and Si QDs were coated in two ways. Because each layer occurred different physical properties, they are analyzed by Photoelectron spectroscopy (PES) to know band diagrams as well. This investigation is expected to be an indicator that extends the way of low-cost and highly efficient photovoltaic cells in the future.

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Keywords:

hybrid solar cells, silicon nanostructure, down shifting, energy transfer, silicon quantum dots

고에너지 볼밀링을 이용한 $\text{CaTiO}_3: \text{Eu}^{3+}$ 페로브스카이트 형광체 분말의 합성과 광학적 특성

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Abstract:

본 연구에서는 CaTiO_3 에 Eu^{3+} 이온을 도핑시킨 $\text{CaTiO}_3: \text{Eu}^{3+}$ 페로브스카이트 형광체 분말을 고에너지 볼밀링(high-energy ball-milling; HEBM)을 이용하여 상온에서 합성하였다. Eu^{3+} 이온의 도핑 농도와 어닐링 온도에 따른 페로브스카이트 형광체 분말의 구조적 특성과 광발광 특성을 연구하였다. $\text{CaTiO}_3: \text{Eu}^{3+}$ 페로브스카이트 형광체 분말 시료의 제작을 위해 CaCO_3 , TiO_2 , Eu_2O_3 을 지르코늄 용기에 혼합한 후 볼과 시료의 무게비가 50:1이 되도록 지르코늄 볼을 사용하여 400 rpm으로 4h 밀링을 하였다. Eu^{3+} 이온의 도핑 농도는 2, 4, 6, 8, 10, 12 mol%로, 열처리온도는 600, 800, 1000, 1200, 1400°C로 각각 합성하여 구조적 특성과 광발광 특성을 분석하였다. EDS 분석 결과 Ca(Calcium), Ti(Titanium) O(Oxygen), Eu(Europium)으로 구성으로 되어 있으며 다른 불순물은 존재하지 않았다. X-선 회절(XRD) 분석 결과 $\text{CaTiO}_3: \text{Eu}^{3+}$ 페로브스카이트 형광체 분말의 결정구조는 사방정계임을 확인하였다. $\text{CaTiO}_3: \text{Eu}^{3+}$ 페로브스카이트 형광체 분말의 광발광 (photoluminescence emission, PL) 특성은 파장 398 nm 로 여기 시켰을 때 Eu^{3+} 이온의 $^5\text{D}_0 \rightarrow ^7\text{F}_2$ 전이에 의해 614 nm에서 강한 발광 피크가 나타났으며, Eu^{3+} 이온의 도핑 농도 6 mol%, 열처리온도 1200°C에서 가장 강한 광발광 특성을 나타냈다.

Keywords:

고에너지 볼밀링(HEBM), 페로브스카이트(Perovskite), 형광체, $\text{CaTiO}_3: \text{Eu}^{3+}$, 광발광(Photoluminescence)

비선형 위상 이동을 이용한 광경로차의 모호성 해결 방법 Method for resolving ambiguity of optical path-length difference using non-linear phase shift

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Abstract:

간섭계에서 발생하는 간섭신호는 간섭계 양팔의 광경로차에 의해서 주어진다. 측정된 간섭신호로부터 측정 당시 광경로차를 알기 위해서는 간섭신호에 푸리에 변환을 취하거나 다양한 기법의 신호처리를 통해서 광경로차를 해석해 낼 수 있다. 하지만 간섭신호가 우함수인 코사인 함수인 점을 고려할 때 광경로차의 부호를 결정할 수는 없다. 하지만 간섭계에 위상 이동이 일어날 정도의 작은 광경로차를 유도하여 간섭신호가 이동하는 방향을 측정함으로써 광경로차의 부호를 결정할 수 있음을 실험적으로 확인할 수 있었다. 본 실험에서는 위상 이동을 원활하게 제어하기 위해서 광섬유에 펄프광을 인가하여 발생하는 비선형 굴절률 변화에 기반을 둔 위상 이동 기법을 적용하였다. 한쪽 팔의 반사거울의 위치를 고정하고 다른 팔의 반사거울의 위치를 푸리에 변환의 결과를 보면서 이동시켜 광경로차가 상대적으로 다른 부호를 가지도록 하고 각각의 경우에 대해서 펄프광을 인가하여 간섭신호의 이동방향을 관측하였다. 푸리에 변환에서는 구분할 수 없던 광경로차의 부호를 위상 이동 특성으로부터 확인이 가능함을 확인할 수 있었다. 이러한 효과를 이용하여 광경로차의 모호성을 해소하고 광경로차 부호가 다른 곳에 위치한 반사체 사이의 간격을 정확히 구분할 수 있는 기법으로 발전시키고자 한다.

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Keywords:

비선형 위상이동, 광경로차, 푸리에 변환, 위상이동기법, 비선형 굴절률 변화

Frequency conversion platform towards quantum photonic integrated circuits

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Abstract:

양자상태의 생성, 조작, 그리고 측정이 상대적으로 쉽게 구현 가능한 광플랫폼은 큰 관심을 받고 있다. 최근 양자정보기술 소자의 소형화와 이동 편의성이 강조되면서 광집적소자 활용의 범위가 양자정보기술로 넓혀지고 있다. 양자정보를 위한 광플랫폼에 양자상태의 생성은 단일광자를 통해 이루어지는데 양자 컴퓨팅이나 양자통신에서 사용되는 단일광자의 파장대역이 달라 다양한 파장을 갖는 단일광자 광원의 연구가 요구되고 있다. 본 발표에서는 실리콘 링 공진기 구조를 이용해 광집적회로에서 near-IR 파장부터 광통신 파장범위까지 주파수를 변환할 수 있는 가능성에 대한 연구 진행사항을 보고한다.

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Keywords:

Frequency conversion, 단일광자, 양자정보기술, 광집적회로

Theoretical Study of the Cross-Cross-Resonance Gate in Circuit QED system

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Abstract:

We theoretically study the cross-cross-resonance (CCR) gate in circuit QED system. It has been recently argued that the CCR gate, where the microwave input pulses corresponding to the two individual qubit frequencies are fed into the relatively other qubits, can achieve shorter gate operating time than the cross-resonance (CR) gate. Their result is mainly based on the study of the coupled two-qubit system. In this work, we thoroughly investigate the CCR gate based on the two transmon system coupled by a bus resonator. We will derive the effective Hamiltonian both by using numerical diagonalization and perturbative analysis. Using the quantum optics simulation, we analyze the fidelity of the CCR gate, which will be compared with that of the CR gate.

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Keywords:

Transmon, Cross-Cross-Resonance gate

포획된 이온의 특성 계산과 고충실도 얽힘 발생을 위한 위상 공간 궤적 분석

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Abstract:

본 연구에서는 이온 트랩 기반의 양자컴퓨터를 구성하는 포획된 이온 사이의 거리, 움직임의 고유진동수, 고충실도, 2큐비트-양자게이트의 구현을 위한 이온 움직임의 위상 공간 궤적을 계산하였다. 선형 폴 트랩에 포획된 이온의 위치는 전체 퍼텐셜에 의한 힘과 이온 사이의 쿨롱 힘의 균형점에 의해 정해지며[1,2], 우리는 해석적, 수치적인 방법을 이용해 이온 2개~5개까지의 평형 위치를 찾았다. 또한 변환 행렬의 고유화를 통해 이온의 축방향, 수직방향의 움직임 고유벡터와 고유값 역시 계산하였다. 2큐비트-양자게이트 구현을 위해 각각의 표준 모드에 따른 위상 공간 궤적이 게이트 시간에 이르렀을 때 원점으로 되돌아오므로써 이온과 그 움직임의 얽힘이 풀리는 것을 확인하였고[3], 주파수 편이에 따른 충실도는 일정한 펄스일 때보다 조각 펄스일 때 더 높게 나타남을 확인하였다[4]. 나아가 기계학습 방법을 통해 고충실도를 가지는 최적의 레이저 세기와 주파수 변조 방법 연구를 계획하고 있다.

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Keywords:

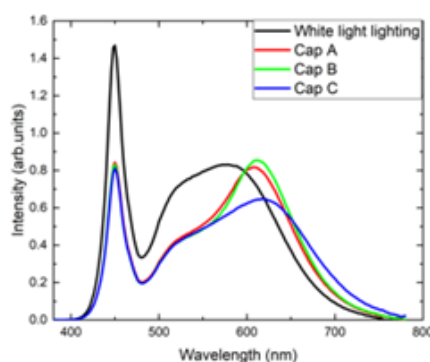
Ion trap, 2-qubit quantum gate, Normal mode, Fidelity, Segmented pulse

개발된 형태의 CdSe/ZnS 적색 양자점 캡을 활용한 백색 조명의 성능 향상 연구

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Abstract:

조명의 성능을 평가할 때 가장 중요한 평가 기준은 조명의 방출 색상을 절대온도 값으로 보여주는 상관 색 온도 (Correlated Color Temperature)와 연색성을 수치화해서 보여주는 연색지수(Color Rendering Index) 값이다. 조명에 사용되는 백색 LED의 경우 일반적으로 청색 LED의 발광 면적 위로 황색 YAG($Y_3Al_5O_{12}$)를 도포하여 제작하며, 이러한 제조 방식은 적색 광의 결핍 [1,2]으로 인해 연색성이 떨어진다는 단점을 가지고 있다. 본 연구에선 CdSe/ZnS계 코어-셸 구조의 적색 양자점과 Siloxane계 PDMS (Polydimethylsiloxane) 경화제를 혼합해 조명의 LED에 직접 부착 가능한 개방된 원경 형광체 구조의 캡 형태로 가공하였으며, 사용된 적색 양자점의 농도와 중심 파장에 따른 광 특성을 평가하기 위해 양자점의 농도 혹은 중심 파장이 다른 사용된 3종류의 적색 양자점 캡을 제작하였다. 적색 양자점 캡을 색 균일도가 가장 높은 배치로 조명의 백색 LED에 부착해 측정한 결과 83.1 이었던 기존 백색 조명의 CRI 값은 최대 94.5 까지 개선되었으며, 적색 양자점 캡의 종류와 상관없이 CRI 값을 90 이상을 달성하였다. 그리고 2종류의 적색 양자점 캡을 혼합해 사용할 때 광 특성의 변화를 확인해보기 위해 방출 파장과 농도가 다른 2종류의 적색 양자점 캡을 동시에 부착시킨 후 서로의 비율을 변화시키며 측정을 진행했다. 측정 결과 2종류의 적색 양자점 캡을 동시에 사용할 때, CCT 값이 2종류의 적색 양자점 캡을 단일로 사용했을 때의 범위 내에서 조절되는 것을 확인했으며, 이러한 결과는 사용자가 간단하게 조명의 색 온도를 제어 할 수 있는 고연색 조명의 가능성을 보여준다.



(a)

(b)

[그림1] (a) 중심 파장이 450nm인 청색 LED 위에 적색 양자점 캡 올린 뒤 발광 한 사진 (b) 측정에 사용된 조명과 3종류의 적색 양자점 캡을 조명의 백색 LED에 각각 부착했을 때 방출 스펙트럼

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Korean journal of optics and photonics, 2013. 24(2): p. 64-70.

Keywords:

Quantum dot, Cdse/ZnS core-shell, YAG phosphor, White LED , Open remote structure

적색 양자점 필름을 이용한 백색 조명의 고연색성 구현 Realization of High Color Rendering Index of Conventional White Lighting by Using Red Quantum Dot Films

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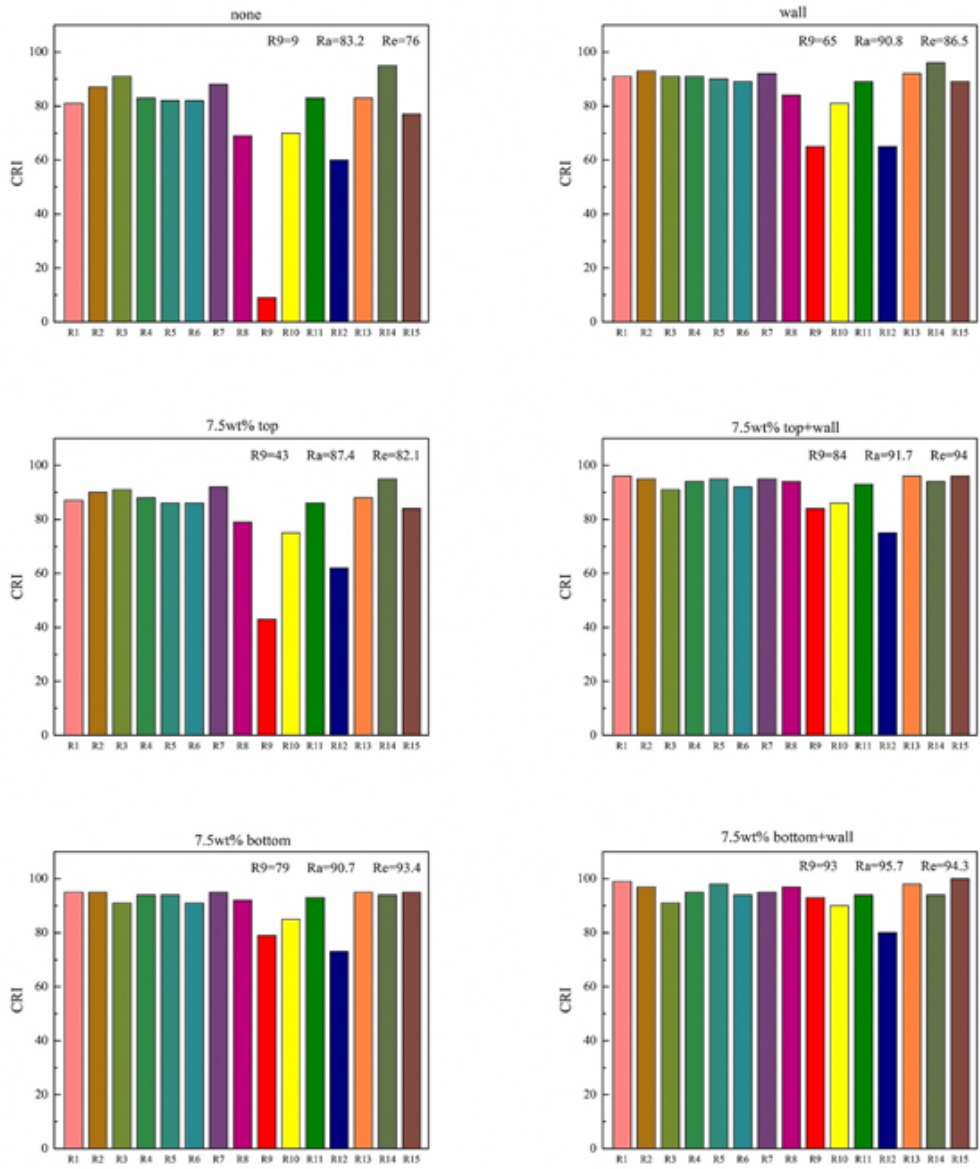
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Abstract:

조명 시장에서 사용되는 많은 백색 LED는 황색 형광체 YAG($Y_3Al_5O_{12}$)와 InGaN 청색 LED 칩으로 구성된다. 이 경우, 적색 파장 영역의 세기가 부족하여 연색지수(Color Rendering Index, CRI)가 떨어진다.⁽¹⁾ 이를 개선하기 위해 녹색-적색 형광체를 청색 LED에 적용하는 방법이 있지만, 열적 안정성이나 비용과 같은 문제가 있다.

또 다른 방법으로는, 적색 양자점을 적용, 부족한 적색을 보완하여 LED 조명의 연색지수를 개선하여 고품질의 인간중심 조명을 개발하는 실험들이 진행되고 있다.⁽²⁾ 이를 검증하기 위해 15W의 소비전력에 72개의 백색 LED가 장착되어 있고 연색지수는 80 이상, 상관 색온도(Color Correlated Temperature, CCT)는 5,700 K인 일반 LED 조명에 양자점을 적용했다. QD film과 QD wall은 주 방출 파장이 630 nm 근처인 CdSe/ZnS Core/Shell로 합성되었으며, QD wall은 반사 필름이 내장되어 있다. 두께 2 mm인 Diffuser plate의 위, 아래에 각각 QD film을 부착하거나, QD wall을 조합하여 6가지의 방법으로 실험을 진행하였다. 기존 조명을 none, QD wall을 설치한 것을 wall, Diffuser plate의 위에 QD film을 부착 시 top, 아래에 부착 시 bottom으로 정의하였다. 시야각 특성을 확인하기 위해 -70° 부터 70° 까지 10° 씩 늘려가며 연색지수를 측정하였다. 실험 결과, 기존 조명의 연색지수는 평균 83.2였으며, QD wall을 사용 시 평균 90.8까지 증가하였다. 특히 top과 bottom을 비교하였을 경우 bottom의 연색지수가 더 높았으며, QD wall을 함께 사용하였을 때 연색지수가 더욱 증가하는 것을 [그림1]을 통하여 확인할 수 있다. 특히 bottom+wall의 경우 연색지수가 평균 95.7까지 도달하는데, 이는 bottom이 QD film으로 인한 적색 여기가 일어난 후에 Diffuser plate를 통과하여 변환되지 않은 청색광을 추가적으로 활용하기 때문으로 해석된다. 또한, top과 top+wall은 각도에 따라 청색광이 한번 통과하고 빠져나가는 광 경로 차이가 크기 때문에 시야각에 따른 연색지수의 차이가 크게 나는 것을 확인할 수 있다. 즉, 본 연구는 QD film의 적절한 배치를 통해 연색지수를 90 이상 높일 수 있고, QD wall과 같이 적용함으로써 추가적 개선을 기대할 수 있다는 점을 보였다.

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[그림1] 7.5wt% 정면에서의 6가지 조합의 연색지수

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Keywords:

양자점(Quantum Dot), 연색지수(CRI), 조명(Lighting)

Deterministic spin state initialization of silicon-vacancy in silicon carbide

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Abstract:

Defect spins in solids are a useful resource for quantum information technologies including quantum computing, and quantum sensing applications. While the well-known color centers in diamond such as the nitrogen-vacancy (NV) center have been a leading candidate for decades, deep defects in silicon carbide (SiC), which is a wide bandgap semiconductor, are another attractive candidate.

Silicon carbide (SiC) hosts many types of point defects whose spins can be used as quantum bits. The negatively charged silicon-vacancy (V_{Si}^-) is one of them. (V_{Si}^-) in SiC has a long spin coherence time both in the room and low temperature. Besides, like the NV center in diamond, its ground spin state can be initialized optically through the spin-dependent intersystem crossing. However, (V_{Si}^-) with spin 3/2 has an issue that spins naturally becomes equally populated into two of the quartet spin sublevels. It is, therefore, necessary to get a better understanding of the optical spin initialization process of the spin 3/2 system which will allow us to develop deterministic spin state initialization methods.

In this study, we will demonstrate the deterministic initialization by simultaneous optical and spin resonance control. Also, using the magnetic double resonance technique, we investigate the underlying mechanism of optical initialization and state measurement of the (V_{Si}^-) spin. This research will give a positive outlook for the possibility of various quantum applications exploiting (V_{Si}^-) in SiC.

Keywords:

Silicon-vacancy, Optically detected magnetic resonance, deterministic spin state initialization

The Development of Infrared Cloud Monitoring for the GroundBIRD Telescope

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Abstract:

We have developed an infrared cloud monitoring for the GroundBIRD telescope (GB) that assists the measurement of the telescope. The housing is made of aluminum and designed for weather-proof solidity to be installed in the outfield. The infrared imaging core was selected as an infrared sensor. Because it has a small field of view (FOV), around 57 x 44 degrees, four sensors watch the sky at the same time pointing in different directions to cover GB's FOV. These cores are attached to a PCB module to operate as a USB thermal webcam. Finally, a single-board computer is adopted to control four cameras. It records sky pictures regularly and transforms them into a sky map. The assembled system is installed and under commissioning.

Keywords:

infrared, camera, telescope, cloud, groundbird

Air Shower Reconstruction using Deep Learning with the HAWC Observatory

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Abstract:

The High-Altitude Water Cherenkov (HAWC) Observatory observes gamma rays with energies between 300 GeV and a few hundred TeV. Gamma rays from astronomical sources interact with the atmosphere, producing an air shower of particles that in turn produce Cherenkov radiation in water tanks. This Cherenkov radiation is then detected by photomultiplier tubes which measure the energy and time of the shower particles. In the HAWC Observatory, there are 300 water tanks positioned in a 2D array. The energy and time can be represented as a 2D image which makes the convolutional neural network (CNN) an excellent option to perform classification and regression tasks for HAWC. We train a CNN to measure the angles of the air showers and compare the performance against the standard HAWC reconstruction algorithm.

Keywords:

Gamma rays, the energy and time of the shower particles, A 2D image, Convolutional neural network, the angles of the air showers

Convolutional Neural Networks for Gamma-Hadron Classification with the HAWC Observatory

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Abstract:

The High Altitude Water Cherenkov (HAWC) Experiment is a gamma ray observatory. It consists of 300 water tanks, each of which contains four photomultiplier tubes (PMTs). In the atmosphere, cosmic and gamma rays produce air-showers, which is a cascade of ionized particles and electromagnetic radiation. Ionized particles produce Cherenkov light in the water tanks. HAWC measures both time and effective charge of these Cherenkov lights and this data can be represented as a 2D image where each tank corresponds to one pixel of the image. We train a neural network to distinguish gamma from cosmic rays using a semi-supervised method so that we can train using real data. However, due to the extremely low proportion of gamma rays compared to cosmic rays, this semi-supervised training is not trivial.

Keywords:

HAWC, CNN, Deep Learning, gamma, cosmic ray

Electron dynamics in HHG from solid based on Houston states

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Abstract:

High harmonic generation induced by the interaction of a solid with a laser has been reproduced through many experiments and theoretical calculations. However, efforts to understand the electron dynamics in solids have not been clearly explained despite many attempts. We try to give a clearer description of electron dynamics by approximating the equations of motion in Houston basis, which can control electron path in the energy band. Through time-frequency analysis of HHG, we find out when an electron jumps between energy bands, and interpret it by using semiclassical methods such as stationary phase approximations.

Keywords:

High harmonic generation, solid, electron dynamics

Realization of automatic frequency offset locking with RedPitaya FPGA module

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Abstract:

본 연구에서는 루비듐 원자 양자 중력계 레이저 시스템에 사용되는 레이저인 리프트 레이저와 라만레이저의 주파수를 원자 분광학 신호에 주파수 안정화된 기준 레이저(cooling laser)로부터 각각 6.8GHz와 1~2GHz만큼 red-detuning되도록 주파수 안정화시키기 위해 Tunable frequency offset locking method를 사용하였다. 6.8GHz와 1~2GHz의 beat frequency를 이용하여 2개의 광섬유 레이저를 수백 kHz의 servo bandwidth를 갖는 Redpitaya Stemplab 125-14 FPGA module을 이용하여 주파수 안정화를 수행하였다. linien이라 불리는 통합 소프트웨어 모듈을 통해 주파수 잠금의 알고리즘 수정이 가능하고, 자동적으로 원하는 slope에 주파수 안정화를 기대할 수 있어, 이에 대한 실험내용에 대해 자세히 설명하고자 한다.

Keywords:

automatic frequency offset locking, Redpitaya Stemplab 125-14 FPGA module

Design and construction of an electro-optic modulator yielding a moderate index of modulation by using a resonant circuit

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Abstract:

We present design considerations and construction of a home-built electro-optic modulator (EOM), yielding the index of modulation $M > 3$, which can be utilized as a tuning knob, for instance, in optimizing a modulation transfer spectroscopy signal. The EOM is designed to operate at a resonant frequency range of 3~10 MHz with the Q-value >10 . The carrier-to-sideband ratio of a phase-modulated beam is investigated by directly observing the transmission of the Fabry-Pérot interferometer. Technical considerations for achieving a required index of modulation with low-power consumption will be discussed as well.

Keywords:

Resonant electro-optic modulator, index of modulation

자기장을 이용한 87Rb의 변조전이분광학 신호 강화

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Abstract:

87Rb 원자의 $5S_{1/2}(F = 1) \rightarrow 5P_{3/2}(F' = 0, 1, 2)$ 전이에서의 변조전이분광학(Modulation Transfer Spectroscopy, MTS) 신호는 자기장에 의해 강화되는 특성이 보고된 바 있다. 이러한 특성을 연구하기 위해 증기 셀 근처의 지구 자기장을 보상하고 원하는 방향의 자기장을 가할 수 있는 직육면체 (570x350x265mm³)의 6축 헬름홀츠 코일을 제작하여 사용하였다. 또 프로브빔, 펌프빔에 반파장 편광판과 Extinction ratio가 높은 편광기를 사용해 편광 방향과 자기장 방향과의 각도를 두 가지 서로 다른 방향으로 정렬하고 이에 따른 MTS 신호 차이를 확인하였다. 이러한 실험 결과를 바탕으로 이론으로 예측한 결과와 비교하여 MTS 신호가 강화됨을 검증하였고, 같은 구조의 제만 에너지 준위를 가진 다른 원자에서도 적용될 수 있는 가능성을 보았다.

Keywords:

변조전이분광학, 87Rb 원자의 $5S_{1/2}(F = 1) \rightarrow 5P_{3/2}(F' = 0, 1, 2)$ 전이

탄소-13 동위원소를 이용한 분광기반 호흡 진단 시스템 Carbon-13 Isotope Breath Test System based on Spectroscopic Technique

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Abstract:

호흡은 인체의 상태를 나타내는 중요한 지표이다. 호흡을 이용한 진단의 역사는 고대 그리스의 의학자인 히포크라테스로부터 환자의 호흡에서 나오는 냄새를 진단에 이용할 것을 가르치며 시작 되었다. 근래에는 사람보다 우수한 개의 후각을 이용한 뇌전증의 발작 전조 확인, 알츠하이머 및 코로나 감염 진단 등이 보고된 바 있다. 현재는 과학기술의 발전으로 단순히 냄새가 아닌 보다 정밀한 화학성분의 분석을 통하여 병증의 유무를 판단하고 있으며, 대표적으로 헬리코박터 파일로리(H. Pylori)에 대한 감염 검사(요소호기 검사기)가 있다. 이렇듯 호흡은 사람의 건강 상태와 관련이 있는 유용한 정보를 담고 있으며, 호흡을 분석하여 건강상태 및 질병의 유무를 진단하는 연구가 활발히 이루어지고 있다.

본 논문에서는 분광 기반의 호흡 진단 장비를 구성하여, 탄소-13을 표지자로 호흡 내 CO₂의 농도를 측정하여 병증을 진단하는 시스템을 구성하고자 한다. 분광기반의 호흡진단법은 기존의 전통적인 진단법과 비교하여, 비침습성, 신속성, 정확성 및 편의성에서 장점을 가진다. 특히 호흡을 이용하여 병증의 유무를 진단할 수 있다는 것은 편의성에서 큰 장점이 있으며, 측정에서 전문인력이 필요하지 않기 때문에 유지 보수 및 측정비용을 매우 저렴하게 할 수 있다.

탄소-13은 현재 요소, 메타세틴 등의 물질에 표지자로 사용되며, 위, 간 등의 장기에 대한 진단에 응용되고 있다. 탄소-13은 신체 내부에서 반응을 통해 ¹³CO₂로 변환되고, 호흡에 포함되어서 배출되게 된다. CO₂는 중적외선 영역에서 ro-vibrational mode에 해당하는 강한 흡수선을 가지므로, 중적외선 광원을 이용한다면 단순한 시스템으로 호흡 내 ¹³CO₂의 농도를 정밀 측정 가능하다.

¹³CO₂의 농도를 측정하기 위해서 중적외선 대역의 LED와 QCL(Quantum Cascaded Laser)을 광원으로 단일 경로 흡수 분광 시스템을 각각 설계 및 구축하였다. LED는 저렴한 가격으로 신속한 측정이 가능하다는 장점이 있다. 선정된 LED는 4.3 μm를 중심파장으로 700 nm 영역의 대역폭으로 발진하며, 이를 ¹²CO₂와 ¹³CO₂의 파장에 해당하는 대역통과필터를 이용하여 각각의 광량 변화를 측정하였다. 레이저 기반의 시스템의 경우, ¹²CO₂와 ¹³CO₂의 단일 흡수선을 측정하며, 이를 통해 측정 감도(Sensitivity)를 향상시킬 수 있다. 선정된 QCL의 경우 4.3 μm를 기준으로 ~4 nm의 연속 파장 변조가 가능하며, ¹²CO₂와 ¹³CO₂의 흡수선을 측정 분석하였다. 시스템의 측정감도는 < 1% 수준으로 확인되었다.

개발된 시스템은 사용 광원 및 형태에 따라서, 측정 감도, 측정 방식, 진단 가능 질병의 종류가 차이가 있다. 향후 실제 호흡을 직접 포집하여, 실시간으로 호흡내 CO₂를 측정하고 LED와 QCL 기반 시스템의 비교 분석을 통해 현재 진단하고 있는 위(헬리코박터 균 감염여부)를 포함하여 간, 췌장 등 장기의 건강상태 진단으로 확대 적용할 예정이다.

Keywords:

호흡진단, 중적외선, 분광, 탄소-13, 동위원소

호흡진단 응용을 위한 아세톤/에테인의 중적외선 스펙트럼 연구 Study on Mid-IR Spectrum of Acetone and Ethane for Breath Test Application

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Abstract:

호흡에 포함된 특정 분자를 측정하여 병증의 유무를 비침습적으로 진단하는 호흡진단 기술은 호흡만으로 진단이 이루어지므로 편의성이 우수하고, 신속하게 진단이 가능하므로 많은 연구가 진행되고 있다. 호흡진단을 위해서는 병증과 관련된 표지자(biomarker)를 찾아내고, 이를 정밀하게 측정하는 두 가지 기술이 필요하다. 특히 휘발성 유기 화합물(VOC)의 경우에는 하나의 분자가 여러 병증과 연관되어 있는 경우가 많아 단일 분자만으로는 진단이 어렵기 때문에 다수의 분자를 동시에 측정하여 병증을 진단하는 방향으로 연구가 진행되고 있는데, 특히 최근에는 다수의 전기화학 센서 어레이를 이용한 “전자코” 등이 활발하게 연구되고 있다.

2~10 μm 의 중적외선 영역은 다양한 분자들의 흡수 스펙트럼의 세기가 가시광이나 근적외선 영역에 비해 수십~수백 배 정도로 크기 때문에 미량 기체 분석에 장점을 가지고 있다. 또한 최근 QCL(quantum cascade laser) 등 광원 기술과 광학 소자들의 발전으로 중적외선 영역에 대한 접근이 쉬워졌기 때문에 이를 이용하여 하나의 장비에서 높은 정밀도로 여러 종류의 VOC를 측정할 수 있다면, 호흡진단에 활용할 수 있을 것으로 기대된다.

본 연구에서는 다중 VOC 측정 기반 호흡진단을 위한 기초 연구로서 아세톤과 에테인을 동시에 측정할 수 있는 광학계를 구성하고자 한다. 아세톤은 당뇨와, 에테인은 산화 스트레스와 연관이 있는 것으로 알려져 있으므로 아세톤과 에테인 측정 자체에도 의미가 있으며, 이를 동시에 측정하는 시스템을 구성하여 추후 다수의 VOC 측정으로 확장하려고 한다. 기존 여러 그룹의 연구들에서는 아세톤은 8 μm 대역, 에테인은 3.35 μm 대역의 흡수단면적이 가장 큰 영역들을 주로 사용하였는데, 하나의 광학계로 두 분자를 동시에 정밀하게 측정하기 위해서는 가까운 파장 영역에 있으나 서로 구분되는 흡수선을 찾아야 하므로 새로운 파장 대역을 찾아야 했다.

이를 위해 접근 가능한 여러 데이터베이스 및 참고문헌을 기반으로 3.4 μm 영역을 선정하였으며, 이 파장 영역에서 각각의 스펙트럼을 측정하였다. Nanoplus사의 QCL laser를 광원으로 사용하여 1 m 길이의 셀에 500 ppm 농도로 공기와 혼합된 아세톤과 에테인을 각각 주입한 후 흡수선을 측정하였고, 이를 데이터베이스와 비교하여 두 분자를 동시에 측정할 수 있는 파장 영역을 선정하였다.

향후 선정된 파장 영역에서 OA-ICOS(off-axis integrated cavity output spectroscopy)와 CRDS(cavity ring-down spectroscopy) 분광법을 적용하여 각 분자에 대해 ppb 이하까지 정밀하게 측정할 수 있는 광학계를 구성하여, 실제 호흡을 측정할 예정이다.

Keywords:

Breath Test, Mid-IR, Acetone, Ethane, Spectroscopy

Application of a commercial blazed grating as a mirror for matter waves

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Abstract:

Mirrors for atoms and molecules could open new frontiers in matter-wave optics with neutral particles. However, the realization of such components for atoms and molecules has required sophisticated electromagnetic fields, nano-fabrication, or particle cooling because of their inherently short de Broglie wavelength and strong interaction with a surface. We demonstrate that blazed gratings designed for photons can work as a mirror for atoms and molecules of thermal energy with up to 47 % reflectivity when used under grazing incidence conditions. The matter-waves of He atoms are reflected from four blazed gratings of different periods (20, 3.33, and 0.417 μm) that are commercially available. The reflection probability from the gratings mounted in an in-plane configuration qualitatively follows the specular reflection probability of the multiple edge-diffraction reflection (MEDR) model [1]. When a wave scatters off an array of half-planes at grazing incidence, it undergoes multiple diffractions over an edge of each half-plane. Within the MEDR model the reflection probability increases with decreasing incidence angle and grating period [1]. This allowed us to observe reflection of fragile He clusters (He_2 and He_3) with the 417-nm-period grating, which implies that the grating mirror based on the MEDR mechanism can also work for other exotic particles, such as antihydrogen atoms. It will be possible to prepare an almost perfect mirror for any neutral particle of 100% reflectivity by tailoring edges of grating and shortening its period. In summary, our experiment and analysis show that commercial optical blazed gratings can serve as a mirror in matter-wave optics, which paves the way toward developing various optical instruments such as interferometers and microscopes.

1. J. H. Lee, L. Y. Kim, Y. T. Kim, C. Y. Lee, W. Schöllkopf, and B. S. Zhao, Phys. Rev. Lett. **122**, 040401 (2019)

Keywords:

Matter-wave, Optical blazed grating, Atomic mirror, Multiple edge-diffraction reflection

numerical study of strongly coupled atom-cavity system

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Abstract:

본 연구에서는 자기 광 포획 (magneto-optical trap)에 포획된 루비듐 원자를 중력 방향에 있는 고휘도 공진기의 진공 모드에 떨어뜨리는 공진기 강결합 시스템을 QuTiP 시뮬레이션을 통해 분석하였다. 원자가 공진기 모드를 통과하는 궤적을 계산하고, 측정된 진공 라비 스펙트럼 (vacuum-rabi spectrum)을 시뮬레이션 결과와 비교하였으며, 평균 광자수, 위상, 그리고 2차 상관 함수 (second-order correlation function)역시 계산하였다. 나아가 강결합된 원자-공진기 시스템에 주문형 단광자 발생을 위한 ν -STIRAP (vacuum-stimulated raman adiabatic passage) 실험 변수를 찾았다.

Keywords:

Strongly coupled atom-cavity system, Vacuum Rabi splitting, STIRAP

Mechanisms of transformation of EIA and EIT resonances at D2 lines of ^{85}Rb atoms

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Abstract:

Transformation of electromagnetically induced absorption and transparency in the coupling-probe experimental resonance spectra at D2 lines of ^{85}Rb atoms are solved considering Optical Bloch equations with and without neighboring hyperfine states near the degenerate two-level system (DTLS). The mechanisms of transformation between electromagnetically induced absorption and transparency are clearly determined to be the effect of the neighboring states due to the Doppler broadening, power ratios between coupling and probe beams, and openness of the excited state in a real atomic system.

Keywords:

electromagnetically induced absorption, degenerate two-level system

Quantum search on complete graphs using interpolated quantum walks

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Abstract:

In 2004, Szegedy developed a quantum search algorithm on Markov chain to show a quadratic speed-up compare to the classical search algorithm. In 2016, Krovi *et al* modified the algorithm by introducing partially absorbing Markov chains and showed that the quantum search can find a marked vertex quadratically faster than classical search for any reversible Markov chain. Their proof is based on quantum phase estimation and certain properties of the stationary state. By considering the complete graph with m marked vertices, we offer an alternative viewpoint of the underlying mechanism of the quantum search. We can find that the quantum search can be well explained by only two states and the maximal mixing of the quantum states with the initial and final states is the key point to find an optimal parameter s_0 and searching time t_s . We also give an explanation of how to construct the invariant subspace of the quantum walk operator.

[1] M Szegedy. *Quantum speed-up of Markov chain based algorithms*. In 45th, Annual IEEE Symposium on Foundations of Computer Science, pages 32–41. IEEE, 2004.

[2] H Krovi, F Magniez, M Ozols, and J Roland. *Quantum walks can find a marked element on any graph*. *Algorithmica*, 74:851, 2016.

Keywords:

Markov chain, quantum search, complete graph, maximal mixing

중성원자-공진기 양자네트워크 노드 설계

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Abstract:

중성원자와 고휘도의 공진기를 이용한 양자네트워크 실험은 활발히 이루어지고 있다. 본 연구에서는 원자-광자 양자게이트에 특화된 실험장치 설계 및 개발 상황을 보고한다. 자기-광학 포획방식을 이용해 87 루비듐 원자로 구성된 원자구름을 만들고 이를 쌍극자 포획방식을 이용해 공진기로 단원자, 혹은 두 개의 원자를 수송한 후 3차원 쌍극자 포획을 이용해 공진기 가운데 원자를 포획한다. 공진기는 길이 500 마이크로미터로 비대칭적인 반사율의 거울을 이용해 광자의 입사와 투과효율을 최대화하며 원자-공진기 강결합조건을 만족시킨다. 이를 위한 안정적으로 공진기를 잡아줄 수 있는 개선된 지지대와 이를 전체적으로 활용하여 양자네트워크 노드를 디자인하였다. 개선된 지지대의 경우 모달 해석을 통해 역학적 공명 진동수가 주변의 진동으로부터 공진기를 떨림없이 잘 잡아줄 것으로 예상된다. 완성된 공진기와 노드와 선행 연구로 만들어진 다른 노드와 함께 이용하여 다양한 양자네트워크 프로토콜을 구현할 수 있을 것으로 예상된다.

Keywords:

양자네트워크, 87Rb, 자기-광학 포획, 쌍극자 포획, 단광자 발생

An optical feedback design for free-space optical transmitter and receiver system

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Abstract:

Free space optics(FSO) feedback system is an essential part of long-distance quantum applications. Here, We present an optical feedback system for a free-space optical system that utilizes fast-steering-mirror(FSM) and position-sensitive-detector(PSD). For the transmitter part, a CW 810nm probe laser and a CW 660nm guiding laser are coupled to the single-mode fiber and they are sent to the target mirror through an optical telescope. After reflected from the target mirror, two beams are spectrally separated by a dichroic mirror. The probe beam is coupled to the single-mode fiber and the guiding beam goes into the feedback system. Two PSD read beam positions and two FSM drive beam directions to maximize the probe beam fiber coupling efficiency and stabilize the beam fluctuations. Finally, we replace the probe laser with an entangled photon source which is generated by periodically poled potassium-titanyl-phosphate(ppKTP) and detected by the joint measurement.

Keywords:

Free space optics, entangled photo, fast steering mirror

Off-set laser frequency stabilization by modulation transfer spectroscopy

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Abstract:

We investigate and propose the off-set laser frequency stabilization technique that incorporates modulation transfer spectroscopy (MTS) to generate dispersive-like locking signal that does not compromise on peak-peak amplitude and signal gradient. In a pump-probe scheme, the laser frequency is tuned by double passing the pump beam through an acousto-optic modulator (AOM) and phase modulated by passing through an electro-optic modulator (EOM). The phase modulated pump beam transfers this modulation to counterpropagating probe beam in a vapor cell. In our experiment, we use this scheme to stabilize the laser frequency for $5S_{1/2}$ ($F_g = 3$) - $5P_{3/2}$ ($F_e=4$), D_2 resonance line of atoms.

Keywords:

modulation transfer spectroscopy, offset locking

$^{171}\text{Yb}^+$ and $^{40}\text{Ca}^+$ 포획을 위한 다층 이온 트랩 설계 및 제작

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Abstract:

양자 컴퓨터의 다양한 후보 중 이온 트랩은 긴 결맞음 시간과 높은 충실도의 양자 게이트, 높은 연결성으로 유망한 플랫폼이다. 본 연구에서는 58개의 분리된 DC 전극과 2개의 RF 전극으로 구성된 다층 이온 트랩의 개발 상황을 보고한다. 우리의 트랩은 ETH Zurich에서 사용하는 이온 트랩과 매우 유사한 구조를 가진다[ref. 1]. 11개의 알루미늄 기판을 정밀 레이저 가공 후 금 스퍼터링 및 전기도금으로 개별 전극을 제작하였고 이를 위한 극고진공 챔버도 완성하였다. 이론적으로는 포획 포텐셜 에너지와 포획 주파수를 $^{171}\text{Yb}^+$ 와 $^{40}\text{Ca}^+$ 에 대해서 계산하였으며, 전극의 전압을 시간에 대해 바꿔가며 이온의 동역학에 대해서도 계산하였다. 개발된 장치는 확장 가능한 이온 트랩을 위한 양자 CCD 접근법의 최소 모듈이다.

[ref. 1] D. Kienzler. "Quantum Harmonic Oscillator State Synthesis by Reservoir Engineering". Doctoral Thesis. ETH Zürich, 2015.

Keywords:

Ion trap, Quantum Computing, Yb+, Ca+

An Ordering of Bosonic Operators for Computation of Schrieffer-Wolff Generator

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Abstract:

The Schrieffer-Wolff transformation describes second-order perturbation using unitary operators. Computation of the unitary generator is essential, but easily gets complicated when dealing with multiple modes and nonlinear interactions. We propose a method to directly compute the generator when the system is solely described by bosonic operators. Our method is performed by rewriting the Hamiltonian in a particular order to simplify the commutation structure. The Schrieffer-Wolff generator and energy corrections are readily computed. As an illustrative example, we then apply our method to analyze a recently demonstrated quantum-memory system using microwave cavities and a Josephson junction.

Keywords:

Schrieffer-Wolff Transformation, Bosonic Operator, Microwave Quantum Memory, Josephson Junction

A high brightness entangled photon source for free space applications

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Abstract:

Entangled photons are a primary ingredient not only for the fundamental quantum optics research but also for various applications in real-world quantum scenarios. We present a high brightness entangled photon source based on spontaneous parametric down conversion (SPDC) in a 30 mm long periodically poled potassium titanyl phosphate (ppKTP) pumped by a 405 nm laser diode. By using a non-degenerate, collinear type-0 phase matching configuration, polarization entangled photons are generated via Sagnac interferometer. We study the source properties that include single photon spectrum, brightness, fidelity, and etc.

Keywords:

Type-0 phase matching, spontaneous parametric down conversion (SPDC)

Estimating quantum mutual information of continuous-variable quantum states without multi-mode quantum state tomography

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Abstract:

We propose a reliable estimation method for the quantum mutual information of multi-mode continuous-variable quantum states. It stems from the observation that the quantum mutual information of a multi-mode quantum state is lower-bounded by a function of the entropic quantities for its reference Gaussian state and local quantum states. Our method allows us to estimate the quantum mutual information without extensive experimental efforts, i.e., multi-mode quantum state tomography.

Keywords:

quantum mutual information, continuous-variable quantum state, quantum state tomography

Effect of local squeezing in remote target detection using Gaussian states

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Abstract:

We propose a Gaussian remote target detection protocol exploiting local squeezing operations on an initial two-mode squeezed vacuum(TMSV) state. An additionally squeezed two-mode(ASTM) state is generated by applying single-mode squeezing operations on each mode of the TMSV state. The ASTM state is expected to overcome an obstacle of attaining a bright TMSV state. We show that under a fixed mean photon number, the ASTM state can be close to the bright TMSV state in the performance of the target detection protocol.

Keywords:

Remote target detection, Quantum illumination, Quantum metrology, Gaussian state

이온-공진기 양자 인터페이스 개발

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Abstract:

이온-공진기 시스템은 양자 네트워크와 분배식 양자컴퓨팅의 핵심 시스템이다. 본 연구에서는 40Ca^+ 이온을 근동심(near concentric) 공진기에 결합하는 방식에 대해 논의한다. 안정된 포획 주파수를 얻기 위한 인스브루크 스타일의 선형 파울 트랩 구조물에 가해야 하는 RF와 DC 전압을 계산하였다. 또한 근동심 조건을 얻기 위한 거울 사이의 거리를 계산하였고 이온-공진기 결합 상수도 구했다. 공진기 구조물의 기계 고유 진동수를 찾았고, 이에 따른 공진기 주파수 안정화 조건을 논의한다. 본 시스템을 두 개의 공진기에 결합하는 방식에 대해 전망한다.

배승훈, 신용하는 이 일에 기여도가 같음

Keywords:

이온-공진기, 선형 파울 트랩

원자힘현미경 나노리소그래피 방법을 이용한 전이금속 칼코겐화합물의 패터닝 (Patterning of Transition Metal Dichalcogenide Using Atomic Force Microscope Nanolithography)

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Abstract:

최근 많은 연구가 진행 중인 전이금속 칼코겐화합물 (transition metal dichalcogenide, TMD)들을 이용한 나노소자를 구현하기 위해서는, 전이금속 칼코겐화합물을 나노스케일로 패터닝 (patterning)하는 방법이 필요하다. 다양한 나노리소그래피 방법들 중, 원자힘현미경 (atomic force microscope, AFM)을 이용한 나노리소그래피는 그 방법이 매우 간단하면서도 시료의 오염이 거의 없는 장점을 가지고 있다. 본 연구에서는, 원자힘현미경 나노리소그래피 방법을 이용하여 벌크 상태의 전이금속 칼코겐화합물을 패터닝 할 수 있음을 확인하였으며, 원자힘현미경 팁에 인가된 힘과 전압을 변화시킴으로써 패터닝 깊이, 폭 등의 조건들이 조절 가능함을 확인할 수 있었다.

Keywords:

AFM, TMD, Patterning

Fabrication and characterization of Josephson junctions based on two-dimensional electron gas

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Abstract:

A superconductor-semiconductor hybrid system with strong spin-orbit interaction provides a promising platform for realizing topological superconductivity. Here, we fabricated and studied the electrical transport properties of nano-hybrid Josephson junctions (JJs) made of a two-dimensional electron gas (2DEG) system formed by an InAs quantum well, cleanly interfaced with an epitaxial superconducting Al layer. JJs with a gap spacing of ~ 120 nm and a channel width of ~ 3.5 μ m were fabricated by using electron-beam lithography and wet etching process. At $T = 0.3$ K, the critical current of the Josephson junctions was $I_c = 100$ nA, while the normal-state resistance R_n ranged from 50 to 150 Ω . Applied with a magnetic field perpendicular to the substrate, the 2DEG-based JJs exhibited a periodic I_c modulation, so-called Fraunhofer pattern. Temperature dependence of the differential conductance peaks, caused by multiple Andreev reflections, indicated that the superconducting gap energy of the epitaxial Al was about $D_{Al} = 239$ meV. Our observations suggest that the hybrid JJs made of 2DEG with an epitaxial Al film would be a promising platform for exploring topological superconductivity and topological quantum information devices.

Keywords:

Two-dimensional electron gas, Josephson junction, Fraunhofer pattern, Multiple Andreev reflection

Strain dynamics in next generation fuel cell materials by Bragg coherent X-ray diffraction imaging

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Abstract:

Energy generation and storage using hydrogen is paid attention for its high energy generation efficiency and environmentally friendly. In the solid oxide fuel cell (SOFC), the light element ions such as oxygen ions and protons are transported through the solid electrolyte and exchanged at the electrolyte-electrode interface. Therefore, the study of the evolution of the internal lattice deformation, i.e. strain during the ion transport and exchange process provides the crucial information to understand strain-ionic conductivity relation and degradation mechanism in fuel cell. However, it is difficult to measure local information in-situ/operando. Bragg Coherent X-ray diffraction imaging (BCDI) can provide the internal lattice distribution related to the phase, in addition to the electron density distribution by phase retrieval process. The spatial resolution of BCDI is ~10nm with the sensitivity of the displacement at few tens of picometers. Here, we study strain evolution in Gadolinium-doped Cerium Oxide ($Gd_{0.1}Ce_{0.9}O_{2-x}$, GDC) and Ru-doped BCY($BaCe_{0.9}Y_{0.1}Ru_{0.1}O_{3-\delta}$), one of the leading candidates for the next-generation fuel cell and hydrogen production materials, at in-situ operating temperature. From the 3D mapped lattice displacement distribution as a function of time, we obtain the dynamics of the local strain distribution of the nanoparticle that can provide crucial clues for fully understanding of ionic transportation mechanism in next generation fuel cell materials.

This research was supported by the This work was supported by the KIST Institutional Program (2E30994-21-020) and National Research Foundation of Korea (NRF-2021R1A3B1077076).

Keywords:

Coherent X-ray diffractive imaging , Energy storage materials , Hydrogen production

Ultrafast atomic scale picture of the first-order phase transition from direct observation of photo-induced melting using ultrafast multiplexing probes

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Abstract:

Intense femtosecond laser pulses drive material phase transitions through kinetic reactions unnoticed in bulk measurements, which stimulates strong interest to reveal reaction dynamics of individual atoms prompted by photo-depleted bonding electrons. Ultrafast atomic dynamics, however, has been veiled with challenges in resolving accompanied irreversible processes at relevant space-time resolution. Here, by newly establishing a time-resolved multiplexing experimental technique that combines single-pulse imaging and crystal diffraction using the X-ray free electron laser, we overcome this to directly observe kinetic process accompanied during the solid-liquid transition of metallic Au. Initiated from instantaneous melting at the surface to internal melting on thermalization, whole process of the photo-induced transition is now resolved with direct real-time images and crystal structures at sub-picosecond and Angstrom scale. The two-temperature molecular dynamics simulations investigated the atomic dynamics at surface, grain boundary and internal grain to manifest the heterogeneous progression of the first order transition corroborating the experimental results. This study establishes a comprehensive picture elucidating detailed atomic-scale processes during the first-order phase transition deepening the understanding on fundamental aspects of the phase transition in strongly driven systems.

Keywords:

Ultrafast Multiplexing probes, X-ray Free Electron Laser

여러가지 두께를 가지는 MoTe₂에 적용한 극자외선을 이용한 도핑 효과 연구

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Abstract:

극자외선을 이용한 도핑효과로 인해 페르미 레벨을 조절하여 transition metal dichalcogenides (TMDCs)의 전기적, 광학적 특성의 변화를 연구하고자 한다. 이 실험에서는 MoTe₂의 표면에 흡탈착이 된다고 생각되는 질소(N₂)와 산소(O₂)를 이용하여 페르미 레벨을 조절하였다. 첫 번째로, 우리는 p형 특성을 가지고 있는 MoTe₂을 질소(N₂) 가스 환경에 놓고서 Deep Ultraviolet(DUV)를 특정 시간(30, 60, 90, 120, 160, 250, 500, 900, 1200초)동안 쬐어주므로써 점진적으로 n형 특성으로 변화시켰다. 그 후, n형 특성으로 만든 MoTe₂를 산소(O₂) 가스 환경에 놓고서, DUV 아래에서 노광하여 n형 특성을 다시 p형 특성으로 역전시켰다. MoTe₂의 다른 두께(~3 to ~30 nm)에 대하여 같은 DUV 공정 과정을 통해 일어나는 특성 변화를 관찰하였다. MoTe₂가 점점 두꺼워 질수록 DUV+산소(O₂) 공정은 n-MoTe₂의 n형 특성을 완전히 p형 특성으로 변화시키지 못하는 것을 관찰하였다. 추가적으로 여러 가지 MoTe₂ 박막(원래의 p-MoTe₂, DUV+N₂ 공정을 거친 n-MoTe₂, DUV+O₂ 공정을 거친 p-MoTe₂)에 대하여 광반응 효과 실험을 진행하였는데, 세 가지 종류의 MoTe₂에 대하여 각기 다른 photo-resposivity와 응답시간상수를 관찰하였다. 이 실험의 결과는 MoTe₂를 전자적, 광학적인 소재로서 사용할 수 있는 가능성을 긍정적으로 제시하고 있다.

Keywords:

TMDCs, Doping

Small organic molecule as insulation layer improves the performance of inverted perovskite solar cells

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Abstract:

Organic-inorganic hybrid perovskite solar cells show excellent photoelectric conversion efficiency, and their efficiency efficiencies are rapidly increasing. At present, the biggest difficulty in commercialization of perovskite solar cells is the long-term instability of materials and devices. In this work, we used various small-molecule-based insulating layers between the perovskite layer and the electron transport layer in the inverted perovskite structure to block hole transport. We find that these insulating layers can modify band energy offsets at the interface, decrease interfacial loss processes cause by surface recomabination, and improve long-term stability of the device. In addition, small organic molecule interlayer can be deposited by solution-processing at room temperature, making this interface engineering be a low-energy and scalable technique.

Keywords:

perovskite solar cell, insulating layers

Electronic properties of epitaxially strained SrRuO₃/CaRuO₃ superlattices

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Abstract:

In ABO₃ perovskite materials, transition metal-oxide ruthenates (ARuO₃, A = Ca and Sr) with RuO₆ octahedral distortion, these materials have been reported that electronic and magnetic properties can be changed depending on a degree of octahedral distortion. Tuning the octahedral distortion has been extensively studied by inducing epitaxial strain, thickness and stoichiometry control. In this study, we suggest that the electronic properties can be tailored by controlling the octahedral distortion in the artificial SrRuO₃/CaRuO₃ heterostructure. To verify this concept, SrRuO₃/CaRuO₃ superlattices films on SrTiO₃ (001) substrate were grown by pulsed laser deposition. The structure of superlattice was controlled by altering the stacking of [(SrRuO₃)_n/(CaRuO₃)_m] (n or m is the number of unit cell layer) and were characterized by high-resolution 6-circle X-ray diffractometer. The work Function values and electronic transport properties as a function of temperature for these superlattices were systematically analyzed with varying the periodicity of the superlattice. Spectroscopic ellipsometry was also introduced to elucidate the electronic structures of the superlattices.

Keywords:

Thin film, Superlattice, SRO, CRO, Electronic property

First-principles study of electronic structure of janus 2D heterostructures

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Abstract:

Since the discovery of graphene, many scientists have studied two-dimensional (2D) materials that exhibit various interesting physical and electrical properties. A lot of theoretical and experimental studies have been conducted on 2D van der Waals (vdW) heterostructures because they can be easily fabricated by mechanical exfoliation or delamination due to weak vdW interactions. Interestingly, 2D vdW heterostructures have shown superior properties to utilize 2D materials in nano- and electronic devices. In this study, we have investigated atomic and electronic structures of janus 2D heterostructures using density functional theory calculations. Especially, we focus on Rashba spin splitting and Zeeman-type spin splitting at the valleys by studying the effect of interaction between 2D materials in heterostructures. In addition, we investigate Berry curvature depending on strain and out-of-plane external electric field. From the understanding of valley physics in janus 2D heterostructures, we suggest the possibility of their applications in valleytronic and spintronic devices.

Keywords:

Janus, Heterostructure, Berry curvature, valley physics, DFT

A computational study of TiOPc as molecular buffer layer for surface spin systems

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Abstract:

Vanadyl phthalocyanine (VOPc) is a promising candidate for molecular spin qubits, containing a highly coherent (coherence times up to μs) spin $S=1/2$. [1,2]. To reduce the coupling between VOPc and the metallic substrate we considered replacing the commonly used MgO with a monolayer of TiOPc. Our DFT study, in excellent agreement with experiments performed on this system confirms that TiOPc is an effective decoupling layer preserving the *vacuum-like* electronic structure of VOPc ($S=1/2$) on TiOPc. Since TiOPc can be easily grown on a variety of substrates (e.g. Au(111)), it is an attractive candidate for bottom-up assembly of molecular quantum bits on metallic surfaces with implications for a bottom-up approach of the fabrication of VOPc based qubits.

[1] Cimatti et al., Nanoscale Horizons. 2019, 4, 1202-1210

[2] Atzori et al., J. Am. Chem. Soc. 2016, 138, 7, 2154–2157

Keywords:

TiOPc, titanyl phthalocyanine, vanadyl phthalocyanine, VOPc, DFT, spin

V-based kagome metals in two dimensions

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Abstract:

Recently, layered kagome metal AV_3Sb_5 ($A=K,Rb,Cs$) has attracted considerable attention because it serves as an interesting platform to explore the interplay between charge density wave (CDW) and superconductivity with nontrivial topology.

Using first principles calculations, we show that the V-based kagome can be stabilized in its single-layered form which hosts nontrivial band topology.

We also discuss the correlation effects on the competition between CDW and superconductivity captured by mean-field analysis with the minimal tight-binding model.

Keywords:

kagome metal, charge density wave, superconductivity

First-principle Study of Interplay Between Flat and Dirac Band

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Abstract:

Pyrochlore oxides denoted by $A_2B_2O_7$ (or $A_2B_2O_6O'$) have been attracting much attention due to the coexistence of flat and Dirac bands around the Fermi energy. It has been known that the flat bands are originated from the orbital interactions of the geometrically frustrated pyrochlore lattice similar to 2D checkerboard and Kagome lattice, while the Dirac bands are related to the Sn-s orbital. Here, using the first-principles density functional theory calculation, we investigate the interplay between Flat and Dirac bands in $Sn_2Nb_2O_7$ oxide by applying biaxial strain and considering substitutional doping in A-site sublattice. Emergence of long-range magnetic order and novel magnetic ground state will be discussed in detail along with atomistic study of strong interaction between Flat and Dirac band in $Sn_2Nb_2O_7$ oxide.

Keywords:

flat band, Dirac band , Pyrochlore oxides, Density functional theory calculations

Strain-induced 1D ferroelectricity in niobium oxide trihalides

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Abstract:

Switchable electric dipole at reduced dimension can be a breakthrough that overcomes the size limit of nanostructured electronic devices. Interestingly, Niobium chloride oxide (NbCl₃O) is a material that has been successfully fabricated in a one-dimensional Van der Waals(1D-vdW) crystal consisting of two parallel 1D nanowires. 1D nanowire in NbCl₃O has a non-centrosymmetric structure but two parallel 1D nanowires are aligned anti-parallel to each other, which leads to an anti-ferroelectric bulk structure. Here, using density functional theory calculations, we report that a phase transition occurs from anti-ferroelectricity to ferroelectricity by biaxial strain. Our findings not only provide the possibility of 1D ferroelectrics but also suggest directions towards high-density ferroelectric devices.

Keywords:

1D Van der Waals crystal, density functional theory calculations, ferroelectricity

A new automated protocol for melt-quench simulations

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Abstract:

Disordered materials, such as liquid and amorphous phases, have received much attention due to their distinguishing properties from crystalline phases. For example, the application of amorphous materials in In-Ga-Zn-O in displays and Ge-Sb-Te in PRAM (Phase-Change Random Access Memory) has been studied. Disordered phases also hold a variety of information about crystalline phases. We recently revealed that liquid and amorphous structures can be a good training set of machine learning potential for crystal structure prediction (CSP). It is shown that training sets with a reasonable temperature profile can sample various local atomic environments and thus the trained MLPs are accurate in evaluating the energies of stable and meta-stable phases. In order to cover the wide range of applications, it is crucial to adapt the melt-quench profile such as the melting point and duration of each stage. However, it is very difficult to make adjustments without available knowledge of the melting point. Although some computational methods have been developed to determine the melting point, the computational cost is too high to perform with limited resources. In this work, we present a faster method for determining the melting point and duration of the melt-quench-anneal profile of given chemical compositions in an automated manner. Mean squared displacement and other transport properties are used to determine the melting points within a limited computational budget. We expect that the automated protocol will facilitate high-throughput calculations for amorphous materials with less human errors and more efficient molecular dynamics simulations

Keywords:

density functional theory, automation, disordered phase, melt-quench

First-principle study of magnetic anisotropy of 1T RhO₂

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Abstract:

Two-dimensional magnetic materials have been attracted attention since they are not only ideal platforms to investigate exotic physical phenomena [1-3] but also are technically promising for applications [4]. Although magnetic anisotropy is often observed in bulk magnetic oxides, such the property has been rarely reported in two-dimensional system. Using first-principles calculation, we predict that 1T RhO₂ can have magnetic anisotropy, stabilizing the out-of-plane ferromagnetic configuration. To understand the origin of the anisotropy, magnetic anisotropy energy is evaluated. In addition, the strain effect on the magnetic anisotropy is examined.

[1] K. S. Novoselov *et al.*, Nat. Mater. **6**, 183-191(2007)

[2] Hui Li, Shuangchen Ruan, and Yu-jia Zeng, Adv. Mater. **31**, 1900065 (2019)

[3] J. Wang *et al.*, RSC Adv. **7**, 16801 (2017)

[4] S. Bhatti *et al.*, Mater. Today **20**, 530-548 (2017)

Keywords:

2dimension transition metal oxides, magnetic anisotropy, first principle calculation

Counter-intuitive Ferroelectric Property and Orbital Magnetic Moment in Cr/Cu-based Perovskite Metal-Organic Frameworks

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Abstract:

Metal-organic frameworks (MOFs) possess a hybrid nature, combining the inorganic properties from the metal ions and the organic properties from the molecular linkers. Stroppa et al. showed that the perovskite-type MOF $[C(NH_2)_3]M[(HCOO)_3]$ ($M = Cr, Cu$) exhibits the magneto-electric coupled multiferroicity [Angew. Chem. Int. Ed. 50, 5847 (2011) and Adv. Mater. 25, 2284 (2013)]. Moreover, their ferroelectricity arises from the hybrid improper mechanism, which also explains the magneto-electric coupling. In this work, we further examine the electric and magnetic properties of $[C(NH_2)_3]M[(HCOO)_3]$. We find that the hybrid model composed of non-polar modes induces purely electronic polarization even without the polar mode. The polar mode compensates for the purely electronic polarization. It leads to a counter-intuitive argument that the inversion of the polar mode rather enhances the polarization. We provide microscopic origin and macroscopic analysis for this polarization property. In addition, we find that the orbital magnetic moment is comparable to the spin contribution in the Cu-based MOF. Finally, we establish the model for the orbital magnetic moment based on the perturbation theory.

Keywords:

Density functional theory, Multiferroic, Ferroelectricity, Metal-organic framework, Orbital magnetism

First-Principles Study of Br–Cl Mixed Halide Solid Electrolyte for All-Solid-State Batteries

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Abstract:

Halide solid electrolytes recently attracted increasing attention as a key ingredient of all-solid-state batteries because of high Li ion conductivity (about 1 mS cm⁻¹) at room temperature and good electrochemical stability [1]. Here, the structural properties and ion diffusion pathways of Br–Cl mixed halide solid electrolyte Li₃Y(Br₃Cl₃) (LYBC) have been studied using density-functional theory calculations and ab initio molecular dynamics simulations. The site preference of 6 Li, 2 Y, 6 Br, and 6 Cl atoms in the unit cell was determined by investigating more than 400 different structures. Further, the simulated X-ray diffraction and neutron diffraction patterns were compared with the experimental patterns to refine the LYBC structure. In the LYBC the Li ions can occupy not only the octahedral sites of the Li and Y layers but also the tetrahedral sites of the Li layer, which is different from the Li ions in Li₃YBr₆ and Li₃YCl₆ occupying only the octahedral sites. This tetrahedral-site occupation of Li ions affects the ion transport of LYBC. Details of the structures and diffusion mechanism of LYBC will be discussed.

Reference

[1] Z. Liu, S. Ma, J. Liu, S. Xiong, Y. Ma, H. Chen, High Ionic Conductivity Achieved in Li₃Y(Br₃Cl₃) Mixed Halide Solid Electrolyte via Promoted Diffusion Pathways and Enhanced Grain Boundary, ACS Energy Lett. 6 (2021) 298–304.

Keywords:

all-solid-state batteries, halide solid electrolytes, diffusion mechanism, density-functional theory

Hybrid density functional theory calculation of halide perovskite alloys

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Abstract:

Solar cells as sustainable energy sources have been over decades in research. Among many materials, hybrid inorganic-organic perovskites have attracted much attention in the recent decade. Its high absorption coefficient and defect tolerance contribute to the high solar conversion efficiency. The bandgap of halide perovskites is usually tuned by alloying halogen atoms. We investigated halide perovskite alloys by performing density functional theory (DFT) calculations. Random alloy models of CsPb(I,Br)₃ and CsPb(Br,Cl)₃ were fully relaxed by using generalized gradient approximation (GGA) exchange-correlation functional [1] with a van der Waals correction [2]. The materials are miscible because of the entropy term. For the most stable configurations for each composition ratio, we performed hybrid DFT calculations [3] considering the spin-orbit interaction. The electronic bandgap calculated by the hybrid functional was in better agreement with the experimental bandgap than the GGA bandgap.

[1] J. P. Perdew, K. Burke, and M. Ernzerhof, Phys. Rev. Lett. 77, 3865 (1996).

[2] S. Grimme, J. Antony, S. Ehrlich, and H. Krieg, J. Chem. Phys. 132, 154104 (2010).

[3] J. Heyd, G. E. Scuseria, and M. Ernzerhof, J. Chem. Phys. 118, 8207 (2003).

Keywords:

DFT, solar cell, perovskite, alloy, bandgap

Anomalous Hall effect in compensated ferrimagnet: Symmetry analysis in Mn₃Al

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Abstract:

It has long been believed that the anomalous Hall effect (AHE) can only be observed in ferromagnets. However, any magnetic material can exhibit AHE due to the broken time-reversal symmetry. In this work, we present a nontrivial AHE on the compensated ferrimagnet Mn₃Al using symmetry arguments and first-principles calculations. Nonzero components of anomalous Hall conductivity $\sigma_{\alpha\beta}$ are determined based on the magnetic space group of Mn₃Al. The explicit first-principles calculation confirms $\sigma_{xy} = -320 (\Omega \text{ cm})^{-1}$. The nature of Berry curvature responsible for the intrinsic origin of AHE is further identified using group theory: a lifted degeneracy at L and a level repulsion around $\frac{1}{2}K\Gamma$. Moreover, the global behaviors of Berry curvature are shown over the whole Brillouin zone which reveal the overlooked contributions to $\sigma_{\alpha\beta}$.

Keywords:

Anomalous Hall conductivity, Magnetism, Magnetic space group

Understanding of hydrogen formation in transition metal oxides

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Abstract:

Hydrogen is easily incorporated as an impurity, which alters the host properties and leads to new phenomena [1-3]. Alternatively, numerous efforts have been made to utilize hydrogen as a renewable energy resource. Regarding doping or incorporation, the formation energy of hydrogen is a key quantity that is able to assess whether hydrogen forms easily or not. In this study, using first-principles calculations, we investigate the formation energy of hydrogen in rutile-like (rutile, monoclinic, marcasite structure) transition metal oxides. To obtain comprehensive and reliable results, the systems composed of 3d, 4d and 5d transition metals and various Hubbard U values were considered. We found that the formation energy of hydrogen correlates with covalent bond strength. This can be interpreted that a large (small) energy is required to overcome the strong (weak) metal-oxygen bonding strength of the host material.

Keywords:

Hydrogen, Formation energy, Transition metal oxides, First-principles calculations

Lithiation-induced structural change of microporous carbon anode material for Li-ion batteries

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Abstract:

Microporous carbon has recently attracted much attention as an ultra-high-capacity anode material for lithium-ion batteries because it provides very high initial and reversible capacities of 2950 and 1550 mA h g⁻¹, respectively [1], which are greatly higher than the theoretical capacity (372 mA h g⁻¹) of graphite. Using ab initio molecular dynamics simulations, we examined the lithiation of microporous carbon structures with initial densities of 1.5, 2.0, and 2.5 g cm⁻³ and average pore size of 0.60, 0.39, and 0.28 nm, respectively. These carbon structures exhibit the capacities above 2604 mA h g⁻¹ corresponding to the composition Li_xC₆ ($x > 7$), in good agreement with the initial capacity of 2950 mA h g⁻¹ (Li_{7.9}C₆) for the zeolite-templated microporous carbon with the pore size of 0.92 nm [1]. Our result demonstrates the excellent lithium storage ability of microporous carbon. As the lithiation proceeds, the average coordination number of carbon atoms and the average pore size of microporous carbon decreases and increases, respectively. Details of the lithiation-induced structural evolution of microporous carbon will be presented.

[1] Y. Kwon, K. Kim, H. Park, J.W. Shin, R. Ryoo, Anomalously High Lithium Storage in Three-Dimensional Graphene-like Ordered Microporous Carbon Electrodes, *J. Phys. Chem. C.* 122 (2018) 4955–4962.

Keywords:

Microporous carbon, Lithiation, Lithium ion batteries, Ab initio molecular dynamics

Predicting Critical Temperature of Cuprates by Machine Learning Models

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Abstract:

Cuprates have been at the center of long debate regarding their superconducting mechanism; therefore, predicting the critical temperatures of cuprates remains elusive. Herein, using machine learning and first-principles calculations, we predict the maximum superconducting transition temperature ($T_{c,max}$) of hole-doped cuprates and suggest the functional form for $T_{c,max}$ with the root-mean-square-error of 3.705 K and R^2 of 0.969. We have found that the Bader charge of apical oxygen, the bond strength between apical atoms, and the number of superconducting layers are essential to estimate $T_{c,max}$. Furthermore, we predict the $T_{c,max}$ of hypothetical cuprates generated by replacing apical cations with other elements. Among the hypothetical structures, the cuprates with Ga show the highest predicted $T_{c,max}$ values, which are 71, 117, and 131 K for one, two, and three CuO_2 layers, respectively. These findings suggest that machine learning could guide the design of new high- T_c superconductors in the future.

Keywords:

Machine Learning, Cuprate, Superconductivity, Density Functional Theory

Efficient discovery of multiple minimum action pathways using Gaussian process

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Abstract:

We present a new efficient transition pathway search method based on the least action principle and the Gaussian process regression method. Most pathway search methods developed so far rely on string representations, which approximate a transition pathway by a series of slowly varying replicas of a system. These methods are computationally expensive in general because they require many replicas to obtain smooth pathways. Our approach employs the Gaussian process regression method, which infers the shape of a potential energy surface with a few observed data and Gaussian-shaped kernel functions. Here we demonstrate a drastic elevation of computing efficiency of method about five orders of magnitude compared to existing methods. Further, to demonstrate its real-world capabilities, we apply our method to *ab initio* calculations on that of alanine dipeptide. Owing to improved efficiency of GPAO, multiple transition pathways of alanine dipeptide and calculate their transition probabilities were successfully obtained with *ab initio* accuracy.

Keywords:

Onsager Machlup

Time-resolved resonant soft X-ray scattering (RSXS) Endstation at PAL-XFEL

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Abstract:

The general user program of PAL-XFEL has been successfully operated from 2017. PAL-XFEL provides intensive, ultrashort, and coherent X-ray pulses in both hard (2.5-14 keV) and soft (250-1300 eV) X-ray energy region. In Soft X-ray Scattering and Spectroscopy (SSS) beamline, XAS/XES (X-ray absorption and emission spectroscopy) endstation has been operated from the initial stage. As a second endstation, RSXS (resonant soft X-ray scattering) endstation has been developed and open to the general users from 2020. This endstation mainly supports optical pump (800-nm-wavelength and harmonics) soft X-ray probe (400-1300 eV) time-resolved RSXS experiments, particularly in magnetic materials and strongly correlated electronics systems. The time resolution is estimated better than 100 fs and ultrafast dynamics of magnetic order, charge order, and phonon dynamics have been successfully explored. In this presentation, engineering details of the endstation and recently experimental results will be introduced.

Keywords:

PAL-XFEL, time-resolved resonant soft X-ray scattering, ultrafast, X-ray scattering, pump-probe

Deep-Learning-Based Denoiser for Phase Recovery of Single-Shot Diffraction Patterns Using XFEL

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Abstract:

Phase recovery is a well-known inverse problem prevalent across science disciplines and attracts active research interests to develop a number of theoretical and experimental methods. Recent developments in artificial intelligence have further prompted research activities in processing the experimentally collected imperfect data, but applications have been limited to slow-varying data such as real images. Experimental noises present in largely fluctuating diffraction data, in particular, add practical challenges to hamper consistent phase recovery. Here, we introduce a convolutional-neural-network-assisted k-space denoising method that can directly manage noisy diffraction signals. It showed superior performance on denoising the diffraction data, which promote improved phase recovery from noise-buried single-pulse diffraction signals obtained by the X-ray free-electron laser. Adapting our method to general diffraction data can expand boundaries of interpretable data and enhance observability of faint objects with weak signals.

Keywords:

Deep Learning, Phase Retrieval, Coherent Diffraction Imaging, XFEL

Effective Resolution Improvement in Coherent Diffraction Imaging by Extending Fourier Space

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Abstract:

Coherent diffraction imaging (CDI), empowered by deep penetration and short wavelength of X-ray, probes non-destructive 3D image of micron-scale object ($> 1 \mu\text{m}$) in nanometer-scale resolution. The resolution is not limited by optics but depends on the maximum angle of scattered photons recorded by detector which is increased by the total coherent photons. Exponential increase of coherent flux allowed by latest X-ray sources improve the resolution, ultimately up to diffraction-limit. The unperturbed X-ray photons overlapped in the low-angle scattered photons, however, limit the resolution in imaging large object. Micron-sized object usually requires a long propagation distance around several meters to obtain adequate un-overlapped low-angle photons that contains crucial information for robust image reconstruction. Thus, a finite physical area of a detector limits the spatial resolution in a few tens of nanometer, ~ 100 times larger than the wavelength. Here, we developed a synthetic CDI that extends Fourier space by combining different diffraction patterns. First, a long-distance diffraction pattern is recorded for low-resolution image with large field-of-view. Then we measured a diffraction pattern 3~5 times shorter distance which scales up the maximum scattering angle but cannot solely produce image due to the missing data. We confirmed a robust reconstruction of image with resolution proportional to the enlarged Fourier space by multiple diffraction patterns both in numerical simulation and optical experiment. The reconstructed image has a resolution comparable to the wavelength. Also, we conducted 3D imaging of micron-sized mesoporous particle with synchrotron X-ray and acquired high-resolution 3D image. This work provides a way to improve spatial resolution in CDI, which would find broad application in observing nanoscale phenomena in extreme condition or short timescale.

Keywords:

coherent diffraction imaging, 3D imaging

Improvement of signal-to-noise ratio in single particle imaging with X-ray free electron laser

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Abstract:

With increasing interest in atomic scale structure of nano-sized objects, single particle imaging with X-ray free electron laser(XFEL) has emerged as a high-resolution imaging technique. The achieved spatial resolution, however, remains at tens of nanometers with difficulty in collecting diffraction signals at high frequency with enough signal-to-noise ratio(SNR). To overcome this difficulty, various resolution-enhancement methods have been proposed, but few experimental demonstration are available. Using XFEL single particle imaging experimental data, we reveal the dependence of SNR on incident X-ray flux, data averaging and multiparticle interference. In addition to this investigation, we propose a new data-accumulation method called as resolution-shell averaging as a robust scheme to improve the SNR. This study provides a guideline for high-resolution XFEL single particle imaging experiments.

Keywords:

Signal-to-noise ratio, XFEL

Synthesis of high energy density material under extreme condition

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Abstract:

Materials composed of many nitrogen atoms generally contain a lot of energy, and they have been actively studied in academia, industry and defense science, and aerospace fields for the past several decades in order to develop them. Using a laser-heating device and a diamond anvil cell to realize extreme high pressure (120 GPa) and temperature (4,500 K) conditions, cubic-gauche nitrogen and CON_2 reported in the literature were synthesized for the first time in the Republic of Korea, and they were confirmed by confocal Raman spectroscopy.

Keywords:

High energy density material, Laser heating, Diamond anvil cell, Raman scattering

Study of ultrafast thermodynamics probed by X-ray Free Electron Laser

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Abstract:

The crystal melting process is fundamental phenomena which has not been fully understood. Until now, these effort has been limited to model dependent interpretation or weakly perturbed, reversible process. So any investigation on transition irreversible phenomena has remained challenging so far. In addition, fundamental factors like atoms and electrons is changed in below picosecond timescale which can be probed by X-ray Free Electron Laser. So, we performed pump-probe XFEL diffraction imaging experiment and captured directly the change of the electron distribution in crystal. This provides deep understanding of ultrafast dynamics at fundamental timescales.

Keywords:

Coherent imaging, X-ray Free Electron Laser, Ultrafast, Time-resolved, melting

Control of the Metal-Insulator Transition (MIT) of VO₂(200)/R-Al₂O₃(012) thin film by interfacial strain combined x-ray diffraction & electrical transport measurement

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Abstract:

Vanadium dioxide (VO₂) exhibits a property of a metal-insulator transition (MIT) near room temperature ($T_c = 68\text{C}$). The properties of VO₂ thin films are noticeably affected by the different substrate, which sometimes leads to the emergence of unexpected things (intermediate phase, specific domain shape etc.)

In particular, we were able to confirm the temperature-dependent behavior of the VO₂ thin film grown on R-cut in three-dimensional reciprocal space through theta rocking measurement at the beamline of the Pohang Accelerator Laboratory (PAL). It was found that there are two tilted domains. In addition to these two tilting domains, we separated the epitaxial layer component grown along the substrate, and by separating these three components, it was confirmed that the kinetics were different depending on the temperature.

Also, it was confirmed how the two domains divided by strain relaxation and the change of the interface layer behave in relation to electrical properties. It is expected that our work will be able to find out how the interface effect affects the properties of MIT depending on the thickness and the contribution of the two tilting domains.

Keywords:

Vanadium dioxide, 3D-Reciprocal space mapping, combined X-ray diffraction (XRD) & Electrical transport measurement

3D X-ray micro-diffraction of poly-crystals using absorption filters

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Abstract:

X-ray micro-diffraction (XMD), which is using micron scale focused X-ray beam is useful experimental method for investigating regional distribution of crystal structure variations in the sample. However, normal XMD provides only 2-D data obtained from the scanned X-ray beam. The 3-D data from differential aperture X-ray microscopy (DAXM) requires additional hardware and cumbersome alignments with very long scanning time. In this study, we developed the strategy for 3-D imaging in XMD using a few absorption filters. This strategy is simpler and cheaper with much shorter measuring time. Our preliminary results showed ~7mm resolution in the depth direction, which was good enough to identify relative positions of the grains.

Keywords:

X-ray diffraction, X-ray micro-diffraction

화학적 치환과 결정 결함에 따른 CaYAlO₄:Eu의 형광 특성 변화 연구

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Abstract:

CaYAlO₄(CYAO)는 K₂NiF₄구조를 가지는 산화물로, 높은 화학적, 열적 안정성을 가지고 있어 형광체의 모체(host) 물질로 많이 연구되고 있다. Eu³⁺이 도핑된 CYAO는 높은 적색 발광 특성을 보여주지만, 녹-청색 영역의 낮은 발광 특성에 기인하는 낮은 연색지수(color rendering index, CRI)의 단점을 가지고 있다. 이를 극복하기 위해 결정 구조, 결함 제어 등을 통한 형광 특성 조절 연구가 활발히 진행되고 있다^[1]. 본 연구에서는 1) Si 첨가와 2) 환원 후처리에 따른 CYAO:Eu의 형광 특성 변화 연구를 수행하였다. CYAO 분말을 합성하기 위해 고상반응법(solid-state reaction)을 활용하였다. 제작 공정의 최적화를 위해 밀링조건과 열처리 조건을 달리하여 시료를 제작하였으며, 공정 조건에 시료의 균일도와 CYAO 상의 형성 정도가 매우 의존적임을 XRD와 PL 측정을 통해 확인하였다. Si 첨가 전후 형광 특성의 유의미한 변화는 관찰되지 않았다. 환원 후처리에 따른 CYAO에서의 형광 특성 변화를 산소 결함의 형성과 연관지어 논의하고자 한다. 이번 연구는 형광체 물질에서 형광 특성을 이해하고 디자인하는데 정보를 제공해 줄 수 있을 것으로 기대된다.

이 성과는 2021년도 정부(과학기술정보통신부)의 재원으로 한국연구재단의 지원을 받아 수행된 연구임 (No. 2021R1C1C1009863, 2020R1A6A3A01100374)

[1] Zhang, Y. *et al.*, *ACS Appl. Mater. Interfaces.* **7**, 2715–2725(2015)

Keywords:

CaYAlO₄:Eu, 형광 특성, 산소 결함, 화학적 치환

극저온 양자 광-마이크로파 실험 구성

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Abstract:

Yttrium Iron Garnet 단결정체와 3차원 마이크로파 공진기 간의 상호작용을 이용하면 광파(1,550nm)를 마이크로파(X-band)로 변환이 가능하다. 이를 위해 광학 실험 장치와 극저온 실험 장치를 각각 구성한 뒤 광 섬유를 통하여 두 시스템을 연결하였다. 본 포스터에서는 극저온 양자 광-마이크로파 실험을 소개한다.

Keywords:

양자주파수변환

Application of inverse problem by using multi-band signal acquisition system with WbLS-like LS

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Abstract:

고에너지 물리의 의학적 응용인 의학 물리에서, X-ray 영역을 사용하는 컴퓨터 단층 영상(CAT), 단일 광자 방출 단층 영상(SPECT), 양전자 방출 단층 영상(PET), 핵자기 공명 영상 (NMRI), 그리고 천문학에서 사용되는 영상 재구성은 응용 수학 관점에서 모두 역 문제의 응용으로 볼 수 있다. 이 포스터 발표에서는 역 문제를 간략하게 소개한다.

포스터 발표의 나머지 부분은 실제 응용한 사례를 소개한다. 차세대 중성미자 실험을 위해서 액체섬광검출용액(LS)에서 나오는 형광 신호와 체렌코프 복사 신호를 구별할 수 있는 광학적 다중 밴드 (or color) 의 이미지 획득 시스템을 이용. LS와 CMOS 이미지 센서 기반한 디지털 색상 카메라를 이용하여 광학적 단층 재구성 영상을 구현하였다.

Keywords:

Inverse problem, Radon transformation, Filter-based monochromator, Optical tomography, CMOS sensor

Background modeling for COSINE-100 data

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Abstract:

COSINE-100 is a direct dark matter search experiment that uses an array of scintillating NaI(Tl) crystals as a target/detector. The experiment started taking data in September 2016, and has been running stably ever since. We have fitted the NaI(Tl) crystals' measured energy spectra for about 3 years of data with a Monte Carlo simulation model which contains a variety of background components. With a long term data taking, we become able to get properly understand the activities of decaying radioactive components. Based on such better understandings, updates on modeling of background sources for the COSINE-100 WIMP search data will be presented.

Keywords:

Darkmatter, BackgroundModeling, MonetCarlo, Geant4

HPGe and Alpha counting measurements of detector material samples at Yangyang underground laboratory

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Abstract:

The Center for Underground Physics (CUP) conducts two main rare event search experiments, AMoRE, which searches for neutrinoless double-beta decay, and COSINE, which searches for WIMP dark matter, both running at the Yangyang underground laboratory. Due to the rare event experiments, it is essential to reduce radioactivities (particularly from U,Th,K, and Pb) in respective detector materials. There are three systems for radioactive assay atCUP, inductively coupled plasma mass spectrometry (ICP-MS), high purity germanium (HPGe) detectors, and alpha counting. Each technique has different characteristics, measuring different, but related, radioactivity signatures with different sampling constraints. Combined, they enable cross-validation and material selection for a range of materials. HPGe detectors have narrow gamma-energy resolution and can be used to accurately quantify low levels of various radioactive isotopes. The alpha counter, an argon ionization chamber, can resolve spectral differences from surface and bulk alpha-emitting isotopes such as ²¹⁰Pb. This poster will present alpha counting and HPGe measurements of detector materials which are used in, or are candidates for use in, the rare event search experiments.

Keywords:

HPGe detector, Alpha counter, Radioactive assay, Y2L, Material selection

Study of a methode to identify the neutral particles for searching a weakly interacting dark matter

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Abstract:

For several decades, we have studied about Pulse Shape Discrimination (PSD) to search for Weakly Interaction Massive Particle (WIMP) that is a strong candidate of non-baryonic dark matter. Generally, PSD provides the clue to discriminate a Minimum Ionization Particle (MIP) and a Heavy Ionization Particle (HIP) with comparison just the pulse shapes. In this study, we would reveal the fundamental reason to produce such different pulse shapes in the microscopic view point. This study will provide us to discriminate the neutral particles and to be used in searching for the non-baryonic dark matter, WIMP.

Keywords:

Dark matter, WIMP, PSD

1-Dimensional Convolutional Neural Network for NaI(Tl) Crystal Pulse Event Selection

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Abstract:

An event selection algorithm with a low energy threshold and high efficiency is significant in a dark matter detection experiment. The COSINE-100 group has achieved the 1-keV threshold using BDT (Boosted Decision Tree) machine learning (ML) technique with the help of artificially defined variables. The new deep learning technique can analyze the whole waveform directly, and it can outperform old ML with a large number of training data. In this poster, we show the performance of the deep learning-based event selection algorithm, especially the 1-dimensional convolutional neural network with physically proper sample weight.

Keywords:

Dark Matter, Deep Learning, Event Selection, COSINE-100, Convolutional Neural Network

Stopping muon tagging in the JSNS2 experiment

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Abstract:

The JSNS2 experiment aims to search for the existence of neutrino oscillations with Δm^2 near 1eV^2 at J-PARC MLF. A 1MW beam of 3 GeV protons incident on a spallation neutron target produces an intense neutrino beam from muon decay at rest. The experiment will search for muon antineutrino to electron antineutrino oscillations which are detected by the inverse beta decay interaction followed by gammas from neutron capture on Gd. The detector has a fiducial volume of 17 tons and is located 24 meters away from the mercury target. Currently, the muon tagging of the JSNS2 experiment includes the stopping muons and through-going muons. In this slide, I will show how to separate the stopping muons and through-going muons.

Keywords:

JSNS2, Stopping muon

The status of AMoRE-II background simulation

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Abstract:

The Advanced Mo-based Rare process Experiment (AMoRE) is an underground experiment searching for the neutrinoless double beta ($0\nu\beta\beta$) decay of ^{100}Mo isotopes using cryogenic detection techniques. We are preparing the second phase of the experiment (AMoRE-II) at the Yemilab located at Handeok iron mine near Yemi mountain, Jeongseon, Gangwon-do. To estimate the background conditions in the AMoRE-II, we performed the simulations with the GEANT4 toolkit. We studied the background levels from external sources such as the cosmic muons and environmental neutrons, as well as backgrounds from materials in the nearby detector systems, including the internal lead shield, the outer lead shield, and boric acid rubber. Details of the various background simulations and estimated background levels in the region of interest (ROI) will be presented.

Keywords:

Underground experiment, AMoRE, Geant4 simulation, neutrinoless double beta decay

Two-stage temperature control system using an MMC readout for long-term data taking in AMoRE-I

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Abstract:

We developed a two-stage temperature control system for a long-term stable measurement using a dilution refrigerator. The first stage is a standard PID system using an AC bridge with a ruthenium oxide thermometer to measure the temperature of the mixing chamber (MC) plate. The second stage control is a metallic magnetic calorimeter (MMC) configured to be sensitive to the temperature of a detector tower, one of the central detector elements. While the first stage regulates the temperature of the MC plate within a few tens of μK , the other stage maintains the temperature better within a few μK . We report the principle and application of this method to long-term data taking in the AMoRE experiments.

Keywords:

AMoRE, Cryogenic, Particle, Majorana, Double beta decay

Characterization of a NaI(Tl) scintillation crystal detector with two SiPM readouts

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Abstract:

A silicon photomultiplier (SiPM) is a photodetector that produces 10^5 to 10^6 electrons in response to the absorption of a photon. The detection efficiency of SiPM and NaI(Tl) crystal is well known to have cryo-reliability. This poster is going to describe ongoing work with a NaI(Tl) scintillation detector based on two SiPMs in different temperatures.

Keywords:

Silicon PhotoMultiplier, Dark Matter Search, Detector

Characterization of 20-Inch Micro Channel Plate Photomultiplier Tube (MCP-PMT)

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Abstract:

The Korea Neutrino Observatory(KNO) proposed to observe neutrinos utilizing the Watercherenkov phenomenon requires thousands of PMTs to detect weak light.

The present study aims to measure the properties of MCP PMT, a potential candidate for use as a photosensor in KNO. This research presents the properties of MCP-PMT in depth. This study shows the values of properties of MCP-PMT such as gain, linearity, energy resolution, peak to valley ratio, signal to noise ratio, dark rate, rising and falling time of single photo-electron, and dark rate according to temperature.

Keywords:

MCP PMT , PMT characterization

Muon tagging study for AMoRE-I

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Abstract:

The AMoRE phase-I experiment is running in Yangyang Underground Laboratory to search for the neutrinoless double beta decay process using Molybdenum-100 based scintillation crystals. Muons can penetrate deep underground and can produce background events in the energy range of interest. To reduce this background, we use a muon counter detector consisting of twenty plastic scintillator panels surrounding the AMoRE-I detector system. In this presentation, the developments of the muon selection criteria and the correlation between the muon detector events and the crystal events are shown.

Keywords:

AMoRE, AMoRE-I, Molybdenum-100, Muon

Study of scintillation properties of pure NaI crystal at low temperature

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Abstract:

Scintillators are widely used as detectors for searching dark matter and NaI(Tl) crystal scintillator is one of them. Many dark matter search experiments such as ANAIS, COSINE, and DAMA are using NaI(Tl) crystal as detectors. Scintillators are required that have lower background and higher light yield to improve the sensitivity limit. Since the light yield of pure NaI crystal at low temperature is two times higher than the light yield of NaI(Tl) crystal, this crystal can be a good candidate for low temperature dark matter search experiments. We studied the characteristics of pure NaI crystal at low temperature to confirm its feasibility for dark matter search. The NaI crystal measured in this experiment was grown in our laboratory by using Czochralski method. The scintillation light yield, alpha/beta ratio, decay time, and pulse shape discrimination in the temperature range of 10 K to 290 K were measured. We will present the temperature dependence of scintillation properties of pure NaI crystal in this study.

Keywords:

scintillator, NaI

Simulations for a light collection of various geometrical shape scintillators

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Abstract:

In usual low-background particle experiments, a cylinder-shape or box-shape scintillator with an optimized number of PMTs attached is used for efficient light collection. Assuming the same efficiencies, the larger the volume of the scintillator per PMT, the more advantageous it is, since a background noise generated from the PMT can be reduced and is more economical. However, in both of the above-mentioned forms, the scintillator lengths must be increased in order to increase the volume (target), which increases the propagation length of scintillation photons, thereby reducing the detection efficiency. We report photon propagation studies for a ellipsoid-shape scintillator using a Geant4 simulation.

Keywords:

scintillator, PMT, photon, simulation, Geant4

Lowering threshold to 0.5keV in COSINE-100 data

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Abstract:

COSINE-100 is a direct dark matter search experiment that uses an array of scintillating NaI(Tl) crystals as a target/detector. The experiment started taking data in September 2016, and has been running stably ever since. As the region of interest for WIMP search is in low energy with a few keV, it is important to achieve low threshold to detect WIMP signal more sensitively. COSINE-100 has already achieved its threshold to 1keV in previous study, using Boosted Decision Tree (BDT) technique. In this presentation, I will present about our new event selection criteria for 0.5keV threshold, using BDT technique.

Keywords:

COSINE-100, BDT, EventSelection

Particle Identification using machine learning at KNO

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Abstract:

The KNO(Korean Neutrino Observatory) is a project which proposed as a next generation water Cherenkov detector in Korea. Water Cherenkov detectors in neutrino experiment are generally used to distinguish between electrons and muons. Standard particle identification algorithm is used the PMT charge distribution and timing information. We attempt to apply the machine learning using different shapes characteristic of electron and muon. In this presentation, we report the result of particle identification using the machine learning algorithm.

Keywords:

KNO, Water Cherenkov detector, machine learning, deep learning, particle identification

Test of 4-MU as WLS material in water Cherenkov detector for AMoRE -II.

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Abstract:

Water Cherenkov detector is one of muon veto expected to be used for AMoRE II experiment. The light yield of water based Cherenkov detector can be improved through an additional of wavelength shifter (WLS) material that absorb Ultraviolet Cherenkov photons and re-emit them to a longer wavelength range detectable by photomultiplier tubes (PMTs). In this work we have designed a prototype water Cherenkov detector to test the light yield of 4-MU (as WLS) loaded water. The test results on optical property, stability and light yield are reported.

Keywords:

4-MU, AMoRE, Water Cherenkov detector,

Reconstruction of Low Energy Neutrino Events at KNO

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Abstract:

The KNO (Korean Neutrino Observatory) project has been proposed as a future neutrino physics experiment. There have been several discussions on what kind of physics KNO can study. Considering the importance of detecting low energy neutrinos from the Sun, galactic center, supernovae and many others, it is essential to have an event reconstruction software optimized for low energy neutrinos. The KNO software group has been developing a reconstruction tool for such low energy neutrino events. In this presentation, we report the status of the reconstruction tool development and its performance.

Keywords:

KNO, Neutrino, Low Energy, Event Reconstruction Tool

Noise Canceling Method in the $\text{Li}_2^{100}\text{MoO}_4$

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Abstract:

The AMoRE (Advanced Mo-based Rare process Experiment) is an international project to search for neutrinoless double beta decay ($0\nu\beta\beta$) expected to appear in case that neutrino is a majoron particle. The AMoRE project uses molybdenum-based enriched scintillating crystals, and we discriminate alpha particle background from beta-gamma signals through the phonon-photon simultaneous measurement in the crystals. However, we have experienced serious difficulties on the alpha background rejection by significant noise generated in the photon signal by refrigerator pressure. Thus, we developed a completely new method that removes low frequency noise in the $\text{Li}_2^{100}\text{MoO}_4$ whose light signal amplitude is very smaller than other crystals' in the AMoRE project.

Keywords:

AMoRE, neutrinoless double beta decay, the alpha background rejection, the photon signal

Geant4 simulations of scintillation photons for the development of a SiPMT detector prototype for KNO

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Abstract:

Monte Carlo simulations have been performed for the development of a Silicon Photomultiplier Tube (SiPMT) prototype as a detector candidate for KNO (Korean Neutrino Observatory), a project proposing a next-generation neutrino detector in Korea. This SiPMT prototype consists of a photocathode, a scintillator crystal, and a silicon photomultiplier (SiPM) in a vacuum tube. Incident light on the photocathode generates photoelectrons which induce scintillation light when reaching the scintillator crystal, and the scintillation photons are then detected by the SiPM. To optimize the detector design, we performed Geant4 simulations of scintillation photons induced by electrons in a BC-408 scintillation crystal, for different values of electron energy and scintillator thickness. We studied the energy deposition of the electrons and the optical photon process inside the scintillator crystal.

Keywords:

Monte Carlo simulations, Geant4, Scintillation photons, Neutrino, KNO

KSTAR Tokamak의 초전도 코일에 대한 AC 손실 특성 조사

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Abstract:

KSTAR 초전도 코일은 2007년부터 10여년 넘게 운전되어 왔으며, 매년 AC losses 특성 분석을 위한 실험이 진행되었다. 총 30개의 초전도 자석이 KSTAR 토카막에 설치 되었으며, 특히 AC 모드로 운전되는 PF1UL ~ PF7UL의 Cable in conduit conductor의 경우 hysteresis loss, coupling loss, eddy current loss 등과 같은 AC losses가 발생된다. 따라서 코일 중 가장 크고 높은 전류인가 높은 ramping rate 을 가지는 PF1UL 자석에 대하여 AC losses 측정이 시행 되었다. 초전도 자석의 AC losses는 극저온 배관에서 측정된 초임계 헬륨의 온도, 압력, 유량을 바탕으로 enthalpy방법을 사용하여 수치적으로 계산 되었다. PF 1 자석에 4 kA, 15kA 전류를 다양한 ramping rate 에 대하여 실험이 진행 되었으며, 같은 전류에서 hysteresis loss는 일정하고, coupling loss는 ramping rate에 비례하여 증가 한다고 예측하여 4 kA/s ~ 0.15 kA/s 까지 실험이 수행되었다. Coupling loss 는 ramping rate에 비례하기 때문에 ramping rate이 zero 에 근접할 수록 hysteresis loss 를 명확히 할 수 있을 것이라고 예측 하였다. 하지만, 0.5 kA/s 이하에서 갑작스런 손실 증가가 발생되었으며, 낮은 ramping rate에서 인가 전류에 AC 파형이 관측되는 것을 확인하였다. 따라서 이번 논문에서는 낮은 ramprate에서 AC 파형으로 발생된 loss부분을 수치적으로 분리하여 KSTAR PF1UL 자석의 hysteresis loss를 규명 하고자 한다.

Keywords:

KSTAR, AC losses, Cable in conduit conductor, coupling loss, Hysteresys loss

KSTAR Single Crystal Dispersion Interferometer(SCDI)의 3채널 확장

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Abstract:

분산간섭계는 기존 단파장 간섭계(일반적으로 10 um 이하)에서 발생하는 문제 중 제일 대표적인 기계적 진동으로 인한 소음 문제를 원천적으로 감소하는 장점이 있어 다양한 핵융합 연구 장치에서 플라즈마 밀도 변화 측정에 활용되고 있다. KSTAR에서도 2019년부터 1064 nm의 파장의 Nd:YAG 레이저를 사용하는 Single Crystal Dispersion Interferometer (SCDI)를 설치하여 운영하고 있다. KSTAR의 기존 SCDI는 광경로가 하나인 단채널 시스템이므로 장치 운영에 관여하는 광원, 광학계, 빔정렬 등 여러가지 다양한 원인으로 시스템에 문제가 발생할 경우 데이터 획득이 불가능하거나 혹은 신뢰도가 크게 저하될 우려가 있다. 또한 장치가 성공적으로 작동하더라도 주반경 1.8 m, 부반경 0.5 m에 달하는 전체 토카막 플라즈마의 국부적인 정보만 측정할 수 있다는 한계가 있다. 이러한 단점을 개선하기 위하여, 기존의 KSTAR SCDI를 3개의 다른 광경로를 가진 다채널 시스템으로 확장 개발하여 설치하였다. 이를 통해 특정 채널에서 문제가 발생하여도 나머지 채널의 정보를 통해 SCDI의 특징적인 주요 목표인 shattered pellet injection (SPI)의 정상 발사 여부를 성공적으로 확인할 수 있었고, 플라즈마의 여러 구역에서 발생하는 밀도 정보를 동시에 측정할 수 있었다. 본 발표에서는 3채널 SCDI의 구체적인 설치 과정과 이를 통해 측정된 데이터를 제시한다.

This work was supported by Ministry of Science and ICT under KFE R&D Program of "KSTAR Experimental Collaboration and Fusion Plasma Research (KFE-EN2101-12)," was done in collaboration with the ITER DMS Task Force and was funded by the ITER Organization under contract IO/CT/43-1918. This work is also partially supported by the National R&D Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (Grant No. NRF-2020M1A7A1A03016161).

Keywords:

플라즈마, 간섭계, plasma, interferometer

SOLPS-ITER 전산모사를 통한 KSTAR 구조에서 리튬 주입에 의한 디버터 열속 제어 타당성 조사

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Abstract:

토카막에서 플라즈마로부터 디버터 타겟으로 입사하는 막대한 열속을 제어하기 위한 방법 중 하나로 불순물 주입이 중요하게 연구되고 있다. 특히, 리튬은 다른 불순물 원소들과 비교하여 상대적으로 코어에 잘 진입하지 않는 성질을 가지고 있어 주목받고 있다. 본 연구에서는 KSTAR 구조에서 리튬 주입에 의한 디버터 열속 제어 타당성을 SOLPS-ITER 전산코드를 이용하여 분석하였다. 리튬 주입 시 감소하는 중수소 recycling coefficient를 0.84-1.00 범위에 대하여 스캔하는 시뮬레이션을 수행하였다. 또한, 리튬 주입 위치를 각각 내측과 외측 디버터 영역으로 설정한 경우에 대해서도 전산모델링을 수행하였다. 리튬 주입률이 $0-1 \times 10^{22} \text{ s}^{-1}$ 의 범위에서 증가할 때, Li^+ 와 Li^{2+} 가 방출하는 복사가 증가하였으며, 이에 따라 리튬을 주입한 영역의 디버터 타겟으로 입사하는 열속이 감소함을 확인하였다.

Keywords:

SOLPS-ITER, 리튬 주입, 디버터 열속 제어

Geodesic acoustic modes and Stringer spin-up driven by the poloidally asymmetric particle source in gyro-Landau fluid model

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Abstract:

In this study, a gyro-Landau fluid model is presented to find the two-dimensional plasma dynamics due to a poloidally inhomogeneous particle source in a tokamak. The ExB flow is likely growing initially in the presence of the poloidal particle source. Compared to the reduced MHD model, which was used by Hassam to describe the Stringer spin-up (SSU), this model includes crucial damping physics (i.e. Landau damping) by adapting parallel closures of Hammet-Perkins. A crucial difference between two models is that there exists a source threshold to initiate an instability in our gyro-fluid model. While analyzing underpinnings of the threshold physics, it is found that the SSU has an oscillatory motion for weak sources, which is referred to as "source-induced GAM", and makes a transition to the non-oscillatory SSU when source intensity exceeds a certain value. Both threshold and transition in terms of the source intensity are highly affected by the Landau damping coefficient, implying that the Landau damping matters. For the case when the Landau damping is strong enough, source-induced GAM is always stable for any given source intensity, while SSU can be excited. On the other hand, when the Landau damping is weak, not only SSU but also source-induced GAM can be unstable depending on the source intensity.

Keywords:

gyro-Landau fluid model, poloidal source, GAM, Stringer spin-up, Landau damping

Development of two dimensional full wave spectral code for the ICRF H&CD of a nuclear fusion reactor

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Abstract:

A full wave code is indispensable to design an antenna and analyze the experimental results of ICRF(Ion Cyclotron Range of Frequency) H&CD(Heating & Current Drive) for nuclear fusion plasmas. In particular, it is very important for the full wave code to include capability to simulate the SOL(Scrape Off Layer) plasma as well as core inside of the LCFS(Last Closed Flux Surface) for the prediction of the coupling between antenna and core plasma. A full wave code based on a Fourier spectral algorithm is able to facilitate the simulation of the SOL plasma considering collision as well as kinetic effect since it does not use flux surface coordinate of fusion plasma unlike conventional FEM(Finite Element Method) full wave codes. In addition to that, it can be used to easily extend to other frequency range of RF H&CD. A full wave code has been developed based on the Fourier spectral algorithm through ITER non-procurement project of KFE(Institute of Korea Fusion Energy). One dimensional version of full wave code was developed already for the confirmation of the algorithm and identification of probable problems in advance for the development of two dimensional code which has so much larger dense matrix that it is difficult to identify and debug. Based on the successful one dimensional code for the last two years, two dimensional code has been being developed. The main routine code is completed recently and the initial calculation result shows the electric field pattern clearly in agreement with the dispersion relation. Currently, the post processing routine is being made which includes the calculation of magnetic field, poynting vector representing energy flow, power absorption of each plasma species, and energy balance between radiation RF power from the antenna and total power absorption of plasma which is a norm to see whether the code is developed correctly or not. After the completion of the code programming, a validation will be carried out by comparing with the TORIC code which is a well-known and widely-used FEM code in the fusion research. The detailed code development status and updated result will be presented in the conference.

Keywords:

nuclear fusion, ICRF, Fourier spectral algorithm, FEM, heating and current drive

Nonlinear Dynamic Analysis of Metastable Plasmas in KSTAR

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Abstract:

Metastable plasma experimental data were analyzed in KSTAR Tokamak. MHD stability and NTM was analyzed by using GATO code and various nonlinear dynamic exponents were obtained from the time series of MC data in each region by python code. The nonlinear dynamic exponents are correlation dimension, Lyapunov exponent, Hurst exponent, and Detrended Fluctuation Analysis (DFA). DFA can quantitatively measure the self-similarity of data when the correlation time is relatively large in time series data. DFA quantifies the correlation between signals that are separated from each other, and can also solve problems caused by various trends in time series. As time passes, the correlation dimension decreased, and the Lyapunov exponent is appeared unstable in the transition region, but becomes negative in the ELM region and shows a repeating pattern at regular intervals, indicating that the trajectory is stabilized. It can be seen that the transition region has a longer range correlation characteristic than that of the NTM region, and after the transition occurs, the correlation range is shortened, and the Hurst exponent is obtained as 0.54, which is closer to Brownian motion.

Keywords:

KSTAR, Metastable Plasma, Nonlinear Dynamics

KSTAR 플라즈마에 주입한 크립톤 불순물이 내부수송장벽 생성에 미치는 영향 연구

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Abstract:

핵융합 반응의 효율성 향상과 플라즈마 열속의 제어를 위한 최적의 핵융합 운용 시나리오 개발은 핵융합 상용화 실현을 위한 주요 과제이며, 불순물 가스 주입은 이를 달성하기 위한 획기적인 방법 중 하나로서 전 세계적으로 활발히 연구되고 있다. 또한 각 불순물 종류별로 원자 구조에 따라 복사 냉각 효율이 다르기 때문에 이를 고려한 최적화된 시나리오가 개발되어야 한다. 차세대 핵융합 장치에서는 훨씬 고온 환경에서 플라즈마가 운용되므로 높은 방사효율을 갖는 불순물이 적용될 가능성을 높으므로 이를 고려한 연구 수행이 필수적이다. 본 연구에서는 KSTAR 플라즈마에서 크립톤 불순물 가스 주입을 통하여 내부수송장벽이 생성됨을 실험적으로 확인하였다. 일반적으로 내부수송장벽의 형성 기작은 sheared E×B flow로 인한 난류 억제의 결과로 해석되기도 한다. 따라서 E×B flow 형성에 지배적인 역할을 하는 반경 방향의 전기장 E_r 의 크립톤 가스 주입 전후 변화를 계산 및 비교함으로써 내부수송장벽 형성에 대한 불순물의 영향을 분석하였다. 또한 불순물 주입으로 인해 난류가 감소된 상태에서 플라즈마 중심을 국부적으로 가열하는 중성입자빔을 주요 가열원으로 사용함으로써 증가하는 E_r 의 토로이달 속도 향의 프로파일 변화를 얻었다. 이를 통해 E×B flow의 shearing rate 증가에 불순물과 중성입자빔이 시너지 작용하여 플라즈마 방전 후반부까지 내부수송장벽이 유지됨을 확인하였다.

Keywords:

토카막, 불순물, 내부수송장벽

Application of statistical divergence for detection of solitary perturbation

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Abstract:

Preventing plasma disruption and sustaining high performance plasma confinement are major challenges for attainment of nuclear fusion. Recently, solitary perturbation (SP) has been proposed as a precursor of the periodic collapse of the edge confinement region (pedestal)^[1]. During the pedestal collapse, a significant amount of heat and particle are lost, leading to damages of plasma-facing surfaces. Therefore, detection of the SP before pedestal collapse is desired to mitigate or prevent the confinement loss. The SP is spatially localized and can be identified by multi-channel toroidal Mirnov coil (MC) array. The SP can be more clearly captured by band-pass filtered MC signals from a few kHz to tens of kHz. We propose a faster detection method based on statistical divergence between raw MC signals to the filtered SP signals. In particular, Jensen-Shannon divergence works well for catching the SPs from the raw MC signals in KSTAR. This work is supported by NRF of Korea under grant no. NRF-2019M1A7A1A03088456.

Keywords:

Nuclear fusion, KSTAR, Pedestal collapse, Solitary perturbation, Statistical divergence

KSTAR에서 발생하는 불순물 연구를 위한 Visible Spectrometer system 현황

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Abstract:

토카막 플라즈마 내부에서 발생하는 불순물 이온은 플라즈마에서 방사광의 형태로 에너지 손실이 발생하여 핵융합 발전효율을 현저하게 떨어뜨린다. 불순물 이온이 발생하는 과정에는 핵융합 플라즈마와 내벽의 상호작용과 방사 디버터에 활용되는 이종가스, 그리고 핵융합 반응을 통해서 생성되는 불순물 등이 있다. 이러한 불순물은 플라즈마의 냉각을 유발하여 핵융합 반응을 감소하는 등 핵융합 플라즈마의 제반 성능을 감소시킨다. 따라서, 지속적인 고성능 플라즈마를 유지하기 위해, 플라즈마 내 불순물 입자의 분석 및 제어는 핵융합 연구에 있어 중요한 연구분야이다.

KSTAR에서는 이러한 불순물 이온을 분석하고 모니터링하기 위하여 visible spectrometer system을 설치하여 운영하고 있다. 이번 논문에서는 KSTAR에 설치되어 있는 spectrometer의 성능 및 플라즈마에서 발생하는 불순물의 종류를 설명하고자 한다. 특히 장시간 고성능 플라즈마를 유지하기 위한 기계학습(Machine Learning) 기법을 통한 ELM(Edge Localized modes) 불안정성 제어시 불순물의 변화를 분석할 것이다.

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Keywords:

plasma, impurity, spectrometer, KSTAR, Fusion

Impact of negative triangularity plasma shape on the $n=0$ resistive wall mode in a tokamak

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Abstract:

The recent experimental results of TCV and DIII-D tokamaks with negative triangularity plasma revealed many benefits of physics and fusion engineering. The reduced electron heat transport [1] and the high confinement in L-mode operation is a specific characteristic of negative triangularity plasma showing increased normalized beta and H factors by reducing localized Mercier/ballooning modes [2]. However, the elongations of plasma in those experiments are not yet optimized, showing somewhat lower value than the usual value of the positive triangularity plasma while a large elongation is desirable to increase energy confinement time [3]. Here, we have developed axisymmetric vertical stability code AVSTAB [4] to find the marginally controllable elongation for a system in a given feedback capacity parameter against $n=0$ resistive wall mode, which initiates the vertical instability. We investigate the impacts of the plasma parameters such as poloidal beta or internal inductance and the geometric characteristics between plasma and wall boundaries on the controllable elongation [5]. Unlike a positive triangularity plasma, increasing poloidal beta stabilizes vertical instabilities of the negative triangularity. The decrease of the internal inductance is stabilizing for both positive and negative triangularity plasma. In terms of the geometry, non-conformal shapes between the wall and the plasma can be helpful for stabilizing the vertical instability, unless the gap distance between the nulls of plasma and the wall boundary become excessively close.

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Keywords:

negative triangularity, resistive wall mode, vertical stability

Generalized cyclotron resonance closures with perpendicular components derived from Vlasov equation

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Abstract:

To solve plasma fluid equations, higher order moments, or the closures, should be expressed with the fluid moments in interest.

Previous studies only considered the closures in the parallel direction to the magnetic field inside the plasma. This study generalizes the linear equations of closures for the $\{n, \mathbf{V}, T\}$ equations, which are the heat flow \mathbf{h} and viscosity tensor $\boldsymbol{\pi}$, by considering the perpendicular components. First, the closure equations are derived from the Vlasov equation with the BGK(Bhatnagar-Gross-Krook) collision operator ν , by removing the approximate fluid equations and performing the Fourier transformation. The resulting system of closure equations relates the heat flow and viscosity to the cyclotron frequency Ω , temperature, and flow velocity components. Next, we take the collisionless limit ($\nu \rightarrow 0$) and the unmagnetized limit ($\Omega \rightarrow 0$) and compare the result of each limit with previous studies, respectively. In particular, when excluding the perpendicular components, the closure equations reduces into and reproduces the previous results. Since the derivation only uses the approximation for the collision operator, this should give more accurate formula, including the cyclotron resonance effects by plasma wave related to perpendicular components of the flow velocity.

Keywords:

Vlasov equation, Cyclotron Resonance, Plasma wave, Moment closures

Extension of bounce-kinetic model for trapped electron mode turbulence simulations

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Abstract:

Bounce-kinetic model based on the modern nonlinear bounce-kinetic theory[1] has been used for gKPSP gyrokinetic simulations before[2,3]. However, only deeply trapped particles were considered in those ITG (ion temperature gradient) and TEM (trapped electron mode) turbulence simulations. This work reports on an extension including a more accurate description of barely trapped particles, and its applications. The extension is done by integrating asymptotic expansion of bounce frequency ω_b to obtain unperturbed Hamiltonian. Expressions for the Hamiltonian are derived in deeply trapped and barely trapped limits as h_{deeply} and h_{barely} , which are used in the following equation of motion:

$$\frac{\partial H_0}{\partial \psi} \simeq \left[1 - \left(\frac{J_b}{J_{b*}} \right)^2 \right] \frac{\partial h_{deeply}}{\partial \psi} + \left(\frac{J_b}{J_{b*}} \right)^2 \frac{\partial h_{barely}}{\partial \psi} \quad (1)$$

Here, J_b is the bounce action of bounce gyrocenter, J_{b*} is the bounce action at trapped/passing boundary, H_0 is the exact unperturbed Hamiltonian, and ψ is the flux function. Using this extended bounce-kinetic model, we observed an improvement of collisionless TEM behavior at low magnetic shear from the existing model.

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Keywords:

Tokamak plasma, Gyrokinetic theory, Trapped electron mode, Bounce-kinetic simulation

Surface treatment of hydrogen-isotope permeation in SS316LN for nuclear fusion applications

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Abstract:

In order to obtain transport parameters of hydrogen-isotope permeation for nuclear fusion devices, we polished chemically the surface of a disk-shaped SS316LN (supplied by ThyssenKrupp, diameter: 20 mm, thickness: 0.5 mm) and coated the its surface by using argon-ion sputtering to minimize the effects of its native oxide layer of surface. Its transport parameters (permeability, diffusivity, and solubility) of hydrogen isotopes were determined in the temperature range of 650-800 °C. The results will be presented and compared with previously reported results of a pristine sample.

Keywords:

permeation, hydrogen isotope, SS316LN, nuclear fusion

Nonlinear MHD Simulation on the 5% neon mixture SPI in KSTAR

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Abstract:

Shattered pellet injection (SPI) is the baseline concept for the disruption mitigation system (DMS) in ITER, in which a cryogenic pellet is shattered into a disrupting plasma to mitigate the consequences of a disruption [1, 2]. SPI has experimentally shown improved disruption mitigation performance compared with other DMS concepts, and numerical studies are being widely conducted to reveal its physical mechanisms [3-7].

Since its first deployment of SPI [8], KSTAR has conducted a variety of SPI experiments including multiple injection schemes [9]. This work aims to numerically explore the complex interplay between the pellet and the plasma using the nonlinear 3D Magneto-Hydrodynamics (MHD) code, JOREK [10, 11]. The simulations mainly focus on the 5% neon mixture pellet as KSTAR took it as the reference case in the 2020 campaign. Qualitative matches were found in the duration of the pre-thermal quench phase and in the trends of radiation measurements, and further results and the comparison with experimental measurements will be presented.

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Keywords:

Shattered Pellet Injection, Tokamak, Disruption

KAERI divertor plasma simulator using applied-field MPD thruster: 10 MWm^{-2} heat flux and $10^{23} \text{ m}^{-2}\text{s}^{-1}$ hydrogen/deuterium particle flux

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Abstract:

KAERI divertor plasma simulator was developed using the applied-field magnetoplasmadynamic (AF-MPD) thruster for studying innovative divertor heat sink and divertor materials. The AF-MPD thruster was chosen because it can produce a plasma beam with high plasma density in cw mode. Two types of AF-MPD thruster were developed and used in this work: a type I source with a wide thruster channel was used for a heat flux test with Ar gas, while a type II source with a narrow thruster channel was used for an ion flux test with H₂, D₂, and He gases. The maximum heat flux provided by our AF-MPD thruster was measured to be 10 MWm^{-2} using a custom-made heat flux sensor, while the maximum hydrogen/deuterium ion flux was measured to be $1 \times 10^{23} \text{ m}^{-2}\text{s}^{-1}$ using a Langmuir probe. The electron temperature ranges between (4–5) eV, while the electron density at the target region (downstream) ranges between $(1\text{--}4) \times 10^{18} \text{ m}^{-3}$.

Keywords:

fusion divertor, heat flux, particle flux, electric propulsion, MPD thruster

Alternate beam extractor design for positive and negative ions from multi-pulsed negative ion source

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Abstract:

The Alternate beam extractor of positive and negative ions from multi-pulsed negative ion source has been designed for study on technology to solve current issues of an electric propulsion concept in space. This technology is applicable to space neutralizer needed in a current electric propulsion system to ensure charge neutrality of the spacecraft. Two ICP-based single pulsed plasma source produce positive and negative ions and diffuse to the center chamber. Alternate beam extractor will be installed at center of the chamber. Applying a time-varying square-wave bias to the grids of the beam extractor, successive high-energy($\sim 1\text{keV}$) beams of positive and negative ions will be extracted. Designed beam extractor consists of 3-grids; plasma grid(G1), extraction grid(G2), target grid(G3). Permanent magnets were inserted inside the G2 grid to deflect co-extracted electron current from plasma grid during negative ion beam extraction and secondary electron current flow from the target grid to the plasma grid during positive and negative ion beam extraction. This presentation describes its design feature and simulation study.

Keywords:

negative ion, positive ion, Alternate beam extractor, ion beam extraction, pulsed plasma source

Progress in the optimization of nuclear fusion reactor plasma design points with 0D optimization and transport solution.

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Abstract:

Following previous work, a machine learning-based approach is being applied to predict plasma design points for a future nuclear fusion power plant[1].

In the original method, a 0D plasma code is used as an objective function by an evolutionary optimization algorithm to optimize the figures of merit considered of interest by changing some input parameters and constraining the solution with physical and technological limits.

The obtained solution is then used as an approximate solution for a transport solver, which provides a more reliable and self-consistent solution based on 0D optimization.

The transport solver solution is in turn used to estimate some parameters of the plasma 0D code with linear regression and subsequently produce a new iteration.

In this contribution, we report the current state of our research and results, and outline work ongoing in the improvement of the previous model.

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Keywords:

nuclear fusion, plasma, optimization, conceptual design, machine learning

Structural evolution and optical properties of CsPbBr₃ nanocrystals

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Abstract:

All-inorganic cesium lead halide perovskite nanocrystals (NCs) have emerged as a promising class of materials owing to their higher durability compared to that of the methylammonium lead halide perovskites in optoelectronic applications. The CsPbX₃ NCs include bright luminescence and broad spectral tunability over the entire visible range, which make them suitable candidates for photonic sources. However, still little is known about the understanding mechanisms that control their formation and transformation, although they are the crucial factor to enhance quality development in commercial formulations. The precipitation derived perovskite induces large morphological variations, providing a non-ideal platform based on fundamental properties of these materials. Therefore, controlled synthesis of high quality CsPbBr₃ nanocrystals and well-ordered morphology offer unique opportunities for both fundamental research and practical applications. In this work, we investigate structural and optical properties of CsPbBr₃ NCs with the different reaction parameters. The transmission electron microscopy images were obtained on a field-emission transmission electron microscopy. UV-vis absorbance and fluorescence spectra were acquired by a FLAME-S spectrophotometer.

Keywords:

CsPbBr₃ nanocrystals, Morphological variations, Structural properties, Optical properties, Reaction parameters

Introduction of Sodium Doping Process to InP-based Quantum Dot for Narrow Full Width at Half Maximum

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Abstract:

Quantum Dots (QDs) have been arisen promising candidates for emission layer material in display because of their various advantages, such as tunability of emission wavelength, high color purity, and high stability. Despite of these unique properties, market disregarded QD-based display because of its toxicity which comes from the usage of cadmium precursor in synthesis process. To solve this issue, intensive researches have been operated to find alternative materials for QD with no toxicity, accordingly InP-based QDs are considered as cadmium free QDs with broad emission wavelength coverage. However, it is difficult to synthesize uniform sized InP-based QDs which require high temperature and reactive precursors to acquire strong covalent bonding results in broadening of the particle size distribution. Herein, we introduced doping process via injecting sodium precursor such as sodium iodide while QD core growth. By introducing doping process, sodium ion passivated core vacancy defects so that it reduces lattice mismatches and dislocations between core and shell. As a result, we could get uniform sized quantum dot which has narrow full width at a half maximum (FWHM) in photoluminescence (PL) spectrum. In specific, FWHM reduced about 3 nm and 4 nm red shifted in PL peak wavelength. These sodium-doped core based QDs could soon be applied in QD-based display.

Keywords:

InP-based Quantum Dot, Sodium-doped Core, Narrow Full-Width-at-Half-Maximum

Manipulating edge current spin polarization in zigzag MoS₂ nanoribbon

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Abstract:

We use the six-band tight-binding model of a zigzag monolayer molybdenum disulfide (MoS₂) nanoribbon and numerical approach to calculate electronic band structure and quantum transport. For metallic edge modes, considering both an intrinsic spin-orbit coupling and local exchange field effects, spin degeneracy and spin inversion symmetry are broken so that spin selective transport is possible. We suggest a model that has three-terminal device with a circular-shaped gate voltage in the middle of the scattering region. Our model measures the top edge current and the other measures the bottom edge current respectively. By controlling the gate voltage, each terminal can detect a totally spin-polarized edge current. The results from our calculation present possibility as spin filters using implanted MoS₂ nanoribbon.

Keywords:

MoS₂, spin polarization, quantum transport, edge current, numerical calculation

라만 분광법을 통한 단일층 WS_2 의 결함 유발 형광 변화 분석

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Abstract:

2차원 전이 금속 디칼코게나이드 (TMD)의 광학 특성을 이해하기 위해 결함에 대한 명확한 분석이 필요하다. 본 연구에서는 단일층 WS_2 에 레이저 조사를 수행하여 결함을 생성하고 형광 및 라만 산란에 대한 광학 특성 변화를 조사하였다. 결함에 의해 유도된 형광에서는 엑시톤 및 바이엑시톤, 결함 결함 엑시톤의 강도 및 피크 위치 변화가 나타났으며, 형광 변화의 원인을 설명하기 위해 형광과 동시 측정이 가능한 라만 분광법을 사용하였다. SV 형성과 관련된 D 라만 모드와 산화 관련 라만 모드의 출현 및 변화를 확인하였고, 결함 유형에 따라 형광 특성이 다르게 변화됨을 상관관계를 통하여 확인 하였다.

Keywords:

WS_2 , 결함, 라만 분광법, 형광

Intra- and Inter-band carrier transition in ternary nitrides

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Abstract:

There are a lot of discussions on the degradation of nitride semiconductor devices such as light emitting diodes, photovoltaic cells etc., and the defect-related recombinations are pointed out as a main degradation mechanism. However, the discussions are mainly focused on the quantum well structure and nanowires, and are mostly made theoretically. The quantum well structure is yet governed by quantum Stark effect due to piezoelectric nature of wurtzite crystal structure and nanowires are overwhelmed by surface recombination due to high surface-to-volume ratio, thereby probing intrinsic carrier transitions due to the intrinsic defects are disturbed. In this article, we probe the ternary nitride thin-films with optical pump terahertz probe (OPTP) method and time-resolved photoluminescence (TRPL) to fully map the intrinsic carrier transition across inter- and intra-band.

Keywords:

III-N semiconductors, Molecular beam epitaxy, Spectroscopy

Hardware implementation of neuromodulated synaptic plasticity by combining a memristor and a redox transistor

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Abstract:

Spiking neural networks (SNN), which allows for more energy-efficient operations and dense-information encoding, emulate the human brain more realistically than non-spiking artificial neural networks. One of the main building blocks of the SNN is artificial synapse with faithful emulation of biological synaptic learning rules. Memristors have been considered good candidates for artificial synapse in that they successfully mimic a classical spiking-timing-dependent plasticity (STDP) learning. However, the classical STDP learning rule considering only presynaptic and postsynaptic activity neglects a third factor such as neuromodulators such as dopamine, acetylcholine and noradrenaline known to serve as reward and modulate the synaptic learning. Unfortunately, the conventional 2-terminal memristor devices can hardly emulate neuromodulated synaptic plasticity or three factor learning. Although several efforts to emulate neuromodulators using multi-terminal memristor devices have been reported, no dynamic three-factor learning was successfully demonstrated yet. In this study, we demonstrate a hardware implementation of neuromodulated synaptic plasticity using an analog memristor and a redox transistor. The nonvolatile memristor consisting of a HfOx/TaOx bilayer is especially engineered to exhibit analog synaptic function by tailoring oxide stoichiometry and thickness of each layer. The volatile redox transistor adopts electrochromic device structures sandwiched with a redox couple and electrolyte. Tungsten oxide and nickel oxide were employed as the anodic and cathodic redox layers, respectively, and solid oxide as the electrolyte layer. The redox transistor device is also tuned to mimic a dynamic neuromodulator behavior by optimizing ionic transport and redox reactions in the multi-layered structures. By combining the memristor with the redox transistor in series connection, we successfully show that the neuromodulated STDP curves, i.e. time-dynamic three-factor learning, can be emulated. We expect the scheme proposed in this study will provide a compact building block for more efficient neuromorphic hardware.

Keywords:

Memristor, redox transistor, artificial neural network, neuromodulated, STDP

Comparative analysis of properties of InGaZnO thin film according to the deposition method

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Abstract:

산화물 반도체 박막은 flexible/wearable electronic device, see-through display, smart window, gas sensor, solar cell 및 piezoelectric 등 다양한 분야에 연구 및 응용되고 있다. 특히, 비정질 상태에서도 높은 이동도($>10\text{cm}^2/\text{Vs}$)를 가지 수 있는 장점 때문에 디스플레이 backplane에 switching/driving 박막 트랜지스터의 활성 층 (active layer) 재료로써 연구가 많이 진행되었다. InGaZnO (1:1:1 at. %) 재료는 2004년 H. Hosono Group에서 보고된 이후 현재까지 가정 널리 사용되는 활성 층 재료로 스퍼터링 (sputtering) 방법으로 비교적 간단하게 증착 할 수 있고 박막 트랜지스터로 제작되었을 때 대략 $10\text{cm}^2/\text{Vs}$ 의 이동도 특성을 보인다. 하지만 디스플레이 성능 고도화 (고해상도, 고속구동) 가 요구됨에 따라 $10\text{cm}^2/\text{Vs}$ 이상의 이동도를 가지는 활성 층 재료를 확보하는 것이 중요하다. 다양한 연구를 통해 InGaZnO 재료 대비 높은 이동도를 확보할 수 있는 활성 층 재료로써 InSnZnO, ZnON, WInO 등이 보고되고 있지만 기존 InGaZnO 대비 재료에 대한 이해가 떨어져 고 이동도 확보에 따른 전기/광학/열 적 신뢰성 저하, 공정 window 협소, 재현성 미확보 등의 어려움을 극복하지 못하고 있다. 고 이동도 박막 트랜지스터 확보를 위한 또 다른 방법으로는 비교적 오랫동안 연구되어 재료에 대한 이해가 풍부한 InGaZnO 재료의 조성을 변동하여 이동도를 높이는 방법이다. 그 중에서도 MOCVD (metal-organic chemical vapor deposition) 증착 방법은 스퍼터링 증착 방법과 비교하여 주입하는 전구체 (precursor)의 양 및 반응체 (reactant)의 반응시간 조절을 통해 조성 및 이동도 특성을 자유롭게 조절할 수 있을 뿐만 아니라 밀도 높은 활성 층 증착을 통해 신뢰성 특성도 확보 할 수 있는 장점을 가진다.

본 연구에서는, MOCVD 방법으로 증착된 InGaZnO 박막과 스퍼터링 방법으로 증착 된 InGaZnO의 물리적/전기적/광학적 물성비교를 통해 향후 고 이동도, 고 신뢰성 박막 트랜지스터의 구동 메커니즘을 이해 할 수 있는 근간을 마련하고자 한다.

Keywords:

산화물반도체, InGaZnO

고성능 슈퍼커패시터 응용을 위한 코발트 몰리브덴 산화물 마이크로 구조의 합성 및 특성

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Abstract:

나노/마이크로 아키텍처를 사용하는 새로운 전이 금속 산화물 (transition metal oxide: TMO) 재료는 전도성 및 형태학적 특성으로 인해 에너지 저장 분야에서 놀라운 전기화학적 특성을 나타낸다. 본 발표에서는 소성 없이 간단한 수열합성법을 사용하여 $\text{Co}_2\text{Mo}_3\text{O}_8/\text{CoO}_2$ 마이크로아키텍처 물질의 합성 및 전기화학적 특성에 대해 발표한다. 다양한 반응 온도에서 합성된 $\text{Co}_2\text{Mo}_3\text{O}_8/\text{CoO}_2$ 기반 전극 재료를 조사하였다. 최적화된 $\text{Co}_2\text{Mo}_3\text{O}_8/\text{CoO}_2$ 전극은 안정적인 사이클링 특성을 나타냈다. 또한, 최적화된 $\text{Co}_2\text{Mo}_3\text{O}_8/\text{CoO}_2$ 물질(양극)과 활성탄 물질(음극)을 사용하여 비대칭 슈퍼커패시터 소자가 제작되었고, 우수한 최대 에너지 및 전력 밀도가 얻어졌다. 명백하게, 얻어진 뛰어난 전기화학적 결과는 $\text{Co}_2\text{Mo}_3\text{O}_8/\text{CoO}_2$ 전극이 에너지 저장 응용을 위한 유망한 전극 재료가 될 수 있음을 시사한다.

Keywords:

몰리브덴 산화물, 전기화학적 특성, 슈퍼커패시터

리튬이온 배터리용 고성능 음극 재료로서 니켈 바나데이트@산 처리된 CNT의 합성 및 특성

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Abstract:

저렴한 바나듐기반 혼합 금속 산화물은 주로 리튬이온 배터리를 위한 엔지니어링으로 층상 결정을 형성하여 높은 에너지 밀도를 제공한다. 수많은 산화 상태의 존재와 바나듐의 배위 상호 작용은 형태 및 표면 효과를 확장하기 위해 비용 효율적이고 강력한 방법이 필요하다. 다른 압력과 온도 환경에서 absolute phase와 다양한 형태를 달성하기 위해 수열합성법은 매우 적절한 합성 중 하나이다. 본 발표에서는 간단한 수열합성법을 사용하여 산 처리된 다중벽 탄소 나노튜브(CNT) 장식된 니켈 바나데이트 하이브리드 복합 나노구조와 상호 관련된 미소구체를 준비하였다. 자가 조립 경로는 수열합성 하에 연결된 미소구체를 생성했다. 제작된 전극은 높은 비표면적, 상호 관련된 미소구체의 다공성 유형 및 CNT로 인해 뛰어난 전기화학적 특성을 나타냈다. 이러한 높은 표면적과 높은 다공성 특성은 더 많은 공극이 리튬화/탈리튬화 경로에서 막대한 양의 리튬 이온을 조정할 수 있도록 하여 리튬이온 배터리의 음극재로 그 가능성을 나타냈다.

Keywords:

니켈 바나데이트, 리튬이온 배터리, 전기화학적 특성

회전 기계 에너지 하베스팅 응용을 위한 PET기반 마찰전기 나노발전 소자 제작 및 특성

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Abstract:

풍부하게 이용 가능한 미활용 회전 기계 에너지를 수확하는 것은 전 세계적으로 발생하는 에너지 위기에 대한 해결책이 될 수 있다. 마찰전기 나노발전소자 (triboelectric nanogenerator: TENG)는 미활용 회전 운동을 전기로 효과적으로 수확할 수 있는 잠재력을 가지고 있다. 본 발표에서는 자가발전 가능한 풍속 센서 뿐만 아니라 주변 회전 에너지 수확기로서의 회전 TENG에 대해 발표한다. 비용 효율적이고 내구성이 있으며 화학적 및 내열성이 있는 PET (polyethylene terephthalate) 시트와 구리 테이프는 TENG의 제작을 위해 각각 음극 및 양극 마찰전기 재료로 사용되었다. 소자 구조는 3D 프린터를 사용하여 제작되었으며 접촉-분리 및 슬라이딩 작동 모드에서 작동하므로 전체 전기 출력을 향상시킨다. 회전 TENG의 전기 출력은 광범위한 회전 속도에서 분석되었고, 상당한 시간 동안 안정적인 전기 출력을 생성하였다. 회전 TENG의 전기적 성능은 바람 감지 시스템으로 오픈 소스 Uno Arduino 전자 하드웨어 및 소프트웨어를 보정하기 위해 다양한 풍속에서 조사되었다. 이러한 결과는 제안된 회전 TENG가 회전 에너지 수확기 및 자가발전 풍속 센서로 효과적으로 사용될 수 있음을 나타낸다.

Keywords:

회전 기계 에너지, 나노발전소자, 에너지 하베스팅

Bathocuproine을 중간층으로 사용하여 제작한 전자수송층이 없는 광 안정성이 높고 유연한 그래핀 양자점/페로브스카이트 태양전지

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Abstract:

전자수송층이 없는 페로브스카이트 태양전지 구조는 일반적으로 전자수송층으로 많이 쓰이는 TiO_2 와 같은 물질들로 인한 태양전지의 불안정성을 줄일 수 있고 특히, 태양전지의 저온공정에 매우 유용하다. 전자수송층이 없는 페로브스카이트 태양전지에 관한 많은 연구들이 진행되었지만 대부분은 투명하고 전도성이 있는 산화물을 기반으로 한 구조로서, 유연한 태양전지에는 적합하지 않다. 본 연구에서는 bis(trifluoromethanesulfonyl)-amide가 도핑된 그래핀, 절연체인 bathocuproine (BCP), 그리고 그래핀 양자점이 혼합된 페로브스카이트를 각각 태양전지의 투명전극, 중간층, 및 광활성층으로 사용하여 전자수송층이 없고 광안정성이 높은, 최대 15.72%의 광전효율을 나타내는 페로브스카이트 태양전지를 제작하고 특성을 평가하였다. BCP 중간층은 페로브스카이트와 그래핀층 사이에서 전하 재결합을 감소시켜 전자 이동 특성을 효과적으로 향상시킬 수 있다. 본 태양전지의 광전효율은 500시간 동안 대기중에 단순히 보관했을 때는 최대 8%, 빛을 조사했을 때는 최대 17% 감소하였다. 또한, 곡률 반경 4 mm에서 1000회 반복적으로 굽힘 테스트를 한 후에도 광전효율이 초기 값의 83% 이상 유지되는 것을 확인하였다. 이는 매우 우수한 장기 및 기계적 안정성을 나타내는 것이다.

Keywords:

페로브스카이트, 전자수송층, 중간층, 그래핀, 그래핀 양자점

그래핀 양자점을 중간층으로 사용한 그래핀/Si 나노결정층의 전기적 특성 및 광검출기 특성 연구

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Abstract:

이온 빔 스퍼터링 증착법으로 Si 기판 위에 $\text{SiO}_x/\text{SiO}_2$ 다층박막 시료를 제작하였다. 박막 성장 후 Si 양자점을 형성하기 위해, 급속 열처리를 이용하여 1100°C 에서 20분 열처리하였다. 고분해능 투과전자현미경 사용하여 SiO_2 박막 안에서 Si 나노결정이 형성되었음을 확인하였다. 개선된 Hummers method에 의해 제작된 그래핀 양자점 (GQDs)를 spin coater를 사용하여 Si 나노결정을 가진 SiO_2 박막 (SQDs) 위에 스피ن코팅하였다. 원자 힘 현미경으로 관찰한 결과 GQDs 박막이 매우 균일하게 형성되었음을 확인할 수 있었다. 이어서, 화학 기상 증착법에 의해 제작된 단층 그래핀을 GQDs 박막 위에 전사하였다. 532 nm 파장의 레이저를 이용하여 라만 스펙트럼을 측정하고, 그래핀과 관련된 G ($\sim 1580 \text{ cm}^{-1}$) 및 2D ($\sim 2780 \text{ cm}^{-1}$) 라만 peak가 관찰되었다. 최종적으로, 그래핀/GQDs/SQDs/Si 구조의 광 검출기를 제작하고 특성을 평가하였다. GQDs 존재 유,무에 따른 광검출기의 성능을 평가한 결과 GQDs 중간층이 존재하는 소자에서 모든 파라미터가 높았다. 이러한 결과는 GQDs 중간층이 SQDs와 그래핀 층 사이에서 전하 재결합을 감소시켜 소자의 성능을 향상시킨 것이라 판단된다. 본 연구에서는 실험적인 결과들을 토대로 GQDs중간층에 의한 광검출기 성능 메커니즘을 규명하고자 한다.

Keywords:

그래핀, 그래핀 양자점, 실리콘 양자점, 광검출기

Heterocyclic compound-assisted antisolvent strategy for fabricating low defects CsFAMA Perovskite solar cells

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Abstract:

In this work, we introduce a new strategy to enhance photovoltaic performance and passivate the defect of CsFAMA perovskite solar cell by mix the anti-solvent with a heterocyclic compound. Generally, the fabricating hybrid perovskite will come with cracks on the surface of the absorbent layer, which can bring defects or even short circuits during working. With this optimization, the power conversion efficiency of the champion device was improved from 16.14% to 19.26%. The crack visible to the naked eye was reduced significantly and the defects inside were passivated. Because of less defects of perovskite, the stability of solar cells was improved at the same time. This strategy will be a commercially benefited way to improve the performance.

Keywords:

perovskite solar cells, passivation of defects, anti-solvent

에너지 하베스팅을 위한 동축 InGaN/GaN 나노와이어의 압전 특성 연구

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Abstract:

에너지 하베스팅이란 외부로부터 전원 없이 스스로 주위 환경으로부터 받은 에너지를 전기에너지로 바꾸어 생산 저장하는 것을 말한다. 이러한 방식은 외부로부터 전원을 필요로 하지 않아 고립된 공간에 활용이 가능하고 자발적으로 주위의 에너지를 전기에너지로 변환 생산하기 때문에 화석연료를 사용하지 않아 다양한 환경과 장소에서 친환경적으로 적용이 가능하다. 본 연구에서는 GaN nanowire와 GaN/InGaN coaxial 구조의 압전 특성을 비교하기 위해 총 3개의 샘플을 성장시켰다. Core nanowire는 6000초 GaN/InGaN coaxial 구조에서 InGaN은 각각 1500초 750초로 성장되었다. 그리고 나노와이어 보호를 위해 PDMS 증착 후 소자화 하여 압전특성을 비교하였다. 50g 분동으로 탭핑하여 압전을 측정하였으며 GaN nanowire는 4V, 750초동안 InGaN이 성장된 소자는 2V 1500초 성장된 소자는 1.5V 전압값을 보였다. 전류 값은 180uA, 20uA, 10uA정도의 값을 확인하였다. GaN/InGaN coaxial 구조에서 InGaN의 양이 더 많을수록 압전 특성이 낮아짐을 확인 하였다.

Keywords:

InGaN, nanowire, piezoelectric, nanogenerator

Molybdenum Disulfide Ferroelectric Field-effect Transistors on A Series of HfZrO₂ and Al₂O₃

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Abstract:

Subthreshold swing (SS) of conventional metal-oxide semiconductor field effect transistors (MOSFET) have been limited to the 60 mV/dec by the thermionic limitation of Boltzmann tyranny. To overcome the limitation, various approaches have been studied such as ferroelectric based field effect transistors by using a negative capacitance. Several papers show the possibility the ferroelectric field effect transistors can be overcome transistor performance such as low power consumption, high I_{on}/I_{off} ratio, under 60 mV/dec and so on. In this study, we fabricated molybdenum disulfide channel based ferroelectric (HfZrO₂) transistor with and without dielectric layer (Al₂O₃) for the comprehensive understanding of the physics underlying the system.

It is confirmed that sudden current change appear where ferroelectric switching occurs in a structure without dielectric layer, and transistor performance changed according to the amount of polarization switching. In addition, from the structure with dielectric layer, the subthreshold switching less than 60 mV/dec without hysteresis behavior were observed.

Keywords:

Ferroelectrics, HfZrO₂, NCFET, FEFET

Improving Coupling Ratio in 3D Flash Memory with optimal thickness and Oxide – high-k material – Oxide cylindrical structure

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Abstract:

There has been continuous major technological innovation and development in the minor field of Nand flash memory. This has been attributed to by the effective trapping of electrons in the floating gate layer of the threedimensional structure model of flash memory. The existing flash memory structure has a sequence of ONO deposited between the floating gate and the control gate. The role of increasing gate capacitance between the floating gate and control gate is done by the nitride material while the role of handling back tunneling is done by the oxide layer. Despite efforts by engineers to keep reducing the flash device size, setbacks such as leakage and need to trap electrons for a longer period has been our motivation to conduct this research. We looked into the electrical properties of blocking oxide materials which are pertinent to the formation of an effective conductive channel below the gate. Initially, we started off with a simulated search for an appropriate thickness of the nitride material within the ONO(Oxide-Nitride-Oxide) structure in between the floating gate and the control gate, we moved on to simulate interchangeably with high-k materials such as TiO₂, Si₃N₄ and HfO₂ with the aim to better the value of the coupling ratio. We performed our simulations via the Atlas software by TCAD. The results from our simulations show better coupling ratio as well as improved charge mobility.

Keywords:

IGZO 터널접합 박막트랜지스터의 제조 및 특성 분석

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Abstract:

Tunnel 접합 박막트랜지스터(TFT)는 일반 TFT에 비해 낮은 Drain bias에서도 Saturation region에 도달하며, 높은 Gain과 낮은 소비전력, 가파른 문턱전압이하특성을 보여 차세대 소자로 각광받고 있다. 이러한 Tunnel접합 TFT를 보다 잘 이해하고 널리 활용하는데 있어, 다양한 Tunnel 접합의 물리적 특성을 분석하고 이러한 특성이 소자 성능과 어떻게 연결되는지에 대한 연구가 선행되어야 한다.

이번 실험에서는 다양한 물질과 두께로 구성된 tunnel 접합을 가지는 Indium Gallium Zinc Oxide (IGZO) tunneling TFT를 제조하고 그 특성을 조사하였다. Tunnel 장벽을 이루는 물질로 Radiofrequency (RF) sputter로 증착한 Al₂O₃와 a-BN을 이용하였다. Threshold voltage, I_{max}/I_{min} 비, Subthreshold slope, Gain 같은 device의 특성이 장벽의 물질, 두께, 전극 구조에 따라 어떻게 변화하는지 상세히 분석하였다. 이번 실험은 Tunnel 접합 TFT 기반 scalable electronic system 개발에 기반을 제공하며, 디스플레이, 센서, 커뮤니케이터 같은 다목적 애플리케이션에 널리 응용되리라 예상한다.

Keywords:

IGZO, Tunnel 접합 박막트랜지스터

스퍼터링 공법으로 제조된 AlOx박막을 Charge trap layer로 이용하는 뉴로모픽 트랜지스터

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Abstract:

인간의 뇌 속 신경세포는 시냅스의 연결을 통해 정보의 기억과 연산을 병렬적으로 처리하는 특징이 있다. 이러한 신경세포의 동작 방식을 모사한 소자를 뉴로모픽(neuromorphic) 소자라고 하는데, 이 뉴로모픽 소자를 이용하면 기억과 연산을 동시에 수행하지 못하는 기존의 트랜지스터를 대체해 저전력으로 더 복잡한 정보를 처리할 수 있으리라 기대된다. 따라서 뉴로모픽 소자는 대량의 연산을 저전력으로 수행해야 하는 인공지능, 모바일 컴퓨팅 등에 널리 응용되리라 예상하고 있다.

본 연구에서는 RF 스퍼터링 공법으로 증착한 AlOx 층이 charge trap layer로 작용하는 Indium gallium zinc oxide(IGZO) 뉴로모픽 트랜지스터의 제조 및 이의 특성에 대해 다룬다. 본 소자는 게이트 전극에 인가한 전압 펄스가 AlOx film의 charge trap을 충전 혹은 방전하여, trap내 갇힌 전자가 채널의 전류를 조절하는 방식으로 동작한다. 본 소자에서 생물학적 시냅스의 주요 활동인 postsynaptic 전류에서의 흥분 혹은 억제 (EPSC/IPSC), 쌍 pulse에 의한 facilitation (PPF), short term potentiation & depression과 같은 특성이 잘 구현됨을 자세히 분석하였다. 스퍼터링 공법에 기초한 본 뉴로모픽 트랜지스터 연구는 향후 웨이퍼 크기에서 저비용으로 뉴로모픽 소자를 양산할 수 있는 기술적 기초를 제공한다.

Keywords:

RF sputtering, Synaptic transistor, Neuromorphic Transistor, Charge trap layer

Bi_xSe_{1-x} Topological Insulator 기반 CoFeB/MgO Magnetic Tunneling Junction의 High Perpendicular Magnetic Anisotropy를 위한 Diffusion Barrier 물질(TiN, Ta, W) 비교

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Abstract:

정보통신기술의 발달과 함께 등장한 빅데이터, 소셜 네트워크, 사물 인터넷(IoT) 등의 기술로 인해 생성되는 정보의 양이 기하급수적으로 증가하고 있는 상황에서, 다량의 데이터를 빠르게 처리할 수 있는 초저전력 초고속 소자의 개발은 필수적이라 할 수 있다[1]. 이에 따라 등장한 차세대 소자 중, spin transfer torque magnetic random access memory(STT-MRAM)은 read/write current의 path가 동일하여 reading 도중 원치 않는 writing이 일어나는 문제점이 있을 뿐 아니라, large writing current density를 위해 tunnel barrier를 매우 얇게 만들어야 하는 제약 조건이 있었다. Spin-orbit-torque magnetic random access memory(SOT-MRAM)은 STT-MRAM과 동일한 reading mechanism을 가지고, writing current가 storage layer의 plane한 방향으로 인가되므로 read/write path를 분리시킴으로써 STT-MRAM의 문제점을 해결하고, 186ps의 low latency 뿐 아니라, power consumption도 약 3배 줄이는 효과를 얻을 수 있기에 그 중요성이 더욱 강조되고 있다[2].

SOT-MRAM의 MTJ 구조에서 non-magnetic layer(NM)에 Bi_xSe_{1-x}과 같은 Topological Insulator(TI)를 활용 시 Spin Torque Efficiency(θ^{eff})가 in-plane magnetic tunneling junction (MTJ) 구조에서 18.62로 높은 값을 보이는 선행 연구결과가 있었다[3]. 하지만 고집적화를 위한 SOT-MRAM의 수직 나노 스케일 다운을 위해서는 perpendicular magnetic tunneling junction (pMTJ) 구조가 필수적이므로 본 연구팀은 Bi_xSe_{1-x} TI 기반 CoFeB/MgO의 perpendicular magnetic anisotropy (PMA)를 형성하기 위한 최적의 diffusion barrier 물질(TiN, Ta, W) 탐구를 진행하였다.

이 연구에서는 X-Ray diffraction(XRD)를 사용하여 Bi_xSe_{1-x}의 결정성을 확인하였고, 초고진공 (1×10^{11}) 12-inch magnetron multi chamber sputter를 활용하여 SiO₂ sub/MgO/Bi_xSe_{1-x}/diffusion barrier(TiN, Ta, W)/CoFeB/MgO/W 구조를 직접 제작하고 vibrating sample magnetometer (VSM)을 사용하여 PMA 특성을 확인하였다. 분석 결과, TiN은 15.685 μemu , Ta는 4.129 μemu , W은 15.113 μemu 로 diffusion barrier로 TiN을 사용 시 가장 큰 M_s 값을 확보할 수 있음을 확인했다. 자세한 설명은 이어지는 포스터에서 확인할 수 있다.

Reference

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- [3] Mahendra DC, *et al.*, "Room-temperature high spin-orbit torque due to quantum confinement in sputtered Bi_xSe_(1-x) films", Nature Materials. **17**, 800-807 (2018)

Keywords:

SOT-MRAM, Diffusion barrier, Perpendicular magnetic anisotropy

Optimization of the annealing temperature and thickness of a TaO_x based Resistive-Random-Access-Memory

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Abstract:

With the rapid development of artificial intelligence (AI), devices with high operating speed, good reliability, and low power consumption are required. In this situation, ReRAM is widely studied as a next-generation memory. Not only does ReRAM have a simple structure, but it can also increase the density while reducing sneak current through 3D arrays and crossbars. This allows it to have a higher operating speed, lower power consumption, and better reliability. In this study, the conditions for optimal performance were researched by measuring the electrical properties while varying the thickness of TaO_x and annealing temperature. We used a wafer that already patterned a 218 nm size plug type TiN bottom electrode. After patterning by photolithography, the resistive switching layer, TaO_x, metal source layer, Ag, and top electrode, Pt were deposited by RF and DC magnetron sputter. We first investigated the dependency of TaO_x thickness by varying it from 2.5 nm to 7.5 nm. As the thickness increased, the on/off ratio increased from 1.71×10^2 to 1.55×10^6 . When the thickness of TaO_x was 7.5 nm, the device showed the largest on/off ratio. The dependency of annealing temperature on device characteristics was also researched. The device was annealed at 200 °C and 400 °C after the device structure was fabricated. It was confirmed that the number of cycles of devices with all thickness conditions increased more than 5 times. In particular, when the TaO_x thickness was 5 nm and the annealing temperature 200 °C, the device showed the best reliability with the memory characteristics 1.6 V of V_{forming} and 1.7 V of V_{set} .

Keywords:

TaO_x, ReRAM, CBRAM

CVD 단일공정에 의한 2차원 Janus MoSSe 단결정 증착 및 열처리에 의한 성장 메커니즘 규명

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Abstract:

새로운 2차원 Janus dichalcogenide 물질은 최근 초전도, Weyl Fermion, exciton, 및 Valleytronics 관련한 새로운 양자 현상의 발현으로 매우 높은 관심을 받고 있으나 많은 학문적/기술적 가치에도 불구하고 그 제작방법이 까다로워 단 두 가지의 합성법만이 알려져 있었다. [1] 두 방법 모두 여러가지 공정 단계가 필요하며, 특히 고온 공정을 필요로 해서 양질의 단결정 시료를 얻기가 힘들었다. 이러한 한계점을 해결하고자, 본 연구에서는 공정 과정을 비약적으로 단순화시켜 공정 전/후 처리 없이 단일 CVD 공정을 통해 야누스 MoSSe를 합성하는데 성공하였다. 이것은 세밀한 온도 조정으로 가능하였는데, 두 단계의 온도 조절로 chalcogen 원소인 S와 Se을 차례로 활성화시킴으로써 야누스 MoSSe 단결정 성장이 가능하였다. 이러한 과정은 이미 알려진 MoS₂가 열처리 과정 중에 Mo-S 결합 구조의 붕괴로 황 원소를 잃어버린다는 선행 연구를 통해, 황 원소가 있던 자리에 Se 원소가 치환되는 성장 메커니즘으로 확인된 바 있다. [2] 또한, 각 과정 중에서 Mo과 Se의 높은 녹는점을 소금을 이용하여 낮춰서 고온으로 발생하는 문제점을 해결하였으며, 수직 대칭 구조의 MoS₂에서 윗부분의 S만이 Se으로 바뀌어 비대칭의 SeMoS 구조인 단결정 Janus 물질로 변환되었다는 것을 제작한 Janus MoSSe의 구조적 및 광학적 특성을 라만 산란, 광루미네선스, 시간 분해 광루미네선스, 그리고 AFM으로 분석함으로써 규명하였다.

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Keywords:

Janus, 2차원 물질, MoSSe, CVD

Carrier Transport Mechanism in Transition Metal Dichalcogenides hetero-junction

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Abstract:

Transition metal dichalcogenides (TMD)는 적절한 밴드갭, flexible, transparent 등 다양한 장점이 있어 heterojunction application 제작에 주로 사용된다. 이종접합의 계면에서 전하 주입 메커니즘을 분석하는 것은 소자의 특성을 향상시키는데 중요한 역할을 한다. 최근, TMD heterojunction에서 Field emission (FE) 이 계면에서 전류 흐름을 제어하는 것이 보고되었다. 하지만, FE가 potential barrier height와 applied field, 온도와 밀접한 관계를 맺고 있음에도 불구하고 이들의 상관관계에 관한 연구는 아직 미비하다. 이러한 이유로 이 연구에서는 접합부의 전하 주입 메커니즘을 명확히 규명하기 위해 온도와 applied field, potential barrier height를 매개변수로 전하 주입 메커니즘을 분석했다. 이 결과는 TMD heterojunction application의 전하 수송 메커니즘에 대한 통찰력뿐만 아니라 소자의 성능을 향상시킬 수 있는 확장성을 제공한다.

Keywords:

transition metal dichalcogenide, staggered heterojunction, built-in potential, thermionic emission, Fowler-Nordheim tunneling

Fabrication and characterization of hybrid heterostructures consisting of MoS₂ monolayers and fluorescent organic molecules

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Abstract:

Two-dimensional transition metal dichalcogenides (TMDs) can have sizable bandgap energy (1.2~1.8 eV) corresponding to visible and infrared range, and hence they can be candidates to realize novel optoelectronic devices. Organic semiconductors have distinct physical properties compared with inorganic counterparts: large binding energy of excitons, flexibility, and low dielectric constant. In this work, newly-developed p-conjugated organic molecules, named DY1, were integrated with MoS₂ monolayers grown on quartz substrates. We investigated photoluminescence (PL) characteristics of the DY1/MoS₂ hybrid heterostructures. The micro-PL measurements showed that the MoS₂ monolayers could modify the spectra and reduce the intensity of the PL emission from DY1. The emission lifetime at the DY1/MoS₂ was larger than that of bare DY1. Spatially-resolved surface potential maps were obtained using Kelvin probe microscopy, which allowed us to study light-induced charging at local region. In the presentation, we will discuss the energy and charge transfer processes at the DY1/MoS₂ organic/inorganic heterointerfaces, based on the experimental results.

Keywords:

MoS₂, Organic, Charge transfer, Energy transfer

Electrically Controllable Neuromodulation Emulated by 2D Weight-Tunable Memristor for Neuromorphic Application

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Abstract:

Two-dimensional (2D) semiconductors have emerged as a promising material for low-power and high-performance electronics because of the intrinsic atomic thickness and the exceptional properties maintaining even with ultimate scaling. Besides, the competitive ability to electrostatically control the electrochemical potential allows us to design band-modulated 2D heterostructures for implementing a variety of gate-tunable electronic devices. Such a unique capability of 2D materials can also offer great potential for realizing an energy-efficient artificial synapse with high controllability. Nevertheless, the artificial synapse utilizing functionally unique properties has rarely been demonstrated, as appropriate materials and structures with robust memristive switching characteristics and an adequately integrated device architecture are not available.

Here, we report a functionally advanced artificial synaptic architecture, a three-terminal device consisting of a defect-controlled molybdenum disulfide (MoS₂) memristor on hexagonal boron nitride (*h*-BN), termed as a 'weight tunable memristor'. Through the precise defect control of MoS₂ channel, the device exhibits low power switching phenomena even without applying gate voltages, which cannot be implemented in previously reported memtransistors utilizing gate dielectric as a pre-synaptic component. One more step, owing to the electrostatically controlled space charge limited current in the ultrathin channel, the device exhibits gate-controlled memristive switching characteristics. The device can implement essential synaptic characteristics, such as short-term plasticity and long-term plasticity. Notably, by electrostatic tuning with a gate terminal, we can additionally regulate the degree and tuning rate of the synaptic weight independent of the programming impulses from source and drain terminals, with sub-1 fJ pulse input. Moreover, the changed states are within stable region for 1500 consecutive pulses. These capabilities eventually enable the accelerated consolidation and conversion of synaptic plasticity, functionally analogous to the synapse with an additional neuromodulator in biological neural networks. Furthermore, such acceleration improves the recognizing accuracy and reduces learning step in MNIST pattern recognition, with considerable power-saving benefits. Our demonstration represents an important step toward highly networked and energy-efficient neuromorphic electronics.

Keywords:

2d materials, memristor, artificial synapses, neuromorphic application

임피던스 바이오센서를 이용한 NIH 3T3 세포의 센서 점유 면적과 성장에 따른 커패시턴스 분석

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Abstract:

임피던스 바이오센서를 이용하여 NIH 3T3 세포의 성장을 관찰한 선행 연구의 결과에서 세포의 성장 전반부와 후반부에 커패시턴스 증가 폭의 차이가 있음을 확인하였다. 따라서 본 논문에서는 그 차이를 분석하기 위한 연구를 진행하였다. NanoEnTek의 JuLI™ Br 현미경을 통하여 실시간으로 측정된 이미지로 전반부와 후반부의 세포 개수 변화를 관찰하였고, 그 결과를 측정된 커패시턴스와 비교하여 세포 한 개당 커패시턴스를 확인하였다. 전반부는 세포를 시딩한 직후 배지에 떠있던 세포가 센서의 표면 위로 가라앉으면서 커패시턴스가 측정되었고, 후반부에서는 가라앉은 세포가 성장하고 분열하는 과정에서 측정되었다. 이로써 대략적인 세포 하나의 커패시턴스 값을 제시하였으며, 전체적으로 세포의 개수가 증가함에 따라 측정되는 커패시턴스가 선형적으로 증가하는 것으로 보아 세포의 병렬 배치가 지배적이라는 것을 확인하였다.

Keywords:

NIH 3T3 cell, Impedance biosensor, Microscope cell image, One cell's capacitance

NIH 3T3 Cell을 사용한 임피던스 바이오센서의 Pattern width와 spacing size에 따른 주파수 의존도

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Abstract:

본 연구는 NIH-3T3 세포의 성장 및 사멸과정을 실시간으로 모니터링 할 수 있는 임피던스 바이오센서를 반도체공정을 통하여 제작하였다. 실험에 사용된 pattern width와 spacing의 크기는 300 μm 이며, 먼저 300 μm 의 바이오센서로 기초 실험을 하였다. 그 후 168 μm , 211 μm , 518 μm 의 width와 spacing을 갖는 pattern을 직접 제작하여 pattern width와 spacing 크기에 따른 주파수 의존도를 확인하였다.

Capacitance-Frequency와 Capacitance-Time 데이터를 측정하여 각 센서의 크기에 따른 가장 민감한 주파수 영역대와 이에 해당하는 Capacitance-Time 데이터와 그 범위 외의 데이터를 비교할 수 있었다. 그 결과 패턴의 width와 spacing이 감소할수록 낮은 주파수 영역대에서 민감하다는 것을 확인하였다. 본 연구는 전기 임피던스 측정시 민감도 주파수 영역에 적합한 pattern의 width와 spacing size 설계의 필요성을 제시한다.

Keywords:

frequency dependence, pattern spacing, width, impedance bio-sensor, NIH 3T3 cell

고등학생의 과학실험 그래프 작성 오류 유형 분석 및 개선을 위한 수업 개발

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Abstract:

이 연구에서는 고등학생들의 물리학 실험에서 나타나는 그래프 작성의 오류를 검사하고 이를 개선하기 위한 수업을 설계하였다. 우선, 고등학생을 대상으로 실시했던 수행평가에서 드러난 그래프 작성 오류들을 자주 발견되는 5가지 유형으로 정리하였고, 이 오류들을 잡아낼 수 있는 검사지를 개발하여 고등학교 2학년 111명을 대상으로 그래프 작성 검사를 실시하였다. 검사 결과, 검사 전 예상된 유형의 오류 외에도 3가지 유형이 추가로 발견되었다. 실험을 통해 이론이 만들어지는 과정이 '실험, 그래프, 보다 자세한 실험과 그래프, 이론' 순으로 이뤄진다고 볼 때, 발견된 오류들은 다음과 같이 (1) 실험자료를 그래프로 옮기지 못하는 경우, (2) 실험자료를 옮긴 그래프의 활용도가 낮은 경우, (3) 추가실험 없이 보다 자세한 그래프를 얻으려 하는 경우, (4) 이론에서 그래프로 옮기려 하는 경우의 4가지 범주로 분류할 수 있었다. 우리의 오류 유형 분석 방식은 그래프 작성능력 검사로 잘 알려진 TOGS의 9가지 평가목표들에도 잘 적용되며 평가목표들을 효과적으로 분류할 수 있었다. 위와 같은 분석을 바탕으로, 고등학생의 과학실험 그래프 작성 능력을 개선하기 위한 수업을 개발하였다.

Keywords:

graph construction, science achievement level

일반물리학 온라인 문제 출제를 위한 변수 랜덤화 플랫폼 개발

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Abstract:

코로나19로 인한 언컨택트 시대의 도래에 맞춰 비대면 교육을 효과적으로 수행하기 위한 인프라 구축이 중요해지고 있다. 이에 따라 본 연구에서는 온라인 환경에서 시험 출제 및 평가를 효과적으로 수행할 수 있는 물리 교육용 플랫폼을 개발하였다. 이 플랫폼에서 교수자는 사전 저장된 문제은행에서 출제할 문항을 선택하고 시험일시와 시간 등의 정보를 입력하여 온라인 시험을 구성할 수 있다. 그러면 문제 내에 제시된 숫자, 문항의 출제 순서 그리고 문항별 보기 순서와 같은 시험지의 변수들이 랜덤하게 바뀌어 각 학생에게 출제된다. 온라인 상으로 제출된 학생들의 답안지는 자동으로 채점되고 각 문항의 오답 통계 정보도 기록된다. 본 플랫폼은 사용자의 유연성을 위해 숫자 및 문자형 해답에 대한 선다형 객관식 문제뿐만 아니라 단답형 문제도 출제할 수 있도록 설계되었다. 본 플랫폼을 사용한 비대면 평가 상황에서 학생 부정 행위 감소, 교수자의 문제 출제 및 시험 감독 부담 완화, 채점과 등급 부여에 소요되는 시간을 크게 줄일 수 있는 장점이 있다. 또한 데스크탑 뿐만 아니라 모바일 환경에서도 사용이 가능하도록 설계하여 장소에 구애받지 않는 사용 편의성도 높였다. 우리는 이 온라인 기반 플랫폼이 학생들의 물리 학습을 능률적으로 향상시키고 효과적으로 평가하는데 기여할 것으로 기대한다.

Keywords:

물리교육, 일반물리학, 변수 랜덤화 플랫폼, 온라인 시험, 비대면 평가

공과대학 신입생들의 물리교육에 관한 인식(II) - 충청지역 국립대학교 2021학년도 입학생을 중심으로 - (A Study on the Perception of Physical Education in Freshman Students of Engineering College(II))

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Abstract:

충청지역에 소재한 3개 국립대학교 2021학년도 공과대학 신입생들의 물리교육에 대한 인식을 조사하여 2020학년도 자료와 비교하였다. 연구내용은 고등학교에서의 물리교육 및 대학에서의 물리실험에 대한 인식 정도를 조사하였다. 연구방법은 설문지를 제작하여 강의 담당교수가 투여한 후 회수하여 분석하였다. 분석결과 고등학교에서 자연계열을 이수한 현황은 95 %로 전년도와 비슷하였다. 특히 C대학은 자연계열을 이수한 현황이 98 %로 지난 13년 동안 31 % 증가하였다. 자연계열을 이수한 학생자 중에서 물리학 I 과 물리학 II 모두를 공부한 학생은 37%로 전년도에 비해 4 % 증가하였다. A와 C대학은 지난해에 비해 8 % 증가하였으나 B대학은 오히려 5 % 감소하였다. 이수한 물리학 I 과 물리학 II를 아주 잘 이해하고 있다는 응답은 7 %로 아주 저조하였으며, 고등학교에서 물리실험은 거의 이루어지지 않은 것으로 조사되었다. 응답자의 97%가 물리학이 공과대학에서 전공이수에 중요한 기초 교과로 인식하고 있었다. 2021학년도 1 학기 3개 대학 모두 대면실험을 실시하였는데 실험내용에 대해 어느 정도 이해하고 있다는 응답은 58 %로 지난해에 비해 15 % 증가하였다. 실험을 위한 준비상황은 74 %가 비교적 잘 되었다고 응답하였다. 특히 C대학의 준비상황은 94 %로 아주 월등히 높았다. 이 연구를 통하여 공과대학 신입생들의 물리교육에 대한 인식의 단면을 파악할 수 있었다.

Keywords:

물리교육, 물리학 I, 물리학 II, 공학교육인증, 일반물리학 및 실험

2차원에서 두 물체의 충돌 현상에 대한 정량적 분석 (Quantitative Analysis of Two Objects Collision in Two Dimensions)

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Abstract:

두 물체가 2차원에서 충돌할 때 충돌 전후 운동량과 운동에너지 보존 관계를 정량적으로 조사하였다. 2차원 충돌장치의 구름대를 굴러 내려오는 입사구와 지지대 위에 정지한 표적구를 충돌시켜 속도벡터와 환산질량의 개념을 도입하여 해석하였다. 그 결과 2차원 충돌 현상을 벡터의 합성으로 편리하게 해석할 수 있었으며, 강철구와 강철구 그리고 강철구와 유리구 사이의 충돌 현상은 근사적으로 탄성충돌임을 알 수 있었다. 그리고 실험장치의 개선을 통하여 오차를 감소시킬 수 있음을 확인하였다.

Keywords:

2차원 충돌, 속도벡터, 운동량벡터, 탄성충돌, 환산질량

다공성실리콘 광발광의 박막내 간섭효과와 기체 감응 특성을 이용한 프로젝트 중심의 물리 교육 주제 개발

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Abstract:

최근 대학생들의 프로젝트 실험 중심 수업이 새롭게 도입되고 있다. 이를 위해서는 학생들 스스로 실험 데이터를 획득하고 해석하며 결과보고서를 제출하는 일련의 훈련 과정이 필요하다. 또한 성공적인 프로젝트 실험을 진행하기 위해서는 적절한 실험주제의 제시가 필요하다.

본 연구는 그러한 프로젝트 실험에 제시할 수 있는 다공성실리콘 광발광의 간섭 현상과 관련 기체 감응 특성 실험에 대한 물리 교육적 측면에서의 주제 적합성을 다룬다.

다공성실리콘은 규소기판을 불화수소 용액 속에서 에칭하여 제작된다. 제작된 다공성실리콘은 약 500-900 nm 범위에 걸쳐 광발광을 방출한다. 이때 광발광 스펙트럼에서는 박막의 두께에 따른 특유의 간섭무늬가 나타나게 된다. 그리고 다공성실리콘에 유기증기를 노출시켰을 때 광발광 강도의 변화가 일어나는 센서 감응 특성을 갖는다는 것은 잘 알려져 있다.

이에 따라 다공성실리콘으로부터 분광기를 이용한 PL 스펙트럼 측정, 박막의 반사스펙트럼 측정, 유기증기에 따른 PL 강도의 변화를 직접 측정하고 컴퓨터 시뮬레이션을 통해 결과를 해석하는 프로젝트 실험 교육 내용의 개발이 가능할 것으로 사료된다.

대학생에 대한 이론중심의 교육을 벗어나 프로젝트 중심의 물리교육을 도입하기 위한 다양한 실험주제 및 관련 교육자료의 개발과 공유가 더욱 필요하다.

Keywords:

다공성실리콘, 간섭현상, 광발광, 물리교육, 프로젝트 중심 실험 수업

Delivery of Quantum Insights through Optical Experiments

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Abstract:

Clauser, Horne, Shimony, and Holt have devised an alternative form of Bell's inequality that is more amenable to experiments. We designed and performed an optical experiment to show this CHSH inequality indeed breaks down, using polarization-entangled photon pairs generated by spontaneous parametric down-conversion (SPDC) from a BBO crystal, which was very successful ($S = 2.43 \pm 0.03$). We also experimentally proved the existence of photons (light quanta) by measuring the correlation between light signals after a polarizing beam splitter (PBS). Although these experiments can be easily performed by undergraduate or even high school students without too much difficulty, it is a tough job to deliver the deep insights these experimental results contain in the context of quantum mechanics. We discuss how the Bell's argument relates this simple experimental setup with locality and reality, and why we should be truly surprised to see this specific experimental outcome.

Keywords:

Bell's Inequality, SPDC, Entanglement, Quantum Mechanics

대한민국 방사광가속기 도입 30주년 기념 특별전시를 위한 기획연구

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Abstract:

코로나 백신 연구와 같은 신약제조, 배터리 고효율을 위한 고분자 물질 촉매 연구, 반도체 제조 등 기초과학이나 응용과학에 이르기까지 미시세계(원자나 분자 수준)의 연구를 위해서는 방사광가속기라는 빛을 만들어 낼 수 있는 장비가 필수적이다. 우리나라는 포항이라는 도시에 방사광가속기 건설을 추진하여 국내 거대과학 최초의 성공적인 성과를 보였다. 2024년은 대한민국 최초 방사광가속기를 도입하고 첫 시험가동을 한지 30주년이 되는대로 그 의미가 매우 크다고 할 수 있다. 그리고 곧 완공 예정인 중이온가속기(대전)와 건설 확정된 다목적 방사광가속기(청주)에 거대 예산이 투입된 만큼 국민과의 공감대 형성이 필요하다고 할 수 있다. 이를 기념하고 국민들에게 가속기에 대한 이해와 기초과학의 중요성을 공유하기 위한 특별전시를 준비하기 위한 연구를 진행하였다. 포항방사광가속기에 대한 역사를 재조명하고 관람객들에게는 방사광가속기의 원리를 쉽게 이해할 수 있는 전시품을 제작 전시하여 체험할 수 있도록 하고자 한다.

Keywords:

포항방사광가속기, PAL, 30주년, 가속기, 전시기획