台韓雙邊凝態物理交流研討會

The 5th Korea-Taiwan joint workshop

Time: 113 年 1 月 25 日 14:00 – 17:30

Location: 中央大學 健雄館 S4-204(2F)

Chairs: Ya-Ju Lee and Ting-Hua Lu

No.	Time	Speaker	Title of Talk
	14:00–14:05	Opening Remarks: **Prof. Jong Su Kim** and Chih-Wei Luo	
1	14:05–14:25	**Prof. Hongseok Oh**	Fabrication and characterization of photonic synapse devices using ZnO thin films and nanostructures
2	14:25–14:45	Prof. Chi Chen	Near-field optical imaging of local band shifts in WS_2/MoS_2 heterojunction and $W_xMo_{1-x}S_2$ alloy
3	14:45–15:05	**Prof. Jeongyong Kim**	Enhanced optical properties of interfaced quantum semiconductors
4	15:05–15:25	Prof. Chung-Hou Chung	Quantum criticality in semiconductor quantum dots
5	15:25–15:45	**Prof. Mun Seok Jeong**	Studying 2D nanomaterials using Tip-Enhanced Raman Scattering
	15:45–15:50	Break	
6	15:50–16:10	Prof. Cheng-Maw Cheng	Topological phase transition in Sn single layer from stanene to beta-Sn
7	16:10–16:30	**Prof. Jung Hwa Seo**	Interface physics on organic and perovskite optoelectronic devices
8	16:30–16:50	Prof. Yi-Ying Lu	Exploring surface and interface properties of semiconductors via photoemission spectroscopy
9	16:50–17:10	**Prof. Seong Chu Lim**	Weyl Semiconductor 2D Te
10	17:10–17:30	Prof. Shao-Yu Chen	Efficient photon upconversion in atomically thin two-dimensional semiconductors via dark excitons
	17:30–17:35	Closing Remarks	

[1]

Fabrication and characterization of photonic synapse devices using ZnO thin films and nanostructures

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Abstract: We report the fabrication of flexible photonic synapses using ZnO thin films and nanostructures. First, ZnO thin film transistors (TFTs) were fabricated and characterized, where the channel is deposited by radio-frequency (RF) magnetron sputtering method. Fabricated devices not only exhibited basic signal switching characteristics, but also demonstrated excellent synaptic response upon the light-pulse illumination. Notably, we observed excellent linearity during the potentiation process, underscoring their significant potential for applications in artificial neural networks.

Furthermore, we explored the applicability of ZnO nanostructures in photonic synapses ZnO nanotubes, with controlled position and morphology, were heteroepitaxially grown on graphene layers and then formed into Schottky diode structure. I-V characterizations were conducted under various illumination conditions, along with characterizations of temperature-dependent transient photocurrent. The study revealed the persistent photoconductivity (PPC) property which can be attributed to defects caused by oxygen vacancies. Additionally, upon light-pulse applications, these nanostructures exhibited excellent synaptic properties, including excitatory post synaptic currents (EPSC), paired pulse facilitations (PPF), etc. We observed highly linear potentiation-depression characteristics that can be reproduced over 1,000 cycles, demonstrating excellent controllability in the long-term memory region. Thanks to the graphene substrates and vertical device structure, the device exhibited reliable performance even under different bending conditions. This resilience is important for applications in mobile and wearable sensor applications.

Keywords: Photonic synapses, ZnO, artificial intelligence

[2]

Near-Field Optical Imaging of Local Band Shifts in WS_2/MoS_2 Heterojunction and $W_xMo_{1-x}S_2$ Alloy

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Abstract: With the development of advanced chemical vapor deposition (CVD) methods, many artificial 2D semiconductors have been synthesized, which increase the chances of forming disrupted interfaces and nonperiodic or small-sized units (defects and grain boundaries). All such units create local electronic band structures within a finite scale, which cannot be readily explained by solid-state band theory or probed easily using confocal microscopes. We employed near-field photoluminescence (NF-PL) to study the atomically sharp 1D interfaces between WS_2 and MoS_2. With an optical resolution of 68 nm, a 105 nm-wide region for quenched PL was confirmed using NF-PL imaging, which resolved the narrowest quenching width because of the superior spatial resolution and stability of our home-built SNOM instrument. We further developed the near-field broadband absorption (NF-abs or transmission, NF-tr) technique for low-quantum-yield materials. The varying bandgap and bowing factor of a single-layered $W_xMo_{1-x}S_2$ alloy were revealed by NF-tr microscopy. For the bilayer alloy, the bandgap evolution demonstrated the complicated coupling effect between the top and bottom layers. The NF-tr technique provides abbreviation-free and nanoscale-resolution imaging capabilities of the entire conduction band over a highly lateral inhomogeneity.

Keywords: Near-Field Optics, 2D semiconductors, WS_2, MoS_2, alloy.

[3]

Enhanced optical properties of interfaced quantum semiconductors

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Abstract: Quantum semiconductors, characterized by their unique quantum confinement effects, offer remarkable possibilities for tailoring the optical properties at the nanoscale. While two-dimensional (2D) semiconductors and quantum dots (QDs) offer exciting exciton properties [1,2], the hybridization of these quantum semiconductors can provide the further enhanced optical properties that are not achievable by single-element quantum materials. In this presentaion, I will discuss the recent progress of our group on synthesizing MXene QDs [3] and how they can contribute to enhancing the UV response and quantum yield (QY) of monolayer transition metal dichalcogenides (TMDs) by interfacing with 2D semiconductors [4]. As a 2D/2D hybrid configuration, we show that fine tuning of exciton properties of ReS_2 can be achieved by vdW twist angle of stacked ReS_2 [5]. I will also discuss the use of machine learning to predict QY of monolayer WS_2 [6].

Keywords: 2D materials, MXene quantum dots, TMD, quantum yield.

[1] Y. Lee, et al, Nat. Commun. 12, 7095 (2021)

[2] A. S. Sharbirin et al, J. Mater. Chem. C 10, 6508 (2022)

[3] A. S. Sharbirin et al, under review

[4] W. B. Mato et al, under review.

[5] K. Dhakal et al., manuscript in preparation

[6] J. W. P. Khor et al, under review.

[4]

Quantum criticality in semiconductor quantum dots

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Abstract: The zero-temperature continuous phase transitions, or quantum phase transitions, occur in strongly correlated solid-state materials when there are distinct competing quantum many-body ground states (phases) in the systems separated by an unstable quantum critical point. Due to enhanced quantum fluctuations near the quantum critical point, unconventional novel features in charge and spin degrees of freedom show up at finite temperatures. These new quantum states of matter go beyond the well-known Landau's Fermi liquid paradigm for ordinary metals, so-called non-Fermi liquid. New theories are urgently needed to address these fundamentally important open problems in condensed matter physics. The highly tunable semiconductor quantum dots are excellent playgrounds to realize these mysterious quantum states. In this talk, I will present theoretical studies via renormalization group and bosonization approaches on quantum critical states due to the interplay among Kondo effect, magnetic and electron-electron interactions in a dissipative quantum dot as well as in coupled double-quantum-dot devices. New quantum critical points and the corresponding non-Fermi liquid quantum critical states emerge with exotic power-law-in-temperature transport, magnetic and thermodynamic properties. Relevance of these results for the experiments is discussed.

Keywords: quantum phase transitions, quantum criticality, quantum dots, Kondo effect, non-Fermi liquid.

[5]

Studying 2D nanomaterials using Tip-Enhanced Raman Scattering

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Abstract: In recent years, there has been a growing interest in two-dimensional(2D) nanomaterials such as graphene and transition metal dichalcogenides to overcome the limitations of conventional materials and find new applications. The high surface area and layered structure favorable for ion transport of 2D nanomaterials can be utilized as electrode materials in electrochemical energy storage, and inorganic flexible optoelectronic devices with atomic-scale thickness can be realized. In order to expand the applicability of these 2D nanomaterials, it is necessary to improve their quality; for this purpose, research on defects is essential. In this talk, I will introduce our research on finding Raman signals for defects in 2D materials through tip-enhanced Raman scattering.

Keywords: Transition metal dichalcogenides, Tip-enhanced Raman scattering

[6]

Topological Phase Transition in Sn Single Layer from Stanene to beta-Sn

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Abstract: Two-dimensional topological insulators (2D TIs) are prized for unique electronic properties, especially in spintronics. These materials feature spin-polarized, disorder-resistant edge states. In contrast, topological nodal line semimetals (TNLSM) exhibit a distinct one-dimensional ring of degeneracy protected by topology, resilient to disorder. However, 2D TNLSMs lack protected boundary modes, posing experimental challenges. β-Sn, a metallic allotrope with a superconducting temperature of 3.72 K, emerges as a potential topological superconductor for hosting Majorana fermions in quantum computing.

In this work, we successfully prepared single layers of α-Sn(111) and β-Sn(001) on a Cu(111) substrate, employing scanning tunneling microscopy (STM), angle-resolved photoemission spectroscopy (ARPES), and Density Functional Theory (DFT) calculations. The electronic structure of β-Sn(001) undergoes a topological transition from 2D topological insulator α-Sn to 2D topological nodal line semimetal β-Sn, presenting two coexisting nodal lines. This realization in a single 2D material is unprecedented. Additionally, unexpected freestanding-like electronic structures of β-Sn/Cu(111) were observed, highlighting ultrathin β-Sn(001) films' potential for exploring the electronic properties of 2D topological nodal line semimetals and topological superconductors, such as few-layer superconducting β-Sn in lateral contact with topological nodal line single-layer β-Sn.

Keywords: topological nodal line semimetals, topological insulators, STM, ARPES, DFT calculation, stanene

[7]

Interface physics on organic and perovskite optoelectronic devices

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Abstract: Organic and perovskite solar cells are an exciting new type of renewable energy source that has made remarkable progress in the past several years. The rapid increase in power conversion efficiencies for this class of device can be attributed to the development of high performance materials as both active layers and transport materials, as well as continual grown in the understanding of device physics. Despite remarkable progress, the ability to control doping and create p-type or n-type homo-junctions remains a challenge. Although a few examples of controlled p-type and n-type doping can be found in the literature, a systematic understanding of how ions affect the electronic band structure and can be used to create or control this type of junction is lacking. In this contribution we explore the role of ions in controlling the energy band structure of solar cells, focusing on recent results with relatively new class of hole transport materials consisting of anionic polyelectrolytes based on polystyrene sulfonate with different metal cations.

[8]

Exploring surface and interface properties of semiconductors via photoemission spectroscopy

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Abstract: Semiconductor surfaces and interfaces offer a versatile platform for exploring emergent quantum properties. Layered materials enable the isolation and subsequent construction of heterostructures with tailored interfaces, free from lattice matching constraints. Notably, recent advancements in modulating interlayer coupling strength, achieved through adjustments in rotational ordering or pressure regulation in bilayer graphene, have resulted in the creation of a robust correlation system and the unconventional superconductivity. This talk employs photoelectron emission spectroscopy, a surface-sensitive technique (~10 nm), to probe the occupied electronic states of elements with energy and momentum resolution. Focusing on van der Waals interfaces, we systematically discuss critical information such as coupling strength, band alignment, and band structure revealed through operando photoemission spectroscopy. Our exploration sheds light on the quantum phenomena at play in these systems, offering insights into the design and manipulation of emergent properties in layered materials.

Keywords: operando photoemission spectroscopy, coupling strength, layered materials, band alignment

[9]
Weyl Semiconductor 2D Te

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Abstract: The 2-dimensional trigonal tellurium (2D Te) is a bundle of 1D helical atomic chains that stack on the substrate. They are holding together via van der Waals interaction. The crystal structure inherently possesses no inversion symmetry and Te atom has spin-orbit interactions. The band structure of 2D Te reveals a narrow bandgap of ~0.3 eV and shows Weyl points at both the conduction and valence bands. When the Fermi level was shifted inside the band using back gate bias (V_{bg}), we identified the existence of Berry curvature dipole (BCD) near the conduction band edge. The BCD, under time-reversal symmetry condition, gives rise to an electrical Hall voltage in a transverse direction, which increases in parabolic to the current applied longitudinal direction of 2D Te.

Keywords: Weyl semiconductor, Non-linear Hall effect, Berry Curvature Dipole, Thermoelectric, Metal-insulator transition.

[10]

Efficient photon upconversion in atomically thin two-dimensional semiconductors via dark excitons

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Abstract: Photon upconversion has profound applications in photonics, optoelectronics, medicine, and biology by utilizing high-energy photons. In atomically thin two-dimensional (2D) semiconductors, the tightly-bound excitons support strong many-body interactions, which are promising for platforms that support photon upconversion. This work studies photon upconversion in atomically thin transition metal dichalcogenides. We find that photon upconversion is strongly thickness-dependent and with optimal emission for materials with 5-6 atomic layers thickness. Our joint theory-experiment study attributes the process to the exciton-exciton annihilation of intervalley dark excitons, followed by spontaneous emission. This emission occurs at a resonance between the up-converted excitons and high-energy bright excitons in the Γ valley of the Brillouin zone, optimized for few-layer thicknesses, where the up-converted emission even exceeds that from dark excitons. This novel radiative pathway in 2D semiconducting materials may pave the way for exploring the fundamental properties and applications of dark excitons.

Keywords: up-conversion, exciton-exciton annihilation, momentum-forbidden dark excitons, transition metal dichalcogenides.