A3 Foresight Program
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9th International Workshop on 2D Materials

Abstract

2022. 2. 17 Thu 18 Fri

VENUE On-line

Grant-in-Aid for Transformative Research Areas(A)
Science of 2.5 Dimensional Materials
Paradigm Shift of Materials Science Toward Future Social Innovation
2.5D Materials

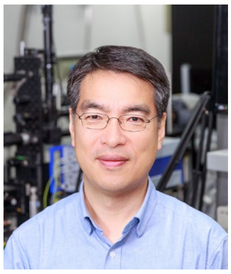
Day 1 (17th)

Japan/Korea	China		Title	Name	Country
9:00-9:10	8:00-8:10	Opening		Yoshihiro Iwasa	
Chair: Yoshihiro Iwasa (JP)					
9:10-9:40	8:10-8:40	Invite K1	Optical spectroscopy of twisted TMD heterostructures	Hyeonsik Cheong	Sogang University, Korea
9:40-10:10	8:40-9:10	Invite J1	Controlling the parity and time-reversal symmetry of non-Hermitian graphene Dirac plasmons and its application to terahertz lasers	Taiichi Otuji	Tohoku University, Japan
10:10-10:40	9:10-9:40	Invite C1	Observation of Chiral and Slow Plasmons in Twisted Bilayer Graphene	Xiaomu Wang	Nanjing University, China
10:40-11:00	9:40-10:00	20-min Break			
Chair: Jiang Pu (JP)					
11:00-11:20	10:00-10:20	YR J1	micro-focused ARPES study on transition metal dichalcogenide flakes	Masato Sakano	The University of Tokyo, Japan
11:20-11:40	10:20-10:40	YR K1	Colossal angular magnetoresistance in a ferrimagnetic nodal-line semiconductor Mn3Si2Te6	Junho Seo	POSTECH, Korea
11:40-12:00	10:40-11:00	YR C1	Population inversion and Dirac fermion cooling in 3D Dirac semimetal Cd3As2	Changhua Bao	Tsinghua University, China
12:00-12:20	11:00-11:20	YR J2	Emergent polarization and spontaneous photovoltaic effect at transition metal dichalcogenide/Black Phosphorus interface	Toshiya Ideue	The University of Tokyo, Japan
12:20-12:40	11:20-11:40	YR K2	Dielectric Engineering for Enhanced Top gate Monolayer MoS2 Transistor Using iCVD-based High-k Dielectric	Seohak Park	KAIST, Korea
12:40-14:00	11:40-13:00	Lunch + PI Meeting			
Chair: Taishi Takenobu (JP)					
14:00-14:30	13:00-13:30	Invite J2	Phase transitions and bulk transport in a correlated quantum Hall magnet	Michihisa Yamamoto	RIKEN, Japan
14:30-15:00	13:30-14:00	Invite C2	Quantum Criticality in Twisted Transition Metal Dichalcogenides	Lei Wang	Nanjing University, China
15:00-15:30	14:00-14:30	Invite K2	Impact of dark excitons on the population and relaxation kinetics of biexcitons in two-dimensional halide perovskites	Joon Ik Jang	Sogang University, Korea
15:30-15:50	14:30-14:50	20-min Break			
Chair: Junho Seo (KR)					
15:50-16:10	14:50-15:10	YR C2	Bosonic metallic state in nanopatterned YBCO films	Chao Yang	UESTC, China
16:10-16:30	15:10-15:30	YR J3	Photo-thermoelectric response in Landau-quantized graphene-based van der Waals heterostructures	Sabin Park	The University of Tokyo, Japan
16:30-16:50	15:30-15:50	YR K3	Field-tunable toroidal moment and anomalous Hall effect in noncollinear antiferromagnetic Weyl semimetal Co1/3TaS2	Pyeongjae Park	Seoul National University, Korea
16:50-17:10	15:50-16:10	YR C3	Self-energy dynamics and mode-specific phonon threshold effect in a Kekulé-ordered graphene	Hongyun Zhang	Tsinghua University, China
17:10-17:30	16:10-16:30	YR J4	Electric-Field-Induced Metal-Insulator Transition and Quantum Transport in Large-Area Polycrystalline MoS2 Monolayers	Hao Ou	Nagoya University, Japan

Day 2 (18th)

Japan/Korea	China		Title	Name	Country
Chair: Hyeonsik Cheong (KR)					
9:00-9:30	8:00-8:30	Invite C3	Quasiparticle interferences of topological materials	Hao Zheng	Shanghai Jiao Tong University, China
9:30-10:00	8:30-9:00	Invite K3	In-situ STEM study on transformation of 2D nanostructures on a Graphene "Hot Plate"	Sang Wook Lee	Ewha Womans University, Korea
10:00-10:30	9:00-9:30	Invite J3	Bilayer graphene: CVD growth, machine learning-based analysis, and intercalation	Hiroki Ago	Kyushu University, Japan
10:30-10:50	9:30-9:50	20-min Break			
Chair: Hiroki Ago (JP)					
10:50-11:20	9:50-10:20	Invite J4	Novel two-dimensional materials stabilized on substrates	Yukiko Yamada-Takamura	JAIST, Japan
11:20-11:50	10:20-10:50	Invite K4	Concurrent Lifshitz Transitions of Zone-Center van Hove Singularity and Type-II Dirac Fermions in Two-Dimensional Biphenylene Network	Young-Woo Son	KIAS, Korea
11:50-12:20	10:50-11:20	Invite C4	Visualization of Chiral Electronic Structure and Anomalous Optical Response in a Material with Chiral Charge Density Waves	Zhongkai Liu	Shanghaitech University, China
12:20-14:00	11:20-13:00	Lunch			
Chair: Jian Wang (CH)					
14:00-14:20	13:00-13:20	YR K4	Van der Waals Schottky gated MoS2 metal-semiconductor field-effect transistor at the Schottky-Mott limit	Yeon Ho Kim	Korea University, Korea
14:20-14:40	13:20-13:40	YR C4	Induced anomalous Hall effect of massive Dirac fermions in ZrTe5 and HfTe5 thin flakes	Yanzhao Liu	Peking University, China
14:40-15:00	13:40-14:00	YR J5	Giant Stark effect in Bilayer MoS2 Field-Effect Transistors	Haruki Uchiyama	The University of Tokyo, Japan
15:00-15:20	14:00-14:20	YR K5	Approaches to minimize operating voltages of MoTe2 channel/P(VDF-TrFE) ferroelectric nonvolatile memory	Yongjae Cho	Yonsei University, Korea
15:20-15:40	14:20-14:40	YR C5	Extrinsic and intrinsic anomalous metallic states in transition metal dichalcogenide Ising superconductors	Ying Xing	China University of Petroleum, China
15:40-16:00	14:40-15:00	20-min Break			
Chair: Yuanbo Zhang (CH)					
16:00-16:30	15:00-15:30	Invite C5	Unconventional excitonic states in layered SiP2	Peizhe Tang	Beihang University, China
16:30-17:00	15:30-16:00	Invite K5	Barristor-based sensor platform with extreme sensitivity	Hyun-Jong Chung	Konkuk University, Korea
17:00-17:30	16:00-16:30	Invite J5	Monolayer in-plane heterojunction light-emitting devices with tunable composition distribution	Jiang Pu	Nagoya University, Japan
17:30-17:40	16:30-16:40	Closing		Hongtao Yuan	

Title of the Presentation: Optical spectroscopy of twisted TMD heterostructures



First Name: Hyeonsik

Last Name: Cheong

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Short Biography:

Hyeonsik Cheong received his B.S. in physics from Seoul National University in 1986 and A.M. and Ph.D. in physics from Harvard University in 1988 and 1993, respectively. After 2 years of postdoctoral fellowship at Harvard, he moved to National Renewable Energy Laboratory in Golden, Colorado, where he worked as a postdoc and a senior scientist. He joined the faculty of Sogang University in 1999, where he currently is a full professor. He served as the president of Korean Graphene Society from 2015 to 2016 and as the chair of the Applied Physics Division of the Korean Physical Society from 2016 to 2020.

Abstract:
Heterostructures of transition metal dichalcogenides (TMDs) have been extensively studied as the alignment of the bands in the constituent materials allow for manipulation of optoelectronic and transport properties. The band offset between the bands is usually the most important parameter in determining the physical properties of these structures. However, as evidenced in the so-called 'magic-angle graphene' [1], the twist angle between the crystallographic directions of the two layers is an important parameter that affect the physical properties. As the twist angle between two layers of a given set of materials is varied, the moiré periodicity changes. The additional periodicity imposed by the moiré superlattice modifies the phonon spectrum as well as the electronic band structure, and the optoelectronic properties of the HSs change systematically. Furthermore, at very small twist angles, atomic-scale lattice reconstruction [2] has been observed and should be accounted for in describing the physical properties of heterostructures. In this talk, I will present some of the latest experimental data on the phonon spectra and the band structures from twisted heterostructures of different combination of TMDs.

[1] Cao Y., et al., Nature (2018); 556, 43; Ibid. 80.
[2]Yoo H., et al., Nature Materials (2019), 18, 448.

9th International Workshop on 2D Materials

Title of the Presentation: Controlling the parity and time-reversal symmetry of non-Hermitian graphene Dirac plasmons and its application to terahertz lasers

First Name: Taiichi

Last Name: Otsuji

Affiliation: Research Institute of Electrical Communication, Tohoku University, Sendai, Japan

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Short Biography:

Taiichi Otsuji received the Ph.D degree in electronic engineering from Tokyo Institute of Technology, Tokyo, Japan in 1994. After working at NTT Laboratories from 1984 to 1999, and Kyushu Institute of Technology from 1999 to 2005, he has been a professor at Tohoku University, Sendai, Japan since 2005. He has served as an IEEE Electron Device Society Distinguished Lecturer since 2013. He is a Fellow of the IEEE, OPTICA (former OSA), and JSAP.

Abstract:

Graphene having a gapless and linear band structure serves electrons and holes as massless Dirac fermions. The graphene Dirac plasmon (GDP) can dramatically enhance the interaction of terahertz (THz) waves with graphene. We proposed an original current-injection graphene THz laser transistor, demonstrating single-mode THz laser oscillation at low temperatures [1,2], and demonstrated the THz giant gain enhancement effect by the GDPs [3]. To realize room-temperature operating, highly intense THz lasing and ultrafast gain-switch modulation, we introduce new physics and principles of actively controlling the parity and time-reversal (PT) symmetry [4] of non-Hermitian GDPs with nanostructures and applied voltages. The PT symmetry can be expressed by a pair of complementary gain and loss mediums, leading to an anisotropic wave propagation of perfect transmission (unidirectionality) [5]. We present new ideas to implement the electrical control of the PT-symmetry of our original dual-grating-gate (DGG) GDP laser transistor structures (Fig. 1). Numerical simulation demonstrates an ultrafast gain-switch modulation capability operating at room temperature in the THz frequency band [5].

This work was supported by JSPS-KAKENHI No. 21H04546, and No. 20K20349, Japan.

[1] V. Ryzhii, M. Ryzhii, and T. Otsuji, J. Appl. Phys. 101, 083114 (2007)
[2] D. Yadav et al., Nanophoton. 7, 741-752 (2018).
[3] S. Boubanga-Tombet et al., Phys. Rev. X 10, 031004 (2020).
[4] M.-A. Miri, and A. Alu, Science 363, eaar7709 (2019).
[5] H. Ramezani, and T. Kottos, Phs. Rev. A 82, 04383 (2010).
[6] T. Otsuji et al., Nanophoton. in press.

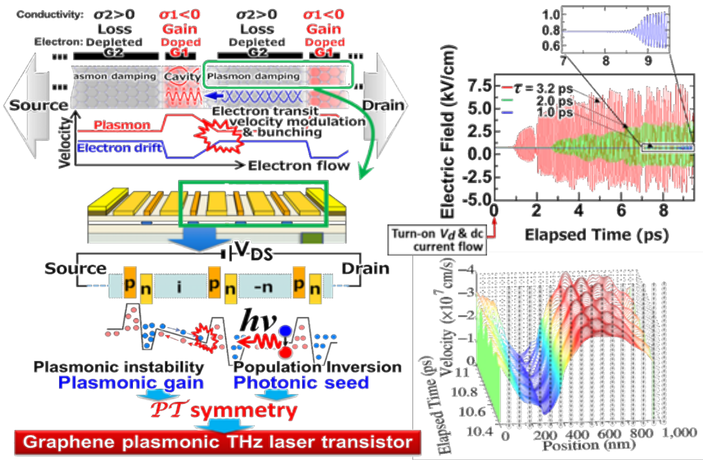

Fig. 1. Controlling the PT symmetry in a DGG-GDP THz laser transistor enabling ultrafast gain switch [6].

Title of the Presentation: Observation of Chiral and Slow Plasmons in Twisted Bilayer Graphene

First Name: Xiaomu

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Short Biography:

Dr. Xiaomu Wang received his Ph.D degree from CUHK on Aug 2012, after studied in the Department of Electronic Engineering for three years. After graduation, he underwent his postdoctoral training at University of Cambridge and Yale University. On October 2016, he entered Nanjing University as a full Professor in the School of Electronic Science and Engineering. His research includes the fields of infrared and nano- photonics of two-dimensional materials. He got Outstanding Young Investigator Award from Qiu Shi Science and Technology Foundation in 2019.

Abstract:

The Moiré super-lattices has led to the observations of exotic emergent electronic properties such as superconductivity and strong correlated states in small rotation angle twisted bilayer graphene (tBLG) [1,2]. Recently, these findings has inspired the search for novel properties in Moiré plasmons. Although plasmon propagation in tBLG basal plane has been studied by near-field nano-imaging technique[3-7], the general electromagnetic character and properties of these plasmons remain elusive. Here, we report the direct observation of two new plasmon modes in macroscopic tBLG with highly ordered Moiré super-lattice. Utilizing spiral structured nano-ribbons of tBLG, we identified signatures of chiral plasmons which arises due to the uncompensated Berry flux of the electron gas under optical pumping. Salient features of these chiral plasmons are revealed through their dependence on optical pumping intensity and electron fillings, in conjunction with distinct resonance splitting and Faraday rotation coinciding with spectral window of maximal Berry flux. Moreover, we also identified a slow plasmonic mode around 0.4eV, which stemmed from interband transitions between the nested subbands in lattice-relaxed AB-stacked domains. It might open up opportunities for strong light-matter interaction within the highly sought-after mid-wave IR spectral window[8]. Our results unveil the novel electromagnetic dynamics of small angle tBLG and exemplify it as a unique quantum optical platform.

[1] Cao, Y. et al. Nature 556, 80-84 (2018).
[2]Cao, Y. et al. Nature 556, 43-50 (2018).
[3]Hesp, N. C. H. et al. Nature Physics 17, 1162-1168 (2021).
[4]Hu, F. et al. Physical Review Letters 119, 247402 (2017).
[5]Sunku, S. S. et al. Science 362, 1153-1156 (2018).
[6]Ni, G. X. et al. Nature Materials 14, 1217-1222 (2015).
[7]Brey, L., et al. Physical Review Letters 125 (2020).
[8]Jalali, B. et al. IEEE Journal of Selected Topics in Quantum Electronics 12, 1618-1627

9th International Workshop on 2D Materials

Title of the Presentation: micro-focused ARPES study on transition metal dichalcogenide flakes

First Name: Masato

Last Name: Sakano

Affiliation: Department of Applied Physics and Quantum-Phase Electronics Center(QPEC), The University of Tokyo, Tokyo, Japan

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Short Biography:

Masato Sakano holds a doctoral degree of engineering from The University of Tokyo. He finished his PhD at the Department of Applied Physics, The University of Tokyo in 2016. Thereafter, he worked as a postdoctral researcher at the Institute of Solid State Physics, The University of Tokyo (2016-2017). Since April 2017, he is a research associate at Quantum-Phase Electronics Center, The University of Tokyo. His present research is on studying the electronic structures in strongly spin-orbit coupled materials, topological materials and two-dimensional materials by means of photoemission spectroscopy, and developing the laser angle-resolved photoemission spectroscopy system.

Abstract:

In atomically thin two-dimensional (2D) materials, a finite number of stacked layers form a peculiar band structure different from that of the bulk crystal, which leads to unique physical properties and phenomena. With the development of exfoliation and dry-transfer techniques, the study of 2D materials has made great progress, mainly by comparing the experimental results of transport and/or optical measurements on the micro-flake devices with those of the first-principles band calculations. However, the experimental methods that can be used for small 2D flakes (~10 μm) are limited, and it is still difficult to determine the atomic coordinates to input to the band calculations. In our study, by using micro-focused angle-resolved photoemission spectroscopy (ARPES) in combination with the 2D materials manufacturing system that can freely stack atomic layers by image recognition, machine learning, and autonomous robots[1,2], we demonstrated the direct observations on the band structure in various 2D flakes [3]. The sample fabrication and preparation process used in this study can be applied to a variety of composite systems including twisted and hetero-structured van der Waals materials and will enable us the direct observation of the complicated electronic structure, which are difficult to calculate, associated with the novel properties and functions.

[1] S. Masubuchi, *et al*., Nat. Commun. **9**, 1413(2018).
[2] S. Masubuchi, *et al*., npj 2D Mater. Appl. 4, 3 (2020).
[3] M. Sakano*, Y. Tanaka*, S. Masubuchi*, (*equally contributed) *et al*., arXiv:2103.11885 (2021).

9th International Workshop on 2D Materials

Colossal angular magnetoresistance in a ferrimagnetic nodal-line semiconductor $Mn_3Si_2Te_6$

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Last Name: Seo

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Short Biography:

Dr. Junho Seo is a postdoc researcher in Prof. Jun Sung Kim's lab at POSTECH, Pohang, Korea. His expertise is single crystal growth and magnetotransport measurements on topological van der Waals magnets.

Abstract:

Topological magnets, where both magnetism and nontrivial band topology coexist, have emerged as promising candidates to realize novel electronic and spintronic functionalities, because their topological band degeneracy can be readily tuned by spin configurations, thus dramatically modulating electronic conduction. Here we propose a new class of topological magnets, namely, magnetic nodal-line semiconductors, in which spin-polarized conduction or valence bands possess topological nodal-line degeneracy. Taking a layered ferrimagnet $Mn_3Si_2Te_6$ as a model system, we show that the topological band degeneracy, driven by chiral molecular orbital states, is lifted depending on the spin orientation, which leads to a metal-insulator transition in the same ferrimagnetic phase. As a result, we have observed extremely large angular magnetoresistance exceeding a trillion percent per radian, which we call colossal angular magnetoresistance. Our findings highlight that magnetic nodal-line semiconductors are a promising platform for realizing extremely sensitive spin- or orbital-dependent functionalities [1].

[1] J. Seo, C. De, H. Ha, J. E. Lee *et al*. Nature 599, 576-581 (2021).

Title of the Presentation: Population inversion and Dirac fermion cooling in 3D Dirac semimetal Cd_3As_2

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Last Name: Bao

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Email: changhuabao@gmail.com

Short Biography:

After receiving the B.S. degree of Mathematics and Physics from department of physics in Tsinghua university in 2016, he began Ph. D. in Prof. Shuyun Zhou's group in Tsinghua University. He focuses on studying the novel electronic structure and light-matter interaction in two-dimensional and topological materials by utilizing state-of-the-art angle-resolved photoemission spectroscopy (ARPES) including time-resolved ARPES and Nano/Micro-ARPES. He has been awarded *Top 10 Graduate Students Award* in Tsinghua university (2021) and *Young Scientist Prize* in RPGR (2019).

Abstract:

Revealing the ultrafast dynamics of three-dimensional (3D) Dirac fermions is critical for both fundamental science and device applications [1]. So far, how the cooling of 3D Dirac fermions differs from that of two-dimensional (2D) and whether there is population inversion are fundamental questions to be answered. Time- and angle-resolved photoemission spectroscopy (TrARPES) is a powerful technique for revealing the ultrafast dynamics, however, TrARPES study of 3D Dirac fermions has been missing so far due to the lack of tunable probe photon energy, which is required to scan through the conical dispersion at the desired out-of-plane momentum. Here we develop a novel TrARPES system with a widely tunable probe photon energy from 5.3 to 7.0 eV [2] and reveal the ultrafast dynamics of 3D Dirac fermions for the first time in a model 3D Dirac semimetal Cd_3As_2 [3]. The energy- and momentum-resolved relaxation rate shows a linear dependence on the energy, suggesting Dirac fermion cooling through intraband relaxation. Moreover, a population inversion is reported based on the direct observation of accumulated photoexcited carriers in the conduction band with a lifetime of 3.0 ps. Our work provides direct experimental evidence for a long-lived population inversion in a 3D Dirac semimetal, which is in contrast to 2D graphene with a much shorter lifetime.

[1] C. Bao *et al.*, Nat. Rev. Phys. 4, 33 (2022).
[2] C. Bao *et al.*, Rev. Sci. Instrum. 93, 013902 (2022).
[3] C. Bao *et al.*, Nano Lett. (2022) doi: 10.1021/acs.nanolett.1c04250

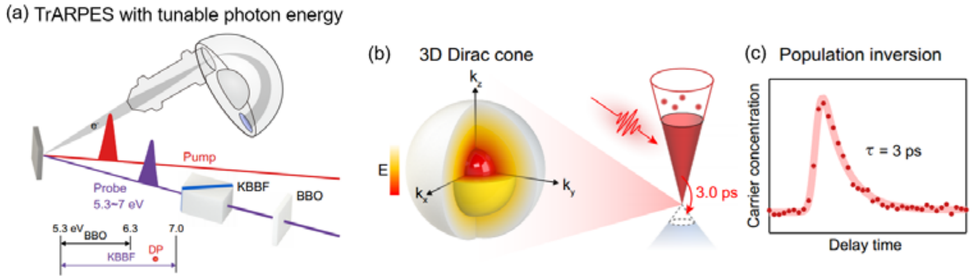

Fig. 1. (a,b) Schematics for TrARPES with tunable probe photon energy and photoexcited 3D Dirac cone. (c) The ultrafast temporal evolution of carrier concentration in conduction band.

9th International Workshop on 2D Materials

Title of the Presentation: Emergent polarization and spontaneous photovoltaic effect at transition metal dichalcogenide/Black Phosphorus interface

First Name: Toshiya

Last Name: Ideue

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Short Biography:

Toshiya Ideue received B.S. and M.S. from the University of Tokyo. After he worked at Fujifilm Corporation, he returned to the University of Tokyo and received Ph.D. in engineering. He is now a research associate in the University of Tokyo. His research interests are the exotic quantum transport and optical properties originating from symmetry breaking.

Abstract:

Interfaces of two dimensional van der Waals crystals are unique material platforms in which we can explore the emergent physical properties and functionalities by selecting the appropriate material combinations and by designing the symmetry of the interface. Although translational symmetry is generally broken in van der Waals interfaces, characteristic nanostructures or symmetries can emerge, which strongly affect the electronic properties at the interface.

In this work, we focused on the polar symmetry in van der Waals interfaces. By combining the two dimensional crystals with different symmetries (three-fold rotational transition metal dichalcogenide and two-fold rotational black phosphorus), in-plane electronic polarization can be realized (Fig.1 A-C), which cause the spontaneous photovoltaic effect along the polar direction (Fig.1D) [1]. Behaviors of the observed spontaneous photocurrent are well explained by a quantum-mechanical shift current [2].

The present results offer a simple guideline for symmetry engineering applicable to a variety of van der Waals nanostructures and also provide the concept of electronic polarization in quasi-periodic systems without translation symmetry.

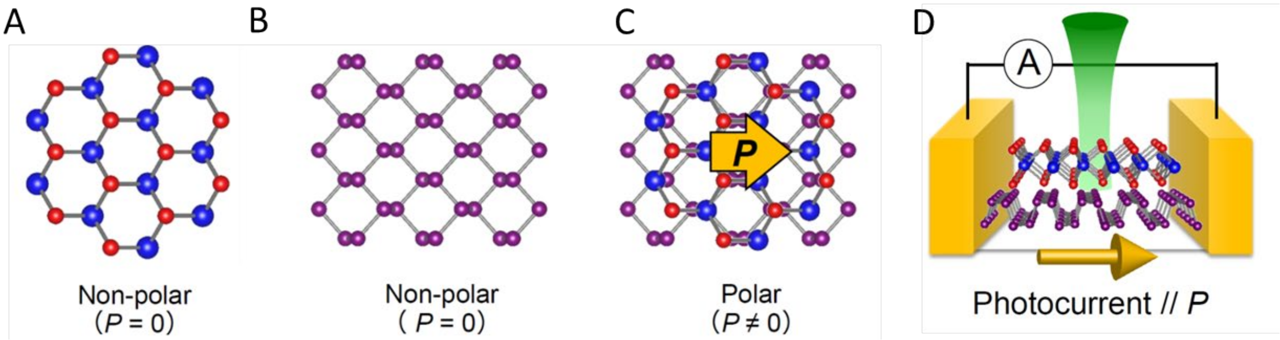

Fig. 1. Schematics of (A) transition metal dichalcogenide(TMD), (B) Black phosphorus (BP), (C) TMD/BP interface, and (D) spontaneous photovoltaic effect at TMD/BP interface.

[1] T. Akamatasu, T. Ideue *et al.*, Science **372**, 68 (2021)

[2]T. Morimoto and N. Nagaosa, Sci. Adv. **2**:e1501524 (2016)

9th International Workshop on 2D Materials

Title of the Presentation: Dielectric Engineering for Enhanced Top gate Monolayer MoS_2 Transistor Using iCVD-based High-k Dielectric

First Name: Seohak

Last Name: Park

Affiliation: School of Electrical Engineering, KAIST, Daejon, South Korea

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Short Biography:

Seohak Park received his B.S. degree in Information Display(2020) from Kyung Hee University. He is now pursuing a M.S. degree at KAIST under the supervision of Prof. Sung-Yool Choi. His research is focused on engineering of 2D-transistor for advanced future logic and flexible devices.

Abstract:

Transition metal chalcogen compounds have high transparency, flexibility, and excellent electrical properties. Among them, molybdenum disulfide(MoS_2) is widely used as an n-type semiconductor material. In the case of MoS_2, it has a relatively high on-off current ratio, high mobility, and excellent flexibility. However, It shows significantly lower mobility characteristics than its electrical potential because of its poor interfacial characteristic with an insulating layer and a substrate.[1] Particularly, because 2D materials have incongruity with a conventional ALD process due to their dangling bond free surface, 2D materials based transistors generally show inferior interface quality when they are applied in a form of top gate transistor.[2] In this study, by applying a newly invented initiated chemical deposition(iCVD) process based high-k dielectric(pHEMA-g-AlO_X) as a top gate insulator of MoS_2 transistor, high performance top gate monolayer MoS_2 transistor with mobility of $13cm^2V^{-1}s^{-1}$, SS of $135mVdec^{-1}$ and low hysteresis(<100mV) value is developed.[3] Furthermore, it shows more than 5-times higher mobility than a conventional Al_2O_3 insulator-based top gate monolayer MoS_2 transistor. Systematic analyses show the reason for this improvement is due to a less coulombic scattering effect and a less surface optical phonon scattering effect of a hybrid dielectric-based top gate MoS_2 transistor than those of Al_2O_3 dielectric-based top gate device.

[1]Subhamoy Ghatak et al., ACS Nano 5, 10, 7707-7712 (2011).
[2]L. Yu et al., IEDM 32, 3, 1-4 (2015).
[3]M. J. Kim et al., ACS Appl. Mater. Interfaces 10, 43, 37326-37334 (2018).

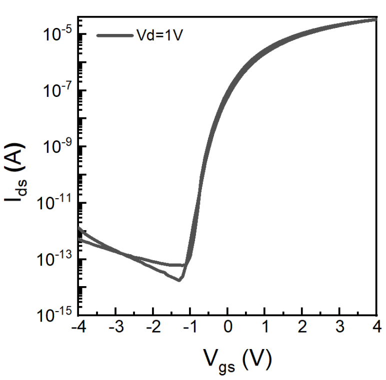

Fig. 1. Transfer characteristic of hybrid dielectric-based top gate 2d-transistor.

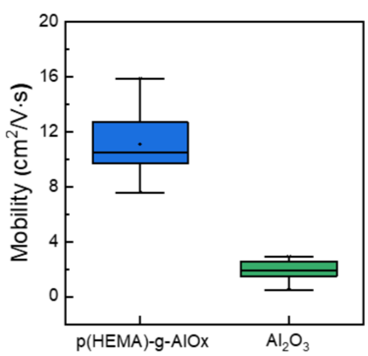

Fig. 2. Comparison of mobility between hybrid dielectric-based and Al_2O_3 dielectric-based top gate 2d-transistor for 10 different devices.

9^{th} International Workshop on 2D Materials

Title of the Presentation: Phase transitions and bulk transport in a correlated quantum Hall magnet

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Last Name: Yamamoto

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Short Biography:

Michihisa Yamamoto received his B. Sc. (1999), M. Sc. (2001), and Ph.D. (2004) in physics from the University of Tokyo. He was a research associate (2004-2014) and a lecturer (2014-2017) in the Department of Applied Physics and an associate professor (2017-2018) in Quantum-Phase Electronics Center at the University of Tokyo. He was a unit leader (2017-2020) and is a team leader since April 2020 at RIKEN Center for Emergent Matter Science. His research interests are quantum transport and manipulation of quantum degrees of freedom in semiconductor nanostructures and atomic layer systems. He was awarded Young Scientist Award of the Physical Society of Japan in Division 4 (2013), Young researcher's prize of Ministry of Education, Culture, Sports, Science and Technology Japan (2013), Funai Science Award (2017), and Sir Martin Wood prize (2017).

Abstract:

The quantum Hall state is known as the strongly correlated state owing to the quenched kinetic energy. When multiple internal electronic degrees of freedom exist, the many-body state undergoes phase transitions. A well-known example that has been intensively studied is the double-layer quantum Hall system at the total filling factor $\nu = 1$ [1]. This system is considered as an easy-plane ferromagnet of the pseudo-spin defined by the layer degree of freedom. While rich varieties of phase transitions have been investigated, observation and characterization of the yet elusive temperature-induced Kosterlitz–Thouless (KT) transition remains as one of the central and long-standing issues in the quantum Hall physics.

In this presentation, we present temperature-induced phase transitions of the ν=0 quantum Hall antiferromagnetic state in bilayer graphene [2]. We employed varieties of devices and transport measurements, such as the two-terminal device, the four-terminal and non-local measurement in the Hall bar, and the Corbino device that does not suffer from the edge transport. The transport experiment over a wide range of temperatures revealed the two-step phase transition associated with the breaking of the long-range order, i.e., the KT transition, and short-range antiferromagnetic order. While the standard four-terminal setup suffers from the edge transport, we find clear correspondence between the non-local transport and the bulk transport measured in the Corbino device. Near the KT transition of the bulk, the non-local transport mediated by the spin dependent valley current [3] is suppressed owing to the disappearance of the long-range order, which supports bulk origin of the non-local transport despite the recent criticism [4].

This work was mostly done by Miuko Tanaka in collaboration with Takashi Taniguchi, Kenji Watanabe, Kentaro Nomura and Seigo Tarucha.

[1] K. Moon et al., Phys. Rev. B 51, 5138 (1995).
[2] M. Tanaka et al., arXiv:2108.11464.
[3] M. Tanaka et al., Phys. Rev. Lett. 126, 016801 (2021).
[4] A. Aharon-Steinberg et al., Nature 593, 7860 (2021).

9th International Workshop on 2D Materials

Title of the Presentation: Quantum Criticality in Twisted Transition Metal Dichalcogenides

First Name: Lei

Last Name: Wang

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Short Biography:

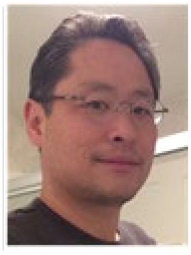
Dr. Lei Wang is a professor in Physics department, Nanjing University. He received the B.S. (2005) in Electrical Engineering from National University of Singapore. In 2014, he earned a Ph.D. in Electrical Engineering at Columbia University, where he studied the electronic transport properties of the atomically thin two-dimensional (2D) materials. In particular, Dr. Wang developed the novel 'pick-up' transfer and edge-contacting technique to achieve 2D material devices in an ultra-clean limit in 2013. These methods also establish a platform to assemble the van der Waals heterostructures layer by layer for device applications in multiple research directions. Between 2015 and 2018, he won the Kavli postdoctoral fellowship at Cornell University, where he has been exploring 2D materials-based unconventional electronics tuned by their topological property changes.

Abstract:

In strongly correlated materials such as cuprates, pnictides and heavy Fermion systems, a plethora of ordered phases have been observed, including Mott insulators, superconductors and density waves. The most intriguing electronic properties of these materials are not found in these ordered phases, but instead in the metallic phases that are adjacent to them. Near criticality, these metallic phases exhibit anomalous transport properties that defy description by the Landau Fermi liquid paradigm. One striking manifestation of this is the temperature and magnetic field dependence of the resistance of the metallic phase, which deviates strongly from the expected T^2 or B^2 dependence predicted by Fermi liquid theory. Here, we use transport measurements to characterize the gate-driven metal-insulator transitions and the metallic phase in twisted WSe_2 near half-filling of the first moire subband. We find that the metal-insulator transition as a function of both density and displacement field is continuous. At the metal-insulator boundary, the resistivity displays strange metal behaviour at low temperature with dissipation comparable to the Planckian limit.

[1] A.Ghiotto…L.Wang✉ et al., ***Nature*** 597, 345-349, (2021).

Title of the Presentation: Impact of dark excitons on the population and relaxation kinetics of biexcitons in two-dimensional halide perovskites



First Name: Joon, I.

Last Name: Jang

Affiliation: Physics Department, Sogang University, Seoul, South Korea

Email: jjcoupling@sogang.ac.kr

Short Biography:

Prof. Jang received his Ph.D. in Physics from the University of Illinois at Urbana-Champaign in 2005. He was a post-doctoral researcher at Northwestern University and an assistant professor at the State University of New York (SUNY) at Binghamton. He awarded Smart Energy Transdisciplinary Area of Excellence from SUNY. He is currently an associate professor of Physics at Sogang University. Prof. Jang specialized in the area of experimental condensed matter physics and nonlinear optics.

Abstract:

Two-dimensional (2D) semiconductors are ideal for studying various excitonic matter under strong quantum and dielectric confinements. However, such effects can be seriously overestimated for Coulomb binding of two excitons to form a biexciton by a naive interpretation of the corresponding photoluminescence (PL) spectrum. By using 2D halide perovskite single crystals of $BA_2Pb_{1-x}Mn_xBr_4$ (x = 0−0.09), we show that the biexciton is formed by binding of two dark excitons, which are partially bright, but it radiatively recombines to yield a bright exciton in the final state. This renders the spectral distance between the exciton peak and the biexciton peak as very different from the actual biexciton binding energy (φ) because of large bright−dark splitting. We show that Mn doping improves the biexciton stability as evidenced by increase in φ and the increase of the exciton−exciton capture coefficient C within our doping range. The precisely determined φ values are significantly smaller than the previously reported ones, but they are consistent with the instability of the biexciton against thermal dissociation at room temperature. Our results demonstrate that electron−hole exchange interaction must be considered for precisely locating the biexciton level; therefore, the φ values should be reassessed for other 2D halide perovskites that even do not exhibit any dark exciton PL. This work is supported by the Basic Science Research Program (2021R1A2C2013625) through the National Research Foundation of Korea.

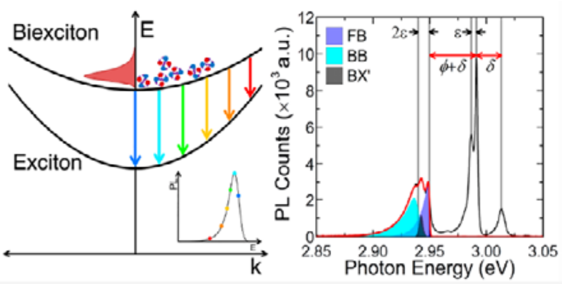


Fig. 1. Schematic for the biexciton PL and the PL spectrum at 8.5 K in a single crystal of 2D perovskite.

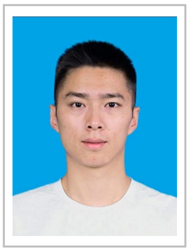
[1] A. Steinhoff et al., Nat. Phys. 14, 1199-1204 (2018).

[2] W. Choi et al., J. Am. Chem. Soc. 143, 19785-19793 (2021).

[3] H. Ryu et al., Adv. Mater. (under review).

9th International Workshop on 2D Materials

Title of the Presentation: Bosonic metallic state in nanopatterned YBCO films



First Name: Chao

Last Name: Yang

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Email: chaoyang@usetc.edu.cn

Short Biography:

Chao Yang is a senior researcher in the department of electronic science and technology, University of Electronic Science and Technology of China. His research interests are superconductor-insulator transitions, bosonic anomalous metal and High-Tc Superconductors. His work is selected as one of top ten breakthrough of science and technology of Chinese academy in 2019.

Abstract:

Fermi liquid theory forms the basis for our understanding of the majority of metals that their resistivity arises from the scattering of well-defined quasiparticles at a rate following $1/\tau \sim T^2$ in the low temperature limit. Various quantum materials[1–8], notably high-temperature superconductors[1-3], however, exhibit strange metallic behavior with a linear scattering rate in temperature, deviating from this central paradigm. Here we show the unexpected signatures of strange metallicity in a bosonic system for which the quasiparticle concept does not apply[9,10]. Our nanopatterned $YBa_2Cu_3O_{7-\delta}$ (YBCO) film arrays reveal T-linear and B-linear resistance over an extended temperature and magnetic field range, respectively. Strikingly, below the onset temperature T_c^{onset} at which Cooper pairs form, the low-field magnetoresistance oscillates with a period dictated by the superconducting flux quantum of $h/2e$ where e is the electron charge and h is the Planck constant. Simultaneously, the Hall coefficient R_H drops and vanishes within the measurement resolution with decreasing temperature, indicating that Cooper pairs instead of single electrons dominate the transport process. Moreover, the characteristic time scale τ in this bosonic system follows a scale-invariant relation without intrinsic energy scale: $\hbar/\tau \approx a \cdot (k_B T + \gamma \mu_B B)$, where $\hbar$ is the reduced Planck's constant, a is of order unity[4,5] and $\gamma \approx 2$. By extending the reach of strange metal phenomenology to a bosonic system, our results suggest that there is a fundamental principle governing their transport which transcends particle statistics.

[1]Keimer et al., Nature 518, 179–186 (2015).
[2]Zaanen. Nature 430, 512–513 (2004).
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[4]Patel, A. A. et al.,Phys. Rev. Lett. 123, 066601 (2019).
[5]Bruin, J. A. N et al., Science 339, 804–807 (2013).
[6]Hayes, I. M. et al., Nat. Phys. 12, 916–919 (2016).
[7]Doiron-Leyraud, N. et al., Phys. Rev. B 80, 214531 (2009).
[8]Cao, Y. et al., Phys. Rev. Lett. 124, 076801 (2020).
[9]Yang, C. et al., Science 366, 1505-1509 (2019)
[10]Yang, C. et al., Nature 601, 205–210 (2022).

9th International Workshop on 2D Materials

Title of the Presentation: Photo-thermoelectric response in Landau-quantized graphene-based van der Waals heterostructures

First Name: Sabin

Last Name: Park

Affiliation: Institute of Industrial Science, The University of Tokyo, Tokyo, Japan

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Short Biography:

Sabin Park is a graduate student in Department of Materials Engineering, The University of Tokyo from 2020. He received the B.S. degree in Materials Science and Engineering from Chonnam National University in Korea. His research focuses on optoelectronic properties in graphene-based van der Waals heterostructure in high magnetic fields.

Abstract:

We investigate photo-thermoelectric effect (PTE) in Landau quantized graphene-based vdW heterostructure in two different types of novel device structures. These are an inner contact geometry and a vertical tunneling transport device.

An Inner contact device [Fig. 1(a)] was fabricated with *h*-BN/BLG/WSe_2/*h*-BN structure and used to detect cyclotron resonance (CR)-induced photovoltage. The inner contact prohibits edge-channel transport in the quantum Hall state (QHS), thus enabling us to detect the photovoltaic response of the QHS bulk region. An image plot of photovoltage (V_{ph}) measured as a function of magnetic field B and carrier density n_e at T = 3 K measured in the inner contact device is shown in Fig. 1(b). Series of resonant peak and dips of V_{ph} in the high B region due to the CR were observed. The horizontal cross-section at B = 10.7 T (corresponding to one of the CR conditions) is presented in Fig. 1(c). The V_{ph} exhibited large signal at QHS state having quantum Hall filling factor ν of ± 4 and ± 8. Presence of QHS at these ν were also confirmed from conductance (G) measurement performed on the same device [Figs. 1(d-e)]; where, G has minima at QHS. These suggest the observation of PTE due to the bulk QHS in the inner contact device.

A tunnelling PTE in *h*-BN/BLG/tunneling barrier (*h*-BN or MoS_2)/MLG/*h*-BN vertical heterostructure will also be discussed.

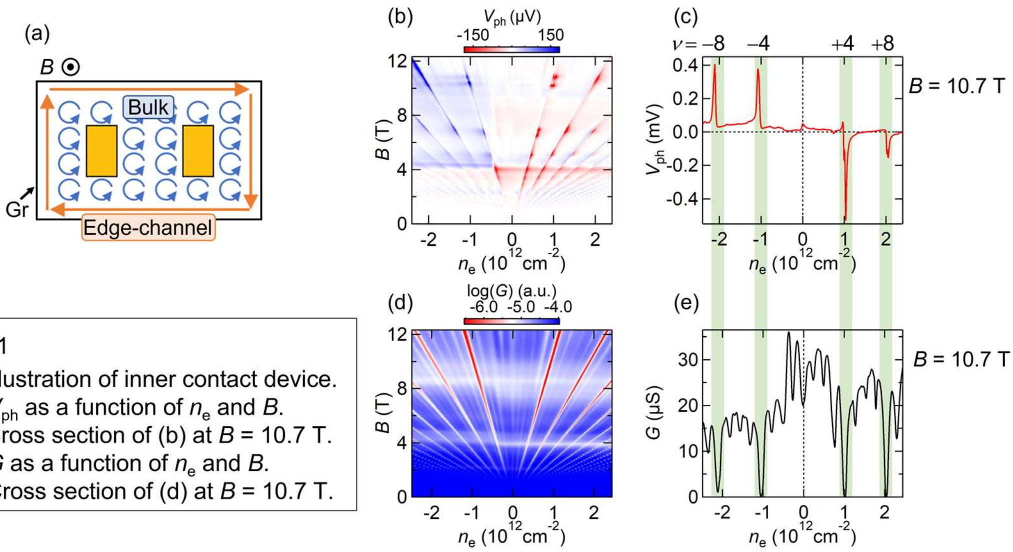

Fig. 1
(a) Illustration of inner contact device.
(b) V_{ph} as a function of n_e and B.
(c) Cross section of (b) at B = 10.7 T.
(d) G as a function of n_e and B.
(e) Cross section of (d) at B = 10.7 T.

9th International Workshop on 2D Materials

Title of the Presentation: Field-tunable toroidal moment and anomalous Hall effect in noncollinear antiferromagnetic Weyl semimetal $Co_{1/3}TaS_2$

First Name: Pyeongjae

Last Name: Park

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Short Biography:

Pyeongjae Park received his BS degree in Physics from Yonsei University (2016). Supervised by Prof. Je-Geun Park, he is currently a Ph.D. student at Seoul National University. His research interest includes magnetism in metallic and noncollinear antiferromagnets, and band topology in magnetic materials.

Abstract:

Combining magnetism with band topology provides various novel phenomena that are otherwise impossible. While anomalous Hall effect (AHE) in metallic ferromagnets is the representative example, the large potential may lie in antiferromagnets; they provide several interesting situations and could, in principle, offer unseen properties arising simply from the enormous number of possible spin configurations [1]. However, due to the lack of suitable materials, only a few studies have successfully materialized the untapped potential of antiferromagnetic metallic systems, especially with triangular lattice antiferromagnets.

This work reports that metallic triangular antiferromagnet $Co_{1/3}TaS_2$ exhibits a substantial AHE related to its noncollinear magnetic order. Our first-principles calculations found that hourglass Weyl fermions from the non-symmorphic symmetry trigger AHE. We further show that AHE in $Co_{1/3}TaS_2$ can be characterized by a field-tunable *toroidal dipole moment*, a vortex-like multipole component distinct to magnetic multipoles. Combined with the possibility of mechanical exfoliation, $Co_{1/3}TaS_2$ is a rare metallic magnet offering a chance of studying noncollinear antiferromagnetism and relevant topological properties in both three and two-dimension.

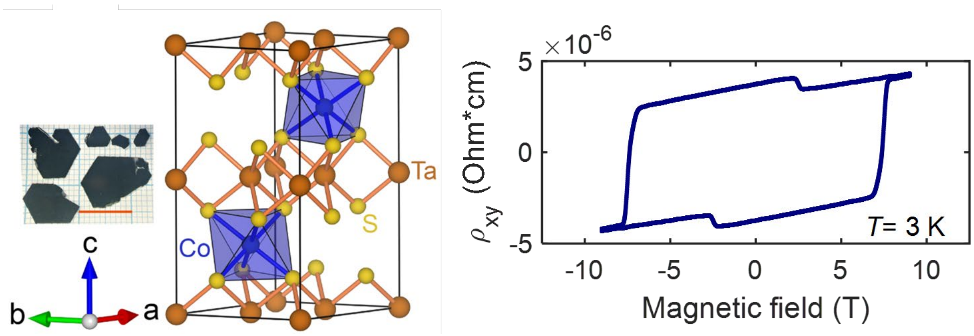

Fig. 1. (Left) A crystallographic unit cell of $Co_{1/3}TaS_2$ and its single crystal. (Right) Field dependence of Hall resistivity ρ_{xy} in $Co_{1/3}TaS_2$ at 3 K.

[1] L. Šmejkal *et. al.*, arXiv:2107.03321 (2021)

Title of the Presentation: Self-energy dynamics and mode-specific phonon threshold effect in a Kekulé-ordered graphene

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Last Name: Zhang

Affiliation: Department of Physics, Tsinghua University, Beijing, China

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Short Biography:

Hongyun Zhang received her Ph. D. in physics from Tsinghua University in 2021. She is currently a Shuimu Tsinghua Scholar working with Shuyun Zhou group at Tsinghua University. Her research focuses on the electronic structure engineering and ultrafast dynamics of two-dimensional materials and heterostructures using angle-resolved photoemission spectroscopy (ARPES) and time- and angle-resolved photoemission spectroscopy (TrARPES).

Abstract:

Electron-phonon coupling (EPC) and related self-energy effects are not only fundamental in determining the equilibrium physical properties of solids, but also critical in determining the non-equilibrium electron relaxation process. Graphene with low-energy excitations resembling relativistic Dirac fermions and strong EPC is an ideal system for investigating the EPC related physics. While the effect of EPC in renormalizing the electronic structure of graphene has been revealed, its role in the non-equilibrium dynamics, especially whether the relaxation is contributed by all phonons or dominated by specific phonon modes is still unclear. In this talk, I will introduce our recent work about the dominant role of mode-specific phonons in the electron relaxation dynamics in a Kekulé-ordered graphene by performing TrARPES measurements [1]. By folding the Dirac cones to the Γ point through Li intercalation [2], we have succeeded in resolving the self-energy effects in the time domain, which are induced by coupling of electrons with two specific phonon modes at Ω_1 = 177 meV and Ω_2 = 54 meV (Fig. 1(a)). Moreover, those two phonon modes set energy thresholds for the relaxation dynamics of electrons with different energies, and induce hierarchical relaxation from “ultrafast”, “fast” to “slow” (Fig. 1(b, c)).

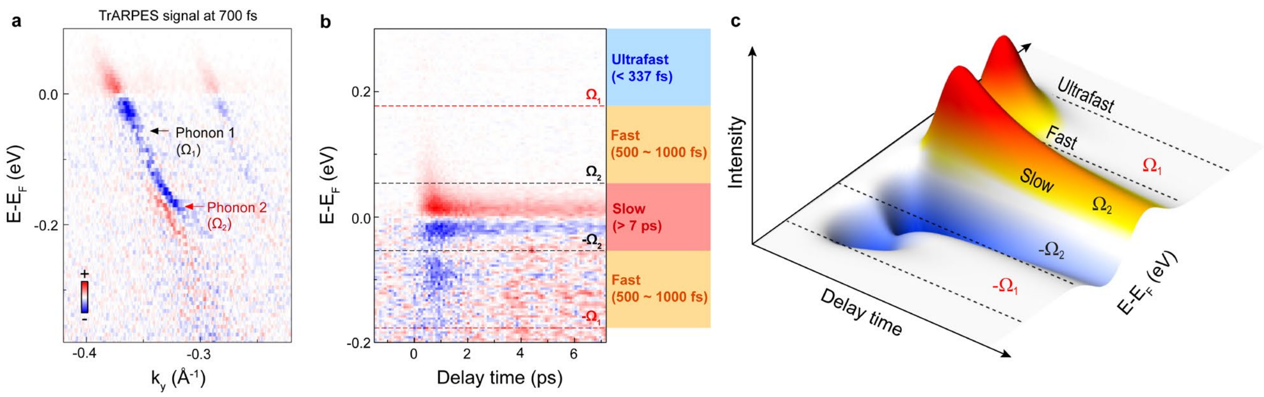

Fig. 1. (a) TrARPES signal measured at 700 fs. (b) TrARPES signal at different delay times and (c) the schematic drawing to show the hierarchical relaxation of electrons.

[1] H. Zhang†, C. Bao†, et al., Self-energy dynamics and mode-specific phonon threshold effect in a Kekulé-ordered graphene. *Natl. Sci. Rev.* (2021) (Online published).

[2] C. Bao†, H. Zhang†, et al., Experimental Evidence of Chiral Symmetry Breaking in Kekulé-Ordered Graphene. *Phys. Rev. Lett.* 126, 206804 (2021) (Editor's suggestion & Featured in Physics).

9th International Workshop on 2D Materials

Title of the Presentation: Electric-Field-Induced Metal-Insulator Transition and Quantum Transport in Large-Area Polycrystalline MoS2 Monolayers

First Name: Hao

Last Name: Ou

Affiliation: Dept. of Applied Physics, Nagoya University, Nagoya, Japan

Email: ou.hao@g.mbox.nagoya-u.ac.jp

Short Biography:

Mr. Ou is a doctoral student of the Department of Applied Physics of Nagoya University, Japan. He received B.E. and M.E. degrees from Huazhong University of Science and Technology, China. His research interest includes the transport and optical properties of two-dimensional TMDC and heterostructures. He is now a fellow of THERS Interdisciplinary Frontier Next Generation Researcher.

Abstract:

As one of the most well-known two-dimensional semiconductor, monolayer MoS_2 have been intensively studied, showing the emergence of metal-insulator transition (MIT), superconductivity [1] and quantum conduction [2], which enables the material not only a potential candidate for future electronic applications, but also an ideal platform for studying two-dimensional electronic systems. However, most studies use single-crystal flakes, which hindered the further functionalities of the material. On the contrast, transistors made of large-area polycrystalline monolayers have been reported [3], while there has been no systematic study on the transport behaviors of the material. Here, we report on the observation of MIT and quantum correction to transport properties in polycrystalline MoS_2 monolayer transistors.

We fabricated electric double-layer transistors (EDLTs) using CVD-grown polycrystalline MoS_2 (Fig. 1a). Electrostatic doping of MoS_2 is introduced by the ion redistribution inside electrolyte, which serves a liquid gate. Because of the electric-induced high carrier density, the polycrystalline MoS_2 readily shows MIT at a relatively low driving voltage (Fig. 1b). Moreover, Hall effect measurement reveals a high mobility of $> 100\ \mathrm{cm^2\ V^{-1}\ s^{-1}}$. The low-temperature magnetotransport presents a crossover between weak localization and weak antilocalization (Fig. 1c). The above results indicate that with sufficiently high carrier density, the negative effect of grain boundary in polycrystalline MoS2 could be greatly suppressed, to enable the intrinsic transport and quantum conduction. This study reveals that polycrystalline MoS2 monolayers have significant potential for the large-area electronic applications.

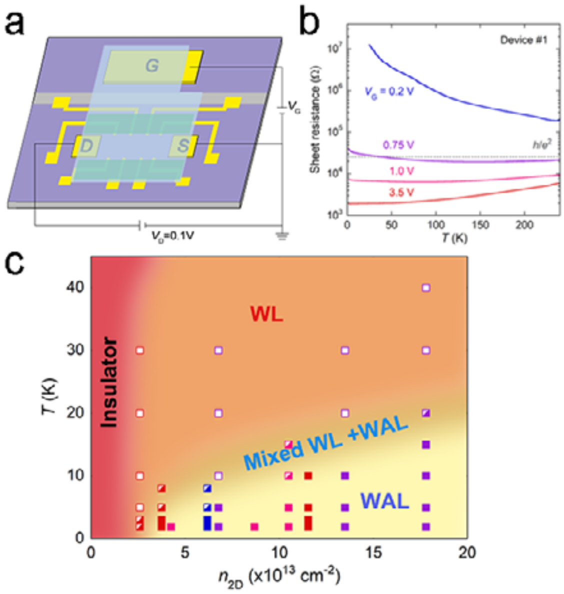

Fig. 1. a) Device structure of fabricated EDLT. b) Temperature-dependent sheet resistance as a function of gate voltage V_G. c) Low-temperature phase diagram against carrier density.

[1]J. Ye et al., Science 338, 1193-1196 (2012).
[2]Y. Schmidt et al., Phys. Rev. Lett. 116, 046803 (2016).
[3]N. Li et al., Nat. Electron. 3, 711-717 (2020).

9th International Workshop on 2D Materials

Title of the Presentation: Quasiparticle interferences of topological materials.

First Name: Zheng

Last Name: Hao

Affiliation: School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai, China

Email: haozheng1@sjtu.edu.cn

Short Biography:

I obtained my Ph.D degree in institute of Physics, Chinese Academy of Science in 2007. Then I have done postdoctoral research in Birmingham University, UK, Kiel University, Germany and Princeton University USA for ten years. In 2017, I joined Shanghai Jiao Tong University as a tenure-tracked associate professor. In 2020, I was promoted as professor. My research interests include experimental study of topological matter, low dimensional material, unconventional superconductors and novel quasiparticles. I have published more than 80 papers, including 3 Science and 13 PRLs. I have been selected as globe highly cited researchers for 2019, 2020 and 2021.

Abstract:

Topological materials, including topological insulator and topological semimetal, are recent discovered novel materials which host many unique properties. In this talk, I will present the main findings of our Scanning tunnelling microscopy investigations on Weyl semimetal [1,2], nodal-line semimetal [3] and superconducting topological insulator [4]. Topological sinking effect, half missing type Umklapp effect and Copper pair momentum induced "segmented" Fermi surface were discovered and will be talked here.

[1]H. Zheng et al., Phys. Rev. Lett. 117, 266804 (2016).
[2]H. Zheng et al., Phys. Rev. Lett. 119, 196403 (2017).
[3]Z. Zhu et al., Nat. Commun. 9, 4153 (2018).
[4 Z. Zhu et al., Science 374, 1381 (2021)

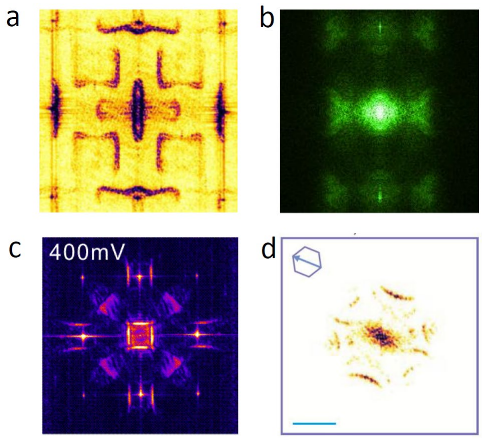

Fig. 1. Quasiparticle interferences on type I (a) and type II (b) Weyl semimetals, nodal line semimetal (c) and superconducting topological insulator(d).

9th International Workshop on 2D Materials

Title of the Presentation: *In-situ* STEM study on transformation of 2D nanostructures on a Graphene "Hot Plate"

First Name: Sang Wook

Last Name: Lee

Affiliation: Department of Physics, Ewha Womans University, Seoul, Korea

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Short Biography:

Professor Sang Wook Lee has achieved his Ph. D at Seoul National University, Korea. He had worked at Gothenburg University in Sweden as a Post Doc. with a support of Nokia Research Center. He appointed as a professor at Konkuk University, Seoul, Korea in 2008-2016, then moved to Ewha Womans University. His main research field is nano electronics and nano mechanics. He is especially interested in following research subjects: Nano transport and nano electromechanical systems, Ultra-sensitive mass and force detector based on nano mechanical devices, In-situ electromechanical measurement of semiconductor nanowires. He received POSCO TJ Park science fellowship (2010) and Applied Physics research award (2016) by Korean Physical Society. He was selected as a Korea's frontier scientist (2012) and Y-KAST member by Korea Academy of Science and Technology.

Abstract:

Dynamic surface modification of suspended graphene at high temperature was directly observed with in-situ scanning transmission electron microscope (STEM) measurement. The suspended graphene devices were prepared on top of the SiN membrane with hole substrate so that STEM observation was conducted under Joule heating processes. Current-voltage characteristics of suspended graphene devices inside of STEM chamber were measured to monitor and control the high temperature condition of graphene surface by estimating electrical power on the devices. During the in-situ STEM observation, it was found that residual materials remained on the graphene surface were removed at high temperature. Dynamic movement of residue on the graphene surface and shrinkage of atomic distance of graphene were also observed while the Joule heating process. The details of substrate and graphene device fabrication, STEM observation, and data analyses with simulation are described in this presentation.

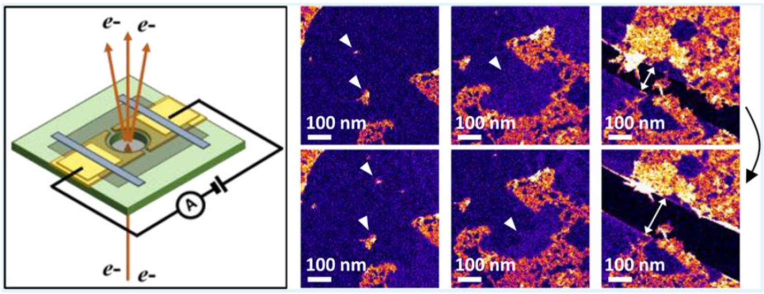

Fig.1 Schematics of graphene "hot plate" device for in-situ TEM investigation (left) and in-situ observation results on graphene surface during Joule heating process (right).

[1] Choi et al. ACS Applied Materials & Interfaces 12, 26313-26319 (2020).

[2] Inani et al. Advanced Functional Materials, 31, 2008395 (2021).

9th International Workshop on 2D Materials

Title of the Presentation: Bilayer graphene: CVD growth, machine learning-based analysis, and intercalation

First Name: Hiroki

Last Name: Ago

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Short Biography:

Hiroki Ago received his PhD from Kyoto University in 1997. After staying at Cavendish Laboratory, Cambridge University during 1997-1999, he moved to National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba as a researcher. In 2003, he moved to Kyushu University and now is a distinguished professor of Kyushu University. His current research focuses on science and applications of nanomaterials, particularly graphene and related 2D materials. He received Iijima Award from the Fullerene-Nanotube Research Society of Japan (2006), Young Scientist Award from the MEXT, Japan (2008), and Best Paper Award from the Japan Society of Applied Physics (2014). Now he is a leader of the new MEXT project "Science of 2.5 Dimensional Materials".

Abstract:

Bilayer graphene (BLG) has attracted increased interest, because of their unique physical properties, such as band gap opening observed in AB-stacked bilayer, and superconductivity found in magic-angle twisted bilayer. In this presentation, the CVD growth of uniform BLG and perfectly AB-stacked BLG are presented with the aid of epitaxial Cu-Ni(111) thin films on c-plane sapphire [1,2]. We developed a new method to determine the twist angle of the CVD-grown BLG by machine learning based on the Raman spectra of BLG [3]. Furthermore, CVD-grown BLG was used to intercalate various metal chlorides molecules [4-6]. In particular, $AlCl_3$ molecules exhibited unique 2D super-structures, which are completely different from the bulk crystal (Fig. 1) [5]. Our work opens a new possibility of making new structures and new materials in the 2D nanospace realized in BLG. I will also introduce our recent work on large-area graphene/hBN heterostructures all made by CVD.

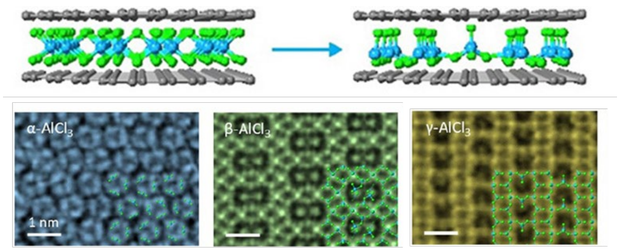

Fig. 1. Intercalation in the interlayer nanospace of BLG. Three new 2D crystal structures of $AlCl_3$ molecules were first discovered in the interlayer nanospace.

[1] Y. Takesaki et al., *Chem. Mater.*, **28**, 4583 (2016).
[2] P. Solis-Fernandez et al., *ACS Nano*, **14**, 6834 (2020).
[3] P. Solis-Fernandez and H. Ago, *ACS Appl. Nano Mater.*, **5**, 1356 (2022).
[4] H. Kinoshita et al., *Adv. Mater.*, **29**, 1702141 (2017).
[5] Y.-C. Lin et al., *Adv. Mater.*, **33**, 2105898 (2021).
[6] Y.-C. Lin et al., *Nano Lett.*, **21**, 10386 (2021).

9th International Workshop on 2D Materials

Title of the Presentation: Novel two-dimensional materials stabilized on substrates

First Name: Yukiko

Last Name: Yamada-Takamura

Affiliation: School of Materials Science, Japan Advanced Institute of Science and Technology (JAIST), Nomi, Japan

Email: yukikoyt@jaist.ac.jp

Short Biography:

Yukiko received B.E. in Materials Science and M.E. and Ph.D. in Metallurgy from The University of Tokyo (UT) in 1993, 1995, and 1998, respectively. She received Doctoral as well as Postdoctoral Research Fellowships from JSPS with which she conducted research on ion-assisted growth of nitride and oxide thin films at UT and Max-Planck Institute for Plasma Physics in Garching. In 2002, She joined the Surface Science Division of IMR, Tohoku University, as a research associate where she conducted *in-situ* scanning probe microscopy studies of nitride and boride thin film growths. In 2006, she joined School of Materials Science, JAIST, to start her research group specialized in the development of nanomaterials based on the understandings of surfaces and interfaces, where she is currently a full professor. She is a member of JIM, JSAP, and APS. Since 2015, she is active as an associate editor of an open access journal "Science and Technology of Advanced Materials". Currently, she is involved in a 10-year MEXT project "Advanced Research Infrastructure for Materials and Nanotechnology in Japan (ARIM)" as an institutional representative.

Abstract:

In this talk, new two-dimensional (2D) materials stabilized only on substrates, so far, which were found in our group will be introduced.

The first one is a 2D Ge lattice having a "bitriangular" structure. Our theoretical study on freestanding bitriangular lattice demonstrated that the flat band of a kagome lattice can be embedded in this very different-looking structure [1]. In parallel, we have grown $ZrB_2(0001)$ thin films on Ge(111) substrates and found that Ge atoms segregate and crystallize into such a bitriangular lattice on the ZrB_2 film surface [2], unlike when the film is grown on Si(111) substrate forming a honeycomb lattice of Si, "silicene" [3].

The second one is a new polymorph "trigonal anti-prismatic" phase of monolayer GaSe which is a semiconducting monochalcogenide. Bulk GaSe is known to crystallize in four polytypes which differ in how layers are stacked via van der Waals interaction, but no polymorph has been reported based on experimental study, including other layered monochalcogenides sharing the same crystal structure, such as GaS or InSe. Through cross-sectional scanning transmission electron microscopy of GaSe thin films grown on Ge(111) substrates, we found that monolayer GaSe with trigonal anti-prismatic structure exist near the film-substrate interface [4]. Our first-principles study [5] implies that the new phase is metastable and can be stabilized by tensile strain.

Our findings add new families of materials to be explored in the ever-emerging field of 2D materials.

[1] C.-C. Lee, A. Fleurence, Y. Yamada-Takamura, and T. Ozaki, Phys. Rev. B, 100, 045150 (2019).
[2] A. Fleurence *et al*., Phys. Rev. B, 95, 201102(R) (2020).
[3] Y. Yamada-Takamura and R. Friedlein, Sci. Technol. Adv. Mater., 15, 064404 (2014).
[4] T. Yonezawa *et al*., Surf. Interface Anal., 51, 95-99 (2019).
[5] H. Nitta *et al*., Phys. Rev. B, 102, 235407 (2020).

Title of the Presentation: Concurrent Lifshitz Transitions of Zone-Center van Hove Singularity and Type-II Dirac Fermions in Two-Dimensional Biphenylene Network

First Name: Young-Woo

Last Name: Son

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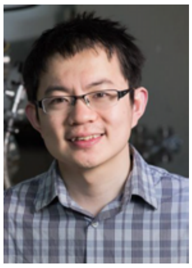
Short Biography:

Y.-W. Son obtained his Ph. D. from Seoul National University and moved to UC Berkeley Louie and Cohen group as a post-doctor. From 2008, he has been a professor at Korea Institute for Advanced Study. His main interests are two-fold: theories of low-dimensional quantum materials and developments of novel theoretical and computational methods for real materials.

Abstract:

We study electronic properties of a new planar carbon crystal formed through networking biphenylene molecules. Unprecedented electronic features among carbon materials such as zone-centre saddle point and peculiar type-II Dirac fermionic states are shown to exist in the low energy electronic spectrum. The type-II state here has a nearly flat branch and is close to a transition to type-I. With a moderate uniaxial strain, a pair of Dirac points merge with the zone centre saddle point, realizing concurrent Lifshitz transitions of van Hove singularity as well as pair annihilation of the Dirac fermion. A new effective Hamiltonian encompassing all distinctive low energy states is constructed, revealing a finite winding number of the pseudo-spin texture around the Dirac point, quantized Zak phases, and topological grain boundary states. Possible magnetic instabilities are also discussed.

Title of the Presentation: Visualization of Chiral Electronic Structure and Anomalous Optical Response in a Material with Chiral Charge Density Waves



First Name: Zhongkai

Last Name: Liu

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Short Biography:

Zhongkai Liu received B.S. in physics from Tsinghua University and Ph. D in Stanford University under the supervision of Prof. Zhi-Xun Shen. After one year experience working as a postdoc in I05, DLS, he started as an assistant professor at ShanghaiTech University. His research interests lie in the photoemission study of topological quantum materials, low dimensional functional materials and development of synchrotron based spatial resolved ARPES.

Abstract:

Chiral materials have attracted significant research interests as they exhibit intriguing physical properties, such as chiral optical response, spin-momentum locking, chiral induced spin selectivity, etc. Recently, layered transition metal dichalcogenide 1T-TaS_2 has been found to host a chiral charge density wave (CDW) order. Nevertheless, the physical consequences of the chiral order, for example, in electronic structures and the optical properties, are yet to be explored. Here, we report the spectroscopic visualization of an emergent chiral electronic band structure in the CDW phase, characterized by windmill-shape Fermi surfaces. We uncover a remarkable chirality-dependent circularly polarized Raman response due to the salient chiral symmetry of CDW, although the ordinary circular dichroism vanishes. Chiral Fermi surfaces and anomalous Raman responses coincide with the CDW transition, proving their lattice origin. Our work paves a path to manipulate the chiral electronic and optical properties in two-dimensional materials and explore applications in polarization optics and spintronics.

Ref:

[1] H. F. Yang et al., under review

Title of the Presentation: Van der Waals Schottky gated MoS_2 metal-semiconductor field-effect transistor at the Schottky-Mott limit

First Name: Yeon Ho

Last Name: Kim

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Short Biography:

Yeon Ho Kim received his B.S. from the Department of Material Science and Engineering of Korea University, Korea. He is currently Ph.D candidate at KU-KIST Graduate School of Converging Science and Technology, Korea University. His research interests are the electrical characteristics of 2D semiconductors and their application to low power electronics.

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 low subthreshold slope even at the atomic scale. To achieve high-performance electronic devices, 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. 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 (MS) 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 within a voltage range of 0.8 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. Due to the steep switching characteristics of the *vdW* MESFET, a voltage gain close to 40 V/V was obtained at V_{dd} = 2.0 V from the serial-connected inverter. Furthermore, the E_F depinning effect in the *vdW* Schottky gate, approaching the Schottky-Mott limit, were verified by investigating the modulation of Schottky barrier heights of various *vdW* junctions with different work functions.

[1] Y. Kim et al., In preparation.

Title of the Presentation: Induced anomalous Hall effect of massive Dirac fermions in $ZrTe_5$ and $HfTe_5$ thin flakes

First Name: Yanzhao

Last Name: Liu

Affiliation: International Center for Quantum Materials, School of Physics, Peking University, Beijing, China

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Short Biography:

Yanzhao Liu obtained his PhD from the International Center for Quantum Materials, School of Physics, Peking University, where he studied quantum transport properties of topological materials under extreme conditions and was supervised by Prof. Jian Wang. He then continued his research in Prof. Jian Wang's group in 2021 as a postdoctoral fellow working on the fabrication and spectroscopic study of two-dimensional high-temperature superconducting systems.

Abstract:

Researches on anomalous Hall effect (AHE) have been lasting for a century to make clear the underlying physical mechanism. Generally, the AHE appears in magnetic materials, in which the extrinsic process related to scattering effects and intrinsic contribution connected with Berry curvature are crucial. Recently, AHE has been counterintuitively observed in non-magnetic topological materials and attributed to the existence of Weyl points. However, the Weyl point scenario would lead to unsaturated AHE even in large magnetic fields and contradicts the saturation of AHE in several tesla (T) in experiments. In this work, we investigate the Hall effect of $ZrTe_5$ and $HfTe_5$ thin flakes in static ultrahigh magnetic fields up to 33 T. We find the AHE saturates to 55 (70) $\Omega^{-1}\cdot cm^{-1}$ for $ZrTe_5$ ($HfTe_5$) thin flakes above ~ 10 T. Combining detailed magnetotransport experiments and Berry curvature calculations, we clarify that the splitting of massive Dirac bands without Weyl points can be responsible for AHE in non-magnetic topological materials $ZrTe_5$ and $HfTe_5$ thin flakes. This model can identify our thin flake samples to be weak topological insulators and serve as a new tool to probe the band structure topology in topological materials.

[1]Yanzhao Liu et al., Physical Review B 103, L201110 (2021). https://doi.org/10.1103/PhysRevB.103.L201110

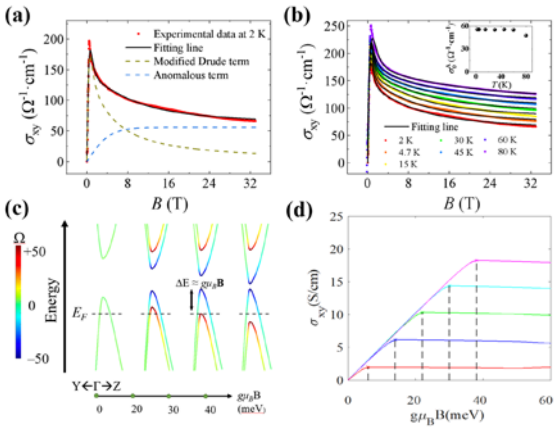

Fig. 1. Anomalous Hall effect in $ZrTe_5$ and $HfTe_5$ thin flakes. (a) Hall conductivity as a function of magnetic fields. (b) Magnetic field dependence of Hall conductivity at selected temperatures. (c) The band structure evolution with respect to the Zeeman splitting. (d) Calculated anomalous Hall conductivity with different carrier densities.

9^{th} International Workshop on 2D Materials

Title of the Presentation: Giant Stark effect in Bilayer MoS_2 Field-Effect Transistors

First Name: Haruki

Last Name: Uchiyama

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Short Biography:

Haruki Uchiyama received his Ph.D. in Engineering from Nagoya University on 2021 under the supervision of Prof. Yutaka Ohno. Now he worked as a postdoc in the University of Tokyo supervised by Prof. Kosuke Nagashio. His research focuses on giant Stark effect in bilayer transition metal dichalcogenide and high-κ oxide on 2D materials.

Abstract:

Large energy modulation has been achieved by the Stark effect in bilayer transition-metal dichalcogenides (TMDs).[1] The giant Stark effect in 2D TMDs have made modulation of exciting optoelectronic features, such as band gaps, energy of interlayer exciton.[1,2] In comparison with the widely studied modulation of optical properties by the Stark effect, studies focusing on transport properties are quite limited. The mobility enhancement is anticipated by applying the Stark effect to a bilayer 2D TMD field effect transistors (FETs). Under the out-of-plane electric field, the top/bottom layers are separated into transport/screening layers. Since scattering sources (ex. impurity, remote phonon from dielectrics) are blocked by the top screening layer, the carriers in the bottom transport layer are expected to have a high mobility.

Here, we demonstrate the enhancement of carrier mobility in bilayer MoS_2 FETs by the Stark effect as shown in Fig. 1. The wide range of out-of-plane electric fields on bilayer MoS_2 FET was achieved by a dual-gate structure with the back-gate dielectric SiO_2 (t= 90 nm, ε= 3.5) and the top-gate dielectric Er_2O_3 (t= 15 nm, ε= 7.5). The total carrier mobility of MoS_2 field-effect transistor increased from 29 cm^2/Vs to 50 cm^2/Vs with increasing the electric field. When the carrier distribution in top/bottom layers in bilayer MoS_2 FET was estimated by simple analytical model, it was elucidated that the carriers were dominantly distributed in the bottom layer under the high electric field. Although the carrier mobility of the top layer was degraded due to the high-κ gate deposition process, the carriers distributed in the bottom layer resulted in the enhancement of the total carrier mobility with the help of the screening effect by the top layer. Our results have paved the way for the realization of high mobility 2D TMD channels by controlling the carrier distribution using the Stark effect in the real application.

[1] T. Chu et. al., Nano Lett. 15, 8000 (2015).
[2] N. Leisgang et al., Nat. Nanotechnol. 15, 901 (2020).

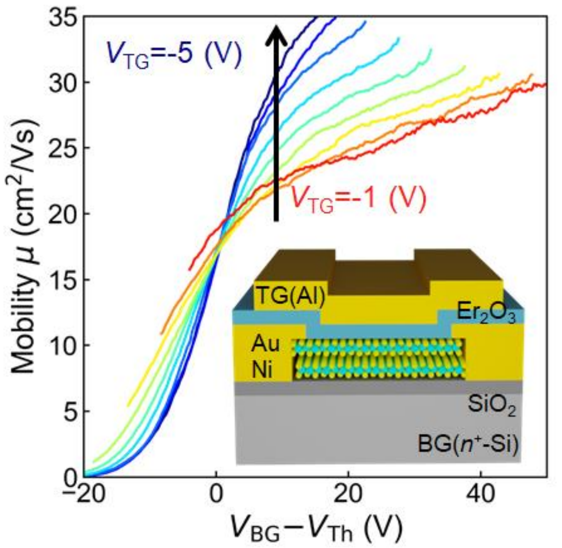

Fig. 1. Giant Stark effect in bilayer MoS_2-FETs

9th International Workshop on 2D Materials

Title of the Presentation: Surface charge transfer doping of TMD transistor channels by a damage-free stamping method

First Name: Yongjae

Last Name: Cho

Affiliation: Department of Physics, Yonsei University, Seoul, South Korea

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Short Biography:

Yongjae Cho received the B.S. degree Ph.D. degree in Applied Physics from Yonsei University in 2017 and 2021. The research area is interface engineering of TMD based transistors.

Abstract:

Charge-transfer doping of 2D TMD transistor has generally been done by thermal deposition of inorganic or organic thin-film layers. Although it is widely known that thermal deposition causes minimal damage compared to e-beam evaporation or sputtering, we found that thermal deposition also damages sub-nm thin 2D channel with the kinetic energy of depositing atoms. It causes hysteresis or certain degradation during transistor operation.

Here, stamping method is employed instead of thermal deposition for more desirable charge-transfer doping. MoO_3 or LiF is initially deposited on the polydimethylsiloxane (PDMS) stamp as a doping medium and the stamp is applied to 2D channel, making a van der Waals-like damage-free interface between the channel and doping media. Hysteresis-minimized transfer characteristics are achieved from stamp-doped FETs, while other devices with direct thermal deposition-doped channels show large hysteresis. The stamp-induced doping is also applied for $MoTe_2$-based complementary inverter, where MoO_3- and LiF-doping by separate stamps modify two ambipolar $MoTe_2$ channels to p- and n-type, respectively.

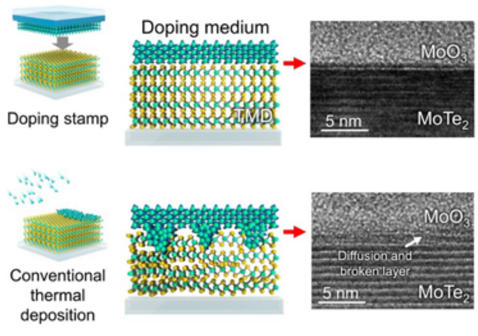

Fig. 1. Damage-free $MoO_3/MoTe_2$ interface achieved by stamping method

9th International Workshop on 2D Materials

Title of the Presentation: Extrinsic and intrinsic anomalous metallic states in transition metal dichalcogenide Ising superconductors

First Name: Ying

Last Name: Xing

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Short Biography:

Ying Xing, associate professor at China University of Petroleum-Beijing, received her bachelor's degree from Inner Mongolia University in 2011, and PhD degree in condensed matter physics from Peking University in 2016 (Adviser: Prof. Jian Wang). From 2016, she worked as an associate professor at China University of Petroleum-Beijing. Her current interests include quantum phase transitions, anomalous metallic state in low dimensional superconductors and superconductivity in topological materials. More details: http://www.cup.edu.cn/cnem/szdw/fg/172830.htm

Abstract:

The metallic ground state in two-dimensional (2D) superconductors has attracted much attention but is still under intense scrutiny. Especially, the measurements in ultralow temperature region are challenging for 2D superconductors due to the sensitivity to external perturbations. In this work, the resistance saturation state induced by external noise, named as "extrinsic anomalous metallic state", is observed in 2D transition metal dichalcogenide (TMD) superconductor 4*Ha*-$TaSe_2$ nanodevices. However, with further decreasing temperature, credible evidence of intrinsic anomalous metallic state is obtained by adequately filtering external radiation. Our work indicates that at ultralow temperatures the anomalous metallic state can be experimentally revealed as the quantum ground state in 2D crystalline TMD superconductors. Besides, Ising superconductivity revealed by ultrahigh in-plane critical field going beyond the Pauli paramagnetic limit is detected in 4*Ha*-$TaSe_2$, from one-unit-cell device to bulk situation, which might be due to the weak coupling between the $TaSe_2$ sub-monolayers.

[1] Ying Xing *et al*. Nano Letters 21(18) 7486-7494 (2021)

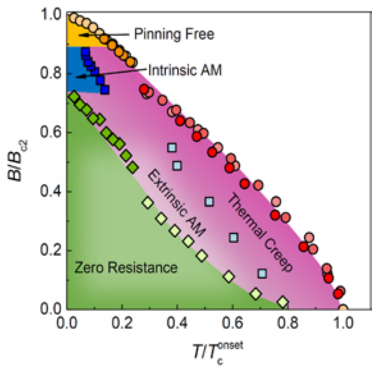

Figure Phase diagram.

9th International Workshop on 2D Materials

Title of the Presentation: Unconventional excitonic states in layered SiP_2

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Last Name: Tang

Affiliation: School of Material Science and Engineering, Beihang University, Beijing, China.

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Short Biography:

Prof. Tang got the Ph.D degree from the Department of Physics in Tsinghua University, Beijing China in 2015. After that, he worked as a post-doctor researcher in Prof. Shou-Cheng Zhang's group in Stanford University, USA until 2017. From 2017 to 2020, he worked as a post-doctor in Prof. Angel Rubio's group in Max-Planck Institute for Structure and Dynamic of Matter (MPSD) in Hamburg, Germany. In 2018, he won the Marie-Currie Fellowship. Since 2020, he is the Professor in the School of Material Science and Engineering in Beihang University, Beijing China. Prof. Tang's research focuses on the topological materials and light-matter interaction by using ab initio methods.

Abstract:

Many-body interactions between quasiparticles (electrons, excitons and phonons) have led to the emergence of new complex correlated states and are at the core of condensed matter physics and material science. In low-dimensional materials, unique electronic properties for these correlated states could significantly affect their optical properties. In this talk, we systemically demonstrate an unconventional excitonic state and its bound phonon sideband in layered silicon diphosphide (SiP2), in which the bound electron-hole pair is composed of electrons confined within one-dimensional phosphorus–phosphorus chains and holes extended in two-dimensional SiP2 layers. The excitonic state and the emergent phonon sideband show linear dichroism and large energy redshifts with increasing temperature. Within the GW plus Bethe–Salpeter equation calculations and solving the generalized Holstein model non-perturbatively, we confirm that the observed sideband feature results from the correlated interaction between excitons and optical phonons. Furthermore, we show the excitonic states could be tuned via layer stacking in SiP2.

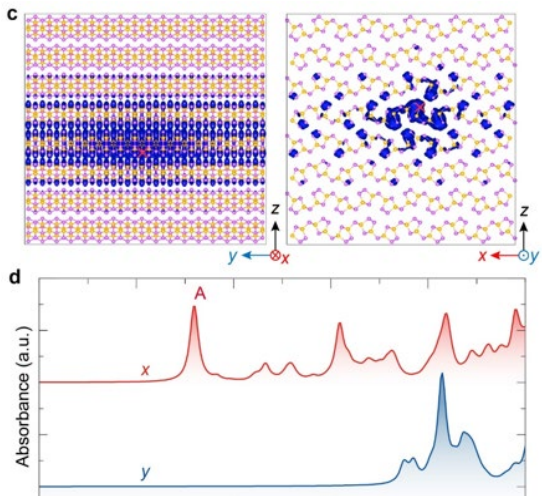

Fig. 1. Exciton's wavefunctions and absorptions in SiP2.

9th International Workshop on 2D Materials

Title of the Presentation: Barristor-based sensor platform with extreme sensitivity

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Last Name: Chung

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Short Biography:

In 2005, he received Ph. D degree in Seoul National University, Korea. Then, he moved to Korea research institute of standard science as a postdoctoral researcher. Since he joined Samsung Advanced Institute of Technology in 2006, where he initiated graphene research, he has conducted research in graphene electronics. Based on the research, he co-authored a review article in Nature with the president of Samsung Advanced Institute of Technology. To solve the well-known switching problem of graphene transistor, he invented a new electronic device, modulating the graphene-Si Schottky-barrier height, published in Science. He named the device "barristor," meaning barrier transistor, since the current can be modulated by modulating the Schottky-barrier. Then he moved to Konkuk University in 2013 and conducted research to discover the barristor's potential and limitations. To discover the potential, he is now conducting research on the graphene electronic device as a sensor framework.

Abstract:

Since graphene has unique properties such as unprecedently high electron mobility up to 140,000 cm2/V·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_{ON}/I_{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 ~ 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.

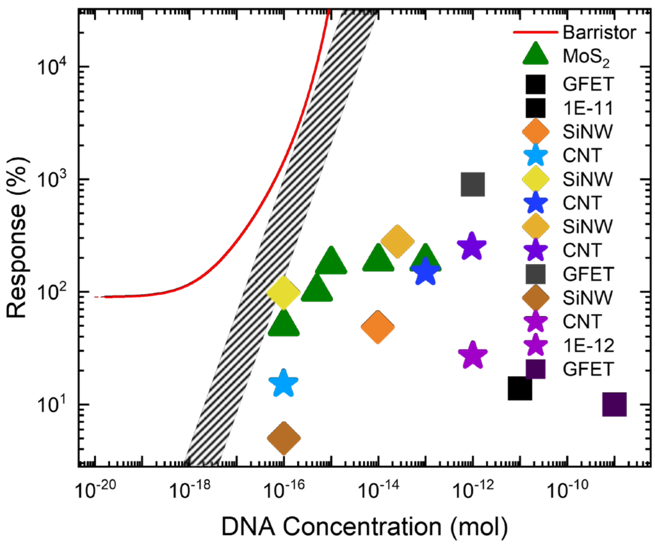

Fig. 1. Sensitivity of graphene barristor and various transistors using graphene, carbon nanotubes, and Si nanowires.

[1] H. Yang, et al., Science. 336, 1140–1143 (2012).

[2] J. Lee et al., Nature Commun. 12, 1000 (2021).

9th International Workshop on 2D Materials

Title of the Presentation: Monolayer in-plane heterojunction light-emitting devices with tunable composition distribution

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Last Name: Pu

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Short Biography:

Dr. Jiang Pu is an assistant professor in Department of Applied Physics at Nagoya University, Japan. He received his B.E and M.E degrees in Applied Physics from Waseda University, Japan. He completed his Ph.D. in the Leading Graduate Program in Science and Engineering at Waseda University in 2017, supported by Ministry of Education, Culture, Sports, Science and Technology (MEXT). During his Ph.D., he also was selected as the Research Fellowship for Young Scientists from Japan Society of Science.

Abstract:

Atomically thin transition metal dichalcogenides (TMDCs) are an attractive material for functional optoelectronic applications because of their diverse bandgaps, robust exitonic emission/absorption, and unique quantum (spin-valley) properties [1]. In particular, the in-plane heterojunctions based on TMDC monolayers provide opportunities to directly modulate band structures and lattice strains by the spatial distribution of constituent elements, leading to further control of light-emitting capability. However, it is still challenging to create light-emitting devices and to explore the electroluminescence (EL) properties using in-plane heterostructures with tunable composition distribution. Here, we demonstrate the EL influenced by composition distribution in monolayer in-plane heterojunctions through by adopting electrolyte-based light-emitting device structures, as shown in Fig. 1 [2,3].

In this talk, we focus on two types of monolayer in-plane heterojunction light-emitting devices. One is the realization of light-emitting devices with atomically sharp heterojunction interfaces that is grown by chemical vapor deposition (CVD). We directly observed interfacial EL in various TMDC heterojunctions (Fig. 1: Left), in which their EL was significantly affected by interfacial strains. As a result of strain effects, we can generate room temperature chiral EL at steep heterojunction interfaces. The other is the demonstration of light-emitting devices using the composition graded monolayer TMDC alloys synthesized by CVD. The spatial composition gradient directly reflect the light-emitting energy varied from 2.1 eV to 1.7 eV (Fig. 1: Right). In this device, we utilized the spatial control of recombination zone in the electrolyte-based devices [4]. As a consequence, we can achieve continuous and reversible color-tunable light-emitting devices (Fig. 1: Bottom). Our results provide a new approach for exploring quantum light sources and developing broadband optical applications based on monolayer semiconductors.

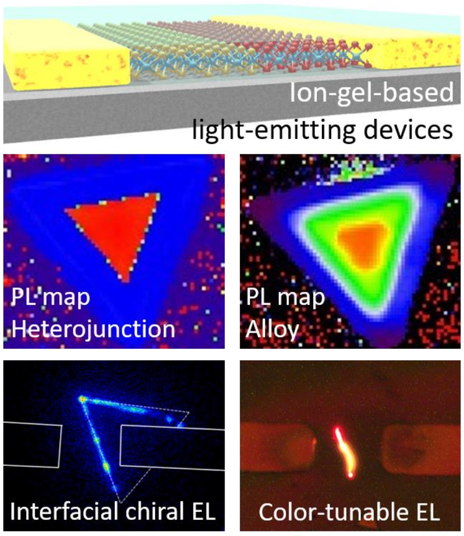

Fig. 1 Functional in-plane hetero-device

[1] J. Pu and T. Takenobu Adv. Mater. 30, 1707627 (2018).
[2] J. Pu, et al., Adv. Mater. 29, 1606918 (2017).
[3] J. Pu, et al., Adv. Mater. 33, 2100601 (2021).
[4] H. Ou, J. Pu, et al., ACS Nano 15, 12911 (2021).