6th International Workshop on 2D Materials

September 24 ~ 25, 2020
Online

A3 Foresight Program

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Japan Society for the Promotion of Science

Co-organized by

Sogang University

vdWMRC
Van der Waals Materials Research Center
Guide to Participants

- Please use a PC or a Mac (including notebook computers) and make sure that your Zoom clients are updated to the latest version.

- **Oral Sessions** (Invited and Contributed Talks)
  - There will be two separate Zoom meetings for the two days.
  - The Zoom links will be distributed through the representatives of the three countries.
  - The speakers and the chairperson are asked to enter the meeting 15 minutes prior to the beginning of each session. The speakers and the chair will be made co-hosts so that they can share screens.
  - All the participants except the speaker and the chair should mute their microphones during the presentation.
  - For Q&A, the participants can ‘raise hand’ in the ‘Participants’ panel. When the chair allows, the participant can unmute his/her microphone and ask questions.

- **Poster Session**
  - The poster session will be hosted by using the ‘Breakout Rooms’ of Zoom.
  - Do not use mobile devices (Android phones & tablets, iPhones, iPads) because you will not be able to move from one poster to another.
  - Each poster will be assigned to a breakroom which will be named with the poster number (C1, J2, K3, etc.)
  - In order to have access and navigate freely through these rooms you will be given co-host rights by the host (otherwise you can only be in one of the break-out rooms and not navigate through them). As you enter the meeting at the start of the session, it may take a few minutes for everyone to be set up with co-host rights. If you are not made co-host within 5 minutes, please raise your hand.
  - After you become a co-host, you will be assigned to the Reception Room. Once there, you will see that you can jump to the other rooms and will also see who is in which room (and how crowded they are). You can navigate among them as you would in a real poster session.
  - If you are a presenter, go to the breakout room with your poster number and stay there for the entire session. When a visitor enters your breakout room, start your poster presentation by sharing your screen (with the PowerPoint slide show). Try to make the presentation brief so that the visitor can ask some questions. When a new visitor joins, repeat this.
  - The poster session will remain open as long as people are engaged in discussions.
• There will be some extra breakout rooms without a poster number. These are for one-on-one discussion among participants who are not poster presenters. If you want to discuss something with a specific person, invite the person (by using the chatting function of Zoom) to a specific breakout room and go there yourself.
# Program

**Thursday, September 24**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session 1</th>
<th>Chair: Hyeonsik Cheong</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:25 – 09:30</td>
<td>Opening Remarks</td>
<td></td>
</tr>
<tr>
<td>09:30 – 10:00</td>
<td>Hyobin Yoo (Sogang Univ.)</td>
<td>Invited-K1</td>
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<tr>
<td></td>
<td>Atomic and electronic reconstruction at van der Waals interface in twisted 2-D materials</td>
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</tr>
<tr>
<td>10:00 – 10:30</td>
<td>Yuya Shimazaki (ETH Zurich)</td>
<td>Invited-J1</td>
</tr>
<tr>
<td></td>
<td>Strongly correlated electrons in a moiré superlattice probed with exciton spectroscopy</td>
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</tr>
<tr>
<td>10:30 – 11:00</td>
<td>Can-Li Song (Tsinghua Univ.)</td>
<td>Invited-C1</td>
</tr>
<tr>
<td></td>
<td>Fulleride superconductivity at the two-dimensional limit</td>
<td></td>
</tr>
<tr>
<td>11:00 – 11:15</td>
<td><strong>Break</strong></td>
<td></td>
</tr>
<tr>
<td>11:15 – 11:45</td>
<td>Ding Zhang (Tsinghua Univ.)</td>
<td>Invited-C2</td>
</tr>
<tr>
<td></td>
<td>Ising pairing in few-layer stanene and modulation of superconductivity via lithium intercalation</td>
<td></td>
</tr>
<tr>
<td>11:45 – 12:15</td>
<td>Tomoki Machida (Univ. of Tokyo)</td>
<td>Invited-J2</td>
</tr>
<tr>
<td></td>
<td>Quantum transport in van der Waals junctions of graphene and h-BN</td>
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</tr>
<tr>
<td>12:15 – 13:15</td>
<td><strong>Lunch</strong></td>
<td></td>
</tr>
</tbody>
</table>

## Session 2

**Chair: Hongtao Yuan**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session 3</th>
<th>Chair: Yashihiro Iwasa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Magnetism of Nanographene-based Nanoporous Carbon and its Applications</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2D Heterojunctions for High-Performance Electronic and Optoelectronic Devices</td>
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<tr>
<td>14:15 – 14:45</td>
<td>Kosuke Nagashio (Univ. of Tokyo)</td>
<td>Invited-J4</td>
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<tr>
<td></td>
<td>In-plane ferroelectricity in monolayer SnS</td>
<td></td>
</tr>
</tbody>
</table>
14:45 – 15:15  Sang Wook Lee (Ewha Womans Univ.)  Invited-K3
Fowler-Nordheim tunneling through 2D atomic layers

15:15 – 15:30  Break

Session 4  Chair: Young-Woo Son

15:30 – 16:00  Yi Zhang (Nanjing Univ.)  Invited-C3
Controllable Growth and Electronic Structures of 2D Transition Metal Dichalcogenides Thin Films

16:00 – 16:30  Hyeon Suk Shin (UNIST)  Invited-K4
Ultralow-dielectric-constant amorphous boron nitride

16:30 – 16:45  Yijun Yu (Fudan Univ.)  Contributed-C1
High-temperature superconductivity in monolayer Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$

16:45 – 17:00  Suhan Son (Seoul National Univ.)  Contributed-K1
Strongly adhesive dry transfer technique by polycaprolactone

17:00 – 17:15  Hideki Matsuoka (Univ. of Tokyo)  Contributed-J1
Magnetic van der Waals heterostructures with Zeeman-type spin-orbit-interaction

17:15 – 17:30  Cheng Chen (Shanghaitech Univ.)  Contributed-C2
Observation of topological electronic structure in a quasi-1D superconductor

17:30 – 18:30  Poster Session

Friday, September 25

Session 5  Chair: Taishi Takenobu

09:30 – 10:00  Katsuaki Sugawara (Tohoku Univ.)  Invited-J5
The electronic state of atomic-layer TMDs studied by high-resolution ARPES

10:00 – 10:30  Joon Ik Jang (Sogang Univ.)  Invited-K5
Boosting optical responses of two-dimensional semiconducting transition metal dichalcogenides

10:30 – 11:00  Qing Zhang (Peking Univ.)  Invited-C4
Stimulated Emission in Solution-processed Two-dimensional Perovskite Semiconductor
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker/Institution</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:00 – 11:15</td>
<td><strong>Break</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:15 – 11:45</td>
<td>Jian Wang (Peking Univ.)</td>
<td>Invited-C5</td>
<td>High-Chern-Number and High-Temperature Quantum Hall Effect without Landau Levels</td>
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<tr>
<td>11:45 – 12:15</td>
<td>Michihisa Yamamoto (RIKEN)</td>
<td>Invited-J6</td>
<td>Electron transport in a correlated quantum Hall antiferromagnetic state of bilayer graphene</td>
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<td></td>
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</tr>
<tr>
<td>12:15 – 12:45</td>
<td>Yujun Deng (Fudan Univ.)</td>
<td>Invited-C6</td>
<td>Quantum Anomalous Hall Effect in Few-layer MnBi₂Te₄</td>
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<tr>
<td>12:45 – 13:00</td>
<td><strong>Closing</strong></td>
<td>Yoshihiro Iwasa</td>
<td></td>
</tr>
</tbody>
</table>
Posters

(17:30 – 18:30, Thursday, September 24)

Poster-C1 Cheng Chen (Peking Univ.)
Zero-energy bound states in the high-temperature superconductors at the two-dimensional limit

Poster-C2 Qiuyu Shang (Peking Univ.)
Exciton–Polariton in a Continuous-Wave Optically Pumped Perovskite Laser

Poster-C3 Miao-Ling Lin (Institute of Semiconductors, CAS)
The angle-resolved polarized Raman scattering in anisotropic layered materials

Poster-C4 Dinghui Wang (Nanjing Univ.)
Large Dynamical Axion Field in Topological Antiferromagnetic Insulator Mn₂Bi₂Te₅

Poster-C5 Dongjing Lin (Nanjing Univ.)
Effects of dimensionality on the charge-density-wave order in 2H transition metal dichalcogenides

Poster-C6 Xuedong Xie (Nanjing Univ.)
Band engineering in epitaxial monolayer transition metal dichalcogenides alloy MoₓW₁₋ₓSe₂ thin films

Poster-C7 Haolin Wang (Nanjing Univ.)
Local conduction at BiFeO₃-CoFe₂O₄ two-dimensional tubular interfaces

Poster-C8 Yichi Zhang (Peking Univ.)
A native oxide high-κ gate dielectric for 2D electronics

Poster-C9 Xuehan Zhou (Peking Univ.)
Molecular Beam Epitaxy of High-mobility 2D Oxychalcogenide Semiconductors

Poster-C10 Haoxiong Zhang (Tsinghua Univ.)
Induced Anisotropic Superconductivity in Ionic Liquid Cation Intercalated 1T-SnSe₂

Poster-J1 Yoshihiro Iwasa (Univ. of Tokyo)
Vortex matter in 2D Superconductors

Poster-J2 Seiya Suzuki (NIMS)
Segregation growth of germanene at interfaces between van der Waals materials and Ag(111)

Poster-J3 Hiroki Sugawara (Tohoku Univ.)
Process development and crystal quality evaluation of van der Waals nanocapacitor using graphene/h-BN heterostructures stacked by transfer/stacking method

Poster-J4 Yan Zhang (Kyoto Univ.)
Charge Transfer and Magnetic Proximity Effect in van der Waals Heterostructure of Monolayer MoSe₂ and Double-layered Manganese Oxide
Poster-J5  Yuma Tanaka (Univ. of Tokyo)
Observation of the layer dependent electronic structures in atomically thin WTe$_2$ flakes

Poster-J6  Miuko Tanaka (Univ. of Tokyo)
Electron transport mechanism in a correlated quantum Hall antiferromagnetic state of bilayer graphene

Poster-J7  Naofumi Sato (Tohoku Univ.)
Controlled synthesis of graphene nanoribbons from liquid phase catalyst

Poster-J8  Tappei Kawakami (Tohoku Univ.)
Electronic states of monolayer VTe$_2$ thin film studied by high-resolution ARPES

Poster-J9  Jiang Pu (Nagoya Univ.)
Chiral electroluminescence in monolayer heterojunctions

Poster-K1  Sohwi Kim (Konkuk Univ.)
Synaptic Performance with Improved Linearity and Endurance by modulating Pb(Zr$_{0.52}$Ti$_{0.48}$)O$_3$/Nb doped SrTiO$_3$ Interface Barrier

Poster-K2  Yeryun Cheon (Sogang Univ.)
Interlayer coupling and structural phase transition in few-layer 1T' and T$_d$ MoTe$_2$

Poster-K3  Jinwon Lee (POSTECH)
Realization of a Honeycomb-Lattice Mott Insulating State on 1T-TaS$_2$

Poster-K4  Junho Seo (CALDES, IBS & POSTECH)
Tunable high-temperature itinerant antiferromagnetism in a van der Waals magnet

Poster-K5  EuiHyoun Ryu (Korea Univ.)
ReS$_2$ based $pn$ Heterojunction Device

Poster-K6  Seohyun Nam (Sogang Univ.)
Population dynamics of excitons and biexcitons in a 2D halide perovskite single crystal

Poster-K7  Taewook Kim (Yonsei Univ.)
2D TMD Channel with 1D ZnO Nanowire for Nonvolatile Trap Memory

Poster-K8  Yongjae Cho (Yonsei Univ.)
Low voltage operating nonvolatile memory transistor with MoTe$_2$ channel and P(VDF-TrFE) ferroelectric

Poster-K9  Yoonseok Kim (Korea Univ.)
Atomic-Layer-Confined Multiple Quantum Wells Enabled by Monolithic Bandgap Engineering of Transition Metal Dichalcogenides

Poster-K10  Hyeok Jun Jin (KAIST)
Atomically thin Schottky junction with a gap-mode plasmon for Enhanced photoresponsivity in MoS$_2$ based photodetector

Poster-K11  Jun Ho Lee (Konkuk Univ.)
High-speed residue-free transfer of two-dimensional materials using PDMS stamp and water infiltration
ABSTRACTS
Atomic and electronic reconstruction at van der Waals interface in twisted 2-D materials

First Name: Hyobin
Last Name: Yoo
Affiliation: Department of Physics, Sogang University, Seoul
Email: hyobinyoo@sogang.ac.kr

Short Biography:
Hyobin Yoo received his B.S. (2010) and Ph.D. (2016) in Materials Science and Engineering from Seoul National University. His graduate study consisted of investigating the atomic structures of compound semiconductor materials using transmission electron microscopy. He was a post-doctoral fellow in the Department of Physics at Harvard University where he studied the correlation between quantum electronic transport and atomic structures of 2-D van der Waals heterostructures. He joined the Department of Physics at Sogang University as a junior faculty member in 2020.

Abstract:
Controlling the interlayer twist angle in two-dimensional (2-D) van der Waals (vdW) heterostructures offers an experimental route to create moire superlattices. One can realize exotic electronic states by adjusting the width of the electronic band widths with a tunable moire length scale. However, in the small twist angle regime, the interplay between the vdW interaction energy and the elastic energy at the interface can cause significant structural reconfiguration, creating the arrays of commensurate domain structures. [1] In this talk, we will discuss the atomic reconstruction at twisted vdW interfaces and its effect on electronic structure and electrical transport behavior. Moreover, we note that one can tune the domain topology at the reconstructed interface using 2-D vdW crystals that has lower symmetry. We will also discuss the connection between crystal symmetry and tunable domain topology.


Fig. 1. Transmission electron microscopy dark-field image of twisted bilayer graphene that shows alternating contrast of AB/BA domains.
Strongly correlated electrons in a moiré superlattice probed with exciton spectroscopy

First Name: Yuya
Last Name: Shimazaki
Affiliation: Department of Physics, ETH Zurich, Zurich, Switzerland
Email: yuyas@phys.ethz.ch

Short Biography:

Yuya Shimazaki received his PhD from University of Tokyo (2016), where he studied electronic transport properties of graphene [1]. He received JSPS overseas research fellowship and currently works as a postdoctoral researcher at ETH Zurich, Switzerland in Quantum Photonics Group. His research interest is exploration and engineering of condensed matter physics in van der Waals heterostructures, and he is developing exciton charge sensing schemes to probe electronic states.

Abstract:

2D material moiré heterostructure constitute a novel platform to study many body physics of electrons and excitons. Transport study of twisted bilayer graphene revealed rich exotic phase of electrons including from Mott insulator state to superconductivity. On the other hand, optical spectroscopy study revealed the effect of moiré lattice potential on excitons in transition metal dichalcogenide (TMD) heterostructure, but the correlated phase of electrons has been elusive.

In this talk, I will present optical spectroscopy study of homo bilayer TMD moiré heterostructure, and report the observation of strongly correlated incompressible electronic state [1]. We utilized a boron nitride (hBN) encapsulated MoSe₂ / hBN (1L) / MoSe₂ heterostructure with top and bottom gates, which enable independent control of the chemical potential and the electric field. Tightly bound excitons in TMD interact with Fermi sea carriers by forming exciton-polaron, and we utilized the energy shift of exciton-polaron resonance to detect layer resolved charge configuration by optical means. In low electron density regime, we found periodic chemical potential dependence of carrier filling behavior indicating existence of moiré subband structure (Fig. 1). By analyzing interlayer charge transfer behavior between top and bottom MoSe₂ while tuning electric field, we figured out abrupt interlayer charge transfer happens at specific filling around 1 electron / moiré unit cell, evidencing the emergence of strongly correlated incompressible electronic state. In this incompressible state, we also observe emergence of new excitonic resonances from umklapp scattering, which is evidencing the emergence of charge order [2].

This highly tunable twisted MoSe₂ homo bilayer system separated by a monolayer hBN barrier with weak moiré potential, provides a promising platform for investigating strongly correlated Mott-Wigner physics.


Fig. 1. Layer resolved periodic charge filling behavior revealed by excitonic charge sensing.
Fulleride superconductivity at the two-dimensional limit

First Name: Can-Li
Last Name: Song
Affiliation: Physics Department, Tsinghua University, Beijing, China
Email: clsong07@mail.tsinghua.edu.cn

Short Biography:

Can-Li Song has been an associate professor in the Department of Physics at Tsinghua University, China, since 2017. He obtained his PhD degree from Tsinghua University in 2011. He received the Lawrence Golub Postdoctoral Fellowship and conducted postdoctoral research in the Department of Physics at Harvard University. His research focuses on molecular beam epitaxy growth and scanning tunneling microscopy studies of quantum materials, such as high-temperature superconductors.

Abstract:

Alkali-fulleride superconductors with a maximum critical temperature $T_c \sim 40$ K share a common electronic phase diagram with unconventional high-$T_c$ superconductors where the superconductivity resides proximate to a magnetic Mott-insulating state\textsuperscript{[1]}. However, distinct from atom-based superconductors such as cuprates, which superconduct through two-dimensional (2D) CuO$_2$ planes, fullerides are attributed to the three-dimensional (3D) members of high-$T_c$ family. In this talk, I will show that both trilayer $K_3C_60$ and $Rb_3C_60$ films display fully gapped strong coupling $s$-wave superconductivity that coexists spatially with a cuprate-like pseudogap above $T_c$ and within vortices\textsuperscript{[1]}. A precise control of merohedral disorder, electronic correlations and doping reveals that superconductivity occurs near a superconductor-Mott insulator transition and reaches its peak at half filling. The $s$-wave symmetry retains over the entire phase diagram, which, in conjunction with an abrupt decline of the superconductivity below half-filling, indicates that alkali fullerides are predominantly phonon-mediated superconductors, although the electronic correlations also come into play.

This work was financially supported by the Ministry of Science and Technology of China, the Natural Science Foundation of China, and in part by the Beijing Advanced Innovation Center for Future Chip (ICFC)

\textsuperscript{[1]} Y. Takabayashi et al., Phil. Trans. R. Soc. A 374, 20150320 (2016).

Ising pairing in few-layer stanene and modulation of superconductivity via lithium intercalation

First Name: Ding
Last Name: Zhang
Affiliation: Department of Physics, Tsinghua University, Beijing, China
Email: dingzhang@mail.tsinghua.edu.cn

Short Biography:

Ding Zhang did his PhD at Max Planck Institute for Solid State Research in Germany from 2008 to 2014. He then joined Tsinghua first as a postdoc and started his tenure track in 2016. He is an experimentalist in condensed matter physics, with the current interest in low-dimensional superconductivity, high temperature superconductivity, and low-temperature transport techniques.

Abstract:

In this talk, I will present our recent studies on the emergent superconductivity in few-layer stanene [1][2] as well as superconductor-insulator or superconductor-metal transition induced by lithium ion intercalation [3]. In the first part, I will report the discovery of superconductivity in few-layer stanene—ultrathin gray tin (111). Few-layer stanene not only exhibits two-dimensional superconductivity but also topologically non-trivial band structures [1]. Furthermore, they host enhanced in-plane upper critical fields that greatly exceed the conventional limit. We propose that this anomalous behavior stems from a novel type of Ising pairing [2]. In the second part, I will present the application of a recently emerged solid-state gating technique. By using this technique, we are able to continuously tune a high temperature cuprate superconductor from the optimal doping to the under-doped regime [3]. We further employ this technique to induce superconductivity in titanium diselenide. Interestingly, we observe the anomalous metal phase even in relatively thick films of titanium diselenide.
Quantum transport in van der Waals junctions of graphene and h-BN

First Name: Tomoki
Last Name: Machida
Affiliation: Institute of Industrial Science, University of Tokyo, Japan
Email: tmachida@iis.u-tokyo.ac.jp

Short Biography:
Professor, Institute of Industrial Science, University of Tokyo

Abstract:
We present our recent experiments on fabrication and quantum transport in van der Waals junctions of graphene and 2D materials [1-5]: (i) We study mid-infrared/THz photoresponse in graphene/h-BN van der Waals heterostructures and discuss cyclotron resonance in monolayer, bilayer, trilayer, twisted bilayer graphene, and graphene under double Moiré superlattice potential. (ii) Hexagonal boron nitride (h-BN) crystals grown under ultrahigh pressures and ultrahigh temperatures exhibit a high crystallinity and are used throughout the world as ideal substrates and insulating layers in van der Waals heterostructures. However, in their central region, these crystals have domains, which contain a significant density of carbon impurities. We reveal that the carbon (C)-rich domain can exist even after exfoliation. Then, we study the carrier transport of graphene in h-BN/graphene/h-BN van der Waals heterostructures, precisely arranging the graphene to straddle the border of the C-rich domain in h-BN. We also study h-BN crystals synthesized with another method, i.e., via synthesis at atmospheric pressure and high temperature (APHT) using a metal alloy solvent in terms of its applicability in van der Waals heterostructures. (iii) We have developed a robotic system that automatically searches exfoliated 2D crystals and assembles them into vdW superlattices. In particular, we demonstrate deep-learning-based image segmentation of various 2D materials. (iv) We demonstrate 3D manipulation of 2D materials such as sliding, rotating, turning, folding, flipping, cleaving, and exfoliating by using micro-dome polymer. (v) Superconducting proximity effect in NbSe$_2$/graphene van der Waals junction. (vi) Superconductivity in a novel transition metal dinitride layered crystal ReN$_2$.

Magnetism of Nanographene-based Nanoporous Carbon and its Applications

First Name: Toshiaki
Last Name: Enoki
Affiliation: Tokyo Institute of Technology, Tokyo, Japan
Email: tenokih@gmail.com

Short Biography:

Abstract:
The structures of nanographenes are described in terms of a combination of zigzag and armchair edges, in the former of which spin-polarized edge states of non-bonding $\pi$-electron are localized (Fig.A). Consequently, the edge state spins mutually interacting through strong intra-zigzag-edge ferromagnetic interaction together with intermediate strength inter-zigzag-edge ferro/antiferromagnetic interaction behave superparamagnetic in nanographenes depending on their geometry and sizes. We investigated guest adsorption characteristics in nanographene-based nanoporous carbon (activated carbon fibers), in which units of 3-4 nanographene sheets stacked (nanographite) are three dimensionally networked in random fashion. Here the edge-state spins can be utilized as a test probe in chemical interaction between nanographenes and foreign molecules. In the adsorption process of H$_2$O molecules, the magnetic susceptibility has a discontinuous drop at a threshold vapor pressure $P_0$ (Fig.(B)). This suggests that H$_2$O molecules filled in the nanopores compress the nanographite, resulting in enhancing antiferromagnetic coupling between the edge-state spins (Fig.(C)). A huge amount of helium gas is condensed in the nanopores exceptionally among various gas species. The collisional process of helium atoms with the edge-state spins works effectively in the energy dissipation from the edge state spins to the environment as shown in the ESR saturation curves (Fig.D).

2D Heterojunctions for High-Performance Electronic and Optoelectronic Devices

First Name: Sung-Yool
Last Name: Choi
Affiliation: School of Electrical Engineering, Graphene/2D Materials Research Center, KAIST, Daejeon, 34141, Korea
Email: sungyool.choi@kaist.ac.kr

Short Biography:

Prof. Sung-Yool Choi is a Professor of Electrical Engineering and the director of two research centers, Graphene/2D Materials Research Center (GRC) and Center for Advanced Materials Discovery towards 3D Display (CAMD3), KAIST. He received BS (with Summa Cum Laude), MS, and Ph.D. degrees from the Department of Chemistry, KAIST, in 1991, 1994, and 1998, respectively.

Prof. Choi invented flexible memristor array devices based on graphene oxide films, which opened the nonvolatile memory and neuromorphic applications of the graphene-related materials. He also demonstrated a large-area organic light-emitting diode with the graphene anode electrode for the first time. During the last decade, his primary research objectives have been mainly in the application of graphene and 2D materials to novel electronic and optoelectronic devices.

Prof. Choi received several academic awards including the Prime Minister’s Award for Research Innovation in Nanotechnology (Nano Korea 2015), the KIDS Award Silver (IMID 2016), the Prize for Academic Excellence of KAIST (2017) and the Convergence Research Award of KAIST (2019).

Abstract:

Unique structures of two-dimensional (2D) materials enable various kinds of heterojunctions, which facilitate synergetic effects on device performance and versatility. The heterojunctions of 2D materials have advantages compared to conventional semiconductor heterojunctions because ultraclean interfaces and the engineered band structures can be achieved. We can easily fabricate 2D-2D heterojunctions of 2D materials as well as 2D-3D heterojunctions between 3D bulk semiconductors and 2D materials. Based on the band engineering of 2D-2D or 2D-3D heterojunctions, we have demonstrated several electronic and optoelectronic devices. In this talk, I will present our recent development of steep-slope vertical tunneling transistors [1-3], high-performance field-effect transistors and logic gates [4], and photodetectors with broadband detection, high responsivity and fast response time [5], in which various heterojunctions of 2D materials improve the device performance metrics.

In-plane ferroelectricity in monolayer SnS

First Name: Kosuke
Last Name: NAGASHIO
Affiliation: Department of Materials Engineering, The University of Tokyo, Tokyo, Japan
Email: nagashio@material.t.u-tokyo.ac.jp

Short Biography:

Kosuke Nagashio received the B.E. degree in Materials Science & Engineering from Kyoto University in 1997 and the M.E. and Ph.D. degrees in Materials Engineering from The University of Tokyo in 1999 and 2002, respectively. From 2002 to 2003, he was a postdoctoral research fellow at Stanford University, California. He is currently Professor with the Department of Materials Engineering, The University of Tokyo. His research interests presently focus on the carrier transport in 2D materials and the crystal growth of 2D materials.

Abstract:

2D van der Waals ferroelectric semiconductors have emerged as an attractive building block with immense potential to provide multifunctionality in nanoelectronics. Although several accomplishments have been reported in ferroelectric resistive switching for out-of-plane 2D ferroelectrics down to the monolayer, a purely in-plane ferroelectric has not been experimentally validated at the monolayer thickness. Herein, a micrometer-size monolayer SnS is grown on mica by physical vapor deposition, and in-plane ferroelectric switching is demonstrated with a two-terminal device at room temperature (RT). SnS has been commonly regarded to exhibit the odd–even effect, where the centrosymmetry breaks only in the odd-number layers to exhibit ferroelectricity. Remarkably, however, a robust RT ferroelectricity exists in SnS below a critical thickness of 15 layers with both an odd and even number of layers. The lack of the odd–even effect probably originates from the interaction with the mica substrate, suggesting the possibility of controlling the stacking sequence of multilayer SnS, going beyond the limit of ferroelectricity in the monolayer. This work will pave the way for nanoscale ferroelectric applications based on SnS as a new platform for in-plane ferroelectrics.

Refs

FIG. $I_D-V_D$ for two terminal SnS device with different applied voltages. Inset: double-wave measurement at 0–2 V.
Fowler-Nordheim tunneling through 2D atomic layers

First Name: Sang Wook  
Last Name: Lee  
Affiliation: Department of Physics, Ewha Womans University, Seoul, Korea  
Email: leesw@ewha.ac.kr 

Short Biography:

Sang Wook Lee received BS (1999), MS (2001), and PhD (2005) at Seoul National University. After staying at Gothenburg University during 2005-2007 as a post doc, he moved to Konkuk University in Seoul as an assistant and associate professor from 2008-2016. In 2016, he moved to Ewha Womans University as a full professor. His main research field is nano electronics and nano mechanics. He is especially interested in ultra-sensitive mass and force detection based on nano mechanical devices, graphene and 2D materials based nano electronics, and in-situ observation of 2D materials at extreme conditions.

Abstract:

Van der Waals (vdW) materials consisting of 2D atomic layers have attracted lots of interest in the future electronic applications thanks to their superior electrical, optical and mechanical properties. Due to their weak interlayer coupling across physical vdW gaps, vertical charge transport through these vdW layered materials is fundamentally different from in-plane transport behaviors. In this study, we investigate detailed vertical charge transport mechanisms, especially in the regime of Fowler-Nordheim (FN) tunneling, through vertical WSe2 junctions while controlling WSe2-layer thickness from a monolayer to multilayers with a single atomic-thick resolution. We implement a simple but reliable device structure, graphite/WSe2/graphite vertical heterojunctions, fabricated on a h-BN/SiO2/Si substrate by mechanical transfer technique. We observe vertical charge transport through WSe2 layers is governed by the FN tunneling even for a monolayer WSe2 when the vertical junctions are applied by sufficiently high electric fields. Moreover, we find out that FN tunneling characteristics can be used for identifying not only the layer number but also characterizing key material properties of layered vdW materials such as effective mass and quasiparticle energy gap.

Controllable Growth and Electronic Structures of 2D Transition Metal Dichalcogenides Thin Films

First Name: Yi
Last Name: Zhang
Affiliation: School of Physics, Nanjing University, Nanjing, China
Email: zhangyi@nju.edu.cn

Short Biography:

Abstract:

The emerging two-dimensional (2D) materials are playing more and more important roles in both fundamental research and practical application potentials in recent years. The 2D transition metal dichalcogenides (TMDCs) have attracted extensive interest due to their remarkable fundamental properties distinct from those of their bulk counterparts. Using molecular beam epitaxial (MBE) method, we achieved the controllable growth of transition metal dichalcogenides MoSe$_2$ and WSe$_2$. Combining with the in-situ angle-resolved photoemission spectroscopic (ARPES) measurements, we directly characterized the electronic structures of them and studied the evolution of their electronic structures in atomically thin limit [1, 2]. Moreover, the growth of a Mo$_x$W$_{1-x}$Se$_2$ monolayer alloys provide an effective way to engineering the band structures in MX$_2$ [3]. We also realized the growth of meta-stable 1T'-WSe$_2$ monolayer, and studied its thermo-driven structure phase transition to stable 2H-WSe$_2$ [4]. With assistance of enhanced interlayer interaction, the 1T’ phase of monolayer WSe$_2$ could be fully stabilized on the SrTiO$_3$(100) substrate. Our findings not only help understanding of TMDC materials but also enrich the family of epitaxial 2D materials toward a fully MBE grown epitaxial heterostructures for light emission and photon-voltage devices. And the selective growth of WSe$_2$ in different phases makes WSe$_2$ an ideal material platform for the further fundamental study and device applications of quantum spin Hall effect.

Ultralow-dielectric-constant amorphous boron nitride

First Name: Hyeon Suk  
Last Name: Shin  
Affiliation: Department of Chemistry, UNIST, Ulsan, Korea  
Email: shin@unist.ac.kr

Short Biography:
Hyeon Suk Shin is a professor at Department of Chemistry and Department of Energy Engineering, Ulsan National Institute of Science and Technology (UNIST), Korea. He received his PhD from Department of Chemistry at POSTECH in 2002. After working as a postdoctoral fellow at University of Cambridge, UK and subsequently as a research Professor at POSTECH, he joined UNIST in 2008. He received Creative Knowledge Award (Minster Award by Ministry of Science, ICT, and Future Planning) in 2015, outstanding researcher award (Materials Chemistry Division, KCS) in 2015, the Faculty of the Year award of UNIST in 2014, and the Minister award of Ministry of Knowledge Economy, Korea in 2012. His current research is focused on 2D materials, including graphene, h-BN, transition metal dichalcogenides, and their heterostructures, and their applications for electrocatalysts and (opto)electronic devices.

Abstract:
Miniaturisation of electronic devices has resulted in increased interconnect resistance–capacitance delay and high power dissipation. Integration of low-κ dielectrics—insulating materials that exhibit weak polarisation under applied electric fields—which also serve as diffusion barriers, facilitates miniaturisation beyond the current state-of-the-art. Recommendations of the International Roadmap for Devices and Systems require low-κ materials to possess dielectric (κ values ≤ 2 by 2028, be mechanically robust, and serve as diffusion barriers against interconnect-atom (typically Cu) migration into semiconductors. However, typical non-polar low-κ materials, such as oxide derivatives (SiCOH), organic compounds, and aerogels, exhibit κ values exceeding 2 and poor thermo-mechanical properties. In this talk, I will demonstrate realisation of ultra-low κ values of 1.78 and 1.16 at 100 kHz and 1 MHz, respectively, in amorphous boron nitride (a-BN) via complementary metal-oxide semiconductor (CMOS)-compatible deposition at 400 °C.[1] The resulting structure is mechanically robust, with excellent diffusion-barrier characteristics. Detailed structural characterisation indicates that a-BN is sp²-hybridised, with no measurable crystallinity. The breakdown strength of a 3-nm thick a-BN sample was 7.3 MV/cm – high enough for contemporary applications. Cross-sectional transmission electron micrographs revealed no diffusion of metal atoms across a-BN under harsh conditions when compared against TiN barriers considered as reference. Hence, our results suggest that the amorphous counterpart of two-dimensional hexagonal boron nitride possesses ideal characteristics for use in next-generation low-κ dielectrics for high-performance electronic applications.

**The electronic state of atomic-layer TMDs studied by high-resolution ARPES**

**First Name:** Katsuaki  
**Last Name:** Sugawara  
**Affiliation:** Department of Physics, Tohoku university, Sendai, Japan  
**Email:** k.sugawara@arpes.phys.tohoku.ac.jp

**Short Biography:**

Ph. D of Physics, Tohoku University, Japan (2009). Recent research interests are the electronic structure of atomic-layer materials (graphene superconductor, TMDs) and 2D topological-insulators.

**Abstract:**

Group-V transition-metal dichalcogenides (TMDs) MX₂ have been studied more than 40 years ago since it shows various strong-correlated electron phenomena such as Mott insulator, charge-density-waves (CDW), and superconductivity [1]. Recently, to clarify the interplay between these novel phenomena and dimensionality, the thinnest limit of TMDs has been intensively studied. Our group also fabricated various monolayer TMDs such as VSe₂, NbSe₂ and TaSe₂ by molecular-beam epitaxy and investigated these novel electronic states by high-resolution angle-resolved photoemission spectroscopy (ARPES). In this talk, we will introduce the recent progress of high-resolution ARPES studies on monolayer TMDs films as follows.

1. We find a 2D Mott-insulating electronic state (Fig.1) and a drastic enhancement of Mott transition temperature up to above 450 K in epitaxially-grown monolayer 1T-TaSe₂ and 1T-NbSe₂. In this talk, we will demonstrate that the realized Mott-insulator phase is considerably robust against external perturbations such as photo-excitation and carrier doping, in sharp contrast to the bulk counterpart [2].

2. We observe a metallic Fermi arc with pseudo gap at low temperature in epitaxially-grown monolayer 1T-VTe₂. Also, in contrast to monolayer 1T-VSe₂ with CDW transition [3], we find that CDW was suppressed in 1T-VTe₂ due to the breaking of commensurability of the Fermi surface nesting [4].


![Fig. 1. The near-E_F electronic structure of (left) 1T-NbSe₂ and (right) 1T-TaSe₂.](image-url)
Boosting optical responses of two-dimensional semiconducting transition metal dichalcogenides

First Name: Joon Ik  
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:

Transition metal dichalcogenides (MX\textsubscript{2}: M = Mo, W and X = S, Se) are two-dimensional (2D) layered semiconducting materials exhibiting strong light-matter interaction in the atomically thin landscape. This however can lead to the two major undesirable effects; 1) a small interaction volume in nonlinear light-matter interaction and 2) a large scattering cross section in exciton-exciton annihilation (EEA). The former puts a stringent limit on maximally attainable second harmonic radiation for nonlinear nanophotonic applications. The latter significantly reduces the quantum yield (QY) of the excitonic photoluminescence (PL) for atomic-scale light-emitting applications. To address the first issue, we prepared noncentrosymmetric 3R-type vertical heterostructures of MoS\textsubscript{2}/MoS\textsubscript{2(1-x)}Se\textsubscript{2x} (0 \leq x \leq 0.45) and investigated the impact of interlayer coupling and band offset on second harmonic generation (SHG) across the exciton resonances. The results indicate that both efficiency and range of SHG can be boosted by the combination of stacking and alloying of the constituent monolayers followed by postannealing. To address the second issue, we prepared semiconductor/insulator/metal (WS\textsubscript{2}/h-BN/Au) structures and investigated the impact of metal screening on the EEA process as a function of h-BN thickness. The results indicate that both QY and exciton lifetime can be substantially enhanced by metal screening of exciton-exciton interaction. We believe that our engineering strategies can be employed to boost the optical responses of 2D transition metal dichalcogenides. This work is supported by the Basic Science Research Program (2017R1D1A1B03035539 and 2020R1F1A1069646) through the National Research Foundation of Korea.

First Name: Qing
Last Name: Zhang
Affiliation: Department of Materials Science and Engineering, College of Engineering, Peking University, Beijing, China
Email: Q_zhang@pku.edu.cn

Short Biography:

Qing Zhang received bachelor degree in Materials Physics from University of Sciences and Technology of China in 2005 and doctoral degree in Physics from Tsinghua University (Supervisor: Prof. Qikun Xue), China in 2011. She had worked as a postdoctoral research fellow (Supervisor: Prof. Qihua Xiong) in Nanyang Technological University in 2011-2016. Since 2016, she joined in College of Engineering, Peking University as a principle investigator and assistant professor. She is interested in the light-matter interaction and laser spectroscopy of low dimensional semiconductors, including TMDCs, II-VI/III-V, and perovskite. She was awarded Nanochemistry Young Scientists of Chinese Chemistry Society in 2018.

Abstract:

Recently, two dimensional (2D) perovskites have attracted much attention for the low-temperature solution-processable fabrication, interesting exciton feature, naturally-formed quantum well structure and good stability. Herein, I will present recent progresses on stimulated emission properties of the solution-processed 2D perovskite ((BA)$_2$(MA)$_{n-1}$Pb$_n$I$_{3n+1}$)[1] and 2.5D perovskite (Cs$_{0.87}$(FAMA)$_{0.13}$PbBr$_3$)/((NMA)$_2$PbBr$_4$)[2]. An $n$-engineered lasing behavior (threshold, color), Auger recombination, electron-hole coupling are revealed for 2D perovskites. A record net optical gain (3030 cm$^{-1}$) of green spectral range is achieved via using 2.5D perovskites.


Fig. 1. Left: Schematics of stimulated emission of (BA)$_2$(MA)$_{n-1}$Pb$_n$I$_{3n+1}$; Right: mechanically-exfoliated (BA)$_2$(MA)$_{n-1}$Pb$_n$I$_{3n+1}$ perovskites.
High-Chern-Number and High-Temperature Quantum Hall Effect without Landau Levels

First Name: Jian (健)
Last Name: Wang (王)
Affiliation: International Center for Quantum Materials, School of Physics, Peking University, Beijing, China
Email: jianwangphysics@pku.edu.cn

Short Biography:
Jian Wang, Professor of Physics, received his bachelor’s degree in Physics from Shandong University in 2001, and PhD degree in condensed matter physics from Institute of Physics, Chinese Academy of Sciences in 2007. From 2006 to 2011, he worked as a Postdoc and Research Associate at Penn State University, USA. He became a Professor at Peking University in 2017. He won Sir Martin Wood China Prize in 2015 and Outstanding Achievement Award for Research in Institutes of Higher Education of China in 2019. His current research interests are quantum transport properties of low dimensional superconductors and topological materials. In recent years, he has authored more than 90 papers including Science, Science Advances, Nature Physics, Nature Materials, Nature Nanotechnology, Nature Communications, PNAS, Physical Review X, Physical Review Letters, Nano Letters, Advanced Materials, ACS nano, JACS etc. Jian Wang’s lab at Peking University possesses ultralow temperature-high magnetic field measurement systems and low temperature scanning tunneling microscopy/spectroscopy-molecular beam epitaxy combined ultrahigh vacuum system etc. More details: http://faculty.pku.edu.cn/JianWangGroup

Abstract:
The quantum Hall effect (QHE) without Landau levels (LLs) has become a long-pursuit research topic since the QHE was discovered around 40 years ago. Previous theoretical proposals and experiments based on two-dimensional (2D) topological systems with time-reversal symmetry broken have revealed the QHE without LLs with Chern number $|C|=1$ at ultralow temperatures. Now the key issues of the QHE without LLs are how to increase the working temperature and realize high Chern number with more dissipationless chiral edge states ($|C|>1$) for emerging physics and low-dissipation electronics. We discovered the high-Chern-number ($|C|=2$) QHE without LLs in nine-septuple-layer and ten-septuple-layer magnetic MnBi$_2$Te$_4$ devices and $|C|=1$ Chern insulator state in seven-septuple-layer and eight-septuple-layer devices displaying nearly quantized Hall resistance plateau at record-high temperatures [1]. The thickness-dependent topological quantum phase transition from $|C|=2$ to $|C|=1$ is uncovered. To our knowledge, this is the first work to report high-Chern-number QHE without LLs above the liquid helium temperature and this is also the first time that the nearly quantized Hall resistance plateau is detected at high temperatures of tens of Kelvin for QHE without LLs.

Reference:
Electron transport in a correlated quantum Hall antiferromagnetic state of bilayer graphene

First Name: Michihisa
Last Name: Yamamoto
Affiliation: Center for Emergent Matter Science, RIKEN, Wako, Japan
Email: michihisa.yamamoto@riken.jp

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 one of the strongly correlated states. When multiple internal degrees of freedom exist, exchange interaction stabilizes a many-body ordered ground state if a Landau level (LL) is partially filled. Zero-energy LL of bilayer graphene offers an exciting platform to study various many-body ground states and phase transitions, owing to the interplay of spin, layer, and orbital degrees of freedom and controllability of the layer degree of freedom by an out-of-plane external electric field $D$. At its half filling ($\nu=0$), the canted antiferromagnetic (CAF) state is believed to be stabilized for a small $D$, while the fully layer polarized (FLP) state becomes the ground state for a large $D$. For an enhanced Zeeman energy in presence of a tilted magnetic field, the ferromagnetic state becomes the ground state.

In particular, the CAF state attracts considerable interest for its unique electronic properties. These include spontaneous Hall effect and its potential for conversion between the valley current and spin current, as presented in a previous workshop. In this presentation, we show that bulk transport in this state is governed by variable range hopping. We employ a Corbino device to extract pure bulk conductivity of this state in a wide range of temperature. Measured temperature dependence is well explained by variable range hopping via localized states at low temperature. Based on our data and analysis, we derive a microscopic picture of the localized states formed by pinned charged vortex-antivortex pairs in the CAF state. The hopping transport though such localized states holds up to the Kosteritz Thouless transition temperature. Our finding is a fundamental step towards full understanding of the correlated $\nu =0$ states in bilayer graphene.

This work was mostly done by Miuko Tanaka at the University of Tokyo in collaboration with Takashi Taniguchi, Kenji Watanabe, Kentaro Nomura and Seigo Tarucha.
Quantum Anomalous Hall Effect in Few-layer MnBi$_2$Te$_4$

First Name: Yujun  
Last Name: Deng  
Affiliation: State Key Laboratory of Surface Physics and Department of Physics, Fudan University, Shanghai, China  
Email: Yujun.Deng@hotmail.com

Short Biography:

Yujun Deng is currently a PhD student in Prof. Yuanbo Zhang’s group in Fudan University, Shanghai, China. Her current research interest is focused on new fabrication methods of nano devices and transport properties of novel 2D materials, especially on magnetic 2D materials.

Abstract:

In a magnetic topological insulator, nontrivial band topology conspires with magnetic order to produce exotic states of matter that are best exemplified by quantum anomalous Hall (QAH) insulators and axion insulators. Here, we probe quantum transport in MnBi$_2$Te$_4$ thin flake that becomes ferromagnetic when the sample has odd number of septuple layers. Using Al$_2$O$_3$-assisted exfoliation method, we fabricate few-layer MnBi$_2$Te$_4$ transport devices with Si backgate. Zero-field QAH effect is observed in a specimen with five septuple layers at 1.4 Kelvin; an external magnetic field further raises the quantization temperature up to 6.5 Kelvin by aligning all layers ferromagnetically. Additional quantum Hall states emerge in the presence of external magnetic field as backgate voltage shifts away from the charge neutrality point. Our results establish MnBi$_2$Te$_4$ as an ideal arena for further exploring various topological phenomena.
High-temperature superconductivity in monolayer Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$

First Name: Yijun
Last Name: Yu
Affiliation: State Key Laboratory of Surface Physics and Department of Physics, Fudan University, Shanghai, China
Email: yuyijun@fudan.edu.cn

Short Biography:

Dr. Yijun Yu is currently a Postdoc researcher in Prof. Yuanbo Zhang’s group in Fudan University, Shanghai, China. He received his doctoral degree in 2018 in the same group. His current research interest is focused on transport properties of correlated 2D materials with an emphasis on controlled modulation of electronic structures. His representative works include the tunable electronic properties on 2D 1T-TaS$_2$, Fe$_3$GeTe$_2$ and Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$.

Abstract:

Superconductivity is presumably more robust in three-dimensional systems than lower-dimensional systems. However, almost all high-temperature superconductors adopt layered structures. Dimensionality plays the central role to the high-temperature superconductivity (HTS). Layered cuprate superconductors hold the record of $T_c$ at ambient pressure. With experimentally accessible 2D cuprates, the greatly enhanced controllability over electronic structure and the cut-off of the spatial dimension would provide invaluable insights on the nature of HTS. Half-unit-cell-thick single crystal of Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ (referred to as monolayer Bi-2212) is such an ideal 2D system. Here we fabricate transport devices from monolayer Bi-2212 samples obtained by exfoliation and study the evolution of superconductivity as the dimensionality is reduced. By controlled annealing, we map out the phase diagram of monolayer Bi-2212. To our surprise, superconductivity remains intact in monolayer Bi-2212. Finite size scaling analysis at superconductor-to-insulator transition (SIT) reveals two distinct critical behaviours, which are driven by the modulation of carrier concentration and disorder level, respectively. This lead to a unified picture of SITs previously reported in cuprate systems.
Strongly adhesive dry transfer technique by polycaprolactone

First Name: Suhan
Last Name: Son
Affiliation: Department of Physics and Astronomy, Seoul National University, Seoul 08826, Republic of Korea
Email: physhson@snu.ac.kr

Short Biography:

Abstract:
The ability to stack van der Waals materials with an atomically sharp interface has provided a new material platform for constructing heterostructures[1]. The technical challenge of mechanical stacking is to pick up the exfoliated atomically thin material after mechanical exfoliation without chemical and mechanical degradation. Chemically inert hexagonal boron nitride (hBN) has been widely used to encapsulate and pick up vdW materials. However, the relatively weak adhesion of hBN has limited the assembly of vdW heterostructures based on hBN[2]. Therefore, in order to overcome these hurdles, we report a new dry transfer technique by using more adhesive polymer, polycaprolactone, PCL. We used two vdW semiconductors (ZnPS$_3$ and CrPS$_4$) to pick up and encapsulate the layers for the vdW heterostructure. Otherwise, it is known to be difficult to manufacture. The diversity of PCL-based vdW stacking methods provides a new route to assemble complex 2D vdW materials without interfacial degradation.


Figure 1. Schematics of dry transfer method and its example
Magnetic van der Waals heterostructures with Zeeman-type spin-orbit-interaction

First Name: Hideki
Last Name: Matsuoka
Affiliation: Department of Applied Physics, The University of Tokyo, Tokyo, Japan
Email: hideki1123@g.ecc.u-tokyo.ac.jp

Short Biography:

Hideki Matsuoka received Master degree at the university of Tokyo in 2018. His research focuses on superconductivity, charge ordering, and magnetism in two-dimensional materials. His target materials are transition metal dichalcogenides (TMD) and cuprate high-Tc superconductors.

Abstract:

A van der Waals (vdW) heterostructure provides an indispensable material platform in modern condensed-matter researches. There, weak interlayer bonding nature ensures formation of an atomically-abrupt heterointerface beyond fundamental constraint imposed by lattice matching condition, while strong electronic coupling enables creation of an emergent electronic ground state that is missing in individual materials. Here we fabricated vdW heterostructures by molecular-beam epitaxy. In the vdW heterostructures, a new type of 2D magnet, vanadium selenide epitaxial thin film, and NbSe₂, where the spins of all electrons are polarized due to the strong Zeeman-type spin orbit interaction, were incorporated. In the presentation, we will show transport properties of those magnetic heterostructures, and discuss the interface proximity effect on 2D magnetism.

Observation of topological electronic structure in a quasi-1D superconductor

First Name: Cheng
Last Name: Chen
Affiliation: Shanghaitech University
Email: cheng514.ustc@gmail.com

Short Biography:
Cheng is currently a joint postdoc between ShanghaiTech University (Yulin Chen/ Zhongkai Liu group) and Lawrence Berkeley National Lab. He completed his PhD degree (2018) from Physics department at University of Oxford and a B.S from University of Science and Technology of China (2014). Cheng’s research interest focuses on exploring the electronic structure of topological materials and 2D materials by using the angle resolved photoemission spectroscopy.

Abstract:
A topological superconductor (TSC) is a new type of superconductor with non-trivial topology in bulk electronic structures that leads to the emergence of Majorana bound states or Majorana Fermions that have great potential in many applications such as topological quantum computation. Despite the intensive research efforts worldwide, up to date, only a few intrinsic (non-heterostructures) materials have been proposed as candidates for topological superconductors, and even fewer have been experimentally confirmed e.g. FeSe_{0.55}Te_{0.45} and 2M-WS_{2}. In this work, by carrying out synchrotron and laser based angle-resolved photoemission spectroscopy (ARPES), we systematically investigated the electronic structure of a quasi-1D superconductor TaSe_{3}, and identified the nontrivial topological surface states. In addition, our scanning tunnelling microscopy (STM) study revealed the high crystal quality with clean cleaved surface and a uniform superconducting gap across quasi-1D TaSe_{3} chains, making it suitable for further investigation of potential Majorana modes. These results prove TaSe_{3} as a stoichiometric TSC candidate that is stable and exfoliable, therefore providing a great platform for the study of rich novel phenomena and application potentials.

Fig. 1. Observation of topological surface state (TSS) in TaSe_{3}. Left panel is experimental data, right is the theoretical calculation.

Zero-energy bound states in the high-temperature superconductors at the two-dimensional limit

First Name: Cheng
Last Name: Chen
Affiliation: International Center for Quantum Materials, School of Physics, Peking University, Beijing, China
Email: chenchengcc@pku.edu.cn

Short Biography:

Cheng Chen, PhD candidate in School of Physics, Peking University, received her bachelor’s degree in physics from Shandong University in 2016. Since 2016, she has been studying for her PhD degree in experimental condensed-matter physics at Peking University supervised by Prof. Jian Wang. Her research interests are low dimensional superconductors and topological materials based on ultrahigh-vacuum MBE-STM combined system.

Abstract:

Majorana zero modes (MZMs) that obey the non-Abelian statistics have been intensively investigated for potential applications in topological quantum computing[1]. The prevailing signals in tunneling experiments “fingerprinting” the existence of MZMs are the zero-energy bound states (ZEBSs). By ultrahigh vacuum molecular beam epitaxy (MBE), we successfully grew large-area and high-quality one-unit-cell-thick high-temperature superconducting FeTe$_{0.5}$Se$_{0.5}$ films on SrTiO$_3$ substrates [2], showing transition temperature Tc of about 60 K. Furthermore, by using in situ scanning tunneling spectroscopy (STS), we detected the ZEBSs upon the interstitial Fe adatoms deposited on the high-temperature superconducting FeTe$_{0.5}$Se$_{0.5}$ films [3]. The spectroscopic results of ZEBSs resemble the phenomenological characteristics of the MZMs. Our findings provide a promising platform to detect MZMs in a single material down to the 2D limit, at a higher operating temperature and under zero external magnetic field.

This work was financially supported by the National Natural Science Foundation of China (nos.11888101 and 11774008), National Key R&D Program of China (nos. 2018YFA0305604 and 2017YFA0303302), Strategic Priority Research Program of Chinese Academy of Sciences (no. XDB28000000), Beijing Natural Science Foundation (no. Z180010), and U.S. Department of Energy, Basic Energy Sciences (no. DE-FG02-99ER45747).


Fig.1. A,B, Isolated Fe adatom and the tunneling spectra on monolayer FeTe$_{0.5}$Se$_{0.5}$ film. C, Tunneling spectra collected along the arrow in A. D, Zero-bias conductance imaging for the adatom in A. E, Exponential fit to the linecut L in D.
First Name: Qiuyu
Last Name: Shang

Affiliation:  Department of Materials Science and Engineering, College of Engineering, Peking University, Beijing 100871, P. R. China

Email: qiuyu_shang@pku.edu.cn

Short Biography:

In 2017, he received bachelor degree in University of Science & Technology Beijing, China. He is currently a Ph. D student at College of Engineering, Peking University (supervisor: Prof. Qing Zhang). His research interests include optical spectroscopy and strong light-matter interaction in low-dimensional semiconductors for optoelectronic applications.

Abstract:

Recently, exciton polaritons (EPs) in strong coupling regime have been demonstrated in perovskite materials benefitting from the large oscillator strength and exciton binding energy [1–4]. Additionally, EP also helps put forward the perovskite laser into continuous-wave (CW) pumped regime in one dimensional nanowire at cryogenic temperature with an uncovered photophysics mechanism. Herein, I will introduce our recent investigations on the role of EP in realizing optically pumped CW perovskite laser. The energy-wavevector of EP, the gain-loss profile, and thermal diffusion process are analysed to unveil the microscopic picture behind. Also, the feasibility of electrically driven laser will be discussed [5].


Fig. 1. Schematic of a CW lasing in a CsPbBr$_3$ nanoribbon on the sapphire substrate.
The angle-resolved polarized Raman scattering in anisotropic layered materials

First Name: Miao-Ling
Last Name: Lin
Affiliation: Institute of Semiconductors, Chinese Academy of Sciences, Beijing, China
Email: linmiaoling@semi.ac.cn

Short Biography:

Miao-Ling Lin is now a postdoc in Institute of Semiconductors, Chinese Academy of Sciences. She received her BS degree (2014) in physics from Nankai University, Tianjin, China. And she obtained her PhD degree from University of Chinese Academy of Sciences supervised by Prof. Ping-Heng Tan. Her current research interest focuses on optical properties of lowdimensional nanomaterials.

Abstract:

The birefringence and linear dichroism in anisotropic layered materials (ALMs) would lead to depth-dependent polarization and intensity of incident laser and scattered signal inside ALMs and thus break down the selection rule for angle-resolved polarized Raman (ARPR) intensity from standard group-theoretical method. Here, by taking the bulk black phosphorus (BP), we developed a so-called birefringence-linear-dichroism model to quantitatively understand the ARPR intensity in ALMs by the same set of real Raman tensor at both normal and oblique incidences. No fitting parameter is needed once the birefringence and linear dichroism effects are considered with the complex refractive indexes. The real Raman tensor and complex refractive indexes along different crystallographic orientations are respectively determined by the relative Raman intensity along its principle axes and incident-angle resolved reflectivity by Fresnel’s law. This model is potential to understand the anomalous ARPR intensity of ultrathin ALM flakes deposited on a multi-layered substrate by considering the depth-dependent polarization and intensity of incident laser and scattered Raman signal induced by the birefringence and linear dichroism and also the interference effects in the multi-layered structure, which depends on the laser wavelength, thicknesses of the ALM flakes and dielectric layer.

Fig. 1. Propagation path of laser (green) and scattered Raman signal (dark red) in ALM flakes and the incident (\(\delta_i\)) dependent ARPR intensity at oblique incident by rotating the BP along x and z axes.

Large Dynamical Axion Field in Topological Antiferromagnetic Insulator Mn$_2$Bi$_2$Te$_5$

First Name: Dinghui  
Last Name: Wang

Affiliation: School of Physics, Nanjing University, Nanjing, China

Email: dz1722031@smail.nju.edu.cn

Short Biography:

Dinghui Wang now is a PhD student in Nanjing University, Nanjing, China. He got his BSc in Applied Physics in Tongji University, Shanghai, China. He focusses on researching new phenomena of topological magnetic insulators (TMIs) by Using ab initio calculations and theoretical technics.

Abstract:

The dynamical axion field is a new state of quantum matter where the magnetoelectric response couples strongly to its low-energy magnetic fluctuations. It is fundamentally different from an axion insulator with a static quantized magnetoelectric response. The dynamical axion field exhibits many exotic phenomena such as axionic polariton and axion instability. However, these effects have not been experimentally confirmed due to the lack of proper topological magnetic materials. Combining analytic models and first-principles calculations, in this work we predict a series of van der Waals layered Mn$_2$Bi$_2$Te$_5$-related topological antiferromagnetic materials that could host the long-sought dynamical axion field with a topological origin. We also show that a large dynamical axion field can be achieved in antiferromagnetic insulating states close to the topological phase transition. We further propose the optical and transport experiments to detect such a dynamical axion field. Our results could directly aid and facilitate the search for topological-origin large dynamical axion field in realistic materials.

References:

Effects of dimensionality on the charge-density-wave order in 2H transition metal dichalcogenides*

First Name: Dongjing
Last Name: Lin
Affiliation: School of Physics, Nanjing University, NanJing, 210093, China
Email: djlin@smail.nju.edu.cn

Short Biography:
Dongjing Lin received his bachelor's degree in physics at Xiamen University in 2017. After that he is studying in Prof. Xiaoxiang Xi's group, Nanjing University. His research interests are using mechanical exfoliation to acquire 2D materials and exploring their properties using Raman scattering and electrical transport methods.

Abstract: Charge-density waves (CDWs) are commonly found in low-dimensional metals. This intriguing phenomenon was discovered in the transition metal chalcogenides more than four decades ago and has been investigated up to date. The mechanism giving rise to such phase transitions, especially in the quasi-two-dimensional transition metal dichalcogenides, is still an open question. The advent of two-dimensional (2D) materials has inspired the realization of CDWs in the true 2D limit, offering a new route to exploring their properties. A growing family of 2D CDW materials have been uncovered, but a coherent understanding regarding the key factors for CDW formation is lacking. In this poster, we will present a collaborative effort to investigate the effects of dimensionality on the CDW order in the 2H transition metal dichalcogenides, including NbSe$_2$, NbS$_2$, TaSe$_2$, and TaS$_2$. Using Raman scattering spectroscopy, we reveal disparate thickness-dependent CDW transition temperatures in these isostructural and isoelectronic compounds. Based on first-principles calculations, we argue that other than the electron-phonon coupling commonly ascribed as the driving force for CDWs, chemical bonding is another key factor that should not be overlooked. The theoretical framework established here offers a consistent explanation for the distinct dimensionality-dependent CDWs observed in these materials.

* In collaboration with Mohammad Saeed Bahramy at the University of Tokyo.
Band engineering in epitaxial monolayer transition metal dichalcogenides alloy
Mo$_x$W$_{1-x}$Se$_2$ thin films

First Name: Xuedong
Last Name: Xie
Affiliation: School of Physics, Nanjing University, Nanjing, China
Email: xuedong@smail.nju.edu.cn

Short Biography:
• 2015-present Ph.D Candidate in Prof. Yi Zhang’s group
• 2011-2015 Bachelor in Wuhan University of Science and Technology

Abstract:
The direct bandgap transition and spin–orbit-coupling-induced spin-splitting in monolayer transition metal dichalcogenides MX$_2$ (M = Mo, W; X = S, Se, Te) show great application potential in high-efficient optoelectronic devices and valleytronics and, thus, have attracted enormous research interest in recent years. Various MX$_2$ monolayers usually show a distinct bandgap and spin-splitting size. Its 2H phase possesses an indirect to direct bandgap transition when the thickness decreases into monolayer (ML) due to the transition of the valance band maximum from Γ to K [1, 2]. Among all the TMDCs, WSe$_2$ owns the largest spin-splitting at K point (~480meV) [2] while MoSe$_2$ is 170meV [1]. Thus, the spin splitting of ML MX$_2$ at K point can be engineered in Mo$_x$W$_{1-x}$Se$_2$ alloy. Here, we realized the molecular beam epitaxial growth of monolayer Mo$_x$W$_{1-x}$Se$_2$ alloys with a controllable stoichiometric ratio x. Combining with the in situ ARPES and XPS measurements, we determined the evolution of the valence band dispersion and the spin-splitting size with the change in the Mo ratio x [Fig. 1]. We found that the energy difference of both the valence band between the Γ and K points and the spin-splitting size at the K point reduce monotonically with the increasing Mo ratio x [Fig. 2]. The growth of Mo$_x$W$_{1-x}$Se$_2$ monolayer alloys and the method to control the stoichiometric ratio of Mo/W atoms provide an effective way to engineer the band structures in the two-dimensional MX$_2$ materials [3].

Local conduction at BiFeO$_3$-CoFe$_2$O$_4$ two-dimensional tubular interfaces

First Name: Haolin  
Last Name: Wang  
Affiliation: School of Advanced Materials and Nanotechnology, Xidian University, Xi’an, China; School of Physics, Nanjing University, Nanjing, China  
Email: hlwang@xidian.edu.cn

Short Biography:  
Dr. Wang is currently a lecturer in Xidian University and visiting scholar in Nanjing University. He received his B.S. degree in material chemistry from China University of Geosciences Sciences Beijing (CUGB) in 2011 and completed Ph.D. degree in material physics and chemistry from Institute of Semiconductors, Chinese Academy of Sciences (CAS) in 2016. Dr Wang’s research interests lie in the area of scalable synthesis of two-dimensional materials and ferroelectric/multiferroic materials, and their applications in electronic and optoelectronic devices.

Abstract:  
The electronic transport at the topological boundaries holds great promise for applications in next-generation devices. Amongst, tubular interfaces have become an emerging two-dimensional topological state to achieve controllable charge transport path for data storage technologies. However, the mechanism and origin underlying the local conduction at tubular interfaces is still under debate. In this work, we fabricated BiFeO$_3$-CoFe$_2$O$_4$ (BFO-CFO) nanocomposites using magnetron sputtering and systematically investigated the local conduction through variable temperature electrical measurements. We found that the observed conductivity can be well described within an interface-mediated Poole-Frenkel (PF) model combining interface tunnelling and PF conduction. And the local current was attributed to the accumulated oxygen vacancies at the tubular interface, which was further confirmed by post-annealing experiments. This study provided further understanding of conduction behavior at complex oxide interfaces and lay the foundation for novel electronic devices.

Fig. 1. (a) AFM and (b) CAFM images of the BFO-CFO nanocomposites, (c) I-V curves at or off the tubular interface

A native oxide high-κ gate dielectric for 2D electronics

First Name: Yichi
Last Name: Zhang
Affiliation: Center for Nanochemistry, College of Chemistry and Molecular Engineering, Peking University, Beijing, China
Email: zhangyc-cnc@pku.edu.cn

Short Biography:

Yichi Zhang received Bachelor degree of chemistry in 2018 and is pursuing his PhD in Physical Chemistry under supervision of Prof. Hailin Peng at Peking University since then. His research focused on the CVD synthesis of 2D Bi$_2$O$_2$Se and its chemical modification as well as applications on electronic devices.

Abstract:

The potential next-generation high-mobility materials in post-silicon era for microelectronics industry, not only bulk III-V but also 2D and 1D semiconductors, are suffering from an absence of high-quality native oxide dielectric. In this work, we synthesized a high-quality high-κ native oxide dielectric on 2D Bi$_2$O$_2$Se, a rising 2D high-mobility semiconductor [1]. Recently, we found that the surface of 2D Bi$_2$O$_2$Se could be thermally oxidized into native oxide Bi$_2$SeO$_5$ layer-by-layer. The insulative native oxide Bi$_2$SeO$_5$ has a band offset as large as ~1.7 eV and an atomic sharp interface with 2D Bi$_2$O$_2$Se, along with a high dielectric constant (κ) of ~21 at room temperature. With the native oxide as gate dielectric, high-performance 2D Bi$_2$O$_2$Se field-effect transistors (FETs) and even inverter circuits were successfully fabricated [2]. In addition, we developed a room-temperature oxidation approach of 2D Bi$_2$O$_2$Se to an amorphous high-κ (~22) native oxide Bi$_2$SeO$_x$ by using O$_2$ plasma. The ultrathin native oxide with equivalent oxide thickness (EOT) as low as ~0.9 nm directly served as the gate dielectric in 2D Bi$_2$O$_2$Se FETs. Besides, area-selective oxidation was also achieved for a dry-process patterning and device fabrications of 2D Bi$_2$O$_2$Se [3].

**Molecular Beam Epitaxy of High-mobility 2D Oxychalcogenide Semiconductors**

**First Name:** Xuehan  
**Last Name:** Zhou

**Affiliation:** Center for Nanochemistry, College of Chemistry and Molecular Engineering, Peking University, Beijing, China

**Email:** zhouxh-cnc@pku.edu.cn

**Short Biography:**

Xuehan Zhou received her Bachelor degree of Chemistry at Zhejiang University in 2018. Currently she is pursuing a PhD in Physical Chemistry under supervision of Prof. Hailin Peng at Peking University. Her research interests focus on molecular beam epitaxy (MBE) and functional devices of high-mobility layered oxychalcogenides (Bi$_2$O$_2$X, X = S, Se, Te).

**Abstract:**

2D semiconductor has been viewed as potential competitor of silicon due to its atomic thickness which is naturally resistant to short channel effect. In 2017, Prof. Hailin Peng group synthesized a ternary 2D semiconductor [1] Bi$_2$O$_2$Se which showed high electron mobility (~450 cm$^2$V$^{-1}$s$^{-1}$ at room temperature) and excellent stability against oxygen and moisture. Since then, most researches mainly focused on the bulk crystals and CVD-grown few-layer or multiplayer samples. It was still a great challenge to grow atomically-thin high-quality Bi$_2$O$_2$Se films. In 2019, Peng group achieved the first MBE of atomically thin Bi$_2$O$_2$Se films down to monolayer on conducting Nb-doped SrTiO$_3$ (001) substrate by co-evaporating Bi and Se precursors in oxygen atmosphere [2]. Very recently, by changing heating mode and optimizing substrate preparing method, we have realized MBE of Bi$_2$O$_2$Se films on insulating SrTiO$_3$ (001) substrate. For evaluation of the electrical properties of MBE-grown 2D Bi$_2$O$_2$Se crystals, Bi$_2$O$_2$Se films were fabricated into top-gated field-effect transistors (FETs), which exhibited a current modulation of $\sim 10^7$ with extracted mobility as $\sim 250$ cm$^2$ V$^{-1}$ s$^{-1}$ from the linear region of the transfer curve. We can obtain different growth mode and multiple morphological features of 2D Bi$_2$O$_2$Se through precise control of substrate growth temperature ($T_s$), Se/Bi flux ratio and oxygen pressure in the MBE chamber. The diversity of morphology in 2D Bi$_2$O$_2$Se might provide an alternative platform to investigate novel physical phenomena or applications of ultrathin Bi$_2$O$_2$Se.


Fig. 1. Molecular beam epitaxy of Bi$_2$O$_2$Se films on SrTiO$_3$(001) substrates and electronic characterization.
Induced Anisotropic Superconductivity in Ionic Liquid Cation Intercalated 1T-SnSe$_2$

First Name: Haoxiong
Last Name: Zhang
Affiliation: Department of Physics, Tsinghua University, Beijing, China
Email: zhanghx16@mails.tsinghua.edu.cn

Short Biography:

Haoxiong Zhang earned his B.S. degree from Nankai University in 2016. He is now a Ph.D. candidate in the Department of Physics, Tsinghua University. His research focuses on growth and property modulation of quasi-two-dimensional materials and angle resolved photoemission spectroscopy (ARPES) study of their electronic structure, topological property and related quantum phenomena.

Abstract:

The weak van der Waals interaction between adjacent layers of quasi two-dimensional (2D) materials provides opportunities for inserting intercalants to induce novel properties distinct from the host materials [1-3]. Here we report induced superconductivity by intercalating large organic cations from ionic liquids into semiconducting 1T-SnSe$_2$. The intercalation of [C2MIm]$^+$ and [DEMB]$^+$ cations increases the interlayer spacing and leads to induced superconductivity with relatively high $T_c$ of 7.1 K and 6.9 K, large superconducting anisotropy and robust sample stability over previously reported superconducting SnSe$_2$ samples. Angle-resolved photoemission spectroscopy (ARPES) and Hall measurements reveal the importance of electron doping by the cations in the induced superconductivity, and the interlayer expansion and electric polarization of the cations in the large anisotropy. Our work reports induced superconductivity in a hybrid material with new intercalants which contribute both charge carriers and interlayer expansion, and provides new insights into the manipulation of superconductivity in 2D materials.

Vortex matter in 2D Superconductors

First Name: Yoshihiro
Last Name: Iwasa
Affiliation: QPEC & Department of Applied Physics, The University of Tokyo, and RIKEN Center for Emergent Matter Science, Japan
Email: iwasa@ap.t.u-tokyo.ac.jp

Short Biography:

Team Leader, RIKEN CEMS, 2010-present
Professor, Quantum Phase Electronics Center & DAP, University of Tokyo, 2010 - present
Professor, Institute for Materials Research, Tohoku University, 2001 - 2009
Associate Professor, Japan Advanced Institute of Science and Technology, 1994 - 2001
Visiting Researcher, AT&T Bell Laboratories, Murray Hill NJ, 1993 - 1994
Lecturer, Department of Applied Physics, University of Tokyo, 1991 - 1994
Research Associate, Department of Applied Physics, University of Tokyo, 1986 – 1991
Ph.D., Department of Applied Physics, University of Tokyo, 1986

Abstract:

2D superconductors exhibit novel aspects which are distinct from those of the 3D counterparts [1]. These include broken-inversion-symmetry driven phenomena such as enhanced in-plane upper critical fields and nonreciprocal superconducting transport. Vortex matter in 2D superconductors is another example. Vortex in 2D superconductors is a single pancake rather than a cylinder-like rod in 3D superconductors. The behavior of pancake in 2D plane should be dramatically different from what we know in 3D superconductors.

We first discovered the quantum metallic state in gate-induced 2D superconductivity [2]. Vortex, introduced by application of out-of-plane magnetic field, keeps the liquid states owing to the quantum fluctuation without forming lattice or glass. This is a striking contrast with all kinds of 3D superconductors, in which vortex motion has been believed to be frozen at T = 0K, and therefore, the vortex state in clean 2D superconductors has caused a continuing serious debate.

Here we investigated dynamical behavior of 2D vortices under large current in gated superconductivity in MoS$_2$ [3,4]. Based on the experimental results, we present a comprehensive vortex phase diagram shown in Fig. 1. We believe this captures the intrinsic nature of vortex states in clean 2D superconductors.

Segregation growth of germanene at interfaces between van der Waals materials and Ag(111)

First Name: Seiya
Last Name: Suzuki
Affiliation: International Center for Young Scientists (ICYS), National Institute for Materials Science (NIMS), Tsukuba, Japan
Email: SUZUKI.Seiya@nims.go.jp

Short Biography:
Seiya Suzuki received his B.S. degree, master degree, and Ph.D. degree from Toyota Technological Institute, Japan. He is now a researcher in Inter Center for Young Scientists (ICYS), National Institute for Materials Science (NIMS), Japan. His research interests include crystal growth of 2D materials such as graphene and germanene.

Abstract:
Germanene is a single atomic sheet of germanium (Ge), which is suitable for electronic applications due to its exotic properties, such as massless Dirac fermions and a tuneable band gap. The growth of germanene has been reported on single crystal metal surfaces, such as Au (111), Al (111), and Ag (111) [1] in ultra-high vacuum. However, there are no reports of germanene-based electronic devices. One of the main reasons is the chemical instability of germanene, which hinders the device fabrication processes.

As one approach, we conceived the direct growth of germanene at interfaces. The oxidation of germanene should be prevented by placing it at an interface that provides a spatial separation between germanene and oxidizing substances in air. A material with excellent gas barrier properties is required to form such an interface.

Here, we report a novel method of growing germanene at interfaces between van der Waals (vdW) materials and Ag(111). Since vdW materials, such as graphene and hexagonal boron nitride (h-BN), have excellent gas barrier properties. We fabricated a Ag(111) thin film on a Ge (111) substrate by e-beam evaporation. After that, a stacked hexagonal boron nitride (h-BN)/graphene flake was mechanically transferred onto the Ag surface in air. Then, we induced Ge segregation and crystallization at the graphene/Ag interface by simple heating in inert ambient. As a result, we found two new Raman peaks at 155 and 255 cm⁻¹ (Fig. 1). Density functional theory calculations revealed that these peaks were assigned as out-of-plane (155 cm⁻¹) and in-plane (255 cm⁻¹) vibration modes of germanene. Because the peaks were perfectly preserved in air for more than 1 months, we empirically proved that the germanene at the interface is stable. We believe that the present work provides new insights for growing 2D materials at interface.


Figure 1. Raman spectra of the annealed h-BN/graphene/Ag(111) on Ge(111)
Process development and crystal quality evaluation of van der Waals nanocapacitor using graphene/h-BN heterostructures stacked by transfer/stacking method

First Name: Hiroki
Last Name: Sugawara
Affiliation: Research Institute of Electrical Communication, Tohoku University, Sendai, Japan
Email: s-hiroki@riec.tohoku.ac.jp

Short Biography:
Hiroki Sugawara is a 2nd-year MS student in the Graduate School of Engineering, Tohoku University. He received the B.S. degree from Tohoku University in March 2019. He is currently working on terahertz device applications using graphene/h-BN heterostructures towards the MS degree.

Abstract:
Atomically-thin two-dimensional (2D) heterostructures have attracted much attention as a platform material for high-performance and functional terahertz (THz) device applications [1]. We have proposed the gated double-graphene-layered (G-DGL) structure as the functional element of new THz light emitters/detectors [2-4]. The DGL is a van der Waals nanocapacitor consisting of an atomically-thin 2D material such as h-BN or MoS$_2$ sandwiched between two graphene layers. The complimentary electrical doping to the DGL and its band offset control may lead to photon/plasmon-assisted tunnelling between the DGL, working for highly efficient THz emission/detection.

We successfully fabricated a h-BN/Graphene/h-BN/Graphene/h-BN DGL structure by using our dedicated transfer/stacking process equipment. We characterized the crystallographic quality of the sample by Raman spectroscopy. We estimated the strain-induced degradation of the crystal quality and doping effects [5] due to mechanical and chemical damages caused by the exfoliation/transfer processes and chemical and thermal damages by the stacking process at high elevated temperatures.

Mapping of the G' peak (2680 cm$^{-1}$) intensity of the sample (Fig. 1) identifies the location of the graphene that is invisible in optical microscopy. From the Raman spectra of three representative points where only DGL, the top graphene, and the bottom graphene in the sample (Fig. 2), it was confirmed that the top and bottom graphene layers were stacked with almost identical high crystal quality. Excellent optoelectronic properties are expected, which are now under measurement.

Charge Transfer and Magnetic Proximity Effect in van der Waals Heterostructure of Monolayer MoSe\(_2\) and Double-layered Manganese Oxide

First Name: Yan
Last Name: Zhang
Affiliation: Institute of Advanced Energy, Kyoto University, Uji, Kyoto 611-0011, Japan
Email: zhang.yan.55s@st.kyoto-u.ac.jp

Short Biography:
Ms. Yan Zhang is in a second-year of Ph. D course in Department of Energy Science, Kyoto University, Japan. She obtained MS degrees from University of Science and Technology, China.

Abstract:
van der Waals (vdW) heterostructures composed of semiconducting monolayer transition metal dichalcogenides (TMDs) on the different types of materials have been attractive for emerging novel properties of semiconducting monolayer TMDs that can be sensitively affected and controlled by the physical properties of underneath materials.

In this work, we study the charge transfer and magnetic proximity effect for optically generated excitons (bound electron-hole pairs) and trions (charged excitons) in monolayer MoSe\(_2\) (1L-MoSe\(_2\)) and double-layered perovskite Mn oxide ((La\(_{0.8}\)Nd\(_{0.2}\))\(_{1.2}\)Sr\(_{1.8}\)Mn\(_2\)O\(_7\)) vdW heterostructure with inserting h-BN, as shown in Figure 1a. The Mn oxide shows phase transition from paramagnetic-insulator (PI) to ferromagnetic-metal (FM) at Curie temperature (\(T_C\)) via double-exchange interactions of \(d\)-electrons in the Mn sites [1]. Inset figure in Figure 1b shows the two-emission peaks from exciton (X) and trion (T). The efficient charge from metallic Mn oxide to MoSe\(_2\) is indicated by the PL intensity ratio of trion and exciton in Figure 1b. The 1L-MoSe\(_2\)/Mn oxide vdW heterostructures inserted with h-BN layers enable to observe excitonic valley splitting of MoSe\(_2\) induced by FM Mn oxide below \(T_C\). The enhanced valley splitting in Figure 1c has been induced by the effective magnetic field equivalent to \(~7.6\ T\) from ferromagnetic spins of Mn oxide via magnetic proximity effect [2]. The controllable thickness of h-BN in the vdW heterostructure allows revealing the characteristic length scale of a few nano-meters in magnetic proximity effect dominated by the exchange interaction from the magnetic spins.

![Figure 1](image.png)

Observation of the layer dependent electronic structures in atomically thin WTe$_2$ flakes

First Name: Yuma
Last Name: Tanaka
Affiliation: Department of Applied Physics, University of Tokyo, Tokyo
Email: tanaka@sssi.t.u-tokyo.ac.jp
Short Biography:
2019-present Master’s course in Prof. Ishizaka’s group
2015-2019 Bachelor of Engineering in University of Tokyo

Abstract:
Development of scotch tape methods on graphene and related van der Waals (vdW) materials has triggered intensive researches on novel properties and phenomena realized in atomically thin two-dimensional (2D) crystals, e.g., the valley-induced circular dichroism, 2D superconductivity, and so on. More recently, to explore a wider variety of quantum phases and yet unknown functions, vdW heterostructures [1] obtained by stacking 2D micro-flake crystals have been attracting much attentions. Here the electronic structures tend to become complicated due to the coupling of stacked 2D layers and their relative stacking angles, which makes it difficult to be investigated by simple transport measurements and band calculations.

In our study, by using micro-focused laser angle-resolved photoemission spectroscopy (ARPES) [2] in combination with the 2D materials manufacturing system (2DMMSS) that can freely stack atomic layers by image recognition, machine learning, and autonomous robots[3,4], we developed a high-throughput procedure for investigating the band dispersions of atomically thin micro-flakes. We prepared 2D WTe$_2$ flake samples for ARPES by using the graphite / h-BN as a substrate and by encapsulating with graphene [5,6]. We successfully observed the thickness-dependent band structures peculiar to WTe$_2$. The 2D sample fabrication procedure used in this study should be applicable to a wide range of micro-flakes, heterostructures and twisted materials.

References

Fig. 1. a. Optical microscope image and schematics of the fabricated sample. b. Electronic structure of the exfoliated WTe$_2$ flake measured by ARPES.
Electron transport mechanism in a correlated quantum Hall antiferromagnetic state of bilayer graphene

First Name: Miuko
Last Name: Tanaka
Affiliation: Applied Physics, University of Tokyo, Hongo, Japan
Email: miuko.tanaka@riken.jp
Short Biography: PhD course student in university of Tokyo and studying about quantum Hall magnetism of graphene.

Abstract:

The quantum Hall state is one of the strongly correlated states. When multiple internal degrees of freedom exist, exchange interaction stabilizes a many-body ordered ground state if a Landau level (LL) is partially filled. Zero-energy LL of bilayer graphene offers an exciting platform to study various many-body ground states and phase transitions, owing to the interplay of spin, layer, and orbital degrees of freedom and controllability of the layer degree of freedom by an out-of-plane external electric field $D$. At its half filling ($\nu=0$), the canted antiferromagnetic (CAF) state is believed to be stabilized for a small $D$, while the fully layer polarized (FLP) state becomes the ground state for a large $D$. For an enhanced Zeeman energy in presence of a tilted magnetic field, the ferromagnetic state becomes the ground state [1].

In particular, the CAF state attracts considerable interest for its unique electronic properties including spin superfluidity [2] and charge neutral current generation [3]. However, we lack in understanding of the most fundamental physical property, transport mechanism of the charge current. This lack makes it difficult to obtain microscopic picture of these fascinating phenomena. Here we measure pure bulk conductivity of this state using a Corbino device in a wide range of temperature and reveal that the transport is governed by variable range hopping.

Figures show the temperature dependence of conductivity at the CAF state. They show nonmonotonic behavior separated into three regions, insulating region I, metallic region II, and insulating region III. (Figs. a, b) This behavior is not explained by simple Alenius behavior. Instead, we find that the conductivity in regions I and II is fitted by a universal formula (Fig. c)

$$\sigma \propto \frac{1}{T} \exp(-\sqrt{T_0/T}),$$

known to represent the variable range hopping via localized states. $T_0$ is the parameter which is inversely proportional to the localization length.

In the poster presentation, we show magnetic field dependence of the fitting parameter and its relation to energy scales of the CAF state. We also argue that this hopping transport is most probably mediated by pinned vortex pairs and holds up to the Kosterlitz Thouless transition temperature.

Controlled synthesis of graphene nanoribbons from liquid phase catalyst

First Name: Naofumi
Last Name: Sato
Affiliation: Graduate School of Engineering, Tohoku University, Sendai, Japan
Email: naofumi.sato.s2@dc.tohoku.ac.jp

Short Biography:

Mr. Naofumi Sato has completed his BC from Tohoku University, Japan, in 2019. He is currently master course student of Electrical Engineering in Tohoku University. His research interests have ranged from structural-controlled synthesis to optoelectrical device application of graphene nanoribbon.

Abstract:

In recent years, graphene nanoribbon (GNR), strips of two-dimensional (2D) graphene into one-dimensional (1D) structure gather intense attentions because of their superior electrical features. Although GNR can be made in a variety of ways, the reliable site and alignment control of GNR with high on/off current ratios remains a challenge.

Until now, we have developed a novel method based on the advanced plasma CVD with nanoscale Ni catalyst (Ni nanobar) for directly fabricating suspended GNR devices [1, 2]. Further adjustments in the GNR structures such as the width, length and layer number can open up the application field of this novel material. From our previous research, it can be conjectured that the locally-formed narrow part within the GNR may be the critical origin of high on/off current ratios. Such local structures can be formed by the Plateau-Rayleigh (P–R) instability during plasma CVD [2].

To improve the structure controllability of GNRs, controlling the P–R instability, especially initiation position of instability within nanoscale material, is one of the important subjects. Based on this background, we have developed a new approach introducing “fluctuation structures” within the initial Ni nanobar. This structure includes circles and straight parts within single Ni nanobar. We expected that the straight (= narrower) part of Ni nanobar might be as a trigger for initiating P–R instability.

Based on this idea, we performed a GNR growth with changing the number of circles in the Ni nanobar. As a result, it was found that averaged on/off current ratios within the multiple GNR devices can be improved by adjusting the number of circles in the initial Ni nanobar, which can be explained by the balance between circle to circle distance and wavelength of P–R instability.


Fig. 1. (a) Schematic illustration of suspended GNR device. (b) Typical scanning electron microscope (SEM) image of suspended GNR grown by our plasma CVD. Scale bar in (b) shows 100 nm.
Electronic states of monolayer VTe$_2$ thin film studied by high-resolution ARPES

**First Name:** Tappei  
**Last Name:** Kawakami  
**Affiliation:** Department of Physics, Tohoku University, Sendai 980-8578, Japan  
**Email:** t.kawakami@arpes.phy.tohoku.ac.jp

**Short Biography:**
Bachelor of Physics, University of Toyama (2019). My research interests are electronic states of low dimensional materials.

**Abstract:**

Initiated by the discovery of graphene exhibiting outstanding physical properties, intensive studies have been performed to search for a new platform of two-dimensional (2D) materials which exhibit physical properties different from the bulk counterpart. Recently, layered transition-metal dichalcogenides (TMDs) are attracting a particular attention since they are a promising candidate to explore exotic physical properties which are absent in bulk. Bulk vanadium ditelluride (VTe$_2$) have been reported to exhibit one-dimensional structural phase transition from the octahedral $1T$ structure to the distorted octahedral $1T'$ structure at high temperature of 482 K [1]; however origin of this transition remains unclear. Moreover, it is still unknown how the physical properties vary when number of layers are reduced down to ultimate 2D limit (i.e. monolayer). Here we have fabricated a monolayer VTe$_2$ thin film on bilayer graphene / SiC by using the molecular-beam-epitaxy (MBE) method [2], and elucidated its electronic states with angle-resolved photoemission spectroscopy (ARPES).

Figure 1 shows the ARPES intensity as a function of 2D wave vector $(k_x, k_y)$ of monolayer VTe$_2$ (top panel), together with the representative experimental band structure along the $\Gamma K$ cut (bottom panel) measured at 40 K. In the Fermi-surface mapping, one can clearly recognize a large triangular Fermi surface centered at the $K$ point. This pocket originates from the relatively flat V $3d$ band as revealed in the experimental band dispersion (bottom panel). We also observed two highly dispersive hole-like bands at the $\Gamma$ point (bottom panel) which are ascribed to the Te $5p$ orbital. These bands do not cross the Fermi level ($E_F$) and do not participate in the Fermi surface.

In this presentation, we will present the electronic states near $E_F$ in detail, and discuss a possibility of 1D structural phase transition seen in bulk VTe$_2$ Main body could consist of a couple of paragraphs.


Figs. 1: Fermi-surface mapping (top) and band dispersion (bottom) along the $\Gamma K$ cut of MBE-grown monolayer VTe$_2$. 
Chiral electroluminescence in monolayer heterojunctions

First Name: Jiang
Last Name: Pu
Affiliation: Dept. of Applied Physics, Nagoya University, Nagoya, Japan
Email: jiang.pu@nagoya-u.jp

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. program, he also was selected as the Research Fellowship for Young Scientists from Japan Society of Science (JSPS).

Abstract:

Recent advances of heterostructure fabrications based on transition metal dichalcogenides (TMDCs) yield atomically regulated interfaces due to their intrinsically passivated surfaces, allowing us to explore unusual optical phenomena, such as interlayer excitons and valley-polarized light emissions [1,2]. Although, numerous experimental demonstrations have been performed in vertically stacked heterostructures, the optical devices with lateral heterojunctions, in which dissimilar TMDCs are artificially stitched together, have been still limited [3]. In particular, the electronic structures at the interfaces of lateral heterojunctions are commonly influenced by the interfacial strains, resulting in peculiar band offsets and optical properties [3,4]. For example, we recently reported the room-temperature chiral electroluminescence (EL) in strained TMDCs [5]; thus, the chiral EL is also expectable for the strained lateral heterojunctions, which is a new way for designing chiral light-emitting devices based on TMDCs. Here, we fabricate electrolyte-based lateral heterojunction light-emitting devices to investigate their EL properties at the junction interfaces.

The monolayer WS$_2$–WSe$_2$ single-crystalline lateral heterojunction films were grown by CVD method (Figs. 1a and 1b). The two-terminal light-emitting devices were prepared by the deposition of two Au electrodes, followed by spin-coating the ion-gel films (Fig. 1b). As applying voltage between two electrodes, holes (electrons) are injected and accumulated in WSe$_2$ (WS$_2$) mediated by electric double layers to form p-n junctions (Fig.1a). Figure 1c show the direct observations of EL image for WS$_2$–WSe$_2$ lateral heterojunction devices. We obviously got EL from the junction interfaces. Thereby, we did spatially- and polarization-resolved EL spectroscopy at the junctions. As a result, we observed chiral EL at room temperature; the EL polarizations were above 10 %, which might be originating from the strained natures of the junction interfaces. These results possibly provide the new directions to engineering practical chiral p-n diodes based on monolayer semiconductors.

Synaptic Performance with Improved Linearity and Endurance by modulating \( \text{Pb(Zr}_{0.52}\text{Ti}_{0.48})\text{O}_3/Nb \) doped \( \text{SrTiO}_3 \) Interface Barrier

First Name: Sohwi
Last Name: Kim
Affiliation: Department of Physics, Konkuk University, Seoul, Korea
Email: a01062428461@gmail.com

Short Biography:
Sohwi Kim received bachelor’s degree in department of physics from Konkuk University, Seoul, Korea, and is currently master course in 2-terminal artificial synaptic device.

Abstract:

Learning in the brain is achieved through the ability of synapses to strengthen/weaken the strength called synaptic plasticity, by which they connect neurons.\[1\] Thus, electrical functionality and structure of 2-terminal memristor device that are considerably similar with biological synapses can be excellent candidate for artificial synaptic device. There are several requirements for synaptic device, such as linear conductance change and low variation for high recognition rate. Fast operation speed, low energy consumption about 10 fJ and high endurance over 100 million times are also necessary to emulate biological synapse.\[2\]. Here we demonstrate that conductance variations (potentiation/depression) can be modulated from Pb(Zr\(_{0.52}\)Ti\(_{0.48}\))O\(_3/Nb\) doped SrTiO\(_3\) (PZT/Nb:STO) interface barrier by redistribution of ferroelectric domains of Au/Ni/PZT/Nb:STO structure, Compared to Au/Ni/Nb:STO device. Based on this physical model, our device performance with gradual control of barrier height and width show improved linearity factor and endurance of potentiation/depression over 30,000,000 that have been not shown in previous researches about ferroelectric/Nb:STO structure. Additionally, we confirmed nano-seconds operation speed due to fast switching speed and in Nb:STO substrate and low energy consumption can be achieved. In combination with fast operation speed and efficient energy consumption, these results offer a promising outlook on the use of ferroelectric memristors with linear control and good P/D endurance as building blocks in artificial neural networks.

\[2\] D. Kuzum et al., Nanotechnology 24, 382001, (2013)
Interlayer coupling and structural phase transition in few-layer 1T' and Td MoTe2

First Name: Yeryun  
Last Name: Cheon  
Affiliation: Department of Physics, Sogang University, Seoul, Korea  
Email: ycheon@sogang.ac.kr

Short Biography:

Yeryun Cheon received her B.S. degree from Sogang university in 2019. She is currently a master student at the same university. She received Best Poster Presentation Award at KPS Meeting (Fall 2019, Spring 2020) and ICAMD 2019. Her research interest mainly focuses on 2D materials and Raman spectroscopy.

Abstract:

We performed polarized Raman spectroscopy on mechanically exfoliated few-layer MoTe2 samples, and observed both 1T' and Td phase at room temperature. Few-layer 1T' and Td MoTe2 exhibited a significant difference especially in interlayer vibration modes, and they were systematically investigated through group theory analysis and fitted to the linear chain model. Furthermore, temperature-dependent Raman measurements showed a peculiar phase transition behavior in few-layer 1T' MoTe2. In contrast to bulk crystals where the phase transition from the 1T' to the Td phase occurs at ~250 K, the few-layer samples exhibited the phase transition at much lower temperatures, mostly below 80 K, and it was suppressed in 3L and 4L samples. Noticeably, even in the same thickness, the phase transition behavior and the critical temperature were dramatically varied from sample to sample. The intermediate phases, neither 1T' or Td phase, were observed with different interlayer vibration modes, and this suggests the several metastable phases exist with similar total energies. Our comprehensive study on interlayer vibration modes will provide indisputable criteria to distinguish the slightly different metastable phases in atomically thin MoTe2.

Fig. 1. Low-frequency Raman spectra of 1T' and Td MoTe2 (a) and (b) in parallel and (c) in cross polarization configuration.
Realization of a Honeycomb-Lattice Mott Insulating State on 1T-TaS$_2$

First Name: Jinwon
Last Name: Lee
Affiliation: Department of Physics, Pohang University of Science and Technology (POSTECH), Pohang, Republic of Korea
Center for Artificial Low Dimensional Electronic Systems, Institute for Basic Science, Pohang, Republic of Korea
Email: jwlee0421@postech.ac.kr

Short Biography:

Jinwon Lee got a B.S. degree in Physics and he is doing a M.S. & PhD. combined degree in Physics. His research interests are strongly correlated phases, such as charge density waves, Mott insulating phase, and excitonic insulator phase in van der Waals layered materials. Especially, how these phases are affected by surface adsorbates is his main research topic. Thus, he uses scanning tunnelling microscopy to investigate the systems in a real space with an atomic resolution. He have received a Global PhD Fellowship from National Research Foundation of Korea (2015-2019).

Abstract:

A narrow-bandwidth system is prone to have an instability with the presence of a weak perturbation due to its metallic electrons with small kinetic energy, resulting in exotic quantum phases. More interestingly, in a two-dimensional (2D) honeycomb lattice, they are combined with Dirac bands and topological properties, described by the Kane-Mele-Hubbard model. With an electronic many-body interaction and the spin-orbit coupling, various exotic phases have been proposed theoretically such as topologically non-trivial states, quantum spin liquids, charge density waves, superconductivity, and topological Mott insulator at or near the half-filling. However, the material realization of the Kane-Mele-Hubbard system system has not been identified yet. Here we show a unique approach to realize a 2D honeycomb-lattice narrow-bandwidth system with strongly interacting 5$d$ transition metals. We engineer a triangular-lattice 2D Mott insulator 1T-TaS$_2$ into a honeycomb lattice using K adatoms as lattice manipulators. At the optimum coverage of K adatoms, they deplete one third of the unpaired 5$d$ electrons in a triangular lattice of 1T-TaS$_2$ and the remaining electrons form a honeycomb lattice. The density functional theory calculations show flat Z$_2$ topological bands and an order of magnitude larger charge gap, measured by scanning tunneling microscopy, confirms the substantial electron correlation, or Mott physics. This could be the first realization of the Kane-Mele-Hubbard system and an artificial honeycomb-lattice Mott insulator with a finite spin Chern number. The lattice manipulation by adsorbates can be exploited with an atom-manipulation technique to realize various narrow-bandwidth structures such as one-dimensional or kagome lattice flat-band systems.

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Tunable high-temperature itinerant antiferromagnetism in a van der Waals magnet

First Name: Junho
Last Name: Seo
Affiliation: ¹Center for Artificial Low Dimensional Electronic Systems, Institute for Basic Science (IBS), Pohang 37673, Korea, ²Department of Physics, Pohang University of Science and Technology (POSTECH), Pohang 37673, Korea
Email: junho2003@postech.ac.kr

Short Biography:
Junho Seo is a PhD student in Prof. Jun Sung Kim’s lab at POSTECH, Pohang, Korea. He mainly do bulk single crystal growth and measuring magnetotransport properties of van der Waals magnet.

Abstract:
Antiferromagnets, due to their negligible stray field, robustness against perturbation and ultrafast dynamics, have great potential for spintronics. Among them, synthetic antiferromagnets, where two ferromagnetic (FM) layers are stacked alternately with non-magnetic layers in-between, are versatile system for antiferromagnetic (AFM) spintronics. Since their diverse spin configuration and functionalities are based on the interlayer exchange coupling mediated by conduction electrons, they are extremely sensitive to material compositions and interlayer distance. Taking this approach and using a metallic van der Waals (vdW) magnet Fe₄GeTe₂ as a model system, we show that the interlayer exchange coupling and magnetic anisotropy is significantly modulated with Co doping, leading to the AFM order with the highest Neel temperature of $T_N \sim 210$ K among vdW antiferromagnets. The resulting spin configurations and orientations are sensitively controlled by magnetic field, temperature, and thickness and effectively read out by their coupling to the electrical conduction. These findings manifest metallic vdW antiferromagnets as intrinsic synthetic anti-ferromagnets, which can serve as a tunable component for AFM spintronics.
ReS$_2$ based pn Heterojunction Device

**First Name:** EuiHyoun  
**Last Name:** Ryu

**Affiliation:** Department of Micro/Nano System, Korea Univ., Seoul, Korea

**Email:** dmlgus9410@gmail.com

**Short Biography:**

EuiHyoun Ryu received the B.S. degree from the School of material science and engineering, Chungnam National University, Deajeon, Korea, in 2017. She is currently studying at the Department of Micro/Nano System, Korea University and Department of physics, Ewha Womans University, Seoul, Korea. She is studying basic properties of nanoelectric / nano mechanical device and their applications.

**Abstract:**

Two-dimensional transition metal dichalcogenides (TMDs) have attracted a great amount of attention in the fields of flexible electronics and optoelectronics owing to their excellent electrical properties as well as the advantage of a substantial band gap. Recently, researches have also been conducted to create more special devices like heterostructures through the combination of two-dimensional materials. TMDs heterostructures have appeared as a fascinating research topic for both fundamental science and applied physics. Pn heterojunctions consist of TMDs semiconductors have been used to demonstrate photodetectors and photovoltaic devices. However, the development of band gap to enhance photo generation in devices made from two-dimensional materials with high light absorption is a promising field that has not been studied much yet. Of the varieties of TMDs, Rhenium disulfide (ReS$_2$) reveals a distinct property as an n-type semiconductor. We are going to analyse its electrical properties through an experiment, and furthermore measure photoelectric current due to its application to a photodetector. In conclusion, the final goal is to make the multifunctional few-layer ReS$_2$/GeSe heterostructure and ReS$_2$/MoS$_2$ QDs device which is technologically promising for next-generation optoelectronics.


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Fig. 1. ReS$_2$ based pn heterostructure device
Population dynamics of excitons and biexcitons in a 2D halide perovskite single crystal

First Name: Seohyun
Last Name: Nam
Affiliation: Physics Department, Sogang University, Seoul, South Korea
Email: seohyun102@sogang.ac.kr

Short Biography:

Seohyun Nam is a graduate student, pursuing the Master’s Degree in Physics at Sogang University. She has been working on novel optical properties of 2D hybrid halide perovskites with a special emphasis on the exciton-biexciton dynamics under Prof. Jang’s supervision. In 2019, she was selected as a scholarship student (LGenius) by LG Display. In 2020, she was awarded the best poster presentation award by the Korean Physical Society (KPS) at the KPS Meeting.

Abstract:

Halide perovskites have attracted significant attention owing to their excellent optical properties. In the case of 2D Ruddlesden-Popper series, \((A')_m(A)_{n-1}Pb_nX_{3n-1}\) \((A', A = \text{organic cations and } X = \text{halogen anion with } n = 1 \sim \infty)\), the \(A'\) cations acts as an insulating barrier that strongly confines charge carriers in the 2D perovskite layer. This specific arrangement of alternating organic-inorganic layers generates a 2D quantum-well structure, under the quantum and dielectric confinement effects. These properties give rise to large Coulomb interaction, leading to the formation of excitons and biexcitons with large binding energies. In this work, we prepared a single crystal of \(PEA_2PbI_4\) \(\text{(PEA} = C_6H_5(CH_2)_2NH_3)\) and investigated the population dynamics of excitons and biexcitons as a function of input photon flux and temperature as well. We found that biexcitons are stable when temperature is cold enough (< 80 K) based on the time-integrated photoluminescence spectroscopy. The measured biexciton binding energy is about \(40 \pm 5\) meV, which is consistent with the recent publication. For the first time, we experimentally determined the exciton-exciton capture coefficient \(C \approx 6.72 \times 10^{-19}\) ns\(^{-1}\)cm\(^3\) to form a biexciton at 10 K under both one-photon absorption (1PA) and two-photon absorption (2PA) by analyzing the simultaneous rate equations for the exciton-biexciton dynamics in the steady-state regime. Our next goal is to find the temperature-dependent \(C\) and lifetimes of excitons and biexcitons in this important material.


Fig. 1. Left: Energy level diagram and associated optical transitions. Right: Exciton and biexciton PL counts vs. input photon flux under 2PA (960 nm excitation).
2D TMD Channel with 1D ZnO Nanowire for Nonvolatile Trap Memory

First Name: Taewook
Last Name: Kim
Affiliation: Department of Physics, Yonsei University, Seoul, South Korea
Email: twwook.kim@gmail.com

Short Biography:

Taewook Kim received the bachelor’s degree in physics from Yonsei University, Korea, in 2017, where he is currently pursuing the Ph.D. degree in the Institute of Physics and Applied Physics. The research area is memory device using TMD.

Abstract:

Two dimensional TMD materials have novel synergy by mixing with other dimensional materials. [1,2] Here, n-type, p-type field effect transistors (FETs) and 2D stack-based interface trap non-volatile memory are fabricated with 2D MoS$_2$, MoTe$_2$ and 1d ZnO nanowire. For the trap memory, two MoS$_2$ flakes are stacked each other on Al$_2$O$_3$/ZnO nanowire and deep level electron traps are formed at 1$^{st}$/2$^{nd}$ MoS$_2$ interface through short cycles of atomic layer deposition. In addition, complementary type memory cell operation is demonstrated by n-type trap memory and p-type FET with the ZnO nanowire as common bottom gate.


Fig 1. 3D schematic of nonvolatile interface trap memory (left) and cross-sectional STEM image of the memory device (inset left), optical microscopy image of the same memory device (inset right). Transfer characteristics of the memory FET (right)
Low voltage operating nonvolatile memory transistor with MoTe\textsubscript{2} channel and P(VDF-TrFE) ferroelectrics

First Name: Yongjae
Last Name: Cho
Affiliation: Department of Physics, Yonsei University, Seoul, South Korea
Email: dntmdgkfl@naver.com

Short Biography:

Yongjae CHO received the B.S. degree in physics from Yonsei University, Korea, in 2017, where he is currently pursuing the Ph.D. degree with the Institute of Physics and Applied Physics. The research area is doping of TMD based transistors.

Abstract:

MoTe\textsubscript{2} channel-based P(VDF-TrFE) ferroelectric nonvolatile memory is fabricated, which operates at minimum switching pulse voltage and minimum drain voltage. For the minimum switching voltage of 8 V, bottom-gate architecture is employed and its advantages are investigated. By using bottom-gate structure, we could avoid a dead layer formed at the interface between thermally-deposited Al and P(VDF-TrFE) at top-gate architecture. A dead layer in top-gated ferroelectric memory transistors increases the coercive voltage so as the switching pulse voltage. And, for the minimum drain voltage, a novel method of H\textsubscript{2}O\textsubscript{2} treatment is developed. By oxidizing the source/drain area of MoTe\textsubscript{2} surface by H\textsubscript{2}O\textsubscript{2} solution, Ohmic contact between Pt and MoTe\textsubscript{2} is achieved even without thermal annealing which would have a destructive effect on the crystal quality of P(VDF-TrFE). To demonstrate the benefit of our memory transistor in aspect of power saving, it is integrated into an OLED operating circuit.

Fig. 1. Comparison plot showing switching pulse and drain/operation voltages of reported nonvolatile memory FETs, Memory hysteresis transfer and displacement characteristics, Power consumption-time plots of memory FETs
First Name: Yoonseok
Last Name: Kim
Affiliation: KU-KIST Graduate School of Converging Science and Technology, Korea University, Seoul, Korea
Email: chungpodo3@korea.ac.kr
Short Biography:

Yoonseok Kim received his B.S. from the Department of Materials Science and Engineering of Yonsei 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 optical properties of 2D materials and their quantum optoelectronic applications.

Abstract:

Quantum wells (QWs), enabling effective exciton confinement and strong light-matter interaction, form an essential building block for quantum optoelectronic devices. For two-dimensional (2D) semiconductors such as transition metal dichalcogenides (TMDs), however, constructing the QWs is still challenging because suitable materials and fabrication techniques are lacking for bandgap engineering and interlayer-coupling-induced indirect bandgap transitions occur at the multilayer. Here, we demonstrate a novel approach to fabricate atomic-layer-confined multiple QWs (MQWs) via monolithic bandgap engineering of TMDs and artificial van der Waals stacking. The WOₓ/WSe₂ hetero-bilayer formed by monolithic oxidation of the WSe₂ bilayer exhibited the type-I band alignment, facilitating as a building block for the stacked MQWs. A super-linear enhancement of photoluminescence with increasing the number of QWs was achieved: ~5-fold for triple-QWs. Furthermore, quantum-confined radiative recombination in 2D MQWs was verified by a large exciton binding energy of 193 meV and a short exciton lifetime of 170 ps. This work paves the way toward monolithic integration of 2D superlattices for novel quantum optoelectronics.

Fig. 1. Schematic illustration, energy band diagram, and cross-sectional TEM image of MQWs with stacking of the WOₓ/WSe₂ hetero-bilayer.

Atomically thin Schottky junction with a gap-mode plasmon for Enhanced photoresponsivity in MoS$_2$ based photodetector

First Name: Hyeok Jun
Last Name: Jin
Affiliation: School of Electrical Engineering, KAIST, Daejeon, 34141, Korea
Email: znfhktzlo978@kaist.ac.kr

Short Biography:
Hyeok Jun Jin received Bachelor’s degree in 2019 from a school of Physics of KAIST, Daejeon, Korea. He is a Integrated Master’s and Doctorate course in the school of Electrical Engineering of KAIST, Daejeon, Korea. He is interested in optoelectronic devices based on 2D materials.

Abstract:
Compared with traditional bulk materials, 2D materials have many extraordinary properties in the field of optoelectronic devices, such as tunable bandgap and absence of dangling bonds. Although their excellent light-matter interaction, a low optical absorption which proportional to the thickness has considered as a major limitation. One possible way to overcome this limitation is to increase the light absorption using plasmonic nanostructures. These nanostructures interact with incident light and generate localized surface plasmon resonance (LSPR), thereby the light absorption can be significantly enhanced near the structure. The magnitude of LSPR can be highly intensified when two metallic nanostructures are placed with a small insulating gap, and called gap-mode plasmon[1]. Here, we apply a gap-mode plasmon structure to the Schottky junction of Au/MoS$_2$ to compensate for the low absorption. The magnitude of gap-mode plasmon is generally known to be inversely proportional to the gap distance, so that the atomically thin thickness of 2D materials can be considered as a good candidate for gap spacer[2]. Owing to the gap-mode plasmon structure, the photoresponsivity of the device is enhanced approximately 11.6 times from 25 to 290 A/W without degradation of the photoresponse time. In order to verify the presence of gap-mode plasmon, surface enhanced Raman spectroscopy, absorption spectroscopy and numerical simulation are also performed. Unlike the conventional Schottky junction photodiode, the device exhibits its highest responsivity in the forward-biased condition because of the traps and photoresistor feature of MoS$_2$.


High-speed residue-free transfer of two-dimensional materials using PDMS stamp and water infiltration

First Name: Jun-Ho
Last Name: Lee
Affiliation: Department of Physics, Konkuk University, Seoul
Email: ab67532@gmail.com

Short Biography:
I am a PhD student within department of physics at konkuk university in south korea. My thesis is concerned with modulating a tunneling barrier height in graphene/hBN/metal heterostructure and its application to photodetector. In addition, I have researched a transfer method for 2D materials to make 2D heterostructure that has a clean interface.

Abstract:
A high-speed residue-free transfer method using PDMS (polydimethylsiloxane) stamp and water infiltration between graphene and a hydrophilic surface is reported. Monolayer graphene was transferred from an enhanced fluorinated Al₂O₃ surface using PDMS. Water infiltration dramatically reduced the time required to separate the graphene from the Al₂O₃ substrate to a few minutes. The graphene was then successfully transferred to a target substrate (SiO₂) using the PDMS stamp. Atomic force microscopy and lateral force microscopy was used to confirm the absence of residue on the transferred graphene surface.

Fig. 1. Schematic illustration of processes to transfer graphene using water infiltration and PDMS stamp.