AEFM ANNUAL CONFERENCE

Advanced Epitaxy for Freestanding Membranes and 2D Materials

PROGRAM BOOK

July 22-24, 2024

TOKYO

Advanced Epitaxy for Freestanding Membranes & 2D Materials

TAKETA Hall, The University of Tokyo, Tokyo
July 22-24, 2024

https://www.freestandingmembranes.com

Advanced Epitaxy for Freestanding Membranes & 2D Materials (AEFM), Tokyo

July 22-24, 2024

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- Ho Nyung Lee, Oak Ridge National Laboratory
- Abdallah Ougazzaden, Georgia Tech Europe

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WELCOME

Dear invited speakers, poster presenters, and attendees,

It is our pleasure to welcome you to the “Advanced Epitaxy for Freestanding Membranes and 2D Materials” Workshop in Tokyo. This event brings together leading researchers and experts to discuss the latest advancements in the synthesis, characterization, and applications of epitaxial freestanding membranes and 2D materials.

Over the next three days, we will explore the cutting-edge research that is enhancing our understanding of the fundamental properties and potential applications of oxides and III-V freestanding membranes in tandem with 2D materials. Discussions will cover a wide range of topics, including the remote epitaxy growth of 3D Nanomembranes, wafer-scale integration of 2D materials, and emerging applications in electronics, sensors, and energy harvesting.

We will specifically explore the integration of 2D materials into existing technology platforms, addressing the complexities of their incorporation into semiconductor devices, flexible electronics, and other advanced technologies. The use of machine learning in screening precursors, optimizing structures, and predicting new properties will also be a focal point, highlighting the interdisciplinary nature of this rapidly evolving field.

We are honored to welcome our Plenary and Keynote speakers, as well as all invited speakers and poster presenters who have travelled from around the world to share their groundbreaking research.

Thank you for joining us. We hope this conference will be a stimulating forum for scientific discourse, the exchange of ideas, and the forging of new collaborations.

Cheers,

Vincent Tung,

Chair of AEFM 2024

On behalf of the AEFM Organization Committee

Sang-Hoon Bae **(Washington University, St. Louis)**
Hyunseok Kim **(UIUC)**
Olga Bubnova **(Nature Reviews Electrical Engineering)**
Stanley Jui-Han Fu **(UTokyo)**

GENERAL INFORMATION

Conference Name Badges

Please wear your name badge at all times for the entire duration of the conference. If you misplace yours, please go to the registration desk, which will open at 7:30 AM on July 22, 2024.

Scientific Session Protocol

Photography, audio, or video recording by audience members of the scientific sessions is not permitted.

Our conferences have an opt-out social media policy. If a speaker or presenter opts out, requesting to keep their presentation closed and in confidence to the conference attendees, honor their request and do not post or share information from their presentation.

Please note that abstracts may not be reprinted, and poster presentations are considered personal communications. Information in these may not be publicly shared without the presenter's prior permission.

Remember to turn off cell phones or set them to vibrate or be silent during the general sessions.

Filming

Representatives from AEFM 2024 or Mr. Kohei Nanjo from the University of Tokyo may film the program throughout. A photographer will also be on site. Please see Ms. Hiramine Miwako at the registration desk if you do not wish to be recorded or photographed.

Location

The conference will be taking place at the **5F** of **Takeda Hall,** located at **2-chōme-11 Yayoi, Bunkyo City, Tokyo 113-0032**. The scientific sessions will take place in the main conference hall. Breaks and Poster Sessions will take place in the lobby area.

Poster Sessions

The poster session will be taking place after the presentation on July 22nd. Session and board number assignments appear in this book's Poster Presenter List section.

For poster presenters: we will advise when and where you can put up your poster upon registration check-in. Posters must be taken down at the close of the poster session.

Guest Wi-Fi Instructions-

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1.) Go to Wi-Fi

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PROGRAM

*All scientific talks will take place at the Takeda Hall (5F)
*All coffee breaks, meals, and poster sessions will take place at the Lobby

Monday (July 22, 2024)

07:30 – 08:20		**Registration**
08:20 – 08:30	**Vincent Tung** **Chair of AEFM 2024, The University of Tokyo**	**Opening remark**

Session 1 – 3D Nanomembranes
(Chair: Kibum Kang, Haozhe Wang)

Time	Speaker	Title
08:30 – 09:10 **Plenary**	**Jeehwan Kim** MIT/SAIT	Seamless wafer-free monolithic 3D integration enabled by confined growth and remote epitaxy
09:10 – 09:40 **Keynote**	**Zhiqiang Liu** Chinese Academy of Science & Peking University	Atomic Evolution Mechanism and Suppression of Edge Threading Dislocations in Remote Epitaxy Using a Graphene Interlayer
09:40 – 10:00	**Jian Shi** Rensselaer Polytechnic Institute	Opportunities for Harnessing Crystalline Membranes Based on Non-centrosymmetric Materials for Computing and Energy Transformation
10:00 – 10:20	**Takuji Maekawa** ROHM Co., Ltd.	4H-SiC remote epitaxy for wafer cost reduction
10:20 – 10:35		**Coffee break (15 min)**

Session 2 – 2D
(Chair : Young Joon Hong, Chulho Lee)

Time	Speaker	Title
10:35 – 11:15 **Plenary**	**Xiangfeng Duan** UCLA	Van der Waals Heterostructures and Superlattices: Boundless Opportunities at Bondless Boundaries
11:15 – 11:45 **Keynote**	**Joan Redwing** Penn State University	Advances in MOCVD for Wafer-Scale Synthesis of TMD Monolayers
11:45 – 12:15 **Keynote**	**Deji Akinwande (Zoom Talk)** UT Austin	2D Membranes for Ion Transport and Energy Devices
12:15 – 12:35	**Gwan-Hyoung Lee** Seoul National University	Hypotaxy of Wafer-scale Single Crystal Transition Metal Dichalcogenides
12:35 – 14:05		**Lunch break (90 min)**

Session 3 – 3D Nanomembranes
(Chair: Hyunseok Kim, Saptarshi Das)

Time	Speaker	Title
14:05 – 14:45 **Plenary**	**Takao Someya** University of Tokyo	Recent Advancements in Electronic Skin for Robotics and Wearables
14:45 – 15:15 **Keynote**	**Tongbo Wei** Chinese Academy of Sciences	Wafer-Scale Transferrable h-BN and AlN membranes for flexible optoelectronic devices
15:15 – 15:45 **Keynote**	**Honyung Lee** ORNL	Precision synthesis and emergent phenomena in naturally and artificially stacked 2D and 3D oxide heterostructures and membranes
15:45 – 16:05	**Young Joon Hong** Sejong University	Non-chemically bonded epitaxy: fundamentals to the interface and practical device fabrications
16:05 – 16:20		**Coffee break (15 min)**

Session 4 – 2D

(Chair :Jian Shi, Stanley Fu)

Time	Speaker	Title
16:20 – 17:00 **Plenary**	**Manish Chhowalla (Zoom Talk)** Cambridge	Chiral two-dimensional MoS2 by molecular functionalization as ultra-sensitive detectors for circularly polarized light
17:00 – 17:30 **Keynote**	**Lain-Jong Li** Hong Kong University	Epitaxy of Two-Dimensional Materials on Crystalline Substrates
17:30 – 18:00 **Keynote**	**Hiroki Ago** Kyushu University	Science of 2.5 D materials: Beyond 2D materials
18:00 – 18:20	**Chul-Ho Lee** SNU	Van der Waals gate stack engineering for high-performance 2D electronics
18:20 – 18:40	**Yui Ogawa** NTT Basic Research Laboratories	In-Situ Ultraviolet Optical Observation of CVD Growth of Graphene
18:40 – 19:10 **Keynote**	**Benjamin Groven** IMEC	Modulating crystalline orientation of two-dimensional semiconductors via substrate design

Poster Session

(Chair : Hyunseok Kim, Sang-Hoon Bae)

19:10 – 20:00	**Poster Session** Food and Beverages will be provided

Tuesday (July 23, 2024)

Session 5 – 2D
(Chair: Kyusang Lee, Ki Jun Yu)

Time	Speaker	Title
08:00 – 08:40 **Plenary**	**Mark Hersam** Northwestern University	Two-Dimensional Neuromorphic Electronic Materials and Applications
08:40 – 09:10 **Keynote**	**Jiwoong Park** University of Chicago	2D Integrated Solids and Hybrid Bilayer Crystals
09:10 – 09:30	**Peng Zhou** Fudan University	12-Inch Growth Of Highly Uniform Monolayer MoS_2
09:30 – 09:50	**Haozhe Wang** Duke University	Towards pristine transition metal carbides leveraging atomic layer etching
09:50 – 10:10	**Saptarshi Das** Penn State University	3D Integration of 2D Devices for Advanced Memory, Logic, and Bio-inspired Computing
10:10 – 10:30	**Yoshiki SAKUMA** NIMS	Wafer-Scale vdW Epitaxy of MoS_2 by MOCVD using MoO_2Cl_2 Precursor
10:30 – 10:45	**Coffee break (15 min)**	

Session 6 – 3D Nanomembranes
(Chair: Sang-Hoon Bae, Sheng Xu)

Time	Speaker	Title
10:45 – 11:25 **Plenary**	**Bharat Jalan** University of Minnesota	From Oxide Epitaxy to Membranes: Challenges and Opportunities
11:25 – 11:55 **Keynote**	**Sung Kyu Lim (Zoom Talk)** Georgia Technology Institute	Advancements in Monolithic 3D ICs through Remote Epitaxy and 2D Material Transistors
11:55 – 12:15	**Sang-Hoon Bae** Washington University in St. Louis	Freestanding nanomembranes as new material building blocks: From artificial heterostructures to monolithic 3D integration
12:15 – 12:35	**Nagashio Kosuke** U Tokyo	2D layered semiconductor FETs: P type operation & large-scale device characterization
12:35 – 12:55	**Kyusang Lee** UVA	Heterogeneous Integration for Intelligent Sensing via Remote Epitaxy
12:55 – 14:25	**Lunch break (90 min)**	

Session 7 – 3D Nanomembranes and applications
(Chair: Jacobo Santamaria, Bharat Jalan)

Time	Speaker	Title
14:25 – 15:05 **Plenary**	**Stephen Forrest** University of Michigan	Thin film air-bridge thermal photovoltaic cells: Approaching the efficiency limits
15:05 – 15:35 **Keynote**	**Jong-Hyun Ahn** Yonsei University	Strain Engineering for high performance 2D TMD transistor and photodetector
15:35 – 16:05 **Keynote**	**Sheng Xu** UCSD	Controlled epitaxial growth and fabrication of hybrid halide perovskites
16:05 – 16:25	**Mun Ho Kim** NTU	Nanostructured Inorganic Wide Bandgap Semiconductors for Advanced Ultraviolet Photodetectors
16:25 – 16:45	**Sean Li** University of New South Wales	New Form of High-k Dielectric Materials for 2D Transistors
16:45 – 17:05	Munho Kim NTU, Singapore	Nanostructured Inorganic Wide Bandgap Semiconductors For Advanced Ultraviolet Photodetectors
17:05 – 17:15	**Coffee break (10 min)**	

Session 8 – Panel Discussion - Meet the Editors
(Chair: Vincent Tung)

Time	Panel	Topic
17:25 – 18:10	**Olga Bubnova, Nature Reviews Electrical Engineering** **Kristina Kareh, Nature** **Jeehwan Kim, Science Advances** **Xin Li, Nature Materials** **Stuart Thomas, Nature Electronics**	**Open discussion with panels, organizers, and attendees**
18:30 – 21:00	**Banquet at Chinzan-so Hotel**	

Day 3 (July 24, 2024)

Session 9 – 3D

(Chair: Yu-Jung Lu, Yun Seog Lee)

Time	Speaker	Title
08:00 – 08:40 **Plenary**	**Ke Xu** Suzhou Institute of Nano-Tech and Nano-Bionics	
08:40 – 09:10 **Keynote**	**Jacabo Santamaria** Universidad Complutense Madrid	Moiré ferroelectric vortex state in twisted $BaTiO_3$ membranes
09:10 – 09:30	**Sungkyu Kim** Sejong University	Role of buffer graphene on defects in remote heteroepitaxy
09:30 – 09:50	**Celeste Chang** Seoul National University	Release layer-free method for producing ultrathin, freestanding, single-crystalline membranes
09:50 – 10:05		**Coffee break (15 min)**

Session 10 – 2D

(Chair: Peng Zhou, Sungkyu Kim)

Time	Speaker	Title
10:05 – 10:45 **Plenary**	**Iuliana Radu** TSMC	
10:45 – 11:15 **Keynote**	**Moon-Ho Jo** POSTECH	One-dimensional van der Waals metals by mosaic epitaxy
11:15 – 11:35	**Yun Seog Lee** SNU	Single-crystalline Ruddlesden-Popper halide perovskite towards next generation opto-electronic devices
11:35 – 11:55	**Kibum Kang** KAIST	Interface Growth and Engineering of 2D Semiconductors
11:55 – 12:15	**Yu-Jung Lu** Academia Sinica	Enhancing Photogating Gain in Scalable MoS_2 Photodetectors using Nitride-Based Plasmonic Metasurfaces
12:15 – 13:45		**Lunch break (90 min)**

Session 11 – 2D and 3D Nanomembranes

(Chair: Celesta Chang, Jong-Hyun Ahn)

Time	Speaker	Title
13:45 – 14:25 **Plenary**	**Rodney S. Ruoff** UNIST	Epitaxial single crystal graphene on Ni(111)
14:25 – 15:05 **Plenary**	**Takashi Taniguchi** NIMS	Boron Nitride single crystals growth under high pressure and their impurity control
15:05 – 15:25	**Xinqiang Wang** Peking University	Quasi-van der Waals epitaxy of transferrable III-nitride films on two-dimensional materials
15:25 – 15:45	**El Kazzi, Salim** Aixtron	
15:45 – 16:05	**Jinkyoung Yoo** Los Alamos National Laboratory	Heterogeneous integration of germanium and two-dimensional materials by growth
16:05 – 16:20		**Coffee break (15 min)**

Session 12 – 2D and 3D Nanomembranes

(Chair: Stanley Fu)

Time	Speaker	Title
16:20 – 16:50 **Keynote**	**Berangere Hyot** LETI	Quasi van der Waals Epitaxy of III-Nitride Semiconductors on 2D materials: Implications for RF Acoustic Filters and Red Emitting micro-LEDs
16:50 – 17:10	**Wenzhong Bao** Fudan University	Wafer-scale fabrication of integrated circuits based on 2D semiconductors
17:10 – 17:30	**Dong-Seon Lee** GIST	
17:30 – 17:50	**Joonki Suh** UNIST	Ultralow-thermal-budget processing for electronic-grade metal chalcogenides and elemental chalcogen films
17:50 – 18:00		**Closing remark**

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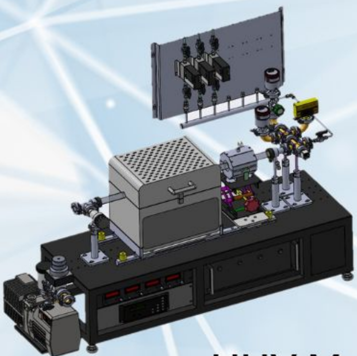

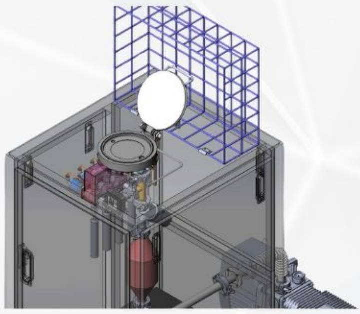

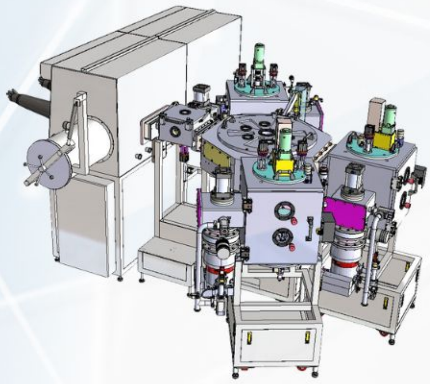

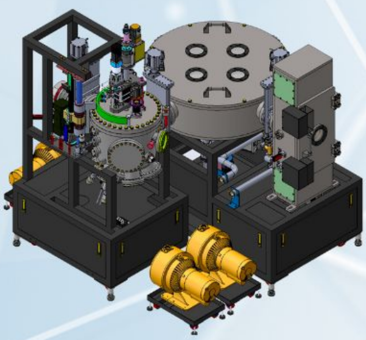

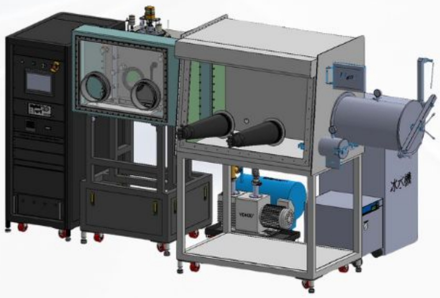

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METALS,MATERIALS&ANALYSIS

Shadow Masks&the Alignment Platforms

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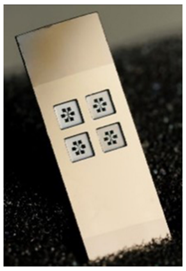
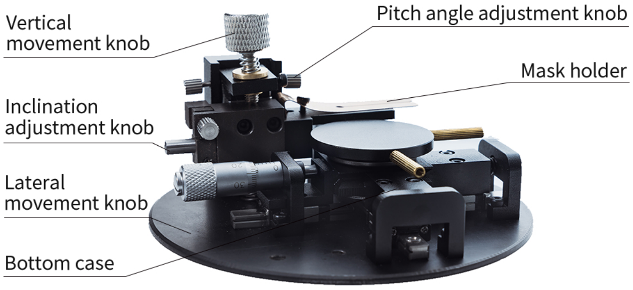
- ultra high resolution shadow mask (minimum linewidth 2um)
- stainless steel masks, sapphire masks， molybdenum mask (minimum linewidth 30um)



silicon-based

stainless steel



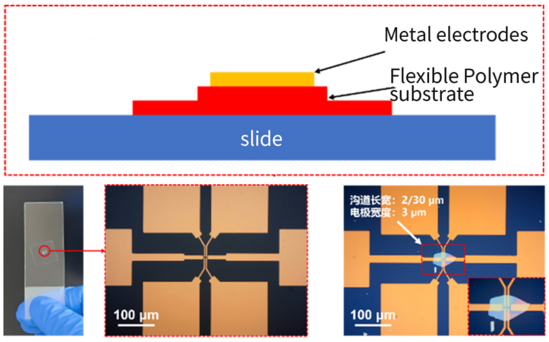
The Alignment Platform

The Alignment Platform:

Function: The sample was sticked on the sample stage, while the shadow mask was fixed by mask holder, we can move the mask to the right position and press them together tightly and carefully for further evaporation. The alignment accuracy is less than **1um**.

Transferred metal electrodes

- In the preparation of 2D heterostructure devices, the transferred metal electrodes can form van der Waals contacts with 2D materials by mechanical stacking, **effectively avoiding the damage to 2D materials caused by traditional MEMS processing**. In addition, the transferred metal electrodes are ready-to-use, it makes the fabrication of devices becomes **easier**, **less time**, thus improving the device performances. We can offer transferred electrodes with Customized design and variable metals.



2D Transfer Systems

- The manual and fully motorized transfer systems contain all the required elements for the fabrication of a high quality 2D heterostructure and also twisted graphene (manual rotation stage with **0.015 degrees** resolution): A high resolution optical microscope with CCD camera, mechanical stage, vacuum chuck which can be heated up to **200℃ with 0.1℃ accuracy**, and cold down to **77K**.
- Currently we offer manual transfer systems with **darkfield** / **brightfield** as well as only brightfield microscopes.
- The compact design of our systems allow for **easy placement inside a glove box**, providing the option to work with air sensitive materials

2D materials

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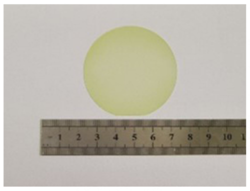

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Sputter Cluster Series

INTRODUCTION

This equipment produces thin films of ITO, TiN, and SiO_2 using three deposition chambers. Each chamber has one sputter cathode, and it is a multi-chamber processing equipment.

FEATURES

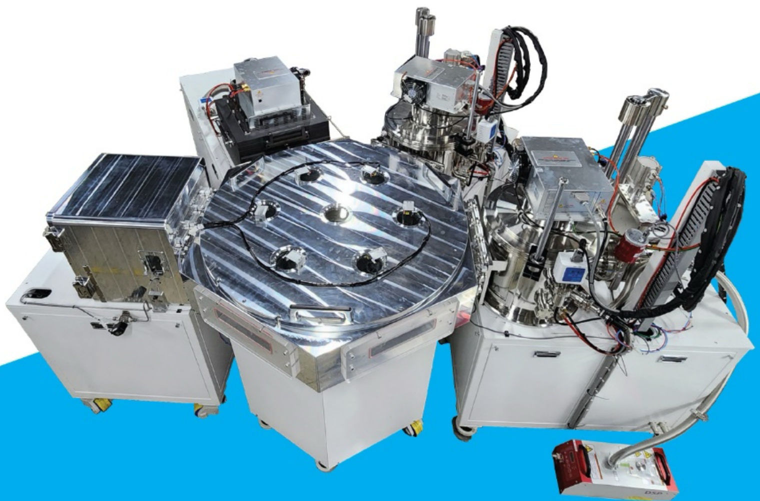
- 8" Samples
- Robot - Arm for sample loading/unloading
- Sputtering for SiO_2, TiN, iTO films
- Etching process using an ion Source
- Auto Process Control

INTRODUCTION

CVD & ICP System consists of two deposition chambers and one etching chamber. SiO_2 and A-Si thin films can be obtained by using PECVD, and the etching process can be performed by ICP & RIE.

FEATURES

- 6" - 8" Samples
- Robot - Arm for sample loading/unloading
- PECVD for SiO_2, A-Si
- ICP & RIE for etching process
- Auto Process Control


CVD & ICP Cluster Series

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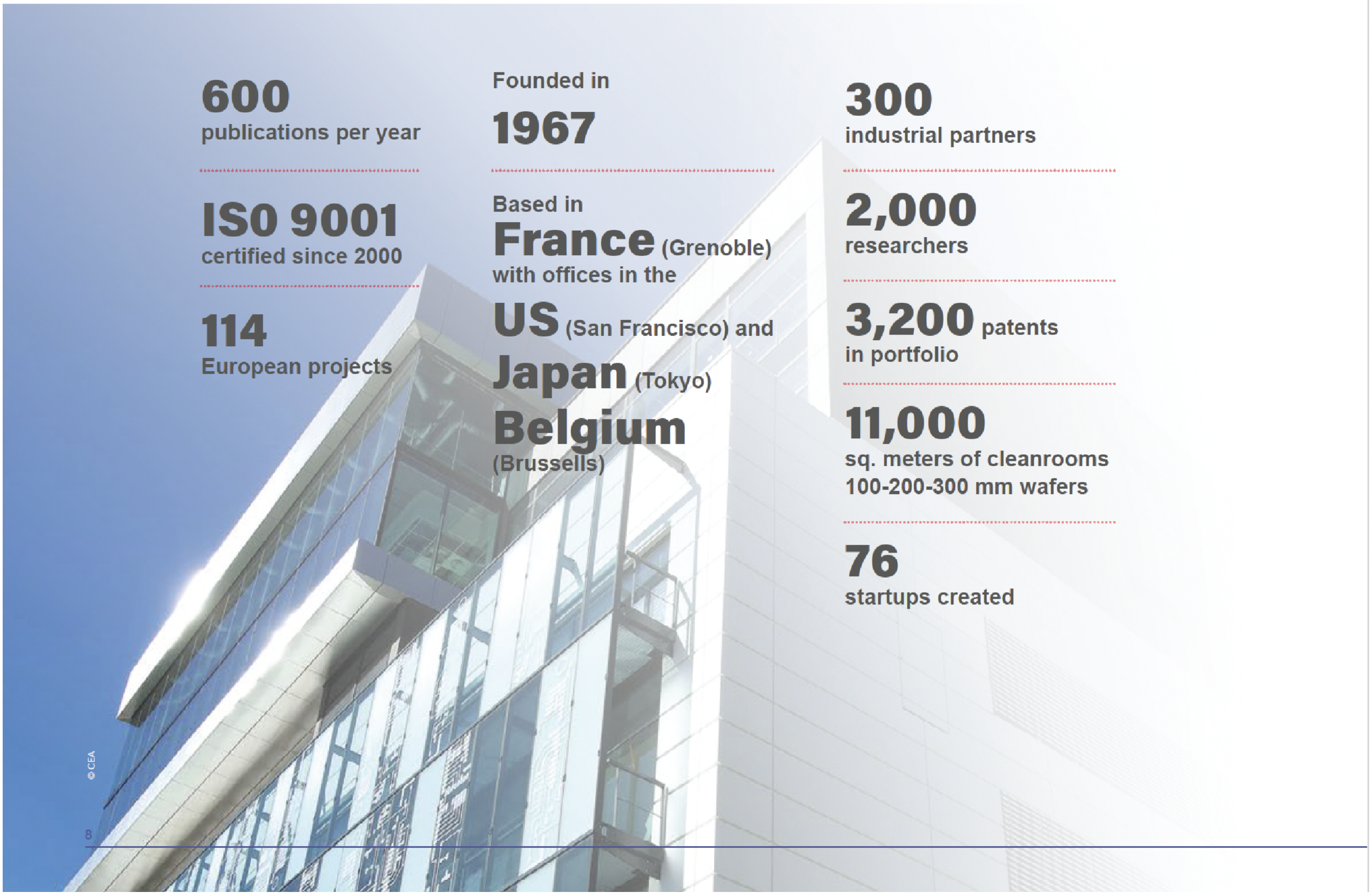

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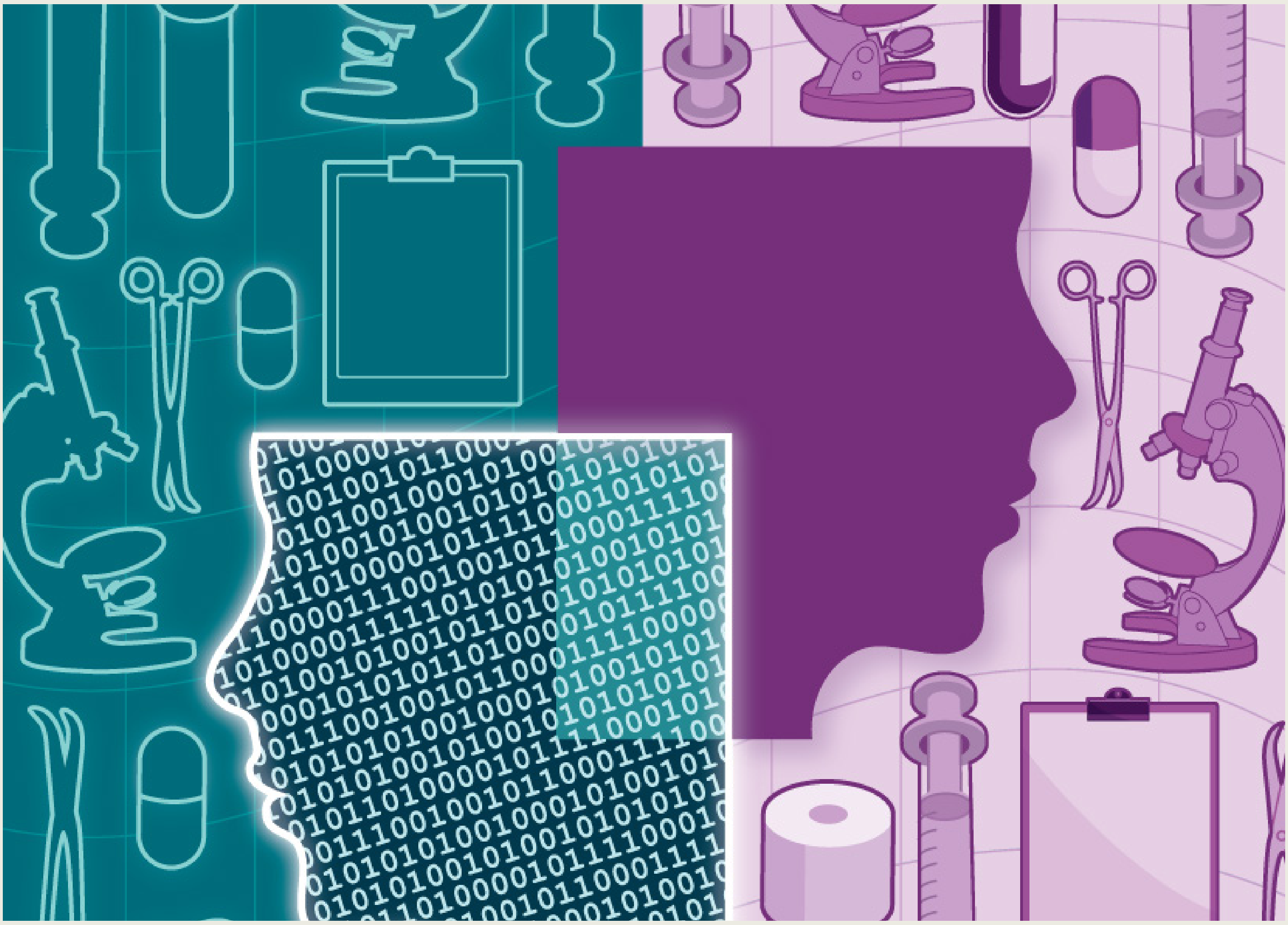

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Chief Editor Olga Bubnova will be attending the conference and is available to meet prospective authors interested in discussing a Review, Perspective or Comment proposal for the journal.

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SPEAKER ABSTRACTS
(IN PROGRAM ORDER)

PLENARY PRESENTATION (Session 3, 14:05 – 14:45 PM)

Recent Advancements in Electronic Skin for Robotics and Wearables

Takao Someya

University of Tokyo, Japan

The human skin, functioning as a large-area, multi-point, multi-modal, and flexible sensor, serves as inspiration for the development of electronic skin in robots, aimed at detecting pressure and thermal patterns simultaneously. With advancements in its flexibility, electronic skin has transcended its initial use in robotics, expanding into next-generation wearable technologies for humans. This evolution has reached a point where ultra-thin semiconductor membranes can be directly adhered to the skin. This seamless integration of electronics with human skin allows for continuous monitoring of health conditions over prolonged periods, facilitating personalized medical care. The ultimate goal of electronic skin is to non-invasively capture human activities in natural settings, fostering interactive synergy between electronic and human skin. In this presentation, I will discuss recent advancements in stretchable thin-film electronics, focusing on their applications in robotics and next-generation healthcare wearables. I will also address the challenges faced in this field and highlight the potential future prospects of electronic skin.

PLENARY PRESENTATION (Session 11, 14:25 – 15:05 PM)

Boron Nitride Single Crystals Growth Under High Pressure And Their Impurity Control

Takashi Taniguchi

National Institute for Materials Science, Japan

In Boron Nitride, which is similar crystal structure with carbon system, its low-density phase, graphite-type boron nitride (hBN), is currently being explored as the only wide-gap semiconductor (= 6.3 eV) in a 2D atomic layered compound. Some progresses in the synthesis of purity BN crystals were achieved by using Ba-BN as a growth solvent material at high (HP) of 5.5GPa. Band-edge natures (cBN Eg=6.2eV and hBN Eg=6.4eV) were characterized by their optical properties. The key issue to obtain high purity crystals is to reduce carbon contamination in the HP growth circumstances. Then an attractive potential a deep ultraviolet (DUV) light emitter and also superior properties as substrate 2-dimensional(2D) atomic layer devices such as graphene were realized. In recent has been applied not only as a 2D substrate material, but also as a low-loss dielectric, infrared confinement device (phonon polariton), and a host material for quantum sensing as post NV- diamond. Also, controlling of boron and nitrogen isotope ratio (10B.11B and 15N) in hBN crystals can be now carried out by metatheses reaction under HPHT. In this paper, recent our activities on the high-pressure synthesis of BN single crystals and their properties' characterizations will be introduced.

PLENARY PRESENTATION (Session 4, 16:20 – 17:00 PM) [Zoom Talk]

Chiral Two-Dimensional MoS_2 By Molecular Functionalization As Ultra-Sensitive Detectors For Circularly Polarized Light

Manish Chhowalla

University of Cambridge, UK

Inducing chirality in optically and electronically active materials is interesting for applications in sensing and quantum information transmission. Two-dimensional (2D) transition metal chalcogenides (TMDs) possess excellent electronic and optical properties but are achiral. Here we demonstrate chirality induction in atomically thin layers of 2D MoS_2 by functionalization with chiral thiol molecules L-/D-penicillamine (L-/D-PEN). Analysis of X-ray absorption near-edge structure and Raman optical activity with circularly polarized excitation suggest chemical and electronic interactions that leads chirality transfer from the molecules to the MoS_2. We confirm chirality induction in 2D MoS_2/L-PEN with circular dichroism measurements that show absorption bands at wavelengths of 380-520 nm and 520-600 nm with giant molar ellipticity of 108 deg·cm^2/dmol – 2-3 orders of magnitude higher than 3D chiral materials. Phototransistors fabricated from atomically thin MoS_2/PEN for detection of circularly polarized light exhibit responsivity of >10^2 A/W and maximum anisotropy g-factor of 1.98 – close to the theoretical maximum of 2.0, which indicates that the chiral states of photons are fully distinguishable by the photodetectors. Our results demonstrate that it is possible achieve chirality induction in monolayer MoS_2 by molecular functionalization and realise ultra-sensitive detectors for circularly polarized photons.

PLENARY PRESENTATION (Session 7, 14:25 – 15:05 PM)

Thin Film Air-Bridge Thermal Photovoltaic Cells: Approaching the Efficiency Limits

Stephen Forrest

University of Michigan-Ann Arbor, USA

The combination of non-destructive epitaxial liftoff and cold weld bonding of III-V materials developed in our laboratory has opened the way to realizing a variety of thin film inorganic semiconductor devices that can serve applications that have heretofore not been accessible to conventional semiconductors. For example, we have demonstrated devices as diverse as cylindrical and hemispherical imagers, the latter of which that undergo a topological transformation during fabrication, and more recently, extremely high efficiency InGaAsP and InGaAs thermal photovoltaics that employ exceptionally long air-bridges where the very thin active semiconductor is suspended between gold pillars. These cells result in almost perfect photon utilization given the very high reflectivity of the air bridge construction. In this talk we will discuss advances and state of the art in thin film air bridge thermal photovoltaic cells and their potential use in widespread thermal energy storage.

PLENARY PRESENTATION (Monday, Session 1, 08:30 – 09:10 AM)

Seamless Wafer-Free Monolithic 3D Integration Enabled By Confined Growth And Remote Epitaxy

Jeehwan Kim

MIT, USA

3D heterogeneous integration, which involves vertically stacking wafers with embedded electronic devices, is emerging as the leading approach for augmenting the performance of electronics and optoelectronics. This method, however, demands complex procedures including creating through-silicon vias (TSVs), filling these vias with copper, and bonding the wafers via micro-bumps or Cu hybrid bonding. Eliminating the use of wafers in this complex 3D assembly, a.k.a. monolithic 3D (M3D), could streamline the process and reduce the length of data paths. Yet, current technologies scarcely allow for the removal and reassembly of active single-crystalline devices from wafers. Moreover, directly epitaxial growths onto existing circuits present additional hurdles. Over the last decade, my group at MIT has pioneered epitaxy techniques for advancing wafer-free M3D integration of single-crystalline semiconductor devices. Firstly, I will introduce our innovation in transfer-based M3D integration of single-crystalline devices based on remote epitaxy. Secondly, I will introduce our recent development of growth-based M3D integration by successfully implementing single-crystalline channel material growths directly on integrated circuits at a BEOL compatible temperature. This really unlocks the way to seamless monolithic integration for advanced 3D logic/memory and AI systems.

PLENARY PRESENTATION (Wednesday, Session 10, 10:05 – 10:45 AM)

TBC

<u>Iuliana Radu</u>

TSMC, Taiwan

TBC

PLENARY PRESENTATION (Tuesday, Session 5, 08:00 – 08:40 AM)

Two-Dimensional Neuromorphic Electronic Materials and Applications

Mark Hersam

Northwestern University, USA

The exponentially improving performance of digital computers has recently slowed due to the speed and power consumption issues resulting from the von Neumann bottleneck. In contrast, neuromorphic computing aims to circumvent these limitations by spatially co-locating logic and memory in a manner analogous to biological neuronal networks. Beyond reducing power consumption, neuromorphic devices provide efficient architectures for image recognition, machine learning, and artificial intelligence. This talk will explore how two-dimensional nanoelectronic materials enable gate-tunable neuromorphic devices. For example, by utilizing self-aligned, atomically thin heterojunctions, dual-gated Gaussian transistors have been realized, which show tunable anti-ambipolarity for artificial neurons, competitive learning, spiking circuits, and mixed-kernel support vector machines. In addition, field-driven defect motion in polycrystalline monolayer MoS_2 enables gate-tunable memristive phenomena that serve as the basis of hybrid memristor/transistor devices (i.e., 'memtransistors') that concurrently provide logic and data storage functions. The planar geometry of memtransistors further allows multiple contacts and dual gating that mimic the behavior of biological systems such as heterosynaptic responses. Moreover, control over polycrystalline grain structure enhances the tunability of potentiation and depression, which enables unsupervised continuous learning in spiking neural networks. Finally, the moiré potential in asymmetric twisted bilayer graphene/hexagonal boron nitride heterostructures gives rise to robust electronic ratchet states. The resulting hysteretic, non-volatile injection of charge carriers enables room-temperature operation of moiré synaptic transistors with diverse bio-realistic neuromorphic functionalities and efficient compute-in-memory designs for low-power artificial intelligence and machine learning hardware.

PLENARY PRESENTATION (Monday, Session 2, 10:35 – 11:15 AM)

Van der Waals Heterostructures and Superlattices: Boundless Opportunities at Bondless Boundaries

Xiangfeng Duan

UCLA, USA

The rise of two-dimensional atomic crystals (2DACs) and van der Waals heterostructures (vdWHs) has catalyzed a bonding-free strategy for constructing heterostructures beyond the limits of traditional epitaxial approaches. In this talk, I will start with a brief overview of the early exploration of van der Waals (vdW) interactions for the heterogeneous integration of highly disparate materials with pristine electronic interfaces. I will then focus on our recent efforts in synthesizing and investigating a rich family of vdW superlattices (vdWSLs) consisting of alternating crystalline atomic layers and self-assembled molecular interlayers of customizable chemical compositions and structural motifs. I discuss how we may use the molecular interlayers to tailor the electronic and optical properties of various 2DACs, and particularly highlight a unique class of chiral molecular intercalation superlattices exhibiting robust chiral-induced spin selectivity and elusive chiral superconductivity. With versatile molecular design and modular assembly strategies, 2D-molecular vdWSLs offer unprecedented flexibility for weaving distinct building constituents into artificial solids with customizable chemical modulation, structural topology, and artificial potential landscapes in 3D space. This opens boundless opportunities to tailor the electronic, optical, and quantum properties, thus defining a rich material platform for diverse emerging technologies.

PLENARY PRESENTATION (Wednesday, Session 11, 13:45 – 14:25 PM)

Epitaxial single crystal graphene on Ni(111)

Rodney Ruoff

UNIST, Korea

We convert polycrystalline, as-received, Ni foils to single crystal Ni foils with large regions that are Ni(111) single crystal (multicentimeter). Such foils are exposed to methane sometimes with hydrogen in our homebuilt 'showerhead' system that allows for fine control of both (i) the (t, T) profile of the Ni(111) foil through Joule heating, and (ii) of the flux of CH_4 & H_2 impinging on the foil surface. Through these foils and this homebuilt system, we have grown exceptionally flat and smooth single crystal monolayer graphene with no discernible surface imperfections of any kind (no: ripples, folds, wrinkles, or evidence of vacancies). I will describe our approach with this homebuilt system and with these Ni(111) foils as substrates and will present some of the measured properties of this graphene obtained through this CVD growth.

PLENARY PRESENTATION (Tuesday, Session 6, 10:45 – 11:25 AM)

From Oxide Epitaxy to Membranes: Challenges and Opportunities

Bharat Jalan

University of Minnesota Twin Cities, USA

The growing demand for integrating functional oxides onto dissimilar substrates has driven extensive research into detaching functional thin films from their original substrates to form membranes, enabling vertical or back-end-of-the-line (BEOL) integration. These functional oxide membranes, while exhibiting intriguing properties under extreme strain or free from clamping effects, present challenges in synthesizing high-quality films. In this talk, I will address these challenges and present our group's efforts to overcome them. Utilizing hybrid molecular beam epitaxy with titanium isopropoxide (TTIP) as a metal-organic precursor, we have successfully grown epitaxial $SrTiO_3$ (STO) films on graphene-transferred bulk STO substrates, and on a water-soluble sacrificial layer. These films were then exfoliated and transferred onto other substrates. Using Raman spectroscopy and high-resolution X-ray diffraction, we demonstrate that the transferred STO membranes are single-crystalline, and possesses the bulk-like dielectric properties, achieving a room-temperature dielectric constant of approximately 300. The presentation will conclude with a detailed study of growth mechanisms investigating remote- vs. pin-hole- vs. vdW-epitaxy, in addition to describing future opportunities in materials physics using 3D oxide nanomembranes, highlighting the importance of a synthesis perspective in broadening the applications and harnessing the unique properties of functional oxide membranes.

PLENARY PRESENTATION (Wednesday, Session 9, 08:00 – 08:40 AM)

Epitaxial Growth and Interfacial Properties of Ⅲ-Nitrides on Two-Dimensional Materials

Ke Xu

SINANO

Two-dimensional materials (2DMs) reduce the forces between Ⅲ-nitride semiconductors and substrates to obtain high-quality, freestanding materials. However, the weak van der Waals forces at the interface result in a difficult to control growth interface The growth mechanism and interfacial properties of Ⅲ-nitride semiconductors on 2DMs need to be further investigated. Here, single-crystal III-nitride films obtained using remote epitaxy (RE) and epitaxial lateral growth (ELOG) on 2DMs. In RE, graphene facilitates attenuative charge transfer (ACT) from substrate to epi-layer to construct remote interactions. Interfacial atoms are assembled into “incommensurate” epitaxial relationships through graphene to reduce misfit dislocations and release strain in the epi-layer. The effect of defects in 2DMs and substrates on RE is also systematically revealed. Moreover, graphene masks with different cycles and patterns were prepared for growing GaN films. The change in Ⅴ/Ⅲ ratio alters the nucleation site of GaN, thus affecting the mechanism of dislocation evolution during the merger process. The revelation of the growth mechanisms and interfacial properties of Ⅲ-nitrides grown on 2DMs provides a more valuable guide to extending three-dimensional materials (3DMs) using 2DMs for application in devices.

KEYNOTE PRESENTATION (Tuesday, Session 5, 08:40 – 09:10 AM)

2D Integrated Solids and Hybrid Bilayer Crystals

Jiwoong Park

University of Chicago, USA

Two dimensional (2D) electron transport has been one of the most important topics in science and technology for decades. 2D van der Waals (vdW) crystals offer new methods for building fully integrated 3D solids that confine and control electron transport in all three dimensions with nanoscale precision. In this talk, I will start with the large-scale processes for generating 2D crystalline semiconductor films and superlattices that could be used to fabricate 2D integrated solids. Then we will discuss exciting new directions, where we combine large scale 2D molecular crystals with vdW monolayers to form 1-nm thick hybrid bilayer crystals with unprecedented properties. First, they generate interlayer potentials and anisotropic hybridized excitons that are tuned by the molecular building blocks. Second, they display conductor-to-insulator transition deep inside of the conduction band caused by the massive interlayer charge transfer aided by molecule to ion coupling.

KEYNOTE PRESENTATION (Monday, Session 2, 11:45 AM – 12:15 PM) [Zoom Talk]

2D Membranes for Ion Transport and Energy Devices

Deji Akinwande

University of Texas-Austin, USA

Electrically driven ion transport is critical to many electrochemical technologies essential to decarbonization such as batteries, fuel cells and electrolyzers. These technologies, particularly fuel cells and electrolyzers, are still in their nascent stages and suffer from both membrane-related failures stemming from parasitic crossover as well as efficiency losses. 2D materials have been demonstrated to act as highly selective ionic conductors in previous work, but have yet to show sufficient performance, durability and scalability for commercial adoption. This talk will focus on 2D materials as optimal ion conductors for proton exchange membrane fuel cells (PEMFC) and electrolyzers while balancing performance with selectivity. In our current work, we demonstrate the power of defect engineering strategies and scalable deposition strategies in to improve fuel cell durability and scalability with limited to no negative impact to performance. These findings highlight the potential of defect-engineered 2D materials to advance the performance and durability of electrochemical energy devices.

KEYNOTE PRESENTATION (Monday, Session 4, 17:00 – 17:30 PM)

Epitaxy of Two-Dimensional Materials on Crystalline Substrates

Lain-Jong Li

University of Hong Kong, Hong Kong

One key challenge for industrial applications of two-dimensional semiconducting transition metal dichalcogenides (2D-TMD) and insulating hexagonal boron nitride (hBN) is achieving large-scale growth on substrates with single crystallinity and spatial homogeneity. To facilitate the large-area, grain boundary-free growth of 2D materials, it is essential to understand the fundamental substrate-2D interactions, ensuring mono-orientation of these 2D domains during nucleation.

Discussing examples such as 2D TMD, hBN, and perovskites, we aim to examine the factors that control epitaxy. A detailed analysis will elucidate the following points:

1. When 2D seeds strongly bind to the substrate's atomic edges (e.g., hBN on Cu(111), TMD on Ga_2O_3(100)), the seed nucleation and orientation are directed by the step edges.

2. In cases where 2D seeds do not strongly adhere to the step edges (e.g., TMD on C- or M-sapphire, TMD on Ga_2O_3(001)), the epitaxy of the 2D material is determined by the atomic surface structures (symmetry) of the substrates. Hence, for single-crystal epitaxy of monolayer TMDs without the assistance of step edges, it is necessary to reconstruct the substrate surfaces to achieve proper symmetry.

3. Precursors might react with substrate surfaces, altering the substrate's atomic structures and, consequently, the orientation of the 2D materials. This reaction can significantly change the orientation preference.

In summary, the substrate symmetry, step edges, and chemical modifications of the substrates or their edges must be considered when reconstructing substrates for the successful epitaxial growth of 2D materials.

KEYNOTE PRESENTATION (Tuesday, Session 7, 15:35 – 16:05 PM)

Controlled Epitaxial Growth And Fabrication Of Hybrid Halide Perovskites

Sheng Xu

UCSD, USA

Organic–inorganic halide perovskites have demonstrated tremendous potential for next-generation electronic and optoelectronic devices due to their remarkable carrier dynamics. Current studies are mostly focused on polycrystals, since controlled growth of high-quality single crystals is challenging. In this presentation, I will discuss strategies that enabled the first chemical epitaxial growth of single-crystal hybrid halide perovskites. Using advanced microfabrication, homo-/hetero-epitaxy, and a low-temperature solution method, single crystals can be grown with controlled locations, morphologies, orientations, and strain levels. By a lifting off approach, single-crystal thin films can be transferred from the epitaxial substrate to a general flexible substrate. Extending this strategy to low-dimensional perovskites yields nanostructured superlattices, based on which a solar cell with an open-circuit voltage exceeding the Shockley-Queisser limit is demonstrated. The anisotropic superlattice also enables superfluorescence in ambient environments. Our approach opens up broad opportunities for hybrid halide perovskite materials based high-performance electronic and optoelectronic devices.

KEYNOTE PRESENTATION (Tuesday, Session 7, 15:05 – 15:35 PM)

Strain Engineering For High Performance 2D TMD Transistor And Photodetector

Jong-Hyun Ahn

Yonsei University, Korea

Strain engineering has emerged as an important technique for enhancing the electrical and optical properties of semiconductors, particularly in two-dimensional (2D) transition-metal dichalcogenides (TMDs). We developed a novel approach to apply tensile strain to MoS_2 films, grown by MOCVD process onto a SiO_2/Si wafer and then selectively removing the underlying Si. This process released compressive residual stress in the oxide layer, inducing strain in the MoS_2. The strain magnitude was finely tuned by adjusting the thickness of the oxide stressors. Subsequently, strained MoS_2 transistors were fabricated and transferred onto plastic substrates, maintaining consistent tensile strain across a large area. In addition, we explore the potential of strained MoS_2 in broadening the absorption spectrum to the near-infrared (NIR) range. The tensile strain effectively reduced the bandgap, enhancing photoresponsivity beyond the visible spectrum. We present the creation of a MoS_2/graphene metal-semiconductor-metal photodetector (PD) array with a strain-modulated photo-response extending into the NIR range. The PD array, subjected to a biaxial tensile strain of 1.19%, demonstrated the ability to capture Vis-NIR images under foggy conditions. This advancement not only present the extended application of MoS_2 PD arrays to NIR imaging but also underscores the potential of strain engineering in developing next-generation flexible electronic devices.

KEYNOTE PRESENTATION (Monday, Session 2, 11:15 – 11:45 AM)

Advances In MOCVD For Wafer-Scale Synthesis Of TMD Monolayers

Joan Redwing

Penn State University, USA

Metalorganic chemical vapor deposition (MOCVD) has emerged as a promising technique for wafer-scale synthesis of 2D transition metal dichalcogenides (TMDs) for device applications. Two general approaches have been pursued: direct growth on oxide-covered substrates at BEOL-compatible temperatures or high temperature epitaxy on single crystal substrates followed by layer transfer. Our work has focused on the later approach with the goal of achieving wafer-scale single crystal TMD films that can be transferred and integrated at BEOL conditions.

It is challenging to reproducibly deposit TMD monolayer films over wafer-scale substrates without additional bilayer islands. Defects in the monolayer serve as nucleation sites for bilayer formation. Once bilayers nucleate, they grow rapidly aided by enhanced adatom diffusion on the monolayer surface. Our work has therefore focused on minimizing defects in the epitaxial TMD monolayers and developing in situ techniques to track and control the process for true layer-by-layer growth.

These efforts are illustrated for epitaxial growth of MoS_2 and WSe_2 on 50 mm diameter c-plane sapphire using metal hexacarbonyls and hydride chalcogen sources in a H_2 carrier gas. The epitaxial orientation of the TMD is found to be strongly dependent on the pre-growth annealing ambient (H_2 vs H_2/H_2Se) and the growth temperature which can be tuned to minimize inversion domains and high angle grain boundaries which negatively impact field-effect mobility. Spectroscopic ellipsometry is demonstrated as a promising in situ monitoring tool for TMD growth, enabling real time measurements of monolayer and bilayer surface coverage enabling improved control of layer number as well as insights into the epitaxial growth process.

KEYNOTE PRESENTATION (Monday, Session 3, 15:15 – 15:45 PM)

Precision Synthesis And Emergent Phenomena In Naturally And Artificially Stacked 2D And 3D Oxide Heterostructures And Membranes

Honyung Lee

Oak Ridge National Laboratory, USA

Complex oxides are known to possess the full spectrum of fascinating properties, including magnetism, colossal magnetoresistance, superconductivity, ferroelectricity, ionic conductivity, and more. The breadth of remarkable properties is the consequence of strong coupling among charge, spin, orbital, and lattice degrees of freedom. Spurred by recent advances in the synthesis of such artificial materials at the atomic scale, the physics of oxide heterostructures containing atomically smooth layers of such correlated electron materials with abrupt interfaces is a rapidly growing area. We have established a growth technique to control complex oxides at the level of unit cell thickness by pulsed laser deposition. The atomic-scale growth control enables to assemble materials from atoms to functional systems in a programmable manner, yielding many intriguing physical properties that cannot be found in bulk counterparts. In this talk, examples of complex oxide thin films and heterostructures grown by advanced pulsed laser deposition and their correlated and topological properties will be presented, highlighting the importance of precision synthesis for heterostructuring, interfacing, and straining. The main topics include (1) oxide Dirac semimetals with extreme high mobility that exhibit fractional occupation of the Landau level and (2) corrected 2D metal Pd-based delafossites as an extreme metal that may revolutionize interconnects in the next generation of microelectronics by their excellent electronic conductivity combined with Mottness.

KEYNOTE PRESENTATION (Wednesday, Session 10, 10:45 – 11:15 AM)

One-dimensional van der Waals Metals By Mosaic Epitaxy

Moon-Ho Jo

POSTECH, Korea

In a transition metal dichalcogenide (TMDC) monolayer (ML), grain boundaries – the line defects between adjacent crystal grains with tilted in-plane rotations – are omnipresent. A mirror twin boundary (MTBs) is an intriguing one, where two adjoining ML crystals are reflection-mirroring with the 60° in-plane rotation, as it can host one-dimensional (1D) electron liquid of a topological nature with tunable interactions. Here, we show epitaxial realizations of deterministic MoS_2 MTBs by controlled mosaic epitaxy, and these epitaxial MTBs are indeed 1D metallic to a circuit length scale Electron transport measurements of isolated individual MTBs exhibit power-law behaviors as a function of temperature and bias voltage up to room temperature, consistent with electron tunneling into a Luttinger liquid. By utilizing the ultimate 1D feature (the width of ~ 0.4 nanometre and the length up to a few tens of micrometre), we incorporated the epitaxial MTBs as the 1D gate to build integrated 2D field-effect transistors and demonstrated the state-of-the-art performances for low-power logics in both individual and array FETs. Epitaxial realization of local 1D electronic systems in this study suggest a novel synthetic pathway for construction of diverse 2D heterostructure electronic systems.

KEYNOTE PRESENTATION (Wednesday, Session 9, 08:40 – 09:10 AM)

Moiré Ferroelectric Vortex State In Twisted $BaTiO_3$ Membranes

Jacabo Santamaria

Universidad Complutense de Madrid, Spain

The recent realization of freestanding perovskite films, the so-called oxide membranes, has enabled their deterministic mechanical assembly into twisted homo bilayers. These structures bypass the limitations of conventional epitaxy, which promotes film growth with crystalline axes aligned with those of the substrate. In this talk I will show that the stacking of freestanding ferroelectric perovskite layers enables manipulation of mechanical boundary conditions, otherwise immovably determined by the constraints of epitaxial growth. Ferroelectric membranes with controlled twist angles unlock a “chirality” degree of freedom opening an unprecedented opportunity to tailor topological polar landscapes in a way determined by the lateral strain modulation driven by twisting. Interestingly, we find that a peculiar pattern of polarization vortices and antivortices emerges from the flexoelectric coupling of polarization to strain gradients. This finding opens exciting opportunities to create two-dimensional high density vortex crystals that would allow us to explore novel physical effects and functionalities.

KEYNOTE PRESENTATION (Monday, Session 4, 17:30 – 18:00 PM)

Science of 2.5 D Materials: Beyond 2D Materials

Hiroki Ago

Kyushu University, Japan

2D materials have intriguing properties and many potential applications due to their unique 2D structures with atom-level thicknesses. The control of van der Waals (vdW) interaction and utilization of vdW nanospace are expected to extend the field of materials science, and such research direction can be expressed with a new concept of “Science of 2.5D materials”. In this presentation, our recent research is introduced based on this 2.5D concept, first showing the controlled CVD growth of bilayer graphene (BLG) and the intercalation of metal chloride molecules and alkaline metal ions, revealing new unique 2D structures with increased electrical conductivity. We have also developed the CVD growth of high-quality and large-area multilayer hBN to be used as a building block of various 2.5D materials, such as graphene field-effect transistors (FETs) and magnetic tunnel junction (MTJ) devices. I will also introduce our new result of the tape transfer of 2D materials, which is expected to accelerate the 2D/2.5D materials research and applications. We achieved clean and user-friendly transfer of graphene, MoS_2, WS_2, and hBN using the UV tapes whose adhesive force can be decreased about 1/10 by UV light illumination. We do not need to use organic solvent so that we can transfer them onto plastics, and the robust tape allows “cut-and-transfer” for site-selective transfer, which saves 2D materials and production cost. Finally, our national project named, “Science of 2.5 Dimensional Materials: Paradigm Shift of Materials Science Toward Future Social Innovation (2021-2026)”, supported by MEXT, Japan is briefly introduced.

KEYNOTE PRESENTATION (Monday, Session 1, 09:10 – 09:40 AM)

Atomic Evolution Mechanism And Suppression Of Edge Threading Dislocations In Remote Epitaxy Using A Graphene Interlayer

Zhiqiang Liu
Peking University, China

GaN is mostly hetero-epitaxially grown on the sapphire substrate, resulting in large biaxial stress in nitride crystals and high threading dislocation (TD) densities of 108-1010 cm−2. The majority of dislocations in nitride epilayers are edge threading dislocations, which determine the photoelectronic and electronic performance of nitride devices. However, due to the lack of available slip systems and mobile dislocations' interactions, reducing the edge threading dislocations is extremely difficult. Here, we systematically investigated the formation mechanism of edge threading dislocations by the plan-view high-resolution transmission electron microscopy, which proves that besides originating at the coalescence boundaries these dislocations are also closely related to the geometrical misfit dislocations at the interface. Based on this understanding, we propose a novel strategy to reduce edge threading dislocations of the heteroepitaxial GaN film by graphene-assisted remote epitaxy. We discover the density of edge threading dislocation is reduced by nearly an order of magnitude compared to that of the conventional heteroepitaxy. The first principles calculations confirm that the insertion of graphene dramatically reduces the energy barrier required for interfacial sliding, which provides a new channel for lattice strain release and ultimately prevents the formation of edge threading dislocations. This work provides a unique approach to effectively suppress the formation of edge threading dislocations by directly inhibiting their source, i.e., geometrical misfit dislocations and paves a way for the epitaxy of high-quality III-nitride films on large lattice mismatched foreign substrates, promising advancements in the fabrication of advanced photoelectronic and electronic devices.

KEYNOTE PRESENTATION (Monday, Session 3, 14:45 – 15:15 PM)

Wafer-Scale Transferrable h-BN and AlN Membranes For Flexible Optoelectronic Devices

Tongbo Wei

Chinese Academy of Sciences, China

High-quality, uniform and continuous wafer-level hexagonal boron nitride (h-BN) is essential for the development of other III-nitride semiconductors in alleviating lattice mismatch and constructing flexible devices. In this report, we realize wafer-level h-BN with controllable thickness on 2-inch c-plane sapphire with a flow modulation epitaxy (FME) method by metal organic chemical vapor deposition (MOCVD). It is revealed that the pulsed ammonia and triethylboron interruptions greatly improve the surface morphology and crystalline quality of h-BN, attributed to the unintentional nitridation, the decrease of C impurity concentration and the increase of B atom surface mobility. Besides the flat morphology with uniform wrinkles, the well-ordered layered h-BN structure with a lattice spacing of 0.34 nm is also revealed. When the thickness of h-BN is greater than about 4 nm, micro-wrinkle morphology is formed on the originally flat h-BN surface. The formation mechanism of micro-wrinkle morphology on h-BN is revealed and the finite element analysis method is used to build a mechanical model, and fit the critical thickness between h-BN with wrinkle-free morphology, micro-wrinkle morphology and spontaneous exfoliation based on thermal mismatch. The stress distribution between h-BN layers and the formation mechanism of wrinkles is helpful for us to understand the exfoliation behavior of h-BN-based flexible films. In addition, we also present the stress-free AlN film with improved crystal quality by the assistance of h-BN, and demonstrate the mechanical exfoliation of wafer-scale single-crystal AlN freestanding membrane and reveal the controllable exfoliation mechanism of AlN. This work provides an effective strategy for the quality improvement of III-nitride films and paves the way for the vertical structure and flexible deep-ultraviolet optoelectronic devices.

KEYNOTE PRESENTATION (Tuesday, Session 6, 11:25 – 11:55 AM) [Zoom Talk]

Advancements in Monolithic 3D ICs through Remote Epitaxy and 2D Material Transistors

Sung Kyu Lim

Georgia Institute of Technology, USA

This presentation details advancements in monolithic 3D ICs enabled by remote epitaxy-based layer transfer technology and 2D material transistors. Prior work has validated improvements in processing temperatures, mechanical properties, alignment precision, and inter-tier via sizes, along with enhanced electron mobility and reliability in high voltage operations for transistors. Our research extends these findings by demonstrating their combined benefits at the full-chip level for AI applications. We will report on our progress in integrating these technologies, focusing on system-level metrics such as power, performance, area, and reliability, showcasing the potential for next-generation semiconductor enhancements.

KEYNOTE PRESENTATION (Wednesday, Session 12, 16:20 – 16:50 PM)

Quasi van der Waals Epitaxy of III-Nitride Semiconductors on 2D Materials: Implications For RF Acoustic Filters And Red Emitting Micro-LEDs

Bérangère Hyot

LETI, France

III-nitride semiconductors are essential materials for various device applications, including optoelectronics, high-power electronics and radio-frequency electronics. One promising direction for the further development of III-nitrides is achieving their monolithic integration with diverse materials through epitaxy, even when there is significant lattice mismatch. 2D-material-assisted epitaxy is considered as a promising approach to achieve these goals, offering several potential advantages. These include relaxation of the strict substrate requirements, possibility of transferring nitride devices to arbitrary substrates, and the ability to tailor the properties of the nitride semiconductors to realize new device architectures. In this talk, we will discuss how the introduction of 2D materials in the nitride growth strategy can improve some physical features of III-nitride based devices. In the field of radio-frequency (RF) acoustic filters, we will discuss how an innovative material strategy combining a few monolayers of MoS_2 with AlN layers from different growth techniques (sputter deposition and metal organic vapor phase epitaxy (MOVPE) can enhance the crystalline quality of thick AlN films grown on silicon-based substrates . In the second example dedicated to the challenging case of red emission in “all-nitride” red-green-blue (RGB) micro-light emitting diodes (micro-LEDs), we will discuss the MOVPE growth of InGaN nanopyramids on monolayer graphene on SiC emitting at 620 nm from regular quantum wells with a record InN mole fraction up to 40%.

KEYNOTE PRESENTATION (Monday, Session 4, 18:40 – 19:10 PM)

MODULATING CRYSTALLINE ORIENTATION OF TWO-DIMENSIONAL SEMICONDUCTORS VIA SUBSTRATE DESIGN

Benjamin Groven

IMEC, Belgium

Future manufacturable deposition approaches for semiconductors need to provide solutions to mitigate defective grain boundaries in semiconductors. Grain boundaries limit the fabrication of highly performing semiconductor devices with two-dimensional semiconductors for industry's Angstrom technology nodes. Therefore, in this presentation, we review two deposition approaches to reduce crystal grain boundaries in two-dimensional semiconductors molybdenum and tungsten disulfide (MoS_2, WS_2) during chemical vapor deposition (CVD). We explore how the number of crystal grain boundaries can be modulated through substrate design and CVD precursor chemistry, enabling further integration in a 300 mm industrial pilot line.

INVITED TALKS (Tuesday, Session 6, 12:15 – 12:35 PM)

2D Layered Semiconductor FETs: P Type Operation &Amp; Large-Scale Device Characterization

Kosuke Nagashio

The University of Tokyo, Japan

Within the last decade, considerable efforts have been devoted to fabricating transistors utilizing 2D semiconductors. While steady progress has been made on 2D integration technology, some bottlenecks are still present. This presentation focuses on the p-type operation and large-scale device characterization of MOCVD-grown MoS_2. For p-type operation, we propose a novel approach involving surface segregation in Bi/Pt bilayer electrodes for WSe_2 FETs. Through annealing of these bilayer electrodes, Bi segregates onto the Pt surface due to significant differences in adsorption energies. This direct Pt contact with WSe_2 enables p-type functionality.

In the context of large-area MOCVD MoS_2 on sapphire substrates, the main issue remains the lower mobility compared to powder-source CVD. Mobility decreases with temperature, indicating the presence of thermally-activated trap sites within the MoS_2 band gap. By precisely controlling growth conditions, we observed a change in the temperature dependence of mobility, where mobility increases as temperature decreases due to reduced phonon scattering. This represents a critical advancement towards further enhancing MOCVD MoS_2 performance.

INVITED TALKS (Tuesday, Session 4, 09:10 – 09:30 AM)

12-Inch Growth Of Highly Uniform Monolayer MoS_2

Peng Zhou

Fudan University, China

Two-dimensional (2D) semiconductors, such as transition metal dichalcogenides (TMDs), provide an opportunity for beyond-silicon exploration. However, the lab-to-fab transition of 2D semiconductors is still in the preliminary stages, and it is challenging to meet the manufacturing standards of stability and repeatability. Thus, there is a natural eagerness to grow wafer-level, high-quality films with industrially acceptable scale-cost-performance (SCP) metrics. Here, we report an improved chemical vapor deposition (CVD) synthesis method, in which novel precursor preparation methods and substrates pre-deposited with amorphous Al_2O_3 ensure uniform synthesis of monolayer MoS_2 as large as 12 inches while also enabling fast and non-toxic growth to reduce manufacturing costs. Transistor arrays were fabricated to further confirm the high quality of the film and its integrated circuit application potential. This work achieves unprecedented co-optimization of SCP metrics and lays the foundation for advancing the integration of 2D semiconductors in industry-standard pilot lines.

INVITED TALKS (Monday, Session 4, 18:00 – 18:20 PM)

van Der Waals Gate Stack Engineering For High-Performance 2D Electronics

Chul-Ho Lee

SNU, Korea

A gate stack that facilitates a high-quality interface and tight electrostatic control is crucial for realizing high-performance and low-power field-effect transistors (FETs). However, when constructing conventional metal-oxide-semiconductor structures with 2D TMD channels, achieving these requirements becomes challenging due to inherent difficulties in obtaining high-quality gate dielectrics through native oxidation or film deposition. In this talk, I will present a gate-dielectric-less device architecture of vdW Schottky gated metal-semiconductor FETs (MESFETs) using a MoS_2 channel and surface-oxidized metal gates such as nickel and copper. Benefiting from the strong gate coupling, MoS_2 MESFETs operate at remarkably low gate voltages, < 0.5 V. Notably, they also exhibit Boltzmann-limited switching behavior featured by a subthreshold swing of ~60 mV/dec and negligible hysteresis. These ideal FET characteristics are attributed to the formation of a Fermi-level (EF) pinning-free gate stack at the Schottky-Mott limit. Furthermore, we experimentally and theoretically confirm that EF depinning can be achieved by suppressing both metal-induced and disorder-induced gap states at the interface between the oxidized metal gate and the MoS_2 channel. This work paves a new route for designing high-performance and energy-efficient 2D electronics.

INVITED TALKS (Monday, Session 2, 12:15 – 12:35 PM)

Hypotaxy Of Wafer-Scale Single Crystal Transition Metal Dichalcogenides

Gwan-Hyoung Lee

SNU, Korea

With the great interest in two-dimensional (2D) semiconductors for advanced electronics beyond silicon, significant developments have been achieved in the synthesis of transition metal dichalcogenides (TMDs). Highly crystalline TMDs have been epitaxially grown on limited types of crystalline substrate by chemical vapor deposition (CVD). This process, however, necessitates subsequent transfer onto a desired substrate for device fabrication, posing challenges in thickness and scalability control. In this talk, we report the hypotaxy of wafer-scale single crystal TMDs, enabling downward growth of these films through overlying 2D template even on amorphous or lattice-mismatched substrates, while preserving interlayer crystalline alignment with the 2D template. By sulfurizing or selenizing a pre-deposited metal film covered by graphene, TMD nuclei form with crystalline alignment with the graphene nanopores that are generated during the process. These aligned TMD nuclei coalesce as the graphene is gradually removed, resulting in the fabrication of a single crystal TMD film. Our method allows for precise control of MoS_2 thickness, ranging from monolayer to several hundred layers, on various substrates. Employing wafer-scale single crystal graphene template fosters the growth of 4-inch single crystal MoS_2. The hypotaxially grown single crystal monolayer MoS_2 shows remarkably high in-plane thermal conductivity (~120 $Wm^{-1}K^{-1}$) and carrier mobility (~87 $cm^2V^{-1}s^{-1}$) with high uniformity in a wafer scale. Additionally, by preforming nanopores in graphene via oxygen plasma treatment, the MoS2 can be hypotaxially grown at lower temperature of 400 ^oC, aligning with back-end-of-line (BEOL) semiconductor process. This hypotaxy approach also extends to other TMDs, such as $MoSe_2$, WS_2, and WSe_2, utilizing the same growth mechanism. Our work shows a novel way to overcome the substrate constraints inherent in conventional epitaxial growth and to fabricate wafer-scale single crystal TMDs on arbitrary substrates, required for monolithic 3D integration.

INVITED TALKS (Wednesday, Session 12, 17:30 – 18:00 PM)

Ultralow-Thermal-Budget Processing For Electronic-Grade Metal Chalcogenides And Elemental Chalcogen Films

Joonki Suh

UNIST, Korea

van der Waals coupled chalcogenides show a wealth of exotic physical phenomena when confined into the 2D lattice, and the relevant electronic devices thus far have defined themselves as a promising building block of nanoelectronics owing to the near-atom thickness, superior electrostatic control, and adaptable device architecture. In is talk will highlight how such emerging materials can further benefit from ultralow-thermal-budget processing and new device configurations. I will mainly introduce vapor-phase synthetic strategy for wafer-scale, thickness-controlled, and low-temperature deposition techniques to bring such new electronic functionalities into device-level applications. To be specific, we demonstrate the wafer-scale growth of mono-elemental 2D tellurium (Te) thin films using an annealing-free, low temperature ALD process. As-deposited Te films exhibit exceptional homogeneity, precise layer controllability, and 100 % step coverage in high aspect ratio nanostructures. As a 2D building block with intrinsic p-type transport characteristics, ALD-grown Te films are employed for fabricating 2D/2D and mixed-dimensional 2D/3D vertical p-n heterojunction diodes exhibiting well-defined current rectification. Additionally, we showcase an ALD-Te-based selector device with fast switching time, selectivity and low Vth. As a second example, we also developed phasetailored synthetic strategies where we achieve wafer-scale production of tin selenides (SnSe and $SnSe_2$) in the 2D limit by utilizing a low-temperature MOCVD process. Directly grown 2D $SnSe_2$ exhibits outstanding crystallinity and tunable thickness of nm-precision, and SnSe, which has intrinsic limitations for 2D film growth, can be prepared via a thermally driven phase transition, thereby retaining all of the advantages in the MOCVD-grown product. With those developed low-temperature processing, I will share more recent progress toward BEOL compatible low-power steep-slope switch and cryogenic nonvolatile memory devices, all based on synthetic chalcogenide thin films.

Single-Crystalline Ruddlesden-Popper Halide Perovskite Towards Next Generation Opto-Electronic Devices

Yun Seog Lee

SNU, Korea

Ruddlesden-Popper perovskite (RPP), quasi-two-dimensional organic-inorganic hybrid halide perovskite, have gained attention as a promising material for future opto-electronic applications. Their advantages include defect tolerance, solution-based processing, band-gap tunability, and improved chemical stability compared with their three-dimensional counterparts. In particular, RPPs offer a tunable bandgap range from 2 to 3 eV by adjusting the number of inorganic octahedron slabs sandwiched between ligand layers, making them well-suited for opto-electronic devices. We develop a method for synthesizing inch-scale, phase-pure RPP single crystals using the inverse temperature crystallization technique. Furthermore, we devise a novel technique for separating these two-dimensional perovskites into an array of patterned monolayers that self-align with predetermined patterns on substrates. Finally, we demonstrate the assembly of RPP heterostructures through layer-by-layer stacking, paving the way for RPP-based opto-electronic devices.

INVITED TALKS (Tuesday, Session 5, 09:30 – 09:50 AM)

Towards Pristine Transition Metal Carbides Leveraging Atomic Layer Etching

Haozhe Wang

Duke University, USA

Transition metal carbides (TMCs) have garnered significant research interest due to their unique properties. However, a remaining challenge is the precise engineering of atomic-scale surface terminations to achieve pristine TMC films. In this work, we present a plasma-based atomic layer etching (ALE) strategy that enables the controlled tuning of surface terminations. Through characterization techniques such as X-ray photoelectron spectroscopy (XPS) and Raman spectroscopy, we confirm the successful modification of surface terminations from -F to =O and -H. By optimizing the surface terminations, we achieve ultrahigh conductivity in TMC films, approaching their intrinsic properties. To demonstrate the practical implications of this advancement, we fabricate a light-driven soft robotic system that exhibits optimal response times and high actuation forces. These findings highlight the potential of precise surface engineering in TMCs for enhanced performance in various applications.

Enhancing Photogating Gain In Scalable MoS_2 Photodetectors Using Nitride-Based Plasmonic Metasurfaces

Yu-Jung Lu

RCAS, Academia Sinica, Taiwan
Department of Physics, National Taiwan University, Taiwan

Absorption of photons in atomically thin materials has become a challenge in the realization of ultrathin high-performance optoelectronics. While numerous schemes have been used to enhance absorption in two-dimensional semiconductors, such enhanced device performance in scalable monolayer photodetectors remains unattained. Here, we demonstrate wafer-scale integration of monolayer single-crystal MoS_2 photodetectors with a nitride-based resonant plasmonic metasurface to achieve a high detectivity of 2.58 × 1012 Jones with a record-low dark current of 8 pA and long-term stability over 40 days. We observed an enhancement factor greater than 100 compared to control devices, which can be attributed to the local strong EM field's enhanced photogating effect by the resonant plasmonic metasurface. The combination of monolayer 2D materials with plasmonic metasurfaces opens new possibilities for boosting the performance of optoelectronic devices with design flexibility that accommodates various 2D materials. Given that 2D semiconductors and hafnium nitride (HfN) are not only Si CMOS process compatible but also achievable over wafer scales, our results pave the way for seamlessly integrating 2D semiconductor-based photodetectors into imaging, sensing, and optical communications applications. The detailed mechanisms and potential applications of this technology will be explored further in the presentation.

INVITED TALKS (Wednesday, Session 10, 11:35 AM– 12:15 PM)

Interface Growth And Engineering Of 2D Semiconductors

Kibum Kang

KAIST, Korea

This presentation focuses on the critical role of interface engineering in the growth and integration of materials in contact with 2D semiconductors. Given the potential of 2D semiconductors as next-generation logic channels and for Monolithic 3D integration, understanding and optimizing these interfaces is paramount. Achieving high-quality interface on 2D semiconductors without the use of plasma or seed layers presents significant challenges. The interface between the 2D semiconductor and the deposited thin films often acts as a trap, significantly affecting the performance of the semiconductor. Additionally, conventional plasma or high-temperature processes tend to damage the delicate mono or bilayer structures of 2D materials. Firstly, I will discuss our breakthroughs in selective area ALD (AS-ALD) processes, particularly on laterally heterogeneous 2D semiconductor surfaces. Our findings highlight the importance of physisorption of ALD precursors, which is essential for achieving selective deposition patterns, thereby expanding the applicability of AS-ALD beyond traditional limits and potentially forming high-quality interfaces between ALD materials and 2D semiconductors. Secondly, the presentation will explore the vertical, hetero, and epitaxial growth of 2D and 3D materials, with a particular emphasis on the 2D/3D interface within van der Waals epitaxial growth. This research underscores the potential and understanding of utilizing van der Waals epitaxy for forming interfaces between 2D and 3D materials, paving the way for more reliable and efficient integration of 2D semiconductors in advanced electronic applications. Lastly, I will briefly introduce the recent advancements in low-temperature MOCVD growth and device processing in my group, including new 2D semiconductor materials beyond TMDs.

INVITED TALKS (Tuesday, Session 6, 11:55 AM – 12:15 PM)

Freestanding Nanomembranes As New Material Building Blocks: From Artificial Heterostructures To Monolithic 3D Integration

Sang-Hoon Bae

Washington University, St. Louis, USA

Thin film technology involves depositing extremely thin layers of material, typically ranging from a few nanometers to several micrometers, onto a substrate. These films, made from a wide range of materials such as metals, semiconductors, and insulators, are essential in applications across electronics, optics, energy, and sensing. While silicon has long been the cornerstone of thin-film innovation due to its well-established processing techniques, the pursuit of higher performance and novel functionalities has led to the exploration of new materials. Emerging freestanding nanomembranes, 2D materials and ultrathin 3D nanomembranes, offer unique properties and are paving the way for groundbreaking devices and the discovery of new physical phenomena.

Our team has pioneered new methodologies to create these materials, which exhibit properties such as extreme thinness, low stiffness, and minimal internal stress. These attributes enable seamless vertical stacking and 3D integration, making them ideal for exploring new physical phenomena and creating innovative device architectures through the formation of unprecedented heterostructures. In this presentation, I will discuss the fundamental principles behind the production of these nanomembranes and our team's recent effort to discover new physical coupling in the heterostructures. Moreover, emerging monolithic 3D integrated electronics have been demonstrated based on the nanomembranes.

INVITED TALKS (Tuesday, Session 5, 10:10 – 10:30 AM)

Wafer-Scale vdw Epitaxy Of MoS_2 By MOCVD Using MoO_2Cl_2 Precursor

Yoshiki Sakuma

NIMS, Japan

To establish atomically thin TMDs to practical applications, a highly reproducible and scalable growth technique is indispensable. MOCVD meets these requirements in principle; however, it should be brushed up to be appropriate for TMDs monolayer growth. One of the vital factors affecting the MOCVD process is the choice of precursors because it plays a key role in the thickness controllability of grown layers as well as crystalline quality. We have focused on epitaxial growth of MoS_2 on 2-inch c-plane sapphires by employing volatile MoO_2Cl_2 as a novel molybdenum precursor in MOCVD.

Firstly, I will present the advantages of MoO_2Cl_2. Combined with H_2S as sulfur source, MoS_2 can be grown under carbon-free condition. As a result, high-quality MoS_2 monolayers were routinely obtained over a wide range of growth conditions, which was confirmed by Raman and PL. Another notable feature derived from MoO_2Cl_2 is a quasi-self-limiting mechanism. By using MoO_2Cl_2, MoS2 growth proceeds two-dimensionally on sapphire and then growth rate greatly slows down around monolayer coverage, leading to an excellent thickness uniformity of fully covered MoS_2. We confirmed this unique growth behavior is completely different from that observed by more popular $Mo(CO)_6$ precursor.

Secondly, results related to van der Waals (vdW) epitaxy of MoS_2 on sapphire will be presented. We studied in-plane epitaxial orientation of fully covered MoS_2 monolayers grown under different conditions by in-plane XRD measurements. It is clarified that the epitaxial alignment is sensitive to growth conditions such as temperatures and H_2S flow rate. In addition, from systematic studies on samples with a series of different MoS_2 coverage, we clearly observed the evolution of XRD spectra which reflect intriguing coalescence process of MoS_2 nuclei on sapphire substrates. From these results, a new seamless stitching mechanism during vdW epitaxy of MoS_2 will be proposed.

INVITED TALKS (Tuesday, Session 7, 18:25 – 16:45 PM)

New Form Of High-K Dielectric Materials For 2D Transistors

Sean Li

UNSW, Australia

The scaling of silicon metal–oxide–semiconductor field-effect transistors has followed Moore's law for decades, but further thinning of silicon at sub-ten-nanometre technology nodes incurs detrimental issues such as leakage current. Two-dimensional (2D) layered semiconductors, with an atomic thickness that allows superior gate-field penetration, are of interest as channel materials for future transistors. However, the integration of high-dielectric-constant (κ) materials with 2D materials, while scaling their capacitance equivalent thickness (CET), remains challenging. Here we exploit transferrable ultrahigh-κ single-crystalline perovskite strontium-titanium-oxide membranes as a gate dielectric for 2D field-effect transistors. Our perovskite membranes exhibit a desirable sub-one-nanometre CET with a low leakage current (less than 10^{-2} amperes per square centimetre at 2.5 megavolts per centimetre). We find that the van der Waals gap between strontium-titanium-oxide dielectrics and 2D semiconductors mitigates the unfavourable fringing-induced barrier-lowering effect resulting from the use of ultrahigh-κ dielectrics. Typical short-channel transistors made of scalable molybdenum-disulfide films by chemical vapour deposition and strontium-titanium-oxide dielectrics exhibit steep subthreshold swings down to about 70 millivolts per decade and on/off current ratios up to 10^{7}, fulfilling the low-power requirement specified in the latest International Roadmap for Devices and Systems.

INVITED TALKS (Wednesday, Session 11, 15:05 – 15:25 PM)

Quasi-Van Der Waals Epitaxy Of Transferrable III-Nitride Films On Two-Dimensional Materials

<u>Xinqiang Wang</u>

Peking University, China

Two-dimensional (2D) materials provide a promising platform for growth and lift-off of III-nitride semiconductor beyond limitation of conventional substrate. Due to the unique interfacial coupling of van der Waals forces and covalent bonds, quasi-van der Waals epitaxy (quasi-vdWe) facilitates the realization of transferrable and/or single-crystal III-nitride films on both monocrystalline and polycrystalline substrates. Despite its significant fundamental and technological importance, the tolerance of quasi-vdWe on underlying substrates for III-nitrides has not been adequately demonstrated. Herein, we demonstrate the quasi-vdWe of III-nitride films on various substrates by employing 2D materials such as graphene, h-BN, and MoS_2 as buffer layers. By utilizing single-crystal graphene or h-BN as novel buffer layers, we successfully fabricate transferrable single-crystal gallium nitride (GaN) films and visible light-emitting diodes on 4-6 inch single-crystal sapphire substrates, as well as high-quality single-crystal GaN films on 2-inch polycrystalline diamond substrates. The dislocation density in graphene-assisted epitaxial GaN films on sapphire is lower than 2×10^8 cm^{-2} while that in graphene-assisted epitaxial GaN films on diamond is lower than 1×10^9 cm^{-2}, respectively. It is found that the thickness of the 2D material layer and its crystallinity play crucial roles in establishing a continuous and complete III-nitride/2D material/underlying substrate interface, thereby enabling the growth of high-quality single-crystal III-nitride films on diverse substrates. Moreover, the lattice polarity of those single-crystal III-nitride film can be controlled by manipulating the interfacial atomic configuration. The crystallinity of a 2D material buffer layer dictates the crystallinity of the subsequent upper film; therefore, we present growth and lift-off process of polycrystalline AlN films from polycrystalline MoS_2. This work will significantly advance research into III-nitride semiconductor devices integrated with 2D materials.

INVITED TALKS (Wednesday, Session 11, 15:45 – 16:05 PM)

Heterogeneous Integration Of Germanium And Two-Dimensional Materials By Growth

Jinkyong Yoo

Los Alamos National Laboratory, USA

Integration of emerging materials in device architectures is an essential topic of advanced devices research, next-generation semiconductors, and quantum information sciences. Incommensurate material systems, composed of compound semiconductors, quantum materials, and two-dimensional (2D) materials, have been successfully demonstrated by various epitaxy and growth techniques, such as remote epitaxy and van der Waals epitaxy. However, integration of conventional group-IV semiconductors (Si, Ge) and emerging materials has rarely been studied due to difficulty in nucleation of Si and Ge on 2D materials. The heterogeneous integration of group-IV can utilize the established infrastructure of fabrication and synthesis of solid-state semiconducting materials for Si and Ge. Recent studies of silicon and germanium revealed that Si and Ge still show unique characteristics when the materials form heterostructures with emerging materials at nanoscale. In the talk, a few examples of novel properties of Si-Ge at nanoscale in heterostructures will be presented.

A representative example is preparation of exotic hexagonal phase of germanium on monolayer molybdenum disulfide. The heterostructures overcome materials incompatibility for stacking transferrable membranes toward advanced device manufacturing. Beyond the stacked thin film structures, we explored novel opportunity of Si-Ge on 2D materials. We observed that the nucleation of hexagonal Ge grains within a continuous crystalline film. Hexagonal Ge has direct band gap, which has been a holy grail in group-IV semiconductors. Moreover, growth of hexagonal Ge has been unfeasible through traditional epitaxy techniques. First-principle calculation showed that the hexagonal Ge nucleation is thermodynamically preferrable to cubic Ge when growing on top of monolayer MoS_2 with sulfur vacancies. Two other examples will be briefly discussed in the talk.

INVITED TALKS (Monday, Session 1, 10:00 – 10:20 AM)

4H-SiC Remote Epitaxy For Wafer Cost Reduction

Takuji Maekawa

Rohm Research and Development Center, Japan

Expanding the SiC power semiconductor market requires lowering device pricing per ampere compare with Si device. The major cost of SiC devices does not come from the epitaxy process or the wafer process, but from the substrate. This mainly prevents the widespread use of SiC power devices improve the energy conversion efficiency. To this end, the authors present the application of remote epitaxy technology through graphene to SiC alternative substrates with epitaxial membranes. The 4H-SiC remote epitaxy growth was successfully achieved via graphene formed on the SiC substrates. The films have the same crystal orientation direction as the SiC substrates used. This remote epitaxy method allows the reuse the SiC substrates for fabrication of SiC epitaxial layer and significantly reduces the cost of crystal growth and material loss for SiC wafer production compared to existing methods.

Wafer-Scale Fabrication Of Integrated Circuits Based On 2D Semiconductors

Wenzhong Bao

Fudan University, China

Extensively studied 2D semiconductors such as MoS_2 and WS_2, which are accessible by large-scale synthesis methods, are remarkably stable and allow superior electrostatic control due to their atomically thin nature and favourable electronic transport properties, suggesting a bright future for large-scale IC applications. However, the transition of 2D semiconductors from the lab to the factory is still in its infancy. Here, I will first discuss some of the major obstacles that need to be overcome to achieve wafer-scale, uniform and high-quality continuous films as electronic-grade materials. I will then focus on the silicon-compatible IC fabrication process based on wafer-scale MoS_2 films, mainly on the formation of electrical contacts and the deposition of dielectric layers for field-effect transistors. Analog/logic/memory circuits will also be demonstrated.

INVITED TALKS (Monday, Session 4, 18:20 – 18:40 PM)

In-Situ Ultraviolet Optical Observation Of CVD Growth Of Graphene

Yui Ogawa

NTT, Japan

In-situ observations are effective for clarifying the growth mechanisms for graphene and other two-dimensional (2D) materials. In previous reports, however, the growth conditions and setups have so far been limited, such as a high-vacuum condition with environmental scanning election microscopy (SEM) and a cold-wall chamber with radiation microscopy. In this talk, we will report a new in-situ observation method of chemical vapor deposition (CVD) growth of graphene on a Cu surface by using an ultraviolet (UV) optical microscope and an analysis of its CVD growth process.

INVITED TALKS (Tuesday, Session 7, 16:45 – 17:05 PM)

Nanostructured Inorganic Wide Bandgap Semiconductors For Advanced Ultraviolet Photodetectors

<u>Munho Kim</u>

NTU, Singapore

The UV microscope was mounted on the conventional CVD setup having a hot-wall chamber, and graphene CVD growth above 1000 °C near atmospheric pressure was directly observed. The optical reflection of graphene largely changed at UV wavelengths around 270 nm, which is attributed to the interband optical transition at the M point in the Brillouin zone of graphene. As a result, the in-situ observation in the UV region gives image contrasts stronger than those in visible regions. In addition, the UV optical observation is not affected by the strong thermal radiation in the visible-infrared region from the hot-wall chamber at high growth temperatures. This in-situ observation captures the CVD growth process of graphene from the initial stage of nucleation to coalescence of domains and layer formation in a single experiment. We analyzed the evolution of graphene growth by the Johnson-Mehl-Avrami-Kolmogorov (JMAK) model describing the phase transformation process of metal crystals. This model allows us to determine key growth parameters, e.g., growth rate and surface coverage. These methods will be useful for studying growth mechanism and controlling CVD growth.

INVITED TALKS (Monday, Session 1, 09:40 – 10:00 AM)

Opportunities For Harnessing Crystalline Membranes Based On Non-Centrosymmetric Materials For Computing And Energy Transformation

Jian Shi

Rensselaer Polytechnic Institute, USA

The successful development of various methods for creating crystalline freestanding membranes in functional materials creates the possibility for designing and developing novel computing and energy devices. In this talk, I will present our recent progress in developing freestanding crystalline nanomembranes based on non-centrosymmetric materials for energy and computing applications. By editing the mechanical boundary conditions, electron-phonon coupling, and symmetry of nanomembranes, I will demonstrate the experimental and theoretical observation of effective tuning of their polar, spin, and topological properties. These observations highlight the uniqueness of using nanomembranes as promising building blocks for designing future computing devices such as spin logic or topological devices.

INVITED TALKS (Wednesday, Session 9, 09:10 – 09:30 AM)

Role Of Buffer Graphene On Defects In Remote Heteroepitaxy

Sungkyu Kim

Sejong University, Korea

Although the conventional epitaxy grown on the seed substrate provides high-quality single-crystalline materials for future electronic, spintronic, and energy storage applications, there are critical issues such as defect density formed by lattice mismatch and substrate dependence. In addition, additional processes such as chemical etching, mechanical spalling, and thermal-induced lift-off are required to fabricate freestanding films. Recently, freestanding epitaxial films grown on a two-dimensional (2D) graphene have been reported. However, it is essential to understand the origin of remote epitaxy and fabricate low-dimensional materials on the substrate via direct growth for obtaining high-quality freestanding films.

Here, we clearly demonstrate the origin of epitaxial growth using low-dimensional materials such as monolayer graphene and a buffer layer graphene. Based on the previous studies, the role of monolayer graphene for the growth of III-V compound semiconductors has been successfully demonstrated by remote homoepitaxy and heteroepitaxy. Although these epitaxial films have low defect density, it is very difficult to completely control defects inside the grown films due to the presence of unstable interfaces bordering low-dimensional materials. In order to dramatically reduce the defect, we artificially form a low-dimensional buffer layer to create a homogeneous epitaxial condition in heteroepitaxy. In the initial growth stage, the buffer layer with the same crystal structure as the substrate is formed through the unstable buffer graphene, and graphene is recrystallized on the 2D buffer layer. Using epitaxy 2D films, we confirmed that it is possible to repeatedly grow and transfer the freestanding films with effectively controlled defects. These findings suggest that the growth of heterogeneous materials on graphene/2D buffer provides a uniform interface by controlling interatomic diffusion and can be utilized in various fields.

Non-Chemically Bonded Epitaxy: Fundamentals To The Interface And Practical Device Fabrications

Young Joon Hong
Sejong University, Korea

The chemical bond between the epilayer and substrate is a driving force for epitaxial growth, facilitating the emulation of the substrate's crystallographic registration (i.e., crystal symmetry and orientation). As wafers are replaced by two-dimensional (2D) material-coated substrates, which lack surface dangling bonds, the epitaxy is directed either by the van der Waals (vdW) force inherent to 2D materials or by an interactive force from the underlying 3D substrate, even across a 2D layer within the 2D-on-3D substrate. This occurs irrespective of chemical bond, leading to what is termed as vdW and remote epitaxy. In this talk, we briefly discuss what happens at the interface of both the epitaxial types, drawing insights from first-principle and density-functional theory simulations. Furthermore, we present the fabrication of practical devices through the non-covalent epitaxy, including Post-it®-like bendable and customizable light-emitting diodes (LED), as well as, high-density full-color micro-LED pixel architectures.

3D Integration Of 2D Devices For Advanced Memory, Logic, And Bio-Inspired Computing

Saptarshi Das

Penn State, USA

In this presentation, I will delve into the exciting realm of monolithic 3D integration, where emerging 2D FETs take center stage, empowering advanced memory, and logic devices. Notably, our recent breakthroughs have culminated in the successful demonstration of wafer-scale 2-tier and 3-tier 3D integration, utilizing MoS_2 and WSe_2 FETs as the building blocks. These achievements have paved the way for multifunctional circuits that hold immense promise for the future of electronics. Furthermore, I will also discuss our work on bio-inspired neuromorphic computing. We have harnessed the potential of 2D materials to design solid-state devices with low power consumption mimicking auditory processing in barn owl, collision avoidance in locust, probabilistic computing in dragonfly, and multisensory integration in octopus. By combining the power of 2D materials with bio-inspired principles, our work lays a solid foundation for the creation of highly compact and functionally diverse integrated circuits in the revolutionary third dimension. The implications of this technology are far-reaching and hold the potential to shape the future of electronics and computing.

INVITED TALKS (Tuesday, Session 6, 12:35 – 12:55 PM)

Heterogeneous Integration For Intelligent Sensing Via Remote Epitaxy

Kyusang Lee

UVA, USA

Recent advances in heterogeneous integration technology have made it possible to combine multiple functionalities on a single system. Among various, remote epitaxy techniques can produce single-crystalline membranes on graphene, readily exfoliatable to form freestanding single-crystalline membranes. We have recently discovered that "any types" of single-crystalline compound materials, such as III-V, III-N, and complex oxides, can be epitaxially grown on 2D materials-coated substrates. 2D material is sufficiently thin such that crystalline growth can be guided by the substrate beneath 2D materials. The slippery 2D surface allows the epitaxial films to be released from the substrate while the substrate can be reused. Based on this technology, various electronic and optoelectronic components can be fabricated and integrated. Integration of sensors and artificial neurons for artificial neural networks (ANNs) attracts great interest for the applications of artificial intelligence of things (AIoTs). Here, I will discuss how this advanced technology revolutionizes various sensors integrated with neuromorphic components for edge computing towards AIoTs.

Release Layer-Free Method For Producing Ultrathin, Freestanding, Single-Crystalline Membranes

Celeste Chang

SNU, Korea

The capability of producing ultrathin, single-crystalline, freestanding complex oxide systems have sparked industry interest in their potential for next-generation commercial devices. However, mass production of these ultrathin complex oxide membranes has been limited by the need to insert a buffer layer that would later release the epilayer from the substrate. Here, we introduce a release layer-free technique capable of atomic precision lift-off, facilitating fast, high-throughput production of scalable, ultrathin, freestanding perovskite systems. Leveraging both theoretical insights and empirical evidence, we have identified the pivotal role of lead (Pb) in weakening the interface. This insight has led to the creation of a universal exfoliation strategy that enables the production of diverse ultrathin perovskite membranes under 10 nm. Remarkably, our pyroelectric membranes demonstrate a record pyroelectric coefficient, a result of their exceptionally low thickness and freestanding nature. Moreover, this method offers a groundbreaking approach to manufacturing cooling-free detectors capable of covering the full far-infrared spectrum, marking a significant advancement in detector technology.

POSTER ASSIGNMENTS

July 22, 2024, 19:00 p.m. – 20:00 p.m.

First Name	Affiliation	Poster Board Number
Iryna Kandybka	Ku Leuven	**1-1**
Yating Ruan	Advanced Thin Film Technology, Institute for Materials Science, Technische Universität Darmstadt	**1-2**
Keiju Sato	Rohm Co., Ltd.	**1-3**
Jung Ho Yoon	Sungkyunkwan University	**1-4**
Jin Yong An	Korea University	**1-5**
Yen-Yu Wang	RCAS, Academia Sinica	**1-6**
Tzu Yu Peng	RCAS, Academia Sinica	**1-7**
Mitsuru Morimoto	Rohm Co., Ltd.	**1-8**
Takayasu Oka	Rohm Co., Ltd.	**1-9**
Shuto Araki	Rohm Co., Ltd.	**1-10**
Dongyoung Kim	Korea Advanced Institute of Science and Technology	**1-11**
Seongdae Kwon	Korea Advanced Institute of Science and Technology	**1-12**
Ryo Nanae	the University of Tokyo	**1-13**
Jongho Ji	Yonsei University	**1-14**
Hanjoo Lee	Yonsei University	**1-15**
Beom Jin Kim	Yonsei University	**1-16**
Min-gyu Kim	Korea Advanced Institute of Science and Technology	**1-17**
SeHoon Kim	Yonsei University	**1-18**
Heo-Min Kwak	Electronics and Telecommunications Research Institute (ETRI)	**1-19**
Seunghyeon Ji	Yonsei University	**1-20**
Seungmin Yang	Yonsei University	**1-21**
JongGyu Choi	Yonsei University	**1-22**
Jaehyeon Kim	Seoul National University	**1-23**
Minseung Gyeon	Korea Advanced Institute of Science and Technology	**1-24**
Taemin Kim	Yonsei University	**1-25**
Saeyoung Oh	Korea Advanced Institute of Science and Technology	**1-26**
Suhyun Kim	Korea Advanced Institute of Science and Technology	**1-27**
Hyeon-Tak Kwak	Electronics and Telecommunications Research Institute (ETRI)	**1-28**
Yuseok Kim	Korea Advanced Institute of Science and Technology	**1-29**
Atsumi Keisuke	The University of Tokyo	**1-30**

Mingyu Sang	Yonsei University	**1-31**
Jaehyun Lee	Korea Advanced Institute of Science and Technology	**1-32**
Zi-Liang Yang	National Taiwan University	**1-33**
Yukihiro Endo	NTT Basic Research Laboratories	**1-34**
Ayoung Ham	Korea Advanced Institute of Science and Technology	**1-35**
Jianxi Xu	Suzhou Institute of Nano-Tech and Nano-Bionics(SINANO), Chinese Academy of Sciences	**1-36**

POSTER ABSTRACTS

First Name	Abstract Title
Iryna Kandybka	MoS_2 grains orientation controlled by Metal Precursor Concentration During Chemical Vapor Epitaxy on Sapphire
Yating Ruan	Freestanding $SrMoO_3$ Membrane Single Layers and Complete Devices: Strain Mechanisms and high-performance Varactors
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