AMULET

16 – 19 SEPTEMBER 2026

SECOND CZECH – JAPAN WORKSHOP ADVANCED MULTISCALE MATERIALS

SECOND

CZECH – JAPAN

WORKSHOP

ADVANCED MULTISCALE MATERIALS

Book of Abstracts

Co-funded by the European Union

Ministry of Education, Youth and Sports of the Czech Republic

Chairs' Welcome Message

It is my great pleasure to welcome all participants to the Second Czech–Japanese Meeting on Advanced Multiscale Materials, organized within the framework of the AMULET (Advanced MUltiscaLe materials for key Enabling Technologies) project.

While our first meeting in 2024 was strongly focused on the rapidly developing field of 2.5D materials, this year's event has a broader ambition. Beyond presenting the latest scientific achievements, we aim to identify new opportunities for long-term Czech–Japanese collaboration and to explore joint research directions in emerging technologies that will shape the coming decades.

The Czech Republic and Japan share a long tradition of scientific cooperation, dating back more than a century to the pioneering work of Jaroslav Heyrovský and Masuzo Shikata. Today, this partnership continues through joint research projects, researcher exchanges, and collaborations between leading universities and research institutes in both countries.

The scientific programme reflects the multidisciplinary nature of the AMULET project, covering advanced materials, nanotechnology, energy conversion and storage, sensing, photonics, and data-driven materials design. Particular attention will be devoted to future-oriented research areas, including quantum materials and quantum technologies, which are expected to play a key role in next-generation computing, communication, sensing, and sustainable technological development.

We believe that addressing the most challenging scientific questions requires international cooperation and the combination of complementary expertise. Bringing together researchers from the Czech Republic and Japan provides a unique opportunity to exchange ideas, develop new partnerships, and lay the foundations for future joint projects with global impact.

We would like to thank all participants, speakers, and organizers for their contribution to this meeting. We look forward to inspiring discussions and to the new collaborations that will emerge from our shared commitment to scientific excellence and innovation.

Prof. Martin Kalbac & Prof. Jana Kalbacova Vejpravova
Chairs of the Second Czech - Japanese Meeting on Advanced Multiscale Materials

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PROGRAM I

Day 0 – 16th September 2026		
	Arrival	Hotel Duo
19:00	Informal dinner	Hotel Duo

Day 1 – 17th September 2026		
9:00	M. Kalbáč, J. Kalbáčová Vejpravová	Opening
9:10	Prof. Hiroki Ago	Science and Applications of 2.5 Dimensional Materials
9:40	Dr. Jiří Červenka	From Electrolyte Chemistry to Interfaces: Designing Stable Aqueous Zinc-Ion Batteries
10:10	Prof. Yasumitsu Miyata	Diameter-Tunable Nanoscrolls Based on Janus Transition Metal Dichalcogenides
10:40	Coffee break	
11:00	Prof. Kazunari Matsuda	Advanced Robotic Fabrication of 2D Material and its Application for Quantum Technology
11:30	Dr. Romana Mikšová	2D materials/polymers modified by ion beams for multifunctional use
12:00	Dr. Jan Sýkora	Self-assembled supported lipid bilayers formed on modified graphene surfaces tailored for super-resolution optical microscopy
12:30	Lunch	
13:45	Prof. Yukiko Yamada-Takamura	Epitaxial Xenes and Beyond: Novel 2D Materials Stabilized on Surfaces
14:15	Dr. Luka Pirker	Metal-Assisted Exfoliation of MoS2 and TMDC Heterostructures
14:45	Prof. Toshiaki Kato	Engineering Two-Dimensional Quantum Materials: From Graphene Josephson Junctions to Janus TMD Excitonic Devices
15:15	Coffee break	
15:30	Prof. Hidehiro Sakurai	Buckybowl as a New Motif (Molecule) for 2.5-Dimensional Materials
16:00	Prof. Tomoki Machida	Symmetry, moiré, and subband engineering using van der Waals junctions of 2D materials
16:30	Michal Gulka	Dense Fluorination of Nanodiamonds for Quantum Sensing
17:00 – 18:30		Excursion I
19:00	Dinner – all participants	Cobolis https://www.cobolis.cz/

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PROGRAM II

Day 2 – 18th September 2026		
9:50		Welcome
10:00		Round table – funding schemes follow up (Horizon Europe, Bilateral projects,)
11:10	Coffee break	
11:40		Roud table - Collaboration opportunities within AMULET project (mobilities, joint experimental proposals)
12:30	Lunch	
14:00 – 18:00		Excursion II
19:00	Dinner	Brasileiro U Radnice https://brasileiro.uzelenezaby.ambi.cz/en

Day 3 – 19th September 2026		
9:30	J. Vejpravova, M. Kalbac	Welcome
9:40		Round table – joint degree, student and postdoc exchange – opportunities within AMULET project
12:00		Wrap-up, Closing

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Science and Applications of 2.5 Dimensional Materials

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2D materials have attracted great interest because of their unique physical properties and various applications. 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 2.5D materials [1-3].

In this presentation, our recent research is introduced based on this 2.5D concept. We have developed the CVD growth of high-quality, large-area multi/few-layer hBN to be used as a building block of various 2.5D materials, such as graphene field-effect transistors (FETs) [4] and magnetic tunnel junction (MTJ) devices [5]. The 2D nanospace of bilayer graphene can be used to intercalate molecules and ions which exhibit unique structures, which are distinct from their bulk materials [6-8].

I will also introduce the tape transfer of 2D materials with a novel concept of "Read-to-transfer", which is expected to accelerate the 2D/2.5D materials research and applications [9]. 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. Recently, this UV tape transfer method has been developed to synthesize an aligned graphene nanoscroll array with the highest density reported so far [10].

Finally, the CVD synthesis of dense arrays of aligned MoS_2 nanoribbons and their application to hydrogen evolution reaction (HER) will be also demonstrated [11].

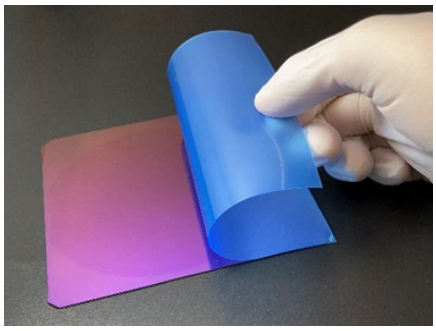

Figure 1. Concept of the "Ready-to-transfer" tape.

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From Electrolyte Chemistry to Interfaces: Designing Stable Aqueous Zinc-Ion Batteries

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Aqueous zinc-ion batteries (AZIBs) are promising candidates for safe, low-cost, and sustainable energy storage. Their practical development, however, is hindered by a complex interplay of electrolyte instability, parasitic reactions, zinc dendrite formation, and degradation of electrode materials. Addressing these challenges requires a system-level understanding of how electrolyte chemistry, ion transport, interfacial processes, and electrode structure interact to determine battery performance.

In this talk, I will present our recent work on the development of stable and durable AZIBs through the combined regulation of electrolyte chemistry and electrode interfaces. We investigate how salt concentration, anion chemistry, and functional additives modify water activity, Zn^{2+} solvation, ion transport, and interfacial reactions. In particular, high-concentration electrolytes can substantially alter the hydrogen-bonding network of water and extend the electrochemical stability window, while specific anions and additives provide additional control over zinc-ion solvation and interphase formation.

Building on these principles, we demonstrate several approaches to stabilizing zinc electrodes through the formation of robust, ion-conductive interphases. Organic additives, polymers, nanoparticles, and novel salt-particle suspension electrolytes can regulate the local chemical environment and improve ion availability at the electrode surface, enabling highly reversible zinc deposition and extended cycling stability.

The same interface-oriented approach is applied to cathode materials, including manganese and vanadium oxides, as well as graphite systems. By combining morphology control with binder- and polymer-mediated interfacial engineering, we improve Zn^{2+} transport, homogenize ion flux, and suppress degradation processes such as dissolution and structural collapse. These strategies enable full cells with improved capacity retention and long-term cycling stability.

Overall, the results highlight the importance of treating the electrolyte, interfaces, and electrodes as an interconnected system rather than as independent components. The emerging relationships between electrolyte structure, interfacial chemistry, ion transport, and electrode stability provide a general framework for designing more durable aqueous zinc-based batteries for future energy-storage applications.

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Diameter-Tunable Nanoscrolls Based on Janus Transition Metal Dichalcogenides

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Nanoscrolls of transition metal dichalcogenides (TMDs) have recently emerged as promising nanostructures for exploring curvature- and chirality-dependent physical phenomena. However, systematic strategies to fabricate TMD nanoscrolls with controlled diameters and to elucidate their structure-dependent optical properties remain limited. In this talk, we present our recent studies on the fabrication of diameter-tunable nanoscrolls derived from Janus TMDs and their heterostructures [1-3]. The incorporation of a Janus monolayer promotes the scrolling of the heterostructures and enables continuous tuning of the nanoscroll outer diameter over a remarkably broad range, from ~10 nm to ~1 μm. Notably, the inner diameter increases with the number of layers approximately following a power law with an exponent of 2.3, reflecting the balance between the spontaneous curvature of Janus WSSe and the increasing bending rigidity of van der Waals multilayers. Optical characterization reveals anisotropic Raman responses and strain-induced modulation of second-harmonic generation. These results establish Janus-based nanoscrolls as a versatile platform for investigating structure–property relationships and for developing rolled TMD systems for advanced photonic and optoelectronic applications.

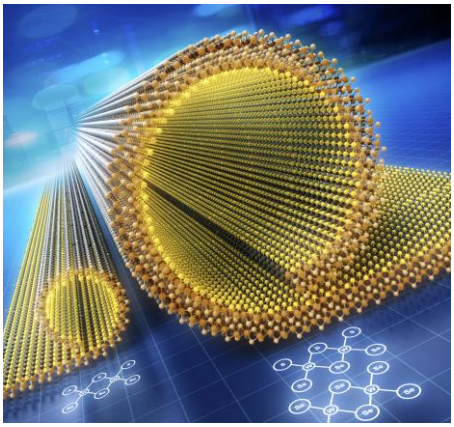

Fig.1 Schematic illustration of nanoscrolls based on (left) a monolayer Janus TMD and (right) a Janus $WSSe/WSe_2$ heterobilayer.

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Advanced Robotic Fabrication of 2D Material and its Application for Quantum Technology

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Two-dimensional (2D) materials of monolayer transition metal dichalcogenides and their van der Waals (vdW) heterostructures have been intensively studied from the viewpoint of fundamental physics and potential applications [1–9]. The quantum-confined excitonic states in the defects of monolayer material and the periodic moiré potential (moiré excitons) formed by stacking 2D material heterobilayers provide a new platform for studying novel optical physics, and quantum optics. I will introduce selected recent topics on recent progress of advanced robotic fabrication [8] and optical studies towards quantum technology in monolayer 2D semiconductors and artificial vdW material heterostructures [4,5,9].

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2D materials/polymers modified by ion beams for multifunctional use

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Two-dimensional (2D) transition metal dichalcogenides, particularly molybdenum disulfide (MoS_2), integrated with flexible polymer supports represent an exceptionally promising platform for environmental catalysis, flexible electronics, and advanced sensing devices. However, optimal performance demands precise defect and interface engineering without disrupting structural integrity. In this work, we present a versatile strategy utilizing ion beam technologies both for the architectural tailoring of polymer substrates and for post-deposition defect engineering of hybrid MoS_2/poly(ethylene terephthalate) (PET) heterostructures. In the first strategy, porous polymer substrates were prepared by irradiating 19 µm thick PET foils with swift heavy ions (1×10^6 cm$^{-2)}$ followed by track etching to produce cylindrical channels with different pore diameters. Thin MoS_2 were subsequently deposited onto the porous PET membranes. The structural, morphological, and chemical properties were evaluated using scanning electron microscopy (SEM), Rutherford backscattering spectrometry (RBS), elastic recoil detection analysis (ERDA), X-ray photoelectron spectroscopy (XPS), and Fourier-transform infrared spectroscopy (FTIR). SEM revealed a textured surface characterized by microcracks and droplet-like particulate morphology typical of PLD. RBS and XPS analyses confirmed the deposition of continuous MoS_2 layers maintaining characteristic Mo^{4+} and S^{2-} bonding states, while FTIR and XPS confirmed that alkaline track etching introduced polar carboxyl and hydroxyl functional groups along the membrane surface and pore walls. The dual-mode functional performance was investigated through the adsorption and photocatalytic degradation of Bisphenol A (BPA) under UV-A irradiation, alongside electrical humidity sensing. In dark conditions, MoS_2-coated porous membranes displayed accelerated adsorption kinetics, achieving the highest pseudo-first-order rate constant of 0.0528 min^{-1} due to the combined effect of surface texturing and electrostatic interactions with polar sites. Under UV-A illumination, the etched PET membrane with narrow pores reached the highest photocatalytic degradation rate constant (0.0083 min^{-1} 64.4% BPA removal after 240 min). The MoS_2-coated membranes demonstrated pronounced humidity-sensing capabilities, exhibiting a linear drop in electrical sheet resistivity between 20% and 50% relative humidity [1]. In the second strategy, thin MoS_2 films were deposited onto flexible PET foils and subsequently structured by energetic ion irradiation. The samples were irradiated across fluences ranging from 1×10^{12} to 5×10^{14} cm^{-2}. Comprehensive characterization was carried out using different analytical methods. RBS and ERDA analyses confirmed that ion irradiation induced a progressive dehydrogenation and deoxygenation of the PET substrate accompanied by carbonization, alongside a preferential erosion of sulfur in the active MoS_2 layer. High-resolution XPS revealed an increase in the Mo/S ratio, an enrichment of defect-associated sulfur vacancies, and a slight phase conversion toward the metallic 1T-MoS_2 phase. FTIR showed systematic bond scission in the ester backbone of the PET substrate, particularly the attenuation of the carbonyl band at 1715 cm^{-1}. AFM and SEM analyses demonstrated contrasting morphological developments: while C and O ions induced modest, linear increases in surface roughness without compromising interfacial bonding, Au ions produced extreme texturing at intermediate fluences followed by crack network formation and delamination at high fluences. The functional impact of ion beam structuring was assessed via the photocatalytic degradation of Rhodamine B under UV illumination. All irradiated heterostructures exhibited enhanced degradation reaction rates relative to the pristine reference (k = 3.2×10^{-3} min^{-1}). The highest degradation rate constant of 12.3×10^{-3} min^{-1} was achieved for oxygen-irradiated samples, attributed to the combination of surface oxygen/hydroxyl functionalization, sulfur vacancy active sites, and intact interfacial contact.

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Self-assembled supported lipid bilayers formed on modified graphene surfaces tailored for super-resolution optical microscopy

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Studies of lipid bilayer organization are of considerable biological importance. Owing to the nanometer-scale thickness of lipid bilayers, their detailed characterization requires advanced super-resolution microscopy techniques. Among these, graphene-induced energy transfer (GIET) [1,2], which exploits the distance-dependent quenching of fluorescence lifetimes of probes embedded within supported lipid bilayers (SLBs), has emerged as a powerful approach. A major challenge in the implementation of GIET lies in the modification of the graphene surface to gain a hydrophilic platform compatible with SLB formation, while ideally introducing a soft cushioning layer to minimize substrate-induced perturbations of membrane dynamics [3]. Therefore, we developed a novel and simplified one-step graphene functionalization strategy based on the adsorption of pegylated aromatic moieties through π–π interactions. By systematically evaluating different molecules and experimental conditions, PEG1000-perylene bisimide (PEG1000-PBI) was identified as an effective cushioning agent that promotes SLB formation on graphene. GIET measurements confirmed the formation of lipid bilayers with the expected thickness on PEG1000-PBI-functionalized graphene. The presented functionalization strategy therefore provides a simple and effective route for graphene cushioning in advanced GIET-based membrane studies. However, further optimization is required to improve the reproducibility of the proposed approach. Additional strategies aimed at achieving this goal will be also discussed.

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Acknowledgement:

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Epitaxial Xenes and Beyond: Novel 2D Materials Stabilized on Surfaces

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"Xenes" [1] are post-graphene mono-elemental two-dimensional (2D) materials represented by silicene: Si-version graphene [2]. Since silicene and most of the Xenes lack layered-structure mother crystals, they are synthesized on single crystal substrates as "epitaxial Xenes". Crystal and electronic structures of epitaxial Xenes are often different from those predicted for their free-standing forms, and therefore, it is very important to characterize epitaxial Xenes using complementary techniques.

Through close collaboration with groups specialized in photoemission spectroscopy and first-principles calculations, we have successfully demonstrated that a surface reconstruction observed on zirconium diboride (ZrB_2) thin films grown on Si(111) substrates is from silicene sheet spontaneously formed by surface-segregated Si atoms [3]. Angle-resolved [4] and core-level [5] photoemission spectroscopies, together with first-principles calculations of "unfolded" band structure [6] and absolute binding energies including final-state effect [7], have determined the details of buckling in silicene honeycomb lattice on ZrB_2 thin film and its electronic structure details.

In this talk, I will introduce our recent results from the studies on group 14 epitaxial Xenes, such as silicene, germanene (or 2D bitriangular lattice of Ge) [8], stanene, and also their 2D hybrids.

References

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Metal-Assisted Exfoliation of MoS_2 and TMDC Heterostructures

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Gold-assisted exfoliation is an effective route for selectively producing large-area monolayers of transition metal dichalcogenides (TMDCs), yet the microscopic origin of this selectivity and its extension to other metals remain incompletely understood[1]. Here, we investigate metal-assisted exfoliation and the resulting metal–TMDC interfaces using monolayer MoS_2 as a model system. By direct mechanical exfoliation of bulk MoS_2 onto polycrystalline Au, Ag, Cu, Pd, Co, Pt, and Ni under controlled atmospheres, combined with photoemission and vibrational spectroscopy and density functional theory, we reveal strongly metal-dependent modifications of MoS_2. In particular, asymmetric hybridization of the bottom and top sulfur atoms emerges as a key factor that weakens interlayer MoS_2-MoS_2 van der Waals interactions and promotes selective monolayer exfoliation[2]. Extension to reactive metals under ultra-high vacuum further shows that, although MoS_2 can be exfoliated onto Ti with high monolayer yield, substantial interfacial chemical degradation occurs at room temperature, while thicker layers provide increased protection[3]. We further demonstrate that metal-substrate morphology critically governs the mechanical, vibrational, and optical response of exfoliated MoS_2. Correlative atomic force microscopy, Raman and photoluminescence spectroscopy, and molecular dynamics simulations show that increasing Au roughness reduces conformal contact, promotes locally suspended regions, and enhances tensile strain, whereas a Pt adhesion layer enables exceptionally smooth ultrathin Au films and efficient exfoliation. Building on these insights, we establish sequential Au-assisted exfoliation as a polymer-free route to large-area TMDC heterostructures with clean, conformal interfaces and strong interlayer coupling, evidenced by characteristic Raman signatures and stacking-angle measurements. Together, these results identify chemical bonding, interface morphology, and metal reactivity as key parameters governing exfoliation and heterostructure quality, and provide guidelines for engineering clean metal-2D material interfaces for electronic, optoelectronic, catalytic, sensing, and quantum applications.

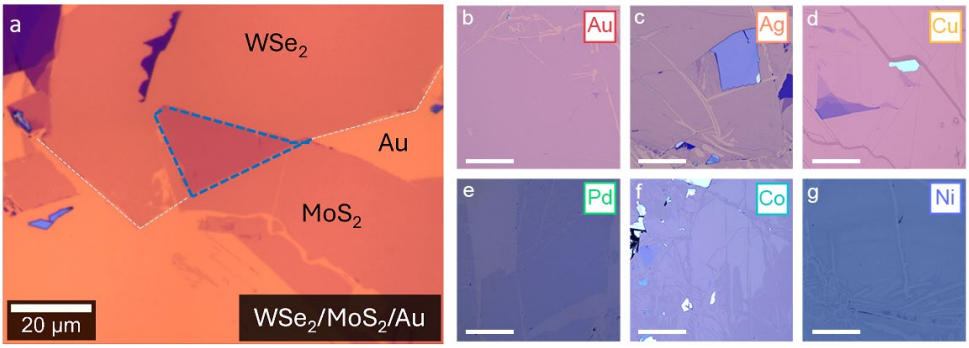

Figure 1. (a) Optical image of a WSe_2-MoS_2 heterostructure outlined by a blue dashed line. (b-g) Optical images of large-area MoS_2 monolayers exfoliated on Cu, Ag, Au, Co, Ni, and Pd.

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Engineering Two-Dimensional Quantum Materials: From Graphene Josephson Junctions to Janus TMD Excitonic Devices

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Two-dimensional (2D) materials provide a versatile platform for engineering quantum devices, where their electronic, superconducting, and optical properties can be tailored through atomic-scale control of interfaces, symmetry, and stacking configurations. In this lecture, I will present our recent efforts to develop 2D quantum devices based on two complementary approaches: interface engineering in graphene Josephson junctions and symmetry and stacking engineering in Janus transition metal dichalcogenides (TMDs).

Graphene-based Josephson junctions (JJs) have emerged as promising gate-tunable superconducting devices for future quantum technologies and scalable superconducting electronics. Among various superconducting electrodes, MoRe has been widely employed because of its exceptionally high superconducting transparency to graphene. However, the microscopic origin of this superior interface has remained elusive. By combining low-temperature transport measurements with detailed structural characterization of MoRe electrodes, we demonstrate that the high superconducting transparency originates from a metastable A15 phase of MoRe rather than its equilibrium crystal structure. Furthermore, we propose that the enhanced interface transparency can be understood in terms of atomic registry between the A15 lattice and the zigzag edge of graphene. These results reveal how atomic-scale interface and crystal-phase engineering can be exploited to optimize superconducting proximity effects in graphene, providing a materials-design strategy for high-performance and scalable 2D superconducting quantum devices.

I will then extend this concept of atomic-scale quantum-device engineering to Janus TMDs, in which out-of-plane inversion symmetry is intentionally broken through atomic substitution. The resulting structural asymmetry generates an intrinsic out-of-plane electric dipole, offering an additional degree of freedom for controlling electronic and excitonic states in 2D materials. In particular, we have investigated bilayer Janus TMDs and demonstrated that their optical properties can be markedly modified by controlling the stacking order of the two Janus layers. Different stacking configurations determine the relative orientation and spatial arrangement of the intrinsic dipoles, leading to characteristic excitonic and optical responses that are absent in conventional symmetric TMDs. These findings establish stacking order, together with interface and symmetry control, as a powerful design parameter for engineering excitonic states in atomically thin materials.

Through these examples, I will highlight a unified approach to 2D quantum-device engineering, in which atomic-scale control of crystal phase, interfaces, symmetry, and stacking provides a pathway to deliberately design superconducting and excitonic functionalities for next-generation quantum devices.

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Buckybowl as a New Motif (Molecule) for 2.5-Dimensional Materials

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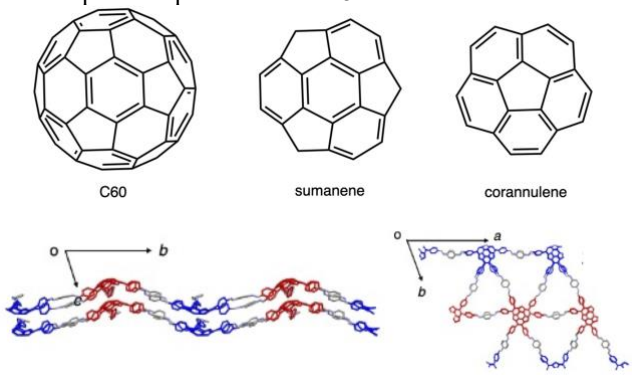
"Buckybowls" refer to a class of organic compounds consisting of fullerene fragments terminated with hydrogen atoms [1]. Among them, two pristine structures are known: corannulene, with five-fold symmetry, and sumanene [2], with three-fold symmetry. In particular, sumanene has attracted attention due to its symmetry, making it a promising candidate for applications across various fields. In the realm of two-dimensional materials, theoretical studies suggest that sumanene derivatives can effectively modulate the band gap of graphene [3]. When intercalated into bilayer graphene, they function as efficient piezoelectric conversion elements [4]. Moreover, the synthesis of network structures [5,6] such as covalent organic frameworks (COFs) incorporating the sumanene motif enables the construction of non-planar carbon network architectures. These materials can be considered "2.5-dimensional" materials [7], offering added functionality beyond conventional two-dimensional systems. In this presentation, I will introduce the chemistry of sumanene and explore its potential as a 2.5D material.



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Symmetry, moiré, and subband engineering using van der Waals junctions of 2D materials

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Few-layer transition metal dichalcogenides (TMDs) exhibit subband quantization induced by the out-of-plane quantum confinement of the wavefunctions, i.e., a few-layer TMDs is a naturally-formed quantum well (QW). We investigate QW states in WSe_2/h-BN/WSe_2 vdW tunnel junctions, which are analogous to double quantum well (DQW) structures. Resonant tunneling in the vdW DQW device gives rise to pronounced negative differential resistance (NDR). Utilizing this NDR, we demonstrate a resonant tunneling oscillator: when the vdW DQW device is integrated into an LC resonant circuit and biased within its NDR region, sustained AC voltage oscillations are achieved. Furthermore, we realize vertical tunneling in a vdW triple QW (TQW) device, which exhibits enhanced and multiple resonant tunneling peaks accompanied by NDR. In addition, we extend our approach to multilayer MoS_2, where a valence-band minigap at the Γ point enables distinct resonant tunneling characteristics. By employing highly p-doped p^+-MoS_2/h-BN/p^+-MoS_2 tunnel junctions, we observe clear room-temperature NDR associated with tunneling into the Γ-point band. Our results establish TMD/h-BN/TMD vdW multiple QWs as a versatile platform for high-performance resonant tunneling devices and high-frequency electronic and optoelectronic applications.

We will also discuss (i) symmetry control in van der Waals junctions of graphene/h-BN/black phosphorus for shift-current generation, and (ii) the emergence of one-dimensional (1D) moiré superlattices in large-angle (58° and 62°) twisted bilayer WTe_2, and (iii) origami folding of 2D crystal flakes.

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Toward Fully Fluorinated Fluorescent Nanodiamonds

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Nanodiamonds (NDs) with nitrogen-vacancy (NV) centers represent a promising platform for quantum sensing relying, in most cases, on the photoluminescence (PL) from negative NV^- charge state [1]. The fluorine diamond termination provides the highest measured positive electron affinity and is thus expected to significantly stabilize the NV^- charge state due to band bending near the ND surface. Fluorination of bulk CVD diamond can be achieved using SF_6 plasma or CF_4 plasma, however is difficult to apply to nanoparticles due to limited plasma penetration. Selective exchange of carboxyl groups for fluorine represents another approach with limited efficiency, which only leads to mixed F/O ND termination with only low fluorine content [2].

Here, we focused on exploring the possibility of complete fluorination of ~30-nm sized HPHT NDs using a chemical approach on a preparative scale. To achieve maximum fluorination efficiency, we used highly reactive F_2 gas under elevated pressure and temperature, and we tested different starting ND surfaces. Based on FTIR, XPS, XAS and elemental analysis we report on near-full fluorination of the ND surface. Compared to acid oxidized NDs, such particles exhibit 3-times increased NV^- concentration, as measured by EPR. This translates to 94% of PL originating from the NV^- charge state (compared to 57% in oxidized NDs) and stronger total PL signal. Further, we show that the fluorinated NDs can be dissolved in water and were then used for in-solution quantum sensing of paramagnetic complex gadoteridol using *T1* relaxometry.

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