Nano and 2D Materials
Room Naupaka Salon 4 - Session NM1-TuE

Synthesis and Manipulation
Moderator: Sarah Burke, University of British Columbia

6:00pm **NM1-TuE-2 Using a Zeolite Imidazolate Framework-8 Nanomaterial for Adsorption and Removal of Thymol from Water and Heparin Recovery**, *Deepak Ganta,* Texas A&M International University*; Mahmood Karimi Abdolmaleki,* Texas A&M University-Corpus Christi*; Sergio Gonzalez Torres,* Texas A&M International University*; Carlos Velazquez,* Texas A &M International University

There is a strong demand for multiplex sensing and storage capabilities from nanomaterial-based biosensors. To address the limitations in the adsorption capacity of existing materials, porous zeolite imidazolate framework-8 (ZIF-8) 3D nanomaterial, with a larger surface area, was chosen to absorb and remove thymol from water. The experimental adsorption measurement results agree well with theoretical Langmuir and Freundlich isotherm models. The maximum adsorption capacity of thymol on ZIF-8 was determined to be 454.6 mg/g. Furthermore, we also demonstrated the potential of ZIF-8 in recovering heparin from porcine intestinal mucosa. A recovery of 37 mg/g of heparin was reported and verified through kinetic and thermodynamic adsorption models, along with the appropriate surface conditions for the adsorption of heparin molecules. All the characterization methods will be presented.

6:20pm **NM1-TuE-3 Interaction of Defects on Mxene Surfaces: Nonlinear and Anisotropic Effects**, *Steven Goldy,* Colorado School of Mines, USA*; Garritt Tucker,* Baylor University*; Cristian Ciobanu,* Colorado School of Mines, USA

Defects in two-dimensional (2D) materials like hexagonal boron nitride (hBN) and MXene can drastically change mechanical, electronic, and optical properties. Furthermore, surface defects specifically affect the electrocatalytic performance of the material, and their understanding and control can lead to novel materials for catalysis, photocatalysis, and gas sensing. From a fundamental standpoint, understanding the surface-mediated interactions between defects provides insight into their spatial distribution and can serve as a way to control catalytic, sensing, and transport properties. Based on molecular statics simulations, we have developed an approach to extract the formation and interaction energy of vacancies on 2D (hBN) and quasi-2D (MXene, MoS2) materials. We have found that the interaction of defects on 2D and quasi-2D materials shows significant anisotropy, as well as marked departures from the well-used inverse cube distance-dependence associated with linear elasticity. The divergence from linear elasticity is more apparent in MXenes due to their complex, thickness-dependent scaling behaviors and out of plane displacement. Due to highly variable surface chemistries, understanding surface defects on MXenes is critical to their application. These scaling laws inform defect separation distributions that assist in design on 2D composites and catalytic applications.

6:40pm **NM1-TuE-4 Synthesis of Uniform Borophene: In Situ Spectroscopic Analysis and Ex Situ Macroscopic Transfer**, *Marko Kralj, Sherif Kamal, Borna Radatovic, Valentino Jadrisko, Dino Novko, Natasa Vujicic, Marin Petrovic,* Center for Advanced Laser Techniques, Institute of Physics, Croatia

Borophene (Bo), a recently realized polymorphic monoelemental two-dimensional (2D) material, holds promise for diverse applications, including metal-ion batteries, supercapacitors, hydrogen storage, gas sensors, and freshwater production. We present a study of Bo fabricated via segregation-assisted chemical vapor deposition (CVD) epitaxy, where an Ir(111) substrate was exposed to borazine vapors in ultra-high vacuum (UHV) at elevated temperatures. This process yielded structurally uniform and high-coverage $\chi6$ polymorph of Bo, as evidenced by electron diffraction and scanning probe microscopies. Such Bo samples were further subjected to extensive spectroscopic analysis and post-synthesis manipulation, both of which are scarce due to experimental challenges posed by sample inhomogeneity and significant chemical reactivity of epitaxial Bo systems.

In the first part of this talk, we characterize Bo on Ir(111) (Bo/Ir), focusing on electronic properties influenced by the nanoscopic modulation of the Bo sheet. X-ray photoelectron spectroscopy (XPS) and scanning tunneling spectroscopy (STS) data reveal inhomogeneous binding of Bo to Ir, creating a stripe-like structure. This structure acts as a one-dimensional (1D) grating, causing Umklapp scattering of photoelectrons detected in ARPES experiments [1]. Density functional theory (DFT) calculations support our findings, providing insights into the pristine electronic structure of Bo,

unaffected by the Ir substrate.

In the second part, the challenges of developing large-area Bo applications are addressed. We demonstrate large-area growth followed by electrochemical transfer of macroscopic single-layer Bo sheets from the growth substrate to a target Si wafer [2]. Our results show that deterministic manipulation of Bo layers is feasible despite their inherent chemical and mechanical instability, advancing Bo research and utilization. Post-transfer Bo displayed minimal mechanical defects, such as cracks and holes, mostly inherited from the synthesis substrate. Successful Bo transfer was further confirmed by Raman spectroscopy, which showed very good overlap of Raman peaks before and after the transfer, indicating preservation of Bo's original crystal structure.

References:

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[2] ACS Appl. Mater. Interfaces 15 (2023) 57890–57900

7:00pm **NM1-TuE-5 Design at Nanoscale of Thermostable Hybrid Sol-Gel Bondlayer to Functionalize Aeronautical CFRP by Thermal Spray**, *Sophie Senani-de Monredon,* SAFRAN TECH, France*; Laurence Rozes,* Sorbonne Université, France*; Guillaume Penvern,* SAFRAN TECH, Sorbonne Univ., France*; Aurélien Joulia,* SAFRAN TECH, France*; Simon Bonebeau,* SAFIR, France

Composite Fibers Reinforced Parts (CFRP) are widely used in aeronautic since more than 40 years to contribute to decrease the aircrafts environmental footprint. Indeed CO_2 and NOx emissions have been considerably decreased by lightweighting correlated to significate fuel consumption reduction (15% for last LEAP aircraft engines). Nevertheless to go further and reach the new ambitious target of 20% reduction for the next aircraft engine, functionalization and metallization of CFRP is mandatory to extend them to more aggressive use cases than fuselage, by resistance against high temperature, erosion or icing. To reach this goal, thermal spray coatings are widely studied, even if it remains very complex to implement.

Metallization of CFRP, especially by coldspray is favored by numerous teams [1,2,3], with interesting results but not sufficient to fit performance required for aeronautic qualification. Our approach aims to design a thermostable sol-gel hybrid bondcoat. We will discuss how we succeed to control of the chemical composition, the nanostructuration of this bondlayer and the nature of the substrate/bondlayer/topcoat interfaces to influence the thermomechanical bondcoat's properties and thus the building and the thickness increase of the thermal sprayed topcoat layer linked to the adhesion of the stack. Understanding the relation between nanostructuration of the hybrid sol-gel layer and their mechanical and thermal properties is essential to optimize the whole system. Finally, this will widely open the variety of materials (from metals to oxides) reachable to functionalize CFRP part and allow new use cases unthinkable up to now.

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3- CO3 Project– F. Delloro et al (https://www.projectco3.eu/fr/)

Nano and 2D Materials
Room Naupaka Salon 4 - Session NM2-TuE

2D Materials Based on Carbon and Boron
Moderator: Akitoshi Shiotari, Fritz-Haber Institute

7:40pm **NM2-TuE-7 First-Principles Study of Adsorption and Reaction on the Hydrogen Boride Sheet**, *Ikutaro Hamada,* Osaka University, Japan
INVITED

The hydrogen boride (HB) sheet [1] is a newly synthesized two-dimensional material composed of hydrogen and boron atoms with their ratio of 1:1.

The HB sheet has been attracting increasing attention, not only because of its high gravimetric hydrogen content as a hydrogen storage material and its ability to release hydrogen through light [2] and electrochemical [3] means, but also due to its catalytic activities [4]. Furthermore, the HB sheet has been shown to be chemically stable against water [5], unlike many boron hydrides that undergo hydrolysis reactions. The stability is a fascinating considering the practical application of the HB sheet. However, the molecular and mechanistic details of the chemical processes occurring on the HB sheet have yet to be fully addressed. In this talk, I will discuss the electronic and structural properties of the HB sheet [5], as well as the adsorption and reaction on the HB sheet based on our density functional theory calculations. Special emphasis is placed on the interaction with water molecules, and the mechanism of the stability of the HB sheet against water will be discussed [6,7].

References:

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[4] T. Goto, *et al*., Commun. Chem. **5**, 118 (2022).

[5] L. T. Ta, Y. Morikawa, and I. Hamada, J. Phys. Condens. Matter **35**, 435002 (2023).

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8:20pm NM2-TuE-9 N-doped Graphene Synthesis through Nitrogen Ion Irradiation*, **Zbynek Novotny**,* Pacific Northwest National Laboratory*; Buddhika Alupothe Gedara, Prescott Evans, Zdenek Dohnalek,* PNNL

Hydrogen (H_2) is one of the most promising clean and renewable energy carriers. Nevertheless, the ability to store and transport hydrogen is inefficient due to the low volumetric densities. Nitrogen-doped graphene (Gr) has been identified as a potential material for H_2 storage. We study the growth of Gr on a Ru(0001) surface by chemical vapor deposition (CVD) of pyridine (H_5C_5N) and N-doping through N_2^+ ion irradiation using scanning tunneling microscopy (STM) and x-ray photoelectron spectroscopy (XPS). A high-quality Gr film with low N densities was obtained by pyridine CVD on Ru(0001) at 1100 K. Higher concentrations of N-dopants were introduced on the Gr/Ru(0001) through low-energy N_2^+ irradiation at 100 eV. Nitrogen can be embedded in the Gr lattice preferentially in two configurations, namely graphitic N (N substituted in the C lattice) and pyridinic N (substitutional N next to a C vacancy). Atomically-resolved STM images of graphitic and pyridinic-N defects demonstrate their preferential locations within the Gr Moiré. XPS shows that coverage of up to 3.9% of pyridinic-N and 2.3% of graphitic N can be embedded into the high-quality Gr film using N_2^+ irradiation at room temperature, indicating a preferential formation of pyridinic N over graphitic N. Only graphitic N was observed upon annealing the ion-irradiated Gr/Ru(0001) to 1063 K, revealing higher thermal stability of graphitic N over pyridinic N. Our current efforts center on the adsorption studies of atomic hydrogen, its interactions with N dopants, and thermally induced diffusion.

Nano and 2D Materials
Room Naupaka Salon 4 - Session NM1-WeM

Surface Engineering and Characterization
Moderator: Gregory S. Herman, Argonne National Laboratory

8:20am **NM1-WeM-2 Synthesis, Doping, and Encapsulation of 2D Transition Metal Dichalcogenides**, *Yu-Chuan Lin,* National Yang Ming Chiao Tung University (NYCU), Taiwan **INVITED**

Two-dimensional (2D) transition metal dichalcogenides (TMDC), such as MoS_2 and WSe_2, exhibit useful material properties and versatile material chemistry for optoelectronic devices, quantum information, and energy missions. To realize these applications, we need to make them in large areas and be able to control their impurity concentrations. First, I will introduce our metalorganic chemical vapor deposition (MOCVD) process for deposition of TMDC epitaxial monolayers and the approach for growth of epitaxial TMDC multilayers on sapphire. Next, I will discuss how we introduced Re or V dopants into the cation sites of TMDC by MOCVD and their impact on the quality and properties of TMDC films.[3] In addition to cation substitutional doping, we can create Janus TMDC with an intrinsic dipole moment by replacing the elements at the anion sites (i.e., S and Se). I will present our result [4,5]of the conversion of 2D WS_2 and MoS_2 into 2D Janus WSSe and MoSSe by pulsed laser deposition and explain how we confirmed the presence of a dipole moment in 2D Janus TMDC optically. To improve the interface quality between TMDC and oxide dielectric materials for electronic applications, we developed thermal atomic layer deposition (ALD) of amorphous boron nitride (aBN) on both traditional and van der Waals surfaces. In the end, I will talk about nucleation and growth of aBN on MoS_2 surface in our thermal ALD and aBN/MoS_2 integration for improve field-effect transistor performance and quantum well fabrication.[6]

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9:00am **NM1-WeM-4 Small Clusters of Molecular Anions: Locally Probing a Model Hubbard System**, *Sarah Burke,* University of British Columbia, Canada **INVITED**

Electronic correlations drive many important phenomena in materials that cannot be described by a single-electron picture. The Hubbard model captures a remarkable range of this behaviour by introducing an on-site interaction – the "Hubbard U" – that competes with the kinetic energy of the electrons, or delocalization through wavefunction overlap – described by the hopping parameter t. While Hubbard models are not generically analytically or even exaclty solvable, model systems such as clusters often are and can lend insights into more complex extended structures. The success of such models in describing correlated electron phenomena like Mott-insulator transitions, charge density waves, magnetically ordered states, and superconductivity[1], is typically assessed by comparing to macroscopic quantities. However, as a model that captures the local character of electron-electron interactions, local tools provide a unique perspective. Noncontact atomic force microscopy (ncAFM) offers a particularly intriguing view through the ability to probe charge states and electrostatic interactions locally.

We used clusters of PTCDA molecules adsorbed on NaCl bilayer films on silver as an experimental prototype of a 4-site Hubbard model in a regime where U>>t. PTCDA clusters have weak in-plane hybridization (t small), and isolated moelcules have a Hubbard U in gas phase of ~3eV, reduced to ~1.4eV by screening of the nearby silver[2]. The large electron affinity of PTCDA leads to electron transfer from the silver substrate, so that isolated molecules carry a charge of -1. Thus, these clusters represent a half-filled Hubbard model where localization is expected, connected to a reservoir of charge. We used STM, STS, ncAFM and electrostatic force spectroscopy to probe the structures, charge states, and charging energies of two different geometries of 4-moelcule clusters as well as isolated PTCDA- molecules. Equilibrium charge distributions of asymmetric clusters show charge segregation, while symmetric clusters show uniform charge. A 4-site extended Hubbard model was mapped onto the experimental results to identify the necessary interactions required to describe the ground state and charge excitations of the system. Once above a threshold where U/t drives localization, intersite energy differences and repulsion compete with hopping, driving the observed charge segregation and unexpected correlated behaviour.

1. M. Qin, et al., Annu. Rev. Condens. Matter Phys. 13, 1–28 (2021).

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9:40am **NM1-WeM-6 Tunable Areal Density and Defined Morphology Regimes of Langmuir Monolayers of PEGylated Gold Nanoparticles**, *Hannah Cameron, Isabel Curtis, Rin Takai,* Mount Allison University, Canada*; Melissa Radford,* Simon Fraser University, Canada*; Amelia Williams,* Mount Allison University, Canada*; Byron Gates,* Simon Fraser University, Canada*; M.-Vicki Meli,* Mount Allison University, Canada

The interfacial behaviour and control of nanoparticles has important consequences on their assembly into thin films, superstructures and subsequent materials suitable as metamaterials and nanophotonics applications. Our investigations into the interfacial self-assembly of nanoparticles coated with polyethylene glycol (PEG) and tetradecane thiols as a function of ligand shell and subphase composition will be presented. Methyl- and carboxylic acid-terminated PEG thiols are compared as a function of subphase pH. Film morphology is demonstrated as a function of ligand composition, transitioning from island-forming to isolated individual nanoparticles with controllable areal density. Transmission electron microscopy of the self-assembled films will be presented with corresponding surface pressure vs. area compression isotherms.Insights into NP film purity and (in)stability as it relates to the mentioned parameters will also be discussed. Compression-expansion isotherms with exceptionally large onset areas were measured. The effect of added tetradecanethiol into the ligand shell is shown to improve the stability and maintain the separation of the nanoparticles in the films.

Nano and 2D Materials
Room Naupaka Salon 4 - Session NM2-WeM

Properties of 2D Materials
Moderator: Zbynek Novotny, Pacific Northwest National Laboratory

10:20am **NM2-WeM-8 Atomic-Scale Control of Plasmon-Driven Single-Molecular Switch**, *Akitoshi Shiotari,* Fritz-Haber Institute, Germany**INVITED**

Localized surface plasmons provide effective molecule–light interactions that are highly motivating for the realization of advanced molecule-based optoelectronic devices [1]; however, innovative precision in plasmon control is still required to induce local selective reactions at the single- or sub-molecule level. Scanning tunneling microscopy (STM) using a plasmonic metal tip not only creates a local photochemical reaction field, but also enahnces Raman signals from molecules within the STM junction, namely tip-enhanced Raman spectroscopy (TERS). Low-temperature STM-TERS is a powerful tool to evaluate the structure and photoreactivity of single molecules, even on a semiconductor silicon surface [2].

In this talk I will mainly report on a plasmon-induced single-molecule switch in a Ag-tip–anhydride-molecule–Si-surface junction characterized and controlled by low-tempearture STM-TERS [3]. The localized surface plasmon at the tip can dissociate the O–Si bonds between the molecule and the Si(111)-7x7 surface, resulting in the conductance switching between OFF (tunnelling) and ON (point-contact) states of the tip–adsorbate junction. Sub-angstrom scale positioning of the plasmonic tip over the target molecular can tune the switching rate. We also demonstrated that the switching ability can be changed by the single-atom-level substitution of the molecular structure; imide/Si(111) is inert against the tip plasmon. Our demonstrations of the tip-plasmon control and the chemical tailoring for the single-molecule switch pave the way to the fusion of single-molecule electronics and plasmonics, towards ultimate minitualization of optoelectronics, namely "pico-optoelectronics."

Reference:

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11:00am NM2-WeM-10 Tunable Metasurface with Gap and Collective Surface Plasmon Modes, *Anatoliy Pinchuk,* University of Colorado at Colorado Springs

We investigate a tunable metasurface composed of a monolayer of gold nanoparticles on a glass substrate in close proximity to a thin aluminum film, both numerically and experimentally. The extinction spectra of the metasurface exhibit three angle- and polarization-dependent peaks. Using the finite-difference time-domain (FDTD) method, we confirm the positions of both the collective surface plasmon and gap modes. Altering the polarization of the incident light causes a shift in the wavelength of these peaks.

A recent study reported strong coupling between the gap and collective surface plasmon polariton modes in a system consisting of a monolayer of gold nanoparticles supported on a glass substrate, separated from a thin aluminum film by a shellac polymer spacer film of varying thickness [1,2]. Two optical extinction bands were identified: a long-wavelength gap mode and a short-wavelength collective surface plasmon mode. The position and amplitude of both modes were found to depend strongly on the thickness of the shellac dielectric spacer. Varying the spacer thickness causes a shift in the two modes and their degeneration into a single mode as the thickness increases. These findings reveal a complex interplay between the gap and collective surface plasmon polariton modes.

Despite detailed numerical and experimental studies on various geometries of plasmonic metasurfaces, all such studies have been conducted with the probing light beam incident normally. There have been no reports on the polarization dependence of the extinction spectra for monolayers of gold nanoparticles in close proximity to a thin metal film. Our study addresses this gap by exploring the effects of polarization on the optical properties of these metasurfaces, providing new insights into their tunable characteristics and potential applications in nanophotonic devices.

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11:20am NM2-WeM-11 Probing Inherent Optical Anisotropy in Transition Metal Dichalcogenide Substrates via Mie Scattering-Induced Surface Analysis (MISA), *Hwi Je Woo,* Korea Research Institute of Standards and Science, Republic of Korea*; Jaewon Han, Sangmin Ji, Bong Gyu Shin,* Sungkyunkwan University (SKKU), Republic of Korea*; Sung-Gyu Lee,* Nanyang Technological University, Singapore*; **Young Jae Song**,* Sungkyunkwan University (SKKU), Republic of Korea

We present a novel approach to investigate the optical anisotropy of transition metal dichalcogenide (TMD) substrates using Mie scattering-induced surface analysis (MISA). By employing scattering-type scanning near-field optical microscopy (s-SNOM) and finite-difference time-domain (FDTD) simulations, we systematically studied and directly visualized the Mie scattering patterns of superspherical gold nanoparticles (s-AuNPs) at the nanoscale.

Our research revealed distinct differences in the optical properties of molybdenum disulfide (MoS2) and rhenium disulfide (ReS2) substrates. While MoS2 exhibited optical isotropy, ReS2 demonstrated significant anisotropic behavior, particularly in the near-infrared energy range. This anisotropy was manifested through more pronounced spectral and angular responses in the satellite peaks of Mie scattering patterns.

We observed that the distances between satellite peaks in the Mie scattering patterns varied with the incident angle of light for ReS2, but remained constant for MoS2. This angular dependence in ReS2 was consistently observed across different excitation energies, providing strong evidence of its inherent optical anisotropy.

Our findings highlight the potential of MISA as a powerful, non-destructive tool for probing the intrinsic dielectric properties of substrates at the nanoscale. This technique offers superior visualization of nanoscale anisotropies and enables a more nuanced approach to substrate characterization compared to traditional spectroscopic methods.

The insights gained from this study not only advance our understanding of light-matter interactions at the nanoscale but also have significant implications for the development of advanced nanophotonic devices and the field of optical metrology.

Keywords: superspherical-AuNP, scattering-type scanning near-field optical microscope, Mie scattering, anisotropy, substrate

11:40am NM2-WeM-12 Enhancement of Photocatalytic Water Splitting Upon Induced Structural Evolution and Increase of Phase Polarity of Two-Dimensional Covalent Organic Frameworks, *Jrjeng Ruan,* National Cheng Kung University (NCKU), Taiwan

The evolution of smectic liquid crystals of newly designed two-dimensional covalent organic frameworks (COFs) has been disclosed for the first time. With obtained changes of phase morphology, selected-area electron diffraction patterns, and Young's modulus via compressive testing, this smectic phase is realized to transfer to nematic phases upon the ph. changes of surrounding solutions. Furthermore, the coordination of selected metal ions for the preparation of M-COFs is also stimulated by conducted ph. changes, which is surprisingly found able to greatly adjust the out-of-plan phase polarity and thus the piezoelectric responses of evolved liquid crystals of synthesized M-COFs. The controlled adjustment of phase polarity has been clarified able to modify energy bandgap, enhance absorption of visible lights, and increase the efficiency of stimulated electron transition to metal active centers upon the absorption of visible lights. As a result, the coordination of metal ions and accompanied elevation of phase polarity significantly promote the photocatalytic water splitting via synthesized M-COF as photocatalysts. Hence, with the coordination of metal ions on evolved COF liquid crystals, this research has investigated the availability of various levels of phase polarity of M-COF liquid crystals, and comprehensively studies achievable impacts and contributions of phase polarity on photocatalytic water splitting.

Nano and 2D Materials
Room Naupaka Salon 1-3 - Session NM-WeP

Nano and 2D Materials Poster Session

NM-WeP-1 Introduction to Measurement Uncertainty Evaluation Method and Results of Silicon Nitride Thin Film Layer Thickness and Complex Dielectric Constant, *Yong Jai Cho, Won Chegal,* Korea Research Institute of Standards and Science, Republic of Korea

SE (Spectroscopic Ellipsometer) has excellent measurement resolution, but measurement quality control of SE requires careful attention because measurement uncertainty can be easily affected by small changes in the device. For SE measurement quality control, thin film layer thickness certified reference materials are mainly used. SE has the advantages of being non-destructive, ultra-fast, and non-contact, but also has excellent high-precision characteristics that can detect a single atomic layer even before it is completely grown, so demand is increasing as a core measurement equipment for the semiconductor device manufacturing process. As semiconductor device manufacturing technology has recently developed due to the complexity of semiconductor device structures, the introduction of atomic layer-level processes, and the introduction of new materials, there is a need to improve quality control of TTTM (Tool-To-Tool Matching) related to measurement uncertainty. Therefore, in order to improve the measurement quality control level of SE equipment for semiconductor processing, it is necessary to develop higher quality thin film layer thickness certified reference materials. As a first research step, our research team developed a unified uncertainty evaluation method for the measurands of various types of rotating-element spectroscopic ellipsometers with excellent real-time measurement performance[1]. This method allows the measurement uncertainty of ellipsometric transfer quantities (e.g. Psi and Delta) to be calculated directly from observed ellipsometric transfer quantities, so there is no need for the analysis results of unknown optical properties of the sample required to calculate the measurement uncertainty. As a second research step, we developed a method for assessing uncertainty in the values of unknown optical properties of the sample, obtained using a nonlinear least-squares fit from the spectra of the observed ellipsometric transfer quantities[2]. The implicit function theorem was adopted to describe the propagation of uncertainty for nonlinear least-squares calculations[3]. We would like to introduce the method and results of applying the developed uncertainty evaluation method to the uncertainty evaluation of the thin film layer thickness and complex dielectric constant of silicon nitride thin film sample obtained through SE.

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NM-WeP-2 A New Tool for Single Ion Implantation and Nanoscale Materials Engineering: System Design and Source Development, *Paul Blenkinsopp,* Ionoptika Ltd., UK*; Kate McHardy,* Ionoptika, Ltd., UK*; Gianfranco Aresta,* Ionoptika Ltd., UK

Quantum computing is the next great frontier of science. It has the potential to revolutionize many aspects of modern technology, including digital communications, "quantum-safe" cryptography, and incredibly accurate time measurements.

Single impurity atoms in semiconductors are receiving attention as potential quantum technologies, and proof-of-concept devices have shown promise. However, such devices are incredibly challenging to manufacture, as single atoms must be placed within ~ 20 nm of each other within a pure ^{28}Si matrix.

All working devices thus far have been fabricated using hydrogen lithography with an STM followed by atomic layer deposition. This is labour-intensive and requires several days of meticulous preparation to create just a single quantum bit (qubit). Real-world devices will require arrays of hundreds or thousands of impurity atoms, highlighting the requirement for a scalable method of positioning single atoms with nanometer precision.

We report on a new commercial instrument for the fabrication of quantum materials and devices via single ion implantation.

The instrument features a high-resolution mass-filtered focused ion beam (FIB), a high-sensitivity deterministic implantation system, 6-inch wafer handling, and a high-precision stage. The deterministic implantation system allows single ion implantation with confidence levels as high as 98%.

The ion dose delivered to the sample can be adjusted across a wide range, providing many nanoscale materials engineering capabilities in a single tool, from single ion implantation to direct-write capabilities such as isotopic enrichment and targeted ion-implantation of nanomaterials.

The liquid metal alloy ion sources, coupled with and mass filtered column will enable for the implantation of many different elements with isotopic resolution. Available sources include silicon, erbium, gold, and bismuth, while many others of technological interest are in development. We will report on the LMIG source development carried out at Ionoptika in collaboration with our partners.

NM-WeP-3 Graphene-Incorporated Dielectric Composites by Varying the Mixing Method and Degree of Oxidation of Graphene, *So-Yeon Jun, Kwangsin John Ahn, SeGi Yu,* Hankuk University of Foreign Studies, Republic of Korea

Graphene-incorporated dielectric composites by varying the mixing method and degree of oxidation of graphene

So-Yeon Jun, Kwangsin John Ahn, and SeGi Yu

Department of Physics, Hankuk University of Foreign Studies, Yongin 17035, Republic of Korea

To obtain high-performance dielectric properties of dielectric composites, graphene and barium titanate ($BaTiO_3$, BTO) fillers were mixed in the polymer matrix, by varying the degree of reduction of graphene and the mixing method. Two kinds of graphene materials, i.e., graphene oxide (GO) and reduced graphene oxide (rGO); and two kinds of mixing methods for graphene and BTO, i.e., encapsulation of BTO in graphene and subsequent mixing, and simple mixing of BTO and graphene in the polymer matrix. This yielded to four kinds of graphene-incorporated samples, which was compared with the reference sample, i.e., a sample with only BTO fillers in the polymer matrix without graphene. Encapsulation process was performed by the self-assembly of positively functionalized BTO and negatively functionalized GO. After the encapsulation, GO-encapsulated BTO fillers were chemically reduced to become rGO-encapsulated BTO fillers [1,2]. All the four graphene-incorporated samples exhibited better dielectric constant values, i.e., 1.5 to 2.2 times higher than the reference sample. It was thoughted to be caused by the presence of graphene via the interfacial polarization or micro-capacitor effects [1]. However, the increase in dielectric loss, which had frequently occurred for the simple mixing cases of conducting nano-fillers, was successfully suppressed for the encapsulated samples. Here, the dielectric loss was controlled under lower 20%, which was caused by removal of free graphene platelets during the chemical process of the encapsulation [2]. The best performance one is the encapsulation method for rGO material. The next one is GO encapsulation case. The highest enhancement of 120% in the dielectric constant and moderate dielectric loss was obtained for rGO-encapsulation case. Therefore, we can say that encapsulation of BTO in graphene is very promising mixing method for high-performance polymer-based dielectric composite materials.

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NM-WeP-4 Deep Learning-Based Prediction of Adsorption Energies for MoO_2Cl_2 Precursor on SiO_2 Surface Using Density Functional Theory, *Do-Hyun Kwon, Jeong-Myung Lee,* Korea University of Technology and Education, Republic of Korea*; Jason Kim,* Pohang University of Science and Technology (POSTECH), Republic of Korea*; Yeong-Cheol Kim,* Korea University of Technology and Education, Republic of Korea

A search for appropriate adsorption geometries of a MoO_2Cl_2 precursor on an -OH terminated β-SiO_2 surface was conducted using a deep-learning approach. The adsorption geometries were configured by translating and rotating the precursor located near the surface. A deep-learning model was developed to learn important properties of the adsorption geometries; the model consists of three main units to learn positional features of the precursor atoms, to learn distance features among the precursor and surface atoms, and to predict the corresponding adsorption energy. A dataset of adsorption geometry and the adsorption energy pairs was collected by grid search. Using this dataset, the model was trained to predict the adsorption energies with minimal error and optimized to achieve a root mean square error (RMSE) of less than 0.011%. Energetically more favorable adsorption geometries were found using the trained model.

By inputting arbitrary adsorption structures into the trained model and obtaining the predicted adsorption energies, recommendations for energetically stable adsorption structures were received. Through actual calculations, it was confirmed that the model could identify energetically stable adsorption structures that were not included in the dataset. The proposed method is applicable to finding appropriate adsorption geometries of other types of precursors and surfaces.

NM-WeP-5 Induced Self-Assembly of Small (3 - 5 nm) Nanoparticles Into Flexible Nanofilms at Air- and Oil-Water Interfaces, *Hannah Cameron, Yuwei Zhang, Kate Leslie, Bryn Scott, Isabel Curtis, Leah Gamble,* **M.-Vicki Meli,** Mount Allison University, Canada

Thin-film assemblies of gold nanoparticles (AuNPs) at the liquid interfaces have been an exciting research area over the past decade due to their promising applications in optics, sensors, shape-shifting and meta-materials, and catalysis. Autonomous self-assembly at such interfaces is an attractive method of synthesizing these superstructures, however this is a complex process that has proven to be difficult to control. Small AuNPs with core sizes <10 nm pose greater difficulties than larger AuNPs because they have a small free energy of adsorption that is comparable to their thermal energy. Therefore, there are few published examples of the self-assembly of such AuNPs at the liquid-liquid interface. The present research analyzes the effects of various experimental parameters on the adsorption of ~3 nm AuNPs to the oil–water interface, including ligand shell composition, alcohol additive structure and amount, oil phase composition and the phase of NP introduction. Film quality is qualitatively assessed and compared with a recent thermodynamic model to elucidate the primary driving forces of adsorption. Films with tunable optical density ranging from lightly coloured to gold and lustrous, are obtained with variation over a single parameter. Determining approaches that promote the adsorption of 3 nm AuNPs to an aqueous interface and furthering the understanding of its thermodynamic mechanism is necessary to gain precise control and to work towards the industrial use of such thin films.

NM-WeP-6 Molecular Structure and Vapor Pressure of Molybdenum Pentachloride Using Ab-Initio Thermodynamics, *Na-Young Lee,* Korea University of Technology and Educaiton, Republic of Korea*; Sun-Hye Kim, Jong-Yoon Kim,* **Yeong-Cheol Kim,** Korea University of Technology and Education, Republic of Korea

This study aims to elucidate the molecular structure and vapor pressure of molybdenum pentachloride in the gas phase using ab-initio thermodynamics. Molybdenum pentachloride can exist as $MoCl_5$ (monomer) and/or Mo_2Cl_{10} (dimer). The monomer is thermodynamically favored above 215 K, but Cl-Cl bond breakage is required to dissociate a dimer into two monomers. This suggests that the dimer is kinetically favorable even above 215 K, and the calculated dimer vapor pressure agrees well with the experimental data.

NM-WeP-7 Isotropic Atomic Layer Control of 2d Ws$_2$ Using Organic Solvent Vapor, **Hye Won Han**, *Ji Eun Kang, Ji Min Kim, Geun Young Yeom,* Sungkyunkwan University, Republic of Korea

Two-dimensional transition metal dichalcogenides (TMDs) exhibit diverse electronic and optoelectronic properties depending on their thickness, making precise layer control essential for their integration into advanced materials and devices. Atomic layer etching (ALE) techniques are crucial for achieving such precise thickness control and can be performed using either plasma or thermal methods. Previous studies have primarily focused on radical adsorption and ion desorption processes to enable anisotropic etching. However, with the evolution of device structures into three-dimensional configurations, isotropic etching has become increasingly important. In this study, we introduce isotropic thermal ALE of WS_2 using organic solvent vapors. The ALE process consists of the adsorption of reactive radicals generated by oxygen plasma, followed by exposure to organic solvent vapors for desorption. This approach not only enables isotropic etching but also allows for damage-free processing, offering a significant improvement over conventional etching techniques. Additionally, we compare the etching performance based on organic vapors' chemical structures and process temperatures, highlighting their differences in reactivity and volatility during the etching process. By providing precise layer control of WS_2, this study advances the integration of TMDs into next-generation material and device technologies, marking a significant advancement in the field of advanced materials research.

NM-WeP-8 Uniform Vertical Doping of TMDC Materials via *, Jimin Kim, Jieun Kang, Hyewon Han, Geunyoung Yeom,* Sungkyunkwan University, Republic of Korea

Two-dimensional (2D) semiconductors, with their electrical and optical properties varying depending on thickness, are gaining recognition as key materials for future semiconductor technologies. To improve the properties of 2D materials Researchers are focusing on precise thickness control, large-scale production, and doping techniques. Doping, in particular, is an effective technique for adjusting the electrical behavior of 2D semiconductors, but conventional doping methods like ion implantation often damage the delicate and thin 2D semiconductors. To address this problem, alternative surface treatments such as plasma-based radical adsorption, liquid solution spin coating, and immersion techniques have been explored [1]. However, these approaches primarily modify the surface and become less effective as the material's thickness increases. To overcome the challenge of achieving uniform vertical doping, this research introduces an innovative cyclic doping technique utilizing a specialized transfer process. This method enhances the consistency of doping across multiple layers while preserving the distinct layered structure of MoS_2. The cyclic doping technique presents a promising solution to current challenges in doping efficiency and uniformity, marking a significant advancement in the precise manipulation of 2D materials for semiconductor applications.

Thursday Morning, December 12, 2024

Nano and 2D Materials
Room Naupaka Salon 5 - Session NM1-ThM

Nanomaterials - Properties and Applications I
Moderator: Santosh KC, San Diego State University

8:40am NM1-ThM-3 Different Directions In Layered Materials, *Joshua Goldberger,* The Ohio State University   **INVITED**
Layered and 2D materials are currently one of the most well-studied classes of solid-state compounds, due to the plethora of unique physical phenomena found in these anisotropic materials. Here we will describe our recent work in the synthesis, properties, and applications of layered materials that exhibit either n-type or p-type conduction behavior depending on the crystallographic direction, a phenomenon we refer to as "goniopolarity". We will establish the origin of this exotic behavior and the band structure design principles for identifying new goniopolar materials.[1] This has led to a significant expansion in the number of compounds that we have experimentally demonstrated to exhibit this effect, such as $NaSn_2As_2$, $NaSnAs$, WSi_2 and $PdSe_2$.[2-5] Finally, considering that most modern electronic devices require the integration of p-type and n-type regions for functionality, we will show how the unique charge separation in goniopolar materials have the potential to create new efficient energy-harvesting and electronics technologies.

[1] Y. Wang; K. G. Koster; A. M. Ochs; M. R. Scudder; J. P. Heremans; W. Windl; J. E. Goldberger, *J. Am. Chem. Soc.* **142**, 2812-2822 (2020).

[2] B. He; Y. Wang; M. Q. Arguilla; N. D. Cultrara; M. R. Scudder; J. E. Goldberger; W. Windl; J. P. Heremans, *Nat. Mater.* **18**, 568-572 (2019).

[3] K. G. Koster; Z. Deng; C. E. Moore; J. P. Heremans; W. Windl; J. E. Goldberger, *Chemistry of Materials* **35**, 4228-4234 (2023).

[4] R. A. Nelson; Z. Deng; A. M. Ochs; K. G. Koster; C. T. Irvine; J. P. Heremans; W. Windl; J. E. Goldberger, *Mater. Horiz.* **10**, 3740-3748 (2023).

[5] A. M. Ochs; P. Gorai; Y. Wang; M. R. Scudder; K. Koster; C. E. Moore; V. Stevanovic; J. P. Heremans; W. Windl; E. S. Toberer; J. E. Goldberger, *Chem. Mater.* **33**, 946-951 (2021).

9:20am NM1-ThM-5 Evaluation of Vapor Pressure of MoO_2Cl_2 and Its Initial Chemical Reaction on a SiO_2 Surface by Ab Initio Thermodynamics, *Hyun-Kyu Kim, Na-Young Lee, Yeong-Cheol Kim,* Korea University of Technology and Education, Republic of Korea
The vapor pressure of MoO_2Cl_2 and its initial chemical reaction on a SiO_2 surface were evaluated and analyzed using *ab initio* thermodynamics. The vapor pressure of MoO_2Cl_2 was calculated using the Gibbs free energy, while considering the zero-point energy, temperature-dependent enthalpy change, and entropy. The initial surface reaction was also studied as a function of temperature and partial pressure. The calculated sublimation temperature of MoO_2Cl_2 was 410 K, and its vapor pressure at 350 K was 8.2 torr. The partial pressure calculated for MoO_2Cl_2 agreed reasonably well with the experimentally measured value. The surface reaction energy barrier between MoO_2Cl_2 and SiO_2 was 0.8 eV.

9:40am NM1-ThM-6 Development of TiAl Alloys: A Future Light-Weight Material for Extreme Condition, *Seong-Woong Kim,* Korea Institute of Materials Science, Republic of Korea
Research on developing new TiAl alloys for high temperature (> 900°C) applications is introduced. TiAl alloys have been gained interest for automobile and aerospace applications due to their low density, good oxidation resistance and high temperature strength. However, lack of room temperature ductility and the limitation of operating temperature hindered the practical applications of TiAl alloys. At KIMS, we have developed new TiAl alloys which have excellent room temperature and high temperature properties. Expecially, the alloy #16 showed excellent oxidation resistance in the temperature range from 900 to 1000°C by forming stable Al_2O_3 oxidation layer. Moreover, alloy #16 exhibit room temperature ductility up to 0.78% solely by casting.

In addition, we introduced some in-situ transmission electron microscopy experiments in order to understand an underlying mechanism on room temperature ductility of TiAl alloys. Also, molecular dynamics simulation was conducted to calculate the stacking fault energy of TiAl alloys and to show which deformation mode is dominant. The difference in deformation mode was explained by stacking fault energy of the TiAl alloys which was calculated by molecular dynamics. Furthermore, the role of lamellar orientation of tensile direction on deformation behavior was examined using Schmid factor of each orientation. Finally, we proposed the important microstructural factors to have room temperature ductility of TiAl alloys.

Nano and 2D Materials
Room Naupaka Salon 5 - Session NM2-ThM

Nanomaterials - Properties and Applications II
Moderator: Yu-Chuan Lin, National Yang Ming Chiao Tung University (NYCU)

10:20am NM2-ThM-8 2D Metal Carbides (MXenes) for Catalysis, *Yue Wu,* Iowa State University
MXenes, a new group of 2D transition metal carbides, are of considerable interest in catalysis due to their rich surface chemistry, tunable electronic structures, and thermal stability. In this presentation, we will discuss our latest discovery on utilization of metal-support interactions between noble metal and 2D metal carbides to enhance the catalytic reactions, such as alkane dehydrogenation, methane coupling, and electrochemical catalytic reactions. In addition, the nature of active sites in the MXene-based catalysts will be discussed.

10:40am NM2-ThM-9 Investigating 2D-Materials Using Correlative Spectroscopy & Microscopy, *James Lallo, Lu Ping, Tim Nunney, Paul Mack, Robin Simpson, Hsiang-Han Tseng,* Thermo Fisher Scientific
Across a wide range of application areas, understanding the chemistry and structure of surfaces and interfaces is crucial. In the last fifty years, X-ray photoelectron spectroscopy (XPS) has become established as a one of the key techniques for measuring surface and interface chemistry, and advances in instrumentation have enabled it to keep pace with the requirements for both academia and industry. XPS can deliver quantified surface chemistry measurements, and by using depth profiling, an understanding of layer and interfacial chemistry, but the limit on spatial resolution for XPS can prevent it from determining how the surface structure is related to the measured chemical properties. For example, how the changing morphology of the surface during a depth profile could influence the measured composition would be challenging to determine using just XPS.

Other experimental techniques which are unable to match the surface selectivity of XPS are able to provide complementary information to extend the data from XPS. Electron microscopy can provide high resolution imaging, with elemental composition provided by energy dispersive X-ray microanalysis, but without the same surface selectivity seen with XPS or Auger electron spectroscopy (AES). This can be a perfect complement to XPS analysis, so long as the same points of interest can be identified. Molecular spectroscopy, such as FTIR or Raman, can also provide complementary information to XPS, albeit with different sampling depths, which can be extremely useful to validate measurements or confirm particular molecular structures using the wide range of spectral libraries available for those techniques.

In this presentation, we will describe how a correlative approach using both surface analysis instrumentation and scanning electron microscopy can be used to characterize 2D nanomaterials. Samples of MoS_2 grown on Si substrates have been investigated using XPS, Raman and SEM to determine their composition and structure. To facilitate co-alignment of the analysis positions when moving between the instruments, special sample carriers and software alignment routines have been developed.

11:00am NM2-ThM-10 Electronic, and Optical Properties of 2D Metal Chalcogenophosphates, *Hung Chiu, Santosh KC,* San Diego State University
Recently, there have been significant research activities on two-dimensional (2D) materials for their potential use in electronic and optical devices. The structure, electronic, and optical properties of 2D metal chalcogenophosphates are investigated based on the Density Functional Theory. The lattice dynamics, surface, and interface properties with metal and oxides are investigated. Moreover, the electronic properties are tuned with substitutional impurities for metals and chalcogens. Our results indicate that the electronic and optical properties of metal chalcogenophosphates exhibit them as an emerging candidate material for devices.

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