Nano and 2D Materials

Room Naupaka Salon 4 - Session NM1-TuE

Synthesis and Manipulation

Moderator: Sarah Burke, University of British Columbia

6:20pm **NM1-TuE-3 On-Surface Formation of One-Atom Thick Carbon-Based Low-Dimensional (1D/2D) Nanomaterials: A Surface and Nanoscale Science Approach***, Maryam Ebrahimi,* Lakehead University, Canada

The second quantum revolution encompasses novel approaches to manipulate matter at the quantum level which is determined by their design, chemical building units, and lattice symmetry. Low-dimensional nanomaterials including zero-, one-, and two-dimensional (0D/1D/2D) materials have revolutionized the world of materials over the past two decades. On-surface synthesis approach offers a bottom-up platform for the discovery, creating, and the manipulation of carbon-based 1D/2D quantum materials with stable quantum states. Our group works on the rational design and formation of ordered 1D/2D carbon-based nanomaterials with one-atom thickness on single crystalline surfaces. These materials include 2D covalent organic frameworks (2D-COFs), 2D metal-organic frameworks (2D-MOFs), 1D/2D polymers, and 2D self-assembled molecular networks, with different lattice symmetry. We employ the state-of-the-art tools of surface and nanoscale science and technology including scanning tunneling microscopy and spectroscopy, atomic force microscopy, and surface characterization spectroscopy techniques to unveil the structural properties of these nanomaterials. The lattice symmetry of 1D/2D networks together with the chemical nature of their building units determine their electronic band structure and properties, promising for quantum technology and organic electronic applications.In this talk, I will review our recent1-7 and current research on the formation of several 1D/2D molecular-based nanomaterials with different lattice symmetry. I will present the role of molecular symmetry, functional groups, and surfaces, in the formation of molecular self-assembly, metal-organic frameworks, and covalent networks. These ordered nanomaterials are formed and characterized in-situ, on Au(111), Ag(111), Cu(111) under ultra-high vacuum, or at solid-liquid interface on HOPG and Au(111)/mica. In addition to the nanoscale science experimental techniques, we use ab-initio theoretical calculations to provide simulated models for the chemical phenomena, reaction pathways, molecular structure, and electronic properties of these 1D/2D low-dimensional materials. 1 N. Cao et al., Nanoscale, 2021, 13, 19884-198892 G. Galeotti et al., Nature Materials, 2020, 19, 874-8803 G. Galeotti et al., Chemical Science, 2019, 10, 5167-51754 F. De Marchi et al., Nanoscale, 2018, 10, 16721-167295 D. Cui et al., Journal of the American Chemical Society, 2017, 139, 16732-167406 M. Ebrahimi, Nature Chemistry, 2022, 14, 3-47 C. Jing et al., Angewandte Chemie International Edition, 2019, 58, 18948-18956

6:40pm **NM1-TuE-4 Synthesis of Uniform Borophene: In Situ Spectroscopic Analysis and Ex Situ Macroscopic Transfer***, Marko Kralj, S. Kamal, B. Radatovic, V. Jadrisko, D. Novko, N. Vujicic, M. 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 χ6 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:

[1] ACS Appl. Mater. Interfaces 14 (2022) 21727–21737

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

7:00pm **NM1-TuE-5 Fabrication of Advanced Nano and 2D Material Devices - Utilizing the Next Generation NanoFrazor Capabilities***, Nicholas Hendricks, E. Çağin,* Heidelberg Instruments Nano AG, Switzerland

Nano and 2D materials are of intense research interest by both academic and industrial communities as these materials provide great promise for next generation electronic devices and various other applications. When fabricating such devices, patterning the electrical contacts with conventional fabrication techniques (electron beam lithography (EBL), photolithography, focused-ion beam (FIB) lithography) becomes challenging and time consuming due to overlay requirements. The use of energetic particles, such as electrons, photons, or ions, can also lead to less than desired device performance due to damage from the charged particles or ultraviolet irradiation as well as contamination from residual resist. The time intensive processing often comes from the random positioning of nanomaterials or 2D flakes on substrates which makes locating such materials and overlaying the intended patterns challenging.

To confront these challenges, thermal scanning probe lithography (t-SPL), enabled by the NanoFrazor, is offering an alternative direct-write nanolithography method that utilizes thermal energy to perform the patterning process [1-4]. t-SPL generates patterns by scanning an ultrasharp tip over a sample surface to induce local changes with a thermal stimulus. By using thermal energy as the stimulus, it is possible to perform various modifications to the sample via removal, conversion, or addition of/to the sample surface. Along with an ultrasharp tip, the t-SPL cantilever contains several other important functions such as an integrated thermal height sensor and an integrated heating element. To complement the nanopatterning capabilities of t-SPL, the NanoFrazor has a direct laser sublimation (DLS) module to pattern larger (>500nm) features such as electrical traces and contact pads. With nano and microlithography capabilities in a single tool, the NanoFrazor provides the resolutions needed for complete device fabrication, which is interesting for nanoelectronics, photonics, molecular sensing, and quantum computing applications.

In this presentation, the background and workings of t-SPL will be introduced along with the fabrication and electrical performance of nanowire and 2D transition metal dichalcogenide (TMD) devices. To complete the presentation, the next generation NanoFrazor capabilities in parallelized large area patterning and automation of user operations will be shown.

1. S. Howell et al., Microsystems & Nanoengineering, 6, 21 (2020)
2. Talha-Dean et al., ACS Applied Materials & Interfaces, 16, 31738 (2024)
3. B. Erbas et al., Microsystems & Nanoengineering, 10, 28 (2024)
4. L. Shani et al., Nanotechnology, 35, 255302 (2024)

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