Nanoscale Science and Technology
Room Ballroom BC - Session NS-ThP
Nanoscale Science and Technology Poster Session

NS-ThP-1 Single and Dual Sintering Techniques on Flexible Metal Nanoparticle Patterns*, **Md. Mahfujur Rahman**, Rajib Chowdhury, Seonhee Jang,* University of Louisiana

The application of metallic nanoparticle (NP) inks has become the center of developing flexible printed electronic devices such as solar cells, displays, wearables, and sensors. The approach of defining the mechanical, electrical, and material properties of printed patterns depends on the type of metallic NPs. The most utilized NPs are silver (Ag), gold (Au), and copper (Cu). Ag NPs are highly considered for their excellent electrical conductivity and resistance to oxidation. On the other hand, Cu NPs are highly preferred because of their affordability to Ag NPs, yet they are highly prone to oxidation. During printing of metallic NP inks for conductive patterns, a lack of electrical conductivity in the patterns is observed because of induced organic additives and stabilizing agents. Consequently, sintering is essential for removing these organic residues and enhancing the conductivity of the printed patterns.

This study focuses on utilizing two metallic inks of Ag NP ink (PSI-211, NovaCentrix) and Cu NP ink (CP-008, NovaCentrix) to fabricate the conductive patterns on flexible polyimide (PI) sheets. Either single or dual sintering processes were conducted to optimize the electrical conductivity. For the single sintering process, the printed metal NP patterns were subjected to either laser irradiation (LO) or thermal treatment (TO). During the LO sintering process, the Ag and Cu NPs underwent Nd:YAG laser irradiation at 600 and 800 mJ for 15 and 30 s, respectively. For the TO sintering process, Ag and Cu NPs were introduced in a formic acid (FA) vapor environment at 140 and 260 °C for 1.5 and 15 min, respectively. The dual sintering method involved thermal treatment followed by laser irradiation (TL) and laser irradiation followed by thermal treatment (LT).

After sintering, a microstructural analysis was conducted using scanning electron microscopy. The analysis confirmed that the LT condition for sintering of the Ag NP pattern showed improved particle agglomeration and necking. Atomic force microscopy (AFM) analysis revealed the highest roughness of 48 nm, indicating superior grain growth. With a resistance ratio (R/R_0) of 1.75 during the folding test, the Ag NP pattern sintered using the LT condition showed the lowest electrical sheet resistance. Through agglomeration and coalescence during sintering, the Cu NP pattern sintered with the TO condition displayed the most uniform grain growth. The Cu NP pattern sintered under the TO condition had the highest mechanical Vickers hardness of 55.36 N/mm^2 because of the improved connection between the NPs. Additionally, the Cu NP pattern showed the highest roughness value of 51.36 nm.

NS-ThP-2 Impacts of Hydrogen Adsorption on Carbon Nanotube–Metal Schottky Contacts*, Chuntian Huang, Nini Ye, Haijun Luo, Hezhu Shao, **Changkun Dong**,* Wenzhou University, China

Carbon nanotube (CNT)–metal Schottky contacts are widely employed in different types of electronic devices, including field effect transistors (FET) and gas sensors. CNTs are normally considered stable on electronic properties with gas adsorptions. In this work, performance changes of the multi-walled carbon nanotube (MWCNT)–metal junctions related to hydrogen adsorptions were illustrated. MWCNT/Pd and MWCNT/Au Schottky junctions based resistive sensors were constructed to investigate the low-pressure gas sensing performances for hydrogen in the range of 1e−7 to 1e−3 Pa. Two types of sensors presented opposite behaviors with hydrogen adsorptions, i.e., the sensor resistance rose for the MWCNT/Pd sensor but dropped for the MWCNT/Au sensor with increasing hydrogen pressure. The work function reductions of Pd and CNT are considered the key cause, which could change the Schottky barrier properties dramatically.

Such effects were investigated by the first-principles calculations. The work functions of Pd and MWCNT tend to decrease with the dissociated hydrogen adsorptions, while the electronic properties of Au remain constant. The work function of the Pd-CNT Schottky junction drops with hydrogen adsorptions on either CNT or Pd according to the analysis of the density of states (DOS) and charge density difference. It is expected that electrons transfer from Pd of lower work function to CNT after the H adsorption, leading to the resistance increase of the Schottky junction for the p-type MWCNTs. On the other side, the resistance of the Au-CNT Schottky junction would decrease for the electron transformation from CNT to Au. The results are consistent with the experimental investigation and provide important reference significance for applications of metal-CNT junctions.

NS-ThP-3 The Nanoscale Materials Characterization Facility (NMCF) at the University of Virginia*, **Catherine Dukes**, Diane Dickie, Graham Frazier, Helge Heinrich, Art Lichtenberger, Joe Thompson, Richard White,* University of Virginia

The **Nanoscale Materials Characterization Facility** and **Innovations in Fabrication** clean-room microfabrication/biomanufacturing facility are advanced user facilities within UVa's School of Engineering and Applied Science. Our instruments are available for researchers from academic and industrial institutions on a pay-for-time basis. We provide comprehensive services in materials preparation and processing, as well as a suite of advanced analytical techniques. Researchers are welcome to (1) visit the **NMCF** for collaborative sample science or (2) send specimens for remote analyses by one of five expert instrument scientists, ensuring personalized guidance and optimized results.

We operate two transmission electron microscopes: a 200kV Talos system and a 300 kV Themis with probe correction for sub-Å resolution and monochromated EELS. Both offer EDS for compositional analysis and mapping, as well as sample holders for in-situ cooling, heating, biasing, liquid-cell and gas-cell experiments. A Helios dual-beam FIB-SEM is used for surface, cross-sectional, and 3D imaging, EDS analysis, orientation mapping with electron-backscatter diffraction and TEM sample preparation. Additionally, two standalone scanning electron microscopes are available: a Quanta 650 FE-SEM with EDS and EBSD, and a Phenom XLG2 environmental SEM for electron imaging and EDS.

Four X-ray powder diffraction systems are available for analyzing bulk composition and phase orientation, with specialized stages for in situ heating and X-ray reflectivity. An X-ray fluorescence spectrometer provides highly sensitive elemental analysis for Z > 10. The facility also features an integrated Renishaw Raman spectrometer/Bruker AFM system for molecular identification, surface chemistry, and nano-scale topography, along with a Invenio-S FTIR for chemical fingerprinting and organic material identification.

For quantitative surface composition and chemistry, two X-ray photoelectron spectrometers are available: a Versaprobe III small-spot instrument with ion gun for depth profiling, hot-cold stage, and processing chamber; and a HiPP-Lab ambient-pressure XPS with *in-situ* high-temp liquid cell, plasma processing, glove box, sample prep chamber and gas reaction cell. Optical instrumentation includes a white-light profilometer for surface metrology, and a digital light microscope for 2D/3D imaging and videography.

A complete suite of metallurgical equipment for cutting, mounting, polishing, sputter coating, etching, and plasma cleaning, as well as Rockwell and Vickers hardness testing, is also available.

Contact: https://engineering.virginia.edu/NMCF

NS-ThP-4 Exciton-Polariton Devices from Two-Dimensional Chalcogenide Semiconductors*, **Deep Jariwala**[1],* University of Pennsylvania

The isolation of stable atomically thin two-dimensional (2D) materials on arbitrary substrates has led to a revolution in solid state physics and semiconductor device research over the past decade. A variety of other 2D materials (including semiconductors) with varying properties have been isolated raising the prospects for devices assembled by van der Waals forces. Particularly, these van der Waals bonded semiconductors exhibit strong excitonic resonances and large optical dielectric constants as compared to bulk 3D semiconductors..

First, I will focus on the subject of strong light-matter coupling in excitonic 2D semiconductors, namely chalcogenides of Mo and W. Visible spectrum band-gaps with strong excitonic absorption makes transition metal dichalcogenides (TMDCs) of molybdenum and tungsten as attractive candidates for investigating strong light-matter interaction formation of hybrid states. We will present our recent work on the light trapping in multi-layer TMDCs when coupled to reflective substrates. Next, I will show the extension of these results to superlattices of excitonic chalcogenides, multilayer halide perovskites as well as metal organic chalcogenolates. These hybrid multilayers and materials offer a unique opportunity to tailor the light-dispersion in the strong to ultra-strong coupling regime. Finally, if time permits, I will discuss the physics of strong light-matter coupling and

[1] **JVST Highlighted Poster**

it's applications in phase modulator devices, photovoltaic devices as well as control of light in magnetic semiconductors.

NS-ThP-5 Scalable Photonics with Low-Dimensional Superlattices, ***Jason Lynch**, Deep Jariwala,* University of Pennsylvania

Superlattices of III-V semiconductors have long been used in state-of-the-art photodetectors, light emitting diodes, and lasers while plasmonic superlattices promise to surpass the diffraction limit of light and confine light on the nanometer scale. However, both cases typically use three-dimensional media which do not leverage the advantages of improved electro-optical properties, flexibility, and stability found in low-dimensional media. Recent research has demonstrated superlattices with monolayer semiconductors, but they normally use exfoliated flakes which limit their lateral areas to several square microns. As the growth of large-area, low-dimensional materials becomes more common, integrating low-dimensional media into superlattices promises to improve the performance of commercially available photonic devices. In this poster, we highlight two of our recent works that use 2D layers to improve the tunability and stability of centimeter-scale superlattices. First, we stack monolayer transition metal dichalcogenides (TMDCs) into a superlattice to increase the light-matter interaction strength without sacrificing their ideal monolayer properties. By electrostatically doping the TMDC layers, the system is actively modulated between the strong and weak coupling regime of exciton-polaritons which drastically alters reflected light. Using spectroscopic ellipsometry, the TMDC superlattice is observed to produce a full 2π phase shift in the reflected light. Second, we improve the thermal stability in a TiN-dielectric hyperbolic superlattice by replacing the three-dimensional Al_2O_3 with two-dimensional hBN. The new mixed-dimensional interface prevents atoms from diffusing across the TiN-hBN interface. This results in the superlattice maintaining its stratified geometry upon annealing at high temperatures (800 °C) for at least 10 hours. Both works study centimeter-scale superlattices whose fabrication techniques (wet-transfer and sputtering) can be implemented commercially. Therefore, our work promises to bring the improved qualities of low-dimensional media to practical, large-area photonic systems.

NS-ThP-6 Optical Readout Approaches for Photonic Thermometry, ***Kevin Douglass**, Michal Chojnacky, Thinh Bui, CH S S PAVAN Kumar, Nikolai Klimov,* National Institute of Standards & Technology

NIST is developing a fully packaged photonic-based temperature sensor with the aim of replacing resistance-based thermometry.One of the major deliverables of our photonic thermometry project is creating readout methodologies tailored to the measurement need from highest accuracy metrology applications to real world temperature sensing with fit-for-purpose accuracy in a robust deployable system.Over the past year we have developed and tested various photonic readout strategies to achieve these various goals. These approaches will be described in detail with supporting data to compare their respective advantages and disadvantages.

NS-ThP-7 A Comprehensive Investigation of Raman Laser-Induced Structural Modification in CVD-Grown Monolayer MoS_2, ***Sieun Jang**, Seonha Park, Songkil Kim,* Pusan National University, Republic of Korea

Molybdenum disulfide (MoS_2) has been extensively explored to be utilized as an electronic material in a variety of device applications. In particular, the tunability of MoS_2 enhances its electrical properties making it an intriguing candidate for field-effect transistors (FETs), while also extending beyond electrical properties to structural phase engineering. Raman laser irradiation offers a straightforward method to induce modifications via thermal processes without the intervention of other chemical substances. However, most studies on the modification of MoS_2 have focused on multi-layered structures or have been conducted under low-power laser conditions, leaving the feasibility of phase transition in monolayer MoS_2 elusive. In this study, we fundamentally elucidated the effects of high-power Raman laser irradiation on the surface of chemical vapor deposition (CVD)-grown monolayer MoS_2 under ambient conditions and uncovered the underlying mechanisms of laser-induced modifications by applying intense photon energy with highly interactive reactions. Our results revealed both etching and deposition phenomena in two discernible regions, and it can be demonstrated by intensity threshold based on the spatial distribution of laser irradiance within the laser spot. Furthermore, phase transition was found to be inhibited due to the promoted oxidation and the deposition of hydrogenated amorphous carbon, and p-type doping was observed, likely occurring in the region beneath the hydrogenated amorphous carbon deposition as substitutional doping on the 2H phase of MoS_2. To compare the thermal effects, MoS_2 modifications were further analyzed using simplified heat transfer estimations. These findings deepen our understanding of how Raman laser irradiation modifies MoS_2 under ambient conditions, providing guidelines for optimizing its modification processes.

NS-ThP-8 Reconstructing the Cross-Sectional Form Factor in Nanoscale Line Gratings via Critical-Dimension SAXS, ***Philipp Wieser**,* Center for Functional Nanomaterials, BNL, Austria; *Kevin Yager,* Center for Functional Nanomaterials, BNL, Canada

As technology nodes shrink toward single-digit nanometer dimensions, non-destructive shape metrology with sub-nanometer precision becomes increasingly important. Here, we present improvements to critical-dimension small-angle x-ray scattering (CD-SAXS) methods as metrology for line gratings patterned by electron-beam and extreme-ultraviolet (EUV) lithography. We introduce a rounded-trapezoid model to capture realistic cross-sections of lithographic patterns, especially in the developed resist. We further address a fundamental limitation of CD-SAXS: the sparse sampling of reciprocal-space due to the concentration of scattering into sharp grating peaks. To overcome this limit, we explore the concept of engineering the grating repeat (structure factor), to more faithfully reconstruct the pattern's shape (form factor). We explore three complementary strategies: (i) systematically varying the fundamental pitch, (ii) embedding multiple pitches in designed supercells, and (iii) introducing controlled aperiodic disorder. The resulting ensemble of SAXS patterns yields a more complete description of the cross section and enables to include statistical variability of the cross section directly into the model calculations.

NS-ThP-9 Phase Retrieved Atomic Structure of Nanoparticles by Using 4D STEM, ***Chien-Nan Hsiao**,* National Center for Instrumentation Research, National Institutes of Applied Research, Taiwan; *Yu-Ting Peng,* Department of Engineering and System Science, National Tsing Hua University, Taiwan; *Wen-Hao Cho, Wei-Chun Chen, Su-Chun HSIAO,* National Center for Instrumentation Research, National Institutes of Applied Research, Taiwan; *Chien-Chun Chen,* Department of Engineering and System Science, National Tsing Hua University, Taiwan

Atomic resolution microstructure of Au-Pd nanoparticles is characterized by a 4D STEM (scanning transmission electron microscopy). A defocused electron probe is raster-scanned across the specimen atom by atom, with one electron diffraction pattern recorded at each probe position in real-space by a pixelated array detector in reciprocal-space. The acquisition parameters of electron ptychographic experiments were optimal design, such as the electron probe semi-angle, real- and reciprocal space sampling, exposure time and field of view. It is found that the high dynamical range of the detector collection capacity ensures that scattered electron information is complete preserved, which enhances the S/N ratio of convergent beam electron diffraction (CBED) patterns. In addition, the phase image of object and electron probe are retrieval by an algorithm, the resolution of phase retrieved image is approaching to 0.59 Å. Moreover, the simultaneously atomic morphology is mapped by center of mass (COM) analysis differential phase contrast (DPC) technique.

NS-ThP-10 AFM Measurements of Nanoscale Changes on CHO Cell Surface Induced by Met Receptor Activation, ***Kenta Sawada**, Keisuke Miyazawa, Takehiko Ichikawa, Makiko Kudo, Katsuya Sakai,* Kanazawa University, Japan; *Hiroki Sato,* Yokohama City University, Japan; *Kunio Matsumoto, Takeshi Fukuma,* Kanazawa University, Japan

Cell migration and proliferation involve cell surface changes induced by signal transduction via cell membrane proteins. However, detailed mechanisms of these processes have not been fully understood. Atomic force microscopy (AFM) can visualize cell surface changes in liquids and hence has been applied to the studies in drug discovery and medical research by visualizing cell surface changes induced by biological and pharmaceutical molecules. However, practical applications and measurement examples remain limited. In this research, we investigated signal transduction mediated by cell membrane receptor called Met. Cell migration and proliferation are known to be promoted by Met. However, cell surface changes during these processes remain unclear. Thus, we investigated structural changes of the cell surface induced by Met activation by AFM. In this research, we used Chinese Hamster Ovary (CHO) cells. Two cell lines were cultured on plastic dishes: cells not expressing Met (Met-KO) and cells overexpressing Met (Met-in). AFM measurements were performed using NanoWizard 4 (Bruker) in L-15 medium (Fig. 1a). Figure 1b(i) shows AFM image of the Met-in cell surface. In this image, protrusions and fibers are observed as indicated by the arrows in Fig. 1b(i), which are probably microvillus (blue arrows) and F-actins (green arrows), respectively. Thus, in this study, surface areas of microvilli in the AFM images of the Met-

KO and Met-in cells were estimated by extracting areas higher than a threshold value (Fig. 1b(ii)). The result reveals that the Met-in cells show larger surface area of microvillus than Met-KO cells (Fig. 1c). These results suggest that Met activation promotes F-actin formations through subsequent signal transduction, which increases the number of microvilli on the cell surface. This is consistent with the previous report confirming the cell motility enhancement caused by the Met activation. Meanwhile, the spatial resolution of a typical AFM in living cell measurements is not sufficient to visualize molecular-scale distributions or structural changes of Mets on the cell surface. Thus, technical improvements of AFM measurements such as suppressing cell surface fluctuations and increasing measurement speed are required. Thus, we have recently developed techniques aiming for molecular-scale AFM measurements at cell surfaces. In this presentation, we introduce measurement examples using not only a typical AFM method but also our recently developed AFM technique. Such advancements in AFM technology should enable direct visualization of various structural changes of the cell surface and investigation of the mechanisms of cellular functions.

NS-ThP-11 Manufacture of Liquid Metal Alloy Ion Source Tin-Lead for Advancement of Ion Beam Technologies and Applications,
Bryan Flores, *Alex Andrei Belianinov, Michael Titze, Shei Sia Su, Coleman Burdette Cariker,* Sandia National Laboratories; *Ricardo Dacosta,* University of California - Riverside

Focused Ion Beam (FIB) Technology has significantly advanced in capability and performance over the past decades. FIBs in today's research play vital roles in material analysis, imaging, device fabrication, life sciences, and medicine – all at the nano-scale. Initially, Gallium (Ga) was the only available FIB ion source while other elements were largely unavailable. The low melting point of Ga (T_m = 29.6ºC) in addition to the emitted ionic species being 99% majority singularly charged (Ga^+) gave Ga the early advantage over other FIB source technologies. However, the advent of Wien-filter (ExB mass filter) FIBs to separate distinct ion species, in combination with eutectic Liquid Metal Alloy Ion Sources (LMAIS) has vastly increased the library of ion species generated in FIBs enabling nanoscale fabrication and analysis. Ion species with various charge states and with multiple elements can all be emitted from a single LMAIS. With assistance of a Wien filter the desired ion species can be selected from a mass spectrum. Here we detail the creation and characterization of a eutectic Tin-Lead (SnPb) LMAIS through its appropriate IV curves, mass spectrum, and spot size. We expect future applications in nano-scale and/or quantum research and applications such as solid-state quantum emitters or Group-IV color centers in Diamond (SnV^-).

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NS-ThP-12 Characterization of GAA FETs using Noise Spectroscopy after Displacement Damage,
Ricardo Dacosta, *Coleman Cariker, Bryan Flores, Shei Sia Su, Alex Belianinov, Michael Titze,* Sandia National Laboratories, USA

Gate-all-around (GAA) field effect transistors (FETs) have been announced as the next generation of transistors by all major integrated device manufactures. GAA FETs are targeted for logic nodes with sub 3nm size and are projected to operate at ultralow voltages (<0.7 V) and high performance (>4 GHz). By having the gate fully surround the channel GAA FETs isolate the sensitive channel regions of the device from the silicon substrate. This device architecture is expected to make GAA FETs behave like radiation-hard-by-design silicon-on-insulators (SOI) devices by significantly improving the dose-rate upset (DRU) response at similar total ionizing dose (TID) compared to conventional FETs.

Despite GAA NSFETs being expected to be radiation hard against DRU, the full effect of radiation damage on these devices is complex. GAA FETs are much smaller than current state of the art FETs which is an advantage as it allows for scaling device density. Due to this reduction in size each individual device has a much lower chance of being damaged via radiation. However, displacement damage (DD) and subsequent damage cascades have a much larger effect on a singular device, damaging a relatively larger region of devices. Statistical models and experimental data indicate that single ion collision events lead to an increase in subthreshold leakage current. Additionally, high damage levels show a significant reduction on forward current, which can permanently disable devices. Devices are predicted to become increasingly more vulnerable to such damage as they become smaller.

Noise spectroscopy can help illuminate the underlying defects responsible for device degradation in a DD environment. Preliminary noise spectra data show after sufficient irradiation (~2.6e13 ions/cm2) these devices exhibit a significant increase in low frequency noise. Further analysis shows gate-drain tunneling as a source of subthreshold leakage current, with source-drain tunneling increasing with more radiation fluence. In this poster we will explore the effects of DD via irradiation on GAA FETs using noise spectroscopy.

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Author Index

Bold page numbers indicate presenter