

## Nanostructure Synthesis and Fabrication Room Event Hall - Session NS-MoP

### Nanostructure Synthesis and Fabrication Poster Session

#### NS-MoP-1 Structural Modifications of Porous Templates with PbTe ALD Coatings, *Haifeng Cong, Helmut Baumgart*, Old Dominion University

Porous silicon templates have attracted increasing attention because of their controllable geometry, tunable nanoporous structure, large pore volume/high specific surface area, and versatile surface chemistry. Porous templates show significant advantages and application potential in microfluidics, electro-osmotic pumps, biomedical drug delivery, sensing, photonics, integrated opto-electronics, energy conversion, thermoelectrics, thermo-acoustics, electronics and Lab-on-a-chip technology for biomedical, pharmaceutical and environmental monitoring. For this study we have focused on energy conversion with ALD lead chalcogenide PbTe film coatings since PbTe is a useful narrow band gap thermoelectric material that can operate at comparatively higher temperatures in the range of 600~850 K due to its better chemical stability and high melting point. PbTe thin films have been synthesized inside of porous silicon templates with native oxide by Atomic Layer Deposition (ALD) using lead (II)bis(2,2,6,6-tetramethyl-3,5-heptanedionato) ( $\text{Pb}(\text{C}_{11}\text{H}_{19}\text{O}_2)_2$ ), (trimethylsilyl) tellurium ( $(\text{Me}_3\text{Si})_2\text{Te}$ ) as ALD precursors for lead, and tellurium. The Si native oxide surface was functionalized before ALD PbTe thin film deposition to ensure reproducible chemisorption of the ALD precursor compounds. The growth temperature during ALD was varied over a range from 135°C to 170°C. The lead precursor was volatilized at a temperature of 140 °C and the Tellurium precursor was heated at 40 °C. The chamber base pressure was kept at 40 mTorr. Several physical characterization techniques have been employed to determine the ALD PbTe thin film characteristics. The crystal structure and phase purity of samples of PbTe films were analyzed by X-ray diffraction (XRD). The film morphology and structure of the products were determined by field emission scanning electron microscopy (FE-SEM) and high-resolution transmission electron microscopy (HR-TEM). The surface roughness was analyzed by atomic force microscopy (AFM). The analysis of the composition and stoichiometry of the ALD coatings were carried out by Energy dispersive X-ray spectroscopy (EDS). The experimental evidence revealed the ALD growth of lead telluride followed the Vollmer-Weber Island growth model. We found a strong dependence of the nucleation process of the polycrystalline grain distribution on the temperature. We report a systematic study of all ALD parameters required to optimize the coating of the interior walls of porous membranes which open front and backside, straight pores of varying diameter and porosity with dead endings in the substrate and pores with spatially modulated undulating cross sectional shapes.

#### NS-MoP-2 Area-Selective Solid-State Synthesis of Nickel Silicide Nanostructures, *Gabriele Botta*, Nanogune, Italy; *Mato Knez*, nanogune, Croatia

Over the past decade, metal silicides have been re-discovered for their significant potential across various fields of nanotechnology. [1,2,3] However, integrating them into modern devices continues to pose challenges, primarily due to limited control over phase formation during their synthesis. [4] Additionally, since they are typically grown as continuous layers, their structuring often relies on complex top-down patterning techniques, which significantly limit their practical applications. [5] This study addresses these issues by proposing a method for Area-Selective (AS) silicidation (Fig. 1a SD). Our approach ensures that during material synthesis, the resulting silicide nanostructures acquire a predefined morphology and nucleate exclusively in the targeted regions of the substrate.

The AS silicidation process is demonstrated through the formation of  $\text{NiSi}_2$  structures on Si(100) and Si(111) substrates (Fig. 1b SD), and its broader applicability is further illustrated with the successful AS synthesis of  $\text{Cu}_3\text{Si}$  (Fig. 1c SD). To direct growth, the silicon substrates are patterned using ion beams, which create surface defects that promote silicide nucleation in the desired areas. Unlike conventional Solid State (SS) synthesis, which involves annealing a metal thin film on silicon, our method begins with an ALD deposited metal oxide. Silicidation is performed by annealing in the presence of a reductant ( $\text{H}_2$ ), which reduces the metal oxide to its metallic state. The resulting metal then reacts with the underlying silicon, forming a metal silicide. During this two-step reaction, the material re-arranges along

surface defects, which act as templates, guiding both the shape and positioning of the forming silicide crystals.

The effectiveness of this multi-step fabrication method, coupled with its adaptability to various metal-silicide systems, underscores its potential to create functional, structured silicides without the need for post-synthesis nanopatterning.

#### References

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#### NS-MoP-3 Atomic Layer Deposition by Pressure-Driven Convective Flow Through 3D Nanocomposite Structures, *Austin Cendejas, Benjamin Greenberg, Kevin Anderson, Boris Feygelson*, US Naval Research Laboratory

Conformal coating of high aspect ratio tortuous 3-dimensional nanostructures has been shown to require careful consideration of dose and purge times to achieve uniform ALD coatings of high quality.<sup>1,2</sup> Specifically, through static-dosing of ALD precursors cycle times for complete surface saturation are often in excess of 10s of minutes for macroscopic substrates.<sup>2</sup> Recently our group has demonstrated an order of magnitude reduction in saturation dose times by forcing precursor flow through the compact via a pressure gradient of 50-100 Torr across the 3D nanocomposite. In this work, diethylzinc (DEZ) and water were pulsed sequentially to deposit conformal films of ZnO completely through the ~2mm thickness of nanocomposite compacts comprised of 200 nm  $\text{SiO}_2$  nanoparticles. Due to the nonuniform pressure across the nanocomposite compact, precursors undergo a transition from convective to diffusive transport. Preliminary modeling of the internal pressure gradients of the compacts was utilized to determine the relative contributions of these two transport modes in addition to structural nonuniformities (i.e. cracks, large pores, etc.). It was found that uniformity in the internal pore structure and structural integrity of the initial, uncoated, nanoparticle compact was crucial in achieving uniform coatings on the entire surface. Additionally, the effect of precursor partial pressure during doses on saturation dose times and the extent to which the diffusive transport could be enhanced was studied. Saturation dose times were measured via *in-situ* quadrupole mass spectrometry of the effluent gas and film uniformity and conformality were studied via *ex-situ* cross-sectional scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDXS), and X-ray diffraction (XRD).

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#### NS-MoP-4 Atomic Layer Deposition for Novel Nanocomposite Solids with New Functionalities, *Boris Feygelson, Benjamin Greenberg, Kevin Anderson, James Wollmershauser*, U.S. Naval Research Laboratory; *Austin Cendejas*, American Society of Engineering Education, postdoc residing at U.S. Naval Research Lab; *Sarshad Rommel, Mark Aindow*, Department of Materials Science and Engineering, Institute of Materials Science, University of Connecticut

Scaling grains down to nanometer size enhances many properties of polycrystalline solids due to an increase in the grain boundary interfacial volume fraction. Sintering of nanoparticles is the most versatile way to produce nanocrystalline solids of various materials. A crucial prerequisite for achieving advanced, size-dependent properties in these nanocrystalline solids is removing porosity by sintering while preserving nanoscale morphology and grain size. Using our environmentally controlled pressure-assisted sintering (EC-PAS) technique, we have successfully produced fully dense ceramics with grain sizes down to 4 nm [1,2].

By engineering nanoparticle building blocks with designed core/shell structures using particle atomic layer deposition (ALD) [3], we can fabricate novel nanocomposite solids with properties controlled by rationally

designed core/shell geometries, constituent properties, and the resultant vast network of interfaces. We refer to such nanocomposites as artificial interfacial solids (AIS). For instance, when the core/shell nanoparticle structure is preserved during EC-PAS, the resulting nanocomposite comprises isolated nanoparticles (cores of initial core/shells) embedded in a host material (a continuous 3D percolated network of shells from adjacent core/shells merged together).

We have further developed the EC-PAS process to produce percolated AIS (PAIS) nanocomposite solids with two separate and interconnected 3D paths for electron and/or heat transport. The process involves creating a porous compact from nanopowder, followed by ALD infiltration and conformal deposition of a second material on all available surfaces within the porous compact [4], and finally, a sintering stage. The nanopowder in the sintered nanocomposite forms the first 3D percolated network, which becomes surrounded by the deposited and merged 3D network of the second material. Both networks are strongly bonded to each other through sintering.

Examples of AIS and PAIS nanocomposites for various applications will be presented and discussed, highlighting their potential properties, applications, and versatility.

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**NS-MoP-5 Nanostructure and Conductivity of SiO<sub>2</sub>/ZnO:Al Nanocomposites Fabricated by ALD Infiltration and Pressure-Assisted Sintering, Benjamin Greenberg, Kevin Anderson, Alan Jacobs, Joseph Prestigiacomo, Zoey Warecki, Todd Brintlinger, U.S. Naval Research Laboratory; Austin Cendejas, ASEE Fellow Residing at U.S. Naval Research Laboratory; Eric Patterson, James Wollmershauser, Boris Feigelson, U.S. Naval Research Laboratory**

Over the past decade, environmentally controlled pressure-assisted sintering (EC-PAS) has been established as a reliable technique for producing dense, nanocrystalline ceramics with exceptional mechanical properties due to their low porosity (less than 1%) and small grain size (as small as 4 nm). Examples include transparent Mg<sub>2</sub>AlO<sub>4</sub> with hardness up to 22 GPa<sup>1</sup> and WC with hardness up to 39 GPa<sup>2</sup>. Recently, our group has demonstrated that EC-PAS can also be combined with ALD infiltration to produce nanocomposites with unique combinations of optical, electrical, and thermal properties, which are tunable via the sintering conditions and the number of ALD cycles.

In this work, we examine the nanostructure and electrical properties of SiO<sub>2</sub>/ZnO:Al nanocomposites fabricated by this combination of EC-PAS and ALD with the aim of understanding how to maximize electrical conductivity. In an air-free process chain, porous compacts of SiO<sub>2</sub> nanoparticles are infiltrated with ZnO:Al using diethylzinc, trimethylaluminum, and water (15:1 ZnO:Al<sub>2</sub>O<sub>3</sub> cycle ratio) prior to sintering at 450 °C and 2 GPa to produce monolithic nanocomposites with ~1 mm thickness and ~100 nm SiO<sub>2</sub> domain size. 16 or 32 ALD cycles yields conductive ZnO:Al channels comprising 16% or 27% of the nanocomposite's volume with nominal channel width of ~6 or ~12 nm and average zincite crystallite size of ~4 or ~6 nm, respectively. Based on theoretical predictions and experimental measurements of the metal-insulator transition criterion for networks of ZnO nanocrystals,<sup>3</sup> these channel widths are expected to be sufficient for metallic/band-like charge transport. Temperature-dependent resistance measurements down to as low as 0.4 K, however, reveal negative temperature coefficients characteristic of non-metallic charge transport. Specifically, for 16 cycles of ZnO:Al ALD, the charge transport mechanism appears to be Efros-Shklovskii variable-range hopping, and for 32 cycles, the temperature dependence is weaker but still clearly negative. To investigate whether this lack of metallic conduction is due to deviations from the ideal ZnO:Al geometry (percolating channels with uniform thickness), we characterize the nanocomposites' micro- and nanostructure via scanning electron microscopy (SEM) and scanning transmission electron microscopy with energy-dispersive x-ray spectroscopy (STEM-EDS). We also compare the nanocomposites' electrical properties to those of ALD ZnO:Al

films on SiO<sub>2</sub> wafers and explore the influence of the SiO<sub>2</sub>/ZnO:Al interface on conduction.

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**NS-MoP-6 Creation of Nanowire-Bundled Grain Boundaries in Bi<sub>2</sub>Te<sub>3</sub>-Based Thermoelectric Materials via Atomic Layer Deposition, Gwang Min Park, Seunghyeok Lee, Korea Institute of Science and Technology (KIST), Republic of Korea; Jinseok Hong, Seokho Nahm, Hanyang University, Korea; Seung-Hyub Baek, Jin-Sang Kim, Korea Institute of Science and Technology (KIST), Republic of Korea; Seung-Yong Lee, Hanyang University, Korea; Seong Keun Kim, Korea Institute of Science and Technology (KIST), Republic of Korea**

Improving thermoelectric material performance is essential for energy harvesting and solid-state cooling applications. This study demonstrated a novel structure of Bi<sub>2</sub>Te<sub>3</sub>-based thermoelectric materials with ZnO nanowire-bundled grain boundaries, realized via atomic layer deposition (ALD) and subsequent spark plasma sintering (SPS). The ZnO nanowires formed at the interfaces due to the rearrangement of the ALD-grown ZnO ultrathin layer over Bi<sub>0.4</sub>Sb<sub>1.6</sub>Te<sub>3</sub> powder, driven by localized heating during the SPS process and the anisotropic nature of ZnO. The nanowire-bundled interfaces enhanced phonon scattering, thereby reducing lattice thermal conductivity while maintaining excellent electronic transport. This structural innovation achieved a high figure-of-merit,  $zT_{\max} = 1.69 \pm 0.09$  at 373 K and an average  $zT$  of 1.55 over the range of 300–473 K. A thermoelectric module fabricated with 127 p–n pairs achieved a record-high conversion efficiency of 6.57% at a temperature difference of 163 K. These findings highlight the potential of nanowire-bundled interfaces to enhance the thermoelectric material performance and pave the way for scalable next-generation energy conversion technologies.

**NS-MoP-7 Surface Engineered Polymeric Membranes for Improved Fouling Resistance and Superior Oil-Water Separation, Bratin Sengupta, Yining Liu, Seth Darling, Jeffrey Elam, Argonne National Laboratory**

Fouling is a grand challenge which severely degrades membrane system performance, especially for applications in water treatment. Polyvinylidene fluoride (PVDF) is widely used for membrane fabrication due to its inertness and stability. However, PVDF is extremely susceptible to fouling due to its inherent hydrophobicity. Post-synthetic functionalization of PVDF membranes can increase the membrane-foulant interaction energy and reduce fouling. In this regard, vapor phase functionalization is particularly promising since it can produce ultrathin films (<5 nm) which do not alter the membrane pore structure and morphology. For example, thin metal oxide layers impart hydrophilicity and are often positively charged at the pH of the wastewater, realizing high membrane – foulant interaction energy. Atomic layer deposition (ALD) can produce ultrathin metal oxide layers on polymers, but the inert PVDF surface inhibits nucleation necessitating a prohibitively large number of ALD cycles to impart fouling resistance. In this presentation, I describe a novel pretreatment step that dramatically accelerates the nucleation of metal oxide ALD on PVDF. Using this pretreatment, we create highly effective anti-fouling surfaces using one ALD cycle compared to >150 ALD cycles on the pristine PVDF membranes. This strategy is effective for a range of ALD metal oxides including Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, and ZnO. We employ a suite of in situ and ex situ analytical techniques to elucidate the surface chemical mechanism for the enhanced nucleation. We perform extensive characterization and testing of the surface-engineered PVDF to quantify the benefits for water filtration and demonstrate >99% flux recovery with only ~1% irreversible flux loss during operation. We also demonstrate the efficacy of our surface engineered PVDF membranes for oil-water separation. Efforts are underway to perform this surface treatment using our roll-to-roll, atmospheric pressure spatial ALD system.

**NS-MoP-8 Interface Engineering of 2D MoS<sub>2</sub> Devices through ALD Oxidant Selection, Si Eun Yu, Thi Thu Huong Chu, Minjong Lee, Dushyant M. Narayan, Doo San Kim, Dan N. Le, University of Texas at Dallas; Rino Choi, Inha University, Republic of Korea; Jiyoung Kim, University of Texas at Dallas** Two-dimensional transition metal dichalcogenides (2D TMDCs) have emerged as promising semiconductor materials for next-generation electronic devices due to their high mobility within atomic-scale thickness. To preserve the superior performance of 2D semiconductors in field-effect-transistor (FET) applications, gate dielectrics should be deposited via physisorption to prevent chemical reactions between the atomic-scaled 2D surface and ALD precursors.<sup>[1]</sup> A straightforward approach to achieving this is reducing the deposition temperature; however, this is often accompanied by the formation of lower-quality gate dielectrics. It is thus essential to

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establish alternative strategies for gate dielectric deposition, such as exploring precursors and/or employing advanced ALD techniques.

This study will present a promising approach utilizing  $\text{H}_2\text{O}_2$  as an oxidant source for gate dielectric deposition, along with a strategy to achieve uniform deposition without damaging 2D materials. Comparative studies were conducted using  $\text{H}_2\text{O}$ ,  $\text{O}_3$ , and  $\text{H}_2\text{O}_2$  for high-k  $\text{HfO}_2$  growth on 2D  $\text{MoS}_2$ . Each oxidant exhibited distinct growth behaviors. While  $\text{O}_3$  facilitated uniform  $\text{HfO}_2$  deposition, its strong oxidation effect led to Mo-S bond conversion into Mo-O bonds, inducing damage to the  $\text{MoS}_2$  surface. The resulting surface damage led to degraded FET device performance, indicating that  $\text{O}_3$  cannot be a viable candidate for high-k dielectric deposition on 2D semiconductors. For  $\text{H}_2\text{O}$  and  $\text{H}_2\text{O}_2$ , achieving fully conformal coverage remains a significant challenge. To address this limitation, stop-valve techniques were employed to extend oxidant exposure time and dosage, effectively enhancing dielectric coverage while maintaining interface integrity. The interface properties were further analyzed using a top-gate FET structure,<sup>[2]</sup> providing insights into the interface trap density associated with different oxidants.

This presentation will cover material characterization, ALD techniques, and electrical performance, offering a comprehensive evaluation of oxidant effects on 2D semiconductor integration.

This work was supported by Samsung Electronics through GRO program (IO240612-10229-01). We gratefully acknowledge TMEIC for ozone generator (OP-250H) and RASIRC for BRUTE<sup>®</sup> Peroxide. S. E. Yu acknowledges KIAT/MOTIE (RS-2024-00435406).

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## Nanostructure Synthesis and Fabrication Room Tamna Hall B - Session NS-TuA

### 2D Materials and Devices

**Moderators:** Nathanaelle Schneider, CNRS-IPVF, Tamar Segal-Peretz, Israel Institute of Technology

**4:00pm NS-TuA-11 Towards Low-Resistance P-Type Contacts to 2D Transition Metal Dichalcogenides Using Plasma-Enhanced Atomic Layer Deposition, Ageeth Bol,** University of Michigan, Ann Arbor **INVITED**  
One major limitation of 2D transition metal dichalcogenide (TMD) based FETs is the high contact resistance between metallic electrodes and semiconducting channels, particularly for p-type contacts. In this presentation I will address how PEALD of p-type TMDs can be used to improve this contact resistance. First, I will go over controlled doping strategies to form p-type 2D TMD contact materials using PEALD, with an emphasis on Al doped MoS<sub>2</sub> [1] and Nb Doped WS<sub>2</sub> [2]. Our recent results show contact resistance values as low as  $0.30 \pm 0.26$  k $\Omega$ - $\mu$ m between Pd and PEALD Nb<sub>x</sub>W<sub>1-x</sub>S<sub>2</sub> [3], demonstrating that low resistance contacts between metal and p-type TMDs are possible. Then, I will discuss reducing unintentional p-doping introduced during PEALD of TMDs. PEALD TMDs typically contain some level of hydrogen impurities that leads to unintentional p-doping. We have shown that these impurities can be reduced by introducing an Ar plasma C step in the standard PEALD TMD process [4]. Finally, the use of remote plasmas in PEALD for contact deposition can lead to the creation of undesired impurities and defects in the 2D TMD channel, possibly impacting electronic behavior. I will present how adjustments to the PEALD process of WS<sub>2</sub> can reduce the impact of the plasma and maintains the integrity of the underlying TMD channels.

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[3] R. Li *et al.*, Ultra-Low-Resistance Contacts to Heavily-Doped p-Type Nb<sub>x</sub>W<sub>1-x</sub>S<sub>2</sub> Thin Films Grown by Atomic Layer Deposition. *ACS Appl. Mater. Interfaces*, 2025. Accepted.

[4] M. Mattinen *et al.*, "Toolbox of Advanced Atomic Layer Deposition Processes for Tailoring Large-Area MoS<sub>2</sub> Thin Films at 150 °C," *ACS Appl. Mater. Interfaces*, vol. 15, no. 29, pp. 35565–35579, Jul. 2023, doi: 10.1021/acsami.3c02466.

**4:30pm NS-TuA-13 Selective Passivation of 2D TMD Surface Defects by Atomic Layer Deposition for Enhancing Recovery Rate of Gas Sensor, Minji Kim, Inkyu Sohn, Dain Shin, Sangyoon Lee, Hwi Yoon, Jisang Yoo, Seung-min Jung, Hyungjun Kim,** Yonsei University, Korea

Two-dimensional transition metal dichalcogenides (2D TMDs) have gained significant interest as promising materials for gas sensors due to their high surface-to-volume ratio, high electron mobility, tunable band gap, and efficient sensing capabilities at room temperature.[1] However, commercialization of TMD gas sensors is currently limited by low recovery rates due to strong chemisorption of gas molecules on surface defects. Unfavorable desorption of gas molecule from defects hinders reliability and long-term stability of TMD gas sensor.[2] In this study, atomic layer deposition (ALD) is used to selectively passivate surface defects of MoS<sub>2</sub> and WS<sub>2</sub> gas sensors with Al<sub>2</sub>O<sub>3</sub>. SEM analysis confirms that Al<sub>2</sub>O<sub>3</sub> are deposited only at defective sites such as grain boundaries and vacancies of MoS<sub>2</sub> and WS<sub>2</sub>. As a result, Al<sub>2</sub>O<sub>3</sub> passivated TMD gas sensor shows nearly complete recovery rate of 96% even at room temperature, which improved from 74% recovery rate of pristine TMD gas sensor. Also, passivated gas sensor shows higher response toward NO<sub>2</sub> gas compared to pristine gas sensor due to n-type doping effect of Al<sub>2</sub>O<sub>3</sub> on TMD. This result shows that defect-selective passivation is a promising strategy to overcome low recovery rate of TMD gas sensor and enhance its sensing properties.

#### References

[1] Huo, N. *et al.*, *Scientific reports* 4.1 (2014): 5209.

[2] K. Lee, R. *et al.*, *Advanced materials* 25.46 (2013): 6699–6702.

**4:45pm NS-TuA-14 Beyond the conventional AB process: Advanced ALD approaches for controlling the properties and growth of MoS<sub>2</sub> and WS<sub>2</sub> 2D Materials, Cindy Lam, Eryk Gruszecki, Erwin Kessels, Bart Macco,** Eindhoven University of Technology, The Netherlands

As the semiconductor industry is advancing towards the Ångström era of transistor scaling, the ultrathin 2D transition metal dichalcogenides (TMDs) serve as potential candidates in replacing the current Si-based channel material for next-generation field-effect transistors (FETs) in integrated circuits (ICs). Atomic layer deposition (ALD) holds great promise as a deposition technique to grow 2D materials directly on the device (i.e. transfer-less) with good conformality in 3D structures and back-end-of-line (BEOL) compatible temperatures. However, several challenges remain in attaining high-quality, large crystals of semiconducting 2D TMDs like MoS<sub>2</sub>, WS<sub>2</sub>, and WSe<sub>2</sub> in comparison to other techniques such as chemical vapor deposition (CVD). In addition to that, the development of doping strategies is of great interest to control their conductivity type.

In this presentation, we showcase advanced ALD approaches to address these challenges, through the use of plasma treatments with controlled ion energies, supercycles for incorporating dopants, and surface pretreatments to control the nucleation. We showcase that the morphology and electrical characteristics of ALD WS<sub>2</sub> can be improved upon using an Ar plasma treatment (ICP, RF: 13.56 MHz) in an ABC-type PEALD process along with varying the plasma process parameters such as the exposure time  $t_p$  (ranging from 0 to 180 s) and ion energy  $E_i$  (from 16 to 41 eV). Sulfur vacancy formation  $V_s$  within the film likely induces p-type conductivity and enhancement of Hall effect properties with the mobility  $\mu_{Hf}$  ranging between 0.1 and 1.1 cm<sup>2</sup>/(V·s) and a carrier density  $p_{in}$  in the order of 10<sup>19</sup> - 10<sup>20</sup> cm<sup>-3</sup> (See Supplementary Information). In the case for MoS<sub>2</sub>, substitutional transition metal doping by tantalum (Ta) utilizing a supercycle method, leads to MoS<sub>2</sub> with a similar carrier type and  $\mu_{Hf}$  ranging from 0.04 to 0.16 cm<sup>2</sup>/(V·s) and with carrier density  $p$  values around  $\sim 10^{21}$  cm<sup>-3</sup> upon tuning the cycle ratio  $n$  MoS<sub>2</sub> :  $m$  TaS<sub>2</sub>. These results demonstrate a facile method to create degenerate TMDs by PEALD, interesting for potential applications in areas including contact engineering to enhance device performance. Further customizing and refining the design of the ABC process offers a wide range to tune the electrical properties, optimizing them and achieve desired target values.

**5:00pm NS-TuA-15 Deposition and Characterization of Transition Metal Oxide/2d Transition Metal Dichalcogenide Quantum Wells, Shih-Hao Tseng, Yu-Chuan Lin,** Department of Materials Science and Engineering, National Yang Ming Chiao Tung University, Hsinchu, Taiwan

Quantum well heterostructures made of oxide dielectrics and 2D semiconductors provide exciting optoelectronic applications. As this heterostructure is emerging, it is necessary to combine different vapor phase techniques to integrate them in a bottom-up fashion and find ways to characterize them rapidly and non-invasively. We utilize atomic layer deposition (ALD) to deposit aluminum oxide (AlO<sub>x</sub>) on a large area 2D WS<sub>2</sub> film grown by metalorganic chemical vapor deposition (MOCVD) to fabricate quantum well superlattices and explore a variety of characterization techniques to study their structures and properties. First, we tested a range of ALD temperature for effective nucleation and growth of continuous 5 and 10 nm AlO<sub>x</sub> on WS<sub>2</sub> inert surface. Subsequently, we grow another 2D WS<sub>2</sub> film on top of the 1<sup>st</sup> stack of AlO<sub>x</sub>/WS<sub>2</sub> by MOCVD at low temperatures and encapsulate it with another ALD AlO<sub>x</sub>. The single and double AlO<sub>x</sub>/WS<sub>2</sub> quantum wells were characterized with Raman and photoluminescence spectroscopy and scanning probe microscopy to understand their optical properties. Next, we used hard X-ray photoelectron spectroscopy (HXPS) to analyze the WS<sub>2</sub> layers sandwiched between AlO<sub>x</sub> with varied thicknesses (5–20 nm). To obtain the thickness, roughness, and density of the AlO<sub>x</sub> and WS<sub>2</sub> in the quantum wells, X-ray reflectivity (XRR) measurement was performed on the quantum wells. Finally, we examined the impact of AlO<sub>x</sub> thicknesses on the effectiveness of HXPS and XRR and the optical and electrical properties of the AlO<sub>x</sub>/WS<sub>2</sub> quantum wells.

**5:15pm NS-TuA-16 Engineering Al<sub>2</sub>O<sub>3</sub> Interlayer via Atomic Layer Deposition for Enhancing Contact Properties of MoS<sub>2</sub>-Based FET, Minu Cho, Hwi Yoon, Sanghun Lee, Seongyeong Park, Inkyu Sohn, Hyungjun Kim,** Yonsei University, Korea

As transistors have advanced and continued to downscale, 2D transition metal dichalcogenides (TMDCs) have gained attention as a promising channel material. However, high contact resistance ( $R_c$ ) has emerged as a major issue in 2D TMDC field-effect transistors (FETs). This problem is primarily caused by Fermi level pinning, which hinders control over the

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Schottky barrier height, even when the metal's work function (WF) is altered, leading to increased contact resistance. Various approaches have been explored to address this issue, among them placing an insulating layer between the metal and the channel has been proposed as a potential solution to mitigate Fermi level pinning. However, a key challenge in implementing this method is achieving optimal thickness for insulating layer and ensuring uniform deposition of the insulating interlayer on the inert surface of the 2D material.

In this study, we aimed to suppress Fermi level pinning by depositing  $\text{Al}_2\text{O}_3$  via atomic layer deposition (ALD) as an interlayer for the metal-insulator-semiconductor (MIS) contact of bottom-gated  $\text{MoS}_2$  FETs. ALD was utilized to optimize the thickness, leveraging its precise thickness control, and to enhance the uniformity of the  $\text{Al}_2\text{O}_3$  interlayer on the inert  $\text{MoS}_2$  surface. We optimized the coverage of ALD-grown  $\text{Al}_2\text{O}_3$  by controlling precursor injection pressures on  $\text{MoS}_2$  and discovered that improved film uniformity significantly reduces  $R_c$ . Additionally, tunneling resistance across the MIS contact was lowered through n-type doping of  $\text{MoS}_2$ , induced by isopropyl alcohol (IPA) used as a mild oxidant in the ALD process. As a result, with the uniform  $\text{Al}_2\text{O}_3$  interlayer which induces n-type doping effect we were able to reduce contact resistance by more than two orders of magnitude compared to other  $\text{MoS}_2$  FETs fabricated in this study.

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