Emerging Materials and Processes
Room Tampa Bay Salons 5-9 - Session EM-MoP
Emerging Materials and Processes Poster Session

EM-MoP-1 Chromium-Doped ALD Lead Telluride Thin Films with Additional Iodine Coating, ***Haifeng Cong***, *Helmut Baumgart,* Old Dominion University; *Tarek Abdel-Fattah,* Christopher Newport University

Thermoelectric materials directly convert heat into electricity, and PbTe is a promising narrow bandgap material due to its high Seebeck coefficient, chemical stability, and ability to operate at elevated temperatures (600–850 K). While PbTe thin films deposited by Atomic Layer Deposition (ALD) have been widely studied, doping thin films to enhance their thermoelectric performance remains less explored.In this study, PbTe thin films were synthesized on silicon substrates with native oxide via ALD using Pb(II)bis(2,2,6,6-tetramethyl-3,5-heptanedionato) and (trimethylsilyl) telluride as precursors. Chromium (Cr) was incorporated into the ALD films to modify electrical properties. An additional surface modification was performed by coating the PbTe:Cr films with iodine, followed by thermal treatment in a furnace at 80 °C for 72 hours, producing films with implanted Cr^+ and iodine.Comprehensive characterization included X-ray diffraction (XRD) for crystal structure, FE-SEM for morphology, AFM for surface roughness, EDS and XPS for elemental composition and chemical states, and measurements of Seebeck coefficient, Hall effect, and thermal conductivity. Comparative analysis was conducted between Cr-doped PbTe films without iodine top coating and those with the iodine-treated top layer. Results show that the iodine modification further influences the electrical properties and thermoelectric figure of merit (ZT), highlighting the potential of combined Cr doping and surface engineering for high-performance PbTe thin films.

EM-MoP-2 Formation of Multi-Heterojunctions via Atomic Layer Etching for High Performance MoS_2 Photodetectors, ***Si Yeon Kim***, *Sun Jae Jeong, Ji Eun Kang, Geun Young Yeom,* Sungkyunkwan University (SKKU), Republic of Korea

In this study, high performance 2D MoS_2 photodetectors incorporating multi-heterojunction structures were fabricated through Atomic Layer Etching (ALE). By precisely controlling the thickness of the MoS_2 thin films using an ALE technique, MoS_2 heterojunctions composed of monolayer and multilayer regions were successfully formed. This engineered bandgap modulation facilitated the generation and separation of photo-induced carriers, thereby significantly enhancing the device's photoresponsivity.

Furthermore, the formation of multi-junction interfaces increased the effective contact area with the electrodes, securing superior electrical characteristics. Unlike conventional approaches that rely on hybrid heterostructures, this work distinguishes itself by simultaneously optimizing electrical and optoelectronic performance within a single material platform. These results demonstrate that ALE is a scalable and effective technique for manipulating 2D materials, paving a new way for next-generation optoelectronic applications.

EM-MoP-3 Plasma-Assisted Defect Engineering of MoS_2 for Controlled N-Type Doping and Phase Transition, ***Ga-Hee Oh***, *Sun Jae Jeong, Ji Eun Kang, Geun Young Yeom,* Sungkyunkwan University (SKKU), Republic of Korea

Precise control of doping type and concentration in transition metal dichalcogenides (TMDs) is essential for realizing TMD-based electronic devices, including p-n diodes, field-effect transistors (FETs), and tunnel FETs. However, conventional ion implantation techniques are not suitable for two-dimensional materials due to severe lattice damage and structural degradation.

This study presents an approach for achieving controlled n-type doping and structural phase transition in CVD-grown MoS_2 through atomic-scale plasma-assisted defect engineering. Although radical-based surface doping is generally limited by shallow penetration depth, Argon plasma treatment was applied to the MoS_2 surface, creating sulfur vacancies that effectively introduced n-type doping characteristics. The density of these sulfur vacancies and thereby the doping concentration was precisely tuned by varying the plasma exposure duration.

In addition to doping, the defect formation induced a phase transformation from the semiconducting 2H phase to the metallic 1T phase. Raman spectroscopy confirmed the emergence of new peaks associated with the 1T phase. Raman spectroscopy confirmed the emergence of new peaks associated with the 1T phase, while X-ray photoelectron spectroscopy (XPS) provided evidence of both chemical and structural changes during the process. These plasma – induced modifications resulted in substantial improvements in device performance, such as increased field-effect mobility and higher on/off current ratios. The ability to simultaneously control both carrier type and structural phase makes this method particularly promising for the design of high-performance two-dimensional (2D) electronic devices.

Overall, the results demonstrate that plasma-assisted defect engineering offers a scalable and controllable pathway for tuning the electronic properties of 2D transition metal dichalcogenides like MoS_2. This technique opens new possibilities for the development of next-generation nanoelectronics and optoelectronic devices.

EM-MoP-4 Fabrication of p-type Al-doped SnO_x Thin Films via Supercycle ALD using Sn4+-based Precursor, ***Suhyeon Park***, *Jiseop Byeon, Minjae Kwon,* Kyungpook National University, Republic of Korea; *Roy Byung Kyu Chung,* Kyungpook National University

Tin oxide (SnO_x) is a promising material for oxide semiconductor devices, such as thin-film transistors (TFTs), due to its tunable electronic properties derived from the multivalent nature of Sn^{2+} and Sn^{4+}. While SnO_2 is a typical n-type semiconductor, SnO exhibits p-type conductivity [1], making it suitable as a complementary material in complementary metal oxide semiconductor (CMOS) circuits. However, SnO is thermodynamically unstable and easily oxidized, requiring precise stoichiometry control. [2, 3] Previous studies have attempted to realize p-type SnO using atomic layer deposition (ALD) processes with Sn^{2+}-based precursors. [4, 5, 6] However, these precursors often suffer from limited commercial availability or high costs, hindering their practical use in research. In contrast, ALD processes employing Sn^{4+}-based precursors tend to favor the formation of stable n-type SnO_2, making p-type conduction difficult to achieve. To overcome these limitations, Al doping was employed as a key strategy to realize p-type SnO_x thin films using Sn^{4+}-based precursors.In this work, p-type Al-doped SnO_x (Al-SnO_x) thin films were fabricated through a supercycle ALD process using Tetrakis(dimethylamino)tin(IV) (TDMASn) as a Sn^{4+}-based precursor and Trimethylaluminum (TMA) as an Al_2O_3 source. The influence of the Al concentration and the spatial insertion position of the Al layer within the supercycle was systematically investigated. The optimal electrical performance was achieved when the Al layer was positioned in the middle of the SnO_2 layers. At an optimized Al concentration of 1.22 at%, the films exhibited a Hall mobility of 1.42 cm^2/V·s and a carrier concentration of 2.35 $\times 10^{18}$ cm^{-3} after post-annealing in a forming gas atmosphere. To evaluate electrical and structural characteristics of the films, Hall effect measurements and Grazing Incidence X-ray Diffraction (GIXRD) were primarily performed.This study demonstrates the feasibility of forming p-type films using cost-effective precursors. The optimization of both Al content and its spatial distribution allowed for precise control over the film's electrical characteristics. Based on these optimized process conditions, the controlled integration of n-type SnO_2 and p-type SnO_x films is expected to contribute to the future realization of tin oxide-based CMOS technology.

EM-MoP-5 Molecular Layer Deposited Hf-Based Hybrid Photoresists for Dual-Tone EUV Lithography , ***Thi Thu Huong Chu***, *Dan N. Le, Minki Choe, Dushyant M. Narayan, Minjong Lee, Soham Shirodkar,* University of Texas at Dallas; *Nikhil Tiwale, Chang-Yong Nam,* Brookhaven National Laboratory; *Jiyoung Kim,* University of Texas at Dallas

Hafnium-based hybrid photoresists have emerged as promising candidates for extreme ultraviolet (EUV) lithography due to their high EUV absorption, superior etch resistance, and potential for sub-10 nm patterning.[1,2] Beyond their conventional single-tone behavior, our studies have revealed that Hf-based inorganic–organic hybrid materials can exhibit dual-tone responses under EUV exposure, enabling both positive- and negative-tone patterning within the same resist platform. This unique capability opens new opportunities for process simplification and enhanced patterning flexibility in advanced lithographic applications.

In this work, we demonstrate dual-tone EUV patterning using Hf-based hybrid photoresists and systematically evaluate their lithographic performance under both EUV exposure and low-energy electron-beam lithography (100 V EBL). We show that the resist tone can be switched via post-deposition treatment, which induces chemical changes within the Hf-based resist and results in tone inversion from conventional negative to positive tone behavior. The Hf-based hybrid resist films were fabricated via molecular layer deposition (MLD) using TDMA-Hf as the inorganic precursor and 2,3-dimercapto-1-propanol (DMP) as the organic linker. The MLD-derived hybrid resist exhibits high sensitivity, with the critical doses of 17.6

and 18.5 mJ/cm^2 for negative- and positive-tone modes, respectively. The critical doses required for both negative- and positive-tone patterning are comparable, indicating minimal sensitivity penalty when switching between tone modes.

Mechanistic investigations were conducted using *in-situ* FTIR and XPS analysis. The results indicate that negative-tone behavior arises from exposure-induced crosslinking, which stabilizes the resist film after development. In contrast, post-treated films exhibit positive-tone behavior, where film hardening is followed by bond scission under EUV or e-beam exposure, leading to enhanced solubility in the developer.

These findings highlight the versatility of Hf-based hybrid photoresists as multifunctional EUV resist materials and underscore their potential for next-generation EUV lithography, where adaptable tone control and simplified process integration are increasingly critical.

This work is supported by the U.S. DOE Office of Science Accelerate Initiative Award 2023-BNL-NC033-Fund. This research is also partially supported by the National R&D program (2022M3H4A3052556) through the National Research Foundation of Korea (NRF), funded by the Ministry of Science and ICT in Korea.

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EM-MoP-6 Deterministic Resistive Switching via Atomic-Layer Control of 2D WS_2 and Confined Ag Electrodes*,* ***Sihoon Son****, Taesung Kim, Hyunbin Choi, Geonwook Kim,* Sungkyunkwan University (SKKU), Republic of Korea

Atomic-scale control of both the active switching medium and the ionic source is a critical requirement for achieving reliable and scalable resistive memory technologies. While two-dimensional (2D) materials offer an intrinsically thin and well-defined switching layer, resistive switching in filamentary memories is still dominated by stochastic variations originating from uncontrolled metal-ion supply. Here, we demonstrate a resistive memory platform in which the resistive switching behavior is deterministically governed by the simultaneous atomic-layer-level control of a 2D WS_2 switching medium and the confined supply of Ag ions, enabled by ALD/ALE-compatible thickness engineering.

The WS_2 switching layer was synthesized with atomic-scale thickness control, allowing systematic modulation of the vertical transport length and defect density. In parallel, the Ag electrode was intentionally confined in both thickness and areal distribution, limiting the total Ag reservoir available for electrochemical metallization. By independently tuning the WS_2 thickness and the Ag supply, we reveal a clear transition in resistive switching behavior from Ag-dominated metallic conduction to vacancy-mediated switching governed by sulfur-vacancy (V_s) percolation. Electrical measurements combined with thickness-dependent statistics show that the high-resistance state is primarily dictated by the WS_2 thickness, whereas excessive Ag supply leads to unstable low-resistance states and increased variability.

Detailed electrical analysis and finite-element simulations indicate that a partially formed Ag tip, generated under confined Ag conditions, produces a highly localized electric-field enhancement at the WS_2 interface. This localized field drives controlled V_s migration along grain boundaries without forming a continuous metallic filament. The resulting sequential switching process—comprising partial Ag filament formation, transient space-charge-limited conduction, and eventual vacancy filament percolation—yields sub-percent switching variability and stable non-volatile memory operation. Importantly, ex-situ structural and compositional analyses confirm the absence of residual Ag within the WS_2 layer after switching, highlighting the non-metallic nature of the final conductive pathway.

By demonstrating that resistive switching characteristics can be deterministically programmed through atomic-scale thickness control of a 2D switching medium and precise limitation of metal-ion supply, this work establishes a materials-level design strategy directly aligned with ALD/ALE processing. The presented approach provides a scalable pathway toward highly uniform RRAM and neuromorphic memory devices, in which variability is suppressed not by circuit-level compensation but by atomically engineered material interfaces.

EM-MoP-7 BEOL Compatible Direct Growth of MoS_2 for Cu free Hybrid Bonding*,* ***Hyunbin Choi,*** Department of Semiconductor Convergence Engineering, Sungkyunkwan University, Republic of Korea*; Sihoon Son,* SKKU Advanced Institute of Nanotechnology (SAINT), Sungkyunkwan University, Republic of Korea*; Geonwook Kim, Taesung Kim,* School of Mechanical Engineering, Sungkyunkwan University (SKKU), Republic of Korea

Hybrid bonding technology is emerging as an essential solution for advanced 3D semiconductor integration, enabling the simultaneous bonding of metals and dielectrics. However, conventional hybrid bonding suffers from copper (Cu) contamination during the O_2 plasma activation step required for hydroxyl (OH) group formation on dielectric surfaces such as SiCN. The harsh plasma conditions induce Cu sputtering and migration, causing chamber and substrate contamination that degrades process reliability over time.To address this issue, we introduce a contamination free hybrid bonding approach employing an ultrathin molybdenum disulfide (MoS_2) barrier layer. The MoS_2 film is formed through plasma-enhanced chemical vapor deposition (PECVD) sulfurization of a Mo layer at low temperature. This barrier effectively suppresses Cu sputtering during O_2 plasma processing, preventing metal induced contamination while maintaining plasma activation efficiency.Furthermore, the MoS_2 layer enables post bonding electrical connection via memristive switching. Upon voltage application across the Cu–MoS_2–Cu structure, Cu ions migrate through the MoS_2 and form conductive filaments, ensuring reliable electrical connectivity without damaging the bonding interface.This work demonstrates a novel, BEOL compatible, Cu contamination free hybrid bonding process that preserves device integrity and enables high yield 3D integration. The proposed method provides a practical route toward cleaner, more reliable, and scalable hybrid bonding for next generation heterogeneous semiconductor systems.

EM-MoP-8 Monolithic 3D Artificial Intelligence Hardware Using four-Tier Vertically Integrated IGZO-Based HZO Ferroelectric Transistors*,* ***Geonwook Kim****, Sihoon Son, Hyunbin Choi, Taesung kim,* Sungkyunkwan University (SKKU), Republic of Korea

The relentless demand for faster, smaller and more energy-efficient integrated circuits has pushed the semiconductor industry to the performance, power and area (PPA) wall, where interconnect delay and energy dissipation dominate system efficiency. While 2.5D and TSV-based 3D integration offer partial relief, they suffer from long interconnects, thermal hotspots and reliability concerns. Monolithic 3D integration (M3DI) provides a transformative TSV-free paradigm, enabling nanoscale vertical interconnects between front-end-of-line logic and back-end-of-line memory tiers, thereby maximizing PPA efficiency and reducing latency. Here we demonstrate monolithic 3D integration (M3DI) of oxide thin-film electronics, integrating amorphous IGZO field-effect transistors with ferroelectric HZO field-effect transistors in a vertically stacked 1T-1FeFET architecture. These oxide-based thin-film devices are fully BEOLcompatible and highly scalable, providing uniform threshold voltage and I_{on}/I_{off} distributions for logic operations, as well as stable ferroelectric switching with narrow variability for memory functions. The resulting M3DI arrays enable ultra-dense integration, reproducible operation, and low-latency performance within a compact footprint. Beyond binary switching, the M3DI 1T-1FeFET architecture exhibits synaptic functionalities, including multilevel nonvolatile memory, spike-timing-dependent plasticity, and excellent array-level uniformity—key attributes for neuromorphic and AI hardware. This work establishes oxide-semiconductor-based M3DI as a promising platform for next-generation intelligent and energy-efficient computing systems beyond conventional CMOS and von Neumann architectures.

EM-MoP-9 Annealing-Induced Structural Evolution and Crystallization Behavior of $CuNb_2O_6$*,* *Deug Hyun Nam,* Korea institute of industrial Technology, Republic of Korea*; Chan Woong Na,* Korea Institute of industrial technology, Republic of Korea*;* ***Yoon Myung****,* Korea Institute of Industrial Technology, Republic of Korea

$CuNb_2O_6$ is an intrinsic p-type metal oxide semiconductor in which hole transport originates from copper-derived electronic states embedded within an orthogonal Cu–O–Nb octahedral framework. This structurally ordered lattice provides stable and directional charge transport pathways, rendering crystallinity control essential for optimizing functional performance.

Herein, $CuNb_2O_6$ powders were synthesized via a sol–gel route followed by systematic thermal annealing to regulate crystal formation. The annealing-induced evolution of crystal structure and electronic states was comprehensively investigated using X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS). Distinct temperature-dependent crystallization regimes were identified, accompanied by progressive stabilization of the Cu^{2+} and Nb^{5+} electronic environments and enhanced lattice ordering.

These results elucidate the coupled structural and electronic evolution of orthogonal $CuNb_2O_6$ during thermal processing and establish a crystallization window for achieving phase-pure and electronically optimized materials.

EM-MoP-10 Bias-Modulated ALD of Zinc Oxide*, **Jessica Jones,*** Argonne National Laboratory, USA*; Shi Li,* Argonne National Laboratory*; Rajeev Assary, Jeffrey Elam,* Argonne National Laboratory, USA

Biasing substrates during atomic layer deposition (ALD) in gaining popularity as a method to alter the resulting film. This is hypothesized to alter precursor–surface interactions and provide a means to tune material properties. We performed zinc oxide (ZnO) ALD using diethylzinc (DEZ) and water on silicon with native oxide substrates at 150 °C in a sample holder designed to create a static electrical field by biasing one plate of a parallel plate capacitor during deposition. ZnO films prepared in an electric field/on a biased sample holder were thinner, changed relative crystalline composition, and contained more carbon compared to samples grown under identical conditions without bias. Density functional theory (DFT) calculations showed enhanced electron migration between dissociatively adsorbed DEZ molecules and the ZnO (002) facet with increasing force from an electric field at the substrate surface, which strengthens the electronic interactions between the surface and the adsorbate. These models offer a compelling explanation for the inhibited growth, changes in the crystallinity, and increased carbon content of films grown in an electric field/on biased plates.

EM-MoP-11 Plasma-Enhanced Atomic Layer Deposition of Ferroelectric Aluminum Nitride*, **Nicholas Strnad,*** US Army Research Laboratory*; Gilbert B. Rayner Jr., Noel O'Toole,* The Kurt J. Lesker Company*; Nastazia Moshirfatemi,* General Technical Services, LLC*; Daniel Drury, Brendan Hanrahan,* US Army Research Laboratory*; Glen Fox,* Fox Materials Consulting, LLC*; Jeffrey Pulskamp,* US Army Research Laboratory

Piezoelectric aluminum nitride (AlN) and doped-variant aluminum-scandium nitride ($Al_{(1-x)}Sc_xN$) thin films are commercially essential for RF filters for wireless communication and have additional applications as sensors for piezoelectric ultrasound transducers (PMUTs), and energy harvesters. Recently, there have been a flurry of reports of ferroelectric sputtered $Al_{(1-x)}Sc_xN$ since its published discovery by Fichtner in 2019. Ferroelectric $Al_{(1-x)}Sc_xN$ has enormous potential as a memory thin film due to its extremely large, switched polarization (>>100 µC/cm^2) and Curie temperature > 1000° C, making it suitable for operation in extreme environments. Despite this excitement, there are few reports showing ferroelectricity in nominally undoped aluminum nitride, typically deposited using sputtering, due to the large electric fields (>6 MV/cm) required for switching. Here, we show ferroelectric AlN thin films grown by plasma-enhanced atomic layer deposition (PEALD) grown using ultra-high purity conditions. This is the first demonstration of ferroelectric PEALD AlN and only the second report of any ferroelectric nitride grown by PEALD. The PEALD AlN thin films were deposited at a substrate temperature of 300° C and exhibit room-temperature ferroelectric switching which is enabled by their enormous breakdown fields > 9 MV/cm. Trimethylaluminum (TMA) and alternatively N_2 and N_2/H_2 plasmas were implemented as co-precursors. The PEALD AlN films exhibited the wurtzite phase and grew in the c-axis (0002)-orientation on {111}-oriented Pt bottom electrodes deposited on (001) silicon with a 500 nm-thick thermal oxide.

EM-MoP-12 Thermal Atomic Layer Deposition and Post-Deposition Annealing of Molybdenum Oxide and Sulfide Thin Films*, Wesley Jen, **Nolan Olaso**, Icelene Leong, Steven M. Hues, Elton Graugnard,* Micron School of Materials Science and Engineering, Boise State University

In order to enable further advances in microelectronics, new processes capable of precisely depositing films are required. This is especially true of processes meant for depositing transition metal dichalcogenides such as MoS_2, a material of particular interest due to its high potential mobility even at a thickness of a few atoms. Molybdenum oxide (MoO_x) is a wide bandgap transition metal oxide that has been of growing interest for several different applications in the semiconductor community, including for use as gate dielectrics in ultra-thin transistors, carrier-selective contacts in solar cells, and chemical selective materials in gas detection sensors. In this work, we report on an industry-compatible processes for depositing MoO_x and MoS_x thin films at 200 °C using bis(tert-butylamino)bis(dimethylamino)Mo (BTBDM) with H_2O or H_2S, respectively. Post deposition annealing in oxygen formed MoO3 from MoO_x, while annealing either MoO_x or MoS_x in H_2S formed crystalline MoS_2. ALD processes were characterized using in situ quartz microbalance measurements, while the resulting films were characterized using X-ray photoelectron spectroscopy, atomic force microscopy, optical absorption, Raman spectroscopy, and photoluminescence measurements. These results provide insight into methodologies for both precisely depositing crystalline MoS_2 and its oxide to accelerate the integration of 2D materials into leading edge microelectronics.

EM-MoP-13 Phase Complexity in Two-Dimensional Iron Sulfide on Au(111)*, **Alessandro Baraldi,*** University of Trieste, Italy

Despite extensive research on two-dimensional (2D) materials, almost all experimentally synthesized 2D systems derive from van der Waals crystals. Beyond this class, only a limited number of compounds have so far been theoretically predicted to be stable in the 2D limit [1]. In this context, iron–sulfur compounds have recently emerged as promising candidates. Density functional theory predicts that both hexagonal FeS_2 and tetragonal FeS phases can exist as stable monolayers, exhibiting strain-tunable magnetic properties [2-4]. Although the Mermin-Wagner theorem precludes long-range magnetic order in ideal 2D isotropic systems, magnetic anisotropy can lift this constraint and allow stable ordering, enabling tunable magnetism at the atomic scale [5], which is essential for spintronics [2-4], as well as other emerging phenomena such as topological effects [6], multiferroicity [7], and proximity effects in heterostructures [8]. However, compared to their bulk counterparts, Fe–S systems generally display a rich phase diagram, characterized by multiple stoichiometries and atomic arrangements [9]. A similar complexity may also persist in the 2D limit, highlighting the need for a systematic experimental investigation into which 2D FeS_x phases can actually form. For this purpose, we systematically grow and characterize iron sulfide monolayers on Au(111) via in-situ co-deposition of Fe and S. Low-energy electron diffraction (LEED), scanning tunneling microscopy (STM), and X-ray photoelectron spectroscopy (XPS) reveal two primary phases: one with a hexagonal atomic arrangement consistent with FeS_2, forming a moiré superstructure, and one with a square arrangement. By tuning sulfur exposure, we observe additional phases with varying stoichiometry and atomic arrangement, all belonging to the same 5×5 superstructure family. These results confirm the existence of a complex 2D phase diagram for FeS_x monolayers, establishing them as a versatile and tunable platform for exploring 2D magnetism in non-van der Waals systems.

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EM-MoP-14 Research on New-material Screening Methods toward the Development of Chemical-reaction-based Surface-roughness Reduction Processes*, **Taiki Kato**, Hirokazu Ueda, Mitsuhiro Tachibana,* Tokyo Electron Ltd., Japan*; Peter Ventzek,* Tokyo Electron Ltd.

In semiconductor device manufacturing processes, substrate surface roughness should be minimized because it leads to increased electrical resistance and added parasitic capacitance. Critical for device scaling, this is even more so when considering two-dimensional materials. Conventional methods for reducing substrate roughness include atomic layer deposition (ALD) and atomic layer etching (ALE), but a method that could reduce only the substrate roughness via surface chemical reactions without changing film thickness would represent a major breakthrough. We developed a numerical analysis method to evaluate the roughness-reduction effects of novel materials. The planarization capability of new precursors on various substrate materials was ranked for different topographic structures. The goal of the study at this stage is to prove the feasibility of chemical planarization of common interconnect metals.

Numerical evaluation of roughness-reduction effects followed two approaches: molecular dynamics (MD) and direct evaluation of the reaction-pathway thermodynamics. First, machine-learned potentials (MLP) based MD simulations described how novel precursor molecules interact on various metal surfaces with different roughness features. The analysis produced a picture in which certain reactive precursors, upon impinging on rough metal substrates, bond with surface metal atoms promoting their mobility, diffusion and surface flattening. By comparing the MD simulation temperature conditions at which metal surfaces become flattenable, we can rank the relative ease of planarization among different metals including ruthenium, cobalt and gold. Our second approach employed reaction-pathway (thermodynamics) to evaluate the activation energy for step-edge collapse for various metal surfaces. Smaller activation energies imply an easier to planarize surface. The same three metals in the MD study were evaluated and found to scale consistently. We also found that adsorption of the novel precursors reduces the activation energy for step-edge collapse, clarifying a mechanism in which precursor adsorption promotes diffusion of surface metal atoms and thereby enables surface planarization.

The presentation summarizes scaling trends we see from simulation-based studies of substrate-roughness adsorbate mediated planarization for various materials. Specifically, we show improvements in device characteristics resulting from reduced substrate surface roughness, experimental evaluations of roughness reduction versus film-thickness change, and potential process applications. We finish with an outlook for future development.

EM-MoP-15 Molecular Layer Deposition of Metalcones Using Salicylaldehyde as an Organic Precursor*, **Henry Yu-Jun Tang**, Hao-Wei Chan, Bo-Yuan Gu, Zhen-Rou Chang, Fang-Yu Lin, Yi-Jung Liao, Feng-Yu Tsai,* National Taiwan University, Taiwan

This study demonstrates molecular layer deposition (MLD) of alucone and hafnicone thin films using a previously unexplored organic precursor, salicylaldehyde, paired with trimethylaluminum (TMA) and tetrakis(dimethylamido)hafnium(IV) (TDMAHf), respectively. MLD of alucone and hafnicone at deposition temperatures between 120 and 190°C was confirmed with in-situ quartz crystal microbalance (QCM) and chemical analyses. The alucone chemistry was observed to be prone to self-termination, which could be mitigated with two methods: using an exposure process, and using H_2O as a coreactant. Conversely, the hafnicone chemistry showed strong resistance to self-termination owing to the high functionality and large ligand-to-ligand steric hindrance of TDMAHf. The potential of the alucone and hafnicone films as low dielectric constant (k) materials was evaluated, with the alucone and hafnicone films exhibiting k value of 4.2 and 4.7, respectively. The alucone and hafnicone films showed good thermal stability, with ~25% and 20% reduction in thickness upon baking in vacuum at 500°C for 15 min, respectively.

EM-MoP-16 The Effect of Remote Ar Plasmas on the Crystalline Structure of VO_2*, Peter Litwin,* U.S. Naval Research Laboratory*; Neeraj Nepal,* US Naval Research Laboratory*; Andrew Lang,* U.S. Naval Research Laboratory*; David Boris,* US Naval Research Laboratory*; Michael Johnson,* Naval Research Laboratory, USA*; Scott Walton,* US Naval Research Laboratory*; **Virginia Wheeler**,* U.S. Naval Research Laboratory

The effect of chemically inert plasmas on the surface of thin film materials is of interest because it allows for an additional means to deliver energy to a material beyond increasing the material's temperature. This could be of use in cases where energy needs to be delivered to specific layers or interfaces in a heterostructure without subjecting the entire material stack to higher temperatures or to overcome energetic barriers, such as those associated with material crystallization (or amorphization) or the formation of metastable phases. However, plasmas make for a complex environment due to the various energy contributions from ions, electrons, excited species, and photons. Despite this complexity, an increased understanding of energy transfer at the plasmas-surface interface opens additional avenues in material engineering. This may be particularly true for plasma enhanced atomic layer deposition (PEALD) processes where deposited thin films are cyclically exposed to plasmas and thus could benefit from an increased understanding of the interaction between plasmas and material surfaces.

In this work we look at the impact of chemically inert remote Ar plasmas on crystalline VO_2 (c-VO_2) thin films deposited by ALD. Thermal ALD of VO_2 was carried out at 150 °C using TEMAV and O_3 and subsequently crystallized in a dedicated thermal annealing vacuum system using our typical process[1]. We demonstrate that under certain plasma conditions we can remove the Raman signature of the c-VO_2 films without any change to the surface morphology of the material, and this capability was greater when operating at lower pressures during the plasma exposure. Additionally, by changing the Ar plasma conditions used, we are also capable of recovering the crystalline nature of the previously damaged films; this was accomplished by treating the sample to subsequent plasma exposures of descending power. This presentation will discuss the details of these experiments and, with the aid of in situ plasma diagnostics, attempt to elucidate the mechanisms responsible for the behavior observed.

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EM-MoP-17 Vapor Phase Infiltration of Metal Oxides into Polymeric Water Treatment Membranes*, Jiaman Wang, Daewon Kim, Soobin Cho, **Bezawit Getachew**,* Rice University

Vapor phase infiltration of metal oxides into polymeric membranes may offer a novel way to combine the benefits of polymeric and ceramic membranes and enable improved capabilities in water treatment membranes. In this paper, we investigate the infiltration of alumina into four different types of polymeric membranes used in water treatment, namely, polyamide reverse osmosis membranes, commercial cation and anion exchange membranes, and polyethersulfone ultrafiltration membranes. The infiltration is characterized by using X-ray photoelectron spectroscopy (XPS) to confirm the presence of metal oxide, quantify the amount of incorporation at the surface and as a function of depth, and probe the type of bonding taking place. Complementary SEM-EDX (Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy) experiments show the distribution of the inorganic phase within the membranes. We find that bulk infiltration is possible on all types of membranes, with commercial anion exchange membranes and polyethersulfone membranes showing the greatest uptake, while polyamide RO and cation exchange membranes result in greater surface deposition. Preliminary results show that in the case of anion exchange membranes, transport properties are not altered due to infiltration while the stability of the membranes in high pH and hypochlorite environments is greatly improved.

EM-MoP-18 Tunable Phase Change Behavior of VO_2 Thin Films Grown by Atomic Layer Deposition*, **Jeremy Bairan Espano**, Joe Klesko,* Sandia National Laboratories

Vanadium Dioxide (VO_2) is an emerging phase change material with numerous applications including sensors, transistors, and photonics. Presently however, VO_2 thin films possess synthetic challenges. While established methods of synthesizing VO_2 (e.g. sputter deposition, physical vapor deposition, chemical vapor deposition, and hydrothermal synthesis) have been successful at growing this material phase-pure, these approaches do not support conformal deposition on 3D or high-aspect ratio surfaces. Additionally, tuning the phase change temperature has proven to be costly and not well controlled, with many methods using expensive doping processes (e.g. Ta, Mo, Fe, N) to modulate the transition temperature. In this study, we leverage atomic layer deposition (ALD) to synthesize VO_2, due to its unique ability to grow conformal films with angstrom-level thickness control. By optimizing the post-ALD annealing parameters (e.g. O_2 flow rate/partial pressure, temperature, ramp rate, etc.), we can tune the phase-transition transition temperature and width of the hysteresis. Herein, our exploration of annealing environments, coupled with microscopic and spectroscopic thin film measurements supports precise tunability of thin film VO_2 for next-generation technologies.

EM-MoP-19 Scalable and Controllable Deposition of Extrinsically Doped P-Type MoS_2 via Thermal Atomic Layer Deposition*, **Sungjoon Kim**, Jeffrey Elam,* Argonne National Laboratory

Computational energy consumption is increasing exponentially, making energy-efficient microelectronics and computing an urgent need. Three-dimensional integrated circuits (3D ICs) and neuromorphic computing promise to revolutionize information technology by drastically reducing the energy consumption of computers, and two-dimensional (2D) semiconductors like molybdenum disulfide (MoS_2) can enable such technologies. However, the development of complementary p-type MoS_2 is needed to fully leverage the benefits of 2D semiconductors. Moreover, thermal processes for thin film deposition are preferred over plasma-based techniques in high aspect ratio applications such as vertical gate-all-around transistors and 3D NAND. Here, we demonstrate the uniform and controlled deposition of extrinsically doped p-type MoS_2 using thermal atomic layer deposition (ALD). By varying the dopant cycle ratio, the final MoS_2's resistivity and charge carrier concentration can be precisely tuned. The resulting p-type MoS_2 was characterized using techniques including Raman spectroscopy, X-ray photoelectron spectroscopy, and Hall measurements, and was used to fabricate and test memtransistors. This work offers a pathway to deposit p-type 2D materials with tailored material properties.

EM-MoP-20 Mechanistic Transformation Pathway to Continuous and Impurity-Free Tellurium Films*, **Seung Ho Ryu**, Seungsu Kim, Jihoon Jeon, Gwang Min Park, Seong Keun Kim,* Korea University, Republic of Korea

As Si-based devices approach their physical scaling limits, monolithic three-dimensional (M3D) integration has emerged as a promising strategy for continued performance enhancement. In this architecture, transistors are vertically stacked within the back-end-of-line (BEOL) layers, imposing a strict process temperature limit below 400 °C to prevent degradation of front-end CMOS circuits. This restriction necessitates new channel materials that can be processed at low temperatures while maintaining high performance. Although substantial advances have been achieved in n-type oxides such as In_2O_3 and IGZO, the development of BEOL-compatible p-type channels remains limited.

Tellurium (Te) has attracted attention as a promising p-type semiconductor owing to its intrinsically high hole mobility and low melting point. However, direct ALD growth typically yields discontinuous, island-like films due to poor wettability and weak interchain van der Waals bonding. Previous approaches, such as increasing precursor pressure or introducing TeO_2 adhesion layers, have shown limited success because of poor conformality and interfacial oxygen residues. Here, we present a transformation-based strategy in which ALD-deposited TeO_2 is subsequently reduced to elemental Te. This method enables the formation of ultrathin, continuous, and oxygen-free Te layers with excellent conformality. Comprehensive structural and electrical analyses confirm complete phase conversion, smooth morphology, and stable p-type conduction, demonstrating a viable route for BEOL-compatible p-type channel integration in next-generation M3D electronics.

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