Advanced Microelectronic Materials and Devices Mini-Symposium
Room 318 - Session AM1+EM+TF-WeA

Industry Perspective

Moderators: Dr. Robert Grubbs, IMEC Belgium, **Dr. Sarah Lynch**, TEL Technology Center, America, LLC, USA

2:15pm **AM1+EM+TF-WeA-1 Memory Centric AI and the Role of Advanced Materials in Future Semiconductor Technologies***, **Shivani Srivastava***, Micron Technology **INVITED**

The rapid growth of artificial intelligence (AI) is shifting system design from compute-centric to memory-centric architectures, where bandwidth, capacity, and energy efficiency increasingly determine performance. For AI workloads, the resulting memory bottleneck is creating new demands on semiconductor materials, processes, and integration schemes.

This talk will examine how these demands are influencing the future direction of advanced DRAM, High Bandwidth Memory (HBM), 3D and emerging nonvolatile memory technologies.

In DRAM, continued scalingis increasingly associated with efforts toward leakage reductions, variability minimization, and the exploration of novel integration schemes to optimize performance.

In parallel, industry trends toward increasing 3D DRAM layer counts are driving the need for high aspect-ratio etch and gap fill, conformal deposition, and high-quality epitaxial growth approaches.

While HBM, advanced CMOS integration, and heterogeneous packaging are becoming essential to reducing the compute-memory gap, thermal-mechanical reliability, power efficiency, and co-packaged optics are expected to play an increasing role in improving system-level performance.

Across these platforms, thin-film process control, conformality, interfaces, defect management, thermal-mechanical reliability, and system-level co-optimization are emerging as central levers for overcoming the AI memory wall.

2:45pm **AM1+EM+TF-WeA-3 Angstrom-Era Logic: From Nanosheets to Hybrid Bonding***, **Biswajeet Guha***, Intel Corporation **INVITED**

Advanced microelectronics scaling has entered an era in which performance and density gains can no longer come from transistor miniaturization alone. Innovation now spans two tightly coupled fronts—front-end device architecture and advanced heterogeneous packaging—unified under the emerging paradigm of System Technology Co-Optimization (STCO). This talk presents a material-centric perspective on both, highlighting opportunities for the AVS community to contribute foundational research.

At the transistor level, the transition from FinFET to gate-all-around (GAA) nanosheet architectures, exemplified by angstrom-class nodes such as 18A, restores electrostatic control while introducing demanding materials challenges in high-k interfaces, work-function metals, and inner-spacers. Backside power delivery further reshapes the device stack, imposing new requirements on wafer thinning, through-silicon contacts, and thermal management, while contact and interconnect resistance remain critical bottlenecks demanding novel liner/barrier schemes and interface engineering.

Equally consequential are the materials challenges in advanced packaging, where scaling has shifted to the system level through heterogeneous integration. Fine-pitch hybrid bonding makes void-free Cu–Cu and dielectric–dielectric joining a surface-science problem governed by oxidation control, CMP dishing, and surface activation. Stacked high-power dies intensify the need for advanced thermal interface materials and careful management of CTE mismatch, while fine-line redistribution layers, low-loss dielectrics, underfills, and interposers each present challenges in adhesion, stress, and warpage.

By framing transistor and packaging innovation together through an STCO lens, this talk argues that the future of microelectronics depends on co-optimizing materials, processes, and architectures across the entire system—offering fertile ground for the surface- and materials-science community.

3:15pm **AM1+EM+TF-WeA-5 Epitaxial CVD Ruthenium for High-Performance Interconnects at A7 and Beyond***, **Gyana Pattanaik***, Tokyo Electron America

Ruthenium is projected to replace Cu in A7 node or beyond, likely bringing back subtractive integration that Cu replaced with damascene almost 3 decades ago. To enable this transition, integration of Ru interconnect metal lines and vias with lower resistivity need to be demonstrated. Ru thin films with very low resistivity (~8 μΩ-cm at 30nm; bulk =7.4 μΩ-cm) has been reported [1], by depositing epitaxial PVD Ru on Si (111) with buffer layers like AlN (001). Layer transfer approach has been proposed for integration of such epitaxial Ru [1]. PVD epi-Ru can be suitable for interconnect metal lines through patterning and direct metal etch. However, it may not be ideal for via, even though some integration approaches explore to use it. CVD via filling remains an attractive integration approach for via metal [2]. Here we demonstrate epitaxial CVD Ru for selective via filling (Fig 1).

In this study, we used epitaxial PVD Ru (6 and 8 nm)/AlN (001)/Si(111) as substrates for CVD Ru experiments conducted in a CVD reactor. A series of preclean steps was applied to eliminate surface oxides and refresh the surface before CVD Ru growth under different deposition conditions. Powder XRD patterns (2θ-ω scans) show only Ru (*00l*) peaks, indicating CVD Ru film growth along *c*-axis. Representative CVD Ru film growth is shown in Fig 2. Laue oscillations at the bottom of Ru (002) peak are signature of epitaxial film growth. The Ru (101) Φ-scans collected at c=61.3^0 show six-fold symmetry (Fig 3), like the underlying PVD epi-Ru, further confirming epitaxial CVD Ru film growth [1]. This paper will summarize systematic studies of CVD Ru film growth on PVD epi-Ru and characterizations including microstructure and electrical properties.

References:

1. C. Adelmann et.al, Epitaxial Ruthenium for Advanced Interconnects, IITC (2025) P32.
2. M. H. van der Veen, et. al, Selective Deposition and Ruthenium Superfill Exploration Beyond A10 Node Interconnects, VLSI Symposium (2025), T18-3.

Keywords: Interconnects, Ruthenium, Epitaxy, CVD

Advanced Microelectronic Materials and Devices Mini-Symposium
Room 318 - Session AM2+EM+TF-WeA

Devices I

Moderators: Dr. Devika Choudhury, ASM, **Dr. Philip Lee**, University of Kentucky

3:30pm **AM2+EM+TF-WeA-6 Beyond Binary Erasure: Harnessing a Constrained RESET Operation for Analog Synaptic Plasticity in ReRAM***, **Marius Orlowski***, Virginia Tech

Neuromorphic computing overcomes von Neumann bottlenecks by co–locating memory and processing. Filamentary ReRAM and CBRAM are promising synaptic candidates due to compactness, non–volatility, and analog tunability, but conventional binary SET/RESET offers coarse control over conductance. This work reports a novel regime in Cu/TaO_x/Pt CBRAM—constrained RESET—where a compliance–limited RESET strengthens rather than ruptures the filament. For high–resistance filaments (R_{on} > 1 kΩ), constrained RESET reduces resistance up to tenfold, while robust filaments are unaffected, making the effect self–limiting and most useful for fragile states. The reconstruction of the Cu atom filament leads to reduced electric fields, reduced Joules heat, and reduced resistance, rendering this mechanism self-limiting. Electrostatic simulations show that a weak filament (truncated cone) concentrates electric field at its narrow tip (>1.6×10^6 V/cm) under negative bias, driving Cu^+ electromigration toward the constriction and forming a stable hourglass (double–cone) morphology. To harness this for analog weight control, we integrate the memristor with a series transistor operating in saturation, providing tunable compliance current (I_{cc}). Using pulse trains, we implement two programming techniques: (i) Incremental Step Pulse with Verify Algorithm (ISPVA), modified to stay below the rupture threshold, and (ii) Incremental Gate Voltage with Verify Algorithm (IGVVA), where gate voltage (hence I_{cc}) is incremented with fixed programming pulses. The three control parameters (ramp rate, compliance current, stop voltage) map to biological learning mechanisms, enabling precise, linear, symmetric synaptic weight updates. This work addresses three persistent challenges: instability of high–resistance states, asymmetry between potentiation/depression, and lack of linear analog control. The constrained RESET operation,

implemented with transistor–based compliance control, provides stable, fine–grained weight updates. It is fully compatible with existing ReRAM stacks, adds no fabrication complexity, and improves retention and variability, accelerating commercialization for edge AI, robotics, and autonomous systems. The advantages of the new potentiation technique include: (i) Precise and stable analog resistance control for reliable synaptic weight updates, (ii) Non-destructive constrained RESET enabling symmetric and linear weight modulation, (iii) High-resistance state stabilization for improved memory retention and device reliability.

4:15pm **AM2+EM+TF-WeA-9 Epitaxial β-Ga_2O_3 Thin Films on Mica Integrated with Copper Heat-Dissipating Electrodes for High-Power Devices**, ***Ping-Hsien Wu***, *Ying-Hao Chu,* National Tsing Hua University, Taiwan

Gallium oxide (Ga_2O_3) has recently attracted significant attention as an ultra-wide-bandgap semiconductor for next-generation high-power electronic devices. In high-power applications, device operation generally relies on high voltage and low current to reduce conduction losses. However, conventional device design faces a trade-off between reducing on-resistance and maintaining high breakdown voltage, as thinner drift layers lower resistance but also degrade voltage endurance. To address this limitation, materials with high critical electric fields are essential. Ga_2O_3 offers a significantly higher critical electric field than conventional semiconductors such as Si and SiC, enabling high breakdown voltage operation even at reduced thickness, thereby improving power efficiency. Nevertheless, its low thermal conductivity remains a critical challenge due to heat accumulation and potential thermal breakdown. In this work, high-quality Ga_2O_3 thin films with a rocking curve full width at half maximum (FWHM) of approximately 0.3° were achieved, indicating excellent crystalline quality. The Ga_2O_3 films were epitaxially grown on two-dimensional artificial mica substrates and subsequently transferred onto high-thermal-conductivity copper foils to enhance heat dissipation. In addition, a pn heterojunction composed of 600 nm-thick Ga_2O_3 and NiO was fabricated, exhibiting a breakdown voltage exceeding 500 V. The proposed structure simultaneously preserves high-voltage capability and improves thermal management, demonstrating a promising approach for high-power Ga_2O_3-based electronic devices.

4:30pm **AM2+EM+TF-WeA-10 Ultra-thin nickel films for 4H-SiC Schottky barrier diode**, ***Renato Beraldo***, UNICAMP, Brazil

4H-SiC Schottky barrier diode (SBD) devices were fabricated on n-type 4H-SiC substrates using an ultrathin nickel film of 2 nm as the Schottky contact layer, deposited via electron-beam evaporation. First, the ohmic contact was formed using 100 nm of nickel, and the samples were annealed at 950 °C for 5 minutes. Subsequently, 2 nm of Ni was deposited, and the devices were subjected to various annealing temperatures. To create the metallic contact, 300 nm of Al was deposited by thermal evaporation and patterned into pads of 2 mm diameter without any shielding structure. The influence of annealing temperature on electrical performance and interface quality was evaluated. Electrical characteristics were measured using a parameter analyzer, and surface morphology was analyzed by atomic force microscopy (AFM). For comparison, reference SBDs with a conventional 100 nm Ni film were fabricated and characterized under identical conditions.

A set of samples was annealed at temperatures ranging from 500 to 700 °C in 50 °C steps for each sample. After the annealing treatment, the final thickness was approximately 8 nm, as measured by AFM. Electrical measurements showed that diodes were obtained at all annealing temperatures, but the best electrical performance was achieved at 650 °C, with devices annealed at 500 °C and 700 °C showing inferior rectifying behavior. For comparison, a reference Schottky diode with a 100 nm thick Ni film was fabricated. The results revealed that the 2 nm diodes exhibited a Schottky barrier height (SBH) of 1.2 eV compared to 1.6 eV for the 100 nm diodes. However, the 2 nm diodes showed a rectification ratio two orders of magnitude larger and a leakage current of 22 pA compared to 3.2 nA at -200 V. Leakage current was also measured as a function of temperature from 25 to 175 °C. From 25 °C to 50 °C, the leakage current was approximately five times lower for the 2 nm devices compared to the 100 nm devices. Finally, the density of interface states was extracted from the 2 nm device, yielding a value of $10^{12} cm^{-2} eV^{-1}$, while the 100 nm device showed values around 10^{13} $cm^{-2} eV^{-1}$.

For future analysis, devices with lateral shielding will be fabricated to compare the breakdown voltage. Additionally, HRTEM and XPS characterization will be performed to verify the silicide composition stoichiometry and the presence of undesirable carbon clusters.

4:45pm **AM2+EM+TF-WeA-11 GaN Nanoscale Vacuum-Channel Transistors**, ***Huu Nguyen***, *George Wang, Keshab Sapkota,* Sandia National Laboratories

Field-emission-based nanoscale vacuum-channel transistors (NVCTs) can combine the robustness of vacuum devices with state-of-the-art lithography techniques enabling low operating power, on-chip integrability, energy efficiency, and high-performance stability in extreme environments such as high temperatures and high radiation. By scaling device channels to be below the electron's mean-free path in air, the NVCTs can be operate in air while maintaining the ballistic electron transport characteristic of vacuum. Here, we report experimental and modeling results of top-down fabricated, single emitter gallium nitride (GaN) lateral NVCTs. We used electron beam lithography along with dry and wet etching to fabricate GaN NVCTs with device channel lengths less than 60 nm. The devices exhibited stable high field-emission current up to 100 nA, with tuning on/off ratio greater than 10^3. Minimal leakage current from the gates was observed to be less than 0.1 nA. Finite-element (COMSOL) modeling showed strong electric field penetration of GaN emitter led to emission current modulation by the gate voltage. This study elucidates the operation of field emission based lateral gated devices and provides important understanding in the design and operation of these new class of devices. *Sandia National Laboratories is managed and operated by NTESS under DOE NNSA contract DE-NA0003525. This work was performed, in part, at the Center for Integrated Nanotechnologies, a U.S. Department of Energy, Office of Basic Energy Sciences user facility. This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.*

5:00pm **AM2+EM+TF-WeA-12 Atomic Layer Etching of Yttrium Orthovanadate Using Sequential Exposures of H_2 and SF_6/Ar Plasma**, ***Mariya Ezzy***, *Emanuel Green, Will Pajak, Andrei Faraon,* California Institute of Technology*; Joonhee Choi,* Standford University*; Austin Minnich,* California Institute of Technology

Yttrium orthovanadate (YVO) is a promising host crystal for rare-earth ion (REI)-based quantum devices, such as quantum memories and quantum transducers. The long optical lifetimes of REIs require coupling to optical resonators for faster single-photon emission and for enabling single-ion control. Such resonators are currently fabricated through focused ion beam (FIB) milling, which can leave rough, defect-rich surfaces that can degrade optical and spin properties, such as spectral diffusion. Atomic layer etching (ALE) has the potential to mitigate these fabrication-induced defects through precise, nanometer-scale etching and its surface smoothing effect. Here, we report the first ALE process for YVO in a home-built plasma etcher using an H2 plasma modification step followed by an SF6/Ar plasma removal step. Preliminary results indicate an etch rate of 0.35 Å per cycle. The etch rates, surface morphology, and surface chemical composition are characterized using atomic force microscopy and X-ray photoelectron spectroscopy (XPS).

Advanced Microelectronic Materials and Devices Mini-Symposium
Room 318 - Session AM+EM+TF-ThM

Ferroelectric Thin Films

Moderators: Prof. Dr. John F. Conley, Jr., Oregon State University, **Dr. Daniel Pennachio**, Naval Research Laboratory

8:00am **AM+EM+TF-ThM-1 Processing and Properties of Ferroelectric Wurtzite Thin Films**, ***Jon-Paul Maria,*** Penn State University **INVITED**

Ferroelectricity in wurtzite-based crystals was observed in 2019 and immediately introduced exciting opportunities to explore and discover new structure-property relationships in novel formulation spaces. These observations lead one to speculate that ferroelectricity might be found much more broadly, even “everywhere”, by introducing the appropriate disorder in a variety of hosts.

The presentation will begin with a brief history of ferroelectricity with specific attention to the last 10 years where this important property was discovered in new oxide and nitride crystals. The remaining content will focus on the structure-process-property relationships in the B-substituted AlN and Mg-substituted ZnO wurtzite systems. Materials can be prepared between 100 °C and 350 °C with very little difference in electrical properties. In the best cases, capacitors can be prepared down to 10 nm thickness while still exhibiting ferroelectric switching. Below 25 nm, however, leakage current becomes problematic during low frequency hysteresis measurements. Challenges to thickness scaling will be discussed with attention to the origins of property dependencies on structure , defects, and microstructure with film thickness. The presentation will also include examples where proximity effects in layered ZnO/$Zn_{1-x}Mg_xO$, AlN/$Al_{1-x}B_xN$, and $Zn_{1-x}Mg_xO$/AlN heterostructures can induce switching in pure ZnO and AlN layers, with opportunities for reducing net coercive voltage values.

8:30am **AM+EM+TF-ThM-3 Interfacial Control and Property Enhancement Through Proximity Ferroelectricity**, ***Ian Mercer,*** *William Prudnick, Saeed Almishal, Pochun Hsieh, Stanislav Udovenko, Darren Pagan, Venkatraman Gopalan, Jon-Paul Maria,* Penn State University

Ferroelectric layers can induce switching in neighboring polar non-ferroelectric layers, this phenomenon is referred to as proximity ferroelectricity. Prior studies have only focused on bi- and trilayer geometries, leaving room to further study on interface effects. Here, we explore interfacial and surface contributions more broadly, including, for example, the density effects in AlN/$Al_{1-x}B_xN$ and AlN/$Al_{1-x}Sc_xN$ superlattices grown using reactive magnetron sputtering. In addition, we examine compositionally graded structures that smear the same chemical contrast into an interface-less continuum. To complement this understanding, we also compare materials whose surfaces are plasma modified to create a partnering interface that can also influence switching. Thin film morphology and structural quality is probed using atomic force microscopy (AFM) and x-ray diffraction (XRD), revealing smooth films with RMS roughness below 1 nm in all cases. For superlattices, distinct satellite peaks indicating sharp, periodic interfaces are present. Deep UV photoluminescence (PL) measurements surprisingly reveal evolution with increasing interface density. By examining coercive field, current transport, and switching kinetics, we find that the internal interfaces act as barriers to both domain propagation and leakage transport. We also find grading $Al_{1-x}Sc_xN$ from x = 0.38 to x = 0 through the film thickness produces a substantial increase in coercive field, with some structures exhibiting strong insensitivity to Sc composition. These results establish interface, compositional grading, and surface processing – well-established opportunities in III-nitride alloys – as new degrees of freedom in wurtzite ferroelectric materials, demonstrating that engineered surfaces and gradients can strongly modify bulk switching behavior beyond conventional composition control. This transition towards interface engineering allows finer control over coercive field, domain structure, and leakage current barriers, ultimately enabling surfaces to enhance navigation through property space.

8:45am **AM+EM+TF-ThM-4 Unveiling the Hidden Role of Interfacial Layer in Ta/HZO Ferroelectric Tunnel Junctions Band-Profile and Tunneling-Electroresistance Engineering**, ***Sanghyun Lee,*** University of Kentucky*; Kent Price,* Morehead State University*; M. David Henry, Samantha Jaszewski,* Sandia National Laboratories, USA*; Alexander Blevins,* University of Kentucky, United States Minor Outlying Islands (the)

Ferroelectric tunnel junctions (FTJs) are promising two-terminal devices for neuromorphic computing, providing non-volatile, analog-tunable conductance via polarization-controlled tunneling. Their compact metal–ferroelectric–metal structure, low programming energy, and compatibility with CMOS processes make them suitable as synaptic elements for computing-in-memory. Hafnium oxide-based systems, such as $Hf_{0.5}Zr_{0.5}O_2$ (HZO), are especially notable for maintaining robust ferroelectricity at thicknesses below 10 nm, which supports scalable crossbar arrays for high-density neuromorphic computing.

The electrical performance of metal/HZO/metal FTJs is significantly influenced by interfacial chemistry; however, previous research efforts have consistently assumed an ideal, abrupt metal/HZO interface. In particular, Ta/HZO or Ti/HZO devices tend to form the unavoidable sub-stoichiometric TaO_x or TiOx layer due to tantalum's oxygen-scavenging properties. To bridge this research gap, we have investigated the interface layer and their material and device characteristics to unveil key physical mechanism. Utilizing in-house MATLAB modeling suites with Sentaurus TCAD simulators, the impact of this interlayer on band profile, tunneling pathways, and the resulting tunneling electroresistance (TER) is quantitatively assessed.

After fabricating and validating Ta/HZO (6 nm)/TaN devices, we characterized FTJs and developed a graded TaO_x interlayer device model with thicknesses from 0.3 to 1.5 nm and various permittivity values. Our model incorporates realistic oxygen vacancy concentrations (10^{19}–10^{21} cm^{-3}) and trap levels 0.5–1.2 eV below the HZO conduction band, which agrees well with experimental data. By integrating ferroelectric polarization, band bending, vacancy charge balance, the simulations represent the complete electrostatic and defect-mediated conduction mechanism at the Ta/HZO interface.

Our preliminary results uncover distinct regimes in which TaO_x either enhances or degrades FTJ performance. Thin, moderately defective layers (approximately 0.5 to 0.8 nm, oxygen vacancies around 10^{19} cm^{-3}) create a beneficial asymmetric barrier that increases TER by a factor of 3 to 6 compared to an ideal Ta contact, while maintaining read current. In contrast, thicker or highly oxygen-deficient TaO_x layers function as parasitic resistive elements, reducing low-resistance state current by more than an order of magnitude and generating significant internal bias fields. Simulated internal bias fields and coercive voltage shifts align with experimentally observed imprint trends, supporting the validity of the model.

9:00am **AM+EM+TF-ThM-5 Processing Window and Property Enhancement via Tellurium Co-Doping in Sputtered Ferroelectric $Zn_{1-x}(Mg, Te)_xO$ Thin Films**, ***William Prudnick,*** *Ian Mercer,* Pennsylvania State University*; Ece Günay,* Carnegie Mellon University*; Po Chun Hsieh, Saeed Almishal,* Pennsylvania State University*; Elizabeth Dickey,* Carnegie Mellon University*; Venkatraman Gopalan, Jon-Paul Maria,* Pennsylvania State University

Wurtzite ferroelectric materials show promise for application in non-volatile random-access memory (RAM). $Zn_{1-x}Mg_xO$ (ZMO), a wurtzite material first reported to be ferroelectric in 2021, shows significantly higher polarization retentions than perovskite ferroelectrics, similar to $Al_{1-x}Sc_xN$ and $Al_{1-x}B_xN$ but with markedly lower coercive fields compared to other wurtzite ferroelectrics (~2-3 MV/cm vs. ~4-6 MV/cm). However, leakage current, imprint, and intolerance for elevated growth temperatures remain persistent hinderances. Herein, we report tellurium incorporation within ZMO via reactive RF co-sputtering. $Zn_{1-x}(Mg, Te)_xO$ (ZMTO) films maintain consistently low coercive fields (~2.4 MV/cm) even at elevated growth temperatures (up to 350° C with no diminishment in ferroelectric properties) while simultaneously decreasing imprint. X-ray diffraction (XRD) data indicate highly c-oriented films with improved out-of-plane crystallinity. Omega rocking curves show reduction in mosaicity compared to previously reported values (< 2° FWHM vs. ~4° FWHM). X-ray reflectometry (XRR) data demonstrate low rms roughness values consistently below 1.5 nm. Transmission electron microscopy (TEM) data indicate columnar growth and planar defects such as stacking faults consistent with previous reports. Selected-area electron diffraction (SAED) supports wurtzite phase uniformity. X-ray photoelectron spectroscopy (XPS)

indicate tellurium is in the +4 oxidation state. Fourier transform infrared (FTIR) and Raman spectroscopies show tellurium with a 4-coordinate geometry indicative of Zn-site occupancy. We highlight photoluminescence spectroscopy (PL) data and expound upon dopant and temperature dependence of the defect landscape. We emphasize the underlying defect chemistry and doping strategies to overcome challenges in synthesis as they relate to material properties and structure enhancements.

9:15am **AM+EM+TF-ThM-6 Structurally Compatible Al-doped ZnO Bottom Electrode for Wurtzite Ferroelectric Mg-substituted ZnO Thin Films**, ***Sharon Yang***, The Pennsylvania State University; *Ece Gunnay,* Carnegie Mellon University; *William Prudnick,* The Pennsylvania State University; *Elizabeth Dickey,* Carnegie Mellon University; *Jon-Paul Maria,* The Pennsylvania State University

Epitaxial wurtzite heterostructures are prepared to eliminate, to the extent possible, structure defects and microstructure that may, in principle, interfere with or limit their ferroelectric properties and performance. In so doing, we attempt to achieve and understand the true intrinsic response. To do so, we begin with epitaxial c-axis oriented Al-doped ZnO (AZO) bottom electrodes grown on (0006)-Al_2O_3 via dual-cathode reactive RF magnetron co-sputtering. X-ray diffraction (XRD) indicates a single-phase c-axis oriented growth with x-ray omega and two-theta peak widths, electrical resistivity, and surface roughness values that all decrease with increasing substrate temperature and aluminum cathode power. The optimal AZO thin films exhibit an omega FWHM of 0.04° and surface roughness of 900 pm RMS, and a peak Hall mobility of 47 $cm^2/V{\cdot}s$, a Hall carrier density of 1.3E20 cm^{-3}, a minimum Hall resistivity of 1E-4 Ω·cm, and a STEM-EDS confirmed a composition of 1.7 at.% Al and uniform thickness of 43 nm. Infrared spectroscopic ellipsometry as function of Al content demonstrates tunable epsilon-near-zero behavior where the zero-permittivity wavelength ranged between 1970 and 3170 wavenumbers for 4.1E19 cm^{-3} and 1.3E20 cm^{-3} carrier concentrations respectively. Subsequently, $Zn_{0{\cdot}78}Mg_{0{\cdot}22}O$ (ZMO) films were deposited at room temperature, XRD indicating a strong c-axis growth of ZMO on AZO with FWHM of 0.86°. High-resolution TEM and STEM-EDS analysis revealed chemically abrupt ZMO/AZO interfaces. The heterostructure displays robust ferroelectric switching with a remanent polarization exceeding 88 $\mu C{\cdot}cm^{-2}$ and a coercive field below 2.8 $MV{\cdot}cm^{-1}$. Compared to previously reported ZMO films grown on non-epitaxial Pt bottom electrodes, these epitaxial oxide heterostructures exhibit comparable ferroelectric switching behavior while providing substantially improved structural compatibility and crystallographic coherence throughout the stack. These stacks are additionally attractive because they remain transparent throughout the visible spectral range, and these findings establish epitaxial AZO as a viable, highly compatible oxide bottom electrode platform for high-performance wurtzite ferroelectric thin films.

9:30am **AM+EM+TF-ThM-7 Stabilization of Antipolar Pbca Phase in Hafnium Zirconium Oxide via Aluminum Substitution**, ***Yong Kyu Choi***, University of Virginia, USA; *MinChul Kang,* Ames National Laboratory; *Tinase Ale,, Nicolas Lam, Andrea Watson, Kory Burns, Stephen McDonnell, Lin Zhou, Jon Ihlefeld,* University of Virginia, USA

Hafnium zirconium oxide (HZO) shows significant potential for non-volatile memory applications due to its ferroelectric properties. However, practical limitations such as insufficient endurance remain a significant challenging prior to commercialization. One promising approach to overcome this limitation is the implementation of antiferroelectric (AFE) behavior in HZO-based materials. Previous studies have demonstrated that cation substitution in HZO can induce AFE-like behavior within certain substitution concentration ranges. In Zr-rich HZO systems, this AFE response has commonly been attributed to the tetragonal phase. However, recent reports indicate that the observed AFE behavior may instead originate from the antipolar orthorhombic (*Pbca*) phase. This presentation discusses how varying an aluminum substitution concentration influences the phase stability and electrical properties of HZO thin films. Grazing-incidence X-ray diffraction, Fourier transform infrared spectroscopy, and scanning transmission electron microscopy are employed to investigate the structural transformation and AFE behavior of Al-substituted HZO capacitors. The results demonstrate that low aluminum substitution concentrations, such as 8:1 and 6:1 Al:HZO ratios, exhibit AFE behavior associated with stabilization of the antipolar orthorhombic *Pbca* phase.

11:00am **AM+EM+TF-ThM-13 Ferroelectricity in Atomic Layer Annealed Nitride-Based Thin Films**, ***Andrew Meng***, *Dominic Dalba, Dilan Gamachchi, Indeewari Karunarathne, Bipin Bhattarai,* University of Missouri-Columbia; *Xiaoman Zhang,* University of North Alabama; *Wangwang Xu,* Louisiana State University; *Somayeh Saadat Niavol,* University of Missouri-Columbia; *Dongmei Cao, W.J. Meng,* Louisiana State University **INVITED**

Wurtzite AlN-based materials exhibit strong ferroelectric behavior and offer potential for a wide memory window due to their high coercive field, making them promising candidates for non-volatile memory applications. Most studies on wurtzite AlN-based ferroelectrics focus on reactive sputtered thin films, which can suffer from deleterious effects of point defects caused by ion bombardment. Atomic Layer Deposition (ALD) can lead to films with fewer electronic defects at significantly lower growth temperatures. However, the crystallinity can be low even in plasma assisted processes. Nitrogen incorporation in ALD films also remains challenging. We demonstrate the growth of nanocrystalline wurtzite AlN thin films deposited by a three-step atomic layer annealing (ALA) process at 350°C consisting of trimethylaluminum and hydrazine precursor pulses and a nitrogen plasma annealing step. Interestingly, these films are ferroelectric without intentional extrinsic alloying, which we attribute to very high dielectric strength in excess of 10 MV cm^{-1}. The films exhibit a remanent polarization of ~ 35 μC cm^{-2}, and piezoresponse force microscopy experiments show phase and amplitude changes after DC poling consistent with ferroelectricity. We also demonstrate growth of AlBN using an ALA process. The ALA growth process for wurtzite AlN-based ferroelectric materials is potentially compatible with processing for silicon electronics and holds promise for next-generation semiconductor devices.

11:30am **AM+EM+TF-ThM-15 Ferroelectric and Rf Electrical Properties of Peald Scaln Thin Films**, ***Virginia Wheeler***, *Vikrant Gokhale, Margo Staruch,* US Naval Research Laboratory; *Jaime Hart,* Nova Research Inc; *Jonathan Chin, Peter Litwin,* NRC, US Naval Research Laboratory; *Neeraj Nepal,* US Naval Research Laboratory; *Gilbert Rayner, Jr, Noel O'Toole,* Kurt J. Lesker Company; *Nicholas Strnad,* Army Research Laboratory

Scandium aluminum nitride (ScAlN) has emerged as a transformative material for advanced microelectronics, driven by its exceptional piezoelectric response and robust ferroelectric properties. While traditional deposition methods, such as magnetron sputtering and molecular beam epitaxy (MBE), have enabled its initial integration, these line-of-sight techniques inherently lack the conformality required for next-generation, three-dimensional device architectures. Plasma-enhanced atomic layer deposition (PEALD) addresses this critical manufacturing bottleneck by providing self-limiting, atomic-scale control over film thickness and composition, enabling the uniform coating of complex, high-aspect-ratio structures. These benefits make PEALD ScAlN appealing for advancements in RF filters, where sub-nanometer thickness uniformity directly dictates acoustic performance and high-frequency bandwidth, and high-density 3D non-volatile memory (NVM) architectures requiring high-quality ultrathin layers. Consequently, the development of PEALD processes for ScAlN represents a critical pathway toward achieving next-generation, scaled, high-performance communication and at the edge computing technologies.

Using the PEALD process developed by Rayner et. al [1], 20-60nm ScAlN films were deposited on 50nm NbN/sapphire and Pt/SiO_2/Si templates with both 18% and 30% Sc. XRD and TEM confirm that all films are texture, polycrystalline in nature with roughness directly related to increasing Sc concentration and thickness. The 18% films exhibit low leakage, very flat permittivity (ε_r ~12-14) from 20 Hz to 3GHz, and low dielectric loss. However, increasing the Sc content results in more leaky films with strong dispersive permittivity and high loss, remarkably similar to MBE ScAlN/NbN films with 32% Sc.

Additionally, the 18% ScAlN/NbN film is confirmed to be ferroelectric, with measurements at the highest electric field achieved showing a remanent polarization value of 80 $\mu C/cm^2$. The coercive field, E_C, is approximately 5.5 MV/cm at room temperature and 50 kHz, comparable to previous reports of this composition. Although the measured polarization is below anticipated values, this is attributed to instrument limitations that precluded the application of higher electric fields, resulting in a minor loop with full saturation anticipated at increased field strengths. In-depth analysis of ferroelectric properties as a function of Sc content and substrate will be presented.

[1] Rayner et al, *JVSTA* 43, 020401 (2025).

11:45am **AM+EM+TF-ThM-16 Atomic-Scale Structure and Domain Mapping in Hafnia-Based Ferroelectrics***, **Ece Gunay**,* Carnegie Mellon University*; Sebastian Calderon,* Carnegie Mellon University, USA*; Rintaro Maki, Yuichi Shimakawa,* Kyoto University, Japan*; Daisuke Kan,* Osaka University, Japan*; Elizabeth Dickey,* Carnegie Mellon University, USA

Growing-memory architectures in logic circuits offer a promising pathway to reduce the energy cost associated with dense computing. These emerging device concepts require the integration of scalable, CMOS-compatible ferroelectric materials. Hafnium oxide, widely used as a gate dielectric, is inherently CMOS-compatible, and its ferroelectricity can be activated through cation alloying (e.g. Si, Zr, La, Y, etc.), which stabilizes a metastable orthorhombic phase and introduces new functionalities.

Because ferroelectric domains evolve and interact under applied bias, understanding their atomic-scale structure is critical for guiding device design. In this work, we investigated $Hf_{0.93}Y_{0.07}O_2$ freestanding membranes with in-plane polarization, enabling direct, real-space mapping of ferroelectric domains. Y-alloyed membranes were fabricated on (100) $SrTiO_3$ using a $La_{0.67}Sr_{0.33}MnO_3$ buffer layer, which was selectively etched to produce freestanding membranes for atomic-scale characterization.

Aberration-corrected scanning transmission electron microscopy (STEM) with annular dark-field (ADF) imaging was used to resolve cation positions, revealing ferroelectric domains oriented along the [001], [010], and [100] directions of the orthorhombic phase, forming 90° domain walls. Differential phase contrast (DPC) imaging enabled direct imaging of the oxygen sublattice. Vector pair correlation function analysis was used to map structure and domains across more than ten regions.

The results revealed that tetragonal-like inclusions are consistently observed near grain boundaries and domain walls. These inclusions are only a few unit cells thick and preserve overall lattice parameters while exhibiting local in-plane distortions. Additionally, lattice defects are frequently observed near 90° domain walls, likely accommodating strain arising from domain misorientation.

Overall, this study provides atomic-scale insight into the structural heterogeneity and domain behavior of hafnia-based ferroelectrics, offering guidance for optimizing their functional properties in next-generation electronic devices.

This material was based upon work supported by the Center for 3D Ferroelectric Microelectronics Manufacturing (3DFeM2), an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences Energy Frontier Research Centers program under Award Number DE-SC0021118.

12:00pm **AM+EM+TF-ThM-17 Correlating Biaxial Stress to Metastable Phases in $Hf_{0.5}Zr_{0.5}O_2$ on Substrates with Different Coefficients of Thermal Expansion***, **Nooreen Qureshi**,* University of Virginia, USA*; Luke Johnson,* Purdue University, USA*; Jordan Hachtel,* Oak Ridge National Laboratory, USA*; Jon Ihlefeld, Kory Burns,* University of Virginia, USA

Zirconium-substituted HfO_2 (HZO) has emerged as a leading candidate for next-generation ferroelectric memory and logic devices due to its Complementary Metal-Oxide-Semiconductor (CMOS) compatibility, scalability, and demonstrated ferroelectricity at thicknesses approaching 1 nm. Among the competing factors governing the ferroelectric phase stability in HZO including dopant density, oxygen vacancy concentration, electrode capping, and grain size; mechanical biaxial stress remains comparatively underexplored yet critically influential.

In this work, HZO thin films were deposited by Atomic Layer Deposition (ALD) on substrates with systematically varied coefficients of thermal expansion (CTE) to controllably tune the biaxial strain state. Macroscopic characterization via X-Ray Diffraction (XRD) and Infrared Spectroscopy (IR) reveal strain-dependent peak shifts that directly reflect the biaxial stress imposed by the substrate. Electrical measurements demonstrate a clear strain-dependent phase transition; films on low-CTE substrates exhibit ferroelectric polarization-voltage responses, while high-CTE substrates drive an antiferroelectric-like response, implicating strain as a tunable lever for phase stabilization.

To connect macroscopic behavior to local structural heterogeneities, scanning nanodiffraction 4D-STEM (Scanning Transmission Electron Microscopy) was employed to map lattice strain at the nanoscale. The correlation between local strain fields and bulk electrical response provides mechanistic insight into how nanoscale inhomogeneities propagate to device-level performance. This multi-scale characterization framework offers a comprehensive approach for engineering phase stability in fluorite-structure ferroelectrics.

Advanced Microelectronic Materials and Devices Mini-Symposium
Room 318 - Session AM+EM+TF-ThA
ALD Fundamentals to Devices & Flash Session

Moderators: Prof. Andrew Meng, University of Missouri, **Prof. Dr. Greg Parsons**, North Carolina State University

2:15pm **AM+EM+TF-ThA-1 When Growth Has Not Yet Begun: Nucleation and Interface Control in Atomic Layer Deposition**, ***Zsófia Baji,*** Centre for Energy Research, Hungary; *Zsófia Bérces,* Centre for energy research, Hungary; *Zoltán Szabó,* Centre for Energy Research, Hungary **INVITED**

Atomic layer deposition (ALD) is generally described as a self-limiting thin-film growth technique producing conformal and compositionally controlled layers with atomic-scale precision. However, in the earliest stages of growth, precursor adsorption, surface chemistry, and substrate-dependent reaction pathways limit growth. These phenomena become increasingly important in the deposition of ultrathin functional films for emerging electronic technologies, where the target thickness often lies entirely within the nucleation regime. Understanding the atomistic and chemical mechanisms governing the transition from isolated nuclei to continuous films is therefore essential for the development of next-generation memory, logic, and two-dimensional device architectures.

The classical nucleation behaviour of oxide ALD systems is largely influenced by the chemistry and crystallinity of the substrates: the initial ALD cycles are controlled not only by precursor saturation but also by the density and distribution of chemically active surface sites and lattice matching. The role of precursor size, ligand configuration, and available hydroxyl density in determining growth-per-cycle behaviour and nucleation efficiency can be examined using phenomenological nucleation models. The comparison between experimental film morphologies and theoretical growth descriptions give insight to the initial stages of film growth. Mathematical nucleation modelling used to analyse the transient growth behaviour can be used to derive the unknown boundary conditions governing the initial deposition stages.

The difference between precursor chemistries can be demonstrated by oxide and sulfide nucleation pathways. Sulfide growth is fundamentally hindered by the mismatch between conventional hydroxyl-terminated oxide substrates and sulfur-based film chemistry, therefore sulfide ALD repeatedly re-enters a renucleation regime during the early cycles, resulting in delayed film closure and poor ultrathin continuity.

To overcome these limitations, different nucleation-enhancement treatments can be employed to increase the density of reactive surface sites and enhance nucleation. The hydroxylation of the surface enhances the nucleation of oxide films, while controlling other growth chemistries requires a chemically engineered approach for the targeted functionalisation surfaces. Thus, nucleation must be considered as an interface-controlled process governed by the compatibility between precursor chemistry and surface termination.

2:45pm **AM+EM+TF-ThA-3 MoO_2Cl_2 as an alternative Mo ALD Precursor for MoS_2 with Improved Thin Film Properties**, ***Nihal Khatiwoda,*** University of Michigan; *Ian Campbell,* IMEC USA; *Pierre Morin,* IMEC Belgium; *Benjamin Groven,* IMEC, Belgium; *Ageeth Bol,* University of Michigan

ALD of MoS_2 is a promising route for scalable and conformal synthesis of 2D semiconductors for nanoelectronics applications. However, it is often limited by small grain sizes and out-of-plane features, which degrade device electrical properties. In this work, we investigate MoO_2Cl_2 as a novel molybdenum precursor for ALD of MoS_2. Compared to conventional Mo precursors, MoO_2Cl_2 exhibits enhanced vapor pressure, leading to more efficient precursor delivery. Additionally, its chlorine-based chemistry introduces the possibility of in-situ etching which can help suppress undesirable nucleation, out of plane growth, and thus facilitate lateral expansion of domain features.

Both thermal and plasma-enhanced ALD processes were developed using MoO_2Cl_2 and H_2S as co-reactant. For the thermal process, a stop-flow approach was implemented to increase co-reactant residence time and enhance the reaction kinetics.

In-situ spectroscopic ellipsometry reveals that MoO_2Cl_2 exhibits a substrate enhanced transient growth regime during the initial ALD cycles, characterized by rapid nucleation. This is followed by a slower homo-deposition growth where the system enters a steady state growth regime. This behavior suggests the possibility of tailoring the precursor-substrate chemistry to reduce nucleation density and enhance lateral growth.

Ex-situ characterizations further support the effectiveness of this precursor system. XPS confirms the absence of chlorine incorporation in the resulting films, indicating clean ligand removal and absence of unwanted chlorine doping into the films. AFM reveals improved surface morphology with increased grain size and, notably, absence of out-of-plane features.

Overall, this study demonstrates that MoO_2Cl_2 is a promising precursor for ALD of high-quality MoS_2. Its favorable volatility, combined with chlorine-mediated surface chemistry, enables improved control over film morphology and crystallinity. These findings highlight a viable pathway toward overcoming longstanding challenges in ALD MoS_2 growth, advancing its potential for integration into next generation nano-electronic devices.

3:00pm **AM+EM+TF-ThA-4 Impact of Ti Adhesion Layer and ALD Al_2O_3 Thickness on Interfacial Energy Barriers in metal/insulator/metal (MIM) Devices**, ***Jessica Haglund,*** *John Conley,* Oregon State University

Control and understanding of interfacial energy barriers at metal insulator contacts is essential for designing MOS and MIM based devices. These barriers depend not only on the details of the metals and dielectrics used, but also on processing conditions, deposition order, and structure of the interface. To use noble metal electrodes, a thin interfacial metal is essential for good adhesion. Thin interfacial metals have also been investigated as a way to tailor barrier heights. Ultrathin dielectrics are needed for MOS gates and high capacitance MIM capacitors. However, the dielectric constant, density, and optical refractive index of ALD Al_2O_3 have all been reported to be a function of film thickness. In this work, we investigate the impact of Ti adhesion layer and ALD Al_2O_3 film thickness on interfacial electron energy barriers in Pt/Ti/Al_2O_3/TiN MIM devices.

100 nm TiN bottom electrodes were reactive ion sputtered. ALD with TMA and H_2O was used to deposit Al_2O_3 using 50, 75, 100, 125, 150, 175, and 200 ALD cycles in a Picosun R150 and 100 and 200 cycles in a Picosun R200. Following ALD a thin Ti IL (0.5, 1, 2, 5, 10 nm) and a 10 nm Pt top electrode were deposited via electron beam evaporation using a shadow mask. CV and IV measurements were taken on the completed MIM structures. Energy barriers were measured suing internal photoemission (IPE) spectroscopy using a house-built system.[1] Top gate voltage was swept from 0 to 2 V and 0 to -2 V using 0.1 V steps. At each bias, incident photon energy was swept from 1.7 to 5.5 eV. IPE thresholds were determined at each voltage using yield plots and zero field barriers were determined using Schottky plots.

Both the top Pt/Al_2O_3 and bottom TiN/Al_2O_3 electron barriers were a function of Al_2O_3 thickness. While both electron barriers were roughly constant at ~3.6 eV for Al_2O_3 films ≥ 12 nm thick, both decreased by roughly 0.5 eV as Al_2O_3 thickness decreased down to 5 nm. For Ti, a 0.5 to 1.0 nm thick interfacial layer was sufficient to completely dominate the electron energy barrier of the Pt/Ti stack. Insertion of a Ti layer also resulted in band tailing, likely due to oxygen scavenging, but had no impact on the bottom Al_2O_3/TiN electrode barrier. The degradation of electron barriers with insulator thickness and dominance by a very thin layer of metal at the interface are important considerations for the prediction and optimization of leakage currents and performance in these devices. Additional measurements on Ga_2O_3 will be discussed.

[1] J. Haglund, T. Mimura, J.F. Ihlefeld, and J.F. Conley, Jr., ACS Appl. Electron. Mater. **6**(5), 3249–3256 (2024)

3:15pm **AM+EM+TF-ThA-5 Evaluation of Barium-Based Precursors for Atomic Layer Deposition of Barium Titanate Thin Films**, ***Aenakshi Sircar,*** Boise State University; *Peter Micah,* boise State University; *Steven Hues, Elton Graugnard,* Boise State University

Atomic Layer Deposition of Barium titanate (BTO) has been a topic of interest for its potential application in high-k dielectric and ferroelectric material for energy-efficient logic and low-voltage memory devices. It is a perovskite ferroelectric with a low coercive field and switchable polarization at room temperature. Several deposition methods have been explored for integrating conformal BTO thin films into high-aspect-ratio structures for advanced memory applications. Among these, atomic layer deposition (ALD) stands out due to its ability to achieve highly conformal low-temperature growth through self-limiting surface reactions using reactive precursors. Despite these advantages, the development of a comprehensive ALD process for barium titanate remains challenging, particularly due to the limitations associated with barium precursor chemistry. The low volatility and poor thermal transport of many barium-based precursors limit the ALD process window. Additionally, most barium-

based precursors are extremely hygroscopic in nature and often form $Ba(OH)_2$, which can readily react with carbon-containing compounds to form $BaCO_3$. This introduces unfavorable conditions for the formation of BTO, since $BaCO_3$ and TiO_2 require higher energy to form BTO compared to $Ba(OH)_2$ and TiO_2. This behavior further complicates film characterization and can also negatively impact the electrical properties of the films.

Here, we report progress toward precursor selection for carbon-free barium titanate deposition. We investigate three different barium-based precursors: isopropyl [$Ba(iPr_3Cp)_2$], tertbutyl [$Ba(tBu_3Cp)_2$], and a novel imidazolate-based precursor, [Ba-Zttt]. The deposition cycles are optimized over several parameters, including the ALD temperature window (250–350 °C), growth per cycle, and film structure. The films are further characterized for thickness, density, roughness, phase composition, and dielectric properties to assess the feasibility of the different precursors for ALD of BTO and their potential contribution toward quaternary barium-based oxides.

3:30pm **AM+EM+TF-ThA-6 Deposition of Metastable ZrO_2 Crystalline Films at Low Temperatures by Electron-Enhanced Atomic Layer Deposition (EE-ALD)**, *Zachary Sobell,* ***Steven George,*** University of Colorado at Boulder

The metastable cubic and tetragonal ZrO_2 crystalline phases are important as high-k dielectric materials.Electron-enhanced atomic layer deposition (EE-ALD) was used to grow metastable ZrO_2 crystalline films with thicknesses of ~30 nm at low temperatures < 100 °C.This EE-ALD process employed alternating exposures of tetrakis(ethylmethylamido)zirconium (TEMAZr) and low energy (~70-100 eV) electrons concurrent with an oxygen (O_2) reactive background gas (RBG).ZrO_2 EE-ALD displayed rapid nucleation on silicon native oxide and linear growth in the steady state region.

The ZrO_2 EE-ALD was performed using an electron beam from a hollow cathode plasma electron source (HC-PES) with sample currents of ~30 mA over 10 cm^2.The electron beam can desorb surface species by electron stimulated desorption.The electron beam also travels through the O_2 RBG in the reactor at pressures of ~1-3 mTorr.Electron induced dissociation can form ions and radicals that facilitate the growth and oxidation of the ZrO_2 film.In addition, a negative bias voltage (-30 V) can be applied to the sample.This negative bias is believed to pull positive ions to the surface to enhance the film crystallinity and refractive index (RI).

With no applied sample bias and 5 s electron exposures, ZrO_2 EE-ALD proceeded at 1.2 Å/cycle and displayed an RI of 1.63 at 589 nm. Moderate crystallinity was observed by grazing incidence X-ray diffraction (GI-XRD) as shown in **Figure 1**. Increasing the electron exposure time increased the crystallinity and RI. A 10 s electron exposure increased the RI to 1.75. The crystallinity also increased significantly as displayed in **Figure 2**.The ZrO_2 EE-ALD growth rate was measured at 0.8 Å/cycle.

For the shorter electron exposure of 5 s, the application of a -30 V sample bias also increased the RI and crystallinity slightly versus no bias.The RI was measured at 1.70 and the EE-ALD growth rate was 0.8 Å/cycle. Increasing the electron exposure to 15 s with the simultaneous application of a -30 V bias increased the RI further and produced the most pronounced crystallinity as shown in **Figure 3**.A growth rate of 0.9 Å/cycle was measured along with an RI of 1.9.

The crystallinity and RI of the metastable ZrO_2 crystalline films with thicknesses of ~30 nm grown by EE-ALD depends on electron beam exposure time and negative sample bias voltage.The primary incident electrons may increase film crystallinity and RI by enhancing surface atomic mobility.The negative sample bias voltage may increase crystallinity and RI by facilitating oxidation by attracting O_2^+ positive ions to the sample.

3:45pm **AM+EM+TF-ThA-7 Zirconium Phosphate ALD Electrolyte for TiO2-Channeled H+ ECRAM**, ***John Hoerauf,*** *David Stewart,* University of Maryland, College Park*; A. Alec Talin,* Sandia National Laboratories, USA*; Gary Rubloff,* University of Maryland, College Park

Artificial Intelligence (AI) computing energy demands are on pace to surpass global energy production. Analog in-memory computing (IMC) hardware development represents a paradigm shift to reduce the energy required for these calculations by up to six orders of magnitude. Electrochemical RAM (ECRAM) is a promising non-volatile three-terminal transistor technology to realize physical neuromorphic IMC circuits. To program information, ECRAM utilizes reversible electrochemical reactions between the gate and drain terminals to change the conductance of the channel material between the source and drain terminals, representing the state of information during read-out. ECRAM transistors that utilize H^+ as the electrochemically active species are compatible with CMOS devices, offer faster programming speed, and have increased cycle durability compared to Li^+ ECRAM. Due to the mobility of protons, H^+ ECRAM also provides an excellent platform for studying the underlying phenomena that govern informational state retention across all ECRAM chemistries, but further studies require a solid-state electrolyte with properties not yet reported in thin-film electrochemistry.

Zirconium Phosphate (ZrP_xO_y) is a promising electrolyte with the requisite properties, including a composition-dependent H^+ conductivity. This presentation discusses a novel atomic layer deposition (ALD) development for ZrP_xO_y and the successful application of this thin-film electrolyte in H^+ ECRAM. ALD ZrP_xO_y was deposited using both super-cycling and phosphate plasma polymerization to alter the phosphorous to zirconium ratio between 1.5:1 and 4.2:1. This change in composition resulted in a one decade change in proton conductivity (3e-10 to 4e-9 S/cm) while exhibiting electronic conductivities below the measurement resolution limit (<1e-11 S/cm), ideal for studying state retention in ECRAM. The higher conductivity $ZrP_{2.6}O_{6.6}$ electrolyte was applied to an ECRAM singe-transistor platform that utilizes TiO_2 between the source and drain for readout. Two decades of programming range were demonstrated with a projected 4-hour state retention time. This represents the first successful demonstration of a full solid-state H^+ ECRAM transistor with an anhydrous ALD electrolyte. Additionally, a novel electrochemically-induced phase transition at the composition $H_{0.01}TiO_2$ was observed in Titania, as confirmed both through cyclic voltammetry and a metal-to-insulator behavior between the source and drain terminals. This phase transition is similar to that observed in the Li-TiO_2 system and is the key to understanding how H^+ conductivity in the electrolyte affects informational state retention in future studies.

4:00pm **AM+EM+TF-ThA-8 Unique Optical and Electrical Properties of Ald Deposited Zno on Top of Poly(3-Hexylthiophene)**, ***Anil Yadav,*** *Aditya Sadhanala,* Indian Institute of Science, India

Vapor Phase Infiltration (VPI) is a technique used to infuse the inorganic material inside porous films. It is inspired by the well-established Atomic Layer Deposition (ALD) process, which is typically performed on flat substrates such as silicon and glass. Here, we demonstrate the deposition of ZnO onto poly(3-hexylthiophene) (P3HT) thin films using a custom-built infiltration chamber. We are exploiting the infiltration process to explore the optical and electrical properties of the well-studied semiconducting polymers, such as P3HT. The sub-surface deposition of metal oxide, along with surface deposition, alters the optical and electrical properties of polymers. The hybrid material exhibited distinct and unique electrical and optical signatures, with applications in solar cells and organic light-emitting diodes (OLEDs). The UV suppression at the UV absorption peak indicates a distortion in the crystallinity of the semicrystalline P3HT thin film. Other characterizations showed that ZnO is predominantly deposited in the amorphous region, which improves the material's electrical properties.

Advanced Microelectronic Materials and Devices Mini-Symposium
Room Ballroom A - Session AM+EM+TF-ThP
Advanced Microelectronic Materials and Devices Mini-Symposium Poster Session

AM+EM+TF-ThP-1 AlScN Ferroelectric Diode-based Non-volatile Memory on $TaSi_2$ for Harsh-Environment Computing, ***Nghi Pham***, University of Pennsylvania, Viet Nam; *Dhiren Pradhan,* Agni Semiconductor; *Xindi Yang, Ravali Gudavalli, Deep Jariwala,* University of Pennsylvania

Electronic systems capable of operating in harsh environments—including space exploration (e.g., Venus and near-solar probes), aeronautics, oil and gas exploration, nuclear power plants, and heavy industrial processes—must withstand extreme temperatures and radiation. These applications demand in situ computing and sensing with stable performance under extreme conditions. However, no NVM technologies reliably function above 250 °C, creating a critical gap in high-temperature electronics. Despite well-established high-temperature logic with reliable operation > 800 °C, the absence of a compatible NVM technology hinders fully integrated computing for extreme environments. Ferroelectric diodes (FeDs) are promising candidates for selector-free, non-volatile memory (NVM) due to their nonlinear current–voltage behavior, potential multistate operation, and simple two-terminal architecture. For harsh-environment electronics, however, maintaining a high ON/OFF ratio and stable switching at elevated temperatures remains a major challenge, largely due to stronger internal fields and increased charge trapping.

In this work, we have successfully grown 45 nm of $Al_{0.68}Sc_{0.32}N$ on $TaSi_2$ despite the large lattice mismatch. $TaSi_2$ is a well-known high-temperature metal electrode and has been employed in NASA's Junction Field Effect Transistors (JFETs). The XRD omega scan of $Al_{0.64}Sc_{0.36}N$ reveals a full width at half maximum (FWHM) of 4.06°. Stacks with and without an AlO_x interlayer were compared to evaluate the role of interfacial engineering in leakage suppression, switching behavior, and ON/OFF ratio retention at elevated temperatures. The devices consisted of Ni top electrodes, a ~10 nm AlO_x interlayer (IL) dielectric, a ~45 nm AlScN ferroelectric layer, and $TaSi_2$ bottom electrodes.

Temperature-dependent DC-IV, AC-IV, and Positive-Up Negative-Down (PUND) measurements were performed up to 800 °C. For the 32% Sc AlScN device without an IL dielectric, the ON/OFF ratio remained measurable, decreasing from ~10 at 25 °C to 2.37 at 800 °C. By contrast, devices with an AlO_x IL dielectric exhibited substantially higher ON/OFF ratios, reaching values above 500 at room temperature and ~6 at 800 °C. These results highlight the role of AlO_x interfacial engineering in suppressing leakage and improving state distinguishability at elevated temperatures. High-temperature ferroelectric polarization switching, and other NVM characteristics such as read and write endurance, retention measurements of the ferrodiodes of $Al_{0.68}Sc_{0.32}N$ on $TaSi_2$ with 10 nm AlO_x IL dielectrics up to 900 °C are currently underway and will be presented at the meeting.

AM+EM+TF-ThP-2 Flexible Ag and Cu Pattern Films: A Comparative Study on Conductivity, Adhesion, and Mechanical Stability, ***Seonhee Jang***, *Samuel Goutierrez, Kenneth Lathrum,* University of Louisiana

The integration of metallic nanoparticles (NPs) has revolutionized the fabrication of flexible electronic devices. Compared to their bulk counterparts, metallic NPs exhibit unique shape and size-dependent properties that make them indispensable to the electronics industry. However, achieving superior electrical conductivity requires specialized post-processing to remove the stabilizing agents and additives used during NP synthesis.

In this study, silver (Ag) and copper (Cu) NP inks were employed to fabricate conductive patterns via printing and sintering processes for flexible electronics applications. These inks were printed onto 0.1 mm thick flexible Kapton polyimide (PI) sheets. The Ag ink was formulated with a solid content of 42±2 wt%, a density of 1.6 g mL^{-1}, and a viscosity of 3.5-6.0 Pa S at 10 s^{-1}. The Cu NP ink featured a solid content of 88 wt%, a density of 3.9 g mL^{-1}, and a viscosity of 20-40 Pa S at 50 s^{-1}.

Metal NP patterns were printed using a single-nozzle printing system and subsequently dried and sintered under four distinct sintering conditions: thermal treatment only (TO), laser irradiation only (LO), thermal treatment followed by laser irradiation (TL), and laser irradiation followed by thermal treatment (LT). This allowed for a comprehensive comparison of single and dual sintering techniques on the physical, chemical, mechanical, and electrical properties of the metal patterns. Post-sintering evaluations include microstructure analysis, crystallography, chemical composition, electrical sheet resistance, and mechanical strength.

The results demonstrated that for Ag patterns, the LT condition yielded the best performance for flexible electronics, achieving the lowest sheet resistance (0.0031 Ω Sq^{-1}) and superior mechanical stability (R/R_0=1.75) due to enhanced grain growth and effective organic removal. For Cu patterns, the TO condition proved optimal; while the LT condition provided the lowest resistance (0,0117 Ω Sq^{-1}), the TO condition ensured more uniform grain growth and higher flexibility (R/R_0=10.58). Overall, Ag patterns outperformed Cu in both conductivity and adhesion, as Cu suffered from oxidation and brittleness associated with high hardness (37.18-55.36 N/mm^2). These findings suggest that optimizing sintering parameters such as laser intensity and thermal atmosphere can further enhance the overall properties of Cu. Moreover, the adoption of dual sintering methods can improve the performance of printed flexible electronic devices, and there are more scopes for continuing research related to this method.

AM+EM+TF-ThP-3 Study of Acoustoelectric Interactions in α-In_2Se_3 - $LiNbO_3$ Heterostructure for Efficient RF Communication System, ***Marzia Sultana***, *Jackson Anderson,* University of Vermont

The growing global demand for energy is creating an urgent need for more efficient computation and communication technologies (Figure 1a) [1]. Despite vast improvements in computational efficiency, modern radio systems integrated on-chip still cannot simultaneously transmit and receive data (Figure 1b). Although circulators enable concurrent transmission and reception, conventional designs rely on magnetic fields, making them difficult to integrate with modern semiconductor technologies (Figure 1c) [2]. Acoustoelectric devices provide a promising magnet-free alternative for realizing compact and energy efficient circulators. In this work, we explore a novel heterostructure based on α-In_2Se_3 which is a two-dimensional ferroelectric semiconductor with moderate bandgap (1.39 eV) and carrier mobility up to 3392 cm2/(V*s) [3]. This study will be carried out in three main stages. The first stage focuses on simulating the acoustoelectric device gain to optimize heterostructure dimensions based on key material properties of α-In_2Se_3, such as carrier mobility and doping concentration. The second stage involves 2D material fabrication through mechanical exfoliation and characterization of exfoliated α-In_2Se_3 flakes to evaluate practically achievable device performance (Figure 2). In the final stage, the optimized structure will be integrated into a complete device design guided by simulation results. The simulation framework for the α-In_2Se_3–$LiNbO_3$ heterostructure was first validated against an existing InGaAs–AlScN design [4]. The proposed model exhibits higher gain in the low-frequency regime (Figure 3a). Additionally, the gain-to-power ratio (Figure 3b) indicates improved efficiency, attributed to the moderate carrier mobility of α-In_2Se_3. While higher mobility (InGaAs) can increase gain, it also leads to greater power dissipation, reducing overall efficiency. Figure 4 illustrates the impact of doping concentration on performance. Maximum gain is observed near a doping level of 10^{16} cm^{-3} (Figure 4a), whereas efficiency is higher at lower doping levels (Figure 4b). An optimal operating region is identified (Figure 4c), where both gain and efficiency are balanced. At 1 GHz, the device achieves a gain of 37.8 dB with a low power dissipation of only 0.02 mW. Mechanical exfoliation of α-In_2Se_3 using different adhesives initially produced poor-quality flakes, prompting investigation of process parameters such as substrate baking conditions. Increasing the baking temperature from 150°C to 200°C improved flake uniformity and size, and a Design of Experiments approach will be used to further optimize yield for device fabrication.

AM+EM+TF-ThP-4 Spatial Mapping of Spin Wave Dynamics in Shape-Optimized Magnetostatic Wave Cavity Filters, ***Kelsey Collins***, Air Force Research Laboratory

Yttrium iron garnet (YIG) magnetostatic wave (MSW) radio frequency (RF) cavity filters offer wide frequency tunability, making them highly promising for sixth-generation (6G) communication systems. However, finite cavity dimensions generate severe spurious modes that degrade filter performance. While tailoring the transducing electrode shape can suppress these undesired modes and enhance the primary passband, the underlying wave dynamics remain poorly understood. This study utilizes micro-focused Brillouin light scattering (BLS) spectroscopy to spatially map and analyze the excited spin waves within the cavity. Spatial profiles reveal that conventional straight-line electrodes exhibit frequency-dependent mode propagation. Conversely, optimized half-cone electrodes maintain consistent spin wave propagation across the entire frequency range. These

findings demonstrate that electrode shaping directly controls the RF passband by stabilizing constituent spin wave propagation, offering critical insights for designing high-performance, spur-free nonreciprocal devices.

AM+EM+TF-ThP-5 Nanoscale structural and chemical characterization of AlxTi1-xN wurtzite thin films., ***Sai Saswat Tripathy***, *Elizabeth Dickey,* Carnegie Mellon University*; Ian Mercer, Jon-Paul Maria,* Penn State University

Wurtzite ferroelectrics based on the composition $Al_{1-x}M_xN$, with M representing transition metals, have shown to possess large remnant polarization values, and higher thermal stability than conventional ferroelectrics like lead zirconate titanate (PZT) or barium titanate (BTO), and thus find potential applications in high operating temperature non-volatile memories. In this study, transmission electron microscopy (TEM) and scanning transmission electron microscopy-based energy-dispersive X-ray spectroscopy (STEM-EDS) were employed to investigate the structural and chemical characteristics of a stack comprising of a silicon substrate, titanium bottom electrode with a thin TiN layer, $Al_{0.92}Ti_{0.08}N$ thin film and tungsten top electrode. $Al_{1-x}Ti_xN$ based wurtzite thin films have previously been used for piezoelectric applications, and have potential ferroelectric applications, if polarization switching by the application of external electric field can be shown. Electron-transparent cross-section lamellae were prepared from the stack using focused ion beam (FIB) milling to enable site-specific TEM/STEM analysis. Bright-field (BF) and dark-field (DF) TEM images revealed a fiber-texture in the film with columnar grains aligned parallel to the growth direction. Zone-axis diffraction patterns (ZADPs) acquired from the film demonstrated wurtzite phase purity and c-axis oriented growth of the film. STEM-EDS revealed uniform distribution of Al, Ti and N throughout the film, further confirming wurtzite phase purity, which is essential for ferroelectric switchability.

AM+EM+TF-ThP-6 IGZO Thermal ALD application in 3D High Aspect Ratio (HAR) Features: Conformality and Elemental Uniformity Studies, ***Adarsh Rajashekhar***, *Fei Zhou,* Sandisk Technologies*; Ritwik Bhatia, Ganesh Sundaram,* Veeco Instruments*; Senaka Kanakamedala,* Sandisk Technologies

Multi-component oxide IGZO ($In_xGa_yZn_zO_p$) has been proposed as the channel material enabling low-cost and scalable future 3D-DRAM technology [1], [2]. This application would necessitate uniform deposition in high pattern density, high aspect ratio (HAR) structures. However, benchmarking of conformality and compositional uniformity in HAR structures is lacking in literature. With this objective, IGZO ALD deposition has been studied within deep hole features with two different aspect ratios (7:1 and 90:1). As a first step, a baseline deposition recipe was developed on blanket substrates. TMIn, TMGa and DEZ precursors were chosen due to their relatively high vapor pressures and well understood ALD processes. An optimal 200˚C deposition temperature avoids decomposition of DEZ and TMIn above 250˚C, while overcoming low growth-rates of GaO_x below 200˚C. Precursors and Reactant (O_3) dose times were separately optimized to ensure growth saturation, with GaO_x growth typically needing ~20x the O_3 dose time to ensure complete reaction, as compared to InO_x, ZnO_x. Based on these optimizations, carbon content in the developed IGZO films were found to be below the detection limit of X-ray photoelectron spectroscopy (XPS). The initial blanket baseline recipe (not optimized for HAR depositions) comprising of In-O-Ga-O-Zn-O growth sub-cycles yielded 50% coverage (bottom/top sidewall) for a 7:1 HAR structure, and 25% coverage for the 90:1 case. Specifically, In (precursor with highest molecular weight and lowest vapor pressure) saw a 21% to 38% reduction in partial fraction from top to bottom, whereas was partially compensated by Ga and Zn partial fractions increase that ranged around -3% to 20% in the different structures. Continuous coverage and compositional uniformity improvements are planned, with longer dose times as one of the knobs (and with particular emphasis on the In component).

1. D. Ha et al, "Exploring Innovative IGZO-channel based DRAM Cell Architectures and Key Technologies for Sub-10nm Node," pp 1-4 IMW (2024)

2. M. Okajima et al, "Highly stackable Oxide-semiconductor Channel Transistor Technology for Future High-density and Low-power 3D DRAM," pp 1-4 IEDM (2025)

Advanced Microelectronic Materials and Devices Mini-Symposium
Room 318 - Session AM1+EM+TF-FrM
Materials Discovery and Synthesis

Moderators: Prof. Michelle Paquette, University of Missouri-Kansas City, **Prof. Dr. Haozhe "Harry" Wang**, Duke University

8:15am **AM1+EM+TF-FrM-1 Machine Learning for Electronic Materials Discovery and Synthesis**, ***Christopher Hinkle***, University of Notre Dame **INVITED**

Recent advances in AI applied to high-throughput materials discovery, synthesis, and processing offer a pathway to accelerated breakthroughs and scaled optimization of advanced electronic materials for data-intensive computation. We will discuss our recent work using high-throughput techniques and ML-aided characterization to synthesize new materials and optimize them in an accelerated manor.

8:45am **AM1+EM+TF-FrM-3 Exploration of Limiting Factors for c-BN Growth by Ion-Beam Assisted Molecular Beam Epitaxy**, ***Tyler Erickson***, *Matthew Hardy, Eric Jin, Andrew Lang, James Hart, Peter Litwin, David Boris, Scott Walton, Neeraj Nepal, Douglas Katzer, Virginia Wheeler,* US Naval Research Laboratory

Cubic boron nitride (c-BN) is a prospective barrier material for high power density electronics due to its high breakdown field of 15 MV/cm and thermal conductivity of 13 W/(cm·K). The low lattice mismatch between c-BN and diamond (~1.3%) provides a direct avenue for pursuing molecular beam epitaxy (MBE) growth of c-BN/diamond heterostructures. The hexagonal phase of boron nitride (h-BN) is the thermodynamically favorable phase over c-BN, promoting h-BN formation for standard growth conditions. The formation of c-BN requires altering the energy dynamics of the growth, such as the addition of a plasma-based Ar^+ ion source during the growth. This introduction of an Ar^+ ion source has led to successful c-BN growths with high phase purity at the cost of overall growth rate. Here, we investigate methods to improve c-BN crystal quality and growth rate using ion assisted MBE on diamond (100) substrates. We prepared diamond substrates with acid cleans and ethanol rinses in air before degassing in vacuo. Substrates are then transferred to the growth chamber and exposed to high temperature annealing to remove residual surface oxides prior to c-BN deposition. Deposition is performed using a boron e-beam evaporator, plasma-based active N source, and plasma-based Ar+ ion source. The boron flux is shuttered at regular intervals during the growth while the N and Ar^+ ion fluxes are constant. This modulation prevents the formation and continued build-up of polycrystalline h-BN in the samples. Systematic variations of the surface preparation, boron flux, nitrogen flowrate and substrate temperature are performed. The c-BN phase purity and thickness are then investigated with Fourier transmission infrared (FTIR) spectroscopy, high-resolution transmission electron microscopy (TEM) and optical profilometry. X-ray photoemission spectroscopy (XPS) measurements give additional insight into the band alignment based on surface preparation. FTIR measurements show a large reduction in the longitudinal c-BN mode (≈1312 cm^{-1}) with reduced B flux, N flow and increase in substrate temperature. The TEM measurements indicate a large dependence of the film thickness uniformity and overall growth rate on the substrate preparation, with thickness variations on the order of the total thickness for hydrogenated substrates. XPS measurements show a change in valence band offset with respect to the diamond substrate of -0.1 ± 0.1 eV for the oxygen terminated surface to -0.5 ± 0.1 eV for hydrogen terminated surface.

9:00am **AM1+EM+TF-FrM-4 Tuning the Physicochemical Properties of Polymer-like a-C:H Thin Films via Ultraviolet C (UV-C) Irradiation**, ***Seonhee Jang***, *Kenneth Lathrum, Jhonatan Romero,* University of Louisiana

Hydrogenated amorphous carbon (a-C:H) thin films represent a versatile class of materials characterized by a unique combination of desirable physical and chemical properties, leading to their adoption across a wide range of industrial applications. The fundamental properties of a-C:H films are governed by two primary factors: their total hydrogen content and the specific hybridization state of the constituent carbon atoms. Based on these parameters, a-C:H materials are generally categorized into four distinct groups: diamond-like, tetrahedral, graphite-like, and polymer-like. Among these, polymer-like a-C:H films have received comparatively limited attention within the research community because they lack the extreme hardness or high thermal stability of their counterparts.

A key advantage of polymer-like a-C:H materials is their exceptional property tunability through post-processing techniques. Specifically, curing via ultraviolet C (UV-C, 200-280 nm) radiation has proven to be a highly effective method for modifying their characteristics. When these films are irradiated under ambient conditions, the interaction between UV-C light and atmospheric molecules generates oxygen radicals and ozone (O_3). Simultaneously, the high-energy photons facilitate the removal of hydrogen atoms from the film surface, creating a high density of dangling bonds.

In this study, polymer-like a-C:H films were synthesized on silicon (Si) substrates using plasma-enhanced chemical vapor deposition (PECVD) with a cyclohexane precursor. The deposition was performed with plasma power varied between 20 and 80 W. Subsequent UV-C irradiation at a wavelength of 275 nm was applied to the samples, utilizing irradiances of 0.0022 and 0.0466 W/cm^2 for durations of 1 and 4 hours.

Experimental results indicated that UV-C treatment led to a reduction in film thickness. However, the films maintained their optically transparent and topological smoothness. Surface analysis revealed a substantial increase in wettability, while the optical bandgap values showed a clear downward trend following UV-C irradiation. Fourier transform infrared (FTIR) spectroscopy confirmed the underlying chemical changes: a reduction in CH_x peak intensity indicated hydrogen removal, while an increase in C=O peak intensity, implying oxygen incorporation and structural rearrangement. It is proposed that unbound carbon and hydrogen atoms present within the as-deposited film reacted to form C=O and O–H bonds, respectively, during the UV-C curing process. This study demonstrates that UV-C irradiation serves as a critical mechanism for precisely tuning the composition and functional properties of polymer-like a-C:H films.

9:15am **AM1+EM+TF-FrM-5 Aerosol–Assisted CVD of NbN Using Novel Thermally Stable Niobium Imido Single–Source Precursors**, ***Narender Kumar***, *Nariman Neekzad, Hao Hung Chen, Tatsuya Kasai, Lisa McElwee White,* University of Florida

Transition–metal nitrides are attracting intense interest for next–generation electronic and superconducting technologies because of their exceptional thermal stability, chemical inertness, and tunable electronic properties. Niobium nitride (NbN) combines a relatively high superconducting critical temperature (≈ 16 K) with a large critical current density, enabling its use in superconducting nanowire single–photon detectors and as an ultrathin Cu diffusion barrier in CMOS interconnects. However, achieving high-quality NbN thin films with precise stoichiometry and conformal coverage at the nanoscale remains a persistent challenge. We report a new class of thermally robust, clean–decomposing niobium imido–based single–source precursors designed for low–temperature aerosol–assisted chemical vapor deposition (AACVD). The strong Nb–N imido bond ensures delivery of the correct metal–nitrogen stoichiometry. The precursors were fully characterized by multinuclear NMR spectroscopy, single–crystal X–ray diffraction, and thermogravimetric analysis, confirming their structural integrity and favorable thermal behavior. Preliminary AACVD experiments demonstrate efficient precursor transport and the formation of NbN thin films, which were analyzed using SEM and XRD.

9:30am **AM1+EM+TF-FrM-6 Ta Doping in MBE Grown WSe_2 2D Semiconductor**, ***Daniel Stokes***, *Stephen McDonnell,* University of Virginia*; David Lawrence,* James Madison University

Two-dimensional (2D) transition metal dichalcogenides (TMDCs) present a range of novel and tunable electronic properties. 2D TMDC semiconductors have potential applications in highly scaled devices owing to their direct electronic bandgap in the single-layer limit and their surface free of dangling bonds. To incorporate 2D TMDC semiconductors into devices, they must be able to be synthesized with high purity and controllably electronically doped. We present results on Ta doping during molecular beam epitaxy (MBE) growth of WSe_2 thin films grown on sapphire substrate. The electrical characteristics of the films indicate that we can controllably introduce Ta dopant atoms during synthesis to tune the resistivity, charge carrier concentration, and charge carrier mobility of WSe_2.

9:45am **AM1+EM+TF-FrM-7 Multilinear Regression Modeling of SiO_2 PECVD Deposition Based on Full Factorial Experiments**, *Tarun Maredla, Rohit Surikuchi, David Barth,* ***Lucas Barreto***, University of Pennsylvania

Silicon dioxide is a fundamental material in microelectronics, MEMS, optical coatings, and several other technological areas. In many of these applications, SiO_2 must be deposited as a thin film with controlled optical and physical properties. Plasma Enhanced Chemical Vapor Deposition,

PECVD, is widely used for this purpose because it enables high-throughput deposition, good process control, and relatively low deposition temperatures. However, PECVD offers a broad and flexible set of deposition conditions, and these parameters are often strongly coupled. Therefore, process optimization based on a One Variable at a Time, OVAT, approach may neglect important interactions between deposition parameters.

In this work, we present a replicated full factorial experimental design study of the SiO_2 PECVD deposition process. Silane, SiH_4, and nitrous oxide, N_2O, are used as the main precursors, and the deposited film properties are measured by ellipsometry. Four process factors are investigated: deposition temperature, chamber pressure, RF power, and silane flow. Two responses are evaluated: refractive index and deposition rate. A multilinear regression model is used to describe the dependence of the responses on the process factors and their interactions. Analysis of variance, ANOVA, is applied to validate the model and assess its predictive capability. The results show that the regression model provides an excellent estimate of the measured responses. Based on coefficient p-values, the most influential process parameters and statistically significant interaction terms are identified, providing a systematic framework for optimizing SiO_2 PECVD thin film deposition.

The results indicate that deposition temperature strongly affects the SiO_2 refractive index, while it has no statistically significant impact on deposition rate within the investigated factor range. In contrast, the remaining factors contribute significantly to one or both responses. In addition, second-order interaction terms are essential for accurately describing the experimental results, since excluding them leads to poor model performance. This confirms that the deposition parameters are coupled and must be considered jointly for an adequate description of the process. Therefore, an OVAT approach may neglect critical factor effects and interactions during process modeling and optimization. The proposed methodology provides a detailed and accurate description of SiO_2 PECVD deposition within the investigated process window and can be used to guide process optimization toward desired film properties.

10:00am **AM1+EM+TF-FrM-8 Transition Metal-Doped Sodium Niobate Thin Films: Microstructure, Ferroelectric Phase Stabilization, and Implications for Plasma-Assisted Catalysis**, ***Shanza Baig***, *Muhammad Abdullah, Vagif Mammadzada, Baharak Sajjadi,* University of Oklahoma

Non-thermal plasma catalysis offers a practical route to activate stable molecules such as methane and carbon dioxide without the high temperatures required by conventional thermal processes. A key challenge, however, is that most existing catalysts are not designed for plasma environments, where energetic electrons, strong electric fields, and non-equilibrium reactive species control the surface chemistry. Ferroelectric materials are attractive in this context because their spontaneous polarization can concentrate local electric fields, increase electron density at active sites, and strengthen plasma-surface interactions relevant to molecular activation. Sodium niobate ($NaNbO_3$) is a perovskite oxide with a well-known antiferroelectric-ferroelectric phase competition that is sensitive to composition and microstructure. In bulk form, $NaNbO_3$ is predominantly antiferroelectric at room temperature, but B-site doping and thin-film strain have been shown to shift the phase balance toward ferroelectric ordering and improve polarization switching. Thin-film geometries are particularly useful here, as they introduce lattice strain and modify grain structure in ways that are difficult to achieve in bulk ceramics. In this study, $NaNbO_3$ thin films were doped with 1 mol% Fe, Ni, and Cu at the B-site to understand how each transition metal influences grain growth, microstructure, and ferroelectric response. Fe, Ni, and Cu were selected because they vary in ionic radius and valence state and are therefore likely to distort the NbO_6 octahedra differently, introduce different defect types, and shift the polarization response in distinct ways. The intent was to determine whether these dopant-driven structural changes, alongside the strain naturally present in thin films, are sufficient to push the material toward a stable ferroelectric phase with reliable polarization switching. Stronger ferroelectric behavior in these films should enhance local field concentration and encourage microdischarge formation under plasma conditions, which directly affects plasma intensity and the efficiency of electron-driven activation. The broader aim of this work is to clarify how dopant chemistry and thin-film microstructure together control polarization behavior in $NaNbO_3$, and to use that understanding to guide the development of ferroelectric catalysts for greenhouse gas conversion.

Advanced Microelectronic Materials and Devices Mini-Symposium
Room 318 - Session AM2+EM+TF-FrM

Devices II

Moderators: Dr. Samantha Jaszewski, Sandia National Labs, **Somil Rathi**, Arizona State University

10:30am **AM2+EM+TF-FrM-10 Development of Metallic Gate Stacks at Atomic Scale : Application to Advanced FD-SOI Transistors**, ***Elouan Le Cun***, *Julien Patouillard, Rémy Gassilloud, Mathieu Bernard, Zdenek Chalupa, Krunoslav Romanjek, Wissem Baik, William Vandendaele, Elhadji-Alhousseyni Diallo, Tadeu Mota Frutuoso, Pauline Hauchecorne, Virginie Loup, Théo Cabaret, Frédérique Glowacki, Mouaad Yassine Aliouat, Elise Arnoux, Gennie Garnier, Marie-Claire Cyrille, Olivier Renault, Claire Fenouillet-Béranger,* CEA-LETI, France

Fully-Depleted Silicon On Insulator (FDSOI) planar technology - an alternative to FinFET (3D field effect transistors) - address technologies involving very high energy efficiency, ultralow power consumption and cost reduction. 10 nm FD-SOI transistor requires complex metal on insulator (MOS) gate stacks. The MOS structure is composed of doped titanium nitride layers as metal gates, and SiON/HfON as gate-dielectric[1]. SiON is also called gate interlayer (IL). Thinning TiN layers results in better MOS performances. This is due to a known phenomenon called IL scavenging, where TiN acts as an oxygen reducer of the IL, which in turn reduces the IL thickness[2]. The targeted TiN thickness in the 10 nm-node FDSOI is closed to 2 nm, and the required equivalent oxide thickness (the electrical thickness of the IL/HfON insulator stack) is below 0,8 nm. As the layers thicknesses reach the nm-scale, it introduces new challenges regarding the electrical behavior of the MOSFET due to the heterogeneity of the materials in the gate stacks.

To address those challenges, the developments of an ultra-thin 2 nm metallic gate stack with sub-stoichiometric titanium nitride ($TiN_{x<1}$) are required. CEA-Leti has acquired a PVD deposition tool by co-sputtering to deposit complex metallic layers on 300 mm silicon wafers with an atomic-scale thickness control.

This study examines TiN_x ultra-thin films with thicknesses below 5 nm. TiN_x structural, optical and electrical properties are evaluated by X-Ray Reflectivity (XRR), stress measurements, sheet resistance measurements, spectroscopic ellipsometry, X-Ray Photoelectron Spectroscopy (XPS) and X-Ray Diffraction (XRD). TiN_x layer composition is investigated by Elastic Recoil Detection Analysis (ERDA) and X-Ray Fluorescence (XRF) analysis. Those layers have been integrated on simplified electrical devices to evaluate their impact on transistor key performance parameters (EOT, Vt, Jg, ...).

This work was carried out in the framework of the FAMES Pilot Line of the Chips JU and the Platform for Nanocharacterisation (PFNC) funded by Horizon Europe grant 101182279, ANR NextGen project ANR-22-NEXTG-001, ANR programs “Recherche Technologique de Base” and "France 2030 - ANR-22-PEEL-0014".

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[1] C. Fenouillet-Beranger, et al, “Pursuing the FD-SOI roadmap down to 10 nm and 7 nm nodes for high energy efficient, low power and RF/mmWave applications,” Solid-State Electron. 231, 109264 (2026).

[2] T. Ando et al., Ultimate Scaling of High-κ Gate Dielectrics: Higher-κ or Interfacial Layer Scavenging, Materials 2012, 5, 478-500

10:45am **AM2+EM+TF-FrM-11 Towards Ordered Growth of Complex Oxide Thin Films for Memristive Devices**, ***Michael Mitchell***, *Xianchao Dong, Shweta Joshi, Tianshu Li, Gina Adam,* George Washington University

We present progress towards the ordered growth of the entropy-stabilized oxide, $(MgNiCoCuZn)_{0.2}O$, via reactive magnetron sputtering for the fabrication of memristive devices. To produce this film, the authors leveraged a custom-designed AJA ATC system with off-axis capabilities to reduce deposited atom kinetic energy and improve film crystallinity. The proposed methodology uses co-sputtering of multiple metal alloy targets in an oxygen-rich environment. Depositions are conducted at multiple substrate temperatures to identify phase transition temperatures. In addition to 100-oriented silicon, substrates composed of materials with improved lattice matching to literature values of $(MgNiCoCuZn)_{0.2}O$ are

employed, and the relationship between substrate material and phase transition temperature is investigated. Various microscopic and spectroscopic characterization techniques, including Atomic Force Microscopy (AFM) and Energy Dispersive X-ray Spectroscopy (EDS), etc., were used to determine the film growth rate and stoichiometry. Molecular Dynamics simulations, with interatomic interactions provided by fine-tunned machine learning models, are employed to study the relationship between phase transition temperature and substrate composition. The computational findings for the influence of substrate composition and deposition stoichiometry on the phase transition temperature are then compared with the experimental results. The pathways for integration of the resulting film into memristive devices are also discussed.

11:00am **AM2+EM+TF-FrM-12 Electron beam lithography enabled nano EC-RAM development and fabrication***, **Stefan Theodoru**, Garry Rubloff,* UMD College Park*; Marshall Schroeder,* DEVCOM ARL

The exponential increase of computing demand is currently only being met with <10% improvement of computational power density per chip generation. Improvements in energy consumption have not kept pace with either industry demand or grid capacity. Electrochemical random-access memory (EC-RAM) is well postured to fulfill this demand, boasting six orders of magnitude modeled energy consumption lower than CMOS technology. EC-RAM models predict downscaling energy consumption based on micron scale devices which should at the nano scale deliver atto J cost per computation compared to the current pico J state of the art. Further boons to EC-RAM include its intrinsic non-volatility, analog states, and co-located compute and memory centers. This makes EC-RAM ideal for use in neural network computation. Scaling studies to prove these modeled results have not yet been conducted in the sub 100nm regime however, leaving a large gap between EC-RAM's modeled capabilities, and what has been experimentally proven.

This presentation describes the process development done to fabricate Au, TiO_2, and LiPON EC-RAM devices and the results of their characterization. We use TiO_2 for its wide range of conductance states as a function of Li content. While LiPON is both well known to the research group, and provides a source of Li provided during the LiPON deposition. Process development was needed to develop sub 100nm feature separation/widths using electron beam lithography, as well as to allow for nanolithography of the reactive LiPON film (Fig.2). Devices built for performance use the vertical architecture, see Fig.1, which minimizes the ion diffusion pathway. Devices built to allow for characterization using Raman and Plume SEM use the lateral architecture, see Fig.3. Both architectures have channels defined by the width of the source/drain and their separation, and have asymmetric and symmetric variants which allow us to test the impact of having a Li reservoir on device performance. The most important parameters for defining EC-RAM performance are state change speed, retention, and cycle life of the device. State change speed is the time it takes to intercalate enough Li^+ ions into the channel that the conductivity, as read by a bias across source and drain, changes to encode a unique conductance state. Retention is defined as the time that a written state endures with no applied gate voltage. The analysis of these characterization results and process development elucidate ideal EC-RAM architecture and fabrication methodology.

11:15am **AM2+EM+TF-FrM-13 Limitations of Layered Dielectrics***, **Peter Dickens**, Brianna Klein, Andrew Binder,* Sandia National Laboratories, USA

Next-generation power conversion systems increasingly rely on SiC power MOSFETs to minimize switching losses and maximize power density. Conventional SiO_2 gate dielectrics limits maximizing the gate capacitance and drive current, making higher-k dielectrics attractive to improve switching characteristics.However, to date, severe defect densities at the direct high-k/SiC interface has prevented strict high-k adoption.Consequently, recent work has focused on utilizing a dielectric bilayer with SiO_2 serving as the interface dielectric with SiC to enable low defect densities and a high-k stacked on top in an attempt to gain the "best of both worlds".Despite some reported successes, there remain critical gaps discussing what fundamental advantages or limitations exist from this dielectric bilayer approach.

In this presentation, we present analysis of the available design space for layered dielectrics in SiC-based MOSFETs.Our analysis operates under three fundamental assumptions related to applied gate bias, avoidance of time-dependent-dielectric-breakdown (TDDB), and the requirement to be high-k (effective dielectric permittivity greater than the permittivity of the semiconductor).We show that when these assumptions are applied then the available design space for layered dielectrics is quite limited and calls into question advantages of a layered approach.

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SAND2026-21413A

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