Electronic Materials and Photonics
Room 318 - Session EM-WeM

Advances in Wide Bandgap, Piezoelectric Materials and Devices

Moderators: Dr. Erin Cleveland, Laboratory of Physical Sciences, **Dr. Seth King**, University of Wisconsin - La Crosse, **Dr. Daniel Pennachio**, Naval Research Laboratory

8:00am **EM-WeM-1 Rigorous Electrostatic Constraints for Interface State Extraction in Wide-Bandgap MOS Devices**, ***Brian Rummel,*** Sandia National Laboratories **INVITED**

Accurate characterization of interface state densities near the band edges is a fundamental requirement for optimizing metal-oxide-semiconductor (MOS) systems. Such deleterious defects are particularly restrictive in wide-bandgap semiconductors (e.g., SiC and GaN), compromising the efficiency and reliability of power transistor devices. A longstanding problem in device characterization is that conventional capacitance-voltage (C-V) methods fail to accurately report interface states in the energy range most relevant for on-state transistor operation. Traditional frameworks are fundamentally limited by inherent electrostatic ambiguities, preventing reliable defect extraction near the band edge. To resolve this challenge, a novel analytical constraint is derived from foundational energy conservation principles to complete the High-Low C-V framework [1]. By enforcing a strict electrostatic boundary, this method eliminates historical measurement uncertainties and enables precise, physically consistent extraction of accumulation interface states. The theoretical validity of this advanced framework is confirmed using analytical modeling, while its practical application is demonstrated through an exemplar case study evaluating the effects of nitric oxide (NO) annealing on silicon carbide MOS structures. Ultimately, this work provides a robust path for evaluating near-band edge defects in next-generation electronic materials.

[1] B. D. Rummel, S. Dhar, R. J. Kaplar; The completed High-Low method for interface state analysis in MOS capacitors. J. Appl. Phys. 14 May 2026; 139 (18): 185708. https://doi.org/10.1063/5.0305772

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8:30am **EM-WeM-3 Doping Dependent Defect Formation in Heavy Ion Irradiated β-Ga2O3**, ***Mark Gordon,*** University of Dayton*; Daram Ramdin,* Air Force Research Laboratory, Materials and Manufacturing Directorate, USA*; Eric O'Quinn,* University of Tennessee Knoxville*; Jian Li, Brenton Noesges, Prescott Evans,* Air Force Research Laboratory, Materials and Manufacturing Directorate, USA*; Maik Lang,* University of Tennessee Knoxville*; Shin Mou, Adam Charnas, Adam Neal,* Air Force Research Laboratory, Materials and Manufacturing Directorate, USA*; Christopher Muratore,* University of Dayton*; Thaddeus Asel,* Air Force Research Laboratory, Materials and Manufacturing Directorate, USA

Gallium Oxide (β-Ga_2O_3) is an ultrawide bandgap semiconductor material with potential in RF, power electronics, & extreme environment applications. Because of its ultrawide bandgap (4.8 eV), β-Ga_2O_3 has a predicted breakdown field of 8 MV/cm, & a demonstrated breakdown field of 5.4 MV/cm in relevant device structures[1] ,[2]. The ultrawide bandgap & large breakdown field of β-Ga_2O_3 make it an excellent candidate for use in high radiation environments such as low earth orbit because β-Ga_2O_3 devices can be operated at higher voltages than conventionally radiation hardened SiC or GaN devices. At this early stage of development for β-Ga_2O_3 radiation hard devices, it is important to understand the ionizing dose effects of heavy ions at the material level in order to differentiate β-Ga_2O_3 material changes from those associated with device structure, such as contacts and interfaces. In this talk, we will discuss the results of recent heavy ion irradiation experiments on molecular beam epitaxy-grown β-Ga_2O_3 thin films irradiated with 946 MeV gold ions. We have observed experimentally a correlation between higher doping concentrations & an increase in carrier concentration after heavy ion irradiation. Two β-Ga_2O_3 film series with doping concentrations of 1×10^{17} & 5×10^{17} cm^{-3} (N1 & N5, respectively) & a thickness of 300 nm were irradiated with 946 MeV Au ions with fluences of $1x10^{6}$ to $1x10^{8}$ cm^{-2}. Before & after irradiation the carrier concentration of the samples was measured using Hg probe capacitance voltage. At a fluence of $1x10^{6}$ cm^{-2} samples in the N1 series showed no difference in carrier concentration after irradiation. Samples in the N5 series showed a ~31% increase in carrier concentration from 6.5 to $8.5x10^{17}$ cm^{-3}. Given the high energy of irradiation, a defect complex is likely formed instead of simple V_{Ga} or V_O & could explain the increase in carrier concentration after irradiation. These defects are consistent with previous proton irradiation studies of β-Ga_2O_3, where low temperature annealing is hypothesized to induce carrier recovery by complex formation[3]. Depth-resolved cathodoluminescence spectroscopy, deep level optical spectroscopy & deep level transient spectroscopy experiments will further identify the defects and defect complexes which are induced after heavy ion irradiation. These results identify important electronic information that is critical for designing β-Ga_2O_3 based electronics for space applications.

[1] C.N. Shah, et al., *Appl. Phys. Lett.* **122**, 182106 (2023).

[2] A.J. Green, et al., *APL Mater.* **10**, 029201 (2022).

[3] M. E. Ingebrigtsen, et al., *APL Mater.* **7**, 022510 (2019).

8:45am **EM-WeM-4 Influence of Substrate Orientation and Surface Treatments on n-Ga2O3/p-GaN Heterointerface Quality**, ***Daniel Pennachio,*** *Frank Kelly, Katie Gann, Emma Rocco, Michael Mastro,* U.S. Naval Research Laboratory

Gallium oxide is a promising ultrawide bandgap semiconductor due to its phenomenal electrical properties such as its high breakdown field and n-type conductivity. Importantly, compatibility with liquid-phase growth techniques allow large-area β-Ga_2O_3 substates to be produced relatively inexpensively and early in the material's development. Despite these benefits, the lack of shallow p-type dopant and the material's low thermal conductivity hinder device performance. Both disadvantages may be resolved by forming heterostructures with compatible p-type semiconductors. This work explores epitaxy of n-type β-Ga_2O_3:Si via metalorganic chemical vapor deposition (MOCVD) on p-type GaN:Mg, with a focus on atomic configuration and associated defects of the heterointerface as a function of Ga_2O_3 growth initiation and substrate polarity.

This work investigates the effect of GaN surface modifications before Ga_2O_3 growth. Surface treatments include *ex situ* O_2 plasma oxidation or an *in situ* MOCVD Ga "flash" clean of the GaN surface [1]. The effects of the polarity of the GaN substrate and the inclusion of a low-temperature Ga_2O_3 nucleation layer are also studied in addition to the surface treatments. The interfacial structure and composition were measured using scanning transmission electron microscopy (STEM) and X-ray energy dispersive spectroscopy (EDS). All grown films exhibited rotational domains with the epitaxial alignment of Ga_2O_3(-201)||GaN(0001). A 6-fold rotational alignment between the substrate and film were confirmed via X-ray diffraction (XRD). Fourier filtering and 4DSTEM were utilized to map grain alignments throughout the cross-sections, showing both vertical and horizontal grain boundaries, as well as various other defects. Predominant crystallographic alignments observed were Ga2O3(-201){0-10}||GaN(0001)[11-20] and Ga2O3(-201){1-32}||GaN(0001)[11-20]. The film grown with *ex situ* oxidation but without a nucleation layer provided the largest lateral grain size as determined via atomic force microscopy (AFM) analysis of surface structure. This growth also exhibited relatively uniform lateral grain size throughout the film thickness in TEM. In contrast, films grown with a nucleation layer resulted in smaller lateral grain sizes near the interface, followed by wider grains near the film surface.For samples treated with *ex situ* oxidation, the interface showed a ~10 nm wide region containing voids, while samples grown without oxidation showed atomically abrupt interfaces.

[1] Katta, Abishek, et al. *Journal of Applied Physics* 135.7 (2024).

9:00am **EM-WeM-5 A Comparison of Cr/Au and Ti/Au Ohmic Contacts on β-Ga_2O_3**, ***Carlo Schettini,*** Carnegie Mellon University*; Kim Kisslinger,* Brookhaven National Laboratory*; Isabella Williams, Xipin Chen, Reid Captain,* Carnegie Mellon University*; Judith Yang,* Brookhaven National Laboratory*; Lisa Porter,* Carnegie Mellon University

Beta gallium oxide (β-Ga_2O_3) is the most promising ultrawide bandgap semiconductor (~4.7 eV) for power electronic applications. Determining what metals can form ohmic contacts to β-Ga_2O_3 is challenging, especially as no low-work-function metals have been predicted and shown to form thermodynamically stable interfaces.[1], [2] Ohmic contacts on β-Ga_2O_3 are typically fabricated as a Ti/Au bilayer. This metallization is not stable due to the growth of an insulating interfacial TiO_x layer when exposed to high temperatures; techniques to lower its contact resistivity and improve its thermal stability include Si^+-ion implantation.[3] Recently, Cr-based ohmic contacts have been reported in β-Ga_2O_3 devices.

In this study, we compare the electrical behavior and interfacial composition profiles of Ti/Au and Cr/Au ohmic contacts to β-Ga_2O_3 as functions of annealing temperature and time. Circular Ti/Au and Cr/Au contacts were deposited in Sn-doped (N_D = 5 x 10^{18} cm^{-3}) (001) β-Ga_2O_3 substrates and annealed sequentially to temperatures between 300 and 700°C in a rapid thermal annealer for intervals of 1 min under N_2 flow to determine the optimal processing temperature for each material. The electrical properties were determined through current-voltage measurements. For Ti/Au and Cr/Au contacts, the lowest resistance occurred at processing temperatures of 500 – 600°C, and 450 – 500°C, respectively. Both degraded when annealed to 700°C. Transmission electron microscopy (TEM) cross-section images combined with energy dispersive x-ray (EDX) analysis of as-deposited and 450°C-annealed contacts showed differences in the interfacial chemistry after annealing: e.g. Au nanoclusters that were detected at the interface in the annealed Cr/Au contacts but not in the Ti/Au contacts. In this presentation we will compare the electrical measurements and TEM/EDX characterizations of the Ti/Au and Cr/Au contacts at different annealing temperatures. We will also discuss recent results of a long-term annealing study (at 300°C for > 250 h) of ohmic contacts with and without a Ni diffusion barrier.

[1] Y. Yao, R. F. Davis, and L. M. Porter, *Investigation of Different Metals as Ohmic Contacts to β-Ga_2O_3: Comparison and Analysis of Electrical Behavior, Morphology, and Other Physical Properties*, J. Electron. Mater. **46**, 2053 (2017).

[2] C.-W. Lee, A. Zakutayev, and V. Stevanović, *Computational Insights into Phase Equilibria between Wide-Gap Semiconductors and Contact Materials*, ACS Appl. Electron. Mater. **6**, 2383 (2024).

[3] M.-H. Lee and R. L. Peterson, *Accelerated Aging Stability of β-Ga_2O_3–Titanium/Gold Ohmic Interfaces,* ACS Appl. Mater. Interfaces **12**, 46277 (2020).

9:15am **EM-WeM-6 Temperature-Driven Reversible Carrier-Polarity Switching in Bi-Doped SnSe***, **Mehmet Ozdogan**, Thomas Iken, Carlos Munoz, Deniz Cakir, Nuri Oncel,* University of North Dakota

Carrier-polarity switching in semiconductors offers a route toward adaptive electronic and thermoelectric functionality beyond conventional static p- or n-type doping. In this work, we investigate temperature-driven reversible n-to-p carrier-type switching in bulk polycrystalline Bi-doped SnSe by combining temperature-dependent transport measurements, structural/chemical characterization, semiempirical transport modeling, and first-principles calculations.

Pristine and Bi-doped SnSe samples, $Sn_{1-x}Bi_xSe$ with x = 0, 0.02, and 0.06, were synthesized and characterized using X-ray diffraction, scanning/transmission electron microscopy, energy-dispersive X-ray spectroscopy, and X-ray photoelectron spectroscopy. Structural analysis confirms that the orthorhombic Pnma SnSe framework is preserved after Bi incorporation, while chemical analysis verifies Bi incorporation and finds no evidence of metallic Bi secondary phases. Temperature-dependent measurements of Seebeck coefficient and electrical conductivity reveal distinct composition-dependent transport behavior. Pristine SnSe remains p-type over the full measured temperature range, whereas Bi substitution drives electron-dominated conduction. The 2% Bi-doped sample exhibits negative Seebeck coefficients at low temperature, followed by a reversible n-to-p polarity reversal near 550 K, while the 6% Bi-doped sample remains robustly n-type up to 880 K.

To clarify the microscopic origin of this switching, the experimental transport data were analyzed using a self-consistent two-carrier model that accounts for competing electron and hole contributions and incorporates the smooth Pnma-to-Cmcm structural evolution. The nonlinear Seebeck response in lightly Bi-doped SnSe is captured by bipolar transport and carrier compensation rather than by a simple single-carrier picture. Density-functional-theory calculations further show that, at low Bi concentration, temperature-driven bandgap narrowing and Fermi-level repositioning promote thermally activated holes that eventually dominate transport. In contrast, higher Bi content pushes the Fermi level deeper into the conduction band, suppressing compensation and stabilizing degenerate n-type behavior.

These results establish Bi-doped SnSe as a model system for tunable carrier compensation and reversible polarity switching, providing design principles for temperature-responsive thermoelectric and multifunctional semiconductor materials [1].

[1]. *Physical Review B* 113, 205202 (**2026**).

9:30am **EM-WeM-7 Hybrid MBE for Freestanding Ultra-wide Bandgap $CaSnO_3$ Thin Films Using a Water-soluble BaO Sacrificial Layer***, **Sooho Choo**, Dong Kyu Lee, Rishi Raj, Alyssa Bragg, Seung Gyo Jeong, Ho-Sung Shin, Shivasheesh Varshney, Jitin Sathish Kumar, K. Andre Mkhoyan, Alexander S McLeod,* University of Minnesota*; Anderson Janotti,* University of Delaware*; Bharat Jalan,* University of Minnesota

In power electronic devices, key figures of merit scale nonlinearly with bandgap, driving significant interest in semiconductors beyond wide-bandgap (WBG) semiconductors, such as GaN (3.4 eV) and SiC (3.2 eV). Ultra-wide bandgap (UWBG) semiconductors, with bandgaps exceeding 3.4 eV, offer superior breakdown electric field resistance and represent a promising pathway for next-generation power electronic devices. Among the UWBG candidates, $CaSnO_3$ is particularly attractive due to its bandgap of 4.3 eV, combined with the compositional and structural versatility of the perovskite framework, enabling bandgap engineering through alloying and performance tunability via heterostructure. In parallel, the realization of monolithically integrated electronic and optoelectronic systems demands flexible heterogeneous integration strategies. Conventionally, integrating 3D crystalline semiconductors has relied on heteroepitaxy, which imposes strict growth requirements on lattice matching and chemical compatibility between the film and substrate, limiting material combinations. Recent advances in freestanding thin films, enabled by remote epitaxy or chemical lift-off, overcome these constraints by decoupling the epitaxial film from the substrate, allowing the epitaxial film to be transferred and integrated onto arbitrary material platforms. Here, we demonstrate epitaxial growth of $CaSnO_3$ thin films with a BaO sacrificial layer on LSAT (001) substrate using hybrid MBE and their successful release and transfer onto other material platforms. Morphological and structural properties were systematically investigated as a function of growth stoichiometry using reflection high-energy electron diffraction (RHEED), atomic force microscopy (AFM), and high-resolution X-ray diffraction (HRXRD). These measurements confirm phase-pure epitaxial growth of $CaSnO_3$ and BaO layers. Furthermore, the dielectric and optical properties of freestanding $CaSnO_3$ thin films were investigated, revealing properties comparable to bulk values, as characterized by impedance spectroscopy, scanning near-field optical microscopy (SNOM), and ellipsometry. This work demonstrates that freestanding $CaSnO_3$ films retain bulk-like properties after transfer, opening a pathway for heterogeneous integration in next-generation power electronic and optoelectronic devices.

11:00am **EM-WeM-13 Suppression of Stacking Fault Expansion in SiC Epitaxial Layers via Substrate Implantation***, **Rachael Myers-Ward**, Alec Imhof, Nadeemullah Mahadik,* U.S. Naval Research Laboratory*; Benjamin Sekely, Jenifer Hajzus,* US Naval Research Laboratory*; Atul Gupta, Hank Chen, Fulvio Mazzamuto, Christopher Lamontagne,* Axcelis Technologies

Silicon carbide (SiC) devices can fail during operation due to bipolar degradation [1], where carrier injection causes basal plane dislocations (BPDs) to expand into single Shockley stacking faults (SSFs), leading to increased on-state resistance and reverse current leakage [2,3]. Previous studies have demonstrated that proton and helium implantation within the epitaxial layer can effectively suppress stacking fault expansion [4]. However, at very high carrier injection conditions, such as pulsed-power applications, BPDs propagate from the substrate or highly doped layers into the epitaxial drift layer [5]. This study explores an alternative approach for mitigating BPD propagation and SSF expansion by performing implantation into substrates prior to epitaxial growth of the drift layer. This approach offers a pathway toward improved high-power device reliability.

In this work, 200 mm diameter 4H-SiC substrates were subjected to implants with different species (silicon, carbon, and phosphorus) at varying energy (50-200 keV) and doses ($5x10^{14}$ – $2.5x10^{15}$ cm^{-2}). Each wafer had 5 implant regions with one region receiving no implant to allow for a direct comparison of the implantation impact on the BPD faulting and SSF expansion. A 10 µm intentionally doped n-type, ~$2x10^{16}$ cm^{-2}, SiC epitaxial layer was deposited on each of the implanted substrates. During the ramp to growth temperature, the H_2 carrier gas was reduced and the pressure was increased to suppress the etching of the implanted SiC substrate.

Ultraviolet photoluminescence (UVPL) was used to image the wafers before and after prolonged (3hr) UV carrier injection stressing at 9 $kWcm^{-2}$. We observed in several wafers, at such high injection conditions, BPDs from untreated SiC substrates propagate into the epi-layer. However, for the majority of the implant conditions, over a magnitude reduction in SSF densities were seen. The SSF blocking mechanism is likely due to reduction in carrier lifetime caused by implantation as well as potential pinning from the point defects introduced during implant that block SSFs from expanding

into the epitaxial layer. The various defect mechanisms along with complete statistical analysis will be presented.

[1] P. Bergman et al., Mat. Sci. Forum, **353–356** (2001) 299.

[2] A. Galeckas et al., Appl. Phys. Lett., **81** (5) (2002) 883.

[3]Agarwal et. al., IEEE Electron Device Lett., **28** (2007) 587.

[4]M. Kato et al., Sci Rep, **12** (1) (2022) 18790.

[5]N. A. Mahadik et al., Appl. Phys. Lett., **100** (4) (2012) 042102.

11:15am **EM-WeM-14 Processing of SiC Pillar Arrays for Quantum and Photonic Applications**, ***Jenifer Hajzus***, *Jose Fonseca, Ignas Lekavicius,* US Naval Research Laboratory*; Samuel Lagasse,* Laboratory for Physical Sciences*; Karl Hobart, Marko Tadjer, Rachael Myers-Ward,* US Naval Research Laboratory

Defects in SiC with optically addressable spin-states (e. g. silicon vacancies, divacancies, nitrogen vacancy centers) have attracted great interest for quantum computing and sensing due to their long spin coherence times, room temperature operation, near infrared emission, and existence in an industrially mature host crystal with wafer scalability, established processing techniques, and exploitable properties such as second order optical nonlinearity and controllable p-and n-type doping. To enhance defect emission and/or improve optical collection efficiency, photonic structures such as nanopillar arrays, solid immersion lenses, and photonic crystal cavities have been utilized [1-3]. Fabrication of these structures in SiC typically involve dry etching in fluorine-based chemistries which can introduce unwanted defects, unfavorable surface states, and roughness on sidewalls and surfaces. Such imperfections have potential to be a source of optical losses, decreased Q-factors, decreased spin coherence times, and high photoluminescence backgrounds [4-6].

This work investigates processing conditions for fabrication of SiC nanopillar arrays, aiming to produce structures with favorable surfaces and morphologies for quantum photonic applications. E-beam lithography is used to define pillars with diameters ranging from 400 nm to 1150 nm in 4° offcut N^+ 4H-SiC substrates. SiC is etched using ICP-RIE in a SF_6/O_2 gas mixture. It is found that the pillar sidewall roughness and morphology are impacted by O_2:SF_6 flow ratio, where a higher O_2:SF_6 ratio produces more vertical sidewalls but increased sidewall roughness. Sidewall roughness can be reduced by modifying the hard mask. A Cr/HSQ hard mask fabricated by an etching process is found to result in smoother sidewalls than a Cr/Ni hard mask fabricated by a lift-off process. Post fabrication annealing is additionally explored as a means to reduce sidewall roughness and reclaim the SiC surface after ICP-RIE. SiC pillar arrays are annealed in hydrogen for a short duration in a SiC CVD reactor. Sacrificial oxidation by annealing in oxygen followed by oxide removal is also performed. The pillars are characterized using SEM, AFM, XPS, and Raman spectroscopy to examine the impact of annealing on surface chemistry, roughness, and pillar array morphology.

[1] M. Widmann, et al., Nat. Mater., 14, 164−168 (2014)

[2] M. Radulaski, et al., Nano Lett., 17, 3, 1782–1786 (2017)

[3] R. L. Myers-Ward, et al., Mater. Sci. Forum, 924, 905–908 (2018)

[4] Y. Zu, et al., Nano Lett. 23, 11453−11460 (2023)

[5] M. Scharin-Mehlmann, et al., Adv. Mater. Interfaces, e70525 (2026)

[6] C. Chia, et al., Opt. Express 30, 9, 14189-14201 (2022)

11:30am **EM-WeM-15 Structural and Electrical Characterization of He Ion Implanted 4H-SiC**, ***Ben Sekely***, *Cory Cress, Jeffery Woodward, Daniel Pennachio, Ignas Lekavicius, Jenifer Hajzus, Rachael Myers-Ward,* U.S. Naval Research Lab

He ion implantation has been used in 4H-SiC devices to generate defects and damage the crystal, thus changing the characteristics of the material at the implanted region. This localized implantation has been utilized for the formation of edge termination structures in Schottky barrier diodes [1] and radiation detectors [2] where the impact of implantation of the neutral species on device functionality is observed for a specific He dose. Most characterization studies conducted previously have investigated the behaviors of He-ion-implanted SiC at a dose >1e14 cm^{-2}.

In this study, we widen the scope by studying the structural and electrical properties of 4H-SiC implanted at room temperature with a range of He ion doses from 1e12 – 1e16 cm^{-2}. He implantation is performed at 9.5 keV in unintentionally doped (UID) 4H-SiC homoepitaxially grown by chemical vapor deposition.

High resolution X-Ray photoelectron spectroscopy spectra of the 1s carbon (C1s) peak for three different implant doses are compared to a non-implanted region. The lower-energy C-Si peak diminishes with increasing dose. As those bonds break, more carbon is available to form C-C bonding, increasing the higher-energy peak signal.

Implanted regions are mapped by Raman spectroscopy and compared to non-implanted regions. The 980 cm^{-1} peak intensity attributed to the A1 (LO) mode of SiC shows a dramatic decrease in the implanted region for He doses of 1e15 cm^{-2} and higher. Similarly, the full-width half-maximum (FWHM) of the peak broadens compared to the non-implanted region. The changes in this peak are below the detection limit at lower doses.

High resolution X-ray diffraction was performed at the 4H-SiC (0004) reflection to probe the modification of the crystalline structure due to the He ion implantation dose. The 2θ/ω scans showed broadening in the intensity tail on the low-angle side of the peak at a dose of 10^{15} cm^{-2}, which indicates expansion of the out-of-plane lattice constant.

Electrical characterization of these regions including capacitance-voltage and current-voltage will be presented and correlated with further structural characterization including atomic force microscopy. Additionally, material resistivity will be obtained using circular transmission line measurement structures. Understanding these material properties could make this approach useful for edge termination in high-power devices.

[1] D. Alok et al. *Proceedings of 1995 International Symposium on Power Semiconductor Devices & IC's: ISPSD ,95, Yokohama* (1995) doi: 10.1109/ISPSD.1995.515016
[https://ieeexplore.ieee.org/document/515016]

[2] B. J. Sekely et al. Presented at the 4th DRD3 Week on Solid State Detectors R&D. Nov 2025.

11:45am **EM-WeM-16 Impact of ZnO Deposition Method on Post-Illumination Charge Trapping and Recovery in Organic Photodiodes**, ***Anna Leonard***, *Neha Chaturvedi, Veena Misra,* North Carolina State University

For organic photodiodes (OPDs) to achieve high sensitivity and operational stability, they must use charge-selective, morphologically stable charge transport layers. ZnO is commonly used as an electron transport layer due to its favorable energetics and solution processability, however, sol-gel ZnO typically contains more defects and structural disorder than films deposited with vacuum techniques. These defects contribute to trap-assisted recombination and persistent photocurrent effects that increase recovery time, making them detrimental to OPD performance. In this work, atomic layer deposited (ALD) and sol-gel ZnO were investigated as electron transport layers to understand the operational stability of PTB7-Th:IEICO-4F OPDs through post-illumination dark current recovery measurements and related structural and electrical characterization. While ALD ZnO has been previously explored in organic optoelectronic devices, its influence on persistent photocurrent effects in OPDs has not been extensively studied.

OPDs were exposed to a controlled light source and dark current density vs. voltage (J_{Dark}-V), capacitance-voltage (C-V), and external quantum efficiency (EQE) were measured before and after light exposure. ALD ZnO devices exhibited improved dark current recovery after light exposure, indicating reduced persistent photoconductivity effects and mitigated trap-assisted charge storage. Differences in post-illumination electrical behavior were further supported by C-V analysis. Grazing incidence X-ray diffraction (GIXRD), atomic force microscopy (AFM), and scanning electron microscopy (SEM) measurements revealed differences in interfacial ordering and morphology between sol-gel and ALD ZnO films.

These results demonstrate that ALD ZnO can mitigate photoinduced trapping in OPDs through improved interfacial quality and reduced metastable charge storage. This work highlights the importance of electron transport layer quality in controlling post-illumination electrical recovery and degradation pathways in organic optoelectronic devices.

12:00pm **EM-WeM-17 Accelerated Data-Efficient Metasurface Simulation Using Deep Learning and Neural-Adjoint Inverse Design**, ***Jack Gude***, *Muhammad Ashar Naveed, Yanan (Laura) Wang,* University of Nebraska - Lincoln

Metasurfaces are ultra-thin nanostructures capable of precise light manipulation for next-generation integrated photonics and quantum technologies. While numerical simulations, such as Finite-Difference Time-Domain (FDTD) provide high-fidelity modeling, the computational cost is significant; optimizing a single 7-parameter geometry can require weeks of simulation time. This bottleneck prevents the rapid iteration required for large-scale design and optimization of metasurface devices. In this work, we

present a neural surrogate model designed to act as a high-speed physics interpolator. Our foundational model successfully reduces simulation time from weeks to milliseconds while maintaining >0.99 R^2 accuracy for Circular Dichroism (CD) spectra predictions.

Building upon this validated surrogate, we introduce an ongoing exploration into novel data encoding strategies to further mitigate the FDTD data generation bottleneck. Standard predictive networks often require massive datasets to predict entire spectra. We present an alternative wavelength-as-input encoding approach. By restructuring the network to accept wavelength as an explicit, continuous input parameter alongside unit cell geometry metrics, we can effectively multiply our dataset size by 121x. We aim to show how this allows for high-fidelity predictions using significantly reduced FDTD sampling.

We will present the comparative performance of this point-prediction encoding strategy against standard spectrum-prediction methods. Preliminary findings regarding the model's ability to maintain high predictive accuracy on constrained datasets will be discussed. Ultimately, refining these neural network strategies and improving data efficiency is a critical stepping stone toward deploying autonomous active learning paradigms, paving the way for real-time inverse design and integrated quantum photonics engineering.

Author Index

Bold page numbers indicate presenter