Wednesday Afternoon, September 24, 2025

Electronic Materials and Photonics
Room 207 A W - Session EM3+TF-WeA

Materials and Devices for Advanced Photonics and Plasmonics

Moderators: Erin Cleveland, Laboratory of Physical Sciences, **John P. Murphy**, Naval Research Laboratory

4:15pm **EM3+TF-WeA-9 Writable and Spectrally Tunable Cadmium Oxide Plasmonics via Gallium-Ion Implantation***, **Maxwell Tolchin,*** The Pennsylvania State University*; Bhaveshkumar Kamaliya,* McMaster University, Canada*; Angela Cleri,* The Pennsylvania State University*; Youngji Kim,* Vanderbilt University*; Morvarid Ghorbani,* McMaster University, Canada*; Anton Ievlev,* Center for Nanophase Materials Sciences, Oak Ridge National Laboratory*; Nabil Bassim,* McMaster University, Canadian Centre for Electron Microscopy, Canada*; Joshua D. Caldwell,* Vanderbilt University, Sensorium Technological Laboratories*; Jon-Paul Maria,* The Pennsylvania State University

Ion beam engineering is a promising field to advance plasmonic and nanophotonic technologies. At high (1s to 10s MeV) and low (10s to 100s keV) ion beam energies, semiconductor chemistries can be modified and constructed into spatially and spectrally coherent devices. A direct beneficiary to ion beam engineering is cadmium oxide (CdO) thin film plasmonics. High-throughput CdO thin films grown by high-power impulse magnetron sputtering (HiPIMS) have an intrinsic affinity for oxygen vacancy formation. Thereby, achieving carrier concentrations of 1.6 to 3.5 x 10^{19} cm^{-3} while maintaining mobilities of 235 to 290 $cm^2V^{-1}s^{-1}$. By the carrier concentration to plasma frequency relation using Drude formalism, spectral ranges can span the mid-wave infrared (MWIR) spectrum. This is evident by reactively co-sputtering HiPIMS CdO with extrinsic dopants (i.e., Y, In, F) to extend carrier concentrations and mobilities to 5 x 10^{20} cm^{-3} and 470 $cm^2V^{-1}s^{-1}$, respectively. These capabilities realize CdO as a highly programmable, low-loss material system with a chemical bandwidth to sustain high crystallinity and structural resilience. Herein, and enabled by the chemical flexibility of CdO and need for localized and wavelength-tunable plasmonics, 30 keV gallium-ion (Ga^+) implantation is employed. Using a focused ion beam scanning electron microscope (FIB-SEM), thermally activated Ga^+ implants facilitate shallow, donor-doped CdO at ion doses ranging from 1 x 10^{14} to 1 x 10^{16} $ions/cm^2$. Beam tilting techniques and iterative thermal activation conditions achieve site-specific and spectrally defined architectures. Microscopy and spectrometry support high-homogeneity Ga^+ distribution and characteristic morphology in CdO. Near- and far-field spectroscopy show observable changes to phonon and plasmon resonances affiliated with Ga-doping behavior. An innovative beam-stitching process affords larger pattern designs to demonstrate Hall Effect transport properties of 1.3 x 10^{20} cm^{-3} and 372 $cm^2V^{-1}s^{-1}$. In summary, spectral tunability by Ga^+ implantation is on-par with optoelectronic properties seen in extrinsically doped-CdO thin films with an added dimensionality of spatially-controlled dopant writability. And, this work acknowledges the reliability of ion implantation doping for next generation plasmonics and nanophotonics by ion beam engineering.

4:30pm **EM3+TF-WeA-10 Rolled-Up Metamaterials (RUMMS) for Infrared Imaging***, **Gokul Nanda Gopakumar,** Stephanie Law,* The Pennsylvania State University

Overcoming the diffraction limit requires accessing large wave vector modes, which typically vanish rapidly near a material's surface. Conventional materials limit the propagation of these waves which contain subwavelength information about an object. Hyperbolic media, characterized by anisotropic permittivity with opposing signs along different axes, facilitate the transmission of these high spatial frequencies within their bulk. These materials have an open isofrequency surface, in contrast to the closed isofrequency surface of normal materials. In a flat hyperbolic material, the sub-diffractional information will still exponentially decay once it leaves the hyperbolic medium. However, in a rolled-up hyperbolic material, the wavevector of the light decreases as it propagates radially, effectively magnifying the image and enabling sub-diffractional information to be projected beyond the material's surface.

In this work, we present rolled up semiconductor-based infrared hyperbolic metamaterials. We fabricate these structures by using a strained bilayer that can be released from the substrate. The strained bilayer is grown using III-V semiconductors in a molecular beam epitaxy system. It comprises of a compressively strained bottom layer and tensile strained top layer grown on top of a sacrificial layer. A heavily doped III-V semiconductor is grown on top and this layer acts as an optical metal in the IR. Fabrication of rectangular mesas is done using standard lithographic and wet etching techniques. Finally, a wet etch that selectively removes the sacrificial layer is used to gradually release the strained bilayer, causing it to roll up. By changing the alloy composition, we tune the stress in the bilayers to change the diameter of the rolled-up tube. The number of turns in the rolled-up tube can also be increased by increasing the etching time. The result is a RUMM that has alternating layers of dielectric and metal in the radial direction.

The growth of the strained bilayer and determination of the strain are evaluated using high resolution X-ray diffraction. Scanning electron microscopy is used to image the rolled-up tubes and correlate their diameter to the bilayer strain. Finally, infrared spectroscopy will be used to measure the optical properties of the RUMMs. This is the first step in creating a fully semiconductor-based curved hyperbolic metamaterial that can be used in subdiffractional imaging in the IR wavelength range.

4:45pm **EM3+TF-WeA-11 Nano-Plasmonics for Hybrid, Far IR Photodetection: Simulation and Fabrication***, **Basil Vanderbie**, Samuel Fedorka, Charles Dickerson, John McElearney,* Tufts University*; Corey Shemelya,* Government*; Thomas Vandervelde,* Tufts University

Far infrared avalanche photodetectors are typically cryogenically cooled to negate thermally excited carriers from being generated in the absorption region which limits potential applications.To remove the need for cryogenic equipment a possible option is the removal of the absorption region and replacement with plasmonic nano-antennas and direct carrier injection. In this work we explore novel methods, materials, and geometries to promote direct injection and anisotropic progression of carriers into the avalanche region of a III-V PIN diode.Our proposed designs were verified by simulation with CST Microwave Studio for electromagnetics and COMSOL Multiphysics for carrier dynamics. Additionally, we have developed a unique fabrication plan for both the multi-axis junction and plasmonic resonator, as well as structures resonant in the RF regime for the purposes of a feasibility study.

5:00pm **EM3+TF-WeA-12 Wide-Bandgap Hybrid Metamaterials: Theory guided Advanced Surface Engineering for UV active Photonic Properties***, **Ufuk Kilic**, Shawn Wimer, Matthew Hilfiker, Raymond Smith,* University of Nebraska-Lincoln*; Christos Argyropoulos,* The Pennsylvania State University*; Eva Schubert, Mathias Schubert,* University of Nebraska-Lincoln

Metamaterials (MMs) -the artificially engineered surface structures with subwavelength scale features- are at the forefront of optoelectronic, quantum, and biomedical advancements [1-4]. Despite the critical importance, their effective operation in the ultraviolet (UV) spectral range by using wide-bandgap materials (WBGM) for aforementioned advancements is seldom discussed in the literature [1]. WBGMs provide exceptional transparency, high stability, corrosion resistance, and UV-active optical responses. These properties enable strong UV-active light-matter interactions, making them ideal for robust, tunable MMs in advanced photonic and quantum applications.

In this study, our methodology is framed over a theory-guided approach for fabricating and optimizing MM platforms from ultra-wide bandgap Zirconia (ZrO_2). While the finite element modeling provides insights on light-matter interaction at nanoscale [2-4], Monte Carlo ballistic simulation method unravels the particle flux dynamics and the structure growth process [5]. Utilizing electron beam assisted glancing angle deposition technique, that is particularly known for its capacity to produce various 3D morphologies over wafer-scale area, and free of masks [2-4], we fabricated highly ordered nano-columnar, and nano-helical MM platforms. Using Mueller Matrix generalized spectroscopic ellipsometry technique, we optically investigated the fabricated MM platforms within the spectral range covers near-IR (0.64 eV) to vacuum-UV (9.5 eV) and found that they exhibit strong optical anisotropies including circular dichroism and birefringence.

Here, we also present and discuss the subsequent depositions of dielectric (ZrO_2) and metallic (silver/Ag) materials leading to hybrid plasmonic MMs with a multiple number of subsegments that achieve enhanced and spectrally controlled optical anisotropies active in visible to UV spectral range. Performing complementary scanning electron microscopy, transmission electron microscopy, and energy-dispersive X-ray spectroscopy, we extracted the integrity, crystallinity, and stoichiometry of the fabricated MM platforms. This work advances photonic and quantum device design by integrating material fabrication, theoretical modeling, and experimental characterization, demonstrating how wide-bandgap ZrO_2 combined with plasmonic metals enables tunable MMs for high-power systems, UV photonic circuits, and chiral sensors.

[1]Duncan, M. A.,et al.,ACS Appl.Mater.Interfaces,14(50),55745-55752,(2022)

[2]Kilic, U.,et al.,Adv.Funct.Mater.31.20:2010329,(2021)

[3]Kilic, U.,et al.,Adv.Opt.Mat.2302767,(2024)

[4]Kilic, U.,et al.,Nat.Comm.15.1:3757,(2024)

[5]Wimer, S.,et al.,Vacuum,(under review 2025)

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