Thin Films Division
Room 316 - Session TF+EM-MoA

Thin Films for Optics, Photonics, Metamaterials, and Soft Electronics

Moderator: April Jewell, Jet Propulsion Laboratory

1:40pm **TF+EM-MoA-1 Strategies for Achieving Tunable Infrared Emission in III-V Materials**, ***Michelle Povinelli***, *H. Chae, A. Ghanekar, B. Shrewsbury, R. Ahsan, R. Kapadia,* University of Southern California **INVITED**

We investigate strategies for creating tunable thermal emitters in III-V platforms. Two fabrication approaches are examined: direct growth of III-V films on metallic substrates and epitaxial transfer. We design corresponding infrared metamaterials and measure their wavelength-dependent absorptivity using FTIR spectroscopy. We demonstrate electrically induced shifts in the absorptivity spectrum. We then introduce device designs for absorptive/emissive switching. We assume that the applied voltage induces a perturbative index shift with double the period of the initial metamaterial. With careful design, the perturbation is predicted to switch the thermal emission on and off within a specified bandwidth and angular range.

2:20pm **TF+EM-MoA-3 Effects of Ultra-Thin Conformal Coatings on the Spectral Location of Reciprocal Plasmonic Metasurface Resonances**, ***Micheal McLamb***, *V. Stinson, N. Shuchi, G. Boreman, T. Hofmann,* University of North Carolina at Charlotte

Optical metamaterials are a group of engineered materials that are composed of an arrangement of artificial structures, which result in properties that are not exhibited in naturally occurring compounds. These unique optical properties can be used to produce extraordinary optical effects including narrow band filtering [1], perfect lensing [2], and perfect absorption [3].

In order to achieve perfect absorption, metamaterial designs that rely on heterostructures have shown promising results [3, 4]. Heterostructured materials are composed of multiple, stratified constituents. We have developed a reciprocal plasmonic metasurface that is composed of two plasmonic metasurfaces with reciprocal surface geometries that are separated by a dielectric spacer. Experimental infrared reflection measurements revealed the expected reciprocal plasmonic metasurface resonance, which was observed for the investigated geometries, at 4.8 µm. The location of this resonance was in agreement with finite element calculations.

We have also explored the optical response of reciprocal metasurfaces when coated with a conformal dielectric, amorphous Al_2O_3, for different coating thicknesses: 10 nm, 20 nm, 30 nm, and 40 nm. In order to experimentally explore the effect of ultra-thin conformal dielectric coatings on the spectral location of the reciprocal plasmonic metasurface resonance, Al_2O_3 coatings were deposited using atomic layer deposition. Our observations indicate that such dielectric coatings can induce a spectral red-shift of the main resonance of the reciprocal plasmonic metasurface allowing for the tuning of the resonant frequency.

1. V.P. Stinson, S. Park, M. McLamb, G. Boreman, and T. Hofmann, Optics, **2**, 284-291 (2021).

2. J.B. Pendry and S.A. Ramakrishna, Physica B, **338**, 329-332 (2003).

3. Y. Li, M. McLamb, S. Park, D. Childers, G.D. Boreman, and T. Hofmann, Plasmonics, **16**, 2241-2247 (2021).

4. M. McLamb, S .Park, V.P. Stinson, Y. Li, N. Shuchi, G.D. Boreman, and T. Hofmann, Optics, **3**, 70-78 (2022).

2:40pm **TF+EM-MoA-4 Integrating Structural Colors with Additive Manufacturing Using Atomic Layer Deposition**, ***Tae Cho***, *B. Rorem, N. Farjam, J. Lenef, K. Barton, J. Guo, N. Dasgupta,* University of Michigan, Ann Arbor

Structural colors, which allow for tunable surface reflectance spectra, are being increasingly used in a variety of applications such as optical displays, prints, decorations, and color photovoltaics. Compared to pigment-based colors, structural color offers many advantages including high brightness, durability, environmental sustainability, and ease of fabrication. However, traditional thin-film deposition processes often suffer from conformality, thickness control, and versatility in material selection. Compared to these techniques, atomic layer deposition (ALD) offers unparalleled control of film thickness and uniformity on complex topologies at relatively low temperatures which is compatible with polymer/biological/organic substrates. In this work, we fabricated asymmetric metal-dielectric-metal (MDM) structures which were sequentially deposited with nickel, zinc oxide (ZnO), and copper layer to form optical cavities. The ZnO thickness was varied from 40 nm to 160 nm which exhibited a full-color cycle from red, blue, and to yellow which agreed with the simulated spectra using the transfer matrix method.

To demonstrate the power of ALD to enable uniform and tunable coloration of non-planar three-dimensional objects, ALD MDM structures were deposited on 3-D printed metal objects. Blue and yellow colors were 'painted' onto the 3-D printed surface using 80 nm and 120 nm thick ALD ZnO, respectively, with 20 nm thick copper top layer. Vibrant and uniform colors were observed across all of the curved features owing to ALD's conformal coating of the microscopic porous topologies from metal 3-D printing.

Furthermore, our previous work has shown that using electrohydrodynamic jet (e-jet) printing, we can locally activate/passivate ALD growth for area-selective ALD (AS-ALD) patterning down to approximately 300 nm resolution [1]. By using e-jet printed patterns to control AS-ALD, multiple colors were printed on the same substrate by patterning the polymer inhibitor layers. This enables color printing of functional ALD materials with resolutions well below that of ink-jet printing. By combining AS-ALD with structural color, this work can open up the possibility of integrating additive nanomanufacturing with structural colors into even more complex 3-D geometries including hierarchical architectures that span nano- to macro-length scales.

[1] T.H. Cho, N. Farjam, C. R. Allemang, C. P. Pannier, E. Kazyak, C. Huber, M. Rose, O. Trejo, R. L. Peterson, K. Barton, N. P. Dasgupta, *ACS Nano* **14**, 17262 (2020)

[2] B. A. Rorem, T. H. Cho, N. Farjam, J. D. Lenef, K. Barton, N. P. Dasgupta, L. J. Guo, *Submitted* (2022)

3:00pm **TF+EM-MoA-5 Biosensor Encapsulation via Photoinitiated Chemical Vapor Deposition (piCVD)**, ***Ruolan Fan***, *T. Andrew,* University of Massachusetts - Amherst

Thin and porous poly(hydroxyethyl acrylate) (pHEA) and poly(3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctyl acrylate) (pTFOA) encapsulating layers were successfully deposited on model electrical and optical glucose sensors via photoinitiated chemical vapor deposition (piCVD). This surface-restricted chain growth process afforded uniform coverage and strong interfacial adhesion of the resulting polymer encapsulation layers, which enabled the whole sensing area to be fully covered, even after being subjected to numerous electrochemical scanning cycles. Meanwhile, the amorphous films allowed rapid ion and analyte diffusion through themselves and, therefore, achieved quick sensing responses. Especially, pTFOA promised well-defined calibration curves with good repeatability. Furthermore, piCVD films maintained their morphology after being dehydrated and rehydrated over multiple days demonstrating their excellent stability as surface protective layers. These promising features of pHEA and pTFOA synthesized via piCVD may serve as a new encapsulating idea to be applied to various wearable sensors with different substrates and serve as a new strategy to extend the shelf life and functionality of biosensors.

3:20pm **TF+EM-MoA-6 Harnessing Wide-Range, Highly Stable Pressure Sensitivity Via PEDOT-Cl Vapor Printed Textiles for Health Monitoring**, ***S. Zohreh Homayounfar****, A. Kiaghadi, D. Ganesan, T. Andrew,* University of Massachusetts, Amherst

The advancement of wearable electromechanical sensors to detect biopotentials and body locomotion is critically important in evaluating human performance and improving off-site care applications. The practicality of most of the so-far-developed sensors is highly restricted by the small range of detection and low stability against aging phenomena such as cycling abrasions, exposure to perspiration, and washing. By vapor deposition of a p-doped conjugated polymer, poly(3,4-ethylene dioxythiophene): chloride (PEDOT-Cl), we introduce an ultra-stable pressure sensor that reveals high sensitivity in detecting real-time signals in such a wide range of pressures that have not been reported before (from heartbeats to more than bodyweight). We leveraged a multi-scale working mechanism by developing two sensors: one with PEDOT-Cl coated cotton fabric and one with PEDOT-Cl coated cotton ball as the active layer. In addition to having percolation on the microscale, our sensors harness piezoionic effect on the nanoscale, which means that the redistribution of ions under the applied mechanical stress leads to the change in resistance. We protected the sensor against all the humidity-induced degradations entangled with ions and other aging processes via vapor deposition of hydrophobic moieties on all the sensor layers. With this protective coating, the sensor shows less than no change in resistance and sensitivity after staying in ~100% humidity for more than 150 hrs and can stand more than 10 laundry cycles without any drop in signal quality. Also, it displays ultra stability with 99.1% over 70,000 bending cycles in ambient conditions. The broad ability of this sensor was further confirmed by acquiring physiological signals and body motions such as heartbeats, respiration, and Joint movements. All these properties, along with the low-cost and robust fabrication process, bear the testimony that this sensor will be uniquely placed in wearable health monitoring electronics for both diagnostic and treatment applications.

Author Index

Bold page numbers indicate presenter

— A —
Ahsan, R.: TF+EM-MoA-1, 1
Andrew, T.: TF+EM-MoA-5, 1; TF+EM-MoA-6, 2
— B —
Barton, K.: TF+EM-MoA-4, 1
Boreman, G.: TF+EM-MoA-3, 1
— C —
Chae, H.: TF+EM-MoA-1, 1
Cho, T.: TF+EM-MoA-4, **1**
— D —
Dasgupta, N.: TF+EM-MoA-4, 1
— F —
Fan, R.: TF+EM-MoA-5, **1**
Farjam, N.: TF+EM-MoA-4, 1
— G —
Ganesan, D.: TF+EM-MoA-6, 2
Ghanekar, A.: TF+EM-MoA-1, 1
Guo, J.: TF+EM-MoA-4, 1
— H —
Hofmann, T.: TF+EM-MoA-3, 1
Homayounfar, S.: TF+EM-MoA-6, **2**
— K —
Kapadia, R.: TF+EM-MoA-1, 1
Kiaghadi, A.: TF+EM-MoA-6, 2
— L —
Lenef, J.: TF+EM-MoA-4, 1
— M —
McLamb, M.: TF+EM-MoA-3, **1**
— P —
Povinelli, M.: TF+EM-MoA-1, **1**
— R —
Rorem, B.: TF+EM-MoA-4, 1
— S —
Shrewsbury, B.: TF+EM-MoA-1, 1
Shuchi, N.: TF+EM-MoA-3, 1
Stinson, V.: TF+EM-MoA-3, 1