## Electronic Materials and Photonics
## Room 102B - Session EM-MoM

### Advances in Photonics

**Moderators:** Michael Filler, Georgia Institute of Technology, Daniel Wasserman, University of Texas at Austin

8:20am **EM-MoM1 Optical Materials for Far-IR Reststrahlen Optics*, Daniel Wasserman,*** University of Texas at Austin **INVITED**

The mid-infrared (mid-IR) spectral range (3-15µm) has become a burgeoning and dynamic field of research both for fundamental exploration as well as for more applied research in health and the environment, security and defense, communication, and sensing. New optoelectronic devices, in particular sources and detectors, have allowed for the rapid growth of the mid-IR, and the development of a range of optical systems for a variety of applications. At the same time, the areas of plasmonics and metamaterials have experienced explosive growth over the past decade, fueled in part by rapid developments in fabrication, characterization, computational science, and theory. These have become increasing important in the mid-IR, where sub-wavelength confinement and manipulation of light offer the potential for new types of optical materials and structures for integration with the ever-improving mid-IR optoelectronic devices. Yet all of the above developments are, in some ways, spectrally limited to wavelengths <20µm, due largely to the strong absorption of light in semiconductors at, or near, to optical phonon energies. The strong absorption of optical phonons results in a far-IR wavelength band, which for simplicity sake we refer to as the Reststrahlen region, from 20-60µm where little to no optical and optoelectronic infrastructure exists.

In this talk, I will discuss our group's recent work developing novel optoelectronic, plasmonic, and phononic devices and structures for far-IR applications. I will present far-IR perfect absorber structures and discuss the potential and limitations of selective thermal emitters in the far-IR. In addition, I will demonstrate how phononic materials can behave similarly to plasmonic materials in a limited spectral band near the longitudinal optical (LO) phonon, showing coupling to both propagating and localized surface phonon modes. I will also show how careful control of doping in semiconductor epilayers offers some wavelength flexibility in designing materials capable of supporting hybrid plasmonic/phononic modes. Finally, I will discuss the opportunities for development of far-IR optoelectronic devices capable of serving as light sources at far-IR wavelengths. In all, I hope to present a picture of the far-IR as a new optical frontier where we can not only apply the lessons from shorter wavelength photonic structures, but also explore exciting new approaches to the development of Reststrahlen band optical infrastructure.

9:00am **EM-MoM3 Mid-IR to THz Nanophotonics: Realizing Alternative Polaritonic Materials*, Joshua Caldwell,*** US Naval Research Laboratory **INVITED**

The field of nanophotonics is based on the ability to confine light to sub-diffractional dimensions. Up until recently, research in this field has been primarily focused on the use of plasmonic metals. However, the high optical losses inherent in such metal-based surface plasmon materials has led to an ever-expanding effort to identify, low-loss alternative materials capable of supporting sub-diffractional confinement. Beyond this, the limited availability of high efficiency optical sources, refractive and compact optics in the mid-infrared to THz spectral regions make nanophotonic advancements imperative. One highly promising alternative are polar dielectric crystals whereby sub-diffraction confinement of light can be achieved through the stimulation of surface *phonon* polaritons within an all-dielectric, and thus low loss material system. Due to the wide array of high quality crystalline species and varied crystal structures, a wealth of unanticipated optical properties have recently been reported. However, these materials also have some limitations, primarily in the limited spectral bandwidth of operation for any given material. This talk will discuss recent advancements to improve the material lifetime and to induce additional functionality through isotopic enrichment and hybridization of polaritonic modes for realizing low-loss, actively tunable/modulated nanophotonic materials.

9:40am **EM-MoM5 Time-Resolved Optical Studies on Reflection and Transmission of Niobium Dioxide Thin Films*, Melissa Beebe*[*],*** College of William and Mary*; J.M. Klopf,* Helmholtz-Zentrum Dresden-Rossendorf, Germany*; D. Lahneman, Z. Xing, M.M. Qazilbash,* College of William and Mary*; Y. Wang, S. Kittiwatanakul, J. Lu, S.A. Wolf,* University of Virginia*; R.A. Lukaszew,* College of William and Mary

Niobium dioxide ($NbO_2$) is a highly correlated material that, like vanadium dioxide ($VO_2$), exhibits a first-order insulator-to-metal transition (IMT) at a material-dependent critical temperature, accompanied by a structural transformation from monoclinic to rutile. The nature of the IMT in $VO_2$ has been discussed at length, while fewer studies have been carried out on $NbO_2$. Here, we present ultrafast pump-probe studies comparing reflection measurements to the first ultrafast transient transmission measurements of this optically-induced transition in $NbO_2$ thin films, as well as compare these studies to similar ones carried out on $VO_2$ thin films.

10:00am **EM-MoM6 Fabrication of Nanosphere-Based Disordered Coatings for Radiative Cooling under Direct Sunlight*, Sarun Atiganyanun,*** *S.E. Han, S.M. Han,* University of New Mexico

In this study, we investigate a facile fabrication of coatings made of silica nanosphere-based disordered structures via evaporation coating and air atomization coating. In both methods, silica nanospheres with a diameter of ~900 nm are dispersed in a water or methanol solution, where the sphere size can be further tuned. The colloidal stability is then disrupted by dissolving salt in the solution. In the evaporation coating, the bulk solution is confined in a substrate and is let to evaporate. In the atomization coating, the solution is atomized by a spray nozzle, and resulting droplets are deposited onto a substrate. Scanning electron microscopy images and subsequent autocorrelation analyses show that the resulting structures are disordered without short- or long-range order. Transmission measurement also indicates that the structures have a short transport photon mean free path of approximately 4-8 µm. These results suggest strong photon scattering properties in the visible region, while providing a strong emission window in 8 to 13 µm range. Such films would enable potential applications in radiative cooling. To investigate this aspect, a computational model is used to calculate the cooling power of the coatings under direct sunlight. The model predicts that the disordered coating with 200 µm thickness has a cooling power of ~250 W/m$^2$ at 27ºC and could reduce the temperature of the sample under a direct sunlight by approximately 37ºC below the ambient temperature. We will further discuss our experimental measurements in this presentation.

10:40am **EM-MoM8 Symmetry-Breaking Nanostructures for Light Trapping in Thin Crystalline Silicon Solar Cells*, Seok Jun Han,*** *S. Ghosh, O.K. Abudayyeh, B.R. Hoard, E.C. Culler, J.E. Bonilla, S.M. Han, S.E. Han,* University of New Mexico

While various materials have been investigated for photovoltaics, solar cells based on crystalline silicon (c-Si) dominate the current photovoltaics market. To reduce the cost of c-Si cells, wafer manufacturing companies have produced competitively priced thin c-Si films, ranging from a few microns to tens of microns, using a kerfless process. In such thin-film c-Si cells, light absorption becomes poorer than in thick films and light trapping is crucial to increase the photovoltaic efficiency. Han *et al.* have demonstrated that, among various light-trapping schemes, symmetry breaking in photonic nanostructures can approach the Lambertian light-trapping limit very closely. However, fabricating symmetry-breaking nanostructures in a scalable, cost-effective, manufacturable manner remains elusive. Here, we introduce a new approach to systematically break the symmetry in photonic nanostructures on c-Si surface. Using our approach, we fabricate low-symmetry inverted nanopyramid structures. Our method makes use of low-cost, manufacturable wet etching steps on c-Si(100) wafers without relying on expensive off-cut wafers. Our experiment and computational modeling demonstrate that the symmetry breaking can increase the Shockley-Queisser efficiency from 27.0 to 27.9% for a 10-micron-thick c-Si film. Further, our computation reveals that this improvement would increase from 28.1 to 30.0% with over-etching for a 20-micron-thick c-Si film.

11:00am **EM-MoM9 Non-thermal Plasma Synthesis of *In Situ* Graphene Shells on Silicon Carbide Nanoparticles*, Devin Coleman,*** *L. Mangolini,* University of California - Riverside

The synthesis of beta-phase silicon carbide nanoparticles exhibiting a hollow core-shell morphology is demonstrated by means of a two-step non-thermal plasma method.[1] Crystalline silicon nanoparticles are

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[*] **TFD James Harper Award Finalist**

nucleated from silane precursor gas in a non-thermal plasma reactor similar to the one described in [2] and injected into a secondary methane-containing plasma reactor, where they are carbonized to form beta-phase silicon carbide nanoshells. Furthermore, at sufficiently high input power in the second plasma, a single-layer graphene coating forms around the silicon carbide particles. These findings are consistent with XRD and Raman spectra. An analytical solution of the 1D diffusion equation in spherical coordinates, as well as the lattice volume expansion from silicon to silicon carbide are used to explain the formation of the interior void. This provides an alternative to previously reported results, which invoke the nanoscale Kirkendall effect to explain the void formation by means of fast out-diffusion of the core element.[3] Further consideration of the system kinetics indicates interactions with the ionized gas leads to particle superheating, allowing for the diffusion of carbon into the silicon matrix and nucleation of beta-phase silicon carbide to occur during the short residence time of the particles in the system. This work expands upon the materials achievable by non-thermal plasma synthesis and suggests that such systems offer the capability to engineer particle morphology, as well as grow conformal 2D materials on freestanding nanoparticles.

References:

[1] Hollow silicon carbide nanoparticles from a non-thermal plasma process. D. Coleman, T. Lopez, O. Yasar-Inceoglu, and L. Mangolini. J. Appl. Phys. In press (2015).

[2] Silicon nanocrystal production through non-thermal plasma synthesis: a comparative study between silicon tetrachloride and silane precursors. O. Yasar-Inceoglu, T. Lopez, E. Farshihagro, and L. Mangolini, Nanotechnology 23, 255604 (2012).

[3] Formation of Hollow Nanocrystals Through the Nanoscale Kirkendall Effect. Y. Yin, R. M. Rioux, C. K. Erdonmez, S. Hughes, G. A. Somorjai, and A. P. Alivisatos, Science 304, 711 (2004).

11:20am **EM-MoM10 Size and Structure Dependence of Electronic Transport Properties at Nanosized Interfaces***, **Dawn Bonnell**, J. Hou,* The University of Pennsylvania

It is an accepted truism that the behavior of surfaces and interfaces is dictated by the interactions of atoms. Consequently, understanding atomic interactions at surfaces and interfaces is the foundational basis for predicting, controlling, and designing devices and processes. This is particularly relevant to devices for memory storage, sensing, and photonics in which electrical contacts must be made at very small scales. We use an ideal system to examine the size and structure dependence of interfaces.

We report that the size dependence of electronic properties at nanosized metal−semiconducting oxide (Au nanoparticle/SrTiO3 ) interfaces is significantly affected by the interface atomic structure. The properties of interfaces with two orientations are compared over size range of 20−200 nm. Three different mechanisms of size dependence occur at various size regimes. The difference in interface atomic structure leads to electronic structure differences that alter electron transfer paths. Specifically, interfaces with a higher concentration of undercoordinated Ti result in enhanced tunneling due to the presence of defect states or locally reduced tunnel barrier widths.

In the case of materials which exhibit resistive switching the observed “eight-wise” bipolar resistive hysteresis loop is modulated by trap/detrap process. The size-dependent high resistance state is consistent with changes in both the interfacial area and Schottky properties. The low resistance state exhibits size independent resistance through the dominant fast conductive path. Detrapping requires more work for smaller interfaces due to the associated larger built-in electric field.

11:40am **EM-MoM11 Metal Nanoparticles formed in Organic Molecular Crystals: HR-TEM and HR-PES Characterisation***, **Olga Molodtsova**,* DESY, Hamburg, Germany*; I.M. Aristova,* ISSP RAS, Chernogolovka, Russia*; S.V. Babenkov,* DESY, Hamburg, Germany*; V.Y. Aristov,* ISSP RAS, Chernogolovka, Russia

The evolution of the morphology and the electronic properties of the hybrid organic-inorganic systems composed of metallic nanoparticles distributed in semiconductor organic matrix (FxCuPc, x=0,4,16), as a function of nominal metal content was studied by high-resolution transmission electron microscopy and by surface- and bulk sensitive high-resolution photoelectron spectroscopy perfermed at different Synchrotron Radiation facilities. Using HR-TEM the images of metal nanoparticles with direct resolving of atomic planes were obtained (see Figure). In particular, by this method for some coatings the coalescence processes of nanoparticles depending on the initial mutual orientation of the nanoparticles was observed. This work supported by the RFBR Grant No. 13-02-00818 and the BMBF-Project No. 05K12GU2, PSP-Element No. U4606BMB1211

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