Nanometer-scale Science and Technology
Room: 304 - Session NS+EN-MoA

Nanophotonics and Plasmonics
Moderator: WeiDavid Wei, University of Florida

2:00pm **NS+EN-MoA1 Sculpting the Flow of Light at the Nanoscale**, ***Harry Atwater***, California Institute of Technology **INVITED**
Understanding the fundamental properties of plasmonic and dielectric materials in resonant subwavelength structures has fueled an explosion of interest in metamaterials and nanophotonic devices. In this seminar, we explore new directions for plasmonics by examining the relationship between plasmons and the electrochemical potential of the electron gas, and we discuss opportunities to observe quantum coherent states in plasmonic structures. Usually plasmons are described in a classical electromagnetic theory context, yet plasmons are fundamentally quantum excitations. Moreover, the carrier density and optical properties of plasmonic materials are typically fixed at the time of fabrication. Field effect tuning of the electrochemical potential in graphene nanoresonators enables the plasmon and phonon dispersion to be measured. Electrochemical and carrier density modulation in metals yields tunable resonances in metal nanostructures and reveals the plasmoelectric effect, a newly-discovered photoelectrochemical potential. By tuning the permittivity and index to near-zero values, expands the length scale over which coherent quantum emitter phenomena (e.g., concurrence, superradiance) can be observed in epsilon-near-zero media. Finally, we demonstrate entanglement or coherent superposition states of single plasmons using two plasmon-quantum interference in chip-based plasmon waveguide directional couplers.

Web resources:

http://www.lmi.caltech.edu/

http://daedalus.caltech.edu/

2:40pm **NS+EN-MoA3 Patterning of Plasmonic Structures for Chiroptical Spectroscopy**, ***Oded Rabin***, *A.P. Lawson, P.C. McAvoy, I.D. Mayergoyz*, University of Maryland, College Park
Fabrication of truly chiral nanostructures is a challenging process, often requiring multiple cycles of patterning, deposition and planarization. Planar and three dimensional plasmonic nanostructures were fabricated through focused ion beam (FIB) milling, electron beam lithography (EBL) patterning, and a combination thereof, achieving truly chiral nanoscale patterns in a single deposition step. Using computational modeling tools, the plasmon resonance spectra of the structures were predicted. We have combined our computational results and novel fabrication methods to achieve chiral plasmonic nanostructures with useful resonances in the visible and near infrared ranges of the EM spectrum. These substrates are promising for the selective manipulation of circularly polarized radiation at nanometer length scales.

3:00pm **NS+EN-MoA4 Hot Electron Generation Enhanced by Carrier Multiplication Probed with a Graphene/TiO_2 Nanodiode**, ***YoungKeun Lee***, KAIST, Republic of Korea, *H.K. Choi*, ETRI, Republic of Korea, *H. Lee*, KAIST, Republic of Korea, *J.S. Choi*, ETRI, Republic of Korea, *E. Hwang*, Sungkyunkwan University, Republic of Korea, *J.Y. Park*, KAIST, Republic of Korea
Graphene has attracted intensive attention for viable applications such as energy conversion and optoelectronic devices. When photons hit the graphene, the photon energy can be transferred to hot carriers above the Fermi level from the valence band of the graphene before the photon energy is lost as heat. The efficiency of the conversion depends on the interaction of photons with electrons/holes in the system. In graphene without a bandgap, the process of energy relaxation consists of the Auger process (impact ionization), which leads to carrier multiplication. Here, we fabricated a graphene/TiO_2 nanodiode to investigate carrier multiplication by experimental detection and theoretical confirmation of hot electron amplification. Our findings indicate that carrier multiplication of the graphene based on the strong electron–electron interaction is highly efficient, compared with Au/TiO_2 at a given photon energy. Multiple generations of hot electrons can induce photocurrent, which suggests the possibility of feasible applications such as photovoltaics and photodetectors.

3:40pm **NS+EN-MoA6 Doping Induced 1D Plasmons in Ag Monolayer Stripes on Si(557)**, ***Timo Lichtenstein***, *U. Krieg, C. Tegenkamp, H. Pfnür*, Leibniz Universität Hannover, Germany
An efficient way to transfer energy, e.g. light, into an electronic system is by excitation of plasmons. Due to their flat and almost linear dispersion, allowing extreme confinement in a broad frequence range, and their natural function as wave guides 1D plasmons are particularly interesting.

As we show here for the system Ag adsorbed on Si(557), the interaction between adsorbate layers of transition metal atoms and strongly anisotropic surfaces can lead to various quasi-one-dimensional (1D) signatures, which, however, are not all necessarily metallic. Using low energy electron diffraction in combination with scanning tunneling microscopy and electron energy loss spectroscopy, we correlate the structure, determined by SPALEED and STM, with the properties of low dimensional collective excitations, as measured with momentum and energy resolving electron loss spectroscopy. Semiconducting structures with double periodicity along the chains are formed Ag coverages below 0.3 monolayers (ML). At higher coverages, the formation of wires with ($\sqrt{3}$x$\sqrt{3}$) order sets in. Only these wires turn out to be metallic, as is evident from the appearance of plasmonic losses, which show 1D dispersion only along the wires. This 1D property even persists up to one monolayer, where a densely packed arrayof metallic ($\sqrt{3}$x$\sqrt{3}$) stripes is formed. We show evidence that the metallic property is induced by an extrinsic doping process of excess Ag (or other) atoms localized at the step edges, which can be reversibly removed and added. With this system we were able to explicitly show that the 1D plasmon frequency depends on the electron density proportional to $\sqrt{n_e}$ also in the 1D case, and that the confinement of the electrons on the wires is also dependent on doping concentration.

4:00pm **NS+EN-MoA7 Surface Plasmon-Mediated Gold Nanoparticle Deposition *via* Two Different Mechanisms**, ***Jingjing Qiu****, *W.D. Wei*, University of Florida
Utilizing intrinsic surface properties to direct and control nanostructure growth on a large-scale surface is fundamentally interesting and holds great technological promise. We have developed a novel “bottom-up” approach to fabricating sub-15 nm Au nanoparticles on a nanostructured Ag surface *via* a chemical solution deposition by using localized surface plasmon resonance (SPR) excitation. Nanoparticle sizes were tunable between 3 to 10 nm by adjusting the deposition time utilizing the photothermal effects on a nanostructured Ag film surface. In addition, Au nanoparticles can be selectively deposited at the tip of a Ag bowtie nanostructure with the enhanced electric field.

4:20pm **NS+EN-MoA8 Enhanced Light-Matter Interactions in Nanoparticle Arrays**, ***Teri Odom***, Northwestern University **INVITED**
Metal nanostructures concentrate optical fields into highly confined, nanoscale volumes that can be exploited in a wide range of applications. This talk will describe new ways to design arrays of strongly coupled nanoparticles and plasmonic hetero-oligomers that can exhibit extraordinary properties such as plasmon lasing and enhanced gas sensing. First, we will describe a new type of nanocavity based on arrays of metal nanoparticles. These structures support lattice plasmon modes that can be amplified and that can result in room-temperature lasing with directional beam emission. Second, we will focus on nanoparticle assemblies composed of more than one type of material. Hetero-oligomers composed of strong and weak plasmonic materials (Au-Pd dimers and trimers) showed unusual wavelength shifts when subjected to hydrogen gas. We performed detailed modeling to understand the near-field coupling responsible for these amplified light-matter interactions.

5:00pm **NS+EN-MoA10 Plasmon-induced Current Enhancement at Nano-sized Metal-Oxide Interfaces**, ***Jiechang Hou****, *D.A. Bonnell*, University of Pennsylvania
Nano-sized metal-oxide interfaces possess unique physical properties and offers new access to novel functionalities. We have shown that at the nano-scale the electronic properties of Au/ $SrTiO_3$ interfaces are size and atomic structure dependent [1]. This size dependence of interface properties has consequences to related behavior, such as resistive switching [2]. Earlier we have shown that plasmon induced hot electrons can be extracted from Au nanoparticles into molecular devices [3]. Here we use Au nano-antennas/$SrTiO_3$ interfaces as a facile model system to study this phenomenon. The study combines nanofabrication, optical spectroscopies, field simulation and advanced scanning probe microscopy. The

*** NSTD Student Award Finalist**

dependences of photocurrent on power density and temperature are quantified, and the mechanism of photocurrent enhancement is discussed. We believe that this study can improve the understanding of the mechanism of plasmon-induce d current enhancement and facilitate the modern device design.

References:

[1] J. Hou, S. S. Nonnenmann, W. Qin, D. A. Bonnell, *Appl. Phys. Lett*. **103**, 252106, 2013.

[2] J. Hou, S. S. Nonnenmann, W. Qin, D. A. Bonnell, *Adv. Funct. Mater*. (2014). doi: 10.1002/adfm.201304121.

[3] D. Conklin, S. Nanayakkara, T. Park, M. F. Lagadec, J. T. Stecher , X. Chen, M. J. Therien, D. A. Bonnell, *ACS Nano***7**, 4479 (2013).

5:20pm **NS+EN-MoA11 Extreme Tunability of Metal-Dielectric Multilayered Structures using Al-doped ZnO Grown by Atomic Layer Deposition**, ***Jonathan Skuza***, *R.M. Mundle, K.C. Santiago,* Norfolk State University*, D.L. Lepkowski,* Louisiana State University*, A.K. Pradhan*, Norfolk State University

Plasmonic metamaterials have been a burgeoning area of research in recent years, where surface plasmon polaritons (SPPs) can manipulate light on the nanoscale. Typically, noble metals (e.g. Ag, Au) have been the key materials in this field of research, but suffer drawbacks (e.g. high loss) especially in the mid- and near-infrared (NIR) spectral ranges. Recently, wide bandgap semiconductors, such as Al-doped ZnO (AZO), have been shown to hold great potential in surpassing the tunability and flexibility of traditional noble metals in nanoplasmonic applications. Generally, these transparent conducting oxides have been extremely important for various optoelectronic applications due to the coexistence of high conductivity and high transparency, which can be tuned through doping. Recent studies have shown that these wide bandgap semiconductors, in particular AZO, are also efficient nanoplasmonic materials in the NIR due to their metallic behavior, strong confinement of SPPs, and low loss. AZO has been studied extensively using a multitude of deposition techniques, especially atomic layer deposition (ALD), which is particularly useful to grow uniform and conformal films with a high degree of thickness control on complex three-dimensional topographies because it is based on a binary sequence of self-limiting surface chemical reactions. Furthermore, the doping concentration can be precisely controlled by adjusting the ALD cycle ratios of the host and dopant materials, thus making ALD a unique and powerful method to deposit AZO into high aspect ratio structures for nanoplasmonic applications. Recently, it has been shown that ALD-grown AZO offers extreme tunability that can be utilized for many applications, including plasmonic components for epsilon-near-zero metamaterials. This extreme tunability is exploited here in metal-dielectric multilayered structures in order to manipulate and control light in subwavelength volumes for various optical applications.

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