Nanometer-scale Science and Technology
Room: 203 B - Session NS+BI+EM-MoM

Nanophotonics and Plasmonics
Moderator: D. Wei, University of Florida

9:00am **NS+BI+EM-MoM3 Predetermining Paths of Nanoscale Crack by Local Thermally Induced Strain Fields**, ***M.R. Cho***, *P.K. Kim, Y.D. Park*, Seoul National University, Republic of Korea

We demonstrate well-defined path control of nanoscale cracks in SiO_2 thin-films on Si substrate. When cracks are initiated their paths are confined in a predetermined track of arbitrary shape. The confinement of the crack paths is attributed to local thermally induced strain fields. We define the strain fields by utilizing the large differences between coefficients of linear thermal expansion between metallic thin-films and SiO_2. On top of the substrate, a metallic strip of arbitrary shape is first predefined. Next, a layer of SiO_2 is e-beam evaporated, followed by a thermal cycling. We then initiate the cracks by either a predetermined notch or by, more simply, a macro scratch far from the predefined track. Once the leading edge of the crack enters the predefined track, the crack, with width at the surface of SiO_2 of ~50-200 nm, is laterally confined within a width > 2 µm, predefined path length in the millimeter range (or higher), and a minimal turn radius of curvature > 20 µm, and its path shape within the confined track is of nontrivial oscillatory. We present finite element analysis simulations as well as a model that explains and fits well the crack path shape within the track. We also discuss utilizing our results to realize bulk fabrication of nano-gap plasmonic device, nano-gap electrode and nano fluidic channel devices.

9:40am **NS+BI+EM-MoM5 Single-Molecule Surface Enhanced Raman Scattering using Silver Coated Nickel Nanorod Arrays**, ***A. Nash***, *D. Ye*, Virginia Commonwealth University

Nickel nanorods arrays were prepared on silicon (100) substrates using the glancing angle deposition (GLAD) technique. Subsequently, the nanorods were coated with 30 nm thick silver on the tip of the nanorods without breaking vacuum. The surface enhanced Raman scattering (SERS) at near single molecule levels was verified in a Horiba confocal Raman microscope using low concentration Rhodamine 6G. At the concentration 3×10^{-14} M, blinking of the Raman peaks were observed. We found that the Raman signal intensities can be related to the concentration of the analytes by the Langmuir-Freundlich adsorption isotherm.

10:00am **NS+BI+EM-MoM6 Merged Photonic Crystal Slot Waveguide - ALD Coated Silicon Nanophotonics**, ***P. Stenberg***, *M. Roussey, S. Honkanen, M. Kuittinen*, University of Eastern Finland

Research related to Silicon photonics is a topic of high interest in the photonics community. Demands in the field of all optical signal processing are driving research and industry towards faster and more efficient devices and processes. The interest against Silicon is not merely because of the optical characteristics of the material but also because the fabrication of Silicon photonic devices can be adapted to the existing production lines enabling cost efficient mass fabrication.

Our study is focused on a Silicon photonic nanodevice called Merged Photonic Crystal Slot Waveguide (MPCSW), in which features of photonic crystals (PhC) and slot waveguides are compiling, by taking advantage of the slow light effect in the PhC [1] and the field confinement in the slot region [2]. We propose to create the PhC by directly patterning the rails of the slot waveguide. The device is designed on a Silicon on insulator (SOI) substrate and it is coated with amorphous TiO_2 by Atomic Layer Deposition (ALD) technique to fill the structure with optically interesting nonlinear material.

We have studied the possibility to use the device as a band pass filter in near infrared region. The MPCSW structure is designed by using three dimensional Finite Difference Time Domain (3D-FDTD) method to create a photonic band gap (PBG) and a transmission peak appearing in the center of it.

For easier coupling, the input and output waveguides are 3 µm wide and are tapered to nano-waveguides. Coupling from a nano-waveguide to a slot waveguide is made by using an adiabatic coupler to reduce the conversion loss. The adiabatic couplers and nano-to-micro tapers are at both ends of the fabricated waveguide structure. The MPCSW is placed in the middle of the waveguide structure and it contains 10 periods of photonic crystal on both sides of the cavity. The whole device is embedded in conformally coated amorphous TiO_2.

In our presentation we show results concerning simulation and characterization. In simulation we introduce normalized transmission spectra as a function of the fill factor, the cavity length and the period. Also the group index corresponding to the transmission spectra for the same parameters is presented. The fabrication of the structure is discussed where electron beam lithography, plasma etching and ALD techniques are used. Finally we propose possibilities to use the device in nonlinear guided-wave optics by taking advantages of the slow light effect in the PhC and the field confinement in the slot region when the structure is filled with a nonlinear material.

[1] M. Roussey, J. Opt. Soc. Am. B, **24**, 1416-1422, (2007)

[2] A. Säynätjoki, Optics Express, **17**, 21066-21075, (2009)

10:40am **NS+BI+EM-MoM8 Engineering Multimodal Localized Surface Plasmon Resonances in Silicon Nanowires**, *L.-W. Chou*, ***M.A. Filler***, Georgia Institute of Technology

Semiconductors, as a result of their widely tunable carrier density (10^{19} - 10^{21} cm^{-3}), are emerging as promising plasmonic materials for applications in the infrared and near-infrared. Silicon, in particular, is inexpensive relative to the noble metals and benefits from a robust suite of processing tools due to its extensive use in the semiconductor industry. To this end, we recently reported that phosphorus-doped Si nanowires can support mid-infrared localized surface plasmon resonances (LSPRs) with quality factors comparable to those of the noble metals [1]. Herein, we demonstrate that axial control of dopant profile in individual nanowires permits complex, user-programmable, multimodal spectral responses. Highly aligned Si nanowire arrays are synthesized via the vapor-liquid-solid (VLS) technique with a combination of Si- and P-containing precursors. *In-situ* infrared absorption spectroscopy measurements reveal intense absorption bands (5 – 10 um) with dopant concentration and shape-dependent spectral shifts consistent with longitudinal LSPRs. Discrete dipole approximation (DDA) calculations confirm that the observed spectral response results from resonant absorption and free carrier concentrations on the order of 10^{20} cm^{-3}. We also observe near-field coupling between neighboring plasmonic domains, which varies as a function of intrinsic spacer length and can be described with hybridization theory. Our results highlight the utility of VLS synthesis for surface plasmon engineering in semiconductors, create new opportunities to study basic surface plasmon physics, and pave the way for applications including ultra-sensitive molecular detection and thermal energy harvesting.

[1] Chou, L.-W.; Shin, N.; Sivaram, S. V.; Filler, M. A. *J. Am. Chem. Soc.* **2012**, *134*, 16155.

11:00am **NS+BI+EM-MoM9 Exploiting Plasmon Induced Hot Electrons in Molecular Electronic Devices**, *D. Conklin, S. nanayakkara, T.-H. Park*, University of Pennsylvania, *M. Lagadec*, ETH Zürich, Switzerland, *J. Stecher*, Duke University, *X. Chen*, University of Pennsylvania, *M. Therien*, Duke University, ***D.A. Bonnell***, University of Pennsylvania

Plasmonic nanostructures can induce a number of interesting responses in devices. Here we show that hot electrons can be extracted from plasmonic particles and directed into a molecular electronic device, which represents a new mechanism of transfer from light to electronic transport. To isolate this phenomenon from alternative and sometimes simultaneous mechanisms of plasmon-exciton interactions we designed a family of hybrid nanostructure devices consisting of Au nanoparticles and optoelectronically functional porphyin molecules that enable precise control of electronic and optical properties. Temperature and wavelength dependent transport measurements are analyzed in the context of optical absorption spectra of the molecules, the Au particle arrays and the devices. Enhanced photocurrent associated with exciton generation in the molecule is distinguished from enhancements due to plasmon interactions. Mechanisms of plasmon induced current are examined and it is found that hot electron generation can be distinguished from other possibilities.

11:20am **NS+BI+EM-MoM10 Coherent Imaging of Surface Plasmon Dynamics by Time-resolved Photoelectron Emission Microscopy**, ***H. Petek***, University of Pittsburgh **INVITED**

We study surface plasmon polariton (SPP) generation, propagation, diffraction, interference, focusing, and decay by femtosecond time-resolved photoemission electron microscopy (PEEM) and electromagnetic simulations. Equal-pulse pump-probe pulses with interferometrically defined delay excite two-photon photoemission from Ag surfaces. The imaging of the spatial distribution of photoemitted electrons by PEEM reveals a nonlinear map of the total surface electromagnetic fields impressed on the sample. On a nanostructured surface the images reveal coherent polarization gratings consisting of superposition of the incoming excitation pulses and propagating SPP wave packets that are generated at nanofabricated coupling structures. By changing the delay between the pump and probe plusses in steps of ~330 as we record movies of the evolving coherent polarization at the Ag/interface, which reflects the evolution of the surface electromagnetic fields. Through the combination of femtosecond laser excited photoemission and imaging of photoelectrons we can record <10 fs time scale coherent polarization dynamics with ~50 nm spatial resolution. [1]

The SPP fields are generated by specifically designed coupling structures formed by lithographic techniques in Ag films. The physical properties of the coupling structures and the geometry of the excitation define the subsequent SPP dynamics. To obtain a quantitative understanding of the SPP generation and PEEM imaging we perform FDTD calculations on the coupling of the external field into the SPP mode and compare them to experiments for slit coupling structures with different geometries. [4] Using more complicated coupling structures, we demonstrate SPP interference and focusing. [5] Through time-resolved PEEM measurements on nanostructured metal films we will explore the techniques for the coherent control of electromagnetic fields in nanostructured electronic materials on the femtosecond temporal and nanometer spatial scales.

References

[1] A. Kubo, K. Onda, H. Petek, Z. Sun, Y. S. Jung, and H. K. Kim, Nano Lett. , 1123 (2005).

[2] A. Kubo, N. Pontius, and H. Petek, Nano Lett. , 470 (2007).

[3] A. Kubo, Y. S. Jung, H. K. Kim, and H. Petek, J. Phys. B: , S259 (2007).

[4] L. Zhang, A. Kubo, L. Wang, H. Petek, and T. Seideman, Phys. Rev. B , 245442 (2011).

[5] H. Petek and A. Kubo, in *Handbook of Instrumentation and Techniques for Semiconductor Nanostructure Characterization*, Haight, R.; Ross, F.; Hannon, J., Eds. World Scientific Publishing/Imperial College Press: 2011.

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