Wednesday Afternoon, October 20, 2010

Nanometer-scale Science and Technology
Room: La Cienega - Session NS+EM+EN-WeA

Photonic and Plasmonic Materials and Devices
Moderator: P. Cheng, Cornell University

2:00pm **NS+EM+EN-WeA1 Spatially-Resolved Study of Luminescence and Composition in III-Nitride Nanowires**, ***G.T. Wang***, *Q. Li*, Sandia National Laboratories

Given the strong interest in III-nitride-based nanowires for optoelectronic and energy applications, a better understanding of their optical properties and structure-composition is required, particularly at nanoscale spatial resolutions, which could shed light into issues such as the nature and distribution of radiative defects and alloy compositional variations. Here, we present a spatially-resolved, correlated study of luminescence and composition in GaN, Al(Ga)N/GaN, and InGaN/GaN core-shell nanowires grown by metal-organic chemical vapor deposition. For GaN nanowires, a surface layer exhibiting strong yellow luminescence (YL) near 566 nm in the nanowires was directly revealed by high resolution, cross-sectional cathodoluminescence (CL) imaging, compared to weak YL in the bulk. In contrast, other defect related luminescence near 428 nm (blue luminescence) and 734 nm (red luminescence), in addition to band-edge luminescence (BEL) at 366 nm, were observed in the bulk of the GaN nanowires but were largely absent at the surface. As the nanowire width approaches a critical dimension, the surface YL layer completely quenches the BEL. The surface YL is attributed to the diffusion and piling up of mobile point defects, likely isolated gallium vacancies, at the surface during growth. AlGaN/GaN and AlN/GaN core-shell nanowires were observed to exhibit stronger BEL and weaker YL as compared with bare GaN nanowires, which may relate to the passivation of nanowire surface states. InGaN/GaN core-shell nanowires were also investigated by correlated CL and cross-sectional scanning TEM (STEM). Dislocation-free InGaN layers with up to ~40% indium incorporation were achieved on GaN nanowires. The indium composition distribution in the InGaN layers were qualitatively correlated to the strain energy density distribution as calculated by finite element analysis models. The observed high indium incorporation and high crystalline quality in the heteroepitaxial InGaN layers is attributed to strain-relaxed growth on the nanowires. Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

2:20pm **NS+EM+EN-WeA2 Photonic Crystal Cavities and Vertical Confinement to Increase the Conversion Efficiency of a Thermophotovoltaic Cell**, ***C. Shemelya***, *T. Vandervelde*, Tufts University

For many years researchers have attempted to efficiently harvest waste heat and transform it into a usable energy via thermophotovoltics (TPVs). The low quantum efficiency (QE; i.e. the probability that a photon will be absorbed) in most TPV cells is probably the biggest limiting factor in achieving an economically viable device and directly affects the conversion efficiency (CE; i.e. the probability that a photon will be converted into a carrier that is collected). In many cases, top of the line TPV cells might only have a CE of 20%. Recent advances in micro-/nano-fabrication techniques have enabled the creation of novel structures to enhance the absorption and, therefore, the conversion of the incident thermal photons. In particular, photonic crystals (PhC) interface enhancements have been shown to increase the efficiency of photon to current conversions for infrared photodetectors. The addiction of a back reflecting layer, or vertical confinement layer can further increase conversion efficiencies. Here, we report on the enhancement of photon conversion by integration of PhC structures and vertical confinement layers into the TPV cells. To this end, photonic crystals consisting of rods of either air or dielectric surface-passivation material are placed into the base semiconductor TPV cells to increase duration of thermal photon absorption, resulting in significantly enhanced QE and CE. The use of photonic crystals and vertical confinement in augmenting the conversion efficiency of TPV cells is applicable for most IR wavelengths, making this a widely useful technology. The ability to harvest waste heat for energy will help make many processes and/or systems more energy efficient, which will be a critical component in ushering in an era of energy independence.

2:40pm **NS+EM+EN-WeA3 Unconventional and Broadband Plasmonics**, ***T.W. Odom***, Northwestern University **INVITED**

Breakthroughs in photonics and optoelectronics demand actively controlled materials that are inexpensive, robust, and scalable. The interaction of light with surface plasmons—collective oscillations of free electrons—in metal nanostructures has resulted in exceptional displays of enhanced optical transmission, collimation of light through a subwavelength aperture, and negative permeability and refraction at visible wavelengths. The structures that display these phenomena typically consist of ordered arrays of particles or holes with sizes of the order 100 nm. Surface plasmons can interact with each other over much longer distances, however, and thus the ability to organize nanoscale materials over multiple length scales could lead to new plasmonic metamaterials with novel optical properties.

This talk will describe how superlattices and low symmetry plasmonic lattices provide an important first step to meet these goals. We will introduce new soft nanolithography tools for creating new plasmonic structures, including PEEL (a procedure combining **P**hase-shifting photolithography, **E**tching, **E**lectron-beam deposition, and **L**ift-off) and solvent assisted nanoscale embossing (SANE). These methods can achieve arrays of 50-nm features simultaneously over 6-in2 areas without needing electron, ion, or photon-based lithographies. We will then discuss how the optical properties of the plasmonic crystals and the nanoparticle arrays can be engineered and then manipulated by external factors to produce large optical responses.

4:00pm **NS+EM+EN-WeA7 Controlling Plasmon Enhanced Photoconduction in Porphyrin-Gold Nanoparticle Assemblies**, ***D.J. Conklin***, *S.U. Nanayakkara, T.-H. Park,* University of Pennsylvania, *J.T. Stecher, M.J. Therien,* Duke University, *D.A. Bonnell*, University of Pennsylvania

Recently we demonstrate plasmon-induced electronic transport in hybrid metal nanoparticle-molecular devices that realized enhancements of up to a factor of 200. This was realized in a hybrid structure that consists of an array of gold nanoparticles linked by (porphinato)zinc(II) oligomers. Here we examine the role of metal particle size, spacing, molecular length and radiation power on the photoconductive properties. Controlling these parameters allows the relative roles of nano antennae focus increasing effective photon flux and hot electron distribution to the current enhancement to be compared.

This phenomenon offers a pathway to selectively enhance specific optical energies or to design a hybrid structure that can simultaneously enhance a range of optical wavelengths. Applications in optical devices and a range of photovoltaics could exploit this new phenomenon [ACS Nano, 2010, 4 (2), pp 1019-1025] .

4:20pm **NS+EM+EN-WeA8 From Red-Coloured Coatings to Light Trapping in Solar Cells: on the Tunability and Control of the Surface Plasmon Resonance Behaviour**, ***M. Creatore***, *H. Takeke Beyene, M. Ponomarev, M.C.M. van de Sanden*, Eindhoven University of Technology, Netherlands

The combination of (noble) metal nanoparticles (NPs) with dielectrics is an on-going research subject, due to the generated surface plasmon reasonance (SPR) effect, relevant in several technological applications such as color filters, optical switching devices and sensors, to name a few.

In this contribution, we report on the tunability and control of the surface plasmon resonance behaviour through the engineering of metal NP/dielectric interfaces for two applications, i.e. thickness- and viewing angle- independent red- coloured decorative coatings and light trapping enhancement in silicon- based tandem thin film solar cells. Both studies have been carried out by making use of a vacuum chamber where plasma-enhanced chemical vapour deposition for the dielectric layer and magnetron sputtering for the metal NP deposition are combined.

Multilayer structures composed of gold NPs sandwiched between SiO_2 layers represent a valid solution for the independent control of NP size and density: while a constant NP size guarantees a narrow surface plasmon frequency, an increased NP density leads to an enhancement in the absorption [1]. A multi-diagnostic approach consisting of spectroscopic ellipsometry, transmission electron microscopy and Rutherford backscattering analysis has allowed the characterization of the deposited coatings: gold NPs (diameter 10-15 nm) with a surface area coverage of 26% and sandwiched between 40 nm- thick SiO_2 layers, exhibit a red colour, whereas the color intensity (i.e. from cool to warm deep red) increases with the layer number, i.e. NP density.

While in this first application the main mechanism contributing to extinction is *absorption*, for an efficient sun light management/ trapping within a solar cell, *scattering* plays a dominant role. In particular, for amorphous (a-Si:H)/microcrystalline (μc-Si:H) silicon tandem solar cells a promising approach consists in the incorporation of an intermediate layer (e.g. ZnO) sandwiched between the top a-Si:H and the bottom μc-Si:H cell, able to efficiently scatter photons of a specific frequency range back to the top cell or forward to the bottom cell. In this respect, copper NPs (30-150 nm diameter) when coupled to ZnO layers, are responsible for the generation of a plasmon peak at 700 nm, which shifts towards higher wavelengths with an increase in NP size, therefore showing its potential towards low energy photon forward scattering into the bottom μc-Si:H cell.

[1] H. T. Beyene, F.D. Tichelaar, P. Peeters, I. Kolev, M.C.M. van de Sanden, M. Creatore, accepted for publication in Plasma Processes and Polymers (2010).

4:40pm **NS+EM+EN-WeA9 Index-Matching at the Nanometer Scale**, ***G. Broenstrup***, *C. Leiterer, N. Jahr, B. Hoffmann, F. Talkenberg,* Institute of Photonic Technology, Germany, *S.H. Christiansen*, Max Planck Institute for the Science of Light, Germany

Silicon nanowires (SiNW) show high potential as future building blocks for photonic devices. They show strong resonant enhancement effects resulting in high absorption efficiencies and even higher scattering efficiencies. Since both effects are based on the same underlying physical principles the resonant enhancement of the absorption as well the resonant enhancement of the scattering of light occurs at the same wavelength. These large scattering efficiencies could result in an increased reflectivity of structures based on these SiNWs.

To overcome the increased scattering efficiencies we show an index matching core-shell approach.

The SiNWs are wrapped with a thin oxide layer with a refractive index smaller than the refractive index of silicon. The thickness of the wrapping layer is formed using atomic layer deposition (ALD), which allows to control the thickness of the layer at the Angstrom scale. The microstructure is analyzed using transmission electron microscopy (TEM).

The scattering behavior of these individual SiNWs with an oxide layer are measured using an optical microscope with a coupled spectrometer. The experimental data is analyzed using an extended Mie theory.

It will be shown, that this method can be used to tune the absorption efficiencies and the scattering separately to different wavelengths.

5:00pm **NS+EM+EN-WeA10 20 μs Photocurrent Response from Lithographically Patterned Nanocrystalline Cadmium Selenide Nanowires**, ***S.-C. Kung***, *W.E. van der Veer, F. Yang, K.C. Donavan, R.M. Penner*, University of California, Irvine

Lithographically patterned nanowire electrodeposition (LPNE) provides a method for patterning nanowires composed of nanocrystalline cadmium selenide (*nc*-CdSe) over wafer-scale areas. We assess the properties of (*nc*-CdSe) nanowires for detecting light as photoconductors. Structural characterization of these nanowires by X-ray diffraction and transmission electron microscopy reveals they are composed of stoichiometric, single phase, cubic CdSe with a mean grain diameter of 10 nm. For *nc*-CdSe nanowires with lengths of many millimeters, the width and height dimensions could be varied over the range from 60 to 350 nm (w) and 20 to 80 nm (h). Optical absorption and photoluminescence spectra for nc-CdSe nanowires were both dominated by band-edge transitions. The photoconductivity properties of nc-CdSe nanowire arrays containing ~350 nanowires were evaluated by electrically isolating 5 μm nanowire lengths using evaporated gold electrodes. Photocurrents, i_{photo}, of 10-100× (i_{dark}) were observed with a spectral response characterized by an onset at 1.75 eV. iphoto response and recovery times were virtually identical and in the range from 20 to 40 μs for 60 × 200 nm nanowires.

5:20pm **NS+EM+EN-WeA11 Efficient, Single Layer Organic Light-Emitting Devices Based on a Graded Composition Emissive Layer**, ***N.C. Erickson***, *R.J. Holmes*, University of Minnesota

We demonstrate efficient electrophosphorescence from devices comprised of a single organic active layer. High efficiency is realized by combining both hole- and electron-transporting host materials (HTM and ETM, respectively) into a single, graded composition emissive layer with the green emitter, *fac*-tris(2-phenylpyridine) iridium (III). The composition of the host-material is continuously graded to realize 100% HTM at the anode, and 100% ETM at the cathode. A peak external quantum efficiency of η_{EQE}=(19.3 ± 0.4) % is realized in the forward-viewing direction at a luminance level of 600 cd/m^2, corresponding to a power efficiency of η_P =(66.5 ± 1.3) lm/W. This performance is similar to that realized in more conventional and complex, multi-layered structures. The graded composition of the structure balances electron and hole injection and transport leading to efficient exciton formation, permitting high efficiency using a single active layer. The graded composition architecture may be further utilized to realize simple, efficient organic light-emitting devices for use in display and lighting applications.

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