CINT User Conference and

SSLS EFRC Workshop

Marriott Pyramid Hotel, Albuquerque, NM

September 14, 2011

Schedule:

8:30 AM	Registration Desk opens
9:00 AM	Opening Remarks *Igal Brener, Principal Scientist, SSLS EFRC and Workshop Co-Organizer*
9:05 AM	Welcome *Jerry Simmons, Director, SSLS EFRC*
9:10 AM	Introduction to Solid-State Lighting and Context of Workshop *Jeff Tsao, Chief Scientist, SSLS EFRC*
9:30 AM	Plenary, "Recent Progress in Nanowire-based Nano-Optical Devices" *Lars Samuelson, Director/Coordinator of the Nanometer Structure Consortium at Lund University*
10:15 AM	*Break*
10:45 AM	"Optical Characterization of MBE Grown Nanowires and Nanowire Lasers" *John Schlager, National Institute of Standards and Technology (NIST)*
11:15 AM	"Semiconductor Nanowires for Applications in Energy" *Silvija Gradecak, Massacussetts Institute of Technology, USA*
11:45 AM	"III-Nitride Nanowires: Novel Emitters for Lighting" *George Wang, Sandia National Laboratories, USA*
12:15 PM	Buffet Lunch
1:30 PM	"'Giant' Nanocrystal Quantum Dots: A New Class of Optical Nanomaterials for Light Emission Applications" *Jennifer Hollingsworth, Los Alamos National Laboratory, USA*
2:00 PM	"Spontaneous Coherence and Spin Texture in a Cold Exciton Gas" *Leonid Butov, University of California, San Diego, USA*
2:30 PM	"Quantum Optics with Single Semiconductor Quantum Dot" *Weng Chow, Sandia National Laboratories, USA*
3:00 PM	*Break*
3:30 PM	"Polariton Lasing by Intra-cavity Pumping in the Strong-Coupling Limit and Enhancement of Molecular Fluorescence in Critically Coupled Resonators" *Valdmir Bulovic, Massachusetts Institute of Technology, USA*
4:00 PM	"Unconventional Lasing in Organic Semiconductors" *Stephane Kena-Cohen, Imperial College, UK*
4:30PM	Closing remarks *Igal Brener, Principal Scientist, SSLS EFRC and Workshop Co-Organizer*

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Speaker Abstracts:

Novel Emitters

Moderator: Igal Brener, Principal Scientist, SSLS EFRC and Workshop Co-Organizer

9:30 AM—

Plenary, "Recent Progress in Nanowire-based Nano-Optical Devices"

Lars Samuelson, Director/Coordinator of the Nanometer Structure Consortium at Lund University

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In this talk I will review our present understanding of growth of compound semiconductor nanowires and their use as active devices for on-chip opto-electronic devices as well as for solar-cells and for solid state lighting. I will first describe the special issues related to the structural properties, with different means of controlling and studying the admixture of zinc-blende and wurtzite crystal structures. I will then describe the way we are able to control the nucleation and growth of III-V and III-nitride nanowires using either gold-catalyzed growth or selective area epitaxy for growth control. A special emphasis will be put on recent studies of selective are nucleation of c-oriented GaN nanowires, to function as defect-free substrates for radially grown LED-structures. Finally, I will give examples of axial as well as radial devices, such as IR-emitting radial InP/InAsP QW-structures, axial dual-junction InP-based solar-cells, as well as blue and green-emitting LEDs based on radial GaN/InGaN quantum structures.

Much of this research is performed in cooperation with start-up companies active in the Ideon Science Park, primarily with Qunano AB for on-chip opto-electronics, with Sol Voltaics AB for solar-cells and with Glo AB for the solid state lighting R&D.

10:45 AM—

"Optical Characterization of MBE Grown Nanowires and Nanowire Lasers"

John Schlager, National Institute of Standards and Technology (NIST)

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At NIST, we are interested in gallium nitride nanowires for optoelectronic applications in nanoscale metrology as well as other applications that benefit from this low-defect material. Characterization of this material plays an important role in growth optimization and device production. This talk will focus on the optical characterization of GaN nanowires grown at NIST.

Gallium nitride nanowires grown on Si(111) substrates by nitrogen-plasma-assisted MBE with an elemental Ga source are optically characterized using photoluminescence and lasing threshold measurements. Steady-state and time-resolved photoluminescence (PL and TRPL) measurements reveal pure strain-free GaN that responds predictably to temperature and external stress while being relatively insensitive to the potentially deleterious effects of nonradiative surface recombination. Laser-threshold measurements of optically pumped nanowires show the importance of wire morphology to efficient laser operation.

11:15 AM—

“Semiconductor Nanowires for Applications in Energy”

Silvija Gradečak, Massacussetts Institute of Technology, USA

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Semiconductor nanowires are promising candidates for a range of optoelectronic devices such as LEDs and lasers operating at wavelengths from ultraviolet to infrared. However, functionality of these novel nanomaterials will be ultimately dictated by our understanding and ability to precisely control their structural properties, size uniformity, and dopant distribution at the atomic level. In this talk, I will discuss the growth, doping, and applications of III-V nanowires and nanowire heterostructures using metalorganic chemical vapor deposition, as well as advanced electron microscopy techniques for direct correlation of structural and optical properties with high spatial resolution. We have demonstrated that the cathodoluminescence (CL) technique, coupled with scanning transmission electron microscopy (STEM), effectively bypasses the resolution limit of conventional far-field photoluminescence spectroscopy and allows direct structure-property correlation on the nanoscale. The CL-STEM optical studies of single nanowire heterostructures with spatial resolution of <20 nm will be discussed. Finally, applications of semiconductor nanowires for LED and solar cell applications will be described.

11:45 AM—

“III-Nitride Nanowires: Novel Emitters for Lighting”

George Wang, Sandia National Laboratories, USA

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1D nanostructures, such as nanowires and nanorods, based on the III nitride (AlGaInN) materials system have attracted attention as potential nanoscale building blocks in LEDs, lasers, sensors, photovoltaics, and high power and high speed electronics. Compared to planar films, III-nitride semiconductor nanowires have several potential advantages including higher crystalline quality and reduced strain, which enables growth on arbitrary substrates as well as allowing for a greater range of alloy compositions and hence energies to be achieved. However, before their promise can be fully realized, several challenges must be addressed in the areas of 1) controlled nanowire synthesis; 2) understanding and controlling the nanowire structural, electrical, thermal, and optical properties; and 3) nanowire device integration. Our work seeks to address these areas to lay the scientific and technological foundation for nanowire-based lighting and other energy-related applications.

III-nitride nanowires can be fabricated by a variety of techniques, including “bottom-up” approaches and “top-down” lithographic approaches. Bottom-up techniques have been the dominant method and typically involve a nanoscale metal catalyst particle to direct the 1D growth or anisotropic growth conditions. Advantages of using this approach include nanowires free of detrimental crystal defects known as dislocations, and the ability to grow on inexpensive, lattice mismatched substrates, including glass and metal foil, which we have demonstrated in our lab. I will discuss recent results involving the aligned, bottom-up growth of Ni-catalyzed GaN and III-nitride core-shell nanowires, along with extensive results providing insights into the nanowire properties obtained using cutting-edge structural, electrical, and optical nanocharacterization techniques. Some topics I will cover include: in-situ TEM studies of nanowire electrical breakdown and nanomechanics, spatially-resolved cathodoluminescence studies of band-edge and defect luminescence in NWs; and strain-related spatial variation of In incorporation in InGaN shells. I will also discuss the development of an inexpensive, lithography-free technique employing nanowire templates for the growth of high-quality GaN, which could enable more efficient and longer-lifetime visible LEDs.

Bottom-up nanowire growth methods do however have the disadvantage of requiring highly specific growth conditions to increase the on-axis growth rate while minimizing lateral growth, which can lead to non-optimal material quality and less flexibility in material design, such as doping and heterostructures. I will describe a new “top-down” approach for fabricating ordered arrays of high quality GaN-based nanorods with controllable height, pitch and diameter. This top-down method allows fabrication of nanorods from high quality, arbitrarily doped films grown by metal-organic chemical vapor deposition using standard, optimized conditions. The fabrication, structure, optical properties, lasing characteristics, and device performance of the nanorods and nanorod LEDs will be discussed.

Light-matter Interaction in Nanostructured Materials

Moderator: Willie Luk, Principal Scientist, SSLS EFRC and Workshop Co-Organizer

1:30 PM—

"'Giant' Nanocrystal Quantum Dots: A New Class of Optical Nanomaterials for Light Emission Applications"

Jennifer Hollingsworth, Los Alamos National Laboratory, USA

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Nanocrystal quantum dots (NQDs) are nearly ideal candidates for light-emission applications due to high quantum efficiencies, and narrow-band and particle-size-tunable photoluminescence. However, they suffer from important deficiencies, including intermittency in fluorescence intensity, or "blinking", at the single NQD level and chemical-environment-dependent photo-instability at the ensemble level. We recently reported the first demonstration of an inorganic shell approach to address these outstanding issues; namely, the suppression of blinking and ensemble-level instabilities.1,2 Here, I will review these results, as well as key findings establishing the new "giant" NQDs (g-NQDs) as a functionally new class of colloidal quantum dot: significant suppression of nonradiative Auger recombination,3 highly emissive multiexcitons4 and near-unity biexciton emission. Beyond a summary of these fundamental studies, I will describe the integration of g-NQDs into light emitting devices as (1) robust, "passive" phosphors and (2) active layers in electrically pumped light emitting diodes, where, the thick-shell NQDs provide significant advantages compared to their thin-shell counterparts in terms of device efficiencies, self-reabsorption, and/or stabilities.

2:00 PM—

"Spontaneous Coherence and Spin Texture in a Cold Exciton Gas"

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An indirect exciton is a bound pair of an electron and a hole confined in spatially separated layers. Indirect excitons have long lifetimes and long spin relaxation times, can cool down to low temperatures well below the temperature of quantum degeneracy, can travel over large distances before recombination, and can be in situ controlled by voltage. Due to these properties, indirect excitons form a model system both for the studies of basic properties of cold bosons and for the development of optoelectronic devices. In this contribution, we report on the observation of a pattern of spontaneous coherence, spin texture, and phase singularities in a cold gas of indirect excitons in a GaAs/AlGaAs coupled quantum well structure. The observed features of spin texture include a vortex of linear polarization with polarization perpendicular to the radial direction around an exciton source and a periodic spin texture around the macroscopically ordered exciton state formed in the exciton ring. Extended spontaneous coherence of excitons is observed in the region of the polarization vortices and in the region of the macroscopically ordered exciton state. The coherence length in these regions is much larger than in a classical gas, indicating a coherent exciton state with a much narrower than classical exciton distribution in momentum space, characteristic of a condensate. The observed phase singularities include phase domains and fork-like dislocations in the interference pattern. Extended spontaneous coherence, spin texture, and phase singularities are spatially correlated and emerge when the exciton gas is cooled below a few Kelvin.

2:30 PM—

"Quantum Optics with Single Semiconductor Quantum Dot"

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There is recent interest in strong light-matter interaction in semiconductors and its uses in optoelectronics. Exploring these possibilities requires extending the Jaynes-Cummings model to include many-body effects. The reason is that the matter, even for single quantum dot (QD), consists of multiple interacting charged particles.

This talk will show why the customary cluster expansion has a difficult time doing the job because of slow convergence. An alternate approach is proposed that allows numerical integration of coupled electron-photon-phonon equations of motion to arbitrary accuracy. Application of the approach is illustrated with examples involving quantum coherence, antibunching photon statistics and phonon-assisted polaritons.

3:30 PM—

"Polariton Lasing by Intra-cavity Pumping in the Strong-Coupling Limit and Enhancement of Molecular Fluorescence in Critically Coupled Resonators"

Valdmir Bulovic, Massachusetts Institute of Technology, USA

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The strongly coupled states of light and matter in microcavities, known as polaritons, can enable a radically new class of optoelectronic devices based on the macroscopic coherence of photons and excitons. In particular, strong optical absorption and efficient luminescence of molecular organic materials allow for strong coupling and polariton lasing to be achieved at room temperature and with substantially reduced requirements for cavity quality factor. The first part of the talk will present room temperature polariton lasing in a lambda-thick microcavity where a highly absorbing thin film of molecular J-aggregates serves as the strong-coupling material. We will show a new device excitation scheme of intra-cavity pumping which circumvents exciton-exciton annihilation losses inherent to organic materials at high optical excitation densities. Using this flexible cavity architecture, polariton lasing at room temperature is achieved.

The second part of the talk will show that one mirror and the J-aggregate active layer of the polariton laser microcavity can act as a critically coupled resonator, which can be used for scalable, tunable, and homogeneous enhancement of molecular fluorescence. The operation of this device, called a J-aggregate critically coupled resonator, is based on the excitonic energy transfer from a highly absorptive thin film of J-aggregating dye molecules positioned at the anti-node of an optical half-cavity to a overlaying film whose fluorescence is enhanced in this structure. A 20-fold enhancement in molecular fluorescence is demonstrated, with the role of optical interference, Förster energy transfer, and exciton diffusion quantitatively analyzed to optimize device geometry, which can be broadly useful in light emitting structures.

4:00 PM—

"Unconventional Lasing in Organic Semiconductors"

Stephane Kena-Cohen, Imperial College, UK

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The high optical gain and versatility afforded by organic semiconductors make them an attractive medium for the realization of coherent light sources. It is clear, however, that lasing thresholds must be further reduced to achieve lasing via electrical injection. In this talk we present two novel approaches to organic lasing. In the first, a microcavity containing an anthracene single crystal in the strong exciton-photon coupling regime is realized. Coherent emission of polaritons, the resulting mixed light-matter states, is achieved, via a mechanism that does not require a population inversion. In the second approach, we demonstrate that low threshold random lasing can be obtained using as-grown doped organic films containing dicyanomethylene-based dyes without the need for optical feedback or infiltrated scatterers.