Electronic Materials and Photonics Division
Room: 14 - Session EM+NS-TuM

Nanostructures and Nanometer Films for Electronic and Photonic Devices

Moderators: Jessica Hilton, RHK Technology, Joseph Tischler, U.S. Naval Research Laboratory

8:00am **EM+NS-TuM1 Spin Properties in Semiconductor Colloidal Quantum Dots**, ***Efrat Lifshitz***, Russell Berrie Nanotechnology Institute, Solid State Institute, Israel **INVITED**

Colloidal semiconductor quantum dots (CQDs) have been at the forefront of scientific research for more than two decades, based on their electronic and optical tunable properties. Recent years show a substantial interest in spin properties with significant importance for spin-electronic, spin-photovoltaic and spin-optical devices.

The talk includes the study of two different CQD platforms: (1) CQDs from the II-VI semiconductors and their diluted magnetic derivatives; (2) Halide perovskite CQDs. Both systems show intriguing spin properties of special scientific and technological interests.

Spins in CdSe/CdS and Mn^{+2}@CdSe/CdS: Unpaired spins generated by an absorption of a phonton (electron and hole) can dictate the magneto-optical properties of the host CQDs. Furthermore, magnetic doping by foreign ions (e.g., Mn), induces internal spin interactions between photo-generated species and the dopant spins, leading to giant magnetization. The current study developed a method to position the Mn ions selectively either at the core or at the shell, by which, controlling the electron-guest versus hole-guest exchange interaction. The materials were characterized by magneto-optical methods, including optically detected magnetic resonance, uncovered individual interactions with resident carriers, thus, revealing understanding of a control of a magnetism with a benefit for spin-based devices.

$APbBr_3$ (A=Cs^+, methylamonium)*: The perovskites are minerals that have been studied extensively in the past. They are the focus of new interest in recent years, due to their exceptional performance in photovoltaic cells. Perovskites semiconductors possess high absorption coefficients as well as long-range transport properties. Currently, they are also prepared in the form of CQDs with very interesting properties including ferroelectricity, magnetism and exciton effects. The magneto-optical measurements of excitons in $APbBr_3$ as individuals were investigated by monitoring the micro-photoluminescence spectra in the presence of an external magnetic field, while monitoring either the circular or linear polarization components. Gradual band splitting occurring upon the application of a magnetic field, deviating from a common Zeeman interaction behavior, proposes the existence of a more complex mechanism, when Rashba split is one of the plausible interpretations.

*Collaboration with M. Kovalenko and A. Rappe

9:00am **EM+NS-TuM4 A Platform for Growth of Crystalline Thin-Film Compound Semiconductors on Oxides, Metals, and 2-D Materials**, ***Rehan Kapadia***, *D. Sarkar, W. Wang*, University of Southern California

The electronic and photonic circuits and systems that form the backbone of the modern world are predicated on the ability to create high quality semiconductors. Yet, high-performance electronic and photonic grade semiconductors are nearly exclusively grown on lattice matched substrates. This substrate limitation arises due to the fundamental mechanisms of nucleation and growth in state-of-the-art vapor phase growth techniques, which proves to be extremely limiting and costly. Here we demonstrate a platform for growth of compound semiconductors from microscale liquid metal templates. Using these templates, we can control nucleation and growth of these compound semiconductors, enabling single crystalline devices on non-epitaxial substrates. To grow single crystalline material in the desired form-factors, from liquid metal templates on arbitrary substrates presents a significant challenge, as dewetting of the liquid films prevent control over the ultimate material geometry. Through a basic thermodynamic approach, we show that it is possible to control dewetting on nearly any material, and subsequently grow compound semiconductors on these same substrates. Using this approach, we demonstrate growth and characterization of crystalline InP, InAs, and GaP, on silicon nitride, graphene, gadolinium oxide on silicon, and metals.

Next, we show that compound semiconductors with multiple stable phases can be grown phase-pure using this approach, using tin phosphide as the example. We show that through tuning the growth conditions, we can control which stable phase of tin phosphide precipitates and grows. This control illustrates that our approach is useful for materials beyond simple III-V and II-IV compounds, which only have one stable phase. By carrying out these growths at significantly non-equilibrium conditions, we demonstrate ternary InGaP alloys, with stoichiometry control over nearly the entire In-Ga composition range. Unlike binary III-V or the Sn-P system, where the stoichiometry of the precipitating compound is nearly insensitive to the growth conditions, the ternary systems are alloys, and consequently extremely sensitive to growth conditions, making growth of uniform materials a potential challenge. We show that through control over the growth conditions, we can achieve high-quality, uniform stoichiometry ternary III-V alloys. Finally, we show that by enabling nanoscale phase segregation during growth of these ternary alloys, we can materials with extremely broadband photoluminescence curves, with FWHMs greater than 600 meV, potentially enabling a new class of broadband light sources.

9:40am **EM+NS-TuM6 Nanometer Thick Diffused Metal Oxide Light Sensing Film Structures**, ***Fred Cadieu***, Queens College of CUNY and Graduate Center of CUNY, *J.S. Monaco*, Queens College of CUNY, *L. Mourokh*, Queens College of CUNY and Graduate Center of CUNY

Approximately 10 nm thick light sensing film structures have been fabricated by sequentially sputtering various metals in oxygen, then in argon, and then in oxygen again. The layers have been deposited onto heated silicon substrates to create a diffusion region. The layered thicknesses were calibrated by x-ray reflectivity measurements. The film layers, being mostly oxides, exhibit a high lateral resistivity so that the current path is through the film thickness between a grid of contacts deposited below and on top of the film structures. For such current, a high degree of light sensitivity, and voltage polarity sensitivity, has been observed.[1] Analogous film structures have been fabricated using hafnium,[2] titanium,[2] and aluminum such that exposure to light causes large increases in currents for one voltage polarity, but little or no effect for the opposite polarity. The observed phenomenology has been shown to be consistent with a single-particle model based on the existence of interface states on the metal-oxide interfaces.[2] The details of light sensitivity and current polarity sensitivity are dependent on the deposition temperatures and thicknesses of the film layers. Hafnium based interfaces respond repeatedly to light pulses with current pulses up to several hundred microamperes, while aluminum based interfaces can only respond repeatedly with current pulses up to several tens of microamperes.

1. F.J. Cadieu, Device with Light-Responsive Layers. US Patent No. 9,040,982.

2. F.J. Cadieu and Lev Murokh, Nanometer Thick Diffused Hafnium and Titanium Oxide Light Sensing Film Structures, *World Journal of Condensed Matter Physics***7**, 36-45 (2017).

11:00am **EM+NS-TuM10 Integration of Metallic Nanoparticles in Sensing and Memory Devices for Resistance Modulation and Enhanced Switching**, ***Dimitris Tsoukalas***, National Technical University of Athens, Greece **INVITED**

In this work we present the fabrication of metallic nanoparticles (NPs) in vacuum at room temperature and their incorporation into sensor or memory two terminal devices emphasizing their influence on device resistance modulation or switching. Nanoparticles were manufactured using the gas phase condensation technique with a target of high purity. The NPs production system consists of a smaller vacuum chamber (Nanogen) which is connected via an aperture of diameter ~ 3 mm with a larger central vacuum chamber in which the sample holder is mounted. The Nanogen chamber is equipped with a DC magnetron sputtering head and in between the Nanogen chamber and the central chamber there is a pressure gradient, the pressure in the Nanogen being around 10^{-1} mbar while in the main chamber pressure is 10^{-4} mbar. The atoms produced by the magnetron sputtering because of the high pressure in the Nanogen chamber, undergo a short free path, colliding with the atoms of the inert gas (Ar) and lose part of their kinetic energy. This leads to the creation of a supersaturated vapor of the target material, which is condensed, causing the atoms to form nuclei from the material. Due to the pressure gradient prevailing, these nuclei move towards the central chamber. During this movement they interact among them to form larger NPs finally entering into the central vacuum chamber through the aperture.

Regarding the application of nanoparticle networks to sensors, our group is focusing in the use of metallic NPs in particular for chemical, bio and strain sensing applications. We first review the principle of operation of such devices that is based on the change of percolation current through the NP network when the interspace distance among NPs is modified by an external stimuli. We then discuss the potential of integrating these sensors on flexible substrates as well as the influence on their performance of a protective aluminum oxide coating deposited over the nanoparticle network.

Resistive switching memories (RRAM) based on metal oxides are emerging as a new research field and at the same time are intensively studied as one of the most promising candidates for future non-volatile memory applications. We demonstrate that a wide range of non-volatile memory properties can be affected and improved by embedding NPs into the metal oxide matrix. The concentrated electric field effect around the nanoparticles in combination with the charge trapping effect, are regarded as the driving forces for the recorded switching patterns. As a result NPs increase the on/off switching ratio and at the same time decrease the inherent variability of RRAM.

11:40am **EM+NS-TuM12 Thin-film Metallic Glass: An Effective Diffusion Barrier for Microelectronic Packaging, CIGS Solar Cell and Thermoelectric Modules**, *C.C. Yu,* National Taiwan University of Science and Technology, Taiwan, Republic of China, *H.J. Wu,* National Sun Yat-sen University, Taiwan, Republic of China, ***Jinn Chu***, National Taiwan University of Science and Technology, Taiwan, Republic of China

Thin film metallic glass (TFMG) with its amorphous nature is of great interest owing to its unique properties, including high strength, large elastic limits, excellent corrosion and wear resistance. For many electronics, the atomic inter-diffusion may cause device failure or performance degradation during either fabrication or operation. Thus, the introduction of diffusion barrier layer in the device is a common approach to solve this problem. Crystalline Ni- or Ti-based layers are the most common materials for diffusion barriers. Nevertheless, grain boundaries are generally considered as atomic diffusion path, and thus crystalline metals are not able to block diffusion effectively. TFMG, possessing grain boundary-free structure, is thus thought to efficiently mitigate atomic diffusion.

In this presentation, we report the effects of thin film metallic glass as diffusion barriers on the Sn whisker mitigation in the Cu-Sn couples and the copper indium gallium selenide (CIGS) solar cells on stainless steel (SS) as well as the mid-temperature thermoelectric module. We found that TFMG effectively blocks the Cu/Sn interaction even with the thickness as thin as 25 nm. In addition, with very thin thickness, the introduction of TFMG layer is expected to yield insignificant degrees of compressive stress, which is anticipated to occur when the samples are exposed to thermal cycling. Furthermore, the detrimental iron diffusion from SS into CIGS is found to be effectively hindered by the introduction of a 70-nm-thick TFMG barrier; the cell efficiency is thus from 2.73 for bare sample to 5.25% for the one with TFMG barrier. For application in thermoelectric module, a 200 nm-thick Zr-based TFMG, acting as an effective diffusion barrier layer with low electrical contact resistivity, was deposited on a high-zT Se-doped $AgSbTe_2$ substrate. The reaction couples structured with TFMG/TE were annealed at 673 K for 8–360 hours and analyzed by electron microscopy. No observable intermetallic compounds were formed at the TFMG/TE interface, suggesting the effective inhibition of atomic diffusion.

12:00pm **EM+NS-TuM13 Ultra-Fast Silicon Photodiodes Achieve High Efficiency via the Integration of Light-trapping Micro-/nanoholes**, ***Hilal Cansizoglu***, *Y. Gao, K.G. Polat, S. Ghandiparsi, C. Bartolo Perez, A. Kaya, H.H. Mamtaz, A.S. Mayet,* University of California, Davis, *E. Ponizovskaya Devine,* W&WSens Devices, Inc., *Y. Yamada,* University of California, Santa Cruz, *A.F. Elrefaie, S.Y. Wang,* W&WSens Devices, Inc., *M.S. Islam,* University of California, Davis

Surface-illuminated photodiodes (PDs) for ultra-fast data transmission are typically GaAs-based non-CMOS compatible detectors. Silicon (Si) has long been ignored for being a material of choice in ultra-fast communication links due to its poor responsivity for the wavelengths >800 nm at data rates 10 Gb/s or higher. Recent demonstration of CMOS compatible surface-illuminated Si PDs with photon-trapping micro-/nanoholes paves the way for the use of Si at 25 Gb/s or higher data transmission rate. Such PDs provided ≤30 ps full-width at half-maximum (FWHM) and above 50% quantum efficiency (QE) at 850nm, which is over 400% higher than the QE that a similar Si PD without absorption-enhancement micro-/nanoholes can provide. The micro/nanoholes create an ensemble of modes that radiate laterally by photon trapping and slow light effects, resulting in absorption enhancement in a very thin layer of Si (<2µm) which is required for high speed operations. The broadband efficiency enhancement by photon-trapping micro-/nanoholes enable Si to be considered as the PD material at longer wavelengths (>870 nm) which is below the room temperature bandgap of GaAs. Such broadband and enhanced efficiency of Si integrated with micro-/nanoholes can be useful for applications such as short wavelength division multiplexing (SWDM, 850-980 nm) for data centers, automotive laser radar systems (LIDAR, 850 or 905 nm) and high-performance computers (990-1065 nm). The CMOS-compatible fabrication of micro-/nanoholes can allow Si PDs to be monolithically integrated with CMOS/BiCMOS integrated circuits such as transimpedance amplifiers, equalizers, limiting amplifiers and other application specific integrated circuits (ASIC), which can increase the achievable data rate to more than 50 Gb/s.

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