Electronic Materials and Photonics Division
Room On Demand - Session EM-Invited On Demand

Electronic Materials and Photonics Invited On Demand Session

EM-Invited On Demand-1 Light Management Strategies for Photovoltaics: Luminescent Concentrators and Passive Cooling for Modules, ***Vivian Ferry,*** University of Minnesota, USA **INVITED**

The solar spectrum is a broad and diffuse light source, but solar panels operate most efficiently at wavelengths near the semiconductor bandgap and over a limited range of incident angles. This talk will discuss different strategies to manage the solar spectrum in photovoltaics: the first part will discuss luminescent solar concentrators that harvest diffuse, high energy sunlight and are integrated into architectural panels, where we use nanostructured luminescent materials and photonic surfaces to enhance performance. The second part will discuss optical strategies to reduce the operating temperature of photovoltaic modules.

Our work on luminescent solar concentrators uses two different nanocrystal luminophores, CdSe/CdS core-shell nanocrystals and Si nanocrystals, embedded into a polymer matrix. These light-emitting nanocrystals offer several advantages over dye molecules, but also exhibit detrimental scattering when aggregated. I will discuss the preparation of nanocrystal-polymer composites with high optical clarity for these applications. The CdSe/CdS nanocrystals are embedded into an alternative polymer, PCHE, and coated into very thin films on glass. The Si nanocrystals are incorporated into PMMA and deposited in thin films via blade coating, and we show that this method results in higher loading fractions than bulk composites. We then apply photonic structures to these luminophore-polymer composites that reduce optical losses and assist in guiding light efficiently toward the edge of the concentrator and onto a small-area solar cell.

The second part will discuss photonic structures for light management in photovoltaic modules. These structures are designed to provide both optical and thermal benefit: they act as broadband and omnidirectional antireflection coatings to improve incoupling of sunlight to the module, while simultaneously reflecting near-infrared light to keep the solar cell operating temperature low. We have developed models that predict energy yield improvement for particular locations, based on typical meteorological year data, and agree with experimental measurements on test modules. We use this model to predict and contrast the performance of mirrors on the outer glass, the surface of the cell, and the rear contact, showing that the mirrors on the glass offer the most temperature reduction. Mirrors on the cell surface, while attractive for reduced weathering, are limited by the textured surface of crystalline Si as well as the optical losses of the encapsulant. To circumvent the multiple reflections at the cell surface, we examine an alternative design consisting of idealized scatterers at the cell interface, and compare the performance of these nanostructures to idealized mirrors.

EM-Invited On Demand-7 Epitaxial Quantum Dots for Quantum Science and Technology, ***Sam Carter,*** *J. Grim, A. Bracker, M. Yakes, M. Zalalutdinov, C. Kim,* US Naval Research Laboratory*; M. Kim,* KeyW Corporation*; D. Gammon,* US Naval Research Laboratory **INVITED**

Self-assembled indium arsenide quantum dots are a promising platform for applications in quantum science and technology. This system has the advantages of a robust solid state host, strong optical transitions, mature device fabrication, tunable properties, and a scalable, monolithic architecture. Of particular importance for many applications is the ability to charge the dots with a single electron or hole in order to make use of a spin memory. We have integrated electrical diode structures within various optical cavities and mechanical resonators that allow charging of dots and control over spin. In photonic crystal cavities, this has enabled demonstrations of fast, optical spin rotations, cavity-stimulated Raman emission, and strong coupling [1,2]. In mechanical resonators this has enabled the demonstration of large spin-mechanical coupling with both hole spins and the singlet-triplet system in pairs of dots [3,4].

Quite recently we have also made significant progress in solving two important long-standing challenges with quantum dots. The first challenge is to combine in one system the ability to have both fast, optical control of spin and efficient spin readout, which we have addressed by using a set of higher energy optical transitions with one hole in an excited orbital. These transitions provide fast optical control while the lowest energy transitions give efficient spin readout. The second challenge is inhomogeneity of quantum dot emission energies, which we have addressed using a localized strain tuning technique that allows multiple dots within the same optical waveguide to be tuned into resonance. Using this technique we have demonstrated superradiance of three quantum dots embedded in a nanophotonic waveguide [5].

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[3]S. G. Carter, A. S. Bracker, G. W. Bryant, M. Kim, C. S. Kim, M. K. Zalalutdinov, M. K. Yakes, C. Czarnocki, J. Casara, M. Scheibner, and D. Gammon, Phys. Rev. Lett. 121, 246801 (2018).

[4]S. G. Carter, A. S. Bracker, M. K. Yakes, M. K. Zalalutdinov, M. Kim, C. S. Kim, B. Lee, and D. Gammon, Nano Lett. 19, 6166 (2019).

[5]J. Q. Grim, A. S. Bracker, M. Zalalutdinov, S. G. Carter, A. C. Kozen, M. Kim, C. S. Kim, J. T. Mlack, M. Yakes, B. Lee, and D. Gammon, Nat. Mater. 18, 963 (2019).

EM-Invited On Demand-13 Van der Waals and remote epitaxy of complex materials, ***Jian Shi,*** Rensselaer Polytechnic Institute **INVITED**

Dimensionality effect has been found interesting in exploring new physics and effective in engineering materials' physical properties. However, often intrinsic material behaviors are clouded by the underlying support through strongly-coupled interface. In this talk, I will show our efforts and discovery on developing weakly-coupled epitaxial interface for semiconducting halides. I will present the serendipity and challenges while working on complex oxide interfaces.

EM-Invited On Demand-19 Functional Oxide Materials for Silicon Photovoltaics, ***Kristopher Davis,*** University of Central Florida **INVITED**

The incredible cost reductions realized by the photovoltaics (PV) industry have been, and continue to be, driven by a combination of technology improvements and manufacturing scale. A primary example of such a technological enhancement is the development of Al_2O_3 surface passivation using atomic layer deposition (ALD). The low recombination achieved with thin Al_2O_3 films on crystalline silicon (c-Si) surfaces, coupled with the industry's ability to produce high throughput spatial ALD and later, plasma enhanced chemical vapor deposition (PECVD) tools, ushered in the large scale transition from the Al back surface field (Al-BSF) cell architecture to passivated emitter and rear cells (PERC). Alternative c-Si cell architectures, like a-Si:H/c-Si heterojunctions (SHJ) and interdigitated back contact (IBC) cells, offer higher cell efficiencies, but the manufacturing cost and complexity have limited their market share compared to PERC. An ideal solar cell should feature fully passivated surfaces with carrier-selective layers that: (1) minimize minority carrier concentrations at the absorber surface; (2) maximize majority carrier transport; and (3) minimize parasitic optical absorption. Achieving these criteria with a simple cell architecture and minimal processing steps in a high-volume manufacturing environment is a key challenge. Wide bandgap oxide materials possess a rich diversity in electronic band structure and versatility in synthesis and doping. They have emerged as promising candidates with the ability to provide photon management, surface passivation, carrier selectivity, and lateral carrier transport. This presentation will provide an up to date assessment of the potential for functional oxides in silicon photovoltaics.

EM-Invited On Demand-25 Building MOFs from the Gas Phase at the Molecular Level - Active Surfaces by Combining Organics with Inorganics, ***Ola Nilsen,*** University of Oslo, Norway **INVITED**

The MLD technique could be considered as the ultimate in additive manufacturing where it builds materials one molecular layer at the time from the gas phase. The current presentation will focus on growth of such materials with emphasis on building units containing carboxylic acids. Inorganic carboxylates are mostly stable, offering high saturation of the metal centre's coordination sphere, leading up to the plethora of such structures as metalorganic frameworks (MOF). Such materials can be grown via the gas phase, and examples from growth of the UiO-66 series with variations in linker length and complexity will be given, in addition to alternative systems. This introduces concepts such as modulation of growth, reservoir effects, tuning of chemical reactivity, and amorphous

porosity. The current contribution will provide highlights from such growth of organic- inorganic hybrid materials including MOF materials.

EM-Invited On Demand-31 2020 AVS Peter Mark Memorial Award Lecture: Efficient Graphene Hot Electron Devices: Electrochemistry and Electron Emission, ***Rehan Kapadia***[1], University of Southern California
INVITED

In this talk, we will discuss recent work in hot electron devices, focusing on how graphene enables efficient hot electron devices that go beyond the present state of the art in both electron emission and electrochemistry.

First, we show that the onset of electrochemical and photoelectrochemical reactions on a graphene surface can be modified with a semiconductor-insulator-graphene (SIG) device due to injection of hot-electrons from the silicon to the graphene. We observe that the device functions similar to a catalyst, but modifies electrochemical behavior through purely electronic signals. Unlike a material catalyst, such as platinum, which reduces the overpotential at a given current by modifying the transition state energy, the electronic catalyst explored here tunes the onset potential of the reaction by modifying the energy of photoelectrons with respect to the electrochemical reduction energy levels. As a model systems, the hydrogen evolution reaction on graphene is shown to be modified in an n-Si/Al_2O_3/graphene electrochemical device, and a p-Si/Al_2O_3/graphene photoelectrochemical device. Uniquely, it is shown that for every volt of bias applied across the silicon-insulator-graphene junction, the onset of hydrogen reduction on the graphene surface is modified by 1.45 V with a saturation photocurrent density of ~40 mA/cm^2 indicating nearly ideal minority carrier collection despite the insulator layer.

Next, we show how hot-electron processes can dramatically reduce the optical power densities required for photoemission. In metallic emitters, single-photon, multi-photon, or strong-field emission processes are the three mechanisms via which photoemission takes place. Photons with energy lower than the material workfunction can only drive photoemission through the multi-photon, or strong-field processes, both of which require large optical powers, limiting the integration of photoemitters with photonic integrated circuits. Here, we show that a waveguide integrated graphene electron emitter excited with 3.06 eV photons from a continuous wave (CW) laser exhibits two hot-electron processes that drive photoemission at peak powers >5 orders of magnitude lower than previously reported multi-photon and strong-field metallic photoemitters. Optical power dependent studies combined with modeling illustrate that the observed behavior can be explained by considering direct emission of excited electrons. These processes are dramatically enhanced in graphene due to the relatively weak electron-phonon coupling and the single layer structure. These results show that hot electron devices still offer a rich area of exploration.

[1] **AVS 2020 Peter Mark Awardee**

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