## Thin Films Division
## Room 102A - Session TF+AS-TuM

### Special Session in Honor of Paul Holloway: Luminescent Materials Growth, Synthesis and Characterization

**Moderators:** Sean Jones, National Science Foundation (NSF), Jay Lewis, Defense Advanced Research Projects Agency

8:00am **TF+AS-TuM1 INTRO: Special Session Honoring Professor Paul H. Holloway**, ***Gary McGuire***, Adamas Nanotechnologies

In light of Professor Holloway's many contributions to the AVS and Thin Film Division special recognition will be given to him during a session dedicated to highlighting his prominence as an educator, scientist and leader. Professor Holloway has held many positions within the AVS including AVS President in 1987, Fellow 1993, Honorary Member 1997, Albert Nerken Award Winner, 1999. The Paul H. Holloway Young Investigator Award is given each year by the Thin Film Division to a deserving recipient. During his career he made major contributions to surface science and surface analysis. His research covered a diverse range of luminescent materials including thin film and powder phosphors, organic light emitting diodes, quantum dots and nanocrystals.

8:20am **TF+AS-TuM2 Harnessing Disorder in Detectors**, ***Jay Lewis***, Defense Advanced Research Projects Agency

Most progress in optoelectronic devices has been built upon increasingly perfect materials, where "perfect" implies reducing impurities, point defect, dislocations, and grain boundaries. However the properties of quantum dot devices, such as those demonstrated by the Holloway group, are largely dominated by the surfaces of the nanocrystals. This paper explores the role of nanostructured devices through the lens of DARPA's Wafer Scale Infrared Detectors (WIRED) program, which seeks to develop infrared detector technology that is inherently disordered. Disorder is a byproduct of the program objective to process detectors directly onto the silicon wafers that are used to process and read out the signals. The program is exploring polycrystalline materials deposited by chemical bath deposition, quantum dot materials deposited by spin or dip coating, as well as traditional III-V compounds deposited at low temperatures compatible with complementary metal oxide semiconductor (CMOS) circuitry. These results are presented in the context of the broader portfolio of DARPA programs seeking to advance the state of the art in imaging and sensing technology.

8:40am **TF+AS-TuM3 Luminescent Materials for Solid State Lighting and Solar Cell Applications**, ***Hendrik C Swart***, *J.J. Terblans, R.E. Kroon, E. Coetsee, M.M. Duvenhage, E. Hasabeldaim, A. Balakrishna, A. Kumar,* University of the Free State, Republic of South Africa*; P.H. Holloway,* University of Florida **INVITED**

Luminescent compounds and materials have numerous uses. The emission properties, whether of a fast decay rate fluorescent material or a slow decay rate phosphorescent material, are defined by the chemical composition and the physical structure of the luminescent material. The crystal field that is determined by the environment in the host material in combination with the various dopant ions with the correct valence state can be used to obtain emissions from the Ultra violet (UV) to the infra-red (IR) wavelength ranges. Phosphor materials have been successfully used to improve the efficiency of various applications. Nanoparticles both undoped and doped with different rare earth elements were synthesized by several synthesized techniques. The major problem that limits solar cells' efficiency is their insensitivity to the whole solar spectrum which is the so-called spectral mismatch. Therefore, several mechanisms have been explored based on photoluminescence (PL) to convert the solar cell spectrum where the spectral response of the solar cell is low to regions where the spectral response of the solar cell is high. For single crystalline silicon (Si) photovoltaic (PV) cells with a rather small semiconductor band-gap (Eg: 1.12 eV, corresponding to a wavelength of ~1100 nm), the transmission loss of the sub-band-gap photons can still amount to about 20% of the sun's energy irradiated onto the Earth's surface. For PV cells with a larger band-gap, such as amorphous Si (Eg: 1.75 eV) solar cells, which are limited to absorb sunlight with wavelengths below 708 nm, manifest even higher near infrared transmission losses. Downconversion, up-conversion (UC) and downshifting are some of the mechanisms that may be applied to improve the spectral response. Upconversion nanoparticles (UCNPs) have shown some promising possibilities to be considered in this respect, however, low UC efficiency of UCNPs is still the most severe limitation of their applications. In downshifting the strong deep level emission (DLE) and near band edge emission could be tuned to cover a wide spectral range. The strong DLE, covering a wide spectral range of ~375-650 nm, signifies the potential optoelectronics application in the near white LED applications. Degradation of the different phosphors during prolonged electron/photon bombardment also played a vital role in their possible applications. Examples of different phosphor materials with different applications such as Solid State Lighting will be shown.

9:20am **TF+AS-TuM5 Fluorescent Nanodiamond for Applications in Whole Body Imaging**, ***Olga Shenderova***, *M.D. Torelli,* Adamas Nanotechnologies*; A. Rickard,* Duke University*; N.J. Nunn,* Adamas Nanotechnologies*; M. Backer,* SibTech*; G.M. Palmer,* Duke University*; G. McGuire,* Adamas Nanotechnologies **INVITED**

Fluorescent nanodiamonds (FNDs) containing color centers exhibit distinct properties including very high biological compatibility, infinite photostability, absence of photoblinking, long fluorescence lifetime (>10 ns), and ease of biofunctionalization, which makes them an attractive alternative to quantum dots, organic dyes, and polymer beads as imaging reagents. Potential applications include background-free and long-term cell imaging, flow cytometry, super-resolution imaging, correlative microscopy, labeling of low-abundance cellular components, fiducial markers, and image guided surgery. In this talk, after reviewing unique properties of FND, their utility for in vivo tumor imaging will be presented. To target receptors overexpressed in cancerous tissue, FNDs were functionalized with vascular endothelial growth factor (VEGF) via click chemistry and then validated *in vitro* for functional activity. Thereafter, FND-VEGF was administered via tail vein injection to nude mice induced with a mammary carcinoma, and mice were analyzed both in vivo and ex vivo via whole body imaging and fluorescence microscopy. Ex vivo micro-spectroscopy utilized the unique spectral signature of nitrogen-vacancy induced fluorescence to demonstrate unambiguous determination of ND translocation to tumorous tissue. The results are placed in the context of FND for whole-body imaging and related applications.

11:00am **TF+AS-TuM10 The Apple does not Fall Far from the Tree: A Serendipitous Journey from Luminescent Materials to Nanoscale Focused Electron (and Ion) Beam Induced Processing**, ***Philip D. Rack***, University of Tennessee Knoxville **INVITED**

I graduated from Paul Hollloway's group at the University of Florida in 1997 where I studied luminescent materials for electroluminescent displays. If the saying is true that "imitation is the sincerest form of flattery," then my career speaks volumes of my admiration for the man I had the privilege to call my Phd advisor. In this talk, I will briefly overview some of the luminescent materials research that my group has performed over the years. In true Holloway fashion, I will overview my groups serendipitous journey from luminescent materials to focused nanoscale electron beam induced processing. The remainder of the talk will review topics near and dear to Dr. Holloway's heart, electron(ion)-gas-solid interactions, and illustrate that appropriate understanding of these interactions can result in the directed growth/etching at the nanoscale. I will overview our groups Monte Carlo simulation to illustrate some of the critical electron(ion)-gas-solid interactions that can rate and resolution limit the deposition and etching processes. Next, I will show how a synchronized pulsed laser can photothermally assist both the etching and deposition processes. Finally, I will review our recent research direction in this area, which is controlled 3d nanoscale printing. Along the way, I will recall anecdotes that illustrate principles learned from the "Holloway way" and hopefully illustrate that I am an apple that did not fall far from the Holloway tree.

11:40am **TF+AS-TuM12 Atomic Layer Deposition of Optoelectronic Materials**, ***Markku Leskela***, *M.K. Ritala,* University of Helsinki, Finland **INVITED**

In optoelectronics, i.e. in electronic devices and systems that emit, detect and control light, the active materials are usually II-VI or III-V semiconductors. Historically in Atomic Layer Deposition (ALD) or Atomic Layer Epitaxy (ALE) as it was called in 70s and 80s, zinc sulfide has been very important material. The ALE technology was developed for manufacturing AC driven thin film electroluminescent displays [1]. Monochromic yellow-black displays based on ZnS:Mn luminescent layer sandwiched between dielectrics and electrodes has been manufactured industrially by ALD continuously since 1984. Besides the luminescent layer, the high-quality oxide layers made by ALE have had an important role as dielectrics and passivation layers in the success of the ACTFEL displays. Multicolor displays can be realized by filtering the broad emission band of ZnS:Mn or using other luminescent material, e.g. green-emitting ZnS:Tb.

Despite of intense studies in 1980s and 1990s full-color ACTFEL devices could not been developed to the mass production level because of the missing efficient deep blue-emitting phosphor. Today the strongest developing application area in thin film EL displays is transparent displays used widely in different vehicles [2]. This motivates to re-examine the color displays.

Deposition of epitaxial films of III-V materials is possible with ALD as demonstrated already in 1985 [3]. Processes have been developed for all III-V materials using alkyl compounds for group III metals and hydrides for group V elements as precursors. The advantages of ALD processing compared to MOCVD or MBE have remained, however, modest because of the carbon contamination.

Transition metal dichalcogenides are emerging 2D materials that are potential channel materials in field-effect transistors as well as phototransistors and other optoelectronic devices. The bottle-neck in the large use of these two-dimensional materials is the lack of scalable, low-temperature process for high-quality, large-area films. ALD has been studied as a solution for these problems [4].

In other optoelectronic devices the ALD films find most often use in passivation and encapsulation. Silicon based solar cells is a good example of the former [5] and OLED displays from the latter application area [6].

References

1. T. Suntola, J. Anson, US Patent 4,058,430 (1977).

2. S. Bush, Electronics Weekly. Com, Jan 20, 2017.

3. J.-I. Nishizawa, H. Abe, T. Kurabayashi, J. Electrochem. Soc. 132, 1197 (1985).

4. Y. Kim et al. Sci. Reports 6, 18754 (2016).

5. G. Dingemans, W.M.M. Kessels, J. Vac. Sci Technol. 30, 040802, (2012).

6. J. Meier et al. Appl. Phys. Lett. 94, 233305 (2009).

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