Thin Films
Room 115 - Session TF2-MoM

Thin Films Special Session: Remembering Dr. Paul Holloway I

Moderators: Sean Jones, Argonne National Laboratory, **Robert Grubbs**, IMEC Belgium

10:30am **TF2-MoM-10 Fundamental Aspects of Focused Nanoscale Electron-Ion- and Photon-Beam Induced Processing and Recent Advances in Editing Transition Metal Dichalcogenide Materials and Devices**, ***Philip Rack,*** Department of Materials Science and Engineering, 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 path captures the admiration for the man I had the privilege to call my Phd advisor.In this talk, I will briefly discuss some of the luminescent materials research that my group has performed and overview my serendipitous journey to focused nanoscale electron beam induced processing, highlighting how it has been an eerily mirror image to Dr. Holloway's path. The scientific portion of my talk will review topics near and dear to Dr. Holloway's heart, electron(ion, photon)-gas-solid interactions, and illustrate that appropriate understanding of these interactions can result in directed growth/etching at the nanoscale.I will overview a Monte Carlo simulation we developed to illustrate some of the critical electron(ion, photon)-gas-solid interactions that can rate and resolution limit nanoscale focused beam induced processing.Finally, I will review our recent work in focused electron beam induced etching of MoS_2 multi- and single-layer devices.

11:00am **TF2-MoM-12 Stability of Phosphor Thin Films During Cathodoluminescence and Upconversion**, ***Hendrik Swart,*** University of the Free State, South Africa **INVITED**

Surface characterization and optical characterization techniques play a vital role in the complete understanding of the luminescent properties of phosphor nanomaterials and thin films. Auger electron spectroscopy (AES), X-ray photo electron spectroscopy (XPS), time of flight scanning ion mass spectrometry (TOF SIMS), Photoluminescence (PL) and cathodoluminescence (CL) are used to characterize these different phosphor materials and thin films. 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 Ultraviolet (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 defects incorporated into the bulk material play an important role in the emission efficiency and colour scheme. XPS in combination with PL can be used to identify some of these defects in the material. Thin films of different phosphors have been deposited using the Pulsed laser deposition (PLD) and spin coating techniques. Degradation of the different phosphors during prolonged electron/photon bombardment also played a vital role in their possible applications. The combination of CL, PL, AES and XPS techniques helps to determine the mechanisms behind the degradation. A small number of impurities in the chemicals used during synthesis can play a large role in the final emission intensity and colour of the phosphor materials. TOF SIMS can point out these impurities. It is also important to test the suitability of phosphors powders and thin films during prolonged upconversion photoluminescence. Examples of different phosphor materials with different applications such as Solid-State Lighting will be shown.

11:30am **TF2-MoM-14 Extracting Diffusing Parameters for Indium Segregating form Copper using TOF-SIMS**, ***Jacobus Johannes Terblans,*** *L. Makoloane, S. Cronje, H. Swart,* University of the Free State, South Africa

Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS), with its superior concentration detection limit (in the parts per million (ppm) range) and its ability to operate in static mode (where only the top 1-2 monolayers contribute to the measuring signal), makes TOF-SIMS a technique that is widely used for surface characterisation. This makes TOF-SIMS particularly suitable for studying surface segregation.However, concentration calculations are significantly influenced by the matrix effect, which makes it difficult to perform quantitative measurements.To investigate the segregation of indium with TOF-SIMS, the concentration quantification was addressed by utilising a set of Cu/In thin films of varying concentrations to calibrate the TOF-SIMS system by determining the In sensitivity factor relative to a Cu matrix. The Cu/In thin films used for the calibration were prepared using the Electron Beam Physical Vapor Deposition (EBPVD) co-evaporation method, and the composition of the films was controlled by varying the deposition rates of In and Cu.

To study indium segregation from copper, a polycrystalline Cu crystal was doped with 0.5 at% In by evaporating In onto a polycrystalline Cu crystal and annealing it at 1173 K for 23 days. Indium segregation was stimulated by heating the In-doped polycrystalline Cu crystal linearly from 323 K to 873 K with a heating rate of 0.1 K/s.At the same time, the surface concentration of In was recorded with TOF-SIMS as a function of temperature.The recorded segregation profile was fitted with the modified Fick semi-infinite, the Langmuir-McLean, and modified Darken models.The semi-infinite Fick model successfully extracted the pre-exponential factor (D_0) and activation energy (Q) of 1.44×10^{-5} m^2s^{-1} and 183.3 kJ/mol, respectively, from the kinetic region of the segregation data.With the Langmuir-McLean model, fitted to the equilibrium region, a segregation energy of -64.6 kJ/mol was obtained.The modified Darken model was fitted to the segregation profile, and the segregation parameters were determined as $D_0 = 0.50 \times 10^{-5}$ m^2s^{-1}, Q = 176.0 kJ/mol, and ΔG = -64.4 kJ/mol.These diffusion parameters were in good agreement with the segregation parameters obtained using Auger electron spectroscopy measurements.

11:45am **TF2-MoM-15 Commercializing Nanowire LEDs**, ***David Laleyan,*** *B. Le, G. Frolov,* NS Nanotech Canada*; M. Stevenson, S. Coe-Sullivan,* NS Nanotech

MicroLED display technology consists of many carefully arranged microscopic light-emitting diodes (LEDs) to directly create color pixels. MicroLED displays thus have the potential brightness, efficiency, and response time of inorganic LEDs, but suffer from the high cost of epitaxy, as well as the challenges of creating red, green, and blue materials on a single material and substrate. Furthermore, conventional approaches of growing planar LEDs and then etching them into micron scale devices causes a fundamental loss of efficiency, especially for the smallest devices. In this regard, nanowire-based LEDs for microLED applications have been of great interest and a topic of extensive research for over a decade. This is due to their unique ability to maintain high efficiencies even as the LED size becomes quite small, even into the sub-micron regime, contrary to conventional thin-film LEDs. Another valuable benefit is the ability to form photonic crystal arrangements, such that the formation of a photonic bandgap leads to highly directional and narrow bandwidth emission. More recently, reports have shown nanowire LEDs in the green with >25% external quantum efficiency (EQE) and red with >8% EQE, competitive with the best direct green and InGaN red LEDs ever fabricated – despite being sub-micron in size. These structures were obtained by molecular beam epitaxy (MBE) using a selective area epitaxy (SAE) technique, where nanostructures can be controllably grown on a thin-film template. Novel development and engineering efforts are required for such nanowire LEDs to become commercially viable. This work presents a pathway towards the wafer-scale production of nanowire LEDs for displays. This talk will explain how breakthrough academic research can be made manufacturable by studying run-to-run variability, understanding the process windows, targeting yield-limiting steps, and ensuring process scalability. Focusing on the reproducibility and uniformity of nanowire growth by SAE is the first critical step toward the large-scale deployment of these highly efficient LED that are perfectly suited for the next generation of microLED displays.

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