Electronic Materials and Photonics
Room 102A - Session EM-FrM

Late Breaking News on Electronic Materials and Devices
Moderator: Nikolaus Dietz, Georgia State University

8:40am **EM-FrM2 Pulsed Laser Deposition of In_2O_3-SnO_2: From Films to Nanowires**, ***Davide Del Gaudio***, *C. Reese, C. Boone, S. Yarlagadda, J.T. Heron,* University of Michigan, Ann Arbor*; I. Shalish,* Ben-Gurion University of the Negev, Beersheba, Israel*; R.S. Goldman,* University of Michigan, Ann Arbor

As micrometer sized device structures approach their limits in performance, nano-structures, such as nano-wires (NW) are being considered for next-generation high efficiency energy conversion and storage devices.[1] For example, metal oxides have been identified as promising materials for lithium ion batteries[2] and UV lasers.[3] Furthermore, metal-oxide NWs have been embedded in field-effect transistors, lasers, solar cells, and various chemical sensors.[4] Typically, metal-oxide NW are prepared by vapor deposition[4] or thermal evaporation.[5] Recently, pulsed-laser deposition (PLD)[6][7][8] has emerged as a promising approach for the fabrication of tin-doped indium oxide (ITO), with film or NW growth often determined by the choice of a reactive (O_2) or inert (N_2) atmosphere.[6] To date, cubic NW with up to 5 atomic % Sn incorporated into In_2O_3 have been reported. However, a mechanistic understanding of the influence of growth parameters and substrates on the morphology, composition, and crystal structure of the deposited film is needed. Additionally, PLD of various In_2O_3-SnO_2 mixtures has yet to be considered. Therefore, we report on PLD of various In_2O_3 -SnO_2 mixtures, onto c-plane sapphire and Inconel substrates. Using an inert atmosphere, we have identified parameters to obtain smooth films; pyramid-shaped nano-scale clusters; sparse, tapered nano-rods; and high density, vertically oriented NWs, with and without catalyst spheres. We will present high-resolution transmission electron microscopy (HRTEM) images and selective-area electron diffraction (SAED) patterns illustrating the structure and composition of the films, nanowires, and catalyst spheres. The photoluminescence emission from NWs and films, as well as the electronic transport properties of individual NWs will also be discussed.

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9:00am **EM-FrM3 $ZnSnN_2$: Band Gap Engineering Through Cation Disorder**, *R. Makin,* Western Michigan University*; N. Senabulya, J.P. Mathis, R. Clarke,* University of Michigan*; T. Veal,* University of Liverpool*;* ***Steven Durbin,*** Western Michigan University

Chalcopyrite heterovalent ternary compounds can undergo an order-disorder transition between an ordered chalcopyrite structure and a disordered zinc-blende-like phase. Unlike in adamantine alloys, the disorder results in a band gap reduction in the disordered phase relative to the band gap of the ordered lattice. $ZnSnN_2$ represents an interesting member of the chalcopyrite family of materials, due to its earth abundant element constituents and a band gap of use for solar cells. It is also part of the Zn-IV-N_2 family of materials, whose band gaps span from the infrared to the UV. Density functional theory (DFT) calculations predict the ordered $ZnSnN_2$ phase to have an orthorhombic lattice and a direct band gap of 2.0 eV. Using special quasirandom structures (SQS) to model the disordered Zn and Sn cation sub-lattice, DFT simulations predict that the band gap for the disordered $ZnSnN_2$ phase will be close to 1.0 eV and will have a hexagonal lattice. This almost 1.0 eV reduction of the band gap of $ZnSnN_2$ presents an opportunity for band gap engineering by controlling the disorder on the cation sublattice. Recently, however, an alternative theory of disorder for $ZnSnN_2$ has been proposed that does not depend on cation lattice disorder. This alternate disorder, unlike the cation disorder model, does not violate the octet rule locally and results in a band gap that is independent of the order. If either model is accurate is presently unknown.

A series of films has been grown by plasma assisted molecular beam epitaxy in order to investigate the possibility of controlled cation disorder as well as its effects on physical and electronic properties of the material. By varying the growth conditions, specifically either the metal flux to the nitrogen pressure or the substrate, we have confirmed the existence of both the hexagonal and orthorhombic phases of the crystal via synchrotron x-ray diffraction (performed at Argonne National Laboratory. All of the films at present have a high free carrier concentration (in excess of 10^{19} cm^{-3}). Taking into account the Burstein-Moss shift caused by the high carrier concentration and calculating the effective masses of the carriers from parabolic fits to the density results, the optically measured band gaps appear to be consistent with the DFT calculations; the band gap shows a clear dependence on cation disorder.

9:20am **EM-FrM4 Role of Single Dopants in Inter-Band Current Enhancement of Nano-*pn* Tunnel Diodes: An Atomistic Study**, ***Manoharan Muruganathan,*** Japan Advanced Institute of Science and Technology, Japan*; D. Moraru, M. Tabe,* Research Institute of Electronics, Shizuoka University*; H. Mizuta,* Japan Advanced Institute of Science and Technology, Japan

As the Tunnelling Field Effect Transistor (TFET) overcomes the subthreshold slope thermal limitation of MOSFETs, they are a potential successor of MOSFETs [1]. Moreover silicon-based TFETs are the most attractive because of the well-established silicon technology. However, a large bandgap in silicon results in a small band-to-band-tunnelling efficiency, hence low on-current. In order to improve the on-current, fundamental study of atomistic *pn* tunnel diode is an imperative step. Here, we report that inter-band tunnelling current can be enhanced by the resonance of deepened energy levels of discrete dopants. Number and position of dopants at the *pn* junction interface play a crucial role in enhancing the inter-band tunnelling current. These results are based on the first-principles simulations in comparison with our experimental results for nano-*pn* tunnel diodes [2].

Our simulated atomistic structure consists of *p*- and *n*-type electrodes, which are highly doped with doping concentration similar to the experimental levels and a thin central intrinsic Si channel that corresponds to the depletion region. As realized in the fabricated devices, single P and B dopants are placed in the intrinsic Si channel the depletion region. The uniform bulk doping in the regions away from the depletion region was realized by using the atomic compensation technique [3-4]. We noticed a remarkable current increase by four orders of magnitude for the device with a P-B pair placed 1.3 nm apart as compared to no discrete dopants in the depletion region. This is due to the energy levels created by the P-B pair in the depletion region and their matching to the electrode energy levels when the bias voltage is changed. Moreover, these devices exhibit typical Esaki-diode negative differential conductance (NDC) behaviours as well. When the single dopants were placed nearer to the uniformly doped bulk regions then well aligned energy levels were formed in the depletion region. This leads to an increase in the inter-band tunnelling current. If the number of single dopants in the depletion region is increased then we have more induced states in the depletion region, which also helps to increase the inter-band tunnelling current. These results illustrate the impact of individual dopants in the depletion region and provide pathways to increase the inter-band tunnelling in nano-*pn* tunnel diodes.

References:

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9:40am **EM-FrM5 CVD growth of Hexagonal Boron Nitride Films on Cu-Ni Alloys**, ***Karthik Sridhara***, Texas A&M University; *B.N. Feigelson, J.K. Hite, V. Anderson, A. Nath, F. Kub,* US Naval Research Laboratory; *L.O. Nyakiti,* Texas A&M University Galveston

Chemical vapor deposition (CVD) method of growth of hexagonal boron nitride (h-BN) has been demonstrated on various transition metal substrates such as Ni, Pt, Au and Ag. Of these metals, polycrystalline Cu is by far the most frequently used substrate for CVD growth of h-BN. Despite being extensively studied, issues still persist with Cu, including a high density of nucleation sites where the imperfections in surface morphology act as potential nucleation sites. Recently, Cu-Ni alloys have been reported for the growth of controllable monolayer h-BN with fewer nucleation sites [1]. Despite the promise, there are still questions of optimal Ni concentration and the morphology of Cu-Ni alloys.

In this work, we prepare Cu-Ni alloys by electroplating Ni on high purity (99.98%) polycrystalline Cu foils (25 µm thickness). Four different weight percents of Ni (10, 15, 20 and 25 wt%) are electroplated onto Cu. The electroplated foils are then thermally annealed at 1030°C for 3 hours in an H_2 environment, during which time the Ni diffuses into the Cu foils. We then grow h-BN on these Cu-Ni alloys, with high purity (~99.98%) Cu foils acting as our control samples. The growth uses borazane as the precursor at 1030°C with H_2 and N_2 as carrier gases. FTIR and scanning electron microscope (SEM) are used to confirm and assess the growth of h-BN on the samples. Energy dispersive spectroscopy (EDS) mapping is employed to cross-check the Ni percentage in Cu. From the preliminary results, we observe that with increasing Ni concentration there is an increase in surface roughness with the existence of atomic step edges and various morphological irregularities. Initial FTIR results show that with increasing amount of Ni in the Cu foil, we see a gradual increase in the amount (proportional to the FTIR peak intensity) of h-BN grown where the amount is proportional to the h-BN film effective thickness on the substrate [2]. We see the lowest amount of h-BN is on Cu, while the highest is on $Cu_{0.75}Ni_{0.25}$ foils. The growth kinetics of h-BN on Cu-Ni alloys will be discussed.

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10:00am **EM-FrM6 p-GaAs/AlGaAs Heterostructures with a Current Blocking Barrier for Mid-infrared Detection**, ***Dilip Chauhan***, *A.G.U. Perera,* Georgia State University; *L.H. Li, L. Chen, E.H. Linfield,* University of Leeds, United Kingdom

p-GaAs/$Al_xGa_{1-x}As$ heterojunction is an attractive material system due to its mature III-V material growth and processing technology. Infrared detection in the mid-infrared range is possible by exploiting the intra-valance band hole transitions in the light hole/heavy hole and spin-orbit split-off bands. The wavelength threshold can be tuned by varying the Al mole fraction (*x*), while graded $Al_xGa_{1-x}As$ potential barriers create an asymmetry to allow a photovoltaic operation. The operation under photovoltaic mode is advantageous due to thermal noise limited performance. In a preliminary study in a 2 – 6 µm photovoltaic detector, we implemented a current blocking barrier, which improved the specific detectivity by two orders of magnitude, to 1.9×10^{11} Jones at 2.7 µm, at 77K. At zero bias, the resistance-area product (R_0A) had a value of ~ 7.2×10^8 Ω cm^2, which is five orders higher in magnitude compared to the R_0A value without the blocking barrier. A photoresponse was observed up to 130K. Further work is in progress to optimize the detector at a higher operating temperature.

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10:20am **EM-FrM7 SSI-LEDs - 20,000 Hrs of Lifetime and Failure Mechanism Study**, ***Yue Kuo***, *S. Zhang,* Texas A&M University

Recently, a new type of solid state incandescent LED (SSI-LED) that emitted the broad band warm white light upon the application of a voltage was reported by our group [1-4]. This kind of device also has unique antifuse- and diode-like characteristics in the low voltage operation range [5,6]. The operation of this new device is based on the passing of current through nano-sized conductive paths after the breakdown of an amorphous high-*k* thin film stack deposited on top of a silicon wafer. The principle of light emission of the SSI-LED is the black body effect, which is different from the electron-hole or exciton-exciton recombination in the conventional crystalline compound semiconductor structure. A lifetime of over 12,000 hours was obtained previously [4].

In this talk, authors will present the new result on the lifetime study of the SSI-LED. Without a passivation layer, the device has been successfully operated continuously for over 20,000 hours in air. Changes of electrical and optical characteristics of the device over the whole operation period have been monitored. In order to understand the failure mechanism within a short period of time, we further carried out accelerated voltage stress tests. The change of the surface morphology with the applied voltage has been systematically investigated. Based on these results, authors review the mechanisms of the device operation and failure.

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