PCSI
Room Ballroom South - Session PCSI-SuE
III-V Growth

Moderator: Lincoln J. Lauhon, Northwestern University

7:30pm **PCSI-SuE-1 Understanding the Kinetics of III-V Semiconductor Nanowire Growth using *in-situ* TEM**, *C Maliakkal, D Jacobsson, M Tornberg, A Persson, J Johansson, R Wallenberg, **Kimberly Thelander**,* Lund University, Sweden **INVITED**

Semiconductor nanowires have emerged as a highly promising technology for next-generation electronics and photonics, in particular due to their potential for forming novel metastable crystal phases, complex alloys and heterostructure combinations not achievable in bulk semiconductors. The most common method of fabricating these structures is the vapor-liquid-solid mechanism, which makes use of a catalytic liquid metal droplet. The development of these materials requires a fundamental understanding of how they form. Since nanowire growth is performed in a vapor phase atmosphere at high temperature, the dynamic processes controlling their formation cannot be directly deduced by analyzing only the final grown nanostructure. As such, the current mechanistic understanding of the synthesis process is insufficient for achieving the promised level of control.

In order to address this challenge, we use *in-situ* TEM imaging combined with *in-situ* compositional analysis to study the processes occurring at the interface between the metal droplet and nanowire, and how these control the final structure. Nanowires are grown in a Hitachi HF3300S aberration-corrected environmental TEM connected to a chemical vapor deposition system designed for III-V semiconductor growth. Growth is performed on a SiNx-based MEMS heating chip mounted on a holder with two separate microtubes for supplying the precursor gases. High resolution, high-frame-rate videos enable us to determine the rate at which individual semiconductor bilayers form, along with the interface morphology, catalyst geometry and nanowire crystal structure. The elemental composition of the catalyst is measured by energy dispersive X-ray spectroscopy as a function of the growth parameters. We identify different 'regimes' in which growth occurs that can be identified by the composition and structure of the catalyst, and in which different steps in the growth process control the overall formation rate as well as the structure of the material.

8:00pm **PCSI-SuE-7 *In situ* Studies of Surface Morphological Evolution During Indium Nitride Growth by Atomic Layer Epitaxy**, ***Charles R. Eddy, Jr.**, N Nepal,* U.S. Naval Research Laboratory; *S Rosenberg,* American Association for Engineering Education; *V Anderson,* Sotera Defense Solutions; *J Woodward,* American Society for Engineering Education; *C Wagenbach,* Boston University; *A Kozen,* Amerian Society for Engineering Education; *Z Robinson,* College at Brockport SUNY; *L Nyakiti,* Texas A&M University; *S Qadri,* U.S. Naval Research Laboratory; *M Mehl,* U.S. Naval Academy; *K Ludwig,* Boston University; *J Hite,* U.S. Naval Research Laboratory

Nitride semiconductors have had significant commercial success, but full bandgap engineering of these materials is prohibited by the high temperatures used in conventional growth methods. Recently, we have developed a growth method –low temperature atomic layer epitaxy (ALEp) – that has empirically produced crystalline semiconductor films with properties comparable to those from conventional growth processes, but at roughly half the growth temperature [1,2]. This has eliminated miscibility gaps in ternary III-N semiconductor films and enabled the realization of full bandgap engineering from 0.7 eV to 6.1 eV.

Despite these empirical successes, the fundamental mechanisms involved in ALEp are unknown and the full promise of the method unrealized. To obtain such enabling knowledge we have employed synchrotron-based grazing incidence small angle x-ray scattering (GISAXS) to study the low temperature atomic level processing (ALP) of GaN substrate surfaces for epitaxy and ALEp nucleation and growth of InN on said surfaces. GISAXS allows real-time, in situ monitoring of the surface morphology during these processes.

In this presentation, we will introduce the GISAXS method and the apparatus we have developed to conduct in situ GISAXS measurements of the aforementioned ALP and ALEp processes. We monitor the evolution of GaN substrate surface morphology during a series of low-temperature ALPs including: gallium flash off (GFO), hydrogen plasma clean, and nitrogen plasma nitridation. We learn that the optimum surface results from a GFO conducted at 500° C for only 10 cycles followed by a hydrogen plasma clean. Further, we learn that conventional plasma nitridations are detrimental to smooth surface evolution. When employed to study ALEp InN nucleation and growth, GISAXS data, coupled with Porod[3] and 2D Fourier Transform analysis, affords a clear picture that the growth proceeds by island nucleation and growth and not by the conventionally accepted layer-by-layer growth associated with atomic layer deposition. We have monitored the evolution of island nucleation density, island spacing, island shape and island size as a function of key ALEp growth parameters. We observe that the islands are generally tens of nm or less in size and evolve from a spherical mound shape to a cylindrical shape. Finally, we will present the variations between 2D and 3D growth modes with growth parameter variations that provide insights on process modifications to promote higher quality electronic materials growth.

1. Nepal et al., Cryst. Growth and Des., 13, 1485 (2013)

2. Nepal et al., Thin Solid Films 589, 47 (2015).

3. G. Porod, Kolloid Z., 124, 83 (1951).

8:05pm **PCSI-SuE-8 Growth Strategies for Modifying Heterovalent Interfaces**, ***Kirstin Alberi**, K Park,* National Renewable Energy Laboratory

Integration of dissimilar semiconductor materials is becoming an increasingly important pathway for pushing the boundaries of device performance by expanding the options for material selection. The major challenge that must be overcome is the formation of interfaces between two materials with different valences. Charge imbalances arising at interfaces between conventional semiconductors are often alleviated through re-distribution of atoms, which can lead to intermixing-induced degradation of the adjoining layers.

Here, we show that a combination of elemental treatments combined with UV photon exposure can be used to tailor the properties of model ZnSe/GaAs interfaces formed by molecular beam epitaxy. X-ray diffraction and photoluminescence were used to assess the interface roughness and degree of intermixing. Treatment of an As-terminated GaAs surface with UV light and a Se flux results in both an abrupt interface and passivation of the underlying GaAs epilayer. We propose that this improvement over interfaces grown under dark conditions and treatment with a Zn flux is triggered by light-induced desorption of As atoms followed by enhanced Ga-Se bond formation [1]. Thus, the combination of light and elemental treatment during interface initiation offers a highly tunable approach to significantly alter interface properties.

8:10pm **PCSI-SuE-9 InAs QD Formation on GaAs(110) by Bi-surfactants**, *W Martyanov,* Technische Universität Berlin, Germany; *R Lewis,* Paul-Drude-Institut für Festkörperelektronik, Germany; *H Janssen, P Farin, R Zielinski, C Schulze, A Lenz,* Technische Universität Berlin, Germany; *L Geelhaar,* Paul-Drude-Institut für Festkörperelektronik, Germany; ***Holger Eisele**,* Technische Universität Berlin, Germany

8:15pm **PCSI-SuE-10 Total Tomography of Nonplanar III-As Heterostructures**, *L Lähnemann,* 1Paul-Drude-Institut fu¨ r Festko¨rperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Germany; *M Hill,* Northwestern University; *J Herranz,* 1Paul-Drude-Institut fu¨ r Festko¨rperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Germany; *O Marquardt,* Weierstraß-Institut fur Angewandte Analysis und Stochastik, Germany; *A Al Hassan, A Davtyan,* Naturwissenschaftlich-Technische Fakultat der Universitat Siegen, Germany; *O Hruszkewycz, M Holt,* Argonne National Laboratory; *C Huang,* Northwestern University; *U Jahn,* Paul-Drude-Institut fur Festkoperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Germany; *U Pietsch,* Naturwissenschaftlich-Technische Fakultat der Universitat Siegen, Germany; ***Lincoln J. Lauhon**,* Northwestern University; *L Geelhaar,* Paul-Drude-Institut für Festkörperelektronik, Germany

Nanowire core-shell heterostructures are promising candidates for developing on-chip photonic light sources. Here we investigate the emission characteristics of InGaAs quantum wells grown on GaAs nanowires and the dependence on nanowire polytype, indium mole fraction, quantum well morphology (width), and strain. We have measured each of these structural characteristics through correlated atom probe tomography and x-ray nanodiffraction. Correlated cathodoluminescence was used to map local optical properties, providing a comparison with a model of emission built from the atom probe and x-ray analyses. We find that both composition and polytype play a role in explaining differences in emission between zinc blende and wurtzite regions.

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8:20pm **PCSI-SuE-11 Superconducting Proximity Effect in Two-Dimensional Semiconductor-Superconductor Structures*, Javad Shabani,*** New York University **INVITED**

Progress in the emergent field of topological superconductivity relies on synthesis of new material combining superconductivity, low density, and spin-orbit coupling. Theory indicates that the interface between a one-dimensional semiconductor with strong SOC and a superconductor hosts Majorana-modes with nontrivial topological properties. We present our recent developments in materials synthesis and growth of density-controlled surface 2D InAs quantum wells with epitaxial superconducting Aluminum. These developments have led to unprecedented control over proximity effect in semiconductors where electron densities can be tuned using a gate voltage. We demonstrate Josephson junctions with IV characteristic indicating highly transparent contacts. We focus on multiterminal junctions and superconducting quantum interference device (SQUID) geometry to investigate the subtle interplay between supercurrents and spin orbit interaction in these materials. The amplitude and shape of current phase plot is varied as critical currents in each arm are independently controlled using gate-tunable junctions. The data can be well described using solution of Bogoliubov–de Gennes equation for our SQUID junctions. We discuss potential applications in gate-based qubits as well as exploring topological superconductivity for computation.

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