Electronic Materials and Processing
Room 2003 - Session EM-WeM

New Directions in Compound Semiconductors
Moderator: R. Goldman, University of Michigan

8:00am **EM-WeM1 Growth of GaP on Nanoscopically Roughened (001)Si***, I.K. Kim, X. Liu,* ***D.E. Aspnes,*** North Carolina State University

The chemical mismatch between III-V and Group IV materials makes the growth of III-V materials on Si substrates problematic. This is true even for GaP, which is nearly lattice-matched to Si. While GaP has been grown on (001)Si at low temperatures of the order of 300°C by organometallic chemical vapor deposition using easily decomposed tertiarybutylphosphine and triethylgallium precursors, higher growth temperatures offer the promise of higher-quality material. However, growth at temperatures of the order of 750°C with phosphine and trimethylgallium (TMG) precursors on standard RCA-cleaned (001)Si substrates yields widely separated protrusions of GaP separated by regions of bare Si. Here, we show that continuous films of GaP can be grown on (001)Si at these higher temperatures if the substrate is nanoscopically roughened in situ prior to deposition. Roughening not only increases the density of nucleation sites but also increases surface area and inhibits the diffusion of mobile species over the substrate surface without compromising the crystalline quality of the substrate, all of which act to promote the growth of continuous overlayers. However, we also find that the nanoroughness of the substrate can propagate through to the GaP surface, complicating the process. We take advantage of our in situ polarimetric diagnostic capabilities to explore the effect of different deposition conditions in real time, which allows us to efficiently optimize conditions with respect to both roughness and deposition. Our best films are obtained when TMG is introduced as pulses well separated in time.

8:20am **EM-WeM2 Formation and Ordering of Ga Droplets Using a Focused Ion Beam***,* ***W. Ye****, B.L. Cardozo,* University of Michigan*; X. Weng,* Penn State University*; J.F. Mansfield, R.S. Goldman,* University of Michigan

The directed self-assembly of low-dimensional semiconductor structures has been achieved using a variety of approaches to producing topographical patterns. However, an approach for achieving highly ordered arrangements of nanostructures with well-controlled shapes and size distributions has yet to be developed. Therefore, we are exploring the formation mechanisms of Ga droplets which may in turn be used for the directed seeding of semiconductor nanopillars. Using a Ga focused ion beam, we have investigated the formation and ordering of Ga droplets on a variety of semiconductor surfaces. On GaAs and GaSb surfaces, randomly distributed Ga droplets are observed above a critical dose (~4E16/cm^2). Subsequent ion beam irradiation results in growth and coalescence of the droplets. On silicon surfaces irradiated with similar doses, droplets are not observed, suggesting a droplet formation mechanism associated with preferential group V element sputtering, and subsequent local Ga agglomeration. Under further irradiation, Ga droplet motion is observed, possibly due to Marangoni motion. Interestingly, a higher droplet velocity is observed on GaSb than on GaAs surfaces, suggesting that droplet motion is dependent on the energetics of the Ga-substrate interface. To obtain ordered Ga droplets, we have milled arrays of holes with uniform sizes and shapes. By controlling the ion beam energy, current, and position, hole arrays with various sizes, depths, and periodicities may be produced. After scanning the ion beam over the patterned area, Ga atoms agglomerate within the holes, leading to the formation of ordered arrays of nearly uniformly-sized Ga droplets. We will also discuss the interaction of Ga droplets with various N-source gases, including the formation of GaN-rich nanocrystals upon exposure to ammonia vapor. @FootnoteText@ This work was supported by an Intelligence Community Postdoctoral Fellowship, the Radcliffe Institute of Advanced Study, NSF-NER, and AFOSR-MURI.

8:40am **EM-WeM3 Advances in THz Microelectronics***,* ***M.C. Wanke,*** Sandia National Laboratories **INVITED**

Unlike rf/microwave electronics and IR/visible photonics, applications of terahertz (THz) radiation have historically not enjoyed a strong technical infrastructure in semiconductor microelectronic components. This shortcoming has been particularly apparent in coherent THz sources and THz spectrometers, where existing instrumentation such as molecular gas lasers and Fourier transform or time-domain spectrometers tend to be relatively large, reliant on mechanically moving parts, and require regular maintenance. Over the last four years, some significant new developments in THz microelectronics have offered promising solutions to these problems. THz quantum cascade lasers (QCLs) have introduced a revolutionary new compact, microelectronic continuous-wave THz source that can generate the ~ 10 mW average power necessary for many applications. Also, it has been shown that THz radiation can resonantly excite two-dimensional plasmons, rather than electrons, in a quantum well formed in a semiconductor heterostructure. The ability to electrically tune the resonant plasmon frequency via a gate voltage bias makes possible a THz spectrometer-on-a-chip requiring no mechanically moving parts to generate spectral information across a large frequency range. This talk will discuss recent advances in these two areas. THz QCL performance will be reviewed with emphasis on the particular issues that face integrating THz QCLs, acting as illumination source and/or local oscillator, with microelectronic THz direct detectors and mixers. Recent work in plasmon THz detectors will also be discussed, including improvements in sensitivity, speed, and spectral coverage.

9:20am **EM-WeM5 Recent Development of THz Wave Generation, Detection and Applications****,* ***X.-C. Zhang,*** Rensselaer Polytechnic Institute **INVITED**

Terahertz (THz) radiation offers innovative sensing and imaging technologies that can provide information unavailable through conventional methods such as microwave and X-ray techniques. With the advancement of THz technologies, THz sensing and imaging will impact a broad range of interdisciplinary fields. THz radiation in the range of 0.1-10 THz induces low-frequency crystalline lattice vibrations, hydrogen-bond stretching, and other normal vibrational modes of molecules in many chemical and biological materials including ERCs, drugs and other biomolecules. The transmitted or reflected THz spectra of these materials contain THz fingerprints which provide rich information unavailable in other electromagnetic spectra. THz waves with low photon energies (4 meV for 1 THz, one million times weaker than X-ray photons) will not cause harmful photo ionization in biological tissues. As a potential sensing and imaging modality, THz radiation is considered a safe method for the operators and targets. THz radiation can penetrate through many non-polar dielectric materials including paper, cardboard, textiles, plastics, wood, leather and ceramics, with little attenuation. Therefore, THz technologies can be used for nondestructive/noninvasive sensing and imaging of targets under covers or in containers. I will report recent development of THz wave generation, detection, and applications. @FootnoteText@ * For AVS meeting, San Francisco, November, 2006.

10:40am **EM-WeM9 Influence of Nitrogen Incorporation on Electron Transport in Selectively Doped GaAsN/AlGaAs Heterostructures***,* ***Y. Jin****, M. Reason, X. Bai, H.A. McKay, C. Kurdak, R.S. Goldman,* University of Michigan

Dilute nitride (In)GaAs(N) alloys are useful for infrared laser diodes, high efficiency solar cells, and high performance heterojunction bipolar transistors. Typically, increasing N incorporation results in substantially lower electron mobilities than (In)GaAs. The precise role of N in lowering the electron mobility is not well understood. To determine the N-related electron scattering effects in GaAsN, with minimal contributions from ionized impurity scattering, we have studied modulation-doped AlGaAs/GaAs(N) heterostructures, with Si dopants in the AlGaAs barrier layer spatially separated from the undoped GaAs(N) channel layer. AlGaAs/GaAs(N) heterostructures and corresponding GaAs(N) bulk-like films with a variety of N concentrations were grown via molecular-beam epitaxy. Samples containing GaAs or GaAsN as the channel layer are referred to as "control" or "nitride" samples, respectively. The substitutional and interstitial N concentrations were determined using nuclear reaction analysis and Rutherford backscattering spectrometry studies of the bulk-like GaAsN films. Low T magnetoresistance and Hall measurements of the heterostructures reveal similar free carrier concentrations(in the dark) for the nitride and control samples, suggesting that N is not acting as a trapping center. Manipulation of the channel carrier density via front-gating and illumination with a light emitting diode reveals electron mobilities which increase with carrier density for all samples. For the control samples, μ~n^@gamma@, where @gamma@ is typically 1~1.5, suggesting the dominant scattering mechanism is long-range ionized impurity scattering. For the nitride samples, the mobility saturates for n > 1.5x10@super 11@cm@super -2@, suggesting that short-range N-induced neutral scattering is the dominant scattering source in GaAsN. The effects of varying substitutional and interstitial N concentrations on the transport properties of (In)GaAsN will also be discussed.

11:00am **EM-WeM10 Atomic Scale Morphology, Growth Behaviour and Thin Film Properties of Ga(In)NAs Quantum Wells**, ***T.S. Jones***, Imperial College London, UK, United Kingdom; *W.M. McGee, R.S. Williams, T.J. Krzyzewski, M.J. Ashwin,* Imperial College London, UK; *C.P.A. Mulcahy,* Cascade Scientific Ltd, UK **INVITED**

Dilute nitride III-V-N semiconductor alloys are attracting considerable interest because of their highly unusual electronic properties and their promise as the active layer in a wide range of (opto)electronic devices. It is widely recognised that the structural and optical quality of Ga(In)NAs quantum wells (QWs) degrades significantly at relatively high N contents further development of this materials system requires a more detailed understanding of the growth behaviour and the effects of alloy composition, layer thickness and different growth conditions. In this talk I will present results from a scanning tunnelling microscopy (STM) study of the atomic-scale morphology and growth behaviour of Ga(In)NAs thin films of different composition grown on GaAs(001) by plasma-assisted molecular-beam epitaxy (MBE). High growth temperatures and N contents lead to significant phase segregation, the formation of large pits and an undulating 3D morphology.@footnote 1,2@ Measurements as a function of film thickness provide insight into the growth behaviour, in particular the onset of phase segregation and surface roughening.@footnote 2@ Spinodal decomposition is believed to facilitate lateral compositional modulation across the film, resulting in a strain-wave oscillating between compressed In-rich regions to tensile N-rich regions. Depending on the magnitude of this strain and the curvature of the resulting strain-wave a range of surface morphologies can result. Low growth temperatures are found to suppress phase segregation for N compositions up to 5% and additional characterisation by photoluminescence spectroscopy, X-ray diffraction, transmission electron microscopy and secondary ion mass spectroscopy indicate that high quality multi-QW layers can be grown with minimal clustering and with controllable emission in the range 1000-1600 nm. @FootnoteText@ @footnote 1@W.M. McGee et al., Appl.Phys.Lett. 87 (2005) 181905@footnote 2@W.M. McGee et al., Surf.Sci.Lett. (2006) submitted.

11:40am **EM-WeM12 In-Situ Investigation of Surface Stoichiometry During YMnO@sub 3@, InGaN and GaN Growth by Plasma-Assisted Molecular Beam Epitaxy Using RHEED-TRAXS**, ***R.P. Tompkins***, *E.D. Schires, K. Lee, Y. Chye, D. Lederman, T.H. Myers,* West Virginia University

Reflection high-energy electron diffraction total-reflection-angle x-ray spectroscopy (RHEED-TRAXS) can use high-energy electrons from the RHEED electron gun in an MBE growth system to excite x-ray fluorescence. Since the RHEED electrons just penetrate the surface, and by using a geometry that measures x-rays at the total reflection angle, RHEED-TRAXS probes the top 20 to 30 Å of material. Surface coverage of Ga and In during growth of GaN and InGaN was probed using this technique. Studies of the evolution of the surface layer of Ga on GaN during growth at substrate temperatures between 700°C and 750°C will be reported. RHEED-TRAXS measurements were performed during growth of InGaN by measuring the ratio of the In L@alpha@ to Ga K@alpha@ intensity. A significant surface coverage of In was observed at all temperatures investigated regardless of actual In incorporation. RHEED-TRAXS was also used to investigate surface segregation of Mg in GaN, indicating near monolayer coverage. This is useful for studies of the suppression of surface segregation of Mg for p-type doping of GaN, as well as determining a critical Mg surface coverage for polarity inversion. A second RHEED-TRAXS assembly was constructed for use in an oxide MBE chamber at WVU. Preliminary oxide work was performed using the initial RHEED-TRAXS setup, including measurement of monolayer thick layers and determination of the critical angle of Y L@alpha@ and Mn K@alpha@ x-rays. RHEED-TRAXS measurements performed during growth of YMnO@sub 3@ will be discussed. Because RHEED-TRAXS has near monolayer sensitivity, it is a useful tool for determination of conditions for stoichiometric layer-by-layer growth of YMnO@sub 3@. @FootnoteText@ This work was supported by AFOSR MURI Grant F49620-03-1-0330. R.P. Tompkins was supported in part by a grant from the West Virginia Graduate Student Fellowships in Science, Technology, Engineering and Math (STEM) program.

12:00pm **EM-WeM13 Surface Electron Accumulation in Indium Nitride Layers Grown by High Pressure Chemical Vapor Deposition**, *R.P. Bhatta,* ***B.D. Thoms***, *A. Weerasekera, A.G.U. Perera, M. Alevli, N. Dietz,* Georgia State University

High resolution electron energy loss spectroscopy (HREELS) has been used to characterize vibrational and electronic properties of indium nitride layers grown by high pressure chemical vapor deposition. HREEL spectra acquired using incident electron energy of 7 eV from atomic hydrogen cleaned InN layers showed loss peaks due to the Fuchs-Kliewer surface phonon at 560 cm@super -1@ and bending and stretching vibrations of surface N-H at 870 and 3260 cm@super -1@, respectively, indicating N-polarity of the InN layer. HREEL spectra acquired using incident electron energies from 7 to 35 eV exhibited a peak due to a conduction band plasmon excitation. The peak position shifted to lower energy as the incident electron energy was increased indicating a higher plasma frequency and a larger carrier concentration at the surface than in the bulk, which in turn implies a surface electron accumulation layer. The peak energy of the plasmon varied from 3100 to 4200 cm@super -1@ from a set of locations across the surface of the film. Room temperature infrared reflection measurements in the range of 200-8000 cm@super -1@ were acquired at comparable locations across the film and fit to using a three phase thin film reflection model. Plasma frequencies determined from the model fits are in good agreement with plasmon peak energies observed in HREELS at higher incident electron energies. Carrier concentrations determined from the infrared data vary across the film from 8.2x10@super 19@ to 1.4x10@super 20@ cm@super -3@ and carrier mobilities vary from 100 to 210 cm@super 2@/Vs.

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