Nanometer Structures
Room 316 - Session NS-MoM

Quantum Dots and Nanoscale Devices
Moderator: E.T. Yu, University of California, San Diego

8:20am **NS-MoM1 Conductance and Stability of Atom-sized Al Contacts under High Biases**, *J. Mizobata,* Toshiba Corp., Japan*; A. Fujii, S. Kurokawa, **A. Sakai**,* Kyoto University, Japan

Single-atom contacts (SACs) of metals are known to exhibit various unique properties and considered to be a candidate of interconnects in nanoelectronics. In our previous experiments, we studied high-bias conductance of Au and Au-alloy SACs and showed that they can be observed up to 2 V. In order to know the maximum rating of other metal SACs, we carried out conductance measurements of Al SACs for biases from 0.1 to 0.8 V and investigated the formation and the lifetime of Al SACs as a function of the bias voltage. All measurements were made in UHV at room temperature on breaking Al pin-plate contacts, where SACs were observed just before their complete breakage. We found that the formation probability p@sub Al@ of Al SACs decreases with increasing the bias and leads to the suppression of the first peak in the conductance histogram. Both p@sub Al@ and the first peak vanish at around 0.8 V. On the other hand, the average lifetime of Al SACs, <@tau@@sub Al@>, decreases almost linearly with increasing the bias but remains finite at 0.8 V. For comparison, we re-measured the high-bias conductance of Au SACs and found that p@sub Au@ and <@tau@@sub Au@> show similar bias dependence to that of p@sub Al@ and <@tau@@sub Al@>, respectively, though the relevant bias range is much higher for Au SAC: p@sub Au@, for example, survives up to 2.4 V. We consider that the reduction of p@sub Au@ and p@sub Al@ is due to a contact instability induced by electromigration, which fractures contacts in the middle of their deformation and hence reduces the chance of forming SACs. On the other hand, we found it difficult to explain the observed linear bias dependence of <@tau@@sub Al@> and <@tau@@sub Au@> by a simple rate theory since we know little about the effective contact temperature under high biases.

8:40am **NS-MoM2 In-situ Monitoring of Quantum Conductance in Electrodeposited Magnetic Point Contacts@footnote 1@**, ***C.-S. Yang***, *J. Thiltges, B. Doudin,* University of Nebraska, Lincoln*; M. Johnson,* Naval Research Laboratory

The goal of our research is to investigate the magnetoresistance properties of magnetic quantum point contacts. A two-steps fabrication process is used. First, a 50 nm gap between two planar Au electrodes of 1-2 microns widths is patterned using focused ion beam milling. Second, a metallic film is slowly electrodeposited over the electrodes. In-situ measurements of the inter-electrodes impedance monitors the contact resistance during the growth. Keeping electrochemical control of the electrodes ensures optimum purity of the nanocontact, as well as the absence of oxides. Experiments are performed under sweeping magnetic field reaching 1600 Oe amplitude. Quantum conductance steps in Au and Ni point contacts are observed. For Ni, we find that an external field is helpful to observe quantum conductance in multiples of e@super 2@/h, lifting the spin degeneracy. Opening and closure of nanocontacts seldomly occur during the magnetic field sweeping. No significant magnetoresistance was observed for samples of conductance values smaller than 50 e@super 2@/h. Optimizing the measurement speed, we show that no magnetoresistance values larger than 10 % occur when the resistance is stabilized at quantum plateau values during a few magnetic field sweeps. @FootnoteText@ @footnote 1@This research is supported by ONR and NSF MRSEC.

9:00am **NS-MoM3 Quantum Dot Nucleation and Growth in a Microfluidic Reactor**, ***T.L. Sounart***, *J.A. Voigt, T.A. Michalske,* Sandia National Laboratories

Semiconductor quantum dots have the potential to transform important technologies including (bio-)chemical sensors, efficient light sources, catalysts, and supercapacitors. The current ability to control nanoparticle properties, however, is at a state of infancy. Quantum dots are synthesized in batch operations with no feedback and poor control of thermal, chemical, and fluid transport, resulting in a distribution of particle size and batch-to-batch variations. Microfluidic technology, which has revolutionized analytical chemistry and only more recently has been applied to chemical synthesis, offers numerous potential advantages over existing techniques. It is expected that laminar flow, high heat transfer rates, and short mixing lengths can be exploited to precisely control crystal size and morphology, and that microreactor conditions can be adjusted instantaneously to tune output particle properties in real time. In addition to providing better control of reactor conditions, microfluidic systems provide a unique platform for investigation of fundamental reaction processes. Using optical measurement techniques, which are particularly suitable to quantum dot synthesis, we present here for the first time, an on-chip analysis of the nucleation and growth of nanoparticles. CdS early growth processes that are too fast to observe transiently have been resolved spatially in a continuous flow microreactor, and examined by imaging the fluorescence field in the microchannel upon excitation at 365 nm. Early results indicate, e.g., that cysteine-capped quantum dots are formed in less than a second of contact between Na@sub 2@S and CdSO@sub 4@. We are currently analyzing the fluorescence field using hyperspectral imaging to extract data on particle size and concentration variations within the reactor for different chemistries and flow rates. This data is being incorporated into microreactor models to learn how to control quantum dot size and morphology.

9:20am **NS-MoM4 Formation of 31P Qubit Test Structures by Single Ion Implantation**, ***T. Schenkel***, Lawrence Berkeley National Laboratory*; J. Bokor,* UC Berkeley and Lawrence Berkeley National Laboratory*; D.H. Schneider,* Lawrence Livemore National Laboratory*; A. Persaud,* Lawrence Berkeley National Laboratory*; S.-J. Park,* UC Berkeley and Lawrence Berkeley National Laboratory*; J. Nilsson,* Lawrence Livemore National Laboratory*; J.A. Liddle,* Lawrence Berkeley National Laboratory

Electron and nuclear spins of 31P atoms in silicon are promising candidates for the realization of a scalable solid state quantum computer architecture. Single ion implantation with low energy (<10 keV), highly charged ions offers a path to the formation of single 31P atom arrays. We describe our development of single ion placement technology and the integration of atom arrays with control gates and single electron transistor readout structures. Silicon nanowire based single electron transistors are formed in SOI (silicon on insulator) by electron beam lithography and stress limited oxidation. We will discuss critical process integration issues. @footnote 1@ @FootnoteText@ @footnote 1@ We thank the staff of the UC Berkeley Microlab for technical support. This work was supported by the National Security Agency and Advanced Research and Development Activity under Army Research Office contract number MOD707501, and by the U. S. Department of Energy under contract No. DE-AC03-76SF00098. Work at LLNL was performed under the auspices of the U. S. Department of Energy under contract No. W-7405-ENG-48.

9:40am **NS-MoM5 Spin Based Qubit Fabrication in SiGe**, ***L.J. Klein***, *K.A. Slinker, J.L. Truitt, M. Friesen, D.W. van der Weide, S.N. Coppersmith, R. Joynt, M.A. Eriksson,* University of Wisconsin, Madison

A promising approach to solid-state implementation of quantum computers is electron spins in silicon devices. The design incorporates vertical and lateral tunneling into quantum dots defined by nanostructured top gates in the 2DEG of a strained Si quantum well. The potential in the two-dimensional electron gas is modulated by the voltages applied to the top metallic gates. Work is underway to fabricate quantum point contact and quantum dots in strained Si layer and quantum phenomena are investigated related to discrete charge variations. The ultimate goal is the fabrication of qubit: a quantum dot with single electron occupancy with a well defined spin state which is immune from decoherence. This scalable approach allows entanglement of two qubits by varying the voltage applied to top gates separating two quantum dots. Recent measurements of spin lifetime in stained SiGe structures shows decoherence times larger than micro seconds. This large decoherence time should allow many qubit logic operations, initialization, and read-out of a single spin qubit.

10:00am **NS-MoM6 A Systematic Study of SiGe Quantum Fortresses and Possible Applications to Quantum Cellular Automata**, ***T.E. Vandervelde***, *P. Kumar, T. Kobayashi, J.L. Gray, T.L. Pernell, R. Hull, J.C. Bean,* University of Virginia

In this study we detail conditions that result in the generation and evolution of novel hetero-epitaxial surface structures in SiGe/Si created either by spontaneous self-assembly or by ion beam seeding. These self-assembled structures strongly resemble the proposed parameters for a Quantum Cellular Automata (QCA) unit cell. Specifically, we define the growth conditions (i.e. temperature, epi-layer thickness, Ge concentration, and growth rate) under which self-assembly of strain-stabilized quantum fortresses (QFs) and their precursors form. This growth progression can be dissected into a series of surface features that evolve before and after the

appearance QFs. These kinetically limited configurations exist over a wide range of growth conditions, however they are destabilized by excessive adatom surface mobility or strain relaxation resulting from the introduction of misfit dislocations. To characterize these self-assembled structures and their destabilization, we have systematically studied and are basing simulations on their basic dimensional parameters, within this functional space. One natural application would be to use QFs in QCA based architectures. A fully developed QCA circuit requires arrays of QF-like structures, but nature only provides us with isolated randomly located QFs. To overcome this limitation we also report work directed at a guided self-assembly technique that relies on gently altering the substrate before growth. This is achieved using a 25 KeV in-situ Ga+ focused ion beam to locally enhance Ga+ concentration and alter the substrateâ€™s surface topography. The intent is to use the surfactant-like nature of low Ga doses, to cause local nucleation of Ge clusters without greatly disturbing surface topology. We also explore the effects of higher Ga+ dosages, which cause the appearance of significant surface topology, on the localization of Ge cluster nucleation. This work, in part, was supported by NSF through FRG and MRSEC grants.

10:20am **NS-MoM7 Current Challenges in Nanocrystal-Quantum-Dot Lasing**, ***V.I. Klimov,*** Los Alamos National Laboratory **INVITED**

Semiconductor quantum dots (QDs) offer important advantages for lasing applications that are associated with their size controlled emission wavelengths (and, hence, output color) and low, temperature-insensitive optical-gain thresholds. QDs have been fabricated using epitaxial techniques (epitaxial or self-assembled QDs) or using chemical synthesis routes [nanocrystals or nanocrystal QDs (NQDs)]. Despite the impressive success of laser technologies based on epitaxial QDs, the first unambiguous demonstrations of amplified spontaneous emission@footnote 1@ and lasing@footnote 2@ involving chemically synthesized NQDs were performed only recently. The difficulties in achieving lasing in NQDs are due to both materials-quality issues and the existence of intrinsic physical mechanisms that complicate the development of stimulated emission. One such complication is ultrafast gain decay due to highly efficient, nonradiative, multi-particle Auger recombination. In our work we explore "geometrical" methods (e.g., nanocrystal shape control) for suppressing the multi-particle recombination. In particular, we study the effect of the zero- to one-dimensional (1D) transformation on Auger decay using series of elongated semiconductor nanocrystals (quantum rods). We observe an interesting new effect, namely, the transition from a three- to a two-particle recombination process as the nanocrystal aspect ratio is increased. This transition implies that in the limit of 1D confinement, Auger decay is dominated by Coulomb interactions between 1D excitons that recombine in a bimolecular fashion. One consequence of this effect is strongly reduced decay rates of higher order multi-particle states that lead to the increased optical gain lifetime and efficient light amplification due to excited-state transitions. These unique rod properties suggest that shape control may be key to developing practical lasing applications for nanocrystals. @FootnoteText@ @footnote 1@ V. I. Klimov et al., Science 290, 314 (2000). @footnote 2@ H.-J. Eisler et al., Appl. Phys. Lett. 80, 4614 (2002); M. Kazes et al., Adv. Mater 14, 317 (2002); A. Malko et al., Appl. Phys. Lett. 81, 1303 (2002).

11:00am **NS-MoM9 Si Nanocrystal Synthesis in an Oxide Matrix: A Multiscale Computational Study**, ***D. Yu,*** *G.S. Hwang,* University of Texas at Austin

Nanocrystalline Si (nc-Si) embedded in a SiO@sub2@ matrix is receiving great attention due to its interesting fundamental physical properties and promising applications for advanced microelectronic devices and optoelectronic devices. The unique electrical and optical properties of embedded Si nanocrystals appear to be strongly influenced by their crystallite size, shape, density as well as Si/SiO@sub2@ interface structures. It is therefore necessary to develop a detailed understanding of the nc-Si growth and Si-SiO@sub2@ interfacial interactions. Although experiments offer many clues to the nanocrystal formation and interface properties, their interpretations often remain controversial. In this talk, we will present our multiscale computational model for the synthesis of Si nanoclusters in an oxide matrix. Our multiscale model integrates various state-of-the-art theoretical methods at different time and length scales, such as first principles quantum mechanics, molecular mechanics, and kinetic Monte Carlo. Using the multiscale approach, we have examined i) formation mechanism of Si clusters in silicon suboxide, ii) shape evolution of embedded nanoclusters, iii) Si-SiO@sub2@ interface structure and strains. Our simulations show that small silicon clusters agglomerate very rapidly at the early stage of thermal annealing mostly via coalescence. As the Si cluster density gets lower, the coalescence becomes less probable and the cluster growth continues mainly by Ostwald ripening (which appears be several orders of magnitude slower than the initial stage coalescence). Our theoretical study also demonstrates that the average size of silicon clusters is a strong function of the initial silicon supersaturation. Our results are in good agreement with recent experimental observations.

11:20am **NS-MoM10 Nanocrystalline Structures in Amorphous Silica**, ***J.Y. Cheng,*** Rensselaer Polytechnic Institute; *M.M.J. Treacy,* NEC Research Institute; *P.J. Keblinski,* Rensselaer Polytechnic Institute

We conduct the metamict transformation of crystalline silica in a transmission electron microscope. In this experiment, an alpha quartz crystal was transformed into an amorphous phase by electron irradiation at high dose. In the meantime, diffraction patterns of these phases were taken throughout the process. After that, we measured image fluctuations in dark field for the amorphous structure. From the images, the amorphous silica is "nanocrystalline." From the diffraction patterns, these crystallites are randomly oriented. Our results also show that the original alpha phase has ultimately disappeared in the new structure.

11:40am **NS-MoM11 Investigation of Nucleation and Growth of Si(Ge) Nanocrystals Embedded in HfO@sub 2@ as Floating Gate for Flash Memory Devices**, ***R. Gupta,*** National University of Singapore; *L.K. Bera,* Institute of Microelectronics, Singapore; *W.J. Yoo,* National University of Singapore, Singapore; *D.S.H. Chan,* National University of Singapore; *N. Balasubramanian,* Institute of Microrelectronics, Singapore

Charge storage in semiconductor nanocrystals is a very critical property to determine electrical performance of non-volatile memory devices. Nanocrystals embedded in high dielectric constant materials are not only effective to scale down the device size but also to enhance the programming and retention properties. Also, it is known that Si(Ge) nanocrystals of size @<=@ 10nm can have much better charge storage capability at room temperature than Si nanocrystals. This study is focused on understanding mechanisms to control shape, size, and composition of Si(Ge) nanocrystals that will be used for improving device properties of non-volatile memories. The Si(Ge) nanocrystals were deposited using Silane & Germane at the pressures of 0.5Torr - 5Torr and at the temperatures of 500°C-600°C on 40Å of either thermally grown SiO@sub 2@ or MOCVD HfO@sub 2@. The deposition time was varied from 5 seconds to 70 seconds at different flow rates of Silane & Germane. It was found that the evolution of size and density of Si(Ge) nanocrystals was dependent on pressure, deposition time, and substrate material. We found, as the deposition pressure decreased from 5 Torr to 0.5 Torr, the minimum size of Si(Ge) nanocrystal on SiO@sub 2@ decreased from 50 nm to 2 nm while density increased from 10@super 8@/cm@super 2@ to 10@super 11@/cm@super 2@. We observed that nanocrystal size increased in early stages but agglomeration took over with the further increase of deposition time. For SiO@sub 2@, we found that Ge atomic percent decreased from 18.4% to 14.6% as the deposition time increased from 5 seconds to 15 seconds at 5 Torr. However, Ge atomic percent on HfO@sub 2@ at same conditions at 5 seconds was lower at 12.3 %, showing significant difference in kinetics of the Si(Ge) nanocrystal formation between HfO@sub 2@ and SiO@sub 2@ substrates. Details on nucleation, growth, and electrical results on charge storage of Si(Ge) nanocrystals on HfO@sub 2@ will be presented.

Semiconductors
Room 321/322 - Session SC-MoM
Heteroepitaxy of Wide Bandgap Semiconductors

Moderator: K.H.A. Bogart, Sandia National Laboratories

8:20am **SC-MoM1 III-Nitride Epitaxy on Oxide Substrates: New Understanding and Novel Device Alternatives**, ***W.A. Doolittle,*** Georgia Institute of Technology **INVITED**

Despite the maturity of III-Nitride molecular beam epitaxy and the successful commercialization of III-Nitride products, many important details of the epitaxy of III-Nitrides remain unexplained. Effects of strain on growth kinetics, interface chemistry and electrostatics, polarization, and doping remain incompletely explained. This paper attempts to clarify some of the uncertain issues remaining in III-Nitride MBE while detailing new concepts such as polarization-engineered structures using polarization domains written into ferroelectric substrates. Topics to be addressed include the role of interface chemistry between oxide substrates (sapphire, zinc oxide, lithium gallate and lithium niobate) and III-Nitrides. The

common role that oxygen plays in determining the structure of III-Nitrides near the interface will be examined as will the chemical dependence of and temperatures where oxygen is liberated from sapphire substrates. FET mobility can be varied from 46-1587cm@super 2@/V-sec in identical structures by varying the buffer layer nitridation temperature, buffer layer composition-either GaN or AlN at high or low temperatures, and buffer layer thickness. This variation is correlated to inversion domain, and to a lesser degree dislocation density as measured by electrostatic force microscopy. The use of near lattice-matched substrates supplies insight into the growth of GaN in the elastic strain regime. The surface reconstruction and surface smoothness in this regime differs from mismatched substrates and varies little with III/V ratio. Once the critical thickness is reached (~9 to 10 nm), the surface briefly roughens and further growth proceeds as with all other mismatched substrates. Finally, a new influence on film polarity is described, the control of polarity via electrostatic boundary conditions using ferroelectric substrates. Both potential applications and limitations of this approach for polarization-engineered structures is described.

9:20am **SC-MoM4 Ion-Beam-Assisted Molecular Beam Epitaxy of GaN***, **B. Cui**, I.P. Steinke, P.I. Cohen,* University of Minnesota

Energetic particles, such as photons and ion beams have been widely used to assist semiconductor thin film deposition.@footnote 1,2@ High quality GaN can only be obtained in high growth temperature both for MOCVD and MBE. IBAD provides us with a powerful tool to control the growth kinetics and to grow GaN at relatively low temperatures. In this study, sub-keV ion beams from a 3-cm Kaufman source have been applied at a glancing angle to assist the growth of GaN in a MBE system. Basal plane sapphire and MOCVD GaN templates were used as the substrates. Ga was provided by a thermal effusion cell. Ammonia was used as the nitrogen source. Before growing GaN, the sapphire substrates were pretreated in an ion flux and then annealed for cleaning. The sapphire surface was then nitrided in ammonia at 1100K for about 10 min. After nitridation, a thin GaN buffer layer was prepared by a sequence of adsorption and annealing steps. During the growth, the surface roughness and film quality were monitored in situ using light scattering and RHEED. The height-height correlation functions were obtained from diffraction pattern to quantitatively analyze the surface roughness during growth. The results were compared with that obtained by AFM images. Different ion species, including hydrogen, nitrogen, and argon, were used to study the roles of momentum transfer, energy transfer, and ion reactivity on the evolution of surface morphology. A simplified ion-adatom energy transfer model was used to interpret the results. Partially supported by the National Science Foundation and the Air Force Office of Scientific Research. @FootnoteText@ @footnote 1@R. L. Headrick, et al. Phys. Rev. B 58, 8 4818 (1998) @footnote 2@J. Erlebacher, et al. Phys. Rev. Lett. 84, 25 5800 (2000).

9:40am **SC-MoM5 Optimizing AlGaN-GaN Heterostructures by MOCVD for Microwave Electronics***, **M.E. Aumer**, D.B. Thomson, D.P. Partlow, R.C. Clarke,* Northrop Grumman*; S. Cho, G.W. Rubloff, R.A. Adomaitis,* University of Maryland

GaN-based monolithic microwave integrated circuits (MMICs) for high power, high frequency applications have been reported. Despite impressive initial results, it is clear that realization of the full potential of GaN requires improvement of both the material quality and heterostructure design. To achieve the desired improvements, a set of experiments was performed to uncover material-related factors limiting device performance. Epitaxial films were grown by metalorganic chemical vapor deposition (MOCVD) and characterized by photoluminescence (PL), x-ray diffraction (XRD), x-ray reflectance, reciprocal space mapping, Hall effect, and contactless resistivity mapping. Wafer maps of the data illustrate correlations such as a relationship between substrate rocking curve linewidth and AlGaN-GaN interface roughness. Also, it was found that nucleation layer microstructure has a large effect on GaN crystallinity and HFET performance. Optimization of the nucleation layer resulted in a reduction of the screw and edge dislocation density from over 5x10@super8@ cm@super-2@ to less than 5x10@super7@ cm@super-2@. The defect reduction was not accompanied by a significant improvement in the sheet resistance of the channel region, suggesting that neither the electron density nor the low-field mobility were directly affected; however, devices fabricated on such wafers exhibited improved breakdown voltage and output resistance, both of which are important for MMICs. Results from short-loop fabrication of HFETs will be presented to illustrate the impact of material properties as well as heterostructure design on device properties such as I@subDSS@, transconductance, and breakdown voltage.

10:00am **SC-MoM6 Improvement of Optical and Electrical Properties in Blue Light-Emitting Diodes with InGaN-based Triangular-Shaped Quantum Wells***, R.J. Choi, H.-W. Ra, **Y.B. Hahn**, H.J. Lee, E.K. Suh,* Chonbuk National University, Korea

Improvement of optical and electrical properties in blue light-emitting diodes with InGaN-based triangular shaped quantum wells We report the electrical and optical properties of blue light-emitting diodes (LEDs) fabricated by using InGaN-based multiple triangular quantum wells (QWs). The triangular-shaped band structure in the QW was obtained by modulating the In composition in the InGaN well. LEDs with the triangular QWs were compared with rectangular ones in terms of current-voltage (I-V) characteristics, output power, and electroluminescence (EL) spectrum. Compared to the LEDs with conventional rectangular QW structures, the triangular QW LEDs showed a higher intensity and a narrower linewidth of electrical luminescence (EL), a lower operation voltage, and a stronger light-output power. EL spectra of the triangular-QW-based LEDs also showed that the peak energy is nearly independent of the injection current and temperature, indicating that the triangular QW LED is more efficient and stable than rectangular one.

10:20am **SC-MoM7 Optical Studies on the Incorporation of Carbon as a Dopant in Cubic GaN***, **J.A.N.T. Soares**,* Universidade de São Paulo, Brazil*; J.R.L. Fernandez, F. Cerdeira, E.A. Meneses, M.J.S.P. Brasil,* Universidade Estadual de Campinas, Brazil*; A.M. Santos, O.C. Noriega, J.R. Leite,* Universidade de São Paulo, Brazil*; D.J. As, U. Köhler, S. Potthast, D.G. Pacheco-Salazar,* Universität Paderborn, Germany

The metastable cubic phase of GaN (c-GaN) has attracted a lot of attention for its potential optoelectronic applications, especially since the successful fabrication of light-emitting diodes based on this material. In contrast to the wurtzite variety, no spontaneous polarization or strain-induced piezoelectric field exists in the cubic polytype grown on (001) planes. Hence, a greater optical recombination efficiency in c-GaN is expected, due to a greater overlap between electrons and holes wave functions. For the fabrication of devices it is essential to be able to introduce p- and n-type doping in a controlled manner. Among the possible acceptor impurities, carbon (C) has been regarded as an interesting candidate due to its similarity with nitrogen, both in atomic radius and electronegativity. Recently, D.J.As@footnote 1@ reported p-type doping with C during c-GaN plasma-assisted molecular beam epitaxy (PA-MBE) achieving concentrations of the order of 3x10@super 20@cm@super -3@. In order to render this impurity concentration into a high concentration of mobile holes, the details of C incorporation in the GaN lattice must be understood. In this work we performed Raman, photoluminescence, photoluminescence excitation, and photoreflectance spectroscopies on C doped c-GaN samples, deposited by PA-MBE on (001) GaAs substrates, for various C concentrations. The evolution of all four types of spectra is consistent with C atoms initially entering into N-vacancies producing a marked improvement in the crystalline properties of the material. At higher concentrations they also begin to enter interstitially and form C complexes, with a consequent decrease of crystalline quality. A model calculation of the localized vibrations of the C-atom in the GaN lattice allows for the interpretation of a feature in the Raman spectrum of samples with an "optimum" C concentration, which reinforces this view. @FootnoteText@@footnote 1@D.J.As et al., J.Phys.:Condens.Matter 13, 8923 (2001).

10:40am **SC-MoM8 Effect of Substrate Temperature on Crystal Orientation and Residual Stress in RF Sputtered Gallium Nitride Films***, T. Hanabusa, **K. Kusaka**, K. Tominaga,* Tokushima University, Japan

The crystal orientation and residual stress in gallium nitride (GaN) films deposited on a single-crystal (0001) sapphire substrate using a new sputtering system are examined through x-ray diffraction measurements as part of a study of low-temperature sputtering techniques for GaN. The new rf sputtering system has an isolated deposition chamber to prevent contamination with impurities, and is expected to produce high-purity nitride films. GaN films are deposited at various substrate temperatures and constant gas pressure and input power. This new system is found to produce GaN films with good crystal orientation, with the c-axes of GaN crystals oriented normal to the substrate surface. The crystal size of films deposited at high temperature is larger than that deposited at low Ts. All films except that deposited at 973 K exhibit compressive residual stress, and this residual stress is found to decrease with increasing temperature. Finally, the film deposited at 973 K was tinged with white, and the surface contained numerous micro-cracks.

11:00am **SC-MoM9 Formation of Zinc-blende-structure GaN Thin Films on Si Substrates by Radio Frequency Planar Magnetron Sputter Deposition**, ***J.H. Kim**, P.H. Holloway,* University of Florida

GaN thin films were grown on silicon (100) and (111) wafers with no intentional substrate heating by radio frequency (RF) planar magnetron sputtering of a bulk-GaN-crystal target in a pure nitrogen atmosphere. The N@sub2@ gas pressure during the film growth was varied from 7 to 50 mTorr to investigate the influence of energetic particle bombardment on the phase evolution in the deposited GaN films. The GaN films grown at pressures higher than 20 mTorr exhibited a randomly-oriented polycrystalline wurtzite structure. For pressures between 10 and 20 mTorr, both zinc-blende and wurtzite phases were observed and the relative fraction of the zinc-blende phase increased at lower pressure. Below 10 mTorr, the deposited GaN films had a predominant zinc-blende structure with a preferred orientation in the [111] direction perpendicular to the film surface. As the N@sub2@ gas pressure was reduced from 50 to 7 mTorr, the internal stress of GaN films became increasingly compressive as a result of atomic peening effects and reached a value of about 3.2 x 10@super10@ dyne/cm@super2@ at 7 mTorr. The mechanism responsible for the formation of metastable zinc-blende GaN will be discussed in relation to the energetic particle bombardment of GaN films during growth.

Electronic Materials and Devices
Room 321/322 - Session EM+SC-MoA

Defects and Interfaces in Electronic Materials and Devices
Moderator: C.G. Van de Walle, Palo Alto Research Center

2:00pm **EM+SC-MoA1 Localized Defect States, Impurities, and Doping in Al@sub x@Ga@sub 1-x@N Epilayers**, ***S.T. Bradley,*** Ohio State University **INVITED**

AlGaN and its heterojunction alloys are used in some of the most advanced micro- and optoelectronic devices today and rely on precise control of electronic properties in multilayer film structures on a nanometer scale. Deep level defects in these materials and at their interfaces can alter transport, recombination, contact formation, and doping, yet measuring such small structures is a challenge for conventional techniques. Al-rich AlGaN layers can enable many new applications but little is known of their deep level properties. Also, doping of AlGaN with high Al content is difficult and may be restricted by non-intentional impurities (such as oxygen) and their associated deep levels. We have used a near-surface version of cathodoluminescence spectroscopy (CLS), termed low energy electron-excited nanoluminescence (LEEN), to probe the electronic properties of thin HFET films as a function of lateral position and depth. LEEN spectroscopy can provide electronic properties of states that are localized at the surface, buried interface, and near the middle of these nanometer-scale films. For AlGaN/GaN structures, correlations have been made between deep level defects and the sheet charge density, AlGaN/GaN intermixing, surface roughness, and Ga/N ratio. We have also used LEEN with secondary ion mass spectrometry (SIMS) to correlate deep levels across the AlGaN alloy series with chemical impurities and spatial location at surfaces, interfaces, and in the bulk. Al-rich AlGaN exhibits deep level optical emissions that correlate with O and C impurities. Temperature-dependent CL of the Si-doped films reveal donor energy increases but activation energy decreases with Al content. Coupled with the appearance of an O deep level at mid-gap at highest Al concentrations, these changes can be seen to compensate the intentional Si doping. These results demonstrate how spatially-resolved CL combined with SIMS can provide new understanding of macroscopic III-nitride properties.

2:40pm **EM+SC-MoA3 Contactless Characterization of High Electron Mobility Transistor Structures using Surface Photovoltage Spectroscopy**, ***S. Solodky,*** Tel Aviv University, Israel*; A. Khramtsov,* Ben-Gurion University, Israel*; T. Baksht,* Tel Aviv University, Israel*; M. Leibovitch,* Gal-El (MMIC), Israel*; Hava,* Ben-Gurion University, Israel*; Y. Shapira,* Tel Aviv University, Israel

GaN/AlGaN High Electron Mobility Transistor (HEMT), AlGaAs/InGAs/GaAs pseudomorphic HEMT (PHEMT), and InAlAs/InGaAs metamorphic HEMT (MHEMT) epitaxial structures have been characterized using surface photovoltage spectroscopy (SPS). The interplay between two opposite direction signals coming from the regions with opposite direction of electric fields define the shape of the spectra. The shape of the spectra is interpreted using self-consistent numerical simulations. The effects of the transistor delta-doping levels dtop, dbot and surface charge Qsur on the spectrum features have been studied using numerical simulations. Based on the latter, an empirical model has been developed, which allows extraction and comparison of dtop, dbot and Qsur and is applicable for both double-sided and single sided delta-doped structures. Effect of SiN passivation on GaN/AlGaN HEMT surface is shown. Applying of the model to passivated structure shows reduced Qsur. Prediction of the final device performance by the model is shown for two MHEMT structures. Applying of the model shows sensitivity of the methodology to 7.5% difference of dtop. Devices produced on these structures show relative difference of 8.2% in maximum drain currents, which correlate well with dtop values calculated using the model.

3:00pm **EM+SC-MoA4 Atomic Bonding and Electronic Changes at InGaAs/InP Heterojunctions**, ***P.E. Smith,*** *S.H. Goss, S.T. Bradley, L.J. Brillson, M.K. Hudait, Y. Lin, S.A. Ringel,* The Ohio State University*; S.W. Johnson,* Sandia National Laboratories

Lattice-matched In@sub 0.53@Ga@sub 0.47@As/InP heterojunctions have attracted considerable interest for many opto- and microelectronic applications. Achieving abrupt interfaces is difficult since both group III and V elements must be switched at the interface during MBE growth. To minimize structural defects, growers often employ a sequence of source switching such that new group V elements are switched on for brief exposure times before growth of subsequent layers. Interface-specific atomic bonding and diffusion can occur that can alter local electronic properties. We combined secondary ion mass spectrometry (SIMS) depth profiling with micro-cathodoluminescence spectroscopy (CLS) in cross section to measure atomic bonding and compositional changes and their effect on electronic properties. SIMS and CLS measurements of InGaAs-on-InP interfaces subjected to exposure times of 40, 80, 110, 140, and 170 sec reveal: (1) interface broadening (both As and P) that increases from < 5 to 15 nm with the length of time the InP surface is exposed to As prior to InGaAs growth, (2) InGaAs near band edge (NBE) emissions at ~0.79 and 0.80 eV, whose intensities shift to higher energies with proximity to the heterojunction on a submicron scale and become more evident with increasing As exposure time. These electronic changes suggest either lower In interface concentration and/or local defect formation - the latter consistent with increasing trap densities with As exposure measured via photoconductivity decay. Overall, local electronic structure at a lattice-matched III-V compound heterojunction depends sensitively on the competition of atomic species in the transition region during growth.

3:20pm **EM+SC-MoA5 Nanoscale Electronic Characterization of Semiconductors: from Operating Devices to Atomic Scale Defects**, ***Y. Rosenwaks,*** *R. Shikler,* Tel-Aviv University, Israel*; Th. Glatzel, S. Sadewasser,* Hahn-Meitner Institut, Germany **INVITED**

Scanning probe microscopy has opened new opportunities to image semiconductors electronic properties with unprecedented spatial resolution. The recently developed Kelvin probe force microscopy (KPFM) technique has already been demonstrated as a powerful tool for measuring nanoscale electronic properties and has found many diverse applications in recent years. In this talk several novel applications of the KPFM technique recently developed and demonstrated by our group will be presented. The long-range electrostatic force between the AFM tip and the semiconductor surface deteriorates drastically the KPFM spatial resolution, and poses the problem whether surface atomic scale defects can be quantitatively measured. In addition, the physical understanding of the observed contrast in atomic resolution images is still under discussion. We show that by combining ultrahigh vacuum (UHV) KPFM measurements with rigorous modelling of the tip-semiconductor electrostatic interaction it is possible to extract the surface charge density at the atomic steps of a GaP (110) surface. The third part of the talk will be devoted to the use of KPFM for direct measurement of surface states parameters in semiconductors. The method is based on the measurement of very asymmetric cleaved p++n or n++p junctions. The absolute surface band bending, Us, and the surface charge density, Nss, can can be extracted because one side of the junction is degenerate, and all the band bending is taking place in the low doped semiconductor. Methods to obtain the surface states energy distribution are also discussed.

4:00pm **EM+SC-MoA7 STM Observation of Subsurface Boron Dopants on the Si(001)-2x1 Clean Surface**, ***M. Nishizawa,*** *L. Bolotov, T. Kanayama,* National Institute of Advanced Industrial Science and Technology, Japan

As the feature size of integrated circuits approaches nanometer dimensions, dopant distribution in device regions plays an increasingly larger role in determining device performance. This has motivated research in recent years to identify a suitable technique to profile dopant distribution with atomic scale resolution. Among the more promising technologies is Scanning Tunneling Microscopy (STM). While a number of studies have been made to measure individual dopants on cleaved compound-semiconductor surfaces and cleaved or hydrogen-terminated Si surfaces using STM, no studies have been made on the Si(001)-2x1 clean surface. From a surface science perspective, the Si(001)-2x1 is one of the most widely studied and documented surfaces. However, it has not received attention in dopant measurement studies, as it is believed that surface states in the band gap obscure observation of dopant features. In this report, we show that Boron-dopant features can be successfully observed on the Si(001)-2x1 surface using STM. On the Boron-doped Si(001)-2x1 surface (sheet resistance is 0.01 @ohm@ cm) we have observed a number of specific features which are a few nanometers in size and appear as round-shaped protrusions superimposed on the corrugation of surface reconstruction in the filled-state image. The appearance of these features is quite similar to the dopant images observed previously on the other surfaces. These features can be recognized starting at a sample bias voltage (V@sub s@) of -1.0 V and tunneling current (I@sub t@) of 0.2 nA, can be enhanced by increasing V@sub s@ to -0.4 V and I@sub t@ to 2.0 nA. Area density of these features changes with dopant concentration of the substrate. From these results, we conclude that the specific features

observed here are related to the Boron dopant located in a subsurface layer. This study was supported by NEDO.

4:20pm **EM+SC-MoA8 Surface Defects After the Growth of Highly P and Sb Doped Si**, ***G.G. Jernigan**, P.E. Thompson,* US Naval Research Laboratory

Doping in semiconductors is crucial to the formation of electronic devices, but our knowledge of the physical characteristics of electrical interfaces, as they are formed during device fabrication, is limited. We will present a unique study of Si doping with P and Sb during MBE growth on Si (100) wafers using an in vacuuo STM. The process of doping affects the surface morphology, as compared to an undoped film, leading to surface defects. Under dopant flux conditions of ~10@super 12@ atoms/cm@super 2@/s and Si growth rates ~0.10 nm/s, we will report the changes to the Si surface morphology and the production of defects at growth temperatures of 500 °C. The segregation of the n-type dopants, P and Sb, is observed to affect Si adatom attachment at step-edges resulting in an increase in island formation. For thin films of P less than 50 nm, where less than 0.1 monolayers (ML) of P has segregated, the surface roughness is not increased significantly but line defects parallel to dimer rows can be observed. At high P surface coverages observed on films greater than 50 nm, there are blockages at step-edge sites to form pothole-like defects with a density of 2x10@super 10@ /cm@super 2@. For all Sb films grown, there is an increase in surface roughness with increasing film thickness (>2.0 nm) and Sb surface coverage (>0.01 ML). At high Sb surface coverages (0.8 ML), Si islands form into pyramid-like defects with a density of 8x10@super 10@ /cm@super 2@, and this casts concern for the use of Sb in surfactant assisted growth. The evolution of the surface morphology and defect appearance with film growth and dopant segregation will be discussed.

4:40pm **EM+SC-MoA9 The Effect of Strain on Impurity States in Si and Methods of Calculation Thereof**, ***A. Rockett**, D.D. Johnson,* University of Illinois*; B.R. Tuttle,* University of Pennsylvania*; S.V. Khare,* University of Illinois

We propose a simple model for estimating the contribution of strain to the ionization energy of defect states in semiconductors. The model is illustrated for group III and V impurities in Si. The approach uses an extrapolation technique to determine the ionization energies from the results of density functional theory (DFT) calculations. The method is shown to produce reliable results for a range of dopants with no parameters and none of the usual corrections requried in DFT. The results are generalized through an analysis of the resulting energies based on a screened electrostatic interaction, strain, and a bonding localization term.

5:00pm **EM+SC-MoA10 New Mechanism for Coupling between Properties of Interfaces and Bulk Semiconductors**, ***K. Dev**, E.G. Seebauer,* University of Illinois at Urbana Champaign

A new mechanism is described by which interface electronic properties can affect bulk semiconductor behavior. In particular, experimental measurements by photoreflectance of Si(100)-SiO2 interfaces show how a controllable degree of band bending can be introduced near the interface by ion bombardment and annealing. The resulting electric field near the interface can affect dopant concentration profiles deep within the semiconductor bulk by drastically changing the effective interfacial boundary condition for annihilation of charged interstitial atoms formed during bombardment. Kinetic measurements of band bending evolution during annealing show that the bending persists for substantial periods even above 1000 C. Unusually low activation energies for the evolution point to a distribution of energies for healing of bombardment-generated interface defects. The transformations take place at temperatures higher than those characterizing other defects known to exist at the Si-SiO2 interface. The findings have significant implications for pn junction formation during CMOS device processing.

Semiconductors
Room 321/322 - Session SC-TuM

Narrow Gap Semiconductors
Moderator: P. Desjardins, École Polytechnique de Montréal, Canada

8:20am **SC-TuM1 Antimonide-Based Compound Semiconductors: From Interfaces to High-Speed Transistors**, ***B.R. Bennett***, *R. Magno, J.B. Boos,* Naval Research Laboratory*; R. Tsai, A. Gutierrez,* Northrop Grumman Space Technology **INVITED**

Future high-speed analog and digital systems that will benefit from reduced power consumption and high data transmission rates include wireless applications, space-based, and micro-air-vehicles used for communications, imaging, and sensing. The development of Sb-based electronics for use in low-noise high-frequency amplifiers, digital and mixed-signal circuits could provide the enabling technology to address these needs. Our group has been using MBE to grow heterostructures for Sb-based high electron mobility transistors (HEMTs), resonant tunneling diodes (RTDs) and heterojunction bipolar transistors (HBTs). In this talk, I will discuss the design, growth, and performance of these devices. Growth issues include interface formation, doping, and composition control of alloys containing both As and Sb. The attractive material properties of this system have been demonstrated by our development of high-speed, low-power AlSb/InAs HEMTs with an intrinsic f@subT@ value of 250 GHz at V@subDS@ = 600 mV and an f@subT@ of 90 GHz at 100 mV. Current work is focused on making the technology viable by reducing leakage currents and developing MMIC-compatible processing. We have also fabricated RTDs with InAs contacts, Al(Ga)Sb barriers, and GaSb wells. For barriers that are 9 Å thick, peak currents exceed 10@super4@A/cm@super2@ with peak-to-valley ratios of 10:1 at biases near 100 mV. Other HEMT and RTD technologies (e.g. GaAs and InP) cannot achieve comparable performance at such low voltages. HBTs using InGaSb for the base and InAlAsSb alloys for the collector and emitter are also being explored. The InGaSb base is attractive due to its narrow bandgap and good hole transport characteristics. In addition, a wide range of heterojunction design flexibility is available because of the various InAlAsSb alloys that can be used. Good diode characteristics with an ideality factor of 1.1 have been obtained for InGaSb/InAlAsSb p-n heterojunctions grown with a 6.2 Å lattice constant.

9:00am **SC-TuM3 Understanding the Electronic Properties of Diluted Nitrides Relevant to Optoelectronic Applications**, ***W.M. Chen***, Linköping University, Sweden*; I. Buyanova,* Linkoping University, Sweden **INVITED**

Dilute nitride semiconductors exhibits unusual physical properties, like a giant bowing in the bandgap energy, forming an attractive new material system promising for long wavelength light emitters operating within the optic-fiber communication wavelength window. A full exploration of the alloys potential in device applications requires, however, detailed knowledge of their fundamental physical parameters and material issues. In this talk we shall provide an overview of our present understanding of basic electronic properties of the dilute nitrides such as Ga(In)NAs alloys and some key material-related problems relevant to optoelectronic device applications, such as determination of dominant mechanism for carrier recombination, potential fluctuation and localization effect, identification and formation of non-radiative defects, effects of post-growth thermal annealing and hydrogenation, compositional dependence of the electron effective mass and band alignment in Ga(In)NAs/GaAs heterostructures.

9:40am **SC-TuM5 Nitrogen Incorporation and Strain Relaxation Mechanisms during Metalorganic Vapor Phase Epitaxy of GaAsN Layers on GaAs (001)**, ***J.-N. Beaudry***, École Polytechnique de Montréal, Canada*; G. Bentoumi,* Université de Montréal, Canada*; S. Guillon,* Bookham Technology, Canada*; R. Leonelli,* Université de Montréal, Canada*; R.A. Masut, P. Desjardins,* École Polytechnique de Montréal, Canada

GaAs@sub 1-x@N@sub x@ epilayers (x @<=@ 0.04), nominally 200-nm-thick, were grown on GaAs (001) by metalorganic vapor-phase epitaxy using trimethylgallium, tertiarybutylarsine (TBAs), and dimethylhydrazine (DMHy). We carried out a systematic investigation of N incorporation as a function of the J@sub DMHy@/J@sub TBAs@ flow rate ratio for growth temperatures T@sub s@ varying from 500 to 650°C. Quantitative secondary ion mass spectrometry measurements indicate that N incorporation increases initially linearly with J@sub DMHy@ with a temperature-dependent incorporation probability that decreases from 0.0036 at 500°C to 0.0005 at 600°C to nearly zero at 650°C. The use of very large DMHy flow rates results in larger incorporation probabilities but lower growth rates. High resolution x-ray diffraction (HR-XRD) shows that the GaAs@sub 1-x@N@sub x@ lattice parameter decreases approximately linearly with increasing x up to about 0.02, with a strain coefficient corresponding to a linear interpolation between the lattice constants of GaAs and cubic GaN. At higher N fractions, the lattice parameter decreases more rapidly. Films with x up to approximately 0.02 are perfect single crystals with smooth interfaces as judged by HR-XRD and cross-sectional transmission electron microscopy (XTEM). Atomic force microscopy and cross-sectional imaging by transmission electron microscopy of a 230 nm thick layer with x = 0.0375 show that crack formation is the most important tensile strain relief mechanism although extrinsic stacking faults and misfit dislocations were also observed. Optical absorption and photoluminescence analyses reveal that higher crystalline quality and lower impurity concentrations were obtained for growth between 575 and 600°C.

10:00am **SC-TuM6 Stress Evolution and Nitrogen Incorporation in GaAsN Films Grown by Reactive Molecular Beam Epitaxy**, ***M. Reason***, *W. Ye, X. Weng, G. Obeidi, V. Rotberg, R.S. Goldman,* University of Michigan

Narrow gap nitride semiconductors have shown significant promise for a wide range of applications including long-wavelength light-emitters, high performance electronic devices, and high efficiency solar cells. A consequence of the large N-As size difference is a predicted limited miscibility on the anion sublattice, which often leads to the formation of GaN-rich nanostructures.@footnote 1,2@ In the case of dilute GaAs@sub 1-x@N@sub x@, conflicting results have been reported regarding the mechanism of N incorporation, and recent optical studies have suggested that the shear deformation potential and/or the binary elastic constants have an unusual composition dependence.@footnote 3@ To date, studies of stress evolution in GaAsN have been limited to x-ray rocking curves (XRC), typically interpreted using a linear interpolation of elastic constants. We have investigated stress evolution in GaAsN films, using a combination of in-situ and ex-situ measurements. A comparison of Nuclear Reaction Analysis and Rutherford Backscattering Spectrometry in channeling and non-channeling conditions suggests significant composition-dependent incorporation of N into non-substitutional sites. Furthermore, a comparison of stresses measured via in-situ wafer curvature measurements, with those determined using a Vegard's Law interpretation of XRC, suggests a change in the mechanism of N incorporation for x@>=@0.015. The observed stress differences are likely the signature of significant bowing of the elastic properties of GaAsN. This work was supported in part by the DOE (Photovoltaics Beyond the Horizon Program), the Air Force Office of Scientific Research (MURI Program), and the TRW Foundation. @FootnoteText@@footnote 1@R.S. Goldman et al., Appl. Phys. Lett. 69, 3698 (1996), J. Electr. Mater. 26, 1342 (1997). @footnote 2@X. Weng, S.J. Clarke, W. Ye, R.S. Goldman, et al, J. Appl. Phys. 92, 4012 (2002). @footnote 3@Y. Zhang, A. Mascarenhas, H.P. Xin, and C.W. Tu, Phys. Rev. B 61, 4433 (2000).

10:20am **SC-TuM7 Electronic and Optical Properties of GaAsN/GaAs Quantum Wells**, ***N. Shtinkov***, *S. Turcotte, J.-N. Beaudry, P. Desjardins, R.A. Masut,* École Polytechnique de Montréal, Canada*; G. Bentoumi, R. Leonelli,* Université de Montréal, Canada

We present a theoretical and experimental investigation of the electronic structure and optical properties of GaAs@sub 1-x@N@sub x@/GaAs (001) quantum wells (QWs) with x < 0.045. The electronic structure is calculated using a recently developed empirical tight-binding (ETB) model, taking strain into account, for values of the GaN/GaAs valence band offset (VBO) from -4 to 4 eV. The valence band structure is found to be strongly influenced by the VBO and the strain-induced heavy hole-light hole splitting. At zero VBO only one heavy-hole and one light-hole state are observed. For VBO < 0 the ground hole state is localized in the barrier, but quasi-bound QW-localized heavy-hole states are observed in the continuum. For VBO > 0, the ground state is always a light-hole state localized in the QW, but there exist a number of excited heavy- and light-hole states. In spite of the significant influence of the VBO on the valence band structure, our results show that its effect on the transition energies is rather small for positive VBO. For example, changing the VBO from 0 to 4 eV in a QW with x = 0.04 shifts the ground state transition energy by only 16 meV. Therefore in simple rectangular QWs only the sign but not the value of the VBO can be unambiguously deduced from measurements of the transition energies. In order to compare our predictions with experimental results, we have measured low-temperature optical absorption spectra from fully coherent 7-period 7-nm-GaAs@sub 1-x@N@sub x@/15-nm-GaAs multiple quantum wells with x up to 0.04. We found that the measured ground-state and excited-state transitions are in

good agreement with our ETB calculations when considering a positive GaAsN/GaAs VBO.

10:40am **SC-TuM8 Growth of InN and Related Compounds by RF Plasma Molecular Beam Epitaxy**, ***W.J. Schaff***, *H. Lu,* Cornell University **INVITED**

InN is of interest for small bandgap, low effective mass applications. InN is grown with a remote RF plasma source of nitrogen using molecular beam epitaxy at substrate temperatures near 500C. GaN or AlN buffers on c-plane sapphire substrates are required for best InN quality. More than 200 wafers have been grown. All exhibit a direct bandgap near 0.7eV which is frequently measured for MBE grown InN@footnote 1@ and agrees with theoretical calculations.@footnote 2@ Bandfilling effects explain observations of increased energy of optical transitions at increased electron density.@footnote 3@ Control of electrical conductivity is limited. Undoped InN is n-type with electron densities that are usually high enough to be degenerate. Electron density falls with InN layer thickness and can be as low as 3E17cm-3 in layers beyond 5 microns thick. 300K mobility is beyond 1000 cm2/Vsec in 1 micron layers and is above 2000 in 5-7 micron thick layers.@footnote 4@ Dislocation density also decreases with InN layer thickness. A cause-effect relationship between electron and dislocation density is not established yet. Si is introduced as a shallow donor while unintentional shallow donors have not been identified. InN has not been made p-type. Mg and Be doping affects electron density and mobility, but net p-type conductivity has not been seen. InN can be grown in the a-plane direction when a-plane GaN or AlN buffers are used on r-plane sapphire.@footnote 5@ In contrast, direct growth on r-plane sapphire without a buffer layer creates predominantly a cubic form of InN.@footnote 6@ Mobility is lower and carrier density is higher in InN in the forms which are not c-plane wurtzite. @FootnoteText@ @footnote 1@V. Yu. Davydov, A. A. Klochikhin, R. P. Seisyan, et al, phys. stat. Sol. (b), 229, R1 (2002).@footnote 2@ F. Bechstedt, J. Furthmüller, M. Ferhat, L. K. Teles, L. M. R. Scolfaro, J. R. Leite, V. Yu. Davydov, O. Ambacher, and R. Goldhahn, phys. stat. sol. a 195, 628 (2003).@footnote 3@ V. Cimalla, Ch. Förster, G. Kittler, I. Popa, R. Kosiba, G. Ecke, O. Ambacher,R. Goldhahn, S. Shokhovets, A. Georgakilas, H. Lu, W. Schaff, Proc. ICNS-5 submitted to phys. stat. sol (a) 195, No. 1, 3-10 (2003).@footnote 4@ H. Lu, W.J. Schaff, L.F. Eastman, GaN and Related Alloys - 2001. Symposium (Materials Research Society Symposium Proceedings Vol.693) Mater. Res. Soc, 2002, xv+860 p. (9-14).@footnote 5@ H Lu, W.J. Schaff L F. Eastman, J. Wu, Wladek Walukiewicz, Volker Cimalla, Oliver Ambacher, submitted to Applied Physics Letters.@footnote 6@ V. Cimalla, J. Pezoldt, O. Ambacher, L. Spiess, and G. Teichert, H. Lu and W. J. Schaff, submitted for publication.

11:20am **SC-TuM10 Electronic Band Structure Ge(1-x)Sn(x) Alloys Grown on Silicon**, ***C.S. Cook***, Arizona State University*; S. Zollner,* Motorola*; M. Bauer, J. Kouvetakis, J. Menendez, J. Tolle,* Arizona State University*; C. Bungay,* J. A. Woollam Co., Inc.

The development of manufacturable direct band gap materials on Si is crucial for optoelectronic devices integrated with silicon circuits. Ge-Sn alloys with varying metastable compositions ranging from 2% - 18% were grown by UHV-CVD using a newly developed deuterium-stabilized Sn hydride with digermane. We use deep ultra violet and infrared spectroscopic ellipsometry to determine the optical properties of this new class of Si-based infrared semiconductors in the Ge1-xSnx system. Optical analysis of the energy derivatives in comparison with analytical lineshapes shows a Ge-like bandstructure that is substantially red-shifted compared that of elemental Ge. Tunability of these gaps with composition could have interesting optoelectronic applications.

Electronic Materials and Devices
Room 310 - Session EM+SC-TuA

50th Anniversary Sessions: Electronic Materials
Moderator: L.J. Brillson, Ohio State University

2:00pm **EM+SC-TuA1 Electronic Materials Growth: A Retrospective and Look Forward**, ***C.W. Tu,*** University of California, San Diego **INVITED**
This article reviews the development of electronic materials, primarily III-V compound semiconductors, from substrates to epitaxy and in situ monitoring to heterostructures, quantum wells and superlattices, that are important to various device applications. As the current research direction leads to the immediate future, the article then summarizes some of the recent advancement in quantum wires, nanowires, and quantum dots.

2:40pm **EM+SC-TuA3 Electronic Materials Theory: Interfaces and Defects**, ***C.G. Van de Walle,*** Palo Alto Research Center **INVITED**
The experimental advances in electronic materials over the past decades have been accompanied by a remarkable increase in the ability to predict structural and electronic properties from first principles. Basic theory, along with modeling and simulation, has always been instrumental in understanding materials. Only recently, however, has the capability emerged to accurately predict properties based solely on the composition of the material, without any fitting to experimental quantities. Such a description must be based on a quantum-mechanical treatment, i.e., a solution of the Schrödinger equation for the system of atomic constituents. The seemingly impossible task of solving this vast many-body problem was rendered feasible by the development of density functional theory (DFT), an achievement for which Walter Kohn received the Nobel Prize in Chemistry in 1998. Other important developments that have greatly enhanced the ability to tackle large systems include pseudopotentials, the simultaneous optimization of electronic and atomic degrees of freedom as embodied in the Car-Parrinello method, and the tremendous increase in available computer power. In this talk I will focus on two areas in which these theoretical and computational advances have had a major impact, namely heterojunction interfaces and defects in semiconductors. Both are intimately connected to the high-quality growth techniques that have enabled a host of novel electronic devices. In the area of defects I will describe the effects of point defects and impurities on doping, specifically highlighting the role of hydrogen. A recently discovered universal alignment for the electronic level of hydrogen in semiconductors and insulators reveals a surprising link with the problem of heterojunction band lineups.

3:20pm **EM+SC-TuA5 Progress in Electronic Materials Characterization**, ***P.H. Holloway,*** University of Florida **INVITED**
Progress in characterization of electronic materials over the past 50 years will be illustrated by selected examples of determination of the atomistic reconstruction and formation of electronic states at surfaces and interfaces of semiconductors using surface sensitive characterization techniques. The same techniques have been used to characterize reactions at interfaces and determine the mechanisms by which charge carrier transport is changed from that controlled by Schottky rectifying to contacts with ohmic characteristics. Seconday ion mass spectrometry (SIMS) has been used to measure dopant profiles over dimensions <10 nm below the surface, and optical characterization techniques have been used for real time control of semiconductor growth. Finally, areas of future development in electronic materials characterization techniques will be the subject of speculation.

4:00pm **EM+SC-TuA7 Making Contact - The Evolution of Materials for Silicon Device Contacts and Interconnections**, ***J.M.E. Harper,*** University of New Hampshire*; S.M. Rossnagel, F.M. d'Heurle, L. Clevenger, C. Lavoie, C. Cabral, Jr.,* IBM T.J. Watson Research Center **INVITED**
The evolution of silicon device technology during the 50-year history of the AVS required not only the constant miniaturization of the transistor, but the concurrent miniaturization of contact metallurgy and interconnection structures. With decreasing area and thickness came a series of materials challenges related to deposition processes, interdiffusion, compound formation and phase stability. These challenges were overcome with a steady stream of innovations in alloy metallurgy, deposition methods, diffusion barriers and understanding of phase formation that apply far beyond the field of microelectronics. Many of these advances were developed by active AVS members and award winners, since the AVS has provided a fertile professional arena for bringing together the necessary scientific and engineering perspectives. Examples will be taken from the development of aluminum-copper and copper interconnections and from the evolution of titanium, cobalt and nickel silicide contact metallurgy.

Semiconductors
Room 321/322 - Session SC-TuA

Compound Semiconductor Growth and Processing
Moderator: P.I. Cohen, University of Minnesota

2:00pm **SC-TuA1 Complex Formation between Magnesocene (MgCp@sub 2@) and NH@sub 3@: Origin of the "Memory Effect"**, ***G.T. Wang,*** *J.R. Creighton,* Sandia National Laboratories
Magnesocene (MgCp@sub 2@) is a common Mg precursor for the p-type doping of Group III nitride semiconductor materials. Unfortunately, difficulties remain with controlling the incorporation of Mg during MOCVD film growth, which often exhibits poorly understood memory effects. While the formation of a reaction product between magnesocene and ammonia has been previously speculated, one has never been experimentally isolated or identified. We have spectroscopically observed and identified, for the first time, the adducts formed between magnesocene and ammonia. Density functional theory (DFT) quantum chemistry calculations have also been performed on the system to determine the structures and energetics of the reaction products. It was found that ammonia can form complexes with magnesocene in both 1:1 and 2:1 ratios, i.e. NH@sub 3@:MgCp@sub 2@ and 2NH@sub 3@:MgCp@sub 2@, via NH@sub 3@ attack of the positively charged Mg center of MgCp@sub 2@. Adduct formation is reversible and the 1:1 and 2:1 products can be converted to one another by varying the NH@sub 3@ partial pressure. Both adducts are condensable at room temperature and their formation is the probable origin of the magnesium memory effects that have been observed during MOCVD of III-Nitride materials. Improved understanding of the equilibrium between condensed phase adducts, gas phase adducts, and precursors should allow for reactor and processing adjustments that reduce or eliminate the memory effects. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

2:20pm **SC-TuA2 Real-time Optical Monitoring of Gas Phase Kinetics in InN Vapor Phase Epitaxy at Elevated Pressures**, ***N. Dietz,*** *V. Woods,* Georgia State University
Understanding the kinetics of nucleation and coalescence of heteroepitaxial thin films is a crucial step in controlling a chemical vapor deposition process, since it defines the perfection of the heteroepitaxial film both in terms of extended defect formation and chemical integrity of the interface. The initial nucleation process also defines the film quality during the later stages of film growth. The growth of emerging materials heterostructures such as InN or indium-rich GaxIn1-xN requires deposition methods operating at high vapor densities due to the high thermal decomposition pressure in these materials. High nitrogen pressure has been demonstrated to suppress thermal decomposition of InN, but has not been applied yet in chemical vapor deposition experiments. The extension of chemical vapor deposition (CVD) to elevated pressure is also necessary for retaining stoichiometric single phase surface composition for materials that are characterized by large thermal decomposition pressures at optimum processing temperatures. The here presented research focuses on the base material InN and addresses the real-time optical monitoring of gas phase- and surface chemistry processes during high pressure (100 bar) CVD of InN. The high pressure CVD reactor has integrated optical diagnostics to monitor in real-time gas flow dynamics, gas-phase decomposition kinetics, and the film growth process itself. These experimental data are of crucial importance to provide (a) input parameter for process models and simulation codes, and (b) establish growth parameter sets needed for analysis and control of chemical vapor deposition at elevated pressure. Data are presented for the optical methods of real-time process monitoring to analyze the initial stages of heteroepitaxy and steady-state growth in the different pressure ranges.

2:40pm **SC-TuA3 Chemical Complexities of AlGaInN MOCVD**, ***J.R. Creighton,*** *G.T. Wang, M.E. Coltrin, W.G. Breiland,* Sandia National Laboratories **INVITED**
We have used a variety of experimental techniques to investigate possible sources of the parasitic chemical reactions that occur during AlGaInN MOCVD. Growth rates for GaN, AlGaN, and InGaN were measured over a wide range of reactor conditions and compared to reactive flow

simulations in order to test possible parasitic chemical reaction mechanisms. All of our results indicate that the parasitic chemical reactions require high temperatures and occur in the boundary layer near the growing surface. These reactions ultimately lead to the formation of nanoparticles, which we have recently observed using in situ laser light scattering. Thermophoresis keeps the nanoparticles from reaching the surface, so the material tied-up in nanoparticles cannot participate in the thin film deposition process. In the case of AlN, the particle size was determined to be 48 nm, and the particle density was in the range of 10@super 8-9@ cm@super-3@. At these densities a significant fraction (20% or more) of the input Al is converted into nanoparticles. We have also directly examined precursor chemistry in the 30-300°C range using in situ FTIR. All three commonly used group-III precursors form adducts with ammonia, but this reaction is entirely reversible for trimethylgallium and trimethylindium. In this temperature range only trimethylaluminum reacts irreversibly with ammonia, evolving methane and forming the expected (CH@sub 3@)@sub 2@Al-NH@sub 2@ product. (Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.).

3:20pm **SC-TuA5 Ab initio Prediction of the Gas-Phase Precursors for AlN Sublimation Growth@footnote 1@**, ***Y. Li***, *D.W. Brenner,* North Carolina State University

A free energy model using input from ab initio calculations is used to predict the concentration and saturation state (with respect to the growing crystal) of 16 Al@sub n@N@sub m@ species under conditions typical of AlN sublimation growth. The calculations predict that Al and N@sub 2@ are the dominant species, in agreement with available experimental measurements. However, our calculations predict that the N@sub 2@ molecule is undersaturated and therefore is not likely a growth precursor. Instead, our model predicts that Al@sub 2@N, Al@sub 3@N, and Al@sub 4@N, while in much smaller concentrations than N@sub 4@, are supersaturated and therefore are the source of nitrogen to the growing crystal. This prediction is in stark contrast to assumptions made in prior growth models, and may help explain why very small sticking coefficients had to be assumed for N@sub 2@ in prior modeling studies to match experimental growth rates. @FootnoteText@ @footnote 1@ Funded by the Office of Naval Research through MURI contract N00014-01-1-0302.

3:40pm **SC-TuA6 Reflectance Interferometry During III-V Nitride Growth, Much More than a Growth Rate Monitor**, ***C.R. Eddy, Jr.***, *R.T. Holm, R.L. Henry, J.C. Culbertson,* Naval Research Laboratory

The application of laser interferometry to the monitoring of wide bandgap semiconductor nitride growth has expanded considerably in recent years. At present, a rapidly growing number of III-V nitride growth systems, MBE and MOCVD alike, employ some version of the technique to monitor growth rates. But growth rate monitoring makes use of a small subset of the useful information the technique affords. In this paper, we discuss the application and interpretation of laser interferometry in the MOCVD growth of gallium nitride and aluminum gallium nitride thin films that employ AlN nucleation layers. We employ a 543.5 nm HeNe laser, lock-in amplifier, and ratiometer (to normalize out laser fluctuations) to monitor growth in a simple vertical tube reactor that is rf heated. In this application, the technique has proven useful as a monitor of not only the thickness, but also the quality of the material grown. Further, the technique can help identify drifts in the process from run to run and within a given run. We will comment on the usefulness of the technique in monitoring surface and interface roughness, film stoichiometry (for ternaries) and thickness uniformity. Finally, we will highlight specific examples where the technique has proven useful in troubleshooting growth irregularities.

4:00pm **SC-TuA7 Real-time Diagnostics of OMCVD Epitaxy with an Integrated Rotating-compensator/Rotating-sample Polarimeter**, *K.F. Flock, S.J. Kim,* ***M. Asar***, *D.E. Aspnes,* North Carolina State University

We obtain new insights on III-V epitaxy and heteroepitaxy with a rotating-compensator/rotating-sample ellipsometer/polarimeter for diagnostics and control of organometallic chemical vapor deposition (OMCVD). The system obtains up to 5 1024-pixel spectra per second from 230 to 840 nm, allowing the p- and s-polarized reflectances and the complex reflectance ratio to be determined from the dc, 2@omega@t, and 4@omega@t components of the transmitted intensity. In addition the optical anisotropy follows from the 10@omega@t component, and alignment parameters from the @omega@t and 3@omega@t components, providing the maximum amount of sample information obtainable from optical data over the available spectral range. Rotating-compensator operation eliminates the serious shortcoming of older, rotating-analyzer and -polarizere designs associated with the loss of phase information when the phases of the complex reflectance ratios are near 0 or 180 degrees. The anisotropy data returns surface-chemical information through their spectral dependences. We relate these non-normal-incidence anisotropy spectra to RDS data obtained at normal incidence by numerical analysis of the system transfer function. This combination of capabilities allows OMCVD growth processes to be studied in greater detail, especially when combined with a recently developed algorithm for simultaneously determining the thickness and dielectric function of films in the Å thickness range. For example we follow the growth of nm thick layers of Ga on (001)GaAs substrates, and track the connection between surface reconstruction and film growth. The relatively short data-acquisition time also allows us to follow growth under highly nonequilibrium "burst" conditions, which appear to be necessary to establish uniform layers of some III-V materials on chemically different substrates.

4:20pm **SC-TuA8 GaN Nucleation Layer Evolution on Sapphire**, ***D.D. Koleske***, *J.J. Figiel, M.E. Coltrin, A.A. Allerman, K.C. Cross, C.C. Mitchell, M.J. Russell,* Sandia National Laboratories

For UV, blue, green and eventually white light LEDs, GaN is most often grown on low-cost sapphire substrates. To improve the GaN epitaxial quality and reduce dislocations, a low temperature GaN nucleation layer (NL) is first deposited prior to high temperature (T) GaN growth. Despite the progress in the MOCVD growth of GaN, details of the NL and high temperature growth evolution are not well understood. In this presentation the GaN NL evolution as it is annealed from low to high T will be investigated using optical reflectance and AFM measurements of stopped growth runs. During the anneal, the NL morphology changes from a continuous 30 nm thick layer composed of 20 nm sized grains to a discontinuous layer that contains large grains approaching 500 nm in width to 180 nm in height. Further annealing of the NL causes a decrease in the size of these large grains. Since only NH@sub 3@ and H@sub 2@ are flowing during the NL annealing, the growth of the large GaN grains is explained by partial decomposition of the NL@footnote 1@ and redeposition of the Ga atoms on the growing grains through a gas phase desorption and readsorption mechanism rather than a surface diffusion mechanism. Evidence for this mechanism is obtained from the height-height correlation functions@footnote 2@ measured from the AFM images of the annealed nucleation layers as well as direct measurements of the GaN NL decomposition kinetics using optical reflectance@footnote 1@. Based on details of the decomposition kinetics and NL roughening, fits to the optical reflectance waveform will be presented. Contributions of the surface diffusion, bulk diffusion, and desorption/readsorption mechanisms to the overall GaN NL morphology will also be discussed along with guidance as to when the NL achieves optimal morphology for further GaN growth at high T. @FootnoteText@ @footnote 1@D. D. Koleske, et al., Appl. Phys. Lett 82, 1170 (2003). @footnote 2@Tong and Williams, Annu. Rev. Phys. Chem. 45, 401 (1994).

4:40pm **SC-TuA9 Investigations of Plasma Etching and Contact Processing on AlGaN Alloys Containing 0 to 50% Al**, ***K.H.A. Bogart***, *A.J. Fischer, M.H. Crawford, D.D. Koleske, A.A. Allerman, R.J. Shul, D.E. Peebles,* Sandia National Laboratories*; I. Adesida,* University of Illinois at Urbana Champaign*; S. Jones,* Sandia National Laboratories*; D. Selvanathan,* University of Illinois at Urbana Champaign*; K.W. Fullmer, F. Jalali,* Sandia National Laboratories

AlGaN alloys are suitable for a variety of light emitting devices including LEDs and laser diodes as well as electronic devices such as high electron mobility transistors. Deep UV (<300 nm) LEDs have important applications as UV light sources for chemical-biological sensors, non-line-of-sight optical communications, and UV curing. Optical performance near 300 nm requires Al stoichiometry of 0.25 to 0.5, or more. The difficulty of forming high-quality ohmic contacts to n-type AlGaN materials increases with increasing percent Al due to the difficulty in effectively doping high %Al AlGaN. We performed a series of experiments to study the effects of several contact processing steps on the resultant material and device characteristics for AlGaN alloys with the percent Al ranging from 0 to 50%. For example, during LED device processing, plasma etching of the p-type material and the active material is done in order to access the underlyingn-type material for contact formation. We determined the effect of percent Al in AlGaN alloys on the surface roughness, etching rates, and resist selectivity, as a function of plasma etch method (ICP vs. RIE) and etching parameters such as substrate bias voltage. We also varied the pre-metallization surface treatments using dry plasma etching and wet chemical (BOE and HCl) etching. We evaporated metal contacts of either

TiAlNiAu or TiAlMoAu and determined metal adhesion and specific contact resistance as a function of percent Al (0 to 50%). Annealing studies were also performed on materials after the contact deposition. Surface analysis by XPS, performed before and after plasma etching showed striking stoichiometric differences between the as-grown alloy and the etched surface. The composition of the metal-AlGaN interface was also investigated by XPS. The results from all of these studies will be presented. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

5:00pm **SC-TuA10 Morphological Evolution of GaAs Surface during Damage-free Etching**, ***S.H. Lee***, *H.P. Gillis,* UCLA

GaAs was etched in Cl@sub 2@/H@sub 2@/Ar plasmas both with ion and electron enhancement. Since bombardment with higher energy ions induces structural damage, electron bombardment and low-energy ion bombardment were used to prevent etch-induced damage. Damage was checked with XRD which shows peak broadening after etching when structural damage is induced on a surface or in a sub-surface layer. XRD peak broadening was seen in high-energy ion bombardment, but not in electron or low-energy ion bombardment. In order to study the competition between the thermal reaction and the electron enhanced reaction, temperature and bias for samples were varied as etching parameters. SEM images and AFM images were obtained and compared for the samples etched at different conditions. Under the damage-free etchig conditions morphology development was followed by measuring etch rate, surface roughness, skewness, and autocorrelation function (ACF) for surface roughness. The evolution of ACF was interpreted by scaling theory. Chemical and bombardment effects were explained based on the scaling theory. Morophological evolution steps and a key effect that determines surface morphology during etching were revealed from this study, and a way to control surface smoothness during dry etching was found.

Electronic Materials and Devices
Room Hall A-C - Session EM+SC-TuP

Poster Session

EM+SC-TuP2 A New Method to Produce Silicon-on-Insulator Wafer-Ar@super +@ Implantation with H@super +@-plasma Processing, ***B. Chen,*** New Jersey Institute of Technology*; A. Usenko,* New Jersey Silicon Wafer Tech*; W. Carr,* New Jersey Institute of Technology

In this paper, we describe a new method to fabricate SOI wafer. Ar+ ions were implanted into Si(100) at energy ranging from 30 KeV to 200 KeV and dose from 1*10@super 15@ to 1*10@super 16@ cm@super -2@. To avoid amorphization, the samples were thermally insulated and the beam current was maintained high enough (about 3mA/cm2). After implantation, pieces of these samples were subjected to thermal annealing at temperature ranging from 200°C to 800°C. The evolution of microstructure of these samples were investigated by TEM. In the annealed samples, Argon clusters are found in either 2-D cavities (Nano-cracks) or 3D cavities (bubbles). Then, these samples were processed by H+ plasma. Nano-cracks and bubbles will help trapping H diffused from the surface. Then this hydrogenated wafer was bonded with the other oxidized wafer. After annealed at 600 °C, a thin layer will be transferred from the hydrogenated wafer to the oxidized one. In this way, we can get the thin layer SOI wafer.

EM+SC-TuP3 Effects of Remasking Materials and Dimensions on Sidewall Roughness of Deep Etched Waveguide, ***J.W. Bae,*** *W. Zhao, J.H. Jang, I. Adesida,* University of Illinois at Urbana Champaign*; A. Lepore, M. Kwakernaak, J.H. Abeles,* Sarnoff Corporation

Photonic devices and circuits based on InP/InGaAsP materials require optical waveguides with highly anisotropic and smooth sidewall profile to achieve good optical mode quality and low loss performance. In the fabrication of optical waveguides, critical factors include lithography, masking, and etching. Each factor introduces various degrees of sidewall roughness (SWR). The rough sidewall of waveguides causes scattering loss, which is one of the major sources of optical loss in deep etched waveguides. Therefore, the characterization of sidewall roughness for the various processes is required. In this study, the SWR of InP/InGaAsP heterostructures fabricated using inductively-coupled-plasma etching (ICP) was investigated as a function of the remasking materials and the dimensions of masks. Among the factors introducing SWR, lithography and etching conditions were fixed at optimum condition that was previously determined. Remasking materials including silicon dioxide and silicon nitride were deposited on NiCr (40 nm)/SiO@sub 2@ (600 nm) mask using plasma enhanced chemical vapor deposition. Also, the effects of thicknesses of NiCr mask layer and remasking materials on the SWR were investigated in the range from 40 to 100 nm and 25 to 100 nm, respectively. Atomic force microscopy (AFM) was utilized to directly measure the SWR of waveguides. Electron beam lithography was used to delineate specially designed line patterns that permitted AFM tips to be directly utilized to measure SWR. Results on SWR from various sources will be presented and discussed with relation to optical losses.

EM+SC-TuP4 Sub 100 nm Radius of Curvature Wide-Bandgap III-Nitride Vacuum Microelectronic Field Emitter Structures Sharpened by ICP Etching, ***P.B. Shah,*** *M.D. Derenge, B.M. Nichols, T.S. Zheleva, K.A. Jones,* US Army Research Laboratory

Nanometer scale tips make possible cold cathodes that when used in vacuum microelectronic (VME) devices bring together the advantages of high power that vacuum tubes provide with the advantages of instantaneous turn-on (no need for tedious warm up), miniaturization and long device lifetime. The advantage of gallium nitride (GaN) in these applications is it's very small electron affinity (energy necessary to remove the electron from the material surface into vacuum.) Aluminum nitride (AlN) is even better because it may exhibit a negative electron affinity. For vacuum microelectronic devices we are developing field emitters using inductively coupled plasma (ICP) etching. This technique involves two steps, first, a fast deep etch to define columns of a given aspect ratio followed by etches to sharpen the columns. We investigate and optimized gas flow rates, etch times, gas pressures, ICP coil RF power, chuck RF power, and masking material. Advantages of this technique over other demonstrated techniques for producing GaN based field emitters such as selective area deposition are that it can be easily transferred to existing fabrication lines and that it allows for easy definition of complex VME device structures. Using an ICP etch high aspect ratio field emitters were fabricated from MOCVD grown GaN exhibiting a tip radius of 80 nm and height of 900 nm. Currently we are optimizing the technique to achieve a smaller GaN tip radius. In parallel an etch process is being optimized to produce field emitter tips from AlN. Our presentation will discuss optimized etch chemistries and preliminary electrical performance along with surface passivation and cleanup techniques.

EM+SC-TuP5 A Study of Silicon Carbide (SiC) Etching Characteristics using Magnetized Inductively Coupled Plasmas (MICP), ***H.Y. Lee,*** *D.W. Kim,* Sungkyunkwan University, South Korea*; Y.J. Sung,* Samsung Advanced Institute of Technology, South Korea*; G.Y. Yeom,* Sungkyunkwan University, South Korea

SiC is an attractive material for electronic devices operating at high power levels and high temperatures. In addition, the large Si-C bonding energy makes the components made of SiC resistant to chemical attack and radiation, and thus attractive for the applications in harsh environments. SiC is also used as a substrate for microelectromechanical system(MEMS) and GaN epitaxial devices due to its excellent electrical, thermal, and mechanical properties. However, due to its stability and inertness of SiC in conventional acid or base solutions at normal temperatures, plasma-based etching plays a important role in patterning SiC for the fabrication of electronic devices. Optimum etch strategies for the fabrication of these devices demand excellent profile control, low ion-induced etch damage, smooth etch surfaces, and high etch rates. In this article we report on the SiC etching in SF6 based discharges and the etch selectivity of SiC over various mask materials to obtain high etch rates and low surface damages. The etch characteristics such as etch rates, etch selectivities, and etch profiles in addition to the plasma characteristics were investigated as functions of source power, and dc bias voltage to the substrate, gas mixtures and applied external magnetic field strength.

EM+SC-TuP6 Electroless Copper Deposition as a Seed Layer on TiSiN Barrier, ***Y.C. EE,*** *Z. Chen, S. Xu,* Nanyang Technological University, Singapore*; L. Chan, K.H. See, S.B. Law,* Chartered Semiconductor Manufacturing Ltd., Singapore

Electroless deposition of copper as a seeding technology has received considerable attention in back-end-of-line device fabrication. This work explores the effects of plasmas processing parameters such as argon gas flow rate and nitrogen plasmas treatment time on the properties of electrolessly plated Cu on TiSiN barrier layers formed by a low-frequency inductively coupled plasma process. TiSiN films have emerged as a promising candidate for the future generation barrier material because of its good adhesion to Cu. The properties of deposited electroless copper were characterized by X-ray diffraction (XRD), four-point resistivity probe, atomic force microscopy (AFM) and field emission secondary electron microscope (FESEM). Comparison is made with the Cu seed layer on TiN. It is found that the required palladium activation time is greatly reduced on TiSiN. The results also show that there is a preferred crystal orientation of Cu in (111) plane. Cu grain size is within the range of 24-33 nm. The sheet resistance of the Cu seed layer is less than 1.2 @ohm@ per square area. The roughness of plated Cu layer largely follows the one of the underlying TiSiN. Good surface coverage of electroless Cu seed layer on TiSiN is obtained in our experiments.

EM+SC-TuP8 Thermal Conductivity Analysis of Highly-Oriented Diamond Films for Silicon on Diamond Electronic Applications, ***N. Govindaraju,*** North Carolina State University*; A. Aleksov,* North Carolina State Univeristy*; F. Okuzumi, G.N. Yushin,* North Carolina State University*; S.D. Wolter, J.T. Prater,* Army Research Office / AMSRL- RO-PM*; Z. Sitar,* North Carolina State University

The extremely high thermal conductivity of diamond (~ 22 W/cmK) along with its wide bandgap (5.3 eV) and high specific resistance (~10@super 12@ @ohm@cm) make it an alluring material for incorporation as a dielectric in Silicon On Diamond (SOD) technology. SOD offers enhanced thermal transport properties in addition to the speed and power enhancing properties offered by the traditional Silicon On Insulator (SOI) technology. As the single crystal growth of diamond on silicon proves elusive, the pragmatic approach would entail the use of Highly Oriented Diamond (HOD) films. It is imperative, for the proposed SOD technology, that the thermal properties be well characterized. The current study seeks to fulfill this requirement by measuring all aspects of thermal conductivity of HOD films. Commercially available thin wire thermocouples (Type K) were used in conjunction with a thin film heater to carry out steady state measurements using the traditional heated bar technique. Preliminary results indicated an average value of ~ 8 W/cmK for measurements done on free standing HOD films. To further refine the accuracy of the measured

thermal conductivity, measurements using a thin film heater and thin film thermocouples were implemented. Studies by Graebner@footnote 1@ have shown that grain size has a great impact on the thermal conductivity of randomly oriented polycrystalline diamond. Since it is known that the size of the columnar grains varies as a function of diamond film thickness, we studied thermal conductivity as a function of thickness. This was achieved by etching away the diamond using an argon-oxygen plasma and implementing the thermal measurements recursively. All thermal conductivity data has been measured as a function of temperature. @FootnoteText@@footnote 1@J.E. Graebner, et. al., Diamond and Related Materials, 2 (1993), 1059-1063.

EM+SC-TuP9 Deposition and Field-Emission Characterization of Electrically Conductive Diamond-Like Amorphous Carbon Films, ***H. Kinoshita***, *R. Ikuta, K. Sakurai, S. Murakami,* Shizuoka University, Japan

Diamond-like amorphous carbon films doped with nitrogen (DAC:N) were formed using intermittent supermagnetron plasma chemical vapor deposition (CVD) technique,@footnote 1@ for the fabrication of high performance field emitters. DAC:N films were deposited on Si and glass wafers using i-C@sub 4@H@sub 10@/N@sub 2@ plasma to investigate the influence of discharge-off time, at lower-electrode temperature of 100°C, upper- and lower-electrode rf powers (UPRF/LORF) of 800W/100W, and electrode spacing of 40mm. Discharge-on time was 1min, and off time (cooling time) was controlled to 15sec-10min. With decrease of cooling time, resistivity was decreased. At cooling time of 15sec, however, DAC:N film was peeled off from a wafer by its plasma heating. By reducing the electrode spacing from 40mm to 20mm, resistivity and optical band gap of DAC:N film deposited at 800W/800W rf powers and 5min cooling time decreased to 0.11@ohm@cm and 0eV, respectively. A DAC:N film of 500Å thickness was deposited on a n-Si wafer at 850W/100W, and was patterned in many island shapes of 1μm x 1μm sizes. Using it, a threshold emission current density of 0.01mA/cm@super 2@ was observed at the electric field of 12V/μm. At the electric field of 21V/μm, maximum field-emission current density (IMAX) of 3mA/cm@super 2@ was observed at the electric field of 21V/μm. A flat DAC:N film of 700Å thickness was deposited on a n-Si wafer at 800W/800W. Using the flat DAC:N film, a threshold electric field of 18V/μm, and IMAX of 2.2mA/cm@super 2@ was observed at the electric field of 32V/μm. @FootnoteText@ @footnote 1@H.Kinoshita and T.Murakami, J.Vac.Sci.Tecnol.A 20, (2002) 403.

EM+SC-TuP10 Avalanche Ballistic Electron Emission Microscopy (BEEM) Studies of Subthreshold BEEM Current and STM Induced Photocurrent, ***C. Tivarus***, *E.R. Heller, J.P. Pelz,* The Ohio State University

We present Ballistic Electron Emission Microscopy (BEEM) studies where the metal is deposited directly over an avalanche pn diode. Because the avalanche diode provides a hot electron gain of up to many millions, intrinsic BEEM current noise levels as low as 20 aA are possible. Hence, this technique can be very useful in nm-resolution studies of electronic transport in structures that otherwise show very low ballistic current for traditional BEEM measurements. Using this technique we were able to accurately study the shape of the subthreshold regions of the BEEM current-voltage curves where all the BEEM current is due to thermally excited electrons above the Fermi level in the STM tip. One of the problems encountered when interpreting the measurements for this avalanche BEEM technique is the presence of the Scanning Tunneling Microscopy induced photo current (STM-PC). Since this STM-PC resembles a normal BEEM current, [E.R. Heller and J.P. Pelz, Appl. Phys. Lett. to be published] it can interfere with BEEM measurements of structures with low signal and/or intrinsic BEEM threshold voltage larger than the substrate bandgap. We have characterized this low signal STM-PC effect using the high photon sensitivity and large collector solid angle of the underlying avalanche diode and will discuss methods to distinguish true BEEM current from STM-PC.

EM+SC-TuP11 Submicron MTJ Cell Selectivity and Switching Field Analysis using Scanning Probe Microcopy Technique, ***D.S. Kim***, *J. Heo, I.S. Chung,* SungKyunKwan University, Korea

It has been reported that in a Synthetic Anti Ferromagnet (SyAF) deposited MTJ bit, the demagnetizing magneto static domain will be diminished regardless of its size with a very low aspect ratio. Thus, the anisotropy ratio and the size of the MTJ (Magnetoresistance Tunneling Junction) cell can be reduced more. Scanning Probe Microscopy (SPM) analysis has great advantage in submicron MTJ bit characterization, since it does not need to make a MTJ contact. We have successfully attained the H-R curve using SPM under controlling external magnetic field for submicron scaled MTJ bits. Therefore, We made to investigate the issues in selectivity characteristics and switching field characteristics in terms of various anisotropy ratio and sizes. We can attain the asteroid curve by applying both hard axis and easy axis magnetic field simultaneously either by rotating sample in diagonal or by applying current through write line. We found the newly introduced SPM diagonal field appliance method would be more efficient than conventional ones, in investigating a MTJ bit switching field characterization.

EM+SC-TuP12 The Analysis on the Origin of High Resistivity in Polycrystalline CdZnTe Thick Films, ***K.H. Kim***, *S.Y. Ahn, M.H. Kim, Y.J. Park, K.N. Oh,* Korea University*; S.U. Kim,* Korea University, Korea

The CdZnTe have an inherently high stoping power, an excellent carrier transport property, and relatively wide band gap energy. Therefore detectors using this materials have the potential for sufficient X-ray sensitivity and DQE at a sufficiently low leakage current.@footnote 1@ Although research results have been presented on single crystal CdTe and CdZnTe detectors with small sized silicon readout devices, it would be difficult to apply these results to large area flat-panel detectors. Alternatives of single crystal, we have grown large area (10 x 10 cm @super 2@) polycrystalline CdZnTe films by thermal evaporation method. The thickness, average grain size and Zn composition was 150 μm , 3 μm and 4%. Resisitivity of CdZnTe films is in the order of 2 x 10@super 9@ @Omega@cm which is comparable that of CdZnTe single crystal samples. In X-ray detectors, high leakage current limits the maximum integration time of the a-Si array for X-ray imaging applications so that high resistivity receptor material is required. Recent reports have identified deep level defects which are likely to be associated with semi-insulating property.@footnote 2@ Based on multiple trapping model, the localized state distributions of high resistivity polycrystalline CdZnTe from TOF (time of flight) transient current are examined using Laplace transform and Tikhonov reularization methods.@footnote 3@ We found 3 different deep localized states above valence band related to the resistivity. In TOF measurements, indium was used as top electrode to form Schottky type cotact to prevent carrier injection. @FootnoteText@@footnote 1@ S. Tokuda, H. Kishihara, S. Adachi, T. Sato, Y. Izumi, O. Teranuma, Y. Yamane, and S. Yamada, Proceedings of SPIE Vol. 4682 , 30 (2002)@footnote 2@ A. Zumbiehl, S. Mergui, M. Ayoub, M. Hage-Ali, A. Zerrai, K. Cherkaoui, G. Marrakchi, Y. Daricim, Material Science and Engineering B 71, 297 (2000)@footnote 3@ J. Weese , Comput. Phys. Commun. 69, 99 (1992).

EM+SC-TuP13 Electrical, Thermal, and Elastic Properties of MAX Phase Materials, *S.E. Lofland, P. Finkel,* ***J.D. Hettinger***, Rowan University*; M.W. Barsoum, A. Ganguly, S. Gupta,* Drexel University*; K. Harrell, J. Palma, B. Seaman,* Rowan University

We have characterized physical properties of several materials in the MAX phase family.@footnote 1@ These materials derive their name from the basic chemical formula M@sub n@AX@sub n-1@, where M is an early transition metal, A is an A-group element, and X is either N or C. These highly conductive ceramics are readily machinable and possess very desirable structural properties.@footnote 1@ From a systematic study of the transport properties, we find most of these materials require two conduction bands, one consisting of holes and the other of electrons, to explain the electrical conductivity, Hall coefficient, and magnetoresistance. A Wiedemann-Franz analysis of the thermal conductivity suggests that, in most of the materials investigated, the mean-free-path of the entropy carriers is the same as that for the charge carriers. The Lorenz number at room temperature indicates that the thermal conductivity is mostly electronic in nature. We have also performed heat capacity and speed of sound measurements on many of the MAX phase materials allowing the extraction of the elastic moduli and Debye temperatures. We find very good agreement between the Debye temperature as determined from specific heat and that determined from elastic measurements. We find that the electronic term in the specific heat depends strongly on the transition metal element and very weakly on the A-group element. In general we find that the transition metal element impacts the electrical properties more dramatically than the A-group element. In contrast, the A-group element seems to more strongly impact the elastic properties of the materials. The justification for these statements will be presented. This work was supported by the New Jersey Commission on Higher Education, the NSF under grants DMR-0072067 and DMR-0114073 and Rowan University. @FootnoteText@@footnote 1@M. W. Barsoum, Prog. Solid State Chem. 28, 201(2000).

EM+SC-TuP14 Photo-electronic Properties of n-ZnO:Al/p-Si Heterojunctions, ***F. Mohammed***, *A. Pontarelli, S. Bokhari, J.R. Doyle,* Macalester College

We present a study of the photo-electronic properties of n-ZnO:Al/p-Si heterojunctions. Transparent conducting ZnO:Al layers having resistivities < 1 x 10@super -3@ ohm-cm and transparencies of about 80% are deposited on p-Si using reactive dc magnetron sputtering. In some devices a higher resistance ZnO:Al buffer layer was inserted between the highly conducting ZnO:Al and silicon. The junctions are characterized by dark current-voltage measurements as a function of temperature (IVT), capacitance-voltage measurements (CV), spectral response measurements, and conversion efficiency. Excellent rectification is obtained, with soft breakdown voltages typically in the range of 3-5 V reverse bias. Analysis of the IVT characteristics imply that the carrier transport is mainly tunneling limited, and the CV measurements imply a barrier height of about 1 eV. The presence of the buffer layer has no systematic effect on the dark junction characteristics. However, the buffer layer devices exhibited a significantly enhanced spectral response and efficiency, with the best devices resulting in a 3 % conversion effeciency under 100 mW/cm@super 2@ white light illumination. Possible roles of the buffer layer in enhancing the photoresponse will be discussed, as well as the potential application of these devices as photodetectors and solar cells.

EM+SC-TuP15 Effects of Threading Dislocations and In Composition on Structural and Optical Properties in InGaN/GaN Triangular-shaped Quantum Wells, ***R.J. Choi***, *Y.B. Hahn, H.J. Lee,* Chonbuk National University, Korea

Structural and optical properties of InGaN/GaN multiple triangular quantum well (QW) structures have been studied with different threading dislocation (TD) densities and wavelengths (or In compositions). As the In composition increased, the extent of variation of the linewidth of photoluminescence (PL) measurements increased over a temperature range of 13 - 300 K. The structural quality of the quantum wells is not consistent with the PL intensity. More fluctuation of the local In composition and severer degradation of PL intensity at a higher TD density were observed, which were attributed to the stress field created by the dislocations. Observations by X-ray diffraction, transmission electron microscopy, and monochromated scanning cathodoluminescence imaging revealed that the optical property of the InGaN/GaN triangular-shaped MQWs is greatly affected by structural imperfections.

EM+SC-TuP16 Electroluminescence in the Infrared Region from Thin Film Zinc Sulfide Doped with Rare Earth Fluorides, ***D. DeVito***, *N. Shepherd, A.S. Kale, W. Glass, M.R. Davidson, P.H. Holloway,* University of Florida

While electroluminescent phosphors are routinely studied for flat panel display technology, infrared emission is often ignored. A variety of applications exist for infrared emitters, including chemical analysis, infrared displays, communications and therapeutic medical treatment. Thin film electroluminescent devices could serve as highly efficient, reliable, rugged infrared emitters. Electroluminescence in high-field devices is generated by impact excitation and subsequent radiative relaxation by electronic transitions located on the luminescent centers. Rare earth elements, including erbium, terbium and holmium, are good choices for luminescent centers as they exhibit many transitions ranging from visible (550 nm) to the mid-infrared wavelengths (5 micron), as will be documented with experimental data from ZnS films deposited by RF planar magnetron sputtering. Among these, holmium is particularly interesting because of transitions at 1210 nm, 1400 nm, 2.9 micron, 4.8 micron and 5 micron. Suppression of emission at visible wavelengths and enhanced infrared emission by selective processing of sputter deposited films is achieved through proper selection of annealing temperature. Optimum luminance at characteristic wavelengths was developed by the appropriate choice of luminescent center and activator concentration, deposition temperature and annealing conditions. Low temperature device measurements are presented to evaluate the effects of room temperature on the number of energy transitions and energy transfer mechanisms in thin film devices.

EM+SC-TuP17 Visible and Near-infrared Electroluminescence from Er-doped GaN Thin Films Prepared by RF Planar Magnetron Sputter Deposition, *J.H. Kim,* ***M.R. Davidson***, *N. Shepherd, P.H. Holloway,* University of Florida

Erbium (Er)-doped GaN thin films were prepared by radio frequency (RF) planar magnetron co-sputtering of a commercial GaN target and a metallic Er target in a pure nitrogen atmosphere. The alternating-current thin-film electroluminescent (ACTFEL) devices were fabricated using a standard half-stack configuration with an Al metal electrode, GaN:Er electroluminescent layer, ATO (Al@sub2@O@sub3@-TiO@sub2@) dielectric, and ITO (indium-tin-oxide) transparent conducting electrode. Visible and near-infrared (NIR) EL emission peaks were observed from the fabricated devices at 530, 550, 660, 1000, and 1550 nm. These emissions were attributed to the Er@super3+@ 4f - 4f intrashell transitions from the @super2@H@sub11/2@, @super4@S@sub3/2@, @super4@F@sub9/2@, @super4@I@sub11/2@, and @super4@I@sub13/2@ excited-state levels to the @super4@I@sub15/2@ ground-state, respectively. GaN host films had a wurtzite polycrystalline structure with a preferred orientation in the [0001] direction perpendicular to the film surface. Full width at half maximum (FWHM) of the (0002) wurtzite-GaN diffraction peak and the lattice constant, c both increased from 0.38° to 0.45° and from 5.18 Å to 5.205 Å, respectively, as the Er concentration in GaN host was varied from 0 to around 5 at.%, indicating that incorporation of larger Er atoms into GaN host expands the host lattice. The optimum concentration of Er was determined to be around 1 at.% for both of the green 530 nm and NIR 1550 nm emissions.

Semiconductors
Room Hall A-C - Session SC+EM-WeP
Poster Session

SC+EM-WeP1 STM Observation of Dopant Atoms and Point Defects in the p-type GaAs (110) Surface at 5K, *B. Grandidier,* ***G. Mahieu,*** *D. Deresmes, J.P. Nys, D. Stievenard,* IEMN-CNRS, France*; P. Ebert,* IFF-Julich, Germany

Cross-sectional scanning tunneling microscopy (STM) is used to study dopant atoms and point defects exposed on and in cleaved p-type doped GaAs (110) surfaces at 5K. While Zn dopant atoms have been already characterized in the past, spatial mapping of the conductance variation on individual dopants gives new insights in the origin of the triangular shaped features generally observed if the tip Fermi level is near the bottom of the conduction band. Combining empty and filled state images, we also identify As antisites and complex of vacancies. The stability of complex vacancies are discussed in the light of the available theoretical information.

SC+EM-WeP3 Metal-Oxide-Semiconductor Field Effect Transistors Investigated by Scanning Capacitance Force Microscopy, ***K. Kimura,*** *K. Kobayashi, H. Yamada,* Kyoto University, Japan*; K. Usuda,* Toshiba Corporation, Japan*; K. Matsushige,* Kyoto University, Japan

We have recently developed a novel scanning probe technique, scanning capacitance force microscopy (SCFM) capable of measuring two-dimensional (2D) dopant profiling of semiconducting sample. SCFM, of which operating principle is based on the detection of an electric force between the conducting tip and sample, does@aa n@t utilize ultrahigh frequency capacitance sensor required for conventional scanning capacitance microscopy (SCM). In SCFM, an electric field alternating at an angular frequency @omega@ is applied between the tip and the semiconducting sample and then the induced electric force (ESF) oscillating at its third harmonic frequency (3@omega@) is detected using a lock-in amplifier as an SCFM signal. This is because the magnitude of the induced ESF is proportional to the square of the applied electric field and the capacitance of the semiconducting sample, which is also modulated at @omega@. Thus the amplitude-and-phase (Acos @phi@) signal of the induced ESF alternating at 3@omega@ contains information on the differential capacitance (dC/dV). We performed cross-sectional SCFM imaging of a n-channel metal-oxide-semiconductor field effect transistor (n-MOSFET). In source and drain regions, dopant density decreases from 10@super 21@ cm@super -3@ at the surface to 10@super 17@ cm@super -3@ at about 100 nm in the depth direction. Channel length is 500 nm and dopant density in channel region is 10@super 17@ cm@super -3@. We observed a drastic change in SCFM signal at about 100 nm in the depth direction of the source or drain regions. We also observed a characteristic contrast at the depleted area under the gate oxide corresponding to the channel region. In the presentation, we present SCFM images on MOSFETs obtained both in contact mode and dynamic mode. We discuss the interpretation of the obtained contrast and its dependence on the applied DC voltage. We also compare those SCFM images with SCM images and SIMS profiles.

SC+EM-WeP4 Effect of Mn Composition on Characterization of Zn@sub 1-x@Mn@sub x@Se Epilayers, ***Y.-D. Choi,*** *Y.-M. Yu, D.-J. Kim, K.-J. Lee,* Mokwon University, South Korea*; Byungsung O, K.-S. Lee,* Chungnam National University, South Korea*; I.-H. Choi,* Chung-Ang University, South Korea*; M.-Y. Yoon,* Joongbu University, South Korea

ZnMnSe is one of II-VI diluted magnetic semiconductors, in which the cations of the host crystal are replaced with Mn@super 2+@ ions. Recently, ZnMnSe is used as a material to inject spin inside the quantum structures. The crystal structure of the bulk ZnMnSe is cubic in the range of the Mn composition for x0.05. The absorption and PL spectra at 10 K were compared. In the region of small range x, the band gap energy showed weak bowing effect. It was found that PL peak near the energy band gap was related to the free exciton from the absorption measurements. From Raman measurement at the room temperature, ZnSe-like LO phonon peak was observed, and with the increasing Mn composition x the blue shift of 3.5 cm@super -1@ was observed. The variation of the dielectric constants @epsilon@@sub 1@ and @epsilon@@sub 2@ as a function of Mn composition x by SE was measured. When x is small, it was found that the predominant transition took place in the critical point(CP) of each band structure, and with the increasing x, CP was shifted to low energy side.

SC+EM-WeP5 Linear Magnetoresistance in LaSb@sub 2@: The Role of Charge-Density Waves@footnote *@, *A. Acatrinei,* Louisiana State University*; J.W. Richardson,* Argonne National Laboratory*; D. Young, D. Browne, Y. Losovyj, P.T. Sprunger,* ***R.L. Kurtz,*** Louisiana State University

LaSb@sub 2@ exhibits a giant linear magnetoresistance@footnote 1@ to very high fields (40T) yet it is composed of non-magnetic elements. This work reports on the role of charge-density waves (CDW) in providing a magnetic response within the two-dimensional constraints of this layered compound. Single-crystals of LaSb@sub 2@ were grown in an excess Sb flux using high-purity La and Sb and X-ray diffraction measurements confirm that it has an orthorhombic crystal-structure with a=6.38 b=6.23 and c=18.75Å. The layered structure of Sb planes separated by bi-layers of La-Sb chains gives the material a micacious appearance. X-ray measurements suggest a mosaic spread of ~0.5-1° and it is likely that the material is highly twinned. When the material is cleaved in uhv, STM studies give flat terraces mostly separated by the unit cell height and, occasionally, we observe half-unit cell steps. Neutron diffraction measurements show temperature-dependent peaks that are not from the orthorhombic structure but have been attributed to the CDWs. Further clues to the potential origin of charge-density waves come from a comparison of photoemission and density-functional studies. Photoemission studies show that the electronic structure is highly two-dimensional. Density functional theory predicts nearly square tube-like Fermi surfaces that extend along the c direction and provide the opportunity for a high degree of nesting within the basal plane. It is this nesting that provides an electronic mechanism to couple charge density oscillations to the electronic structure. A high-resolution study of the CDW gap opening at FS will be presented and discussed in terms of the role of CDWs in the magnetic response. @FootnoteText@@footnote *@We would like to acknowledge Argonne's IPNS, the LSU CAMD synchrotron light source, and the NSF for their support of this work. @footnote 1@ Bud'ko, Canfield, Mielke, et al., Phys. Rev. B 57, 13624 (1998).

SC+EM-WeP6 Ferromagnetic Co-Implanted Rutile TiO@sub 2@(110) for Spintronics Applications, ***V. Shutthanandan,*** *S. Thevuthasan, T. Droubay, S.M. Heald, M.H. Englehard, L.V. Saraf, S.A. Chambers,* Pacific Northwest National Laboratory*; B.S. Mun,* Lawrence Berkeley National Laboratory*; R.P. Sears, B. Taylor, B.S. Sinkovic,* University of Connecticut

There is a growing interest in diluted magnetic semiconductor materials due to their potential applications in spintronics area. The ability to efficiently inject spins into multi-layer semiconductor device structures for room temperature operations creates new and exciting possibilities for utilizing DMS materials in semiconductor applications. Some of the dilute magnetic semiconductors with the potential for room temperature spintronics applications include Co-doped ZnO, Mn-doped GaN and Co-doped TiO@sub 2@. Although there are still some issues associated with the growth of single crystal Co-doped anatase TiO@sub 2@, recent experiments show that this material is the most promising candidate because of its room temperature ferromagnetism.@footnote 1,2@ Recently, we have investigated the Co doping in rutile TiO@sub 2@ using ion implantation as a function of implantation temperature and subsequent annealing. Co implantation at room temperature shows that the implanted Co stays as mostly Co metal in TiO@sub 2@(110). Subsequent annealing around 875 K in air promotes Co diffusion towards the surface. During this process Co gets oxidized in the near surface region. Although a portion of the implanted Co appears to be oxidized as a function of implantation temperature up to 875 K, the Co implantation at 1075 K indicates that the implanted Co is mostly oxidized. Some of the implanted Co at 1075 K appears to be substituting for Ti. These samples were characterized using several surface and bulk sensitive techniques including x-ray photoelectron spectroscopy (XPS), Co K and L edge x-ray absorption near edge structure (XANES), and Rutherford backscattering spectrometry (RBS)/channeling. These results with the room temperature vibrating sample magnetometer (VSM) and magneto-optical Kerr effect (MOKE) measurements from these samples will be discussed. @FootnoteText@@footnote 1@ M. Matsumoto et al., Science, 291, (2001) 854.@footnote 2@ S.A. Chambers et al., Appl. Phys. Lett. 79 (2001) 3467.

SC+EM-WeP7 The Crystallization Behavior and Interfacial Reaction between GeTe and Sb@sub 2@Te@sub 3@ Film for the Application to the Phase Change Memory, ***E.J. Jung,*** *S.K. Kang, B.G. Min,* Yonsei University, South Korea*; H. Horii, Y.H. Ha, J.H. Park,* Samsung, South Korea*; D.H. Ko,* Yonsei University, South Korea

Flash memory has been widely used as a non-volatile memory, however, it has limitations, such as low speed and low write endurance. To supplement

the limitation of flash memory, recently phase change memory(PCM) has been investigated using the class of elements known as chalcogenide. This technology is expected to allow chips that have SRAM speed, DRAM cost and FLASH power characteristic and non-volatility. Chalcogenide is a confirmed phase change material used in re-writeable CDs and DVDs. This material changes phases reversibly and quickly between an amorphous state with high resistivity and a crystalline state with low resistivity. Previously, GeSbTe system has been known as pseudobinary GeTe and Sb@sub 2@Te@sub 3@ alloys with different combinations, such as Ge@sub 2@Sb@sub 2@Te@sub 5@, Ge@sub 1@Sb@sub 2@Te@sub 4@, and Ge@sub 1@Sb@sub 4@Te@sub 7@. Recently GeTe-Sb@sub 2@Te@sub 3@ multi-layer structure is studied to improve crystallization time and rewrite cycle time in optical data storage. We investigated interface reaction and crystallization property between GeTe and Sb@sub 2@Te@sub 3@ thin film to observe a created composition at interface in variable annealing temperature and methods. The GeTe-Sb@sub 2@Te@sub 3@ film was deposited on SiO@sub 2@ by D.C. magnetron sputtering method with GeTe and Sb@sub 2@Te@sub 3@ alloy target. The thickness of each layer is 10nm. After the deposition of GeTe-Sb@sub 2@Te@sub 3@ film, TiN was deposited in a same chamber without breaking vacuum as a capping layer. Sample was annealed at temperature between 200°C and 700°C using furnace and RTP. To study crystallization behavior, XRD analysis were performed. In addition, the sheet resistance was measured by using 4-point probe. TEM analysis was performed to investigate interface reaction between GeTe and Sb@sub 2@Te@sub 3@ thin film. And to observe distribution of each element atom in interface reaction, AES depth profile and EDX were carried out.

SC+EM-WeP8 The Dependence of Charge Collection Efficiency on Metal Electrode in Polycrystalline CdZnTe(x=0.04) Material, ***S.Y. Ahn,*** *K.H. Kim,* Korea University*; S.Y. An,* Korea Institute of Science and Technology*; J.K. Hong, K.N. Oh,* Korea University*; S.U. Kim,* Korea University, Korea

There is currently a growing interests on digital X-ray imagers. A direct methods that has several benefits over the indirect methods like convenient image acquistion, storage and transmission, digital image processing, computer-assisted diagosis, real time images, a better spatial resolution dose for equivalent images.@footnote 1@ To generate appropriate e-h pair in CdZnTe film on incident X-ray, thick CdZnTe film was required. Using thermal evaporation method that is generally adquate to deposit thick films, CdZnTe thick films was obtained having ~100 µm in thickness. We investigate the contact between CdZnTe thick film and a variety of metals with the aim of determining whether the choice of metal can improve the performance of X-ray imager detectors, in particular minimizing the dark current. The sample consist of 100 µm thick CdZnTe(x=0.04) with top electrodes formed from Au, In.@footnote 2@ The detection capability of the material has been demonstrated by time-of-flight(TOF) measurements performed on a device made by an n-CdZnTe epilayer. The analysis of the TOF collected charge as a function of the applied voltage give µ @tau@ ~ 10 @super -4@ cm@super 2@/V for this material.@footnote 3@ And we measured resistivity using four-point probe method. CdZnTe(x=0.04) thick film's resistivity is 3 x 10 @super 9@ @ohm@ cm. Au deposited sample is founded to have better properties than others in many respects such as low leakage current, chemicalstability. @FootnoteText@ @footnote 1@ Y. Eisen, A. Shor, J. Crystal Groeth 184/185 (1998) 1302.@footnote 2@ M. J. Mescher, J. F. Hoburg, T. E. Schlesinger, R. B. James IEEE Transactions on Nuclear Science, Vol. 46, NO. 6, December. (1999)@footnote 3@ X. J. Bao, T. E. Schlesinger, R. B. James, Semiconductors for room temperature nuclear detector applications, in: T.E. Schlesinger, R.B. James (Eds.), Semicounductors and Semimetals, Vol. 43, Academic Press, San Diego. (1995).

SC+EM-WeP9 Surface Passivation of HgCdTe by RF Sputtered Silicon Nitride, ***S.Y An,*** Korea University*; Y.C. Joung,* Hanyang University, Korea*; S.H Lee,* Korea University*; S.H. Suh,* Korea Institute of Science and Technology*; J.S Kim,* Korea Institute of Science and Technology, Korea

There have been considerable advances in HgCdTe device technology. However, surface passivation and insulator/HgCdTe interface are still a subject of great interests.@footnote 1@ Up to now, there has been a lot of results reported on passivants for HgCdTe devices. Recently, silicon nitride (SiN@sub x@) deposited by ECR-PCVD has been reported as a passivant for HgCdTe.@footnote 1,2@ But, there was no research report on RF magnetron sputtered SiN@sub x@ for HgCdTe passivation. In this paper we briefly report some experimental results concerning about interface state and fixed charge density in metal-insulator-semiconductor (MIS) structures realized by RF magnetron sputtered SiN@sub x@ on HgCdTe surface. The electrical properties of MIS structure were studied as a function of sputtering power and working pressure of sputtering chamber. Capacitance-voltage (C-V) characteristics were measured at 1MHz and interface state densities were obtained by Terman's method. It was observed that conductivity type of HgCdTe is closely related with deposition rate of SiNx. The p-type conductivity of HgCdTe was converted to n-type conductivity at deposition rate of less than 25Å/min. To prevent p-type HgCdTe from type conversion, it is necessary to maintain high sputtering rate of SiNx at initial stage. The interface state density and fixed charge density of SiN@sub x@ film on HgCdTe were 1.9x10@super 10@cm@super -2@, and 1.5x10@super 11@cm@super -2@, respectively, at sputtering power of 175W. @FootnoteText@@footnote 1@O. P. Agnihotri, C. A. Musca and L. Faraone, Semicond. Sci. Technol. Vol. 13. 839 (1998). @footnote 2@Y. Nemirovsky and G. Bahir, J. Vac. Sci. Technol. A, Vol.7, No. 2, 450 (1989).@Footnote 3@G. Sudo, N. Kajihara, Y. Miyamoto and K. Tanikawa, Appl. Phys. Lett. Vol.51, No.19, 1521 (1987).

SC+EM-WeP10 Growth and Characterization of Thin Films of a New Semiconductor produced by Co-Sputtering of CdTe and Al@footnote 1@, ***M. Melendez-Lira,*** Cinvestav-IPN, Mexico*; M. Zapata-Torres,* CICATA-IPN, Mexico*; S. Jimenez-Sandoval,* Cinvestav-IPN, Mexico*; M.A. Fuentes-Cabrera,* Carnegie Mellon University

The atomic elements Cd, Te and Al form the compunds CdTe, CdAl@sub 2@Te@sub 4@ and Al@sub 2@Te@sub 3@. CdTe and CdAl@sub 2@Te@sub 4@ are semiconductors and their room temperature band gap are 1.5 eV and 2.0 eV, respectively. The existence of these compounds prompted us to produce a new alloy based in CdTe and Al. We have produced thin films of Cd@sub x@TeAl@sub 1-x@ by rf co-sputtering employing targets of CdTe and Al under an argon atmosphere. Aluminum content in the films was controlled by the rf power applied to the aluminum target. The chemical, structural and optical properties of the thin films have been studied by EDS, X ray diffraction, AFM, optical transmission, photoreflectance, photoluminescence and Raman spectroscopies. EDS, X-ray diffraction and Raman results shown clearly that aluminum has been incorporated in the CdTe lattice, for low aluminum content an hexagonal structure is found. For low aluminum contents transmission spectroscopy results indicate a clear blue shift in the band gap of the alloy. Photoreflectance spectroscopy indicates the presence of a direct band gap of 1.6 eV; for an aluminum content of 6%. Band gap values are discussed taking in account theoretical results obtained by first principles employing the Local Density Approximation and Generalized-Density Functional Theory approaches. @FootnoteText@ @footnote 1@Work partially supported by CONACyT-Mexico.

SC+EM-WeP11 Current Mapping of GaN Films, *A.A. Pomarico,* University of Lecce, Italy*; **J.C. Dickinson,*** Virginia Commonwealth University*; R. Cingolani,* University of Lecce, Italy*; H. Morkoc, A.A. Baski,* Virginia Commonwealth University

GaN-based devices have made remarkable advances recently, but still suffer from excessive current leakage, due in part to extended defects in the material and point defects which are not well understood. We have used the technique of conductive atomic force microscopy (C-AFM) to investigate how the local conductivity of GaN films is related to morphology.@footnote 1@ Our studies indicate enhanced conductivity for prismatic planes found around islands on as-grown samples, and on the edges of pits formed by post-growth chemical etching. In the case of etched HVPE samples, AFM images show hexagonal pits produced by the etching of defect sites on c-plane GaN. Simultaneous C-AFM images show detectable current only at the edges of such pits for forward-bias voltages below 4 V. This indicates that crystallographic planes tilted with respect to the c-plane have a significantly higher conductivity than surrounding areas. Although still under investigation, possible mechanisms for this enhanced electrical activity include extended defects, surface states, and modified Schottky barrier heights on prismatic planes. @FootnoteText@@footnote 1@ A.A. Pomarico et al., Appl. Phys. Lett. 82, 1890 (2003).

Electronic Materials and Devices
Room 310 - Session EM+SC+OF-WeA

Future Issues in Electronics and Optoelectronics

Moderator: C.R. Eddy, Jr., Naval Research Laboratory

2:00pm **EM+SC+OF-WeA1 Materials Issues in Solid-State Lighting**, ***J.Y. Tsao,*** Sandia National Laboratories **INVITED**

A quiet revolution is underway. Over the next 10-15 years inorganic-semiconductor-based solid-state lighting (SSL) technology is expected to outperform first incandescent, and then fluorescent and high-intensity-discharge, lighting.@footnote 1@ Nevertheless, SSL is in its infancy, and significant challenges must be met for SSL to achieve its potential for general white lighting. In this talk, we give an overview of these challenges, and of the prospects for overcoming them. We will focus especially on challenges related to the wide-bandgap AlGaInN family of materials: increasing their electrical-to-optical power conversion efficiency, and increasing their range of emitted colors. And, where possible, we will try to connect these challenges to fundamental physical properties, including: high piezoelectric coefficients, high dopant and exciton ionization energies, high microscopic internal strain and chemical immiscibility, and large differences between the bond strengths of the product materials and the chemical precursors used to grow them. @FootnoteText@@footnote 1@J.Y. Tsao, Ed., "Light Emitting Diodes (LEDs) for General Illumination Update 2002" (Optoelectronics Industry Development Association, Washington D.C., 2002); A. Zukauskas, M.S. Shur, and R. Caska, "Introduction to Solid-State Lighting" (Wiley and Sons, New York, 2002); and M.R. Krames, H. Amano, J.J. Brown, and P.L. Heremans, Eds., Special Issue on High-Efficiency Light-Emitting Diodes, IEEE Journal of Selected Topics in Quantum Electronics, Vol. 8, Issue 2 (Mar-Apr 2002).

2:40pm **EM+SC+OF-WeA3 Organic Light Emitting Diodes as a Source of Light for General Illumination**, ***M. Stolka,*** Consultant **INVITED**

Organic Light Emitting Diodes (OLEDs) have a potential to become a technology of choice for general illumination of commercial and residential buildings. There exist no fundamental obstacles to achieve the required power efficiency (>>100 lm/W), lifetime (>50,000 hrs), and the quality of emitted white light with high rendition index. OLEDs will be ten times more energy efficient as incandescent, and twice as efficient as fluorescent lamps. Recent discovery that triplet excitons can be harvested to produce photons with nearly 100% internal quantum efficiency represents a major breakthrough towards achieving the goal. Based on a spin statistics, only 25% of excitons are singlets, which were thought to be the only excitons capable of relaxing the energy as photons, by fluorescence. The remaining 75% of the excitons in triplet states were considered ineffective since the energy, gained by recombination of charges, is typically dissipated as heat. This was thought to impose a 25% fundamental limit on the internal quantum efficiency of photon generation. It was found that phosphorescent emitters, such as complexes of Pt or Ir, enable the utilization of triplet excitons as sources of photons as well. High energy efficiency, flexibility, conformability to any shape and form, light weight, distributed nature of the light sources, and the ability to emit any color including white are the main attractive features of OLEDs. However, significant challenges still remain. The outcoupling efficiency has to be increased beyond the current ~20%. The stability, especially of blue emitters, has to be improved. Better protection against the access of moisture has to be found, etc., etc. Strategies for increasing the power efficiency, increasing the lifetime of OLEDs, and methods of obtaining white light will be discussed.

3:20pm **EM+SC+OF-WeA5 Future Issues in Spintronics**, ***M.E. Flatté,*** University of Iowa **INVITED**

Metallic spintronics, the control of electrical signals through the flow of spin-polarized current, has progressed from a research discovery in 1988 to a key information technology and commercial success. Almost every computer now contains at least one spintronic device - such as the read head for a hard disk drive. Encouraged by this success researchers have explored other material systems, especially those of semiconductors. New possibilities available from semiconductor spintronics include high-speed coupling of spin dynamics to light (optospintronics), nonlinear transport and gain (spin transistors), exceptionally long spin coherence times, and electrical control of ferromagnetism. Progress in these areas has been rapid, and has led to new perspectives on the optical and electrical manipulation or detection of information stored in magnetic systems. Quick summary examples of such new physical and material functionality within semiconductors will be shown. Semiconductor spintronics, however, cannot do without metallic magnetism, for metals provide an exceptional combination of high conductivity and high Curie temperatures. New spintronic devices probably will depend on hybrid structures, where each component is chosen for optimal properties from metallic, inorganic semiconducting, and organic semiconducting materials.

4:00pm **EM+SC+OF-WeA7 Growth and Applications of Epitaxial Metal-semiconductor Nanocomposite Structures**, ***A.C. Gossard,*** *M. Hanson, D. Driscoll,* University of California, Santa Barbara **INVITED**

We explore the growth and ovegrowth of nanoscale semi-metallic islands in GaAs-based semiconductors. MBE-grown ErAs and ErSb islands grow epitaxially and coherently on the semiconductor surfaces with particle dimensions that are controlled by the deposition growth parameters. The islands can be overgrown with epitaxial semiconductors, and further layers of islands and semiconductor films can be grown to form superlattices of layers of metallic islands. The distribution of islands governs the electrical and optical properties of the nanocomposites, including Fermi level position, carrier mobility, photocarrier lifetimes, plasma properties, barrier formation and carrier tunneling.

4:40pm **EM+SC+OF-WeA9 Electronic Devices from Single Crystal CVD Diamond**, ***J. Isberg,*** Uppsala University, Sweden; *D.J. Twitchen, G.A. Scarsbrook, A.J. Whitehead, S.E. Coe,* Element Six Ltd., UK **INVITED**

Diamond is well known as being the hardest of all materials making it useful in various mechanical applications. Perhaps less well known are the extreme electronic and thermal properties of diamond, which have raised considerable speculation over its usefulness as a semiconductor material in a number of applications. The high charge-carrier mobilities, dielectric breakdown field strength and thermal conductivity of high purity diamond makes it especially well suited in devices where high frequencies are required in combination with high power, high temperatures, or high voltages. Nevertheless, despite more than two decades of research, the breakthrough of diamond-based electronics has not yet happened, largely due to the difficulty of synthesising free-standing, high-quality, single crystal diamond. We will describe recent advances in growing single crystal intrinsic and boron doped diamond intended for electronic applications. The material was grown under conditions of extreme purity, resulting in films of exceptionally low defect densities. In the intrinsic material we have measured room temperature drift mobilities of 4500 cm@super 2@/Vs for electrons and 3800 cm@super 2@/Vs for holes. These mobility values were determined by using the time-of-flight technique on thick intrinsic diamond plates. The high values for the electron and hole mobility, as well as a measured carrier lifetime in excess of 2 @mu@s, indicates a huge improvement in the electronic quality of free-standing, single crystal chemical vapor deposited (CVD) diamond. At present commercially available electronic applications of diamond include UV and radiation detectors, X-ray dosimeters, photoconductive switches and surface acoustic wave (SAW) filters. These applications are mainly based on undoped diamond. We argue that even the lack of a shallow n-type dopant does not stop diamond from having an impact in high power and high frequency electronics because effective unipolar devices such as schottky diodes and MESFETs can be made. Many difficulties concerning the fabrication of diamond devices remain to be solved and a number of process technologies need to be developed such as reliable ion-implantation, etching, annealing, surface termination and contact fabrication technologies. However, the improvement in the electronic quality of diamond indicate that the potential of single crystal CVD diamond as a wide bandgap semiconductor is substantial and will eventually allow the expansion of the boundaries of device technology. @FootnoteText@ J. Isberg et al., Science, 6 Sept, 297 (2002) p1670.

Magnetic Interfaces and Nanostructures
Room 316 - Session MI+SC-ThM

New Spintronic Materials

Moderator: B.T. Jonker, Naval Research Laboratory

8:20am **MI+SC-ThM1 Materials for Spin Injection Into GaN-Based Devices**, ***C.R. Abernathy***, *G.T. Thaler, R.M. Frazier, A. Stewart, S.J. Pearton, F. Ren,* University of Florida*; Y.D. Park,* Seoul National University, Korea*; R. Rairigh, J. Kelly,* University of Florida*; J. Lee,* Seoul National University, Korea*; A.F. Hebard,* University of Florida **INVITED**

Future spintronic devices will likely require injection of polarized currents into semiconductor devices. Though significant work has been carried out in GaAs-based materials, the rapid advancement of GaN-based devices for visible light emission and high power electronics makes this an attractive system for investigation. Two types of spin injection layers appear most promising. One approach is to incorporate magnetic ions into the semiconductor. The introduction of Mn into GaN has been shown to produce ferromagnetism at 300K, making it one of the few DMS materials which may be technologically useful. This method may be limited by the relatively low degree of ordering and the possibility of scattering at the DMS/semiconductor interface. An alternative approach is the use of ferromagnetic layers with metallic conduction, such as MnAs. This material has been used to produce polarized injection into GaAs-based structures, though only at low temperature. Though the lattice mismatch to GaN is greater than for GaAs, the MnAs crystal structure possesses the same Group V symmetry as GaN. This may make growth of a good quality MnAs/GaN interface more achievable than for the MnAs/GaAs heterostructure. This talk will discuss the growth and characterization of both of these types of spin injection layers on GaN. Gas-source molecular beam epitaxy using either an RF nitrogen plasma source, for GaMnN, or AsH3, for MnAs, along with elemental sources for Ga and Mn have been used to deposit thin films on MOCVD GaN buffer layers. Conditions for depositing single phase material with optimum magnetic ordering will be described. The processing challenges associated with integrating these materials into standard GaN/AlGaN light emitting diodes (LEDs) will be discussed along with preliminary electroluminescence results from SpinLEDs fabricated using only low temperature processing. This work was supported by the U. S. Army Research Office (ARO-DAAD19-01-1-0701) and NSF (ECS-0224203).

9:00am **MI+SC-ThM3 Characterization of AlGaN and AlN Based Dilute Magnetic Semiconductors**, ***R.M. Frazier***[1], *G.T. Thaler, J. Stapleton, C.R. Abernathy, S.J. Pearton,* University of Florida*; M.L. Nakarmi, J.Y. Lin, H.X. Jiang,* Kansas State University*; R. Rairigh, J. Kelly, A.F. Hebard,* University of Florida*; J.M. Zavada,* U. S. Army Research Office*; R.G. Wilson,* Consultant

The realization of room temperature ferromagnetism in GaN@footnote 1@ has ignited interest in the development of magnetic devices based on existing wide bandgap technology. However, in order to integrate magnetic semiconductors into the existing technology, it may be necessary to tailor the bandgap through addition of Al. Thus, AlGaN and AlN are two promising candidates for investigation, but optimization of the material in terms of choice of dopant, magnetic characteristics and crystalline quality is necessary before device fabrication can be undertaken. Ion implantation has been shown to be an effective survey method for optimization of dopant type and concentration. In this study, AlGaN and AlN grown on sapphire substrates by Metal Organic Chemical Vapor Deposition have been implanted with Mn, Cr, and Co at high doses (3x10@super 16@ cm@super -2@, 250 keV). After implantation the samples were annealed at 900°C for activation. Photoluminescence of the AlGaN-based alloys showed no band-edge luminescence before or after ion implantation, but the implantation process did introduce deep emission lines. In AlN, the Co and Cr doped films showed hysteresis at 300K while the Mn doped material did not. Epitaxial AlMnN by contrast does show hysteresis at room temperature suggesting that defects may be deleterious to magnetic ordering. The effects of dopant type and host conductivity type on the magnetic and electrical properties after implantation into AlGaMnN will also be presented. The work was supported by the Army Research Office under ARO-DADD19-01-0-0701, ARO-DAAF190110701 and DAAF 19021420 and by NSF under ECS-0224203, DMR 0101856, and DMR 0101438. @FootnoteText@ @footnote 1@ G. T. Thaler, M. E. Overberg, B. Gila, R. Frazier, C.R. Abernathy, S. J. Pearton, J. S. Lee, Y. D. Park, Z. G. Khim, J. Kim, F. Ren, Appl. Phys. Lett. 80, 3964 (2002).

9:20am **MI+SC-ThM4 Growth and Characterization of GaMnN/AlN Multiple Quantum Wells**, ***G.T. Thaler***, *R.M. Frazier, J. Stapleton, C.R. Abernathy, S.J. Pearton, R.P. Rairagh, J. Kelly, A.F. Hebard,* University of Florida

Though a number of recent studies have reported room temperature ferromagnetism in GaMnN, some important questions remain including determining the minimum layer thickness needed for ferromagnetic ordering.@footnote 1,2,3@ In this paper, we report on the growth and characterization of a variety of multiple quantum well structures comprised of layers of GaMnN and AlN. XRD analysis of the layers showed sharp satellite peaks indicative of good interfacial quality. By contrast to the GaMnAs system, magnetic ordering was maintained even for structures with 5nm GaMnN layer thicknesses. The magnetic moment of the GaMnN/AlN layers was determined to be ~1.7 Bohr magnetons per Mn, much higher than the 1.1 Bohr magnetons per Mn obtained in 200nm GaMnN films grown under the same conditions. This increase is believed to be due in part to improved crystallinity brought about by the presence of the AlN and also due to strain induced by the smaller lattice constant of the AlN. The use of strained superlattices has been shown to increase the activation of the deep acceptor Mg in p-GaN and p-AlGaN.@footnote 4,5@ It is likely that a similar effect is increasing the concentration of Mn+2 relative to Mn+3, resulting in a higher moment than in the thicker films. Attempts to tailor the strain, and the magnetic properties, by varying the Al content in the buffer and barrier layers will be discussed, as will the potential for using these phenomena to make magnetic strain sensors. This work was supported by the Army Research Office under: ARO-DAAD19-01-1-0701 and by NSF under: ECS-0224203 and DMR 0101856. @FootnoteText@ @footnote 1@ G.T. Thaler, et al. Appl. Phys. Lett. 80, 3964 (2002). @footnote 2@ S. Sonada, et al. J. Cryst. Growth 237-239, 1358 (2002). @footnote 3@M.L. Reed, et al. Appl. Phys. Lett. 79, 3473 (2001). @footnote 4@ Y.-L. Li, et al. Appl. Phys. Lett. 76, 2728 (2000). @footnote 5@P. Kozodoy, et al. Appl. Phys. Lett. 74, 3681 (1999). .

9:40am **MI+SC-ThM5 Theory of Dilute Magnetic Semiconductors**, ***P. Bruno***, Max Planck Institute of Microstructure Physics, Germany **INVITED**

10:20am **MI+SC-ThM7 Materials Characterization and Magnetic Studies of Epitaxial Co@sub x@Ti@sub 1-x@O@sub 2-x@ Deposited on Si(001) by Molecular Beam Epitaxy**, ***T.C. Kaspar***[2], University of Washington*; T. Droubay,* Pacific Northwest National Laboratory*; A.C. Tuan,* University of Washington*; C.M. Wang, S.A. Chambers, J.W. Rogers, Jr.,* Pacific Northwest National Laboratory

For spintronic devices such as spin-FETs, efficient injection of spin-polarized electrons into a semiconductor material is necessary. Progress has been made using ferromagnetic metals to tunnel spin-polarized electrons into AlGaAs/GaAs quantum well structures. However, for devices compatible with current semiconductor technology, efficient spin injection into Si is desired. Diluted magnetic semiconductors (DMSs) that can be grown epitaxially on Si are prime candidates. The epitaxial growth will result in a high-quality interface, reducing depolarization caused by scattering at interfacial defects. Further, the conductivity of the DMS can be tuned by doping to match that of Si, greatly increasing the spin injection efficiency. While most known DMS materials have Curie points well below room temperature, anatase Co@sub x@Ti@sub 1-x@O@sub 2-x@ has been shown to have a Curie temperature of at least 700K when deposited on LaAlO@sub 3@(001). In addition, anatase is well lattice-matched to Si. To prevent interfacial reactions between the film and substrate resulting in SiO@sub 2@ and/or silicide formation, a buffer layer of epitaxial SrTiO@sub 3@ (STO) is first deposited. In this study, a STO buffer layer and Co@sub x@Ti@sub 1-x@O@sub 2-x@ film on Si(001) are deposited by molecular beam epitaxy (MBE), which has been shown previously to result in higher quality Co@sub x@Ti@sub 1-x@O@sub 2-x@ films than pulsed laser deposition (PLD). Magnetic films have been successfully deposited with Co in the +2 charge state. The growth mode of Co@sub x@Ti@sub 1-x@O@sub 2-x@ has been investigated to minimize the formation of Co-rich anatase particles on the film surface. Thorough materials characterization of the Si interface, the STO buffer layer, and the Co@sub x@Ti@sub 1-x@O@sub 2-x@ film will be presented, paying particular attention to the possibility of metallic Co atoms in the film. In addition, the electronic and magnetic properties of the structure will be presented.

[1] **Falicov Student Award Finalist**

[2] **Falicov Student Award Finalist**

10:40am **MI+SC-ThM8 Ferromagnetic Co-doped Anatase TiO@sub 2@: Are All Growth Methods Created Equal?**, ***T. Droubay***, *S.M. Heald,* Pacific Northwest National Laboratory*; T.C. Kaspar,* University of Washington*; C.M. Wang, S.A. Chambers,* Pacific Northwest National Laboratory

With both theoretical and experimental underpinnings, a flurry of activity has centered around new candidate diluted magnetic semiconductors (DMS) based on doping semiconducting oxides with magnetic impurities. With a Curie point of ~700K, high remanence, and high saturation, Co-doped TiO@sub 2@ in the Anatase form stands out as the most magnetically robust oxide DMS. Following the initial discovery in 2001, several groups have explored the synthesis and properties of Co-doped anatase using an array of different growth methods. While most of these techniques produced materials exhibiting room temperature ferromagnetic behavior, the resounding message learned has been to accurately determine if minority phases are present. Thin film growth of this novel oxide material has been dominated by pulsed laser deposition (PLD) and oxygen plasma-assisted molecular beam epitaxy (OPA-MBE) on SrTiO@sub 3@(001) and LaAlO@sub 3@(001). We have consistently produced epitaxial materials by OPAMBE in which the saturation moment is consistently found to be ~1.1 - 1.3 µ@sub B@/Co at room temperature. In contrast, Co@sub x@Ti@sub 1-x@O@sub 2@ grown by PLD typically has a saturation magnetization at room temperature of 0.3 µ@sub B@/Co. We will discuss the similarities and differences between materials produced by these two techniques highlighting morphological, electrical and magnetic properties. We will also discuss our recent post-growth annealing study of MBE grown specimens in which the magnetic properties do not change when the films are annealed in vacuum at 825K. This is particularly interesting in light of recent seemingly contradictory results of annealed PLD grown films. Shinde et al. report that Co metal inclusions in an Anatase film can be dissolved within the matrix and substituted for Ti as a result of a 1200K anneal in 1atm. argon. In contrast, Kim et al. found that Co came out of solution and formed Co metal as a result of a 700K anneal in 10@sup -6@ torr O@sub 2@.

11:00am **MI+SC-ThM9 Ferromagnetism in Optically Transparent Semiconducting Co Doped SnO@sub 2-d@ Films**, ***R.J. Choudhary***[1], *S.B. Ogale, S.R. Shinde,* Univ. of Maryland*; J.P. Buban,* Univ. of Illinois at Chicago*; S.E. Lofland,* Rowan Univ.*; S.N. Kale, V.N. Kulkarni, J. Higgins,* Univ. of Maryland*; C. Lanci,* Rowan Univ.*; J.R. Simpson,* Univ. of Maryland*; N.D. Browning,* Univ. of Illinois at Chicago*; S. Das Sarma, D. Drew, R.L. Greene, T. Venkatesan,* Univ. of Maryland

Thin films of Co doped SnO@sub 2-d@ grown by pulsed laser deposition on single crystal sapphire substrates are examined for their magnetic, structural, electrical, magnetotransport and optical properties. The films exhibit room temperature ferromagnetism with a Curie temperature close to 650 K. In addition, the films with 5 % of Co doping exhibit a giant magnetic moment of 7.5 ± 0.5 µ@sub B@/Co. The films are highly transparent even at 27 % of Co doping. The optical bandgap shows a redshift with Co doping. Ion channeling data show a fair degree of channeling for Sn but no channeling for Co, implying Co atoms to be structurally incoherent. However, no clustering of Co can be observed in high-resolution transmission electron microscopy even up to 27 % of Co doping. The electrical resistivity shows a rapid increase with Co doping. Possible scenarios about the microscopic state of this system and the origin of ferromagnetism will be discussed.

11:20am **MI+SC-ThM10 Elaboration and Characterisation of Cobalt Doped ZnO Thin Films for Spintronic Applications**, ***A. Anane***, *K. Rode, J.L. Maurice, J.P. Contour,* UMP CNRS-Thales and Paris XI University, France

ZnO is a large gap II-VI semiconductor potentially interesting for UV opto-electronic applications. We have investigated the structural and the magnetic properties of cobalt substituted ZnO thin films deposited on sapphire (0001) substrates by pulsed laser deposition. The films show clear ferromagnetic behavior up to 400K, the saturation moment does not exceed 1.3 ÂµB / Co atom which far away from is expected for the ionic Co2+ (3d7). We have ruled out parasitic phases as the origin of the measured magnetism by many experimental techniques, including High resolution transmission electron microscopy, X-ray edge spectroscopy and X-ray magnetic-circular-dichroism. Preliminary transport measurements on magnetic tunnel junctions based on Zn0.75Co0.25O will be presented.

11:40am **MI+SC-ThM11 Ferromagnetism in Cobalt Doped La@sub 0.5@Sr@sub 0.5@TiO@sub 3-d@ Films**, ***S.R. Shinde***, *S.B. Ogale, Y.G. Zhao, J. Higgins, R.J. Choudhary,* University of Maryland*; S.E. Lofland, C. Lanci,* Rowan University*; J.P. Buban, N.D. Browning,* University of Illinois at Chicago*; S. Das Sarma,* University of Maryland*; A.J. Millis,* Columbia University*; V.N. Kulkarni, R.L. Greene, T. Venkatesan,* University of Maryland

Epitaxial films of lightly cobalt doped La@sub 0.5@Sr@sub 0.5@TiO@sub 3-d@ are shown to exhibit ferromagnetism at room temperature. A clear hysteresis loop with coercevity ~150 Oe and the Curie temperature around 450 K are observed for these (001) oriented films grown by pulsed laser deposition at oxygen pressure of 10@super -4@ Torr on LaAlO@sub 3@ substrates. For cobalt doping up to ~2%, no inhomogeneity is observed by scanning transmission electron microscopy (S-TEM). The magnetization is found to change non-monotonically (in the range 1-3 µ@sub B@/Co) as a function of conductivity in films deposited at different partial pressures. The films range from being opaque metallic to transparent semiconducting depending on the oxygen pressure during growth and are yet ferromagnetic at and above room temperature.

Semiconductors
Room 326 - Session SC-ThM
Heteroepitaxy and Strain Engineering

Moderator: R.S. Goldman, University of Michigan

8:40am **SC-ThM2 Strain Engineering of SiGe/Si Structures**, ***P.M. Mooney***, IBM T.J. Watson Research Center **INVITED**

Heteroepitaxy allows the growth of semiconductor structures for a wide variety of device applications. When the materials are also lattice mismatched, the strain can be tailored to enhance the electronic properties of the active device layers. At the same time, however, misfit dislocations and other defects that tend to degrade device characteristics may be present. Strained Si MOSFETS are being developed for high-speed logic applications. These devices are built in a Si layer under biaxial tensile strain that is grown pseudomorphically on a so-called virtual substrate, typically a thick, strain-relaxed SiGe buffer layer on a Si(001) substrate. Key to the success of this application is the control of the misfit dislocations required to relieve the strain in the SiGe layer to achieve a low density of threading dislocations in the active device layers. Two types of SiGe/Si structures will be discussed. Strain-relaxed SiGe buffer layers produced by the implantation of He below the interface between a pseudomorphic SiGe layer and the Si(001) substrate and subsequent annealing are significantly more relaxed compared to layers of the same thickness that were not implanted. Platelet defects that are formed near the top of the Si substrate during annealing serve as dislocation nucleation sources. Elastic (defect free) strain relaxation of SiGe/Si structures is also under investigation. We have recently demonstrated that a pseudomorphic SiGe layer grown on free-standing Si relaxes elastically. The strain is shared with the free-standing Si layer resulting in Si under biaxial tensile strain.

9:20am **SC-ThM4 Strain Relaxation of Step-graded InAsP Buffers on InP Grown by Molecular Beam Epitaxy**, ***M.K. Hudait***, *Y. Lin, S.A. Ringel,* The Ohio State University

Compositionally graded metamorphic buffers grown on InP substrates to increase the substrate lattice constant are of interest to support a range of high-speed electronic and infrared optoelectronic devices based on the InGaAsP material system. Recent work by our group has shown that grading the composition of the anion sublattice using InAsP buffers as opposed to the group-III cation sublattice using In(Al,Ga)As buffers is advantageous for such applications since decoupling the growth rate (Indium flux) from the composition control (As:P flux ratio) results in superior morphological properties of relaxed layers. Here, we discuss the strain relaxation properties of step-graded InAs@sub y@P@sub 1-y@ out to a nominal composition of y = 0.4, representing a total misfit of ~ 1.2% with respect to InP. For this study, InAs@sub y@P@sub 1-y@ buffers were grown on both on-axis and 2° off-cut (001) InP substrates under identical solid source MBE growth conditions with an average grading rate of 20% As/µm. The relaxation of each layer within each buffer was measured along [1-10] and [110] directions using TAXRD to evaluate asymmetric relaxation and tilt relative to the initial substrate orientation. For both substrate types, the strain relaxation was found to be symmetric and greater than 90% for the top InAs@sub 0.4@P@sub 0.6@ layer. This indicates that @alpha@ ([1-10] direction) and @beta@ ([110] direction) slip systems have similar activation energies for dislocation nucleation. Moreover, a

[1] **Falicov Student Award Finalist**

small epilayer tilt of ~190 arcsec was observed for both substrate orientations, which indicates that tilt generated by @alpha@ and @beta@ dislocations will be in proportion to the substrate offcut resolved in [110] and [1-10] directions, respectively. The relation between these observations and properties of group-V and group-III core dislocations, and a comparison to cation based graded layers will be made to optimize the growth of these buffers.

9:40am **SC-ThM5 Effects of InAlSb Buffer Layers on the Structural and Electronic Properties of InSb Films**, ***X. Weng***, *N.G. Rudawski, R.S. Goldman,* University of Michigan*; D.L. Partin, J. Heremans,* Delphi Research and Development Center

InSb is useful for a variety of device applications, including long wavelength light sources and magnetoresistive sensors. InSb films are generally grown on GaAs substrates, with a 14.6% lattice mismatch which results in a high density of threading dislocations. In earlier work, we showed that electron scattering from the strain field associated with threading dislocations is the primary mobility-limiting mechanism in highly mismatched InSb films.@footnote 1@ The electron mobility of InSb films increases with the film thickness due to the decrease of threading dislocation density. Recently, highly mismatched resistive buffers such as InAlSb showed promise for increasing the electron mobility of thin InSb films.@footnote 2@ However, the mechanisms of buffer strain relaxation and the consequent increase in InSb electron mobility are not well understood. Thus, we have studied the effects of In@sub0.94@Al@sub0.06@Sb buffers on the structural and electronic properties of InSb films. We find a significant increase of electron mobility for InSb films grown on In@sub0.94@Al@sub0.06@Sb buffers, in comparison with those grown directly on GaAs. Cross-sectional transmission electron microscopy (TEM) reveals bending of threading dislocations at the InSb/In@sub0.94@Al@sub0.06@Sb interface, suggesting that the InSb/In@sub0.94@Al@sub0.06@Sb heterojunction plays an important role in suppressing the propagation of threading dislocations. Plan-view TEM shows a more than 50% decrease of threading dislocation densities in InSb films grown on In@sub0.94@Al@sub0.06@Sb layers compared with those grown directly on GaAs, suggesting that the electron mobility increase is likely due to the reduction in dislocation density. The effects of the buffer composition on the structure and properties of the InSb films will also be discussed. @FootnoteText@@footnote 1@ X. Weng, R.S. Goldman, D.L. Partin, and J.P. Heremans, J. Appl. Phys. 88, 6276 (2000). @footnote 2@D.L. Partin, J. Heremans, and C.M. Thrush, J. Vac. Sci. Technol. B 17, 1267 (1999).

10:00am **SC-ThM6 Heteroepitaxy of III-Se Materials: Compatibility to Si and Their Growth Studied by In-situ Scanning Probe Microscopy**, ***T. Ohta***, *A. Klust, J.A. Adams, Q. Yu, M.A. Olmstead, F.S. Ohuchi,* University of Washington

Heteroepitaxy of semiconductors on silicon is essential for expanding Si-based technology beyond standard microelectronics. Materials consisting of Group III (Ga and Al) and selenium (Se) are of particular interest, combining Si compatibility with structural versatility and optical band gaps (Eg(Ga@sub x@Se@sub y@)=1.8-2.6eV and Eg(Al@sub x@Se@sub y@)>3.1eV). We present a study of heteroepitaxy of layered GaSe on Si(111) using scanning tunneling microscopy (STM). GaSe is composed of a stack of iono-covalently bonded quad layers (QL) of Se-Ga-Ga-Se with van der Waals interactions between the layers. Of general interest for the growth of layered materials whether the full QL is required for layer nucleation. During growth, we observed: (1) formation of a pseudomorphic GaSe-bilayer, (2) development of triangular QL nuclei, followed by (3) layer-by-layer growth of GaSe layers. The first GaSe bilayer perfectly passivates the Si(111), making its surface environmentally inert. Triangular islands, one QL thick, nucleate on this passive surface with their edges aligned to of Si(111). Nuclei with two orientations, rotated by 180°, are observed, leading to orientational domains in thicker layers. We characterized their electronic structures and the type of defects incorporated in the domains. In thicker films, GaSe layers often extended over substrate atomic steps, showing a "carpet-on-steps" morphology. This work is supported by NSF Grant DMR 0102427 and the M. J. Murdock Charitable Trust. T. O. further acknowledges support by UIF Nanotechnology fellowship of the University of Washington, and A. K., the Alexander von Humboldt-Foundation, Germany.

10:20am **SC-ThM7 Characterization of High Quality GaAs(100) Films Grown on Ge(100) Substrates**, ***A. Wan***, *V.M. Menon, D. Wasserman, A. Kahn, S.R. Forrest, S.A. Lyon,* Princeton University

We have grown GaAs (100) films by MBE on off-axis Ge(100) substrates cut 6° towards the (110) plane and 6Âº towards the (111) plane. The motivation for this work is the integration of GaAs and lattice matched InGaAsN on Si and SiGe. Vicinal surfaces with regular arrays of double steps are crucial in eliminating anti-phase domains in III-V/elemental systems.@footnote 1@ We used electron diffraction, STM, AFM, X-ray and ultraviolet photoemission, electron channeling, photoluminesence (PL) and Raman spectroscopy to investigate the quality of the GaAs films. We observed two domains (1 x 2 and 2 x 1) on the surfaces of the Ge substrates both after annealing and after Ge buffer growth, on each of the off-cut orientations. GaAs films grown on Ge substrates cut towards the (110) exhibited poor morphology, with evidence of faceting and polycrystalline domains, whereas films grown on substrates cut towards the (111) exhibited much higher crystalline quality with a (4 x 2) recontruction. Low temperature PL exhibited a sharp narrow peak at 1.51 eV on samples grown on substrates cut towards (111), indicative of high quality material. We also investigated the effects of using different growth conditions including migration enhanced epitaxy, which have been reported to reduce both the APD and doping at the GaAs/Ge.@footnote 2,3@ We conclude that high quality GaAs can be grown at a variety of growth temperatures and conditions on off axis Ge(100) substrates cut 6° towards the (111). @FootnoteText@ @footnote 1@J.M. Zhou et al., Appl. Phys Lett. 68, 628 (1996) @footnote 2@R.M. Sieg et al., J. Vac. Sci. Technol. B 16, 1471 (1998) @footnote 3@J.A. Carlin et al., Appl. Phys Lett. 76, 1884 (2000).

10:40am **SC-ThM8 In Situ Monitoring of Stress Relaxation in Semiconductors**, ***E. Chason***, Brown University **INVITED**

Understanding stress relaxation in heteroepitaxial semiconductors is important if we want to be able to control surface morphology and dislocation density. Because the relaxation process is a complex interaction of many kinetic processes, it is useful to be able to monitor the evolution of the stress and surface morphology in real time. We have developed several optical diagnostics that can be used during growth without interrupting the growth process. Stress relaxation is monitored by measuring the curvature induced in the substrate by the strained film. The technique is robust and has been used in a number of processing environments including MBE, MOCVD and sputter deposition. Examples of stress relaxation due to islanding and dislocation motion will be presented. Spectroscopic light scattering is used to measure the power spectral density of the surface height distribution without having to rotate the sample or detector. This has enabled us to measure the density of strain-relieving islands in heteroepitaxial layers and to understand the effect of elastic interactions between islands on their shape and alignment.

11:20am **SC-ThM10 Strain Effects in Si-Ge Growth on Vicinal Si Surfaces Prepared by Laser Texturing**, ***F. Watanabe***, *D.G. Cahill, J.R. Serrano, S. Hong, T. Spila, J.E. Greene,* University of Illinois at Urbana-Champaign

Growth of Si-Ge strained layers on Si substrates is of great interest because of its multiplicity of growth modes. These growth modes are a complicated function of temperature, alloy content, growth rate, and substrate vicinality. Laser texturing of Si provides contamination- and defect-free curved surfaces for our studies of how the morphology depends on vicinality. The surface features produced by fluid flow in the laser melt are approximately 5 μm in diameter and 200 nm in depth, and contain vicinal surfaces with orientations 0-10 degrees off (001). SiGe layers are grown by gas-source MBE. At high strain (~80% Ge), film growth is similar to that of 100% Ge, but the formation of dislocated islands at high coverage is less pronounced. At a growth temperature of 600 °C, nucleation of dome-shaped three dimensional islands takes place preferentially on vicinal surfaces with orientations within one degree of (001). Island nucleation is suppressed on surfaces oriented more than a degree off (001). At these higher vicinalities, ripple shaped morphologies form along directions. The preferred regions for these instabilities are 5-10 degrees miscuts in the directions inside and outside the laser dimples.

Semiconductors
Room 321/322 - Session SC+MI-ThA

Ferromagnetic and Dilute Magnetic Semiconductors
Moderator: S.C. Erwin, Naval Research Laboratory

2:00pm **SC+MI-ThA1 Electronic Structure Theory of Mn-doped GaAs**, *A. Zunger,* National Renewable Energy Laboratory; ***P. Mahadevan,*** National Renewable Energy Laboratory, India **INVITED**

(1) Orientation dependent ferromagnetism: Models involving the interaction between the transition metal spin and free carriers have conventionally been used to describe ferromagnetism in dilute magnetic semiconductors. In contrast to the expectations of such a model, we find that the GGA calculated energy of the ferromagnetic state for two 3d transition metal (TM) impurities in GaAs show a strong dependence on the crystallographic orientation of the TM pairs. For Mn in GaAs, the ferromagnetic state is strongly stabilized for pairs in the direction. The stabilization is greatest along the directions for which the p-d hybridization matrix elements coupling the Mn atoms are the largest. (2) Interstitial-substitutional complexes: Examining the formation energy of Mn at various lattice sites, we find that Mn at an interstitial (Mn(i)) site could have comparable energy to Mn at a Ga site (Mn(Ga)). Under epitaxial growth conditions, the solubility of both substitutional and interstitial Mn is strongly enhanced over what is possible under bulk growth conditions. The high solubility opens the possibility of Mn atoms forming small clusters. While isolated Mn(i) are hole killers (donors), and should therefore destroy ferromagnetism, complexes such as Mn(Ga)-Mn(i)-Mn(Ga) are found to be more stable than complexes involving Mn(Ga)-Mn(Ga)-Mn(Ga). The former complexes exhibit partial or total quenching of holes, yet Mn(i) in these complexes provides a channel for a ferromagnetic arrangement of the spins on the two Mn(Ga). This suggests that ferromagnetism in Mn doped GaAs arises both from holes due to isolated Mn(Ga)as well as from strongly Coulomb stabilized Mn(Ga)-Mn(i)-Mn(Ga) clusters.

2:40pm **SC+MI-ThA3 Microscopic Valence Band Structure Near Mn and Local Magnetism in Ga@sub 1-x@Mn@sub x@As**, ***J. Tang,*** *M.E. Flatté,* University of Iowa

The microscopic spin-dependent disturbances to the valence band near Mn atoms in Ga@sub 1-x@Mn@sub x@As and the indirect Mn-Mn interaction are studied. The GaAs host is described by a multiband tight-binding Hamiltonian that incorporates spin-orbit interaction, and the Mn impurity is described by a local p-d hybridization and on-site potential. Local spin-polarized resonances within the valence band that significantly enhance the LDOS near the band edge. The quantitative enhancement we calculate is consistent with angle-resolved photoemission and interband magnetoabsorption measurements. We present the hybridization energy for two parallel Mn magnetic moments. The splitting of the acceptor level is highly anisotropic and exceeds 10 meV even if the Mn impurities are separated by as many as 20 Å. This suggests that scanning tunneling spectroscopy can probe the Mn spin orientation and measure the Mn-Mn interaction energy as a function of distance. This work was supported by the ARO MURI DAAD19-01-1-0541.

3:00pm **SC+MI-ThA4 Cross-sectional STM Study of Mn-doped GaAs***, ***J.M. Sullivan,*** Naval Research Laboratory; *G.I. Boishin,* Naval Research Laboratory and Nova Research Inc.; *S.C. Erwin, L.J. Whitman, A.T. Hanbicki, B.T. Jonker,* Naval Research Laboratory

When doped with Mn, GaAs exhibits long-range ferromagnetic order at temperatures up to ~150K. It is generally believed that ferromagnetism in GaMnAs is mediated by holes created by the substitution of Mn for Ga. Recent studies have suggested that a substantial amount of Mn is also present at interstitial sites, where Mn acts as a donor, partially compensating the holes and reducing the Curie temperature. To characterize the location and electronic configuration of Mn in device-quality Mn-doped GaAs, we have combined the complementary techniques of cross-sectional scanning tunneling microscopy (XSTM) and density functional theory (DFT). XSTM was used to atomically characterize a GaMnAs film across a single {110} cleavage plane. We used DFT to help interpret our images by theoretically simulating the XSTM image of Mn near the GaAs(110) surface. We considered Mn occurring as substitutionals, interstitials, and substitutional-interstitial complexes; a range of physically plausible charge states was considered for each. Defects in the first four layers near the surface were studied. STM filled-state images were simulated at the level of Tersoff-Hamann theory by integrating the local density of states over an energy window given by the experimental bias voltage. Thus, these complementary techniques allow us to identify Mn-related defects in the GaAs zinc-blende structure. *Supported by the US Office of Naval Research and the Defense Advanced Research Projects Agency.

3:20pm **SC+MI-ThA5 Thin Film Mn/GaAs(100) Interfacial Reactions**, ***J.L. Hilton,*** *B.D. Schultz, C.J. Palmstrom,* University of Minnesota

Although a number of ferromagnetic Mn-based compounds have been epitaxially grown on GaAs, there is a lack of detailed understanding of the interfacial interactions and their effects on spin transport. To date, no detailed Mn/GaAs interfacial reaction studies have been reported. In this study, the interfacial reactions of Mn thin films deposited in-situ on molecular beam epitaxy (MBE)-grown GaAs(100) epilayers are studied. Initial studies involved characterization of ex-situ post-growth anneals of Al(50Å)/Mn(2000Å)/GaAs(100) structures at temperatures of 200, 300, 350, 400, and 500°C for times ranging from 1-30 hours. Prior to annealing, the Mn films on GaAs appear from reflection high-energy electron diffraction and x-ray diffraction (XRD) to be polycrystalline, and Rutherford backscattering (RBS) indicates that no extensive interfacial reactions occur during growth. After annealing at temperatures higher than 200°C, XRD diffraction peaks corresponding to a tetragonal Mn@sub 2@As-like phase and a tetragonal MnGa-like phase are observed. RBS data at both normal and grazing geometries indicate significant Mn-Ga-As reactions occur during anneals in excess of 200°C with the formation of a region with Mn@sub 0.6@Ga@sub 0.2@As@sub 0.2@ composition. Higher temperature anneals result in the dissociation of this region into a MnGa-like region near the sample surface and a Mn@sub 2@As-like region near the GaAs substrate. RBS measurements of the reaction layer thickness for various annealing times at 300°C indicate the interfacial reactions are diffusion controlled. Results from RBS, XRD, and transmission electron microscopy of Al/Mn/GaAs structures will be combined with results from in-situ scanning tunneling microscopy and x-ray photoelectron spectroscopy of 0-20 monolayer Mn coverage studies to determine the nature and behavior of the reactions between Mn, Ga, and As at the metal-semiconductor interface. Supported by ONR, DARPA, and NSF.

3:40pm **SC+MI-ThA6 Cross Sectional Scanning Tunneling Microscopy Studies of Mn Segregation in Ga1-xMnxAs Films**, ***J.N. Gleason,*** *M.E. Hjelmstad, R.S. Goldman, S. Fathpour, S. Ghosh, P.K. Bhattacharya,* University of Michigan

Ga@sub 1-X@Mn@sub X@As is a promising candidate for spintronic applications compatible with conventional GaAs technologies. Theoretical studies have predicted that an increase in disorder of Mn atom positions will lead to a significant increase in the Curie Temperature.@footnote 1@ Therefore, we have investigated the effects of Mn segregation in Ga@sub 1-X@Mn@sub X@As grown by low temperature molecular beam epitaxy using ultra high vacuum cross-sectional scanning tunneling microscopy (XSTM). The heterostructures consist of 10-period superlattices of alternating Ga@sub 1-X@Mn@sub X@As (x=0.5, 2.5 and 5.0%) and Al@sub 0.20@Ga@sub 0.80@As layers, sandwiched between thick p+ GaAs layers. Constant current XSTM images reveal nanometer-sized regions with higher apparent tip height, presumably related to a local increase in the density of states associated with the presence of Mn atoms in Ga@sub 1-X@Mn@sub X@As. In the x=0.5% films, the nanometer-sized bright regions appear relatively dispersed, with ~ 5nm separation. For the x=2.5% and 5% films, agglomeration of the nanometer-sized bright regions is observed, and apparently increases with increasing Mn composition. The apparent Mn clustering does not appear to be affected by the presence of adjacent Al@sub 0.20@Ga@sub 0.80@As superlattices, indicating that any local misfit stress does not act as a sink for Mn accumulation. The apparent Mn clustering is likely due to a long-range attractive potential between Mn atoms, and may be associated with charge carrier screening, similar to earlier GaAs:Zn studies.@footnote 2@ As the Mn composition increases, the free carrier concentration increases, and the screening length decreases. This would in turn lead to a lower self-repulsion of Mn atoms, and an increase in Mn clustering. We will also discuss the effects of annealing on Mn segregation in Ga@sub 1-X@Mn@sub X@As. @FootnoteText@ @footnote 1@M.Berciu et al., Phys. Rev. Lett. 87, 107203 (2001).@footnote 2@P. Ebert et al., Phys. Rev. Lett. 83, 757 (1999).

4:00pm **SC+MI-ThA7 Manipulation of Ferromagnetism by Light in III-V-based Magnetic Alloy Semiconductors and Related Nanostructures**, ***H. Munekata,*** Tokyo Institute of Technology, Japan **INVITED**

Because of moderate carrier concentrations (10@super 15@ - 10@super 20@ cm@super -3@), semiconductors and associated hetero- and nano-

structures are suitable electronic systems to control both charges and spins by electromagnetic means. Particularly in magnetic semiconductors, manipulation of carrier spins can result in the cooperative and amplified effects through the spin exchange interaction between carrier spin s and local spin S. Those effects would open ways to develop multi-functional devices with low power consumption. One of such precursory demonstrations is the manipulation of magnetism with light in ferromagnetic III-V alloy semiconductors (In,Mn)As and (Ga,Mn)As. In this paper, we discuss the experimental results on (1) photo-generated carrier-induced ferromagnetism in p-(In,Mn)As/GaSb heterostructures, including ultrafast magnetic softening achieved in collaboration with Kono's group in Rice University, (2) collective rotation of ferromagnetically coupled Mn spins and its picosecond spin dynamics in ferromagnetic p-(Ga,Mn)As caused by the illumination with circularly polarized light without a magnetic field (optical spin injection), and (3) light-induced change in magnetic susceptibility at room temperature in GaAs-Fe composite structures, added with the demonstration of optically-controlled micro-cantilevers by Shinji's group of Tokyo Institute of Technology. Works towards room temperature ferromagnetism by other groups will also be reviewed. This work is supported in part by "Semiconductor Nanospintronics (02-)" of the Ministry of Education, Culture, Sports, Science and Technology, Japan.

4:40pm **SC+MI-ThA9 Growth of (Ga,Mn)N: a Diluted Magnetic Semiconductor by Chemical Beam Epitaxy (CBE)***, **A. Carreno**, C. Boney, A. Bensaoula,* The University of Houston

The GaN material system is a very promising candidate for the realization of electronic devices based on dilute magnetic semiconductor (DMS) films. The incentive behind DMS materials is the potential to form high-density magnetic memory integrated ICs, semiconductor-based magnetic sensors, magneto-optical devices for communications systems, and other spin-based and photonic-based applications. Many reports have indicated that high doping levels of Mn in GaN lead to ferromagnetic materials with Curie temperatures at or above room temperature. To date (Ga,Mn)N has been fabricated by several epitaxial and non-epitaxial techniques. However, to our knowledge, we are the first to report the epitaxial growth of (Ga,Mn)N by CBE. (Ga,Mn)N has been grown on sapphire substrates using TEG, NH3, and solid Mn as precursors. Very smooth GaMnN films exhibiting bright 2D RHEED patterns have been obtained with Mn concentrations between 0.5-2.0% as determined by EPMA and XPS. XPS depth profiling verifies that the Mn is of uniform concentration throughout the films. In addition to RHEED, the CBE chamber employs two Time of Flight Ion Scattering Spectroscopy techniques, Direct Recoil Spectroscopy (DRS) and Mass Spectroscopy of Recoiled Ions (MSRI). These TOF techniques are used as an in-situ, real time analytical process which allows the surface composition information of film components and impurities to be determined as well as analyzing the structural characteristics based on changes in the relative signal levels with azimuthal rotation of the sample. In these ways DRS/MSRI has been used to detect the incorporation of Mn into the GaN matrix during film growth and from azimuthal data extract the surface periodicity which allows construction of surface structure models for GaN and (Ga,Mn)N surfaces. In addition to available Raman and photoluminescence data, characterization of magnetic properties of the (Ga,Mn)N films is currently under way and will be reported.

Magnetic Interfaces and Nanostructures
Room 316 - Session MI+SC-FrM

Semiconductor Spin Injection
Moderator: S.A. Chambers, Pacific Northwest National Laboratory

8:20am **MI+SC-FrM1 Ferromagnetic Nano Fe-Germenide Particles in MBE-grown Ge-Fe**, ***R. Goswami***, Geo-Centers Inc.*; G. Kioseoglou, A.T. Hanbicki, B.T. Jonker, G. Spanos,* Naval Research Laboratory

Ferromagnetic-semiconductors (FMSs) have attracted considerable attention due to the coexistence of semiconductor properties and long-range ferromagnetic (FM) order in these materials. Recently, ferromagnetic order was reported in alloy thin films based on Ge, which provides a simple host lattice to explore the fundamental origins of FM order. A relatively high Curie temperature,120 K, has been experimentally observed in a Ge-3.3at.% Mn film grown epitaxially on GaAs. It has been theoretically predicted very recently that Ge with Fe atoms in the lattice will be ferromagnetic semiconductors and the Curie temperature will increase as a function of Fe concentration. To date, relatively little attention has been paid to understanding the fine scale microstructural evolution within Ge-Fe thin films. It is well known that the microstructure plays a vital role in dictating the ferromagnetic properties. Fe-Ge contains different phases with magnetic properties ranging from ferromagnetic Fe to antiferromagnetic FeGe@sub2@. The purpose of the present investigation is to elucidate the phase transformations and overall microstructural evolution in epitaxial Ge- 4at.% Fe thin films deposited on (100) GaAs substrates at three different temperatures, 150°, 250° 400 ° C, in order to better understand magnetic properties in these materials. The equilibrium phases at this composition (4%Fe) are Ge with negligible amount of Fe and antiferromagnetic FeGe@sub2@. We have observed for all cases that nano-particles of ferromagnetic- Fe@sub3@ Ge@sub2@ form uniformly in a crystalline Ge-matrix. The particle size was observed to decrease with the substrate temperature. We demonstrate that a supersaturated Ge-Fe solid-solution forms initially from the vapor phase resulting in the solid state precipitation of this metastable ferromagnetic- germanide. This work was supported by the Office of Naval Research and DARPA.

8:40am **MI+SC-FrM2 Epitaxial Ferromagnet on Ge(111)**, ***C. Zeng***, The University of Tennessee*; J.R. Thompson,* The University of Tennessee and Oak Ridge National Laboratory*; L.C. Feldman,* Vanderbilt University and Oak Ridge National Laboratory*; S.C. Erwin,* Naval Research Laboratory*; H.H. Weitering,* The University of Tennessee and Oak Ridge National Laboratory

The difficulty of injecting spin-polarized electrons into a semiconductor is a major bottleneck in spintronics research. There are two ways to realize spin injection. One of these is to fabricate a ferromagnetic-metal/semiconductor heterostructure; the other is to use a dilute magnetic semiconductor (DMS) as the spin aligner. The former method does not work well, mainly because of the large conductivity mismatch between the ferromagnetic metal and semiconductor. The latter method is limited by the low Curie temperature, T@sub c@ of DMS. We have developed a novel interface with good potential for spin injection, namely an epitaxial ferromagnetic Mn@sub 5@Ge@sub 3@ film on Ge(111). The Mn@sub 5@Ge@sub 3@ films are fabricated by depositing Mn and subsequent annealing, or by codeposition of Mn and Ge. Mn@sub 5@Ge@sub 3@(001)//Ge(111) epitaxy relationship is verified by X-ray diffraction results, due to the small lattice mismatch. STM images display (@sr@3x@sr@3)R30° honeycomb structure, which perfectly agrees with the theoretical image of the Mn terminated Mn@sub 5@Ge@sub 3@ (001) surface. RBS and ion-channeling experiments confirmed the stoichiometry and epitaxy of the film. Magnetic measurements reveal a T@sub c@ of about 295 K. The easy axis is in-plane which is most likely due to the shape anisotropy. The multiplet splitting of the Mn 3s core level in XPS indicates an average magnetic moment of 2.6 μ@sub B@ per Mn atom, which is in almost perfect agreement with the spin-resolved band structure calculations and SQUID measurements. This research was sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.

9:00am **MI+SC-FrM3 Tunnel Spin Injection from a Ferromagnetic Metal into a Semiconductor Heterostructure**, ***A.T. Hanbicki***, *O.M.J. van 't Erve, R. Magno, G. Kioseoglou, C.H. Li, R.M. Stroud, B.T. Jonker,* Naval Research Laboratory*; G. Itskos, R. Mallory, M. Yasar, A. Petrou,* SUNY at Buffalo

INVITED

Significant effort has been made to incorporate ferromagnetic metals into semiconductor spintronic devices because they offer high Curie temperatures, low coercive fields, and a ready source of spin polarized electrons. Recently it has been shown that the key to efficient spin injection from a metal into a semiconductor heterostructure is a sufficient interface resistance.@footnote 1@ Tunnel barriers have been a common way of satisfying this criterion, and there are a number of recent experimental successes with Schottky contacts, thin metal oxides, and AlAs. We will review the state of the art of spin injection from an Fe Schottky contact into an AlGaAs/GaAs spin-LED. A Schottky barrier at the Fe/AlGaAs interface can serve as an effective tunnel contact if the doping profile of the semiconductor near the interface is engineered to produce a narrow depletion width. In this system, we have successfully injected polarized electrons and obtained electron spin polarizations ranging from 13% to 32% in the GaAs QW,@footnote 2@ where quantum selection rules directly link the measured circular polarization and the electron spin population. We report here recent efforts to characterize transport properties and the physical structure of this interface, and correlate them with the measured spin polarizations. To determine the dominant transport mechanism, we have analyzed the transport process using the Rowell criteria. The parabolic G-V curves and the temperature dependence of the zero-bias resistance demonstrate that single step tunneling is the dominant transport mechanism. The I-V data show a clear zero-bias anomaly and phonon signatures providing further evidence for tunneling. Preliminary data suggest that roughness and Fe segregation at the spin injecting interface suppresses spin injection. @FootnoteText@ This work was supported by the DARPA SpinS program and ONR@footnote 1@E.I. Rashba, PRB 62 (2000)@footnote 2@A.T. Hanbicki, et al., APL 80 (2002); APL 82 (2003).

9:40am **MI+SC-FrM5 Spin Injection Across (110) Interfaces: Fe/GaAs(110) Quantum Well Spin-LEDs**, ***C.H. Li***, *A.T. Hanbicki, G. Kioseoglou, O.M.J. van 't Erve, B.T. Jonker,* Naval Research Laboratory*; G. Itskos, R. Mallory, M. Yasar, A. Petrou,* SUNY Buffalo

Spin-LEDs can be used to reliably measure spin injection efficiency via the quantum selection rules subject to the limits imposed by the ratio of spin to radiative lifetimes. However, to date they have been implemented only in (001) oriented GaAs or InGaAs quantum wells (QWs), where the spin lifetime is shorter, resulting in an underestimate of spin injection efficiency. Recent work has shown that the spin lifetime is longer in (110) GaAs QWs, and increases with temperature.@footnote 1@ In this study we investigate spin injection in (110) oriented spin-LED QW structures to take advantage of this, and to explore the effects of band structure and the non-polar interface on spin injection. AlGaAs/GaAs LEDs have been grown on (110) substrates by molecular beam epitaxy at 450 oC and an As/Ga flux ratio of 20. Atomic force microscopy shows excellent surface morphology with a RMS roughness less than 0.5 nm. Photoluminescence is dominated by the QW excitonic emission with a linewidth of 8 meV. Initial electroluminescence results using a tailored Fe Schottky tunnel barrier injector show that a 10% spin polarization in the GaAs QW has been achieved due to injection across the Fe/AlGaAs(110) interface. The temperature dependence of the polarization, as well as comparison with (001) oriented samples and first principles theory will be presented. @FootnoteText@ Supported by DARPA, ONR, and NSF. @FootnoteText@@footnote 1@Y. Ohno et. al., PRL 83, 4196 (1999).

10:00am **MI+SC-FrM6 Electrical Spin Injection from Ferromagnetic Metal/Tunnel Barrier Injectors into AlGaAs/GaAs Quantum Well Structures**, ***X. Jiang***, Stanford University*; R. Shelby,* IBM Almaden Research Center*; R. Wang,* Stanford University*; R. Macfarlane,* IBM Almaden Research Center*; G. Solomon, J. Harris,* Stanford University*; S. Parkin,* IBM Almaden Research Center

Electrical injection of highly spin-polarized electrons into semiconductors is an essential component for the operation of spintronic devices. In this talk, we present a study of electrical spin injection into semiconductors from injectors comprised of ferromagnetic metals and tunnel barriers. An AlGaAs/GaAs quantum well structure is used to optically detect the spin-polarization of the injected electrons in the semiconductor. Large polarization of the electroluminescence from the quantum well is observed. The bias dependence and temperature dependence of the

electroluminescence polarization will be discussed. This work is supported by DARPA.

10:20am **MI+SC-FrM7 Efficient Electrical Spin Injection in GaAs: A Comparison Between Different Spin Sources**, ***P. Van Dorpe***, *V.F. Motsnyi, Z. Liu, W. Van Roy, G. Borghs, J. De Boeck,* IMEC, Belgium **INVITED**

Electrical spin injection in semiconductors remained elusive for a long time. Recently however, break-throughs have been accomplished in the field. It appeared that tunnel injection of spin polarized electrons from ferromagnetic metals provides an efficient way for spin injection, even at room temperature. We will quantitatively compare different spin sources for spin injection in GaAs, based on tunnel injection from ferromagnetic materials. The injected spin polarization is assessed in a (Al,Ga)As-based spin-LED, using the Oblique Hanle Effect@footnote 1@ as the analysis technique. The first material combination that we successfully applied for spin injection is a CoFe/AlOx based tunnel injector where the AlOx provides a stable tunnel barrier between the ferromagnetic material and the GaAs. We have shown injected spin polarizations which exceed 24% at 80K and 12% at room temperature.@footnote 2@ A second spin source we examined uses the native Schottky barrier between GaAs and an epitaxially grown ferromagnetic metal as tunnel barrier. NiMnSb, MnAs and MnSb have been used and will be compared for their spin injection properties. Finally the results of electron spin injection from a (Ga,Mn)As-based Zener diode will be discussed. The spin polarized holes in (Ga,Mn)As are transferred to electrons in GaAs by Zener tunnelling and create a spin polarization in GaAs of at least 50% at LHe temperature. The results on electrical spin injection regularly show an interesting dependence on the applied bias. This dependence will be shown and discussed in terms of doping and band structure. @FootnoteText@@footnote 1@V.F. Motsnyi et al, Appl. Phys. Lett. 81, 265 (2002) @footnote 2@P. Van Dorpe et al, Jpn. J. Appl. Phys., Part 2 42, L502 (2003) Acknowledgements : SPINOSA (IST-2001-33334), FENIKS(GR5D-CT-2001-00535).

11:00am **MI+SC-FrM9 Electrical Spin Injection from a Ferromagnetic Metal Into a Semiconductor: Schottky vs Al@sub 2@O@sub 3@ Tunnel Barriers**, ***O.M.J. van 't Erve***, *A.T. Hanbicki, C.H. Li, G. Kioseoglou, B.T. Jonker,* Naval Research Laboratory*; G. Itskos, R. Mallory, M. Yasar, A. Petrou,* SUNY Buffalo

Efficient injection of spin-polarized electrons from a metal into a semiconductor requires a high resistance interface contact such as a tunnel barrier.@footnote 1@ The natural Schottky tunnel barrier which forms at the Fe/AlGaAs interface provides highly efficient spin injection, and a polarization of more than 32% has been measured in a GaAs quantum well detector.@footnote 2@ The pseudo-triangular shape and high interface doping level of the Schottky tunnel contact are factors which are quite different from those encountered for the canonical rectangular barrier typically formed from Al@sub 2@O@sub 3@. It is therefore of interest to compare the characteristics and performance of an Al@sub 2@O@sub 3@ tunnel barrier with the Fe/AlGaAs Schottky barrier in essentially identical MBE-grown device structures. The Al@sub 2@O@sub 3@ barrier is formed on top of an AlGaAs/GaAs spin-polarized light-emitting diode (spin-LED) by multi-step in situ natural oxidation of thin evaporated Al layers. A ferromagnetic metal layer is evaporated on top of this tunnel barrier and provides the spin-polarization of the injected electrons. We measure the spectral features, intensities and polarization of the electroluminescence from the surface emitting spin-LEDs, and compare these directly with similar data for the Fe Schottky contact and with literature to obtain insight into various aspects of the spin injection process. @FootnoteText@ This work was supported by the DARPA SpinS program, ONR, and NSF. @footnote 1@ E. I. Rashba, Phys. Rev. B 62, R16267 (2000).@footnote 2@ A.T. Hanbicki et al, Appl. Phys. Lett. 82 (9 June 2003).

11:20am **MI+SC-FrM10 Electrical Spin Injection from CdCr@sub 2@Se@sub 4@ into AlGaAs/GaAs Spin-LED**, ***G. Kioseoglou***, *A.T. Hanbicki, C.H. Li, O.M.J. van 't Erve, R. Goswami, G. Spanos, B.T. Jonker,* Naval Research Laboratory*; R. Mallory, M. Yasar, G. Itskos, A. Petrou,* SUNY at Buffalo

Ferromagnetic semiconductors (FMS) provide an opportunity to control spin dependent behavior and study spin injection and transport in semiconductor heterostructures. Much of the effort has focused on III-Mn-V p-type FMS, where the ferromagnetism is mediated by holes. Since electron transport is the basis for high frequency and low power operation, an n-type FMS grown epitaxially on a device quality substrate is especially attractive. Recent work demonstrated epitaxial growth of n-type CdCr@sub 2@Se@sub 4@, a chalcogenide spinel FMS, on GaAs(001) and GaP(001).@footnote 1@ The measured conduction band offsets indicate a staggered band alignment conducive to electron transport from the CdCr@sub 2@Se@sub 4@ into the AlGaAs.@footnote 2@ We present here spin polarized electron injection from CdCr@sub 2@Se@sub 4@ into an AlGaAs/GaAs LED structure. The circular polarization due to spin injection from the CdCr@sub 2@Se@sub 4@ reaches a maximum value of 6% at B = 0.5T, and mimics the hard axis magnetization determined by SQUID magnetometry measurements. In contrast to previously studied ZnMnSe and Fe contacts in which injection of predominantly m@sub j@ = -1/2 electrons was observed, for CdCr@sub 2@Se@sub 4@ the majority of the injected electrons are in the m@sub j@ = +1/2 state. TEM reveals that the existing interfaces are highly defected, a factor known to limit spin injection.@footnote 3@ Efforts to increase the spin injection efficiency are focused on improving the interface, the contact resistance and electrical properties of CdCr@sub 2@Se@sub 4@. Ga, an n-type dopant in CdCr@sub 2@Se@sub 4@, was introduced in a @delta@-doping configuration, and results on new LED structures with improved electrical characteristics and interface morphology will be presented. @FootnoteText@ This work was supported by DARPA SpinS program, ONR, and NSF. @footnote 1@Y.D. Park et al., Appl. Phys. Lett. 81, 1471 (2002). @footnote 2@H.B. Zhao et al, Appl. Phys. Lett. 82, 1422 (2003). @footnote 3@R. Stroud et al, Phys. Rev. Lett. 89, 166602 (2002).

11:40am **MI+SC-FrM11 Chemical Intermixing and Spin Injection in Fe/AlGaAs Schottky Barrier SpinLEDs**, ***R.M. Stroud***, *A.T. Hanbicki, G. Kioseoglou, O.M.J. van Erve, C.H. Li, B.T. Jonker,* Naval Research Laboratory*; G. Itskos, R. Mallory, M. Yasar, A. Petrou,* SUNY Buffalo

Injected spin polarizations ranging from 13% to 32% have been measured for Fe/AlGaAs Schottky barrier spin-polarized light emitting diodes spinLEDs.@footnote 1@ Transmission electron microscopy studies of these devices show evidence for diffusion of the Fe into the underlying AlGaAs. High-resolution images indicate an expansion of the AlGaAs (100) plane spacing near the interface by up to 15% and a change in contrast. The Fe diffusion is confirmed by energy-dispersive x-ray spectroscopy and Z-contrast imaging. The thickness of the intermixing region estimated from lattice images inversely correlates with the injected spin polarization, ranging from 0.8 nm +/- 0.3 nm for the 32% spin polarization sample up to 1.6 nm +/- 0.3 nm for the 13% spin polarization sample. Spin scattering in this intermixing region may explain the reduction in the injected spin polarization. This work was supported by ONR and the DARPA SpinS program. @FootnoteText@ @footnote 1@Hanbicki, et al., APL 80 (7): 1240-1242 (2002).

Semiconductors
Room 321/322 - Session SC+NS-FrM

Low Dimensional Structures and Amorphous Silicon

Moderator: A.C. Gossard, University of California, Santa Barbara

8:20am **SC+NS-FrM1 Self-Organized Template Formation for Quantum Dot Ordering**, ***R. Noetzel***, Eindhoven University of Technology, The Netherlands **INVITED**

The realization of semiconductor quantum dot arrays and networks in well-defined lateral arrangements is essential for the development of future quantum functional devices. We have successfully created these kinds of networks by self-organized anisotropic strain engineering of (In,Ga)As/GaAs templates for the ordering of InAs quantum dots by local strain recognition: On GaAs (100) substrates, during molecular beam epitaxy of a strained (In,Ga)As/GaAs superlattice, elongated (In,Ga)As quantum dots develop into very uniform and long quantum wire arrays with a well-defined lateral periodicity. Quantum wire formation relies on the anisotropic adatom surface migration and In desorption during annealing of the layers of elongated quantum dots after capping with a thin GaAs layer. The accumulation and improvement of the uniformity of the generated anisotropic strain field in superlattice growth provides a well-defined template for the ordering of InAs quantum dots grown on top in one-dimensional arrays. On high-index GaAs (311)B substrates, strain induced growth instability of (In,Ga)As layers occurs to from a matrix of closely packed cells. The related strain distribution constitutes a uniform template for the full control of InAs quantum dot nucleation in a two-dimensionally connected network. Excellent structural perfection and optical properties are established for these ordered InAs quantum dot arrays by atomic force microscopy, high-resolution X-ray diffraction, and photoluminescence spectroscopy. Temperature dependent photoluminescence measurements reveal efficient carrier transfer from the templates, which themselves are distinct one- and zero-dimensional

quantum nanostructure arrays, to the quantum dots and within the quantum dot arrays. Hence, self-organized anisotropic strain engineering provides a unique route for the realization of well-defined and functional quantum dot arrays and networks of high quality.

9:00am **SC+NS-FrM3 Self-Assembly of Nanostructures in GaAs/InAs and GaAs/GaSb Multilayer Structures**, ***C.A. Pearson***, *C. Dorin, J. Mirecki Millunchick, Y. Chen, B.G. Orr,* University of Michigan, Flint

Reproducibly obtaining regular arrays of phase-separated material is a promising way to acquire low dimensional structures such as quantum dots or wires. Short period superlattice (SPS) structures, where each layer is approximately one or two monolayers thick, can spontaneously phase separate under certain growth conditions resulting in compositional modulations. The appearance of lateral composition modulation is correlated to roughening of the surface front. To further elucidate this progression, in situ scanning tunneling microscopy (STM) was used to examine SPS structures at integral and fractional periods, where one period consists of 2 monolayers (ML) of GaAs followed by 2 ML of InAs or GaSb. For both integral and fractional periods, the surfaces are quite distinct. The as-grown InAs surface is decorated with anisotropic islands that exhibit a (2x4) reconstruction upon a terrace with a (nx3) reconstruction. The GaAs terminated surfaces are characterized by flat mesa structures surrounded by deep trenches. With increasing number of periods, both surfaces evolved towards greater long scale roughness. Furthermore, the islands (InAs terminated) or trenches (GaAs terminated) become larger and show a preferential lateral arrangement with a characteristic separation in the [110] direction of ~20 nm, which corresponds to the modulation wavelength observed using other techniques. Similar results are also observed in the GaAs/GaSb structure where islanding of GaAs is observed in a GaSb matrix. These results are consistent with continuum perturbation models that predict the coupling of morphological and compositional instabilities under the appropriate circumstances.

9:20am **SC+NS-FrM4 Tuning of the Electronic Properties of Self-assembled InAs/InP(001) Quantum Dots by Rapid Thermal Annealing and Low-energy Ion Implantation**, ***C. Dion***, École Polytechnique de Montréal, Canada*; C. Nì Allen, S. Raymond, P.J. Poole,* National Research Council, Canada*; F. Schiettekatte,* Université de Montréal, Canada*; R.A. Masut, P. Desjardins,* École Polytechnique de Montréal, Canada

We have investigated the effect of post-growth rapid thermal annealing on the low temperature photoluminescence (PL) spectra of self-assembled InAs/InP(001) quantum dots (QD) grown by chemical beam epitaxy (CBE) and metal-organic vapor phase epitaxy (MOVPE). Annealing temperatures T@sub a@ and times t@sub a@ ranged from 650 to 800 °C and 30 to 210 s, respectively. As-grown samples are characterized by a broad emission peak centered near 800-900 meV arising from the e1-hh1 transition of an ensemble of QDs and a narrow peak near 1100 meV from radiative recombination in the wetting layer. Detailed analysis of the QD PL emission reveals that it is composed of up to 9 peaks corresponding to families of dots emitting at different energies. A blueshift of the QD transitions, resulting from intermixing, is observed upon annealing. It increases with T@sub a@ and t@sub a@; blueshifts of up to 90-100 meV are obtained for annealing time of 210s at 800 °C. While the PL emission energies of the various QD families shift at different rates upon annealing, their width remains constant. This behavior is consistent with inhomogeneous broadening dominated by monolayer height fluctuations in InAs/InP(001) dots. In order to obtain larger blueshifts, we studied the effect of introducing point defects into thick InP cap layers, either by growing InP at low temperature or by implanting P at energies sufficiently low to insure that the InAs QDs are not damaged. Such point defects, located far from the QDs, dramatically increase diffusion rates; shifts of up to 250 meV have been obtained following annealing at 765 °C for 90 s.

9:40am **SC+NS-FrM5 Anisotropic Stress Relaxation and Ordering of InAs/GaAs Quantum Dot Superlattices**, ***W. Ye***, *M. Reason, X. Weng, R.S. Goldman,* The University of Michigan

Recently, self-assembled quantum dot (QD) superlattices (SLs) have shown significant promise for a wide range of electronic and optoelectronic device applications. In general, self-assembled QD formation is driven by the elastic relaxation of stress via island nucleation. The vertical stacking of QDs is often explained by the preferred nucleation of islands at strain energy minima directly above buried dots. However, the mechanisms of lateral ordering of QD arrays are the subject of continued debate. For example, anisotropic lateral alignment of QDs has been observed in a number of materials systems. A significant remaining question concerns the relative effects of buffer layer patterning and anisotropic stress relaxation on this lateral QD alignment. Therefore, we have examined the patterning effects of buffer layers, as well as the stress relaxation process during the growth of stacked QDs. Our QD SLs consisted of 2.6 ML InAs and 5 nm GaAs grown by molecular beam epitaxy at 500°C. Prior to QD deposition, GaAs buffer layers were grown at 580°C and/or 500°C. During QD growth, reflection high energy electron diffraction (RHEED) reveals a streaky to spotty pattern transformation, typical of the Stranski-Krastanov (S-K) growth mode transition. However, simultaneous wafer curvature measurements using multi-beam optical stress sensor (MOSS) reveal that stress relaxation occurs after the S-K growth mode transition is complete. Ex-situ atomic force microscopy measurements indicate a preferential alignment of QDs along the [-110] direction. This anisotropic alignment is enhanced as the number of SL periods increases and may be due to pre-patterning by the 500°C buffer layer. We will discuss the relative roles of buffer layer patterning and anisotropic stress relaxation on QD ordering. This work was supported in part by DOE (Photovoltaics Beyond the Horizon Program), ARO (MURI Program), and NSF (Nanoscale Exploratory Research Program).

10:00am **SC+NS-FrM6 Ge Island Nucleation on Large-Miscut Si(001) Surfaces**, ***K. Ohmori***, *Y.L. Foo, S. Hong, J.G. Wen, J.E. Greene, I. Petrov,* University of Illinois at Urbana-Champaign

We study self-organized growth of Ge nanostructures on Si surfaces with large off-[001]-axis miscut as a function of the tilt angle @theta@ and in-plane azimuth angle @phi@ with respect to the [100] direction. The off-axis surfaces were fabricated using focused ion beam (FIB) to precisely pattern a variety of structures such as trenches, concave cones, and square-pyramids on Si(001) surfaces. During the FIB processing, the Si(001) substrates were covered with 200-nm-thick protective SiO@sub 2@ films. A 50-nm-thick Si buffer layer was grown at 800°C by ultrahigh vacuum gas-source molecular beam epitaxy using Si@sub 2@H@sub 6@ precursor prior to Ge deposition at 600°C using Ge@sub 2@H@sub 6@. The nominal thickness of the Ge layer is about 7 ML. Diverse Stranski-Krastanov growth modes (Ge domes, elongated islands, and nanowires) were observed as a function of @theta@ and @phi@, which we attribute to differences in anisotropic-strain relief mechanism. While on a vicinal (001) surface (@theta@ = 0.3°), dome-shaped Ge islands with a density of 30.9 µm@super -2@ are formed, the island density increases by 30% on a surface with @theta@ = 5° for all @phi@-values . In the range of @theta@ = 10 to 20°, elongated island shapes emerge in directions near @phi@ = 45 n° (n = 1, 3, 5, 7), while at @phi@ = 90 n° (n = 0, 1, 2, 3) island nucleation is suppressed. With @theta@ @>=@ 25°, Ge nanowires with a length of about 2 µm are formed on planes with @phi@ = 45 n° ± 15° (n = 1, 3, 5, 7).

10:20am **SC+NS-FrM7 Bond-Centered Hydrogen in Amorphous Silicon: New Infrared Studies**, ***J.-F.T. Wang***, Vanderbilt University*; G. Lüpke,* The College of William and Mary*; L.C. Feldman, N.H. Tolk,* Vanderbilt University

Recent infrared absorption spectroscopy measurements taken at 77 K on initially hydrogen free amorphous silicon following hydrogen implantation at low temperature, exhibit an absorption line associated with the bond-centered (BC) hydrogen local vibration stretching mode at 1993 cm-1. This line, newly observed in amorphous silicon, appears at the same wavelength seen in crystal silicon following hydrogen implantation at LN temperatures.@footnote 1,2@ These results indicate that the bond-center (BC) hydrogen defect structure can form in amorphous silicon as well. The experimental data give insight into recent molecular dynamic simulations involving hydrogen's role in the amorphous-to-nanocrystalline phase transition in amorphous silicon.@footnote 3@ In both the crystalline and amorphous case, the 1993 cm-1 line disappears when the samples are annealed to room temperature. However only in the crystalline silicon case does the migrating hydrogen reappear in other IR-active defect sites.@footnote 1,2@ @FootnoteText@ @footnote 1@M. Budde, G. Lüpke, C. Parks Cheney, N. H. Tolk, and L. C. Feldman, Phys. Rev. Lett. 85, 1452 (2000). @footnote 2@B. Holm, K. Bone Nielsen, and B. Bech Nielsen, Phys. Rev. Lett. 66, 2360 (1991). @footnote 3@Saravanapriyan Sriraman, Sumit Agarwal, Eray S. Aydil & Dimitrios Maroudas, Nature (London) 418, 62 (2002).

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