Monday Morning, November 3, 2003

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.

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