Semiconductors
Room 306 - Session SC+EL-FrM
III-Nitride Processing and Devices

Moderator: D.D. Koleske, Naval Research Laboratory

8:20am **SC+EL-FrM1 Process Development For Small-Area GaN/AlGaN HBTs**, ***K.P. Lee***, *G. Dang, A.P. Zhang, F. Ren,* University of Florida*; J. Han,* Sandia National Laboratories*; W.S. Hobson,* Lucent Technologies, Bell Laboratories*; C.R. Abernathy, S.J. Pearton,* University of Florida*; J.W. Lee,* Plasma Therm

A self-aligned fabrication process for small emitter contact area (2x4 µm@super 2@) GaN/AlGaN heterojunction bipolar transistor is descried. The process features dielectric-spacer sidewalls, low damage dry etching and selected-area regrowth of GaAs(C) on the base contact. The junction I-V characteristics were evaluated at various stages of the process sequence and provided an excellent diagnostic for monitoring the effect of plasma processes such as CVD or etching. A comparison will be given with large emitter-area (2.5x10@super 4@ µm@super 2@) devices fabricated on the same material. The small-area devices are alternative for microwave power switching applications.

8:40am **SC+EL-FrM2 Morphology on HDP-Etched III-Nitride Materials**, *T.-N. Kuo, J.-H. Yeh, H.-J. Lee, C.-A. Chen,* ***D.G.-K. Jeng***, Nano-Architect Research Corporation, Taiwan

Needle-shaped morphology or highly textured surface was often observed after GaN/GaInN multiple layered structures have been etched in high-density plasma; this phenomenon was not so often observed in structures containing GaN alone. It is attributed to layers containing indium under certain chemical environments. An experimental procedure was carried out for the characterization of materials etching. It turned out that the needle-shaped morphology or textured surface was possibly the consequence of a micro-masking effect due to low-vapor pressure compound formed on the etched surface, which prohibits underneath layers from being etched. The experiments were conducted in a high-density plasma equipment with a novel plasma source designed exclusively by the authoring group. This equipment has the capability for a typical etch-rate of 7000-8000 Å/min for all types of III-nitride compound materials and structures with good surface morphology.

9:00am **SC+EL-FrM3 Effects of Etch Processing on Contacts to n-GaN**, ***R. Singh***, *C.R. Eddy, Jr.,* Boston University*; H.M. Ng,* Lucent Technologies*; T.D. Moustakas,* Boston University

We report studies on the effects of high density plasma etching on the properties of ohmic contacts to n-GaN. Samples deposited by plasma-assisted MBE on a-plane sapphire and doped with Si are used in this study. Inductively coupled high density chlorine plasmas are applied to etch the surfaces of GaN and subsequent contacts (Ti/Al) to these etched surfaces are evaluated. We identify degradation of contact ohmicity even for very low rf bias powers (ion energies) as a function of the doping level in the GaN film. For films of high doping levels (3x10@super 18@ cm@super -3@), as might be encountered in a laser or LED structure, the degree of contact degradation, compared to the control sample, is a modest factor of 2 (4x10@super -4@ @ohm@cm@super -2@ to 1x10@super -3@ @ohm@cm@super -2@). However, for lower doping level films (10@super 17@ cm@super -3@), as might be encountered in electronic devices, the specific contact resistance is higher by almost two orders of magnitude for the same treatment (5x10@super -3@ @ohm@cm@super -2@ to 2x10@super -1@ @ohm@cm@super -2@). These as-deposited contacts are then rapid thermal annealed (700°C) in a nitrogen atmosphere, where specific contact resistance is monitored as a function of annealing time. Although there is improvement in contact resistivity, the effect of plasma exposure is still evident even at a cumulative rapid thermal annealing time of 280 seconds. We show that even modest ion energies in highly reactive chemistries can lead to contact degradation and that care must be taken in applying such processes if highly efficient power devices are to be routinely realized. In an effort to identify the cause of the degradation, we will also report SEM, AFM and surface sensitive photoluminescence measurements of the as etched surfaces. We will also discuss in-situ and ex-situ efforts to eliminate such degradation.

9:20am **SC+EL-FrM4 Growth of Ga(In)NAs/GaAs Alloys by Plasma-Assisted Molecular Beam Epitaxy**, ***A.L. Holmes, Jr.***, University of Texas at Austin **INVITED**

In recent years, the addition of nitrogen into GaInAs, created via energetic nitrogen species from a RF-plasma or decomposition of hydrazine-based precursors,has attracted a great deal of interest due to the large negative bowing parameter of the resultant semiconductor alloy. As a result, GaNAs/GaAs and GaInNAs/GaAs heterostructures can be grown which emit light at wavelengths applicable for lasers and detectors for fiber-optic communications or absorb wavelengths which make solar cells more efficient. While nitrogen leads to a significant reduction in the band gap of the resultant material, the addition of nitrogen (on the order of a few atomic percent) also leads to a significant reduction in luminescence intensity which has significant consequences for optoelectronic devices. In this talk, growth of the GaInNAs/GaAs alloy system will be discussed. The effects of important growth-related parameters such as growth temperature, RF plasma conditions, indium composition, and arsenic over-pressure will be described. The resultant materials are characterized by x-ray diffraction, photoluminescence, and SIMS to create a picture of how nitrogen is incorporated and how this incorporation affects the resultant material properties. These properties are then compared to GaNAs-based photodetectors which show outstanding device performance with nitrogen concentrations as high as 2.5%.

10:00am **SC+EL-FrM6 Field Electron Emission and Surface Properties of as-grown and Modified AlGaN Films**, *A. Bensaoula, I. Berishev, E. Kim,* University of Houston*; M. Ugarov, V. Ageev, E. Loubnin, A. Karabutov,* General Physics Institute, Russia*;* ***A. Tempez***, University of Houston

The correlation between surface morphology and composition, Si substrate orientation and field emission properties of Al@sub x@Ga@sub1-x@N and GaN/AlN films was investigated. It was demonstrated that a high Ga surface density provides thin films with better field electron emission characteristics such as a higher emission current and lower voltage threshold. It was found that a proper choice of the substrate orientation is crucial to obtaining the desired electronic properties since it plays a major role in the resulting thin film surface microstructure. A post-growth modification by X-ray irradiation was also performed on these films. Our results show a significant improvement in the field emission characteristics of the Al@sub x@Ga@sub1-x@N surfaces. The threshold field was reduced by up to three times and current density increased up to 10 A/cm@super2@. These results are consistent with data previously obtained for field emission and laser photoconductivity enhancement by X-ray irradiation of BN thin films. The effect of the X-ray induced generation of additional density of states in the nitride material band gap, on the changes in film conductivity and surface potential barrier height will be discussed. The project was funded in part by a CRDF Grant assistance program (Project # RP0-698), a Russian Federation for Basic Research grant (# 99-02-16653) and a NASA Cooperative agreement #NCC8-127 to the Space Vacuum Epitaxy Center.

10:20am **SC+EL-FrM7 Effect of Annealing and Carbon Concentration on the PL Intensity from GaN:Er and GaN:Eu**, ***M.E. Overberg***, *C.R. Abernathy, S.J. Pearton,* University of Florida*; J.M. Zavada,* U.S. Army European Research Office, UK

An attractive alternative for emission in the visible and near-IR are rare earth doped III-Nitrides, whose emission wavelength is host-material insensitive and less susceptible to thermal quenching than conventional narrow gap semiconductors. GaN doped with Er and Eu during growth by molecular beam epitaxy (MBE) has been found to produce strong room temperature emission at 1540 nm and 621 nm, respectively. In addition to the electronic characteristics of the host material, impurities such as C and H are expected to play an important role in the emission process. In this study, the effects of carbon doping and annealing in either nitrogen or forming gas on the luminescence intensity from Er-doped and Eu-doped GaN has been investigated. In samples with no added carbon, annealing was found to decrease the room temperature emission. The addition of carbon to the GaN during growth however, not only improved emission relative to non-carbon doped material but also produced material which improved with annealing. For carbon co-doped material the presence of hydrogen in the annealing ambient produced the greatest improvement in emission intensity, suggesting that both C and H are beneficial to the emission process. The effect of annealing on surface morphology and structural quality will also be presented as will a model for the observed PL behavior.

10:40am **SC+EL-FrM8 Probing Nanoscale Electronic Properties in Nitride Semiconductor Heterostructures*, E.T. Yu*,** *K.V. Smith, X.Z. Dang,* University of California, San Diego **INVITED**

III-V nitride heterostructures are of outstanding current interest for both optoelectronic and electronic device applications. However, the high concentrations of point and extended defects typically present even in device-quality nitride semiconductor material necessitates detailed characterization and understanding of local structure and electronic properties at atomic to micron length scales for optimization of device performance. In particular, the presence of a variety of defect structures in combination with strong piezoelectric and spontaneous polarization effects in nitride semiconductors leads to pronounced variations in local electronic properties. Experimental characterization, theoretical analysis, and numerical simulation of these effects, especially in the context of nitride heterostructure field-effect transistor (HFET) structures, will be described. Scanning capacitance microscopy has been used extensively to characterize local electronic structure in AlGaN/GaN HFET structures. Measurement and analysis of capacitance contrast as a function of bias voltage allows submicron-scale lateral variations in transistor threshold voltage, nanoscale depleted regions within the channel of the transistor in the vicinity of negatively charged threading dislocations, and evidence of piezoelectric fields arising from local strain in the vicinity of dislocation lines to be observed. Application of large bias voltages during the imaging process is found to give rise to localized trapping of charge in deep levels. Measurement and analysis of the resulting contrast allows the distribution of trapped charge both laterally and as a function of depth to be probed.

11:20am **SC+EL-FrM10 GaN and AlGaN Power Rectifiers*, A.P. Zhang*,** *G. Dang, F. Ren, X.A. Cao, K.P. Lee, S.J. Pearton,* University of Florida*; J. Han,* Sandia National Laboratories*; J.I. Chyi,* National Central University,Taiwan*; C.M. Lee, C.C. Chuo,* National Central University, Taiwan

We fabricated the GaN & AlGaN rectifiers and p-i-n rectifiers on a range of different MOCVD-grown materials. The reverse breakdown voltages of lateral GaN&AlGaN rectifiers on 3µm thick resistive GaN&AlGaN were in a range of 2.3~4.3kV with a 30µm Schottky metal and Ohmic metal spacing. The p-i-n diodes on 4µm thick GaN epitaxial layer showed a reverse breakdown voltage of 500V with turn-on voltage of ~5V (100A/cm@super 2@). Different edge termination methods were used to improve the performance of GaN rectifiers, including Schottky metal overlap, guard rings, and float rings and junction barrier control (JBS). The edge termination has a strong effect to prevent catastrophic breakdown at the contact periphery. The lowest R@sub ON@ was 0.14 @ohm@.cm@super 2@ for GaN rectifiers and 2.6 @ohm@.cm@super 2@ for AlGaN rectifiers. Figure-of-merit (V@sub RB@)@super 2@/R@sub ON@ are in the 6 -55 MW.cm@super -2@ range, emphasizing the potential of these devices for power switching applications. For the devices we fabricated, we invariantly observed the negative temperature coefficient for V@sub RB@ most likely due to the influence of defects in the heteroepitaxial GaN. For the similar reverse breakdown voltage, current densities are higher in the p-i-n structures, at the expense of higher turn-on voltage, but the on-voltages still need improvement in the Schottky rectifiers. A comparison will be given with state-of-the-art Si and SiC power rectifiers.

11:40am **SC+EL-FrM11 Growth and Characterization of Gadolinium Oxide Gate Dielectric on Gallium Nitride*, B.P. Gila*,** *K.N. Lee, K.K. Harris, W. Johnson, V. Krishnamoorthy, C.R. Abernathy, F. Ren, S.J. Pearton,* University of Florida

Fabrication of high performance metal oxide semiconductor field effect transistors (MOSFETs) on gallium nitride will require both good interfacial electrical characteristics and good thermal stability. While dielectrics such as SiO@sub 2@ and GaGdO have demonstrated low to moderate interface state densities, questions remain about their thermal stability and reliability, particularly for use in high power or high temperature widebandgap devices. In this talk we will discuss the utility of gadolinium oxide, Gd@sub 2@O@sub 3@, as a gate dielectric material on GaN. Gadolinium oxide deposited by gas source molecular beam epitaxy from elemental Gd and an electron cyclotron resonance (ECR) oxygen plasma has been found to produce layers with excellent surface morphologies as evidenced by SEM and AFM, with a surface roughness of less than 1 nm. Surface preparation techniques, both in-situ and ex-situ, have been explored to produce films of different crystal morphologies as evidenced by RHEED and TEM. Stoichiometric films can be easily obtained over a range of growth temperatures, growth rates and oxygen flows. This talk will describe the relationship between deposition conditions and film characteristics for Gd@sub 2@O@sub 3@, and will present electrical characterization and thermal stability of capacitors fabricated from Gd@sub 2@O@sub 3@ on GaN.

Author Index

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