SYMPOSIUM C

New Applications for Wide-Bandgap Semiconductors

April 22 – 24, 2003

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* Invited paper

SESSION C1: SPECIAL INVITED SESSION
Chairs: Jung Han and Wayne H. Chang
Tuesday Morning, April 22, 2003
Golden Gate A2 (Marriott)

8:30 AM *C1.1

WIDE BANDGAP SEMICONDUCTOR MATERIALS: WHERE ARE WE? Laura S. Rea, Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright-Patterson AFB, OH.

Optical and electronic devices based on wide bandgap semiconductor materials have become firmly entrenched in a variety of commercial products. In addition to blue, green and white LEDs, blue and UV gallium nitride (GaN)-based solid-state lasers are now commercially available. Concurrently, new electronic device structures have been explored in this materials class, and RF transistors and power switching devices based on silicon carbide (SiC) are available commercially. As exciting as these early commercial products are, it is quite likely that we are only seeing the tip of an enormous "product iceberg". Combining a unique set of physical (electronic and optical) properties with new capabilities in device processing (including materials integration, nano-scale processing and other novel processing techniques), there is great potential for even broader application of this class of materials. Before this potential can be fully realized, a solid materials science foundation must be in place. This presentation will provide an assessment of the status of wide bandgap materials (including emerging materials), considering quality, availability and cost. Exploration of materials development costs will also be discussed. Finally, some discussion of the potential for new applications will be presented.

9:00 AM *C1.2

WIDE BANDGAP ELECTRONIC DEVICES, HOW WILL THEY BE USED. Harry B. Dietrich, Office of Naval Research, Electronics Division, Arlington, VA.

For over a decade the Office of Naval Research and other government agencies have been funding basic and applied research aimed at the development of SiC and GaN electronic devices. This has been driven in large part by the order of magnitude increase in power density that can be generated with devices based on these materials systems; however there are collateral properties of these devices that enhance their utility for a variety of applications. This talk will overview the properties of WBG devices that make them of technological interest, discuss these applications and outline the major issues that must be resolved before these devices can find their way into the market place.

9:30 AM *C1.3

SILICON CARBIDE POWER DEVICES AND PROCESSING. J.B. Casady, J.R. Bonds, W.A. Draper, J.N. Merrett, and I. Sankin, SemiSouth Laboratories, Inc., Starkville, MS.

SiC power devices have advanced considerably in recent years, with the release of commercial 600 V, 1-10 A Schottky Barrier Diodes (SBD's) in 2001 from Cree, Infineon, and SemiSouth. Higher rated rectifiers are under development, in addition to SiC power switches. Although Gate Turn-Off thyristors (GTO's) and Insulated Gate Bipolar Transistors (IGBT's) have been reported, most of the near-term switch development appears to be focused on basic MOSFET, VJFET, and BJT configurations [1-9]. From a processing and applications point of view, each device type has strengths and weaknesses. The MOSFET is a normally-off, voltage driven switch, ideal for many applications. However, it suffers from poor inversion layer mobility and suspect high-temperature, high-field reliability because of the relatively low barrier to Fowler-Nordheim tunneling on wide bandgap (3.2 eV) SiC. The JFET is also a voltage-driven switch, and is more robust for high-temperature, high-field, and even high-radiation environments because of the absence of the MOS system. It has high input impedance, but is difficult to make normally-off without modification for high-current devices. Finally, the BJT has demonstrated good voltage and current carrying capabilities, but has applications issues in being a current-driven device, and processing issues in surface recombination velocity on the edge of the emitter, potential current crowding from a poorly ionized p-base, and emitter injection efficiency. In this paper, we report recent results in both SiC rectifier and switch development from both our own results and the literature. Processing issues such as surface residue from dry-etched SiC, oxidation rates of implanted and un-implanted SiC, and implant activation are also covered. Finally, design trade-offs, applications, and processing considerations are all explicitly presented. References: [1] Cooper, J.A., Jr.; Agarwal, A.: "SiC power-switching devices-the second electronics revolution?"; Proceedings of the IEEE, Vol. 90, Issue: 6, June 2002, pp. 956-968 [2] Singh, R.; et al., "SiC power Schottky and PiN diodes"; IEEE Transactions on Electron Devices, Vol. 49 Issue: 4, April 2002, pp. 665-672 [3] Elasser, A.; Chow, T.P.: "Silicon carbide benefits and advantages for power electronics circuits and systems"; Proceedings of the IEEE, Vol. 90, Issue: 6, June 2002, pp. 969-986 [4] Clarke, R.C.: "Silicon carbide devices for power applications"; Proceedings of the Bipolar/BiCMOS Circuits and Technology Meeting, 2001 p. 124 [5] Morisette, D.T.; Cooper, J.A., Jr.: "Theoretical comparison of SiC PiN and Schottky diodes based on power dissipation considerations"; IEEE Transactions on Electron Devices, Vol.: 49 Issue: 9, Sept. 2002, pp. 1657-1664 [6] D.C. Sheridan, et al.: "Comparison and optimization of edge termination techniques for SiC power devices;" Conference Proceedings - 13th International Symposium on Power Semiconductor Devices and ICs (ISPSD'01), Jun 4-7 2001, Osaka, pp. 191-194 [7] I. Sankin, et al.; "Fabrication and simulation of 4H-SiC PiN diodes having mesa guard ring edge termination;" Accepted for Conference proceedings - European Conference on SiC and Related Materials (ECSCRM), Sept 1-5, 2002, Linkoping, Sweden [8] J.B. Dufrene, et al.; "High-voltage (600 to 3 kV) silicon carbide diode development;" Conference Proceedings - IEEE Applied Power Electronics Conference and Exposition - APEC, vol. 2, Mar 4-8 2001, pp. 1253-1257 [9] I. Sankin, et al.; "On development of 6H-SiC LDMOS transistors using silane-ambient implant anneal;" Solid-State Electronics, v 45, n 9, September, 2001, pp. 1653-165.

10:30 AM *C1.4

CHALLENGES FOR HIGH TEMPERATURE SILICON CARBIDE ELECTRONICS. Carl-Mikael Zetterling, S.-M. Koo, E. Danielsson, W. Liu, S.-K. Lee, M. Domeij, H.-S. Lee, M. Ostling, KTH, Royal Institute of Technology, Dept of Microelectronics and IT, Stockholm, SWEDEN.

Silicon carbide has been proposed as an excellent material for high-frequency, high-power and high-temperature electronics, and preferably all three should be achieved at the same time. The first two possibilities have been pursued for quite some time, and with a great deal of success in terms of demonstrated high-frequency or high-power devices. However, some devices have experienced self-heating problems due to the much higher power densities that result when ten times higher electrical fields are used inside the devices. High-temperature electronics has not experienced as much attention and success, possibly because there is no immediate market. This talk will review some of the advances that have been made in high-temperature electronics using silicon carbide, starting from process technology, continuing with device design, and finishing with circuits. For process technology, one of the biggest obstacles is long-term stable contacts. Several device structures have been electrically characterized at high temperature (BJTs and FETs) and will be compared to surface temperature measurements and physical device simulation. Some circuit topologies that have been proposed will be presented, and also some novel solutions.

11:00 AM *C1.5

GaN HEMTs AND SiC MESFETs FOR MICROWAVE POWER APPLICATIONS. A.P. Zhang, L.B. Rowland, E.B. Kaminsky, J.B. Tucker, J.W. Kretchmer, R.A. Beaupre, and J.L. Garrett, General Electric Global Research Center, Niskayuna, NY; B.J. Edward, A.F. Allen, J. Cook, and D. Cencetti, Lockheed Martin NE&SS-Radar Systems, Syracuse, NY.

Wide bandgap semiconductors (GaN, SiC) have demonstrated great potential for high frequency, high power and high temperature applications due to the unique combination of intrinsic large bandgap, high breakdown field, high saturation velocity and high thermal conductivity. One particular interest is to develop GaN HEMTs and SiC MESFETs for high power transmitters at UHF through Ka band. Small and large gate periphery GaN HEMTs and SiC MESFETs have been fabricated and tested. 4H SiC semi-insulating substrates were used for both device types. At this stage of development, the quality of substrates and epitaxial layers plays an important role in device performance and stability. Synchrotron white beam X-ray topography, current deep level transient spectroscopy and atomic force microscopy have been used to characterize the material quality and correlation of material defects and device performance has been attempted. Three-dimensional thermal simulations were employed to optimize the gate layout in an effort to lower the junction temperatures while maintaining negligible phase losses. Despite imperfect material quality, impressive device performances have been achieved. For GaN HEMTs at 10 GHz, more than 6.7 W/mm CW power has been obtained from 400 mm gate periphery devices and more than 9.2 W/mm pulsed power were demonstrated from 1.5 mm gate periphery devices. SiC MESFETs have also demonstrated more than 60 watts pulsed power from 21.6 mm gate periphery devices at 450 MHz and more than 27 watts pulsed power from 14.4 mm gate periphery devices at 3 GHz operations.

11:30 AM *C1.6

SUBMICRON RECESSED GATE AlGaN/GaN HEMTS FOR mm-WAVE APPLICATIONS. J.S. Moon, M. Micovic, D. Wong, I. Milosavljevic, M. Hu, M. Antcliffe, and C. Ngo HRL Laboratories LLC, Malibu, CA.

Recent advances in the AlGaN/GaN-based HEMTs grown on thermally conductive SiC substrates have demonstrated the strong potential of this technology for the next-generation microwave power applications, especially near X-band (8 - 12 GHz). Power density of greater than 10 W/mm was demonstrated at 10 GHz by Cornell group, which was ~8 times greater than GaAs-based state-of-the-art devices. Microwave power operations beyond the X-band toward mm-wave have received a great deal of attention. Utilizing 0.15 um gate-length passivated AlGaN/GaN HEMTs grown on semi-insulating (0001) 4H-SiC substrates using RF-assisted MBE, we have reported CW output power density of 6.6 W/mm with PAE of 35% at 20 GHz from 0.1 mm devices. At Ka-band, CW output power densities ranging 1.5 ~2.3 W/mm have been reported with PAE ranging 26% (pulsed) ~22% by several groups. The power density is at least 3 times greater than that of GaAs pHEMTs. Thus, the observed superior power performance indicates its strong potential toward mm-wave power amplifiers. The PAE, however, is very much lacking for the real system insertion, which might be due to both lower linear gain and high knee voltage under the CW high RF power operation. Further improvement in PAE is expected in the gate-recessed devices. Recently, we have reported gate-recessed AlGaN/GaN HEMTs, where the gate area was dry etched using a chlorine-based low power RIE. The 0.85 um gate-recessed devices showed Ids of 0.5 A/mm with knee voltage of <3 V. The small signal RF measurement showed the maximum oscillation frequency (fmax) and unity-gain cut-off frequency (fT) of 44 GHz, and 15 GHz, respectively. Submicron gate recessed AlGaN/GaN HEMTs were also fabricated down to 0.15 um gate length. We observed a systematic reduction both in threshold voltage and Idss, and an improvement in transconductance. For instance, we observed extrinsic transconductance of 350 mS/mm from 0.3 um gate recessed devices with Vt = -0.8 V. Preliminary testing of 0.15 um gate recessed devices with Vt of -4 V and knee voltage of ~3 V, showed extrinsic ft of 67 GHz and fmax of 120 GHz. Power performance of recessed gate AlGaN/GaN HEMTs at mm-wave frequencies will be presented and compared with non-recessed AlGaN/GaN HEMTs.

SESSION C2: GROWTH, PROCESSING, DEVICES

Chairs: Jen-Inn Chyi and Jeffrey Blaine Casady
Tuesday Afternoon, April 22, 2003
Golden Gate A2 (Marriott)

1:30 PM *C2.1

LOW TEMPERATURE GROWTH MECHANISM OF GaN CRYSTAL BY HYDRIDE VAPOR PHASE EPITAXY.
Hai-Ping Liu[a], Jeng-Dar Tsay[b], Wen-Yueh Liu[b], Yih-Der Gua[b], Jung Tsung Hsu[b], In-Gann Chen[a]; [a]Department of Material Science and Engineering, National Cheng-Kung University, Taiwan, ROC; [b]Opto-Electronics & System Laboratories, Industrial Technology Research Institute, Taiwan, ROC.

The low temperature growth of GaN crystal using epitaxy lateral overgrowth (ELO) on SiO2 dot pattern below 900°C by hydride vapor phase epitaxy (HVPE) have been studied. It is observed that the growth rate of GaN hexagonal pyramidal crystals along [1-100] direction increases as growth temperature decreases. At low temperature, many hexagonal GaN columnar crystals can be observed. It is proposed that the diffusion length of precursors, such as NH3 and GaCl, decreases at lower temperature that reduces the probability of desorption. The change of temperature will then change the surface stability of GaN crystal facet and the growth rate of different crystal planes. Therefore, the formation of high index planes such as $\{1-101\}$ and $\{11-22\}$ facet along with a screw dislocation on the top of hexagonal column can be observed. A detailed study of the effect of growth temperature and its crystal growth mechanism will be presented.

2:00 PM C2.2

AlGaN/GaN STRUCTURES GROWN BY HVPE: GROWTH AND CHARACTERIZATION. M.A. Mastro, D. Tsvetkov, A. Pechnikov, V. Soukhoveev, G. Gainer, A. Usikov, V. Dmitriev, Technologies and Devices International, Inc., Silver Spring, MD; B. Luo and F. Ren, University of Florida, Department of Chemical Engineering, Gainesville, FL; K.H. Baik, S.J. Pearton, University of Florida, Department of Materials Science and Engineering, Gainesville, FL.

Recently, the first HEMT devices based on AlGaN/GaN heterostructures grown by hydride vapor phase epitaxy (HVPE) have been demonstrated. Two unique aspects of this technological approach are the growth of Al-containing epitaxial material by HVPE and use of HVPE to form submicron multi-layer epitaxial structures. Due to the significant potential of HVPE growth technology for mass production of device epitaxial wafers, we are performing detailed investigation of grown structures. Results of this study will be presented at the meeting. Grown samples include undoped AlGaN/GaN/sapphire structures and more complicated GaN/AlGaN/GaN/i-GaN/sapphire structures. The samples were grown by atmospheric pressure HVPE process at approximately 1000°C. Thickness and composition of AlGaN layers ranged from 30 to 50 microns and from 20 to 30 mol.% of AlN, respectively. Structures with both doped and undoped AlGaN layers were investigated. Insulating GaN base layers from 2.0 to 8.0 microns thick were grown employing Zn doping. Doping depth profiles for grown layers were measured by SIMS. This method also allowed us to estimate layer thicknesses. Exact layer thickness and interface sharpness was measured using transmission electron microscopy. AlN concentration in AlGaN layers was determined using x-ray diffraction. Hall effect and Low Temperature Photoluminescence were used to investigate the two-dimensional electron gas. Results of material study will be presented together with characteristics of HEMTs fabricated from grown structures.

2:15 PM C2.3

HVPE-GROWN AlGaN/GaN HEMTs. Ben Luo and F. Ren, Department of Chemical Engineering, University of Florida, Gainesville, FL; M.A. Mastro, D. Tsvetkov, A. Pechnikov, V. Soukhoveev, V. Dmitriev, Technologies and Devices International, Inc., Silver Spring, MD; K.H. Baik and S.J. Pearton, Department of Materials Science and Engineering, University of Florida, Gainesville, FL.

GaN/AlGaN HEMTs have demonstrated high current density, power output and low noise figure. This makes them attractive for wireless telecommunication and microwave applications. To date, almost all of nitride HEMTs heterostructures are grown by commonly used Molecular Beam Epitaxy (MBE) or Metal Organic Chemical Vapor Deposition (MOCVD) technological methods. Hydride Vapor Phase Epitaxy (HVPE) has a much higher growth rate as compared to that of MBE and MOCVD and is attractive for high throughput production of HEMT wafers. It is already well established that HVPE is the promising technique for the growth of thick, high-purity quasi-bulk GaN substrates. In this talk, we present the characteristics of first-ever AlGaN/GaN high electron mobility transistors (HEMTs) grown by an HVPE technology. The structures were grown at 1020°C on 2 inch Al_2O_3 substrates. Gallium chloride and ammonia were used as Ga and N precursors, respectively. Excellent surface morphology of AlGaN/GaN structures with root-mean-square roughness of ~0.2nm measured by AFM over $10\times10\mu m^2$ areas was obtained. Capacitance-voltage measurements clearly show the formation of a high concentration sheet charge at the AlGaN/GaN interface. Discrete HEMTs with gate dimensions of $1\times100\mu m^2$ were fabricated. A 0.6A/mm of maximum drain-source current and extrinsic transconductances in excess of 110 mS/mm at V_{DS} of 6V were obtained. A sharp pinch-off at gate bias of -3.5V was evident, which indicates the high quality of the insulating GaN base layer.

2:30 PM C2.4

NUCLEATION AND INITIAL GROWTH KINETICS OF GaN ON SAPPHIRE SUBSTRATE BY HYDRIDE VAPOR PHASE EPITAXY. F. Dwikusuma, J. Mayer, and T.F. Kuech, Department of Chemical Engineering, University of Wisconsin, Madison, WI.

The hydride vapor phase epitaxy (HVPE) technique has been proven capable of producing thin and thick films of GaN materials on sapphire substrates. These materials have found many uses including serving as a commercially viable lattice matched substrate for subsequent nitride-based device layers. Due to the large lattice mismatch between sapphire and GaN, film nucleation is the critical step in the growth of high quality materials, determining the subsequent layer properties. Nevertheless, very little is understood of nucleation kinetics of GaN during the HVPE process. This study focused on the very initial stages of film nucleation by a series of short time growth and quench experiments. The island distribution, size, shape and mass growth rate were determined as a function of surface pretreatment, deposition rate, growth time, and substrate temperature using atomic force microscopy. The substrate surface prior to growth was prepared and characterized in order to mitigate the influence of the pre-growth substrate surface preparation. The nucleation temperatures were studied over the range of 1000 to 1100°C. GaN nucleation on sapphire follows the Volmer-Weber or island growth mode. Lower temperature growths have higher island density and hence smaller spacing between islands due to the lack of adatom mobility. Higher temperature growths typically have larger island size with a hexagonal shape. The nucleation parameter data were analyzed in terms of atomistic nucleation theory and characteristics kinetic energies were extracted as well quantitative estimate of the surface diffusion rate on sapphire. The generation of defects in the films will be correlated with the specific nucleation conditions, based on the analysis of thicker growth on surface prepared under known and characterized nucleation conditions. The mechanism that controls each nucleation parameter was discussed.

3:15 PM C2.5
MOCVD GROWTH OF AlN/GaN DBR STRUCTURE UNDER VARIOIUS AMBIENT CONDITIONS. H.H. Yao, C.F. Lin, S.C. Wang, National Chiao Tung University, Institute of Electro-Optical Engineering; Y.C. Hsien, National Chiao Tung University, Department of Materials Science and Engineering.

AlN/GaN Distributed Bragg Reflector (DBR) structures are important for GaN-based VCSELs. We have grown AlN/GaN DBR structures under different ambient gas mixture conditions, including pure N_2, mixed N_2/H_2 and pure H_2, during the AlN layer growth. Highest reflectivity of about 94.5% with a stopband width of 18 nm at a center wavelength of 442nm was obtained under pure N_2 gas ambient growth condition. However, under the ambient gas conditions of N_2/H_2 mixture and pure H_2, the center wavelength of the DBR structures shows a blue-shifted to 418 nm and 371 nm respectively. Epimatrix measurement showed the reduction in the thickness of Al epilayer with increasing H_2 ambient during AlN growth. Mathematical simulation indicates this could be responsible for the shift in the center wavelength of the DBR structures. Under N_2/H_2 and pure H_2 conditions, the peak reflectivity of these DBR structures showed a reduction to 92% and 79% respectively. This could be due to the increasing GaN band edge absorption. Detail interface structures and surface morphology of these DBR structures were investigated by Cross-section Transmission Electron Microscopy (TEM) and Atomic Force Microscopy (AFM). TEM studies indicate that the interface, under pure N_2 gas ambient growth condition, is more clear and distinct than other growth conditions. While the AFM results show both the surface roughness and the surface grain size show increase with increasing H_2 ambient gas content.

3:30 PM C2.6
HYDROGEN-SENTITIVE GaN SCHOTTKY DIODES. Jihyun Kim[a], B.P. Gila[b], C.R. Abernathy[b], S.J. Pearton[b] and F. Ren[a]; [a]Department of Chemical Engineering, University of Florida, Gainesville, FL; [b]Department of Materials Science and Engineering, University of Florida, Gainesville, FL.

There is huge interest in development of wide-bandgap gas sensors, because it can operate at elevated temperature. The applications include fuel leak detection in automobiles and aircraft, fire detectors, exhaust diagnosis and emissions from industrial processes. Especially GaN gas sensors can be integrated with UV detectors. It was known early that the introduction of hydrogen into Schottky diodes changed the barrier height. The detection mechanism for hydrogen is 1) dissociation of H2 on the surface of a catalytic metal, 2) diffusion into metal 3) the formation of a dipole layer at the interface between metal and semiconductor 4) lowering the barrier height. It is known that the devices using this mechanism can detect on the order of ppm. We fabricated Pt/GaN and Pd/GaN Schottky diodes as hydrogen gas sensors. The forward current of Pd-GaN and Pt-GaN Schottky diodes is found to increase significantly upon introduction of H2 in to a N2 ambient. Analysis of the current-voltage(I-V) characteristics as functions of temperature showed that the current increase is due to a decrease in effective barriers height through a decrease in metal work functions upon absorption of hydrogen. The introduction of 10%H2 into a N2 ambient was found to lower the effective barrier height of Pd on GaN by 50~70 meV over the temperature range 298~423K and of Pt on GaN by 30~60meV over the range 443~473K. The measuremental set-up, forward current-voltage characteristics in both Pd/GaN and Pt/GaN, and time response data will be presented.

3:45 PM C2.7
4H-SiC DMOSFETS FOR HIGH FREQUENCY POWER SWITCHING APPLICATIONS. Sei-Hyung Ryu, Anant K. Agarwal, James Richmond, and John W. Palmour, Cree Inc., Durham, NC.

Very high critical field (~2 MV/cm), reasonable bulk electron mobility (~800 cm^2/V$cdot$s), and high saturation velocity (~2x10^7 cm/s) make 4H-Silicon carbide very attractive for high voltage power devices. These advantages make high performance unipolar switching devices with blocking voltages greater than 1 kV possible in 4H-SiC. Typical silicon switching devices with similar voltage ratings utilize conductivity modulation in the drift layer to reduce the forward drop, resulting in reduced switching speeds and large switching losses, while a 4H-SiC unipolar device has fast, temperature independent switching characteristics and extremely low switching losses. Several exploratory devices, such as vertical MOSFETs and JFETs, have been reported in SiC. However, in most of the previous works, the high switching speeds of the SiC devices did not receive much deserved attention. In this paper, we report static and dynamic characteristics of our 4H-SiC DMOSFETs. A channel mobility of 22 cm^2/V$cdot$s was measured from a FATFET in an implanted p-well. The 4H-SiC DMOSFET blocked 2.4 kV and showed a specific on-resistance of 42 mOhms$cdot$cm^2, which is about 25 times lower than that of a silicon unipolar device with same blocking voltage. When switching a resistive load with a 1 kV power supply, a rise time of 57.3 ns and a fall time of 41.6 ns were measured. This suggests that the 4H-SiC DMOSFETs are ideal for high frequency low loss power switching applications. A simple modeling of the on-state characteristics of 4H-SiC DMOSFETs was also performed, and a comparison of theoretical specific on-resistance values for several cell designs is presented.

4:00 PM C2.8
HIGH POWER, HIGH TEMPERATURE, BIPOLAR JUNCTION TRANSISTORS IN 4H-SiC. Anant K. Agarwal, Sei-Hyung Ryu, James Richmond, Craig Capell and John W. Palmour, Cree Inc., Durham, NC.

In this paper, we present the detailed design and fabrication of a 1300 V/17 A 4H-SiC BJT with a relatively large foot-print (3.16 mm x 3.16 mm) and active area of 0.0665 cm^2. The BJTs showed an on-state current of $I_C = 17$ A @ $V_{CE} = 2$ V (on-resistance of 8 mΩ-cm^2), which outperforms all SiC power switching devices ever reported for this voltage range. A BV_{CEO} of 1300 V was observed. The device showed a maximum current gain of 11 at room temperature which reduces to about 7 at 200°C. The low current gain is attributed to surface recombination and is being addressed through improved oxidation conditions to passivate the high density of interface traps and reduction of damage during aluminum implantation and activation. On smaller test devices, the on-resistance was found to be inversely proportional to the total emitter periphery for a fixed active area showing that the entire emitter length (5-10 μm) does not contribute to the current. Further reduction in the emitter length will lead to a higher current density. The common emitter current gain was characterized at elevated temperatures. At elevated temperatures, the ionization of deep level acceptor atoms increases, which results in a reduction in the emitter injection efficiency. For example, the acceptor (Aluminum in 4H-SiC) doping of 2x10^{17} cm^{-3} is only 10% ionized at room temperature. The percent ionization increases to 50% at 250°C. This effect cancels the effect of increased minority carrier lifetime and reduces the current gain with temperature. This feature along with the positive temperature coefficient in the on-resistance reduces the possibility of a thermal runaway and makes paralleling easy for these devices.

4:15 PM C2.9
OHMIC CONTACT FORMATIONS OF Ti/Al/C FILMS ON P-TYPE 4H-SiC. Weijie Lu, Department of Physics, Fisk University, Nashville, TN; W.C. Mitchel, Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright-Patterson AFB, OH; G.R. Landis, University of Dayton Research Institute, Dayton, OH; T.R. Crenshaw and W. Eugene Collins, Department of Physics, Fisk University, Nashville, TN.

It is known that ohmic contact formation on p-type SiC is more difficult than on n-type SiC. Our previous studies have shown that Ni/C film significantly improves ohmic contacts on n-type SiC. The most commonly used materials for ohmic contacts on p-type SiC are Ti/Al alloy. In this study, we demonstrate that ohmic contacts are improved using Ti/Al/C films on p-type SiC. Ohmic contacts of Ti/Al/C films on SiC are examined with various thickness of the carbon film, annealing time, annealing temperatures, and different doping concentrations in SiC. The annealing temperature for ohmic contact formation in the Ti/Al/C/SiC structures decreases about 100-200°C comparing to the conventional technique, and the specific resistivity reduces by one order of magnitude. The optimal annealing temperature for Ti/Al/C/SiC structures is 900°C, while the annealing at 1000°C results in the best ohmic contact in the conventional Ti/Al/SiC structures. Excellent ohmic contact can be formed on the p-type SiC with one order lower doping concentration than it in the conventional Ti/Al/SiC structures. The relations between carbon graphitization and ohmic contact formation are discussed. These findings increase our scientific understandings of electrical contact properties on SiC.

4:30 PM C2.10
LASER DIRECT-METALLIZATION OF SILICON CARBIDE WITHOUT METAL DEPOSITION. I. Salama and A. Kar, School of Optics/CREOL, University of Central Florida, Orlando, FL; N. Quick, AppliCote Associate, Lake Mary, FL.

Laser direct-write (LDW) is used for in situ metallization and selective area doping in single crystal 4H- and 6H-SiC wafers. Nanosecond-pulsed Nd:YAG (wavelength = 1064 and 532 nm) and excimer (wavelength = 193, 248 and 351 nm) lasers are used to irradiate the SiC samples for metallization and doping experiments. Laser irradiation in inert ambients (Ar and He) produces metal-like conductive tracks in situ in both n-type and p-type SiC wafers. The electrical resistivity of such metallized tracks is four orders of magnitude lower than the as-received SiC samples and the temperature dependence of the resistivity indicated a metal-like behavior that depends on the SiC polytype. The Schottky barrier height (SBH) between the laser-metallized layer and the original n-type SiC (ND= 10^{18}/cm ^{3} is determined to be 0.8 eV and 1.0 eV by the current-voltage and capacitance-voltage measurements at room temperature, respectively. Linear transmission line method pattern is directly fabricated in n-type doped (ND= 10^{18}/cm ^{3}) SiC substrate by pulsed laser irradiation allowing to calculate the specific contact resistance (rc) of the laser fabricated metal-like tracks (rc= 0.04-0.12 $\omega/^2$). The effects of various annealing parameters (ambient, temperature, time and time-temperature product) on the characteristics and the stability of the interface between the laser-treated layer and original SiC structure are investigated. Electron diffraction pattern is used to study the crystalline nature of the laser-synthesized conductive phase and TEM studies are carried out to determine the crystallographic orientation with respect to (0001)-Si face of SiC epilayer. Laser doping is achieved by irradiating SiC wafers in dopant-containing ambients (nitrogen and TMAl/Argon mixture for n-type and p-type doping, respectively). SIMS depth profiling of an n-doped sample indicated a laser-doping depth of 500 nm and a dopant concentration of 10^{17} cm^{3}compared to 10^{15} cm^3 for the as-received epilayer.

4:45 PM C2.11
IN SITU SEM OBSERVATIONS AND ELECTRICAL MEASUREMENTS DURING THE ANNEALING OF Si/Ni CONTACTS TO n-SiC. Matthew H. Ervin, Ken Jones, Tsvetanka Zheleva, Mike Derenge, Pankaj Shah, and Mark Wood, U.S. Army Research Laboratory, Adelphi, MD.

Ni contacts are the most commonly used ohmic contacts to n-SiC. These contacts require a high temperature anneal, ~950C, in order to achieve their good ohmic properties, including a low specific contact resistance. The ohmic nature of these contacts result from a reaction of the Ni with Si from the SiC to form a nickel silicide, which has similar energy levels as the n-SiC. Unfortunately, the reaction to form the silicide liberates C, from the SiC, which can segregate to the contact-semiconductor interface. In addition, these contacts exhibit poor morphology. These two factors limit the reliability of Ni contacts to SiC for high temperature/power applications. In an attempt to mitigate the unintended liberation of C during the silicidation reaction, we have investigated providing an independent source of Si through the deposition of Si on top of the Ni. We made in situ SEM observations of the annealing of these contacts using a hot stage capable of reaching 1200C. The silicidation reaction can be observed to occur at temperatures well below 950C. Real time resistance measurements made, while annealing these contacts, verify that the Si/Ni reaction to form a silicide(s) is not sufficient to produce ohmic behavior. These real time resistance measurements confirm that the typical anneal temperatures of ~950C are required for producing ohmic contacts. This finding suggests that the reaction of the Ni with the SiC to form C vacancies is an essential part of forming these ohmic contacts. Since the solid phase reaction between the separate Ni and Si occurs well below the reaction with the SiC, one might conclude that the deposition of adjacent Ni and Si layers is functionally equivalent to the deposition of a Ni-silicide layer. However, the evolution of topography during the silicidation reaction may argue against this.

SESSION C3: POSTER SESSION
NOVEL APPLICATIONS FOR
WIDE BANDGAP SEMICONDUCTORS

Chairs: Steve J. Pearton and Albert G. Baca
Tuesday Evening, April 22, 2003
8:00 PM
Golden Gate (Marriott)

C3.1
EVIDENCE OF Cr-DOPING IN PULSED LASER DEPOSITED ZnS NANOCRYSTALLINE FILMS FOR MID-INFRARED APPLICATIONS. Shengyuan Wang, Renato P. Camata, Anatoliy Kudryavtsev, and Sergey Mirov, University of Alabama at Birmingham, Dept of Physics, Birmingham, AL.

A review of current mid-infrared laser technologies suggests that wide bandgap II-VI semiconductor crystals doped with divalent transition metal ions (e.g., Cr^{2+}, Ni^{2+}, Fe^{2+}, etc.) may be efficient and affordable materials for 2-3.5 μm room temperature lasing. This range is in high demand for numerous scientific, commercial, and military wavelength specific applications. As a new class of semiconductor lasers, they may offer a unique combination of high efficiency operation under optical excitation, broad gain bandwidth, and potential for direct electrical pumping. In this regard, systems comprising doped ZnS nanocrystals embedded in conducting matrices may offer a viable pathway for direct electrical excitation. In order to explore this possibility we targeted the deposition of Cr-doped ZnS nanocrystalline films by pulsed laser deposition. Targets were prepared by mixing Cr and ZnS micron-sized powders in various concentrations. Films were deposited on Si (100) substrates at 450°C by the ablation of the composite targets using a KrF excimer laser with energy density of 2 J/cm^2 at pressures between 10^{-8} Bar (vacuum) and 10^{-3} Bar (argon atmosphere). Energy dispersive x-ray from films show a strong $K\alpha$ emission line at 2.307 keV, indicating significant sulfur incorporation. X-ray diffraction indicates good-quality ZnS films preferentially oriented along the (111) direction. Thickness in the 5-10 um range was measured by cross-sectional scanning electron microscopy, which also allowed evaluation of the surface morphology. Films deposited at 10^{-3} Bar seem to be nanocrystalline with average grain size smaller than 50 nm. Micro-Raman spectroscopy measurements show a broad feature around 300 cm^{-1} that may be related to a perturbed vibrational mode of the crystal due to Cr doping, thus providing evidence of effective incorporation of Cr in the ZnS lattice. Absorption and luminescence measurements as well as the kinetics of luminescence of Cr-doped ZnS thin films will be discussed.

C3.2
INFLUENCE OF INDIUM INCORPORATION ON RECOMBINATION DYNAMICS IN AlInGaN LAYERS GROWN BY PULSED METAL ORGANIC CHEMICAL VAPER DEPOSITON. Jae Ho Song, Jhang W. Lee, P.W. Yu, K-JIST, Dept of Information and Communications, Gwangju, SOUTH KOREA; Mee-Yi Ryu, AFIT, NRC Research Associate, Dept of Engineering Physics, Wright Patterson AFB,OH; C.Q. Chen, E. Kuokstis, J.W. Yang, G. Simin, and M. Asif Khan, University of South Carolina, Dept of Electrical Engineering, SC.

Data are presented on the effects of the indium incorporation into the AlInGaN layers on the photoluminescence (PL) intensities and decay times. The AlInGaN quaternary samples used in this study were grown on (0001) sapphire substrates by the specially designed pulsed MOCVD process at 750°C. The mol-fractions of aluminum were ~10 % and the mol-fractions of indium were varied by changing the interruption periods of the trimethyl-indium gas flow. The PL intensities and decay times were measured at various temperature ranges between 10 K and 300K. Our photoluminescence data show that the samples with a higher indium-mol-fraction yield red shift effects and also stronger peak intensities. The temperature dependent PL data show that for a higher indium AlInGaN layer the integrated PL intensities are more slowly reduced as the temperature approaches to the room temperature. We believe that such a slow reduction of PL intensity is caused due to strong localized states of segregated indium clusters. The PL lifetime measurement data show that the PL decay time tends to increase at a low temperature range up to 80K-150K, while it decreases above the temperature range, as observed from a good sample. In addition we observed a higher indium sample exhibits slower decrease of the decay time. These results indicate that the presence of the indium appears to keep up the radiative recombination processes effectively. Combining with the intensity data describe above, we can conclude that the high indium contents into the AlInGaN layers generate more localized low energy states, and these low energy states affects the recombination dynamics of the AlInGaN layers as the function of temperature. In result, the indium incorporation in AlInGaN quaternary can be a good candidate for an efficient emission source operating at room temperature.

C3.3
EVALUATION OF SIZE-DEPENDENT SPECTRAL PROPERTIES OF A SINGLE ZINC-OXIDE NANO-DISK. T. Yatsui and T. Kawazoe, Japan Science and Technology Corporation, ERATO, Tokyo, JAPAN; J. Lim and M. Ohtsu, Tokyo Institute of Technology, Interdisciplinary Graduate School of Science and Engineering, Kanagawa, JAPAN; W.I. Park and G.-C. Yi, Pohang University of Science and Technology (POSTECH), Department of Materials Science and Engineering, Kyungbuk, KOREA.

For future optical transmission systems, nano-scale photonic integrate circuits (ICs) [1], which are composed of sub-100 nm scale dots, are necessary to increase data transmission rates and capacity. A nano-scale ZnO dots is a promising material for a nano-scale UV light-emitting devices at room-temperature due to its wide band gap (3.37 eV) and large exciton binding energy (60 meV). To evaluate the optical properties and crystallinity of ZnO nanocrystallites, the optical properties must be measured with nano-scale resolution. In this study, we observed size-dependent features of individual ZnO nanocrystallites using a UV optical near-field technique. The ZnO single nano-disks (well width of 3-nm) with 6-nm ZnMgO barrier layers were grown on the ends of ZnO nanorods with 40-nm mean diameter. ZnO nanorods were grown epitaxially with homogeneous in-plane alignment as well as a c-axis orientation on sapphire substrates at 673 K without employing any metal catalysts. Using a collection-mode near-field optical spectrometer with a UV fiber probe of 100-nm aperture diameter, we obtained spatially and spectrally resolved photoluminescence (PL) images at 10 K. We used. From the near-field PL spectra, emission peak shift (10meV) of ZnO nano-disks were observed. This result indicates the quantum size effect originated from the fluctuation of the well width. Our results are the first to evaluate individual ZnO nano-disks, using an optical near-field method. [1] M. Ohtsu et al., IEEE Journal of Selected Topics in Quantum Electronics, (2002), in press.

C3.4

A NEW LUMINESCENCE SPECTRUM OF Z_nS:M_n FILMS GROWN BY CVD WITH LASER ABLATION M_n DOPING. Takashi Hirate, Makoto Ozawa, Tomomasa Satoh, Kanagawa University, Department of Electrical, Electronics and Information Engineering, Yokohama, JAPAN.

A ZnS:Mn thin film is well known as a fluorescent material for electroluminescent@devices and the various preparation methods of the ZnS:Mn films have been reported. The electroluminescent spectrum of ZnS:Mn films reported so far has a peak at about 585 nm with a wide half value width of about 40 nm independently on the preparation method. We succeed in preparing the ZnS:Mn films that show a new spectrum. The deposition method developed by us is a low-pressure thermal CVD system basically concerning the synthesis of ZnS matrix except that the solid Mn target is set in the deposition chamber. The two main precursors used to synthesize the ZnS are the metal Zn vapor and H_2S. The pulsed Nd:YAG laser beam is used to ablate the Mn target and to dope Mn into the growing ZnS film. The laser power density (Dp) at the surface of the Mn target is 0.12 to 0.83 W/mm^2. When the Dp is low the electroluminescence spectrum of the ZnS:Mn film is usual. However, when the Dp is high a new electroluminescence spectrum is observed. The obtained electroluminescence spectrum shows the two peaks of intensity at about 560 and 600 nm and the half value width of the whole is about 80 nm that is very wider than the usual value. The emission color is orange that is same as usual. This spectrum is more suitable for the light source because of the wide spread in the spectrum. This new spectrum found firstly by us is not caused by the interference, but intrinsic to the ZnS:Mn films prepared by this method. The reason of the occurrence of this new spectrum is not clear at present.

C3.5

Abstract Withdrawn.

C3.6

THE INVESTIGATION OF PREFERRED ORIENTATION GROWTH OF ZnO FILMS ON THE CERAMIC SUBSTRATES. Sheng-Yuan Chu, Te-Yi Chen and Walter Water, Dept of Electrical Engineering, National Cheng Kung University, TAIWAN, R.O.C.

Poly-crystal ZnO films with c-axis (002) orientation have been successfully grown on the lead-based ceramic substrates by r.f. magnetron sputtering technique. The deposited films were characterized as a function of deposition temperature, argon-oxygen gas flow ratio, and r. f. power. Crystalline structures of the films were investigated by X-ray diffraction (XRD) and scanning electron microscopy (SEM). Preferred deposition condition was found to show good film quality for SAW device applications. The phase velocity, electromechanical coupling coefficient and temperature coefficient of frequency of SAW devices with ZnO/ceramic structure were investigated.

C3.7

GaN AND AlGaN STRUCTURES CHARACTERIZATION BY VUV SPECTROSCOPIC ELLIPSOMETRY AND GRAZING X-RAY REFLECTANCE. Pierre Boher, Sophie Bourtault, Jean Philippe Piel, SOPRA, Bois-Colombes, FRANCE.

Reproducible growth of high quality (AlGaN) hetero-structures requires fast and efficient characterization of layer thickness and structural quality. Spectroscopic ellipsometry (SE) has long been recognized as a powerful technique for the characterization of conventional III-V hetero-structures. Different studies have already been devoted to the characterization of GaN and AlGaN by SE. In the proposed paper, we show that SE can be applied to the characterization of this kind of material not only to control the layer thickness and composition but also to understand the structural behavior of these complex structures. SOPRA is well known in the field of spectroscopic ellipsometry for more than 15 years. Different kinds of instruments are currently proposed with variable wavelength range from vacuum UV (140nm) to near infrared (18 μm). In the visible range and the near UV the optical indices of III-V nitrides is very dependent on their electronic structure and in particular the band gap energy which depends on the material composition. The vuv is extremely sensitive to the top surface and interface roughness. The proposed paper will give original results on the characterization of III-V nitrides by SE not only the UV-visible range but also in the infrared and in the vacuum UV. Results will be compared to other experimental techniques like grazing x-ray reflectance and x-ray diffraction. The interest to control the growth of this kind of material by rapid multichannel SE will be also examined.

C3.8

MODIFICATIONS OF LIGHT EMISSIONS IN ZnO THIN FILMS BY ULTRA-THIN METALLIZATION AND CHEMICAL TREATMENT. C.W. Lai, N.C. Hung and H.C. Ong, The Chinese University of Hong Kong, Dept of Physics, Shatin, HONG KONG.

In principle, metallization of ZnO modifies the electronic structure at the metal/ZnO interface, which ultimately alters the entire electrical and optical behaviors. However, study in this regard remains insufficient. In this work, we have focused on the light emission in ZnO due to metallization. We have carried out cathodoluminescence (CL) spectroscopy and imaging on ZnO thin films capped with an ultra-thin ($\sim$3 nm) layer of metal. Our results have indicated that metallization of ZnO can significantly passivate the undesirable deep level emissions in addition to enhance the band edge emission [1]. The increment of band edge emission has been observed to be as large as an order of magnitude but with a complete absence of deep level emissions. Depth- and temperature- dependent CL experiments have shown the effects do not only confine at the near-surface region but also extend to the interior bulk region. We have attributed the origin of these optical improvements to the space charge region which depletes the majority carriers at the surface and therefore reduces both the internal absorption as well as the density of oxygen vacancies that eventually will give rise to the deep level emissions [1]. X-ray photoelectron spectroscopy (XPS) and conductive atomic force microscopy (cAFM) has been conducted on the metallized ZnO films in order to confirm the formation of depleted region. In addition, the effects of chemical treatment on the light emitting properties of ZnO surface by different acidic and alkaline solutions have also been studied. [1]. C.W. Lai, N.C. Hung and H.C. Ong, "Modifications of light emissions in ZnO thin films by ultra-thin metallization" Appl. Phys. Lett. (submitted).

C3.9

ATOMIC AND ELECTRONIC STRUCTURE OF BORON-DOPED DIAMOND GRAIN BOUNDARIES STUDIED BY ARHVTEM AND AB-INITIO CALCULATION. Hiroyuki Togawa and Hideki Ichinose, Department of Materials Science, The University of Tokyo, Tokyo, JAPAN.

Atomic resolution high-voltage transmission electron microscopy (ARHVTEM) and electron energy loss spectroscopy (EELS) were performed on grain boundaries of boron-doped diamond, cooperated with the ab-initio calculation. Segregated boron was detected in $\{114\}$ $\Sigma 9$ and $\{112\}$ $\Sigma 3$ CSL boundaries. A Boron-doped polycrystalline diamond film was grown on a silicon substrate by the microwave plasma CVD method. B2O3 and a gas mixture of acetone and methanol were used as the boron and the carbon sources. The film was thinned by the Ar ion milling down to 5nm so that a projected potential image was obtained by JEM-ARM1250 ARHVTEM. Spherical and chromatic aberration of the objective lens are 1.0mm and 1.4mm,respectively. Even a dumbbell pair 0.09nm in projected separation was clearly imaged. Segregated boron was caught by the EELS spectra of the boundaries at 210 eV. Apparent differnce in image contrast between boron-doped and non-doped boundary was undetectable even by ARHVTEM. However, the change in atomic structure of the segregated boundary was successfully observed from the image. Based on the ARHVTEM image a segregted structure model was obtained via ab-initio relaxation.

C3.10

MOCVD ZINC OXIDE FILMS FOR WIDE BANDGAP APPLICATIONS. C.E. Rice, G.S. Tompa, L.G. Provost, N. Sbrockey, J. Cuchiaro, Structured Materials Industries, Inc., Piscataway, NJ.

ZnO is a wide bandgap (3.2 eV) semiconductor with potential application in LEDs, lasers, and transparent transistors, among other uses. These applications require uniform thickness, high quality materials (amorphous, poly- or single crystal), pinhole- and defect-free-single-and multilayer-conformal coatings. These attributes are generally best achievable by MOCVD. We have mounted a significant effort to develop automated MOCVD systems and process technologies for single and multicomponent oxides. The reactors use high speed rotation and are of a vertical orientation built to all metal UHV standards. We have demonstrated reactor scaled performance from $3'$ to $12'$ diameter depositions planes with modeling scales to $24'$ diameter. Metalorganics are used for zinc and dopant sources as well as dopant gases to optimize performance at low pressures. In this paper we will discuss our most recent results with epitaxial ZnO films, achievements in p-type doping, multilayer structures, and polycrystalline doped ZnO films.

C3.11

THERMOELECTRIC PROPERTIES OF NANO-STRUCTURED ZnO-BASED MATERIALS FABRICATED BY SPARK PLASMA SINTERING. Kyoung Hun Kim, Kwang Bo Shim, Dept of Ceramic

Engineering, CPRC, Hanyang Univ, Seoul, KOREA; Yong Jae Kwon, Dept of Nano Tech, CPRC, Hanyang Univ, Seoul, KOREA; Chang Sung Lim, Institute of Advanced Materials, CPRC, Hanseo Univ, Seosan, KOREA.

The nano-structured ZnO-based thermoelectric materials were fabricated by a spark plasma sintering (SPS) process. Three batch compositions, pure ZnO and $Zn_{1-x}M_xO$ (M=Al or Ni), were prepared from the nano-sized powders which were synthesized by a polymerized complex method. The SPS process was performed in the temperature range of 800 - 1000°C under an applied pressure of 40MPa for 5 minutes in argon atmosphere. The Seebeck coefficient, electrical and thermal conductivity of the specimens were measured with the variation of the temperature. Microscopic features of the specimens were investigated using a SEM-EDS & EBSD and a TEM. It was found that the addition of Al_2O_3 or NiO reduced the electrical conductivity of the sintered bodies, resulting from the presence of Al_2O_3 or NiO nano-particles in grain boundaries as a scattering center against electron conduction. Annealing heat-treatment was very effective for improving the electrical conductivity of the specimens by the formation of substitutional solid solution ZnO with Al_2O_3 or NiO. The oxygen vacancies induced by the solid solution phases also reduced thermal conductivity by the phonon scattering, which is very useful for improving the thermoelectric properties of the specimens.

C3.12

EFFECT OF Si LAYER IN THE ZnO THIN FILMS BY PULSED LASER DEPOSITION. Hong Seong Kang, Jeong Seok Kang, Seong Sik Pang, Eun Sub Shim, and Sang Yeol Lee.

ZnO thin films and ZnO-Si-ZnO multi-layer thin films have been deposited by pulsed laser deposition (PLD). And then, the films have been annealed at 300°C in oxygen ambient pressure. The optical and structural properties changed by Si layer in ZnO thin film. UV and visible peak position was shifted by Si layer. Electrical properties of the films were improved slightly than ZnO thin film without Si layer. The optical and structural properties of ZnO thin films and ZnO-Si-ZnO multi-layer thin films were characterized by PL (Photoluminescence) and XRD(X-ray diffraction method), respectively. Electrical properties were measured by van der Pauw Hall measurements.

C3.13

OPTICAL AND MORPHOLOGICAL PROPERTIES OF POROUS GaN. Todd L. Williamson, Diego J. Diaz, Paul W. Bohn, Dept of Chemistry and Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign, Urbana, IL.

Porous gallium nitride (PGaN) is produced by Pt-assisted electroless etching of GaN. Ultrathin Pt films are sputtered onto the surface of GaN, and etching is carried out in a methanol, hydrofluoric acid and hydrogen peroxide solution. The catalytic reduction of peroxide on the Pt surface injects electron-hole pairs on the GaN, which are subject to in-plane drift and ultimately assist the chemical etching. SEM analysis reveals that etching proceeds by first forming a network of small pores, after which they open up as cracks and eventually ridge structures form, with the porous network in trenches between the ridges. SEM cross sectional analysis and AFM section analysis reveal that the ridge structures are in the order of microns in height. The evolution of the morphology, from pores to ridges is presented. SEM cross section studies reveal that the pores are highly columnar and show little evidence of lateral branching, except at the surface. Cross sectional SEM also reveals structural information about the ridges and that there is etching underneath the ridges. The ridges seem to sit immediately on top of the porous network, and have a morphology which is different than the porous layer underneath. Raman spectroscopy shows that as etching proceeds, two TO modes of GaN, which are forbidden in the $z(xx)z'$ backscattering geometry that is used in data collection, grow in to the spectra. Typically the appearance of polarization-forbidden TO bands in processed semiconductors is taken as evidence of disorder in the lattice, although X-ray diffraction data does not validate such explanation. The correlation between the etched morphology and the optical properties will be addressed.

C3.14

IMPURITY-STATES ENGINEERING IN SEMICONDUCTORS WITH A WIDE-BAND GAP. Tetsuya Yamamoto, Dept. of Kochi University of Technology, Kochi, JAPAN.

We propose an impurity-states engineering technology for large-scale applications in wide-band-gap semiconductors-based electronic and optical devices. For p-type doped semiconductors, such as N-doped ZnO (ZnO:N), ZnS:N and GaN:Mg, we find a large energy lowering from ionic polarization and a narrow impurity band at the top of the valence band on the basis of the analysis of the calculated data of the electronic band structures obtained by ab initio electronic band structure calculations. These are due to the significant difference between the static and optical dielectric constants of ZnO, ZnS and GaN, which have a fair degree of ionic character. At high doping levels, the acceptor orbitals will start overlapping with each other, is to form an impurity band. The effect of the impurity band formation will therefore tend to delocalize the hole with low effective masses and high mobilities, and its energy will be decreased by W/2, where W is the impurity-band width. In order to realize the delocalized holes, it is required that the value of W/2 is larger than the energy lowering from ionic polarization. It is our codoping method that solves the doping problem described above: The condition for the delocalization of the holes will be satisfied. We will discuss the differences in p-type doping between GaN, ZnO and ZnS. References: T. Yamamoto, physica status solidi (a) 193, No.3 (2002) 423-433.

C3.15

PYRAMIDAL-PLANE ORDERING IN AlGaN ALLOYS. M. Benamara, M. Albrecht and H.P. Strunk, Universität Erlangen-Nürnberg, Institut für Werkstoffwissenschaften, Erlangen, GERMANY; L. Kirste, D.G. Ebling, and K.W. Benz Freiburger, Materialforcshungszentrum, Universität Freiburg, Freiburg, GERMANY.

We report the first identification of long-range ordering in AlGaN compounds along the pyramidal normals by transmission electron microscopy. This ordering consists of the alternative stacking of GaN and AlN layers on {1-101} planes and is evidenced by the comparison of experimental diffraction patterns along [01-10] and [11-20] zone axis with calculated patterns. A formation model of this ordering is presented. It is based upon Ga incorporation on reduced-N coordination sites that are located at step edges on {1-101} pit facets.

C3.16

THE PHOTOLUMINESCENCE STUDY OF EXCITON-EXCITON COLLISION PROCESS OF ZnO MICRORODS AND THE Mn PASSIVATION. Y.C. Liu[a], D.G. Zhao[a], X.T. Zhang[a], D.Z. Shen[a], D.O. Henderson[b] and R. Mu[b]; [a]Key Laboratory of Excited State Processes, CIOFMP-CAS, Changchun, CHINA; [b]Chemical Physics Laboratory, Dept of Physics, Fisk University, Nashville, TN.

ZnO, as a wide bandgap semiconductor material, is known to have many technological applications. With a 60 meV exciton binding energy, the brightest light emission, and the recent breakthrough of fabricating p-type, ZnO has become one of the most desirable and cost effective room temperature blue and UV solid state emitter and detector. In this presentation, we will report 1) the room temperature P band emission from ZnO and 2) temperature and excitation intensity dependent photoluminescence (PL) measurements. The room temperature P band emission resulted from an exciton-exciton collision process. The temperature dependent PL showed that P band emission process was also thermally activated. The excitation intensity dependent measurement illustrated that the P band emission occurred at much lower excitation intensity than that reported in literature. Higher order transitions were also observed at the excitation intensity of 7.1 kW/cm^2 or higher. A simple theoretical model was proposed to explain the possible underling mechanisms. It was suggested both the density and activity of free exciton played important role in the exction-exciton collision process. In addition, we also investigated Mn-passivated nanocrystalline ZnO thin films prepared by thermally oxidizing the ZnS:Mn thin films. The photoluminescence spectra showed that with an optimized Mn doping concentration the green emission was completely quenched and only UV emission was observed.

C3.17

STRUCTURAL TEM STUDIES AND CONTACT RESISTANCE OF Au/Ni/Ti/Ta/n-GaN OHMIC CONTACTS. D.N. Zakharov and Z. Liliental-Weber, Lawrence Berkeley National Laboratory, Berkeley, CA; A. Motayed and S.N. Mohammad, Material Science Research Centre of Excellence, Howard University, Washington, DC.

Low resistance ohmic contacts with good thermal stability are necessary for the application of GaN in devices such as light emitting diodes, laser diodes, and heterostructure field effect transistors. The aim of this work was to study a correlation between the microstructure and contact resistance of ohmic contacts to n-GaN. Two types of samples were evaluated. For both types a 5nm thick Ta layer was deposited on (0001) GaN grown by MOCVD on sapphire substrate, followed by a 50nm thick Ti layer, a 20nm Ni layer, and a 5nm Au layer. Samples were then annealed for 45 sec. in argon atmosphere at two different temperatures: 750°C and 775°C, respectively. The sample A, which was annealed at lower temperature, had lower contact resistance ($5 \times 10^{-6}\ \Omega\cdot cm^2$) compared to sample B ($6 \times 10^{-5}\ \Omega\cdot cm^2$), which was annealed at higher temperature. Cross-sectional transmission electron microscopy together with energy dispersive X-ray spectroscopy was used for identification of observed phases formed due to solid state reactions between the metal layers and the GaN film. Both contacts showed multilayered morphology. Some consumption of the GaN layer was observed in both samples. However, different compounds were found at the interface with GaN: Au-Ni alloy for sample A and Au-Ta for sample B. In each case alloys grew epitaxially on basal plane of GaN with epitaxial relationships (111)Au-Ni or (111)Au-Ta ‖ (0002)GaN. This different alloy formation at the interface with GaN is believed to be responsible for observed difference in contact resistance. Formation of other phases above the interfacial area will be also discussed in connection with the performance of ohmic contacts.

C3.18

CATHODOLUMINESCENCE, ELECTROLUMINESCENCE, AND DEGRADATION OF ZnCdSe QUANTUM WELL LIGHT EMITTING DIODES. A. Nikiforov, and G.S. Cargill III, Department of Materials Science and Engineering, Lehigh University, Bethlehem, PA; M.C. Tamargo, S.P. Guo^a, Department of Chemistry, City College-CUNY, New York, NY; Y.-C. Chen, Department of Physics, Hunter College, CUNY, New York, NY; ^{a}Present address: EMCORE Corporation, Somerset, NJ.

We have studied luminescence characteristics and degradation of red (644nm - 665nm) ZnCdMgSe/ZnCdSe/ZnCdMgSe QW LEDs grown by MBE and lattice matched to InP substrates. Results have been obtained from time-resolved and bias-dependent cathodoluminescence spectroscopy and imaging, and from electroluminescence spectroscopy. Reversible and irreversible variations in luminescence intensity up to 40% were observed on 1 sec to 1000 sec timescales during electron bombardment. Irreversible wavelength red shifts up to 2 nm were also observed. Cathodoluminescence from the QW LED was modeled by calculating bias-dependent energy levels, envelope wave functions, and overlap integrals for finite and infinite QWs, following the approach of G. Bastard et al. (Phys. Rev. B (1983)). Electron beam generated minority carrier currents were also calculated for the QW structure, including bias-dependence of the depletion lengths. These model calculations agree qualitatively, but not quantitatively, with bias-dependent intensity and wavelength changes observed in the experiments.

C3.19

Abstract Withdrawn.

C3.20

EFFECT OF Fe AND Mn DOPING IN ZnO THIN FILMS DEPOSITED BY PULSED LASER DEPOSITION. P. Bhattacharya, R.R. Das, K. Uppireddi, and R.S. Katiyar, Department of Physics, University of Puerto Rico, San Juan, PR.

Zinc oxide and related wide bandgap semiconductors have drawn considerable attention for application in short-wavelength semiconductor diode lasers. It has been experimentally demonstrated that the 3d transition metal (Tm) atoms are soluble up to several mole fraction (~0.35) in ZnO host, which made it a promising candidate for fabrication of dilute magnetic semiconductors with a high Curie temperature. Zn$_{1-x}$Tm$_x$O (x=0-0.15, Tm= Mn, Fe) thin films were grown by pulsed laser deposition technique on (0001) Al$_2$O$_3$ substrates. One mole % of In$_2$O$_3$ was also added to the target in order to increase the conductivity of the films. During deposition the substrate temperature was varied in the range of 300-600°C with an oxygen partial pressure of 10^{-3} to 10^{-5} Torr. The hexagonal structure of ZnO was retained with Mn and Fe dopings, however, the crystalline quality of the films was degraded. Optical absorption data showed a shift of ZnO bandgap towards higher energy with increase in Mn contents. The films were highly conducting as measured by Van der Pauw technique. The temperature variation of magneto-resistance of the doped films will be presented in close correlation with the deposition parameters and doping concentrations. This work is supported in parts by DOD-F49620-01-1-1004 and NASA-NCC5-518 grants.

C3.21

CHANGES IN THE ORDINARY AND EXTRAORDINARY REFRACTIVE INDICES FOR DOPED ZnO EPITAXIAL LAYERS. Ailing Cai and John Muth, ECE Dept., North Carolina State University, Raleigh NC; Hugh Porter and J. Narayan, Materials Engineering Dept, North Carolina State Univeristy, Raleigh, NC.

The ordinary, and extraordinary indices of refraction, film thickness and waveguide mode information of zinc oxide, zinc oxide doped with nitrogen and zinc oxide doped with tellurium were measured using a prism coupling wave-guide technique. The films were grown on c-axis sapphire substrates by pulse laser deposition. High accuracy waveguide measurement shows that the ordinary and extraordinary indices of refraction of the ZnO samples change with the introduction of nitrogen or tellurium and were correlated with electronic properties of the resultant films. The crystal structure and optical properties of the films were also characterized by using x-ray rocking curve, transmission electron microscopy, cathodoluminescence and optical absorption methods.

C3.22

HIGH PERFORMANCE AlGaN-BASED VISIBLE-BLIND RESONANT CAVITY ENHANCED SCHOTTKY PHOTODIODES. Ibrahim Kimukin, Ekmel Ozbay, Bilkent Univ, Dept of Physics, Ankara, TURKEY; Necmi Biyikli, Tolga Kartaloglu, Orhan Aytur, Bilkent Univ, Dept of Electrical and Electronics Engineering, Ankara, TURKEY.

We have designed, fabricated and characterized high performance visible-blind Schottky photodiodes using resonant cavity enhanced (RCE) detector structure. We have utilized MOCVD-grown AlGaN/GaN epitaxial layers. Bottom mirror of the resonant cavity was formed by a 15 pair AlGaN/AlN Bragg mirror centered around 350 nm. A 70 nm thick GaN absorption layer was used. Indium-tin-oxide (ITO) and gold (Au) layers were used as Schottky contacts on GaN. Detectors were fabricated using a 5-step microwave compatible fabrication process: n+ ohmic contact formation, mesa isolation, Schottky layer deposition, surface passivation and interconnect metal deposition. The resulting devices had breakdown around 8 V and ~2V turn-on voltage. Au-Schottky devices had slightly lower dark current values than ITO-Schottky photodiodes. Both detectors had less than 10 pA leakage at 2 V reverse bias. Spectral quantum efficiency (QE) was measured using Xenon lamp and monochromator. The photodiodes were illuminated using a UV-fiber. With a lock-in amplifier, the photocurrent was measured in the 300-400 nm wavelength range. The resonant peak was observed at 344 nm with a maximum QE of 38% for ITO and 34% for Au-Schottky detectors. The corresponding peak responsivity values were 104 mA/W and 93 mA/W respectively. More than 3 order of magnitude UV/visible rejection ratio was achieved. To characterize the high-frequency response of our devices, we frequency doubled the output of a picosecond mode-locked Ti:sapphire laser to generate 359 nm pulses. The 3-dB bandwidths achieved for ITO and Au-Schottky detectors were 150 MHz and 780 MHz respectively. These are the first measured high-speed results for visible-blind RCE photodiodes. As a result we have demonstrated the first high-speed visible-blind RCE Schottky photodiodes with ITO and Au Schottky contacts.

C3.23

OPTICAL AND STRUCTURAL INVESTIGATION OF AlN GROWN ON SAPPHIRE WITH REACTIVE MBE USING RF NITROGEN OR AMMONIA. F. Yun, L. He, M.A. Reshchikov, and H. Morkoç, School of Engineering and Physics Department, Virginia Commonwealth University, Richmond, VA; S. Bai, Y. Shishkin, R.P. Devaty, and W.J. Choyke, Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA.

AlN is a very important material in the III-nitride family. Knowledge of optical and structural properties of AlN is highly desired for both fundamental physics and device applications where AlGaN is in the core of many device structures. In the present study, AlN epitaxial layers in a thickness range of 0.065 to 0.6 microns have been grown on double-side polished *c*-plane sapphire by MBE using RF nitrogen or ammonia as the nitrogen source. Al source temperature was about 1000°C, and the growth temperature was in the range of 870-950°C. The samples were characterized by XRD, low temperature PL and room temperature absorption measurements. There is a general trend of improvement for the crystalline quality with increased film thickness. Specifically, The XRD diffraction [002] peak FWHM varies from 380 arcsec to 84 arcsec when the thickness of the AlN films was increased from 65 nm towards 0.6 μm. All the samples grown with NH$_3$, representing N-rich conditions, exhibited optical bandgap exceeding 6 eV at RT. For samples grown with RF nitrogen source, we found that those grown with higher nitrogen flow (equivalent pressure of 8.3-9.4 x 10^{-5} Torr) exhibited optical bandgaps larger than 6.0 eV, regardless of the XRD results. Other samples grown with lower nitrogen partial pressure (1.0-4.5 x 10^{-5} Torr) have optical bandgaps less than 6.0 eV, regardless of thickness of samples and the XRD results. SIMS measurements were carried out on representative samples to find out the probable cause of variation of measured bandgap of AlN under different growth conditions. Preliminary results suggest that N-rich AlN films have their bandgaps near the expected value of 6.2 eV whereas the N-lean AlN films exhibit lower effective bandgaps. At this point it is not clear why the lack of nitrogen could cause a red shift in the band edge.

C3.24

SINGLE-SOURCE CHEMICAL VAPOR DEPOSITION AND N-DOPING OF 3C-SiC FILMS IN A LPCVD REACTOR. M.B.J. Wijesundara, Department of Chemical Engineering, University of California, Berkeley, CA; G. Valente, Dipartimento di Chimica, Ingegniria Chemica Materiali "G. Natta", Politecnico di Milano, Milan, ITALY; R.T. Howe, A.P. Pisano, Departments of Electrical Engineering and Computer Science, and Mechanical Engineering, University of California, Berkeley, CA; C. Carraro, R. Maboudian, Department of Chemical Engineering, University of California, Berkeley, CA.

The deposition of 3C-SiC films on Si(100) wafers is investigated using the precursor 1,3-disilabutane in a conventional low pressure chemical vapor deposition system. The effects of the deposition temperature and flow rates on the chemical, structural, and growth properties SiC films are examined. X-ray photoelectron spectroscopy shows that the films deposited at temperature as low as 650°C are indeed carbidic. X-ray diffraction analysis confirms the films to be amorphous up to 750°C, above which they become polycrystalline. SiC film thickness is highly uniform at 800°C and lower, essentially independent of the flow rate. Controlled doping of 3C-SiC film is achieved by the addition of ammonia to the reactor feed gas. Electrical conductivity is found to decrease from 10 $\Omega\cdot$cm for undoped films to 0.02 $\Omega\cdot$cm for doped films deposited at 800°C. This has been achieved without significantly changing the growth rate and crystalline quality of the 3C-SiC thin films.

C3.25
SOLID-STATE SEMICONDUCTOR QUANTUM DOT-SENSITIZED TITANIUM DIOXIDE NANOCRYSTALLINE SOLAR CELLS. Tingying Zeng, Elizabeth Gladwin, Richard O. Claus, NanoSonic, Inc., Blacksburg, VA.

Semiconductor quantum dots (QDs), as photosensitizers, are very interesting for wide-band gap semiconductor photovoltaic devices, but the produced liquid solar cells suffer from severe photostability problems, such as corrosion and photo-corrosion which results from chemical reactions of charge carriers, leading to photoinduced particle growth, mass transport phenomena, and other effects. Solid-state sensitized wideband gap semiconductor nanocrystalline Grätzel solar cells have been recognized as a very promising new generation of photovoltaic devices for solar energy conversion. They are currently under intensive investigation. Most related research focuses on the solid-state dye-sensitized solar cells, which have been demonstrated to exhibit greater than 50% incident photon-to-electron conversion efficiency (IPCE) and overall efficiencies greater than 3%. Consequently, sensitizing semiconductor QDs are attracting great interest as photosensitizers in development of these solid-state new organic-inorganic hybrid Grtzel solar cells. The solid-state QD-sensitized photovoltaic systems may provide desired environment for efficient QD sensitization, producing high performance solar cells - both in stability and in high IPCE, and thus in high overall efficiency. In this report, InP quantum dots with particle size in the range of less than 8nm were synthesized using colloidal chemistry methods. Extensive characterizations of the InP QDs were performed using UV-visible spectrometry, TEM and XRD. InP QD-sensitized solid-state TiO$_2$ nanocrystalline Grtzel thin film solar cells were designed and fabricated by self-assembly processing using spiro-OMeTAD as the hole-transport material. Fluorescence spectroscopy confirms the charge transfer between the excited InP QD and the TiO$_2$ anatase nanocrystal particle within an InP-stained porous TiO$_2$ thin film. Primary prototype InP QD sensitized solid-state TiO$_2$ nanocrystalline solar cells with illuminated device areas of 25mm^2, produced greater than 480mV open circuit photovoltage, and short-circuit current greater than 0.035mA/cm^2 under the illumination of a solar simulator with integrated spectral power of 58mW/cm^2. Improvement of the cell performance efficiency is underway.

C3.26
A STUDY OF SUFACE ACOUSTIC WAVE PROPERTIES OF AlN ON SAPPHIRE SUBSTRATE. Jianzeng Xu, Greg Auner, Hao Ying, Wayne State University, Electrical and Computer Engineering Dept, Detroit, MI.

AlN films were deposited on Al$_2$O$_3$ (0001) and Al$_2$O$_3$ (1$\bar{1}$02) by plasma source molecular epitaxy system. X-ray data show that highly orient epitaxial growth of c-plane AlN on Al$_2$O$_3$ (0001) and a-plane AlN on Al2O3 (1$\bar{1}$02) have been achieved. Both surface acoustic wave and surface transverse wave devices have been fabricated on these films. The relationship of the acoustic phase velocity in terms of propagation direction and KH (wave number times film thickness) parameter has been studied. The electromechanical coupling coefficient has studied for both c-plane and a-plane AlN films. Temperature effect of the devices is also presented and a near linear temperature coefficient is derived.

C3.27
LUMINESCENCE BEHAVIOR OF GaN CO-DOPED WITH Si AND C. C.H. Seager, D.R. Tallant, A.F. Wright, Sandia National Laboratories, Albuquerque, NM; J. Yu and W. Gotz, Lumileds Lighting, San Jose, CA.

GaN samples, containing various concentrations of carbon and doped intentionally with silicon, have been grown heteroepitaxially on sapphire using Metal-Organic-Chemical-Vapor-Deposition. Previous electrical and optical data, together with Density Functional calculations, have suggested that carbon is incorporated at acceptor and donor substitutional sites in this material; the relative importance of each is determined by the Fermi level position and the growth conditions. Here the luminescence behavior of these materials is examined in more detail, including spectral, temperature, and time dependences under ultraviolet light and electron beam excitation conditions. Particular attention is given to the commonly observed "yellow band" at $\sim$2.2 eV, a blue luminescence at $\sim$3 eV, seen only in samples where carbon is the majority dopant, and ultraviolet 0, 1, and 2-phonon bands near $\sim$3.3 eV. Our data suggest that the blue and uv bands are both donor-acceptor related, with the final state being the negatively charged state of a carbon atom on a nitrogen substitutional site. In samples where both blue and yellow luminescence bands are visible, we observe metastable changes in their intensities after excitation at low temperatures. While similar observations of luminescence metastability in GaN have recently been reported by several other groups, this work is the first to suggest a specific role for carbon impurities in this effect. *This work was supported by the Basic Energy Sciences Office of the Department of Energy. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-ACO4-94AL85000.

C3.28
III-NITRIDE ULTRAVIOLET OPTICAL MODULATOR. Andrew Oberhofer, John Muth, Ailing Cai, ECE Dept, North Carolina State University, Raleigh, NC; Mark Johnson, Materials Engineering Dept, North Carolina State University, Raleigh, NC; Zhiyun Chen, Erin Fleet, and Gregory Cooper, Pixelligent Corporation, Alexandria, VA.

Planar arrays of ultraviolet optical modulators were designed, fabricated, and characterized. GaN was the semiconductor material chosen for the active device layer due to its favorable optoelectronic properties: high exciton binding energy, high breakdown field, and optical band edge location. The modulator operates by changing the absorption at the band edge due to the excitonic resonance with an electric field. By applying high electric fields to the active layer the exciton resonance is suppressed, which lowers the absorption at the exciton peak and increases the absorption below the optical band edge. 20 percent modulation was obtained at 364 nm.

C3.29
STATISTICAL ANALYSIS OF MICROPIPE DEFECT DISTRIBUTIONS IN SILICON CARBIDE CRYSTALS. Troy Elkington, II-VI Inc., Saxonburg, PA; Ejiro Emorhokpor, Tom Kerr, II-VI Inc., Pine Brook, NJ; John Chen, Kevin Essary, Mike Golab, Richard Hopkins, II-VI Inc., Saxonburg, PA.

The density and distribution of micropipes, a screw dislocation with a hollow core defect in SiC, are significant criteria for SiC wafer selection in device fabrication. For this reason the measurement of micropipes in SiC is an important problem. The micropipe distributions of 2$''$diameter 6H SiC wafers from three different PVT furnace designs in three different laboratories were statistically characterized. The micropipe distributions were measured in two ways: by KOH etching the wafer and then counting the hexagonal pits formed on the wafer surface using a microscope and imaging software; and by manually counting with an optical transmission microscope the micropipes within a grid of 0.5mm squares superimposed over the wafer. None of the wafers had a random distribution of micropipes i.e. they did not follow a Poisson distribution. The micropipes were found to associate with each other i.e. there is a higher probability of there being other micropipes near a location where a micropipe has been found. Sampling methods to reduce the total number of samples required for accurate micropipe measurement have been explored. We have analyzed the repeatability of the optical transmission microscopy and KOH etch methods of micropipe characterization and report the results. Finally the degree of correlation between transmission microscopy and KOH etch micropipe measurement methods is studied and reported.

C3.30
CATHODOLUMINESCENCE AND TEM CHARACTERIZATION OF LEO GaN. Eva Campo and G. S. Cargill III, Lehigh University, Bethlehem, PA; C.K. Inoki and T.S. Kuan, University of Albany, SUNY, Albany, NY; M. Pophristic, EMCORE Corp., Somerset, NJ; I. T. Ferguson, Georgia Institute of Technology, Atlanta, GA.

CL and TEM imaging and CL spectroscopy were used to characterize thinned, cross-section samples of LEO GaN grown by MOCVD. Multiple samples were grown and investigated. This work considers two samples produced under the same growth conditions except for the orientation of the lithographic mask. In the sample with the mask oriented along [1 -1 0 0], GaN stripes grew with trapezoidal shape. With the mask oriented along [1 1 -2 0], stripes grew with pyramidal shape. CL imaging at lower resolution with unthinned cross-section samples revealed a strong near band edge (NBE) luminescence in the overgrown LEO regions for both mask orientations. Strong deep level (DL) luminescence was observed in material above the mask windows. Both CL emissions were grossly correlated with the distributions of dislocations shown by TEM, as expected. Additionally, a region with little NBE or DL emission was seen in the central region of the [1 1 -2 0] pyramidal sample. This absence of luminescence could be due to threading dislocations seen in TEM bending away from the central region of the pyramid. CL imaging at higher resolution, with lower beam current on thinned samples, shows more details of the distribution of luminescence. For the [1 -1 0 0] sample, DL emissions are seen to extend partially into the LEO regions where TEM reveals few dislocations and no c-axis tilt. These parts of the LEO regions with strong DL do not show NBE, maintaining the expected complementary character of NBE and DL emissions. Moreover, both DL and NBE intensities are very weak in the top 0.5 μm regions of the stripe and this correlates well with the low defect density found in TEM images in this region.

C3.31

BARRIER MATERIAL IMPROVEMENT IN AlGaN/GaN MICROWAVE TRANSISTORS UNDER GAMMA IRRADIATION TREATMENT. S.A. Vitusevich, ISG, Forschungszentrum Jülich, Jülich, GERMANY; M.V. Petrychuk, Taras Shevchenko, Kiev National University, Kiev, UKRAINE; N. Klein, S.V. Danylyuk, ISG, Forschungszentrum Jülich, Jülich, GERMANY; A.E. Belyaev, R.V. Konakova, A.Yu. Avksentyev, Institute of Semiconductor Physics, NASU, Kiev, UKRAINE; B.A. Danylchenko, Institute of Physics, NASU, Kiev, UKRAINE; V. Tilak, J. Smart, A. Vertiatchikh, and L.F. Eastman, School of Electrical Engineering, Cornell University, Ithaca, NY.

Microwave transistors manufactured on the basis of AlGaN/GaN heterostrustures demand for improvement of material characteristics to attain high power and high speed operation. Today, GaN-based High Electron Mobility Transistors (HEMTs) possess still comparative high level of leakage current due to large dislocation density and material layers imperfections. To decrease the leakage current an intermediate dielectric or ferroelectric layer is grown before metalization to the barrier region. However, this layer results in lowering of the operating frequency due to an increase of capacitance. In this contribution we report an investigation of transport and noise properties of HEMTs irradiated by gamma-quanta. At a certain dose of gamma irradiation an improvement of barrier properties of the transistors was observed. The investigated structures are high performance AlGaN/GaN HEMT devices grown by organic metallic vapour phase epitaxy on sapphire substrates. Each structure consists of the following layers: a nucleation AlN layer, an undoped GaN buffer layer and an AlGaN (33% Al) undoped barrier layer. The devices with several gate lengths ($150-350\ nm$) and widths ($100-400\ \mu m$) were investigated. I(V) and low frequency noise measurements have been carried out at room temperature. The gamma irradiation was provided by Co^{60} gamma rays with doses in the range of $10^4-10^9\ Rad$ at room temperature. Improvement of the barrier characteristics was registered after a dose of $2\times10^6\ Rad$. Considerable decrease of leakage current (up to 5 times) was established. The result is accompanied by a decrease of extra noise connected with capture/emission by/from the traps related to defects in the barrier region. Novel features connected with deviation of the low-frequency noise spectra from 1/f flicker noise were observed and analysed. This work is supported by the Office of Naval Research under Grant No. N00014-01-1-0828 (Project Monitor Dr. Colin Wood). A.E.B. acknowledges Deutsche Forschungsgemeinschaft for research grant.

C3.32

A NOVEL SAPPHIRE SURFACE GROWTH PROCESS AND NEW DESIGN FOR LED SUBSTRATE APPLICATIONS. Hyoungjoon Park, Richard P. Vinci, and Helen M. Chan, Lehigh Univ, Dept of Materials Science & Engineering, Bethlehem, PA.

At present, sapphire substrates for blue LED and laser diode applications are prepared by a combination of mechanical and chemical polishing. The ensuing device performance is highly dependent on the quality of the surface finish and degree of subsurface damage. Results will be presented on a new approach capable of generating a pristine surface layer, starting with a sapphire substrate mechanically polished to a 3 micron diamond finish. The process consists of oxidation of a thin surface film of Al, followed by grain growth of the underlying single crystal substrate. Development of the surface layer was studied using XRD, SEM, OIM (orientation image microscopy), AFM and TEM. Thin foil samples were prepared using FIB (focused ion beam) instrumentation. The influence of coating temperature and heat treatment time/temperature on the final surface finish will be discussed, together with the mechanism of solid-state conversion from polycrystalline alumina to sapphire single crystal. The proposed method has the potential to be more cost-effective than conventional techniques and is also applicable to non-planar substrates. Finally, this approach opens up new possibilities for substrate design through patterning of the Al thin film prior to conversion.

C3.33

INFLUENCE OF LAYER DOPING AND THICKNESS ON PREDICTED PERFORMANCE OF NPN AlGaN/GaN HBTs. K.P. Lee, Univ of Florida, Dept of Materials Science and Engineering, Gainesville FL; A. Dabiran and P.P. Chow, SVT Associates, Eden Prairie, MN; S.J. Pearton, Univ of Florida, Dept of Materials Science and Engineering, Gainesville FL; F. Ren, Univ of Florida, Dept of Chemical Engineering, Gainesville FL.

The effects of base doping and thickness on dc current gain, collector-emitter saturation voltage, saturation current and collector-emitter breakdown voltage of GaN/AlGaN heterojunction bipolar transistors were investigated using a drift-diffusion transport model. Given the low ionization efficiency of Mg acceptors in the base, it is important to design structures that avoid depletion of the base layer. The presence of a resistive base causes current to flow directly to the collector, severely reducing gain. The effect of emitter doping on current gain and of collector doping on the breakdown voltage of the C-E junction were also investigated.

C3.34

CHARACTERIZATION OF HIGH QUALITY CONTINUOUS GaN FILMS GROWN ON Si-DOPED CRACKED GaN TEMPLATE. C.B. Soh, J. Zhang, H.F. Lim and S.J. Chua, Centre of Optoelectronics, Department of Electrical and Computer Engineering, National University of Singapore, SINGAPORE; D.Z. Chi, Institute of Materials Research and Engineering, SINGAPORE.

In this paper, deep level defects in high quality continuous GaN films grown over a cracked Si-doped GaN template has been studied using digital deep level transient spectroscopy and TEM. From TEM observation, it is found that the density of pure screw dislocations has been effectively suppressed while pure edge dislocations remained in substantial quantity. From DLTS measurement, trap levels at E$_c$ -E$_T$ $\sim$0.11-0.12 eV, 0.24-0.27eV, 0.60-0.63 eV were detected in the high quality GaN layer. DLTS measurement was also carried out on the underlying cracked Si-doped GaN template after the top high quality continuous GaN film was removed by plasma etching. An additional defect level at E$_c$ -E$_T$ $\sim$0.37eV was detected which we assigned to that of pure screw dislocation. Both the trap levels E$_c$ -E$_T$ $\sim$0.24-0.27 eV, 0.60-0.63eV are believed to have originated from mixed screw/edge dislocation based on the observation of the logarithmic capture behavior and their response to reverse bias variation. Trap level at E$_c$ -E$_T$ $\sim$0.24-0.27eV, however experiences a more drastic increase in transient capacitance (i.e. in trap concentration) compared to that of the E$_c$ -E$_T$ $\sim$0.60-0.63 eV after plasma etching, illustrating that the latter is attributed to a higher proportion of edge dislocation. The 0.11-0.12eV trap level, which exhibits an exponential capture kinetic, is believed to be related to nitrogen vacancies. It is very promising that this continuous GaN layer can be used as a template to grow any device structure and the underneath cracked Si-doped GaN layer may help to release stress during device structure growth. This can bring about a cracked free epilayer for subsequent device fabrication.

C3.35

STRUCTURAL AND OPTICAL PROPERTIES OF InGaN/GaN MULTI-QUANTUM WELL STRUCTURES WITH DIFFERENT INDIUM COMPOSITIONS. Chang-Soo Kim[a], Sam-Kyu NOH[a], Sunwoon KIM[b], Kyuhan LEE[b] and Jay P. SONG[c]. [a]National Research Laboratory, Materials Evaluation Center, Korea Research Institute of Standards and Science, Taejon, KOREA; [b]Optronix Inc., Taejon, KOREA; [c]SongJee Industrial Corporation, Sungnam, KOREA.

The structural and optical properties of InGaN/GaN multiple quantum wells(MQWs) grown on sapphire by MOCVD have been investigated using HRXRD(high-resolution X-ray diffraction), PL(photoluminescence) and TEM(transmission electron microscope). The samples consisted of 10 periods of InGaN wells with 6.0nm thickness. The designed indium compositions were 15, 20, 25 and 30% (samples C15, C20, C25, C30, respectively). The thickness of GaN barrier was 7.5nm. For HRXRD, $\omega/2\theta$-scans and ω-scans for GaN (0002) reflections, and reciprocal space mapping(RSM) around GaN $(10\bar{1}5)$ lattice points were employed. The MQW in sample C15 maintained lattice coherency with the GaN epilayer underneath, the MQWs in the other samples, however, experienced lattice relaxation, and the degree of relaxation for sample C20 was 6.4%. The crystallinity of the samples decreased considerably with In concentration. As In composition increased, PL peak energy showed a red-shift, and the FWHM of the peaks increased. The increase in the FWHM is attributed to the defects due to the lattice relaxation. For the PL spectra of samples C15, C20 and C25, double peaks were observed, and even for C25 the PL peak intensity increased sharply in spite of the defects due to the lattice relaxation of the sample. It is concluded that the results are related to the In-rich region due to indium phase separation which was observed by TEM image. And the critical conditions for indium phase separation will be discussed.

C3.36

Abstract Withdrawn.

C3.37

ELECTRICAL CHARACTERIZATION OF DEFECTS INTRODUCED IN 4H-SiC DURING HIGH ENERGY PROTON IRRADIATION AND THEIR ANNEALING BEHAVIOR. M. Ahoujja, Department of Physics, University of Dayton, Dayton, OH; H.C. Crocket, M.B. Scott, Y.K. Yeo, and R.L. Hengehold, Air Force Institute of Technology, Wright-Patterson AFB, OH.

The robust nature of SiC makes it an ideal material in both space-based and high temperature environments where conventional Si and GaAs based devices would fail. However, a clear understanding of how SiC behaves under a radiation environment is required before it is incorporated in devices for space applications. In this paper, we report on the electrical properties of defects introduced in epitaxial 4H-SiC by 2 MeV protons using deep level transient spectroscopy (DLTS). After proton irradiation with a dose of about [∼]1.5E14 cm-2, the DLTS measurements were made, and the rate window shows a single broad peak between 280 and 310 K. The intensity of this peak remains unchanged after a thermal anneal at 900°C for 20 min. However, after annealing at or above 1100°C, the peak intensity gradually decreases with anneal temperature up to 1500°C, indicating a decrease in the defect concentration. Because a complete damage recovery of the SiC is not observed even after annealing at 1500°C, we believe a higher temperature annealling is necessary for a complete recovery. Using a curve fit analysis, a set of deep levels of defect centers were found with energy ranging between 585 and 732 meV. These traps do not exhibit a significant change in the trap energy or capture cross-section parameters as a function of anneal temperature, but the decrease in the trap density with increasing anneal temperature demonstrates a damage recovery.

C3.38

A COMPARISON BETWEEN GaN FILMS ANNEALED UNDER HIGH PRESSURE AND THOSE ANNEALED IN FLOWING ARGON. Francis Kelly, Rajiv K. Singh, Stephen J. Pearton, Univ. of Florida, Dept. of Materials Science and Engineering, Gainesville, FL; James Fitz-Gerald, Univ. of Virginia, Dept. of Materials Science and Engineering, Charlottesville, VA.

We present the results of a comparison study between MOCVD-grown GaN films annealed in a novel high-pressure annealing furnace and those annealed in a conventional tube furnace under flowing argon gas at similar temperatures for similar times. Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), Photoluminescence (PL) and Cathodoluminescence (CL) spectroscopy were used to investigate the effects of the high-pressure anneals in comparison to those which were annealed with the more conventional method. The effects of the anneals on surface topology, microstructure, crystalline quality, composition, and thermal stability of the annealed films is discussed.

C3.39

TRANSIENT CAPACITANCE CHARACTERIZATION OF DEEP LEVELS IN UNDOPED AND Si-DOPED GaN. Seiji Nakamura, Pei Liu, Michihiko Suhara, and Tsugunori Okumura, Tokyo Metropolitan University, Department of Electrical Engineering, Tokyo, JAPAN.

GaN is a direct wide band-gap semiconductor which has unique applications in short-wavelength optical devices and high-power electronic devices. In spite of the achievement of efficient light emitting diodes and laser diodes with a high dislocation density, the existence of extended and point defects is detrimental to the device performance. These defects form the deep levels, which act as nonradiative recombination centers. While there has been some work on deep levels in GaN by deep level transient spectroscopy (DLTS), the origin and electronic properties of deeper levels with activation energy about 1 eV below the conduction band edge are not yet understood. This is due to the DLTS measurements required the high temperature in order to excite carriers from these deeper levels. In this work, the electronic and optical properties of deep levels in undoped GaN as well as Si-doped GaN are characterized by means of a combination of isothermal capacitance transient spectroscopy (ICTS) and DLTS. GaN films for this study were grown on (0001) sapphire substrates by both metalorganic chemical vapor deposition and molecular beam epitaxy. Planar-type Schottky contacts were formed by depositing Ni. In ICTS measurements, no notable peak was observed in the ICTS spectrum for the MOCVD-grown undoped GaN with illumination below 1.8 eV. With increasing the illuminated photon energy, a broad negative peak associated with minority carriers becomes observable at time constant of 150 s. When illuminated photon energy was about 3.0 eV, the height of this broad peak was maximum. The peak height decreases with increasing the illuminated photon energy above 3.0 eV. Details of the results and the discussion will be presented.

C3.40

NANOSTRUCTURED ZnO THIN FILMS BY NANOPARTICLE BEAM PULSED LASER DEPOSITION. Masashi Matsumura, John M. Harrison, and Renato P. Camata, University of Alabama at Birmingham, Dept of Physics, Birmingham, AL.

Zinc Oxide (ZnO) is a promising wide bandgap semiconductor for applications in UV light emitting devices and sensors. Current ZnO research is mainly focused on optimization of bulk and epitaxial growth, p-type doping, and production of high quality metal contacts. Less emphasis has been given to ZnO nanostructures although these also present potential for important applications particularly in biosensing devices. Moreover, low-dimensional ZnO structures (e.g., nanocrystals, nanowires) are already produced with greater purity and better crystal quality than bulk crystals and epilayers as low defect concentrations are statistically favored in these nanoscale systems. In this study we have used a novel technique known as Nanoparticle Beam Pulsed Laser Deposition (NBPLD) to deposit ZnO nanoparticle/Al_2O_3 films on silicon and sapphire at room temperature to 400°C. Contrary to conventional PLD, this approach allows decoupling of deposition of nanoparticles and gas-phase species that often coexist in ablation plumes so that these two processes are manipulated independently. This is achieved by operating two independent PLD-based sources, such that one source exclusively generates nanoparticles while the other employs a gas-phase dominated plume. NBPLD delivers a beam of size-selected nanoparticles of controlled chemical composition while gas-phase species of different materials are simultaneously deposited using an independent laser source. Using this technique we have created micron-thick layers of ZnO nanoparticles of well-defined size dispersed in amorphous Al_2O_3. ZnO nanoparticles were deposited by ablating a ZnO target at 0.3-0.7 Bar in the NBPLD source using a KrF excimer laser (248 nm) at fluences of 1-5 J/cm^2 while deposition of Al_2O_3 was achieved by ablation of alumina targets at 5-10 J/cm^2 in a 10^{-4} Bar O_2 atmosphere. ZnO nanoparticle diameter was tuned in the 5-15 nm range for different samples. We will discuss photoluminescence measurements on these films with emphasis on size effects and interface phenomena (Funding: NSF-DMR-0116098).

C3.41

CHARACTERIZATION OF ALUMINUM NITRIDE THIN FILMS DEPOSITED ONTO METAL LAYER FOR ACOUSTIC DEVICE APPLICATIONS. Qianghua Wang, Gregory W. Auner, Wayne State University, Dept of Electrical and Computer Engineering, Detroit, MI; Ratna, Wayne State University, Dept of Physics and Astronomy, Detroit, MI.

Polycrystalline aluminum nitride thin films were grown onto metal layer by plasma source molecular beam epitaxy (PSMBE) system. In order to avoid thermal damage to silicon device and integrated circuit, the deposition temperatures are chosen from 300°C to 500°C, lower than 650°C for expitaxied AlN films in our system. X-ray diffraction (XRD) shows the films exhibit with a c-axis texture. Electrical properties of Al/AlN/Al sandwich structure have been measured as a function of the frequency. The electrical impedance and resistivity of AlN film seem inversely proportional to the frequency in 1kHz ∼1MHz region. The dielectric constant and the piezoelectric coefficient of the films have been shown to depend on the deposition conditions. At deposition temperature of 450°C the dielectric constant is about 17.0 and the piezoelectric coefficient is about 2.85. Optimizing the processing conditons is important to utilize AlN thin films for various acoustic devices such as thin-film bluk acoustic resonators (TFBAR).

C3.42

EFFECTS OF THICKNESS OF AlN NUCLEATION LAYER GROWN BY RADIO FREQUENCY SPUTTER. Min-Su Yi, JASRI Spring 8, Kouto, Mikazuki, JAPAN; Chel-Jong Choi, Tae-Yeon Seong, Ja-Soon Jang, Do Young Noh, K-JIST, Dept of Materials Science and Engineering, Kwangju, KOREA.

The dislocation density and electric resistivity of GaN films grown on AlN nucleation layers has been studied using x-ray scattering, transmission line method (TLM), and transmission electron microscopy (TEM). As increasing the thickness of AlN nucleation layers, the lattice parameter and surface roughness of AlN nucleation layers changes. We find that the lattice parameter and surface roughness of the AlN nucleation layers strongly affects the crystal quality and the resistance of epitaxial GaN film. The strain, coming from lattice mismatch between nucleation layers and epitaxial GaN film, produces screw dislocation being paths of current leakage. The rough surface of AlN nucleation layers, due to crossover from planar to island grains, produces edge dislocation playing compensating acceptors. The high resistive epitaxial GaN film grows with less strain and rough surface of AlN nucleation layers.

C3.43

THERMAL CONDUCTIVITY OF POLYCRYSTALLINE GaN FILMS AND AlGaN ALLOYS. D. Kotchetkov and A.A. Balandin, Department of Electrical Engineering, University of California-Riverside, Riverside, CA.

It is known that the operation of high-power density GaN field-effect transistors and blue light emitters can be significantly hampered by temperature rise in the device active area due to poor heat conduction. Optimization of GaN-based devices requires understanding of thermal constrains and, thus, modeling of heat diffusion in device structures with accurate values of thermal conductivity. We have recently shown theoretically that the presence of large densities of point defects, dopants and dislocations lead to a significant variation of thermal conductivity in bulk crystalline GaN samples even at high temperature [1-2]. In this presentation we report results of our investigation of thermal conductivity in polycrystalline GaN films and AlGaN alloys with high degree of disorder. A theoretical formalism used to model heat conduction in such systems has been modified to include a range of grain sizes and their predominant orientation in polycrystalline samples as well as different Al content in the AlGaN alloys. A frequency dependence of the boundary scattering rates has been taken into account. Using our model, we investigate temperature (T) dependence of the thermal conductivity and find conditions when 1/T dependence, characteristics for high-quality crystalline solids, weakens and becomes completely flat. Such very week temperature dependence has been observed experimentally for many GaN samples. A comparison of our numerical results with crystalline GaN and available experimental data and will also be given. A developed model can be used for accurate heat diffusion simulation in GaN/AlGaN layered structures of different crystalline quality and thermal design optimization of GaN-based devices. This work has been supported by the ONR Young Investigator Award N000140210352 to A.B. [1]. D. Kotchetkov, J. Zou, A.A. Balandin, D.I. Florescu, F.H. Pollak, Appl. Phys. Lett., 79, 4316 (2001). [2]. J. Zou, D. Kotchetkov, A.A. Balandin, D.I. Florescu, F.H. Pollak, J. Appl. Phys., 92, 2534 (2002).

C3.44

LUMINESCENT PROPERTIES OF ALUMINUM AND NITROGEN DOPED ZnO FILMS AND ITS ANNEALING BEHAVIORS. Y.G. Wang, S.P. Lau, H.W. Lee, B.K. Tay, Nanyang Technological Univ, School of Electrical and Electronic Engineering, SINGAPORE; X.H. Zhang, Institute of Materials Research and Engineering, SINGAPORE.

ZnO is a wide bandgap semiconductor with exciton binding energy 60meV. It attracts considerable attentions as an optoelectronic material for ultraviolet and blue light emitting devices. To realize applicable devices such as light emitting diode and diode laser, p- and n- type doping is prerequisite condition, understanding of PL properties of doped films is essential. By now, few investigations are carried out about PL of doped ZnO. In this work, the PL of aluminum and nitrogen doped ZnO films and its annealing behaviors are studied. ZnO films were prepared by filtered vacuum arc technique; aluminum doping was obtained by using aluminum doped zinc target. Nitrogen gas was used as dopant source for nitrogen doping, film resistivity increased greatly upon introducing of nitrogen gas, however no trace of p-type was observed. A sharp near band edge (NBE) emission peak due to free excitonic recombination was observed in undoped and aluminum doped films, peak position blueshifted with the increase of doping concentrations due to Burstein-Moss effect. NBE peak intensity increased with addition of aluminum first and decreased at higher concentrations (>3%). Deep level emission (DLE) was very weak in undoped films and totally depressed in aluminum doped films. Upon annealing, strong DLE emission appeared, an additional emission band was detected around 410nm in aluminum doped films. Suitable annealing procedure could improve the PL of undoped films, while no improvement was observed in aluminum doped films. Nitrogen doping degraded the PL of ZnO films greatly even at very low nitrogen to oxygen ratio of 2%. In nitrogen doped films, two additional nitrogen related DLE were detected at 450nm and 890nm, PL was improved by annealing. A DLE was observed at 760nm in nitrogen doped films excited by 514nm laser, which showed anomalous temperature dependent behaviors- peak position redshifted with the decrease of temperature.

C3.45

SIMULATIONS OF InGaN-BASE HETEROJUNCTION BIPOLAR TRANSISTORS. K.P. Lee, Univ of Florida, Dept of Materials Science and Engineering, Gainesville, FL; F. Ren, Univ of Florida, Dept of Chemical Engineering, Gainesville, FL; S.J. Pearton, Univ of Florida, Dept of Materials Science and Engineering, Gainesville, FL; A.M. Dabiran, P.P. Chow, SVT Associates, Eden Prairie, MN.

GaN/InGaN heterojunction bipolar transistors (HBTs) are very promising for high speed, high power density applications at elevated temperatures. In this paper we report on simulations of the dc performance of GaN/$In_{0.2}Ga_{0.8}N$ HBTs as a function of the layer design and doping levels. The conductivity of p-InGaN is significantly lower than p-GaN, reducing the deleterious effects of high ohmic contact resistance. Predicted dc current gains are given as a function of base doping and thickness and are in excess of several hundred even for aggressive layer designs. Advantages with respect to GaN base HBTs are also discussed.

C3.46

INFLUENCE OF ION ENERGY ON THE REACTIVE ION ETCHING INDUCED OPTICAL DAMAGE OF GALLIUM NITRIDE. Suk Ing Liem and Roger J. Reeves, MacDiamid Institute for Advanced Materials and Nanotechnology, University of Canterbury, Department of Physics and Astronomy, Christchurch, NEW ZEALAND.

Reactive Ion Etching (RIE) induces defects in semiconductor materials. These defects can serve as local non-radiant recombination centres for electron-hole pairs, affecting the radiant lifetimes and luminescence efficiencies of the semiconductors. In particular, this study will investigate the changes in GaN optical properties as a function of etching DC bias voltage, using argon and sulfur hexafluoride as the etching gases. Photoluminescence (PL) of near band gap emission was recorded from the GaN samples before and after etching. Peak intensity, linewidth and position as indications of optical changes were measured and analysed from the PL results. The results of this research using argon as the etching gas have shown that higher etching DC bias voltage tends to produce less optical damage than lower etching DC bias voltage. This surprising result is confirmed by atomic force microscopy that shows the material surface is smoother in the case of the higher etching DC bias voltages. Initial results using sulfur hexafluoride as the etching gas have shown similar results to those for argon gas in that there were no peak shifts, generally broader linewidth after etching, and higher etching DC bias voltage producing less optical damage than lower etching DC bias voltage.

C3.47

DESIGN OF JUNCTION TERMINATION STRUCTURES FOR GaN SCHOTTKY POWER RECTIFIERS. K.H. Baik and S.J. Pearton, Dept of Materials Science and Engineering, Univ of Florida, Gainesville, FL; Y. Irokawa, Toyota Central Research and Development Laboratories, Inc., Nagakute, Aichi, JAPAN; F. Ren, Dept of Chemical Engineering, Univ of Florida, Gainesville, FL; S.S. Park and Y.J. Park, Samsung Advanced Institute of Technology, Suwo, SOUTH KOREA.

Junction termination extension (JTE) structures for GaN power Schottky rectifiers were investigated using a quasi-three dimensional simulator. The use of single JTE edge termination was found to produce an almost 5-fold increase in reverse breakdown voltage (VB) over an unterminated rectifier fabricated on the same bulk GaN substrate. The use of p+ guard rings or planar junction termination with oxide field plates also offers significant enhancements in VB relative to unterminated rectifiers. VB was found to be a strong function of the JTE doping concentration and the p+ guard-ring spacing.

C3.48

MODELING OF NITRIDE SEMICONDUCTOR BASED DOUBLE HETEROSTRUCTURE TUNNEL DIODES. M. Moret, S. Ruffenach, O. Briot, R.L. Aulombard, GES-CNRS, Université Montpellier II, Montpellier, FRANCE.

Double heterostructure tunnel diodes were widely studied in the 80's, based on the use of "classical" III-V materials, i.e. based on (Ga, In, As, P). Negative differential conductivities were predicted in these systems, making them highly interesting for hyperfrequency applications, but experimental results were always far from theoretical predictions, which resulted in a loss of interests for these systems. Recently, there has been a lot of efforts devoted to Nitride semiconductors, based on (Ga,Al,In)N alloys. These materials have been regarded as potential candidates for high frequency, high power applications, since they both exhibits high electron saturation velocities and high thermal and chemical stability. Moreover, although they usually contains a lot of growth defects, devices properties were surprisingly good with regards to the defect densities. In this work, we have modeled double heterostructures tunnel diodes based on

AlGaN/GaN and InGaN/Gan systems. The extremely high conduction band offsets in these materials, along with the quite low dielectric constants, and built-in electric fields (originating both from spontaneous and piezoelectric polarization), are extremely favorable parameters, which may renew the interest for such devices in this material system. It will be shown that the built-in electric field leads to a symetric potential profile under a given external applied polarization, which optimizes the transmission coefficient in the structure. We have calculated extremely high peak/valley ratios, which suggests that even mid quality samples could still exhibit interesting device properties.

C3.49
HIGH REFLECTIVITY AlGaN/GaN BRAGG MIRRORS GROWN BY MOCVD FOR MICROCAVITIES APPLICATIONS. M. Moret, S. Ruffenach, O. Briot, R.L. Aulombard.

Bragg mirrors are highly interesting structures for a large set of applications including vertical cavity lasers and the upcoming range of devices based on microcavities. Although the nitride semiconductors are performing fairly well in optoelectronic applications, it is not straighforward to realize Bragg mirrors based on this material system, due to the low optical index differences between GaN and AlN. Moreover, the lattice parameter difference between these material will generate crystal defects, which prevents the stacking of a large number of periods, adding to the difficulty. In this work we have grown high reflectivity Bragg mirrors, with a band centered in the visible blue range. The structures were first modeled, then grown by low pressure MOCVD, and were optimized using an in-situ reflectivity system. This in-situ reflectivity measurement was compared to a calculated profile, to enable a real time control of the structures. The samples were characterized by x-ray diffraction, scanning electron microscopy and reflectivity. It was possible to realize samples with over 90% reflectivity at 400 nm.

C3.50
ER DOPED GaN BY GAS SOURCE MOLECULAR BEAM EPITAXY ON GaN TEMPLATES. Nicolas Rousseau, Olivier Briot, Daniel Ribes, R.-L. Aulombard, Univ Montpellier II, Groupe d'etude des Semi-Conducteurs, Montpellier, FRANCE.

Since the work of Favennec et al. it is well known that the quenching of luminescence from rare earth ions decreases with the host bandgap. This has led to a large activity with silicon implanted or doped with RE, and then GaAs was used, in hope to realize simple, cheap light emitters. With a band gap of 3.4 eV at room temperature, GaN is even better suited to such applications. As a matter of fact, Steckl et al. have demonstrated a green light emitting device based on Er doped GaN. This resulted in a renewed effort in this direction, but the crystal quality still have to be mastered and the physical phenomenon involved to be understood. In this work, GaN and Er-doped GaN with various Er concentration were grown by gas source molecular beam epitaxy on high quality GaN templates grown by metalorganic chemical vapor deposition. In order to understand the influence of the Er incorporation on the crystal quality of GaN, Er-doped GaN were grown with a concentration between 0,5% and 5%. High quality undoped GaN were also grown, as a reference material, to show how the smallest amount of Er may affect drastically the structural and optical properties. All the samples were characterized by scanning electron microscopy, atomic force microscopy and X-ray diffraction. With this measurements, we demonstrate a strong correlation between the Er concentration and the surface roughness and the crystalline quality. This study shows that the activation of the Erbium luminescence is not improved with improving crystal quality. This asumption support the idea that Er Luminescence should be related to defect center in GaN.

C3.51
ZnO THIN FILM GROWN AT VARIOUS SUBSTRATE ANGLES BY PULSED LASER DEPOSITION. Jeong Seok Kang, Hong Seong Kang, Seong Sik Pang, Eun Sub Shim, Sang Yeol Lee, Dept of Electrical and Electronic Engineering, Yonsei University, Seoul, KOREA.

ZnO thin films were grown at same condition except for the plume-substrate angle and growth time by pulsed laser deposition. The angles between plume and substrate plane were 0°, 45° and 90°. The growth time was changed in order to adjust film thickness. From the XRD pattern exhibiting only the (002) XRD peak of ZnO, all films were found to be c-axis oriented. Optical and electrical properties of ZnO thin films were investigated by PL(Photoluminescence) and van der Pauw Hall measurements respectively. UV/green luminescent intensity of ZnO thin film increased, as the angle between target and substrate plane decrease.

C3.52
LOW OHMIC CONTACT RESISTANCE OF GaN BY EMPLOYING EXCIMER LASER. Seung-Chul Lee, Jin-Cherl Her, Kwang-Seok Seo and Min-Koo Han, Seoul National University, School of Electrical Engineering, Seoul, KOREA.

It is well known that the ohmic contact resistance of GaN is rather high compared with widely used semiconductor materials, such as Si and GaAs, due to the wide band gap. The low ohmic contact resistance of GaN is important for better electrical characteristics of GaN devices, such as MESFETs, MODFETs and LEDs. Metal systems based on Ti/Al are widely used, and various surface treatment methods for lower ohmic contact resistance, have been reported. We proposed a new method for low ohmic contact resistance by widely used XeCl excimer laser annealing. A 300nm thick n-type GaN doped with Si of which the carrier concentration is 1e18 cm^{-3} and 2 μm thick undoped GaN on sapphire substrate were prepared. The 70nm thick amorphous Si is deposited by sputtering on the ohmic contact region after mesa etching, and 200nm thick Ni mask is evaporated in the remained region in order to block the laser beam, followed by 250nm thick capping oxide deposition. We melted amorphous Si on the surface of GaN layer by using XeCl excimer laser, of which energy was 450 mJ/cm^2 that the amorphous Si layer was fully melted. The sample was dipped into a HCl:H$_2$O(1:1) solution for removing native oxide after ohmic patterning, and Ti/Al/Ni/Au(20nm/80nm/20nm/100nm) was deposited. Then, the samples were annealed at 840°C for 30s with RTA. The ohmic contact resistances were measured employing transmission line method(TLM). It is inferred that amorphous Si melted during laser annealing can be diffused into the GaN layer, so that the ohmic contact resistance can be reduced due to increased surface carrier concentration. Relatively low 0.27 ohm-mm ohmic contact resistance was measured while 0.66 ohm-mm ohmic contact resistance was measured in ohmic contact method without a laser annealing. The specific ohmic resistance of the sample by proposed method is 8e-6 ohm-cm^2.

C3.53
TIME OF FLIGHT OF DRIFTING ELECTRONS AND HOLES IN STABILIZED a-Se FILM. Dong-Gil Lee, Ji-Koon Park, Jang-Yong Choi, Inje University, Department of Biomedical Engineering, Kim-Hae, KOREA; Jae-Hyung Kim, Sang-Hee Nam, Inje University, Medical Imaging Research Center, Kim-Hae, KOREA.

Large area, flat panel detectors are being investigated for digital radiogrpahy and fluoroscopy. Theses detectors employ an x-ray imaging layer of either photoconductor ("direct" conversion method) or phosphor ("indirect" conversion method) to detect x-rays. Candidate photoconductor materials include lead iodide(PbI2), mercury iodide(HgI2), thallium bromide (TlBr), and cadmium telluride (CdTe). These materials have both inherently high stopping power and wide band gap energy. The amorphous selenium (a-Se) layer that is currently being studied for the use as an x-ray photoconductor is not pure a-Se but rather a-Se doped with 0.2-0.5% As and 10-30 ppm Cl, also known as stabilized a-Se. The suitability of the stabilized a- Se is largely determined by its charge on generating, transporting and trapping properties. In this paper, a conventional time-of-flight (TOF) measurement was carried out to analyze the transport properties of the charge carrier under the x-ray exposure. A laser beam with pulse duration of 5ns and wavelength of 250 nm was illuminated on the surface of the stabilized a-Se with thickness of 400. The energy required to create a free pair of electrons and holes, WEHP, was measured by integrating the x-ray-induced photocurrent to find the number of free charge carriers and dividing that by the energy absorbed in the a-Se layer. The photo response signals of hole and electron measured at the applied electric field of 10V/ as a function of time. The transit time of the hole and electron depended strongly on the electric field applied for collecting the charge carriers. The measured transit times of the hole and electron were about 229.17 and about 8.73 at 10 V/, respectively. The mobilities of the hole and electron were obtained as a function of electric field by using transit time from TOF measurement. The measured mobility indicated a slight dependence with a respect to applied electric field with a range of 4-10V/. The experimental results showed that the measured mobility of the hole and electron was 0.04584 cm2V-1s-1 and 0.00174 cm2V-1s-1 at the electric field of 10V/. The hole mobility of 0.04584 cm2V-1s-1 measured at 10V/ is somewhat differ from that of 0.13 cm2V-1s-1 reported previously by Kasap et al. This difference of the hole mobility is analyzed due to both the temperature dependence and doping quality in stabilized a-Se film.

C3.54
EXPERIMENTAL EVALUATION OF a-Se FLAT-PANEL X-RAY DETECTOR FOR DIGITAL RADIOGRAPHY. Jang-Yong Choi, Sang-Sik Kang, Hyun-Gi Kong, Inje University, Department of Biomedical Engineering, Kim-Hae, KOREA; Jae-Hyung Kim, Sang-Hee Nam,Inje University, Medical Imaging Research Center, Kim-Hae, KOREA.

A new class of digital detectors, active matrix flat-panel imagers

(AMFPIs), have shown great promise in replacing screen/film for various medical imaging tasks such as mammography and chest radiography. We are developed a large area, flat panel solid-state detector for general application to digital radiology. The proposed detector employs a continuous photoconductive layer of the amorphous selenium (a-Se) to convert incident x-rays to electron-hole pairs, which are then separated and drawn to the surfaces of the a-Se by an applied electric field. The resulting charge image is digitally read out using a large area active matrix array made with amorphous silicon thin film transistors (TFTs). The a-Se detector is fabricated using a direct deposition onto a thin film transistor (TFT) substrate. The detector array format is 10241280 with pixel pitch of 139 . The thickness of a-Se film was approximately 500 . To overcome the problem of TFT array's damage in the case of an accidental over-exposure condition or a high leakage in the a-Se, we deposited the polyparaxylylene between a-Se and top electrode layer as a blocking layer. The geometric fill factor was 86%, but experimental evidence supports the fact that internal electric field bending leads to an effective fill factor approaching unity. The imaging properties of the flat-panel detector have been evaluated with respect to X-ray sensitivity, linearity, and spatial resolution. The measured leakage current remained below 100 pA/cm^2, and the X-ray sensitivity was 1.3E6e-/mRpixel at a sensor bias field of 10 V/. Resolution was measured to be near the theoretically predicted values, with modulation transfer functions(MTFs) of 58% at 3 lp/mm. Phantom and hand images were obtained at 80 kVp filtered by 20 mm aluminum. The a-Se film exhibits a good MTF and a superior linearity, which indicates that the fabricated X-ray detector is suitable for digital radiography.

C3.55

OPTICAL AND ELECTRICAL CHARACTERIZATION FOR ANNEALED Si-IMPLANTED GaN. H.T. Wang, L.S. Tan, E.F. Chor, Centre for Optoelectronics, Dept of Electrical and Computer Engineering, National University of Singapore, SINGAPORE.

In this paper, we investigate the effect of post-implant annealing on the optical and electrical properties of Si-implanted GaN films. Results from several measurement techniques including room temperature photoluminescence, micro-Raman scattering, high resolution x-ray diffraction and Hall measurement are correlated to study the behavior of damage removal, carrier concentration and activation efficiency, etc. It has been found that with high temperature annealing up to 1100°C, the optical characteristics of Si-implanted GaN films correlate very well with the electrical properties. For the study of damage removal, it is found that the PL intensity, even for the best annealing case of 1100°C for 120s, just recovered partially. Whereas XRD results demonstrate that high temperature annealing can effectively decrease the dislocation density of films. This implies that the implantation induced point defect cannot be completely annealed out at 1100°C, which could contribute to the non-radiative recombination centers and act as deep level killers of PL spectrum, whilst dislocations play an relatively insignificant role in PL. Micro-Raman results show the decrease of stress within GaN films after annealing. For the activation efficiency study, the Hall measurement demonstrates reasonable activation percentage with high-temperature annealing. The carrier concentration increases monotonically with elevating annealing temperature. This result is in agreement with results from Raman ($A1_{(LO)}$ phonon damping) and PL (linewidth broadening and downshift at near band edge) measurements. The improvement of mobility may be due to the increased screening effect and decrease of charged dislocation density.

C3.56

GROWTH OF SEMI-INSULATING GaN LAYER BY CONTROLLING SIZE OF NUCLEATION SITE FOR HFET APPLICATION. Jae-Hoon Lee, Jae-Hee Park, Myoung-Bok Lee, Sung-Ho Hahm, Jung-Hee Lee, The School of Electronic and Electrical Engineering, Kyungpook National University, KOREA; Chang-Min Jeon and Jong-Lam Lee, Dept. of Materials Science and Engineering, Pohang University of Science and Technology, KOREA.

AlGaN/GaN heterostructure field effect transistors (HFETs) require a highly resistive GaN base layer both for the purpose of device isolation and for achieving good rf performance. In this work, semi-insulating undoped GaN film was grown by controlling size of nucleation site through two step growth method. A 16 nm-LT-buffer were grown at 550°C and annealed in three different temperatures at 950, 1020, and 1050°C, where 4 min was spent in ramping the temperature from 550°C to these temperatures for all cases. With increasing annealing temperature, the surface roughness of nucleation site in the grown LT-buffer was greatly increased from 2.4 to 24 nm. On the contrary, FWHM of X-ray rocking curve of grown LT-buffer decreased from 8420 to 2714 arc. Five different undoped GaN samples were grown on 16 nm-LT-buffer at temperatures of 950, 980, 1000, 1020, 1050°C for 40 min, respectively. With decreasing growth temperature, the value of sheet resistance was greatly increased from $\sim 10^3$ to $\sim 10^6$/sq and the electron mobility was greatly decreased from 250 to 4 cm^2/Vs. This is believed to be due to generation of many defect center through a small nucleation size. By using single step growth method, high sheet resistance was usually obtained at relatively low growth temperature near 950°C but the surface morphology of the resultant film was shown to be 3-D fashion. To obtain the smooth surface, two step growth was proposed to meet the problem encountered with single step growth. Firstly, the 16 nm-LT-GaN was annealed at 950°C with ramping time for 4 min and then GaN was grown at this temperature for 1 min. Secondly, the growth temperature was increased to 1020°C for 2 min. The growth was continued at this time interval. Finally, the GaN layer was grown at 1020°C for 40 min. The film grown by this technique was turned out the semi-insulating with mirror like surface morphology.

C3.57

MODELING OF HEAT DIFFUSION IN AlGaN/GaN HETEROSTRUCTURES. K. Filippov and A.A. Balandin, Nano-Device Laboratory, Department of Electrical Engineering, University of California, Riverside, CA.

GaN material system has established itself as very important for next generation of high-power density devices for optical, microwave, and radar applications [1]. At the same time, performance of GaN devices has been limited by self-heating. Thus, accurate modeling of heat diffusion and self-heating effects in AlGaN/GaN heterostructures and device optimization based on such modeling become important for further development of nitride technology. In this paper we present results of simulation of heat diffusion in AlGaN/GaN layered structures, which correspond to double-heterostructure light-emitting diodes (LEDs) and heterostructure field-effect transistors (HFETs). It has been recently established that decrease of the thermal conductivity in AlGaN system due to mass disorder is much larger than in other III-V ternary alloys [2]. Thermal conductivity of crystalline GaN strongly depends on doping density as well as concentration of impurities [3]. Our heat diffusion simulations performed for 2D and 3D cases include these effects into account and allow us to accurately predict temperature rise for each structure. The value of Kapitza resistance has been estimated from the acoustic impedance mismatch at the heterointerfaces and available experimental data. Using developed model we compare different types of GaN/AlGaN heterostructures with respect to their thermal management and performance. Specifically, we compare mobility degradation due to temperature rise in two different types of GaN/AlGaN HFETs on SiC substrate: doped-channel HFET with low Al content in the barrier and undoped-channel HFET with higher Al content in the barrier layer to compensate for the absence of doping by stronger piezoelectric field. This work has been supported by ONR Award N00014-02-1-0352. [1]. A. Balandin, S.V. Morozov, et al, IEEE Trans on MTT, 47 (8), 1413 (1999). [2]. B.C. Daly et al., J. Appl. Phys., 92, 3820 (2002). [3]. J. Zou, D. Kotchetkov, A.A. Balandin, et al, J. Appl. Phys., 92, 2534 (2002).

C3.58

INVESTIGATION OF EPITAXIAL THIN FILM GROWTH OF $B_{12}As_2$ BY CHEMICAL VAPOR DEPOSITION. Rajamani Nagarajan, J.H. Edgar, Department of Chemical Engineering, Kansas State University, Manhattan, KS; M. Kuball, H.H. Wills Physics Laboratory, University of Bristol, Bristol, UNITED KINGDOM; T. Aselage, Department 2525/MS0613, Sandia National Laboratories, Aluquerque, NM.

Icosahedral boron arsenide $B_{12}As_2$ is a wide band gap semiconductor3.3 eV exhibiting exceptional radiation hardness as a result of its unusual atomic structure and chemical bonding. The chemical vapor deposition of $B_{12}As_2$ on Si {100}, Si {111}, and 6H-SiC {0001} {on and off axis} substrates was studied using hydrides as the reactants. The effects of temperature and reactant flow rates on the phases deposited and the crystal quality were determined. The growth rate increased from 1.5μm at 1100°C to 7.2μm at 1300°C. X-ray diffraction revealed that the deposits contained amorphous boron when deposition temperature is below 1200°C. Above 1200°C, crystalline $B_{12}As_2$ was obtained. Textured, oriented films were produced on Si {100} with the preferred orientation of {100} Si plane. Smooth epitaxial $B_{12}As_2$ films were formed on 6H- SiC {0001}. The optimum reactant ratio of boron to arsenic was determined to be 1:1 for these samples. Amorphous deposits of boron on Si were also detected for some samples by micro Raman spectroscopy. Compositional analysis of these films will be reported. These materials are potentially useful for the fabrication of beta-cells for direct nuclear to electrical energy conversion.

C3.59

GROWTH OF GaN CRSYTALS USING SANDWICH TECHNIQUE EMPLOYING A HOT TUNGSTEN FILAMENT. E. Bayboru, R. Schlesser, Z. Sitar, North Carolina State University, Department of Materials Science and Engineering, Raleigh, NC.

A sandwich technique employing a hot tungsten (W) filament was used to grow gallium nitride (GaN) single crystals using a metallic gallium (Ga) source and ammonia (NH_3). In this process, Ga droplet formation, caused by the reaction between the liquid Ga and NH_3, was suppressed. Without the filament, Ga droplets landing on the substrate surface lead to secondary nucleation, which inhibited continuous growth of GaN single crystals. The purpose of the hot filament above the Ga source was twofold: (1) it provided local heating of the Ga surface and (2) it cracked NH_3 before it reached the source, thus preventing the undesired reaction and droplet formation. Filament temperatures of up to 1800°C under different combinations of NH_3 pressures (200-750 Torr), flow rates (50-800 sccm) and substrate temperatures (1000-1200°C) were investigated. Experimental details and the long term process stability will be discussed in terms of structural and optical quality of grown GaN crystals.

SESSION C4: OXIDES, HETEROSTRUCTURES, DEVICES

Chairs: Carl-Mikael Zetterling and Randy J. Shul
Wednesday Morning, April 23, 2003
Golden Gate A2 (Marriott)

8:30 AM *C4.1
NOVEL OXIDES FOR PASSIVATING AlGaN/GaN HEMT AND PROVIDING LOW SURFACE STATE DENSITIES AT OXIDE/GaN INTERFACE. Fan Ren, B. Luo, J. Kim, and R. Mehandru Department of Chemical Engineering, University of Florida, Gainesville, FL; B.P. Gila, A.H. Onstine, C.R. Abernathy, and S.J. Pearton, Department of Materials Science and Engineering, University of Florida, Gainesville, FL; R. Fitch, J. Gillespie, T. Jenkins, J. Sewell, D. Via, and A. Crespo, Air Force Research Laboratory, Sensors Directorate, Wright-Patterson AFB, OH.

MgO and Sc_2O_3 were successfully used to passivate AlGaN/GaN high electron mobility transistors (HEMTs) and provide low surface states for GaN metal oxide semiconductor (MOS) diodes. AlGaN/GaN HEMTs show great promise for applications in which high speed and high temperature operation are required, such as high frequency wireless base stations, commercial and military radar and satellite communications. These devices appear capable of producing very high power densities (>12W/mm), along with low noise figures (0.6dB at 10GHz) and high breakdown voltage. One problem commonly observed in these devices is the so-called “current collapse” in which the application of a high drain-source voltage leads to a decrease of the drain current and increase in the knee voltage. MgO and Sc_2O_3 were employed for their effectiveness in mitigating surface-state-induced current collapse in AlGaN/GaN HEMTs. There is also great interest in development of GaN-based metal-oxide-semiconductor (MOS) transistors because of their lower leakage currents and power consumption and capability for greater voltage swings relative to the more common Schottky-gate devices. The interface state densities derived from the Terman method are generally in the mid-to-high 10^{11} $eV^{-1}cm^{-2}$ range using MgO as the gate oxide. Charge modulation from accumulation to depletion is commonly reported, but a clear demonstration of surface inversion has proven elusive due to the very low minority carrier generation rate in GaN at room temperature. Even at 300°C in conventional GaN MOS devices, the minority generation rate is still too low to observe inversion. We report on the clear observation of inversion in MgO/p-GaN gate-controlled MOS diodes in which n^+ gated contact regions were created by Si^+ implantation and subsequent activation annealing with the MgO gate oxide in place.

9:00 AM *C4.2
EFFECTS OF PRE-PROCESS TEMPERATURE STRESSING ON AlGaN/GaN HEMT STRUCTURES. M.J. Yannuzzi, N.A. Moser, R.C. Fitch, J. Gillespie, D. Via, A. Crespo, and T. Jenkins, Air Force Research Laboratory, Sensors Directorate-Electron Devices, Wright-Patterson AFB, OH.

The potential benefits of the wide-bandgap, AlGaN/GaN III-V compound semiconductor system for high frequency, high power, and high temperature electron devices are well known. However, unlike similar high electron mobility transistor (HEMT) structures in the AlGaAs/InGaAs/GaAs system, or AlGaAs/InGaAs/InP system, the peak processing temperature to which AlGaN/GaN HEMT structures are exposed is substantially higher, typically between 800°C and 900°C. The effects, if any, of these processing temperatures on the epitaxial material integrity, particulary the hetero-interface(s), need to be understood. Towards that end, we have subjected AlGaN/GaN HEMT epitaxial material samples to temperatures of 650°C to 1150°C, prior to device processing. Hall measurements were performed on the samples before and after temperature stressing. The 750°C and 1050°C samples were then processed, and electrical parametric data were collected during and after processing. The results of the data analysis for Process Control Monitor, and HEMT DC and small-signal RF measurements will be presented.

9:30 AM *C4.3
NOVEL HETEROSTRUCTURES BASED ON III-NITRIDES. Martin Stutzmann, Tobias Graf, Martin Hermann, Claudio Miskys, Georg Steinhoff, Martin Eickhoff, Jose Garrido, and Martin Brandt, Walter Schottky Institut, Technische Universitaet Muenchen, Munich, GERMANY.

In this presentation we will summarize recent results concerning the use of GaN, AlGaN, and AlN in novel heterosystems. As a first example, AlGaN/GaN heterostructures with their characteristic spontaneously formed two-dimensional electron gas (2DEG) have been combined with lipid bilayers to form an organic/anorganic heterostructure as a model system for future biosensor applications of III-nitrides. As a necessary starting point, GaN and AlGaN layers have been rendered hydrophilic by low temperature oxidation without a destruction of the 2DEG close to the organic/anorganic heterointerface. Bilayers of various lipids have been deposited on these surfaces by vesicle fusion, and the structural integrity as well as the lateral diffusion constants of fluorescence markers within the bilayers have been studied. We find a good membrane integrity over macroscopic areas, the possibility of selective bilayer adhesion by creating a hydrophilic/ hydrophobic contrast, and large differences in the intra-membrane diffusion constants depending on the net charge of the lipid molecules. As a second example, heterostructures of p-type (boron doped)diamond and n-type (silicon doped) AlGaN have been prepared by MBE growth of III-nitrides on diamond single crystals. Already the first diamond/AlGaN pn-heterostructures exhibited a reasonably good structural quality and showed pronounced rectification behaviour as well as efficient electroluminescence in the visible and in the deep UV spectral range. Details concerning the preparation, properties and potential applications of diamond/AlGaN hetero- and quantum well structures will be discussed.

10:30 AM C4.4
CONTACT REPORTING IN SOLAR BLIND $Al_xGa_{1-x}N$ METAL-SEMICONDUCTOR-METAL DEVICES FOR LOW-CURRENT FLAME DETECTION. Mauro Mosca, Jean-Luc Reverchon, Jean-Yves Duboz, Thales Research and Technology, Orsay, FRANCE; Frank Omnès and Nicolas Grandjean, CRHEA, CNRS, Sophia Antipolis, Valbonne, FRANCE.

In this work we report on solar blind $Al_XGa_{1-X}N$ photovoltaic metal-semiconductor-metal (MSM) detectors with cutoff wavelength as short as 270 nm based on a two-layer electrode patterning. $Al_XGa_{1-X}N$ stacked films with different composition $(0 \leq x \leq 1)$ were grown on sapphire substrates by both metalorganic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE). We observed that the contact areas of the interdigitated electrodes contribute to the overall photocurrent. In order to avoid these effects of the contact pads, we deposited a dielectric film onto the semiconductor whereas the metallic contact is sputtered on the dielectric. Moreover, we showed that both the dark current and the responsivity are strongly dependent on the density of semiconductor cracks. Use of the dielectric layer can reduce the crack effects on the dark current. In order to minimize the latter, several dielectrics were tested and our results are reported; values as small as 10-100 fA have been measured at 20 V bias voltage. These excellent performances make these devices able to detect ultraviolet radiation from flames.

10:45 AM C4.5
GaN/AlGaN/GaN HETEROSTRUCTURE AND ITS APPLICATION TO THE DISPERSION REMOVAL IN HEMTS. L. Shen, S. Heikman, Y. Wu[†], D. Buttari, R. Coffie, L. McCarthy, S. Keller, J. Speck[†], U. Mishra, Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA; [†]Department of Materials, University of California, Santa Barbara, CA.

As a promising candidate for future microwave power devices, GaN-based HEMTs have attracted much research interests. However, GaN power HEMTs suffered “DC-to-RF dispersion”, which is due to the slow response of the surface traps. SiN passivation has been used to suppress this problem, but the drawback is that it is very sensitive to both surface and deposition conditions. Therefore the reproducibility is poor. In this paper, we propose an epitaxial solution for dispersion. A novel GaN/AlGaN/GaN heterostructure is introduced: surface/250nm UID GaN/20nm Si-doped graded AlGaN(x=0-0.33)/20nm AlGaN(x=0.33)/0.7 nm AlN/GaN. The ability of the surface states to modulate the channel decreases when the distance between the surface and channel increases. Therefore the thick GaN cap in the access region reduces surface potential fluctuations from affecting device performance. The Si-doped graded AlGaN layer is used to avoid hole accumulation at the GaN/AlGaN interface. The detail of the structure will be explained in the conference. The processing is similar to that of the conventional

HEMTs, except the deep etching is necessary for both source/drain contacts and gate, in order to obtain ohmic contacts (<0.5Ohm-mm), reasonable transconductance (150-200mS/mm)and pinch-off voltage(-5 ∼ -8V). The DC and gate lag pulsed I-V characteristics of the unpassivated sample were measured. No dispersion was observed up to 200ns. At 200ns, current density of 1.25A/mm and transconductance of 230mS/mm were obtained. Small signal RF performance showed 22GHz ft and 40GHz fmax for 0.7um-gate-length device. Power measurement of the unpassivated sample at 8 GHz showed 2W/mm and 3W/mm with PAE 42% and 38% at a drain bias of 10 and 15V, respectively. This indicates that the dispersion is suppressed even in the GHz range. Degradation of the gate schottky at biases above +15V prevented power measurements at higher biases. The mechanism of the degradation is still under investigation.

11:00 AM C4.6
GALLIUM PHOSPHIDE-BASED MIS CAPACITOR WITH SYNTHESIZED GATE DIELECTRIC(S). An Chen, Jerry Woodall, Xie-wen Wang, Dept of Electrical Engineering, Yale University, New Haven, CT.

Gallium Phosphide (GaP), with its wide band gap of 2.26eV, is an excellent candidate for high-temperature, high-power and low noise applications. Its relatively inexpensive price and commercial availability makes it more attractive than SiC and GaN for some industry applications. However, a critical problem with GaP for device applications is the excess leakage current through the gate. A suitable gate insulator with low leakage current and high breakdown strength is, therefore, highly demanded. Attempts in forming gallium oxide by either thermal oxidation or anodic oxidation of GaP have failed to produce an insulator with the quality adequate for device applications. Therefore, there have been very few reports on GaP-based MOS or MIS devices within the past 30 years. In this study, we explore the possibility of making GaP MOS or MIS capacitors with synthesized gate dielectric(s), mainly SiO2, Si3N4 (or a stack of SiO2 and Si3N4), by using the Jet Vapor Deposition (JVD) technique. Our preliminary C-V measurements on Al/Si3N4/GaP capacitors clearly showed the transition from accumulation through depletion to inversion under illumination. Dark C-V exhibited deep depletion due to insufficient minority carrier generation rate. The maximum breakdown electric field was measured above 10 MV/cm, greater than that reported on anodic oxide of GaP. To improve the quality of the dielectric/GaP interface (i.e. to reduce the densities of interface states and oxide fixed charge), a series of experiments are undergoing, including constructing and comparing of various interfaces such as SiO2/GaP, Si3N4/GaP or silicon oxynitride/GaP interface etc. Also included in the series of experiments is the optimization of GaP surface treatments prior to dielectric deposition and dielectric processing parameters as well.

11:15 AM C4.7
ABNORMAL RECTIFYING CHARACTERISTICS OF A Mg DOPED GaN SCHOTTKY DIODE. Jae Wook Kim, Il Ho Ahn, Jhang W. Lee, Phil W. Yu, K-JIST, Dept of Information and Communications, Gwang-Ju, KOREA; Seok Heon Lee, LG Innotek Co. Ltd, Gwang-Ju, KOREA.

Data are presented on the unusual I-V characteristics of Mg doped GaN Schottky diode at low temperature range. With the analysis of temperature dependent Hall measuremet, C-V profile, and I-V measurement data, we found that the Schottky diode, which comprises Schottky contact, p-GaN and ohmic contact, loses its rectifying characteristics and tends to be ohmic-like at the low temperature range below ∼100K. Also both forward and reverse current levels decrease to ∼1/1000 at the low temperature range. We found also that the high frequency capacitance of the Schottky diode is almost vanished at the low temperature range.
Hall measurement shows strong carrier freeze-out effect at ∼100K, which is relatively higher than the freeze-out temperature of other common semiconductors. This freeze-out effect should reduce the number of free carriers and limit the device current both at forward and reverse biases. The carrier reduction due to the freez-out effect seems to reduce the high frequency capacitance of the Schottky diode near to zero at the low temperature range.
We believe that such strong freeze-out is caused by the fact that the Mg acceptor level is deep in GaN (∼150meV) and Mg atoms are not fully ionized even at the room temperature[1]. We expect that, near the metal-semiconductor junction, the strong carrier freeze-out will make the band almost linearly tilt rather than bending caused by the depletion. Accordingly, due to the little band bending, there is little depletion near the metal semiconductor junction and we may not observe the usual rectifying characteristic of the Schottky diode at low temperature, but the ohmic-like characteristics caused by the linear band tilt.
References
[1] D.J. Kim, D.Y. Ryu, N.A. Bojarczuk, J. Karasinski , S. Guha, S.H. Lee and J.H. Lee, J. Appl. Phys. **88**, 2564 (2000).

11:30 AM C4.8
PROGRESS IN AlGaN/GaN CURRENT APERTURE VERTICAL ELECTRON TRANSISTORS. Ilan Ben-Yaacov, Yee-Kwang Seck, Umesh K. Mishra, Electrical and Computer Engineering Department, University of California, Santa Barbara, CA; Steven P. DenBaars, Materials Department, University of California, Santa Barbara. CA.

AlGaN/GaN Current Aperture Vertical Electron Transistor (CAVET) structures have been fabricated in order to address the issues of DC-RF dispersion as well as lower than predicted breakdown voltages observed in nitride-based HEMTs. A CAVET consists of a source region (2DEG at an AlGaN/GaN heterojunction) separated from a drain region (Si-doped GaN) by an insulating layer containing a narrow aperture which is filled with conducting material. Source contacts are deposited on either side of the aperture, and a drain metal contacts the n-doped region below the aperture. Electrons flow from the source contacts through the aperture and are collected at the drain. A Schottky gate, located above the aperture, is used to modulate the current passing through the aperture. Devices are fabricated by first growing the drain region and insulating layer, then etching away the aperture region, and finally regrowing the aperture and source regions. In a HEMT, DC-RF dispersion and reduced breakdown both result from large surface fields located at the drain edge of the gate. In a CAVET, because the virtual drain (or pinched off region) is located underneath the gate, the high field region is buried in the bulk. The CAVET therefore has the potential to support large source-drain voltages, since surface related breakdown is eliminated, and surface related instabilities such as DC-RF dispersion should be mitigated. Previously, CAVETs with no DC-RF dispersion and source-drain saturation currents as high as 750 mA/mm have been demonstrated. However, these devices had large parasitic leakage currents originating from both the source and the gate. In this study, we have carefully characterized all of our leakage paths. Source leakage through the insulating layer was found to be caused by pits formed during regrowth, and we have identified growth conditions that eliminate these pits. Gate leakage still remains a problem; however, we have proposed a novel device design in which the source region is regrown that should address this issue.

11:45 AM C4.9
EDGE TERMINATION DESIGN AND SIMULATION FOR BULK GaN RECTIFIERS. K.H. Baik and S.J. Pearton, Dept of Materials Science and Engineering, Univ of Florida, Gainesville, FL; Y. Irokawa, Toyota Central Research and Development Laboratories, Inc., Nagakute, Aichi, JAPAN; F. Ren, Dept of Chemical Engineering, Univ of Florida, Gainesville, FL; S.S. Park and Y.J. Park, Samsung Advanced Institute of Technology, Suwon, SOUTH KOREA.

GaN bulk rectifiers show excellent on-state resistances (in the milli-ohm.cm-2 range), forward turn-on voltages of ∼1.8V and reverse-recovery times of <50 ns. A key requirement is to develop effective edge termination techniques in order to prevent premature surface-induced breakdown. We have performed a simulation study of the effects of varying the dielectric passivation material (SiO2, SiNX, AlN, Sc2O3 or MgO), the thickness of this material, the extent of metal overlap onto the dielectric and the ramp oxide angle on the resulting reverse breakdown voltage (VB) of bulk rectifiers. We find that SiO2 produces the highest VB of the materials investigated, that there is an optimum metal overlap distance for a given oxide thickness and small oxide ramp angles produce the highest VB.

SESSION C5: PROCESSING AND DEVICES
Chairs: Martin Stutzmann and A. P. Zhang
Wednesday Afternoon, April 23, 2003
Golden Gate A2 (Marriott)

1:30 PM *C5.1
CHALLENGES FOR DEVICE PROCESSING OF GROUP-III NITRIDES AND ZINC OXIDE USING ION BEAM TECHNOLOGIES. J.S. Williams, C. Jagadish, Department of Electronic Materials Engineering, Research School of Physical Sciences and Engineering, Australian National University, Canberra, AUSTRALIA; S.O. Kucheyev, Lawrence Livermore National Laboratory, Livermore, CA.

Ion beams are now routinely used in several processing steps, such as doping, electrical and optical isolation and etching, for the fabrication of semiconductor devices. An often undesirable aspect of ion bombardment is the lattice disorder that must be removed or controlled to avoid deleterious effects on device performance. In diamond cubic semiconductors such as silicon, gallium arsenide and indium phosphide, disorder can be removed or stabilized by an annealing step so that optimum doping, isolation and etching can be achieved with negligible effects on device performance. Recently there has been much interest in the possibility of using ion beams to process wide band gap semiconductors such as gallium nitride and zinc oxide. This paper reviews some of our recent studies in which we have found that defect generation and removal is considerably more complex in such wurtzite semiconductors than is the case in both elemental and group III-V cubic semiconductors. For example, although the wide band gap semiconductors appear to be somewhat resistant to ion damage, due to efficient defect annihilation, the disorder that accumulates is extremely difficult to remove. Furthermore, a range of unusual effects that can occur under some conditions can seriously limit applications in device processing, such as ultra-rapid erosion, the formation of porous material and deeply propagating defects. This paper reviews such effects in III-nitrides, some odd ion damaging behaviour in zinc oxide and suggests possible pathways to satisfactory device processing. Electrical isolation technologies using ion beams are also reviewed in both of these wide band gap semiconductors, where the III-nitrides are particularly receptive to such processing but zinc oxide is not. Finally, we discuss aspects of mechanical damage and defect formation in these materials that can strongly influence device processing methods.

2:00 PM *C5.2
HIGH-DENSITY PLASMA ETCHING OF WIDE-BANDGAP MATERIALS. R.J. Shull, R.D. Briggs, K H.A. Bogart, A.J. Fischer, D.D. Koleske, A.A. Allerman, and C.C. Mitchell, Sandia National Laboratories, Albuquerque, NM.

The ability to dry etch wide-bandgap materials has improved significantly over the past few years. The use of high-density plasma etch platforms, including inductively coupled plasma (ICP) etch systems has improved the ability to control etch rates, selectivity, etch profiles, and reduce plasma-induced-damage. This may be attributed to the high concentration of reactive neutrals and ionic species formed in the plasma and the ability to independently control plasma density and ion energy. In this talk we will summarize advances in dry etching wide-bandgap materials including GaN and SiC. Special attention will be paid to achieving profile control and smooth sidewall etching of GaN mesa structures for the fabrication of nitride-based laser diodes. In addition, recent results on ICP etching of SiC will be discussed for application to cantilever epitaxy (CE) of GaN. Overgrowth techniques have enabled dramatic reductions in vertical threading dislocations (VTD) in GaN. Cantilever epitaxy may have advantages over other overgrowth techniques since it requires only one MOCVD growth run and has the potential to reduce dislocations over relatively large areas. For CE, GaN growth is nucleated on top of stripes that have been etched out of the substrate (such as sapphire, SiC or Si). GaN growth eventually extends laterally over the etched trench until growth fronts from adjacent stripes coalesce. ICP etch conditions for SiC to achieve deep (1 to 5 μm), closely packed (1 to 10 μm pitch) structures with critical dimensions approaching 1 μm will be discussed. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-ACO4-94AL85000.

2:30 PM *C5.3
PROCESSING TECHNOLOGIES FOR AlGaN/GaN HEMTs. Ilesanmi Adesida, University of Illinois, Micro and Nanotechnology Laboratory and Dept. of Electrical and Computer Engineering, Urbana-Champaign, IL.

AlGaN/GaN high electron mobility transistors (HEMTs) are of prime interest as devices for applications in high temperature/high power electronics at microwave frequencies. For excellent performance under the harsh conditions to be encountered in these applications, robust technologies have to be developed for these devices. We will describe our work on ohmic contacts and Schottky gate metals for AlGaN/GaN HEMTs that are suitable for operation at temperatures above 500 C. Etching techniques developed for gate recessing and via-holes wil also be described. The impact of adopting these technologies on devices will be discussed.

3:30 PM *C5.4
ELECTRON INJECTION-INDUCED EFFECTS IN III-NITRIDES: PHYSICS AND APPLICATIONS. Leonid Chernyak and William Burdett, Univ of Central Florida, Dept of Physics, Orlando, FL.

It was recently discovered that electron injection into p-type AlGaN leads to a significant enhancement of minority carrier transport, which is also expressed in pronounced changes of materials optical properties. In this work we present a detail study of electron injection effects in p-type Mg-doped GaN, $Al_{0.2}Ga_{0.8}N$, and $Al_{0.2}Ga_{0.8}N$/GaN superlattices, which were homogeneously and modulation (barrier only) doped. Temperature dependent Electron Beam Induced Current (EBIC) measurements resulted in finding of the activation energies for the electron injection-induced effects. These energies are in the 190-260 meV range, which is close to the thermal ionization energy of the Mg-acceptor in p-AlGaN. The obtained results are in agreement with the previously proposed model of minority carrier transport enhancement due to charging of Mg-related centers. The activation energy of the electron injection effect observed in $Al_{0.2}Ga_{0.8}N$ is consistent with the deepening of Mg-acceptor level due to the incorporation of Al into GaN lattice. The activation energy in the $Al_{0.2}Ga_{0.8}N$/GaN superlattice, homogeneously doped with Mg, indicates that the main contribution to the effect comes from the capture of injected electrons by the wells. As the minority carrier transport is of great importance for bipolar devices, we will discuss the impact of electron injection effects on functionality of heterojunction transistors and photodetectors. A multifold-fold increase of photoresponse for AlGaN p-n junction detectors, as a result of electron injection, will be demonstrated.

4:00 PM C5.5
LOW TEMPERATURE OPERATION OF GREEN/BLUE/UV INGaN/GaN MULTIPLE QUANTUM WELL LIGHT-EMITTING DIODES. X.A. Cao, S.F. LeBoeuf, J.L. Garrett, L.B. Rowland, Semiconductor Technology Lab, GE Global Research Center, Niskayuna, NY; H. Liu, AXT Inc., Monterey Park, CA.

Temperature-dependent electroluminescence (EL) of InGaN/GaN multiple quantum well light-emitting diodes (LEDs) with peak emission wavelengths ranging from green (525 nm) to UV (370 nm) has been studied over a wide temperature range (5-300 K). As the temperature decreases from 300 K to 150 K, the EL intensity increases in all devices due to reduced nonradiative recombination and improved carrier confinement. However, LED operation at lower temperatures (down to 5 K) is a strong function of In ratio in the active layer. For the green LEDs, emission intensity increases monotonically in the whole temperature range, while for the devices with shorter wavelengths, the light output tends to saturate and decrease with decreasing temperature. The discrepancy can be attributed to various amounts of localization states caused by In composition fluctuation in the QW active regions. The enhanced localization effect in the green LEDs is crucial to maintain high-efficiency carrier capture at low temperatures. The mechanisms of carrier injection and recombination in these devices will also be discussed based on light output-current-voltage characteristics.

4:15 PM C5.6
Abstract Withdrawn.

4:30 PM C5.7
DEVELOPMENT OF ULTRAVIOLET III-NITRIDE LEDS. Steven LeBoeuf, Xian-An Cao, Jerome Garrett, Larry Rowland, General Electric Research Lab, Schenectady, NY; Edward Stokes, Department of Electrical and Computer Engineering, University of North Carolina at Charlotte, Charlotte, NC.

Dramatic performance enhancements in lateral, epi-up UV LEDs have been realized by improving current spreading in the transparent contact and the underlying n-doped AlGaN template. It is found that delta-doping of n-AlGaN can reduce the forward voltage at 20 mA by as much as 2 volts. Similarly, by matching the sheet resistance of the transparent p-contact to that of the n-doped underlayer, optimal current spreading and uniform light emission can be achieved. These techniques can be easily adapted to deep UV LEDs having higher Al concentration. UV LEDs have been packaged both individually and as arrays, yielding as much as twice the light extraction as unpackaged die. We also report on progress in the direct infrared ionization of bound acceptors as a method of improving UV LED performance through enhancement of hole concentrations in p-AlGaN.

4:45 PM C5.8
HIGH-SPEED SOLAR-BLIND AlGaN SCHOTTKY PHOTODIODES. Necmi Biyikli, Tolga Kartaloglu, and Orhan Aytur, Bilkent University, Dept. of Electrical and Electronics Engineering, Ankara, TURKEY; Ibrahim Kimukin and Ekmel Ozbay, Bilkent University, Dept. of Physics, Ankara, TURKEY.

We have demonstrated high performance solar-blind Schottky photodiodes with very fast pulse-responses. The detectors were fabricated on n-/n+ AlGaN/GaN heterostructures using a microwave compatible fabrication process. The ohmic and mesa isolation etch processes were accomplished using reactive-ion-etching with CCl_2F_2. Then Schottky contacts were formed by the deposition of indium-tin-oxide (ITO) or gold (Au) films. The process was completed with surface passivation and interconnect metal deposition. Current-voltage measurements showed that both ITO and Au-Schottky detectors exhibited low dark currents and high breakdown voltages. The solar-blind detectors had dark current density below 9 nA/cm^2 at 25 V reverse bias. The breakdown voltages were higher than 50 V. Spectral responsivity of the photodiodes were measured in the 250 350 nm wavelength range. The maximum measured responsivity values were 44 mA/W at 263 nm for ITO-Schottky and 89 mA/W at 267 nm for Au-Schottky photodiodes. These results correspond to 21% and 47% quantum efficiency respectively. True solar-blind operation was achieved for both types of detectors with a 274 nm cut-off wavelength. The solar-blind/near-UV contrast exceeded 3 orders of magnitude. For high-speed measurements, a Ti:Sapphire mode-locked laser and two nonlinear crystals were used to generate picosecond pulses at 267 nm. The resulting pulse-responses were observed using a 50 GHz sampling oscilloscope. Very short rise times (~13 psec) were obtained. For ITO-Schottky photodiodes 190 psec pulse-width and 1.0 GHz bandwidth and for Au-Schottky photodiodes 74 psec pulse-width and 1.2 GHz bandwidth were measured. In summary we have demonstrated first ITO-based solar-blind AlGaN Schottky photodiodes. The high-speed performances achieved with both ITO and Au-Schottky photodiodes correspond to best results obtained for solar-blind photodetectors.

SESSION C6: EMERGING AREAS

Chairs: James S. Williams and Xian-An Cao
Thursday Morning, April 24, 2003
Golden Gate A2 (Marriott)

8:30 AM *C6.1

III-N BASED DILUTED MAGNETIC SEMICONDUCTORS FOR SPINTRONICS APPLICATIONS.

Y.D. Park, D.J. Lim, S.B. Shim, and K.S. Suh, Center for Strongly Correlated Materials Research & School of Physics, Seoul National University, Seoul, KOREA; J.S. Lee and Z.G. Khim, School of Physics, Seoul National University, Seoul, KOREA; G.T. Thaler, M.E. Overberg, C.R. Abernathy, S.J. Pearton, Department of Materials Science and Engineering, University of Florida, Gainesville, FL; S.N.G. Chu, Agere Systems, Murray Hill, NJ; J.-H. Kim and F. Ren, Department of Chemical Engineering, University of Florida, Gainesville, FL.

First observations of ferromagnetic ordering in III-Mn-V compound semiconductors have initiated much renewed interest in diluted magnetic semiconductors (DMS). Incorporation of ferromagnetic properties promises to add new dimensionality and functionality to already well-established semiconductor electronic devices.[1] Although first observed DMS with ferromagnetic ordering, InMnAs and GaMnAs, suffer from low ferromagnetic ordering temperatures (Tc < 110 K), their discovery and attempts to fully understand their ferromagnetic origins had set forth theoretical works that predict promising and truly applicable properties for GaN based DMS. These predictions range from near or above room temperature magnetic ordering for various transition metals including Mn, Cr, and V incorporated into GaN.[2] Realization of such material has been accomplished by varying techniques such as diffusion of Mn in GaN film, ion-implantation, and epitaxial growth by gas-source molecular-beam epitaxy.[3] For functional devices, ion-implantation and epitaxial growth promise to be most easily suited. We report on the magnetic properties of epitaxial GaN based DMS prepared by gas-source molecular-beam epitaxy and ion-beam implantation. We have observed ferromagnetic-like behavior near and above room temperatures for epitaxial (Ga,Mn)N, GaN:Co, and GaN:Cr, the later two prepared by ion implantation. Along with magnetic properties, structural and transport properties will also be presented.
This work is partly supported by KOSEF and Samsung Electronics Endowment through CSCMR. [1] S.A. Wolf et al., Science 294, 1488 (2001). [2] T. Dietl et al., Science 287, 1019 (2000); K. Sato and H. Katayama-Yoshida, Jap. J. Appl. Phys. 40, L485-487 (2001). [3] M.L. Reed et al., Appl. Phys. Lett. 79, 3473 (2001); M.E. Overberg et al., Appl. Phys. Lett. 79, 1312 (2001); N. Theodoropoulou et al., Appl. Phys. Lett. 78, 3475 (2001).

9:00 AM *C6.2

IMPURITY DOPING OF III-V NITRIDE SEMICONDUCTORS WITH MAGNETIC IONS.

John M. Zavada, US Army Research Office, Research Triangle Park, NC.

The III-V nitride semiconductor material system forms the basis of many optoelectronic devices, including bright, long lasting, light emitting diodes and lasers. This development has influenced components for displays, optical storage, and traffic lighting. Another area of growing importance is the doping of the III-V nitrides with magnetic atoms. Currently, a large research effort is centered upon methods to exploit the property of electron spin ("spintronics") in device structures for switching, sensing, logic, and memory storage. The use of dilute magnetic semiconductors (DMS) offers a method for increasing the spin injection efficiency in generic devices. For practical applications, DMS materials that have a ferromagnetic transition temperature (TC) at or above room temperature are required. Experimental results have shown that ferromagnetic ordering with a TC > 300K can be achieved in magnetically doped wide bandgap materials such as GaMnN, Ga FeN, and GaMnN thin films. In this talk, a review of ferromagnetic ordering in the III-V nitride semiconductors will be presented. Aspects of magnetic ion incorporation in the III-V nitride host will be discussed as well as structural properties, and magnetic characterization. In addition, recent results concerning the implantation of AlN thin films with Mn, Fe, and Cr ions and ferromagnetic ordering will be included. Extension of these studies to magnetically doping with other transition metals will be treated.

9:30 AM C6.3

HYDROGEN DRIFT, DIFFUSION, AND TRAPPING IN Mg-DOPED GALLIUM NITRIDE.

A.F. Wright, C.H. Seager, S.M. Myers, D.D. Koleske, A.A. Allerman, Sandia National Laboratories, Albuquerque, NM.

Metalorganic vapor phase epitaxy (MOVPE) of Mg-doped GaN is accompanied by incorporation of H which passivates or compensates the Mg acceptors. After growth, H must be removed in order to achieve p-type doping, and this is typically accomplished with a high-temperature anneal which releases H from the Mg traps whereupon it diffuses to a surface and leaves the material. To improve our understanding of this technologically important process, we have studied the diffusion and trapping of H in Mg-doped GaN employing a complementary set of experimental, theoretical, and modeling techniques. Using density-functional theory with the generalized-gradient approximation for exchange and correlation, we have identified paths for H diffusion parallel and perpendicular to the c-axis. The activation energy for perpendicular diffusion is found to be 0.1 eV lower than for parallel diffusion, indicating that in-plane diffusion is roughly ten times faster in the temperature range of our experiments. The computed activation energies are 0.4 eV higher than earlier theoretical results obtained using the local-density approximation for exchange and correlation, and the sum of the diffusion activation energy and the Mg-H binding energy is 0.2 eV lower than the value (1.8 eV) obtained by modeling our experimental data. The experiments (capacitance-voltage measurements) directly observe the diffusion and field-induced drift of H in p/n diodes grown by MOVPE, and the data is well described by a numerical model which simulates all of the important electronic processes as well as field drift, diffusion, and trapping of H. The results clearly show that H exists in the positive charge state, and demonstrate that H diffusion is anisotropic in GaN. This work was partially supported by the Office of Basic Energy Sciences, U.S. Dept. of Energy. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the U.S. Dept of Energy under Contract DE-AC04-94AL8500.

9:45 AM C6.4

OBSERVATIONS OF H/D IN ZnO.

C.H. Seager and S.M. Myers, Sandia National Laboratories, Albuquerque, NM.

Recent Density Functional Theory calculations indicate that hydrogen is soluble in ZnO, effectively forming a shallow donor state. It has been suggested that these donors are responsible for the large increases in electron concentration seen in zinc oxide samples annealed at elevated temperatures in H_2 gas. To explore this issue, we have annealed Li-compensated single crystal ZnO in D_2 gas at 750°C and compared the observed changes in electron concentration with Nuclear Reaction Analysis and Secondary Ion Mass Spectrometry profiles of deuterium. We find that the amount of deuterium remaining in the gas-charged samples is ~2-4 x 10^{17} cm^{-3}, while the (~100-fold) increase in conduction band electron density measured at 300°K is ~2-3 x 10^{17} cm^{-3} (this spread arises from uncertainty in the carrier scattering mechanism). Several infrared absorption peaks are observed which we identify with local O-H/D stretch modes. The deuteration process causes all but one of the multiple O-H modes to disappear and several prominent O-D modes to appear in the 2400-2650 cm^{-1} frequency region. The relative size and frequency of these modes in c-axis and a-axis oriented ZnO platelets is discussed and compared with DFT predictions of H-site occupations. While these data support the H donor hypothesis, the complexity of the vibrational spectra indicate that there are multiple sites for H/D occupation in this material.
This work was supported by the Basic Energy Sciences Office of the Department of Energy. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-ACO4-94AL85000.

10:30 AM C6.5

FIRST AlGaN FREE-STANDING WAFERS.

Yu. Melnik, V. Soukhoveev, K. Tsvetkov, and V. Dmitriev, Technologies and Devices International, Inc., Silver Spring, MD.

Single crystal AlGaN bulk materials have been fabricated, for the first time. AlGaN thick (up to 0.6 mm) layers were grown by hydride vapor phase epitaxy on SiC substrates. The substrates were removed resulting in free-standing AlGaN wafers up to 0.5 inch in diameter. Fabricated AlGaN wafers were investigated by x-ray diffraction, transmission electron microscopy (TEM), and cathodoluminescence. X-ray diffraction and TEM studies confirmed single crystal structure of grown material. Based on x-ray diffraction results, AlN concentration in grown material was estimated of about 35 mol.%. Cathodoluminescence measurements demonstrated a number of peaks in UV spectral region with the most intense luminescence at a wavelength of about 325 nm (100 K). The wafers demonstrated n-type conductivity with electron concentration in the 1017 cm-3 range at room temperature. We continue to investigate basic properties of these novel bulk materials with different AlN contents and plan to present results at the meeting. Development of AlGaN substrates with controlled alloy composition may lead to stress-free device epitaxial structures for AlGaN-based transistors and UV emitters and sensors. This work at TDI is supported by MDA and managed by the ONR (contract manager Colin Wood).

10:45 AM C6.6

STRUCTURAL PROPERTIES OF FREE-STANDING 50 mm GaN WAFERS WITH (10$\bar{1}$0) ORIENTATION GROWN ON $LiAlO_2$. Jacek Jasinski, Jack Washburn, and Zuzanna Liliental-Weber, Lawrence Berekeley National Laboratory, Materials Science Division, Berkeley, CA; Herbert-Paul Maruska, Bruce H. Chai, David W. Hill, Mitch M.C. Chou, John J. Gallagher, and Stephen Brown, Crystal Photonics Inc, Sanford, FL.

The search for a suitable substrate for expitaxial growth of high quality III-nitride device structures is an extremely important issue. To date, almost all nitride films are grown on highly mismatched substrates, namely on α-Al_2O_3 and 6H-SiC. Recently however, γ-$LiAlO_2$, which has a tetragonal crystal structure, attracted significant attention since its (100) face is very closely matched with the (10$\bar{1}$0) face (M-plane) of wurtzite GaN. Significantly, GaN devices grown with the M-plane orientation are expected to be free from spontaneous electrostatic fields along the growth direction. In this paper we report results of structural studies performed on free-standing 50 mm diameter GaN wafers obtained by growth on the (100)-face of γ-$LiAlO_2$. Boules of $LiAlO_2$ were prepared from the melt by the Czochralski method, and sawed into wafers. After polishing, GaN layers about 350 microns thick were deposited on them by halide vapor phase epitaxy (HVPE) at 875°C. Subsequent to growth, the $LiAlO_2$ was removed by wet chemical etching, leaving GaN wafers with the non-polar (10$\bar{1}$0) orientation. The structural properties of these wafers before and after substrate removal were investigated by transmission electron microscopy (TEM). TEM images of the interface between GaN and $LiAlO_2$ indicate that approximately a 50 nm thick layer at the surface of the substrate has been modified and seems to be much more defective than the remainder of the substrate, which has high structural quality. Surprisingly, selected area electron diffraction shows that the orientation of the GaN film actually matches that of the original substrate, suggesting that the defective regions of the interfacial layer occur as islands surrounded by regions where there is a full coherence. Several types of structural defects were observed inside these HVPE GaN wafers. Layers contained substantial densities of threading dislocations with their lines inclined to the film normal and located on the basal (0001) planes. Dislocations were out of contrast for g-vector parallel to the [10$\bar{1}$0] direction and in a good contrast for g-vector parallel to the [0001] direction, suggesting that they were edge-type. Their density decreased from the value of the order of 10^9 cm^{-2} close to the substrate to the value of the order of 10^8 cm^{-2}at the layer surface. In the areas located close to the substrate some grain boundaries, running primarily parallel to the substrate/layer interface but with segments on different planes, were observed. They were similar to inversion domain boundaries observed sometimes in HVPE GaN layers grown on C-plane sapphire substrate. Finally, the most dominant structural defects observed in HVPE-grown M-plane oriented GaN layers grown on $LiAlO_2$ substrate were planar defects, possibly stacking faults, located on basal (0001) planes. The average separation between them was of the order of few tens of nanometers. They nucleated either at the original interface or at grain boundaries mentioned before. Some of these planar defects have also terminated at these boundaries but many of them propagated to the layer surface. Further studies are underway to determine the real nature of these boundaries and defects.

11:00 AM C6.7

DEEP LEVEL EMISSION IN VANADIUM DOPED AND HIGH PURITY 6H-SiC. G. Tamulaitis, I. Yilmaz, M.S. Shur, Department of ECE and CIE, Rensselaer Polytechnic Institute, Troy, NY; T. Anderson, II-VI, Inc., Pine Brook, NJ; R. Gaska, Sensor Electronic Technology, Inc., Columbia, SC.

We report on characterization of 6H SiC monocrystalline substrates using photoluminescence (PL) techniques. Both undoped and vanadium-doped samples were investigated. After initial characterization in CW regime by using excitation with He-Cd laser emission at 325 nm, the samples were investigated under pulsed (4 ns) excitation. The 5th (212 nm, 5.847 eV) and the 3rd (355 nm, 3.492 eV) harmonics of YAG:Nd laser radiation were used for the PL excitation. The PL spectra were recorded by using Intensified CCD. Time evolution of the PL was measured with resolution of 6.5 ns by gating the ICCD. The PL was measured in the temperature range from 8 K to 300 K in a wide range of intensities of excitation at different wavelengths. The main PL band peaked at 427 nm was found to redshift with increasing pump intensity. As a function of a delay after the pulsed excitation, the 427 nm band was redshifted in some samples and blueshifted in some other samples. In addition, a PL band peaked at approximately 467 nm was also observed and shown to have longer decay time than that of the main band. The study resulted in the selection of PL features useful for mapping of SiC substrates. This mapping is based on spectral features of CW photoluminescence and on decay peculiarities under pulsed excitation. We will present the details of the PL comparison for vanadium-doped and undoped substrates.

11:15 AM C6.8

GROWTH AND ELECTRICAL CHARACTERISTICS OF EPITAXIAL ZnO/GaN(001) p-n HETEROJUNCTIONS. Ashutosh Tiwari and J. Narayan, Dept of Materials Science & Engineering, North Carolina State University, Raleigh, NC.

ZnO has a direct band gap of 3.37 eV with a large exciton binding energy of 60 meV at room temperature. Because of this, it is considered as one of the most promising materials for exciton-based optoelectronic applications. However, for actual devices it is desirable to grow p-n junctions of ZnO. Although it is possible to grow n-type ZnO, the growth technique for conductive p-type ZnO is still not known. In this situation, hetero p-n junctions can provide an alternative for homo p-n junctions. The GaN/ZnO heterostructure is a promising candidate for such applications. It is possible to grow p-type GaN and it has only a slight lattice mismatch of 1.9% with ZnO. Here we report the growth and electrical characteristics of epitaxial ZnO/GaN(001) p-n heterojunctions on sapphire substrates using a combination of MOCVD and Pulsed Lased Deposition techniques.

11:30 AM C6.9

STIMULATED EMISSION AT 258 NM IN AlN/AlGaN QUANTUM WELLS GROWN ON BULK AlN SUBSTRATES. Remis Gaska, Qhalid Fareed, Sensor Electronic Technology Inc., Columbia, SC; Gintautas Tamulaitis, Ibrahim Yilmaz, Michael S. Shur, Dept of ECE and CIE, Rensselaer Polytechnic Inst, Troy, NY; Changqing Chen, Jinwei Yang, Edmundas Kuokstis, Asif Khan, Dept of EE, Univ of South Carolina, Columbia, SC; Juan C. Rojo, Leo J. Schowalter, Crystal IS Inc., Latham, NY.

We report on observation of stimulated emission at 258 nm in AlN/AlGaN multiple quantum wells (MQW). The structures were grown over Al-face single crystal bulk AlN substrates (off c-axis by 5.8 degrees). AlN/AlGaN structures with 50% of Al in the well material were grown using low-pressure MOCVD. Characterization by using X-ray, AFM, SEM and photoluminescence techniques indicated high structural quality of the structures. The defect density in the structures was estimated to be in the range from 106/cm2 to 107/cm2. The stimulated emission was measured using the variable stripe length method. This method is based on exciting a narrow stripe at the edge of the sample and measuring emission, which propagates along the stripe and emerges from the edge. The samples were excited by 4-ns-long pulses of the fifth harmonic of Nd:YAG laser radiation at 213 nm (5.82 eV), which generated carriers only in the quantum well material. A narrow line peaked at 258 nm was observed at elevated pump intensities and longer stripes. This line is about 2 nm to the short-wavelength side from the peak of spontaneous emission. Stimulated emission exhibited a characteristic superlinear dependence of emission intensity on the pump intensity as well as an exponential increase of the line intensity with increasing stripe length up to $\sim$500 μm and the intensity saturation beyond this range. The extracted value of the optical gain coefficient was slightly higher than 100 cm-1. The observation of stimulated emission at 258 nm is very promising for the future development of III-Nitride based deep-UV laser diodes on bulk AlN substrates.

11:45 AM C6.10

SURFACE ACOUSTIC WAVES AND GUIDED OPTICAL WAVES IN AlGaN FILMS. G. Bu, D. Ciplys, M.S. Shur, Rensselaer Polytechnic Inst, Dept of Electrical, Computer, and Systems Engineering, NY; R. Gaska and Q. Fareed, Sensor Electronic Technology, Inc., SC; R. Rimeika, Vilnius University, Dept of Radiophysics, Vilnius, LITHUANIA; J. Yang, A. Khan, University of South Carolina, Dept of Electrical Engineering, SC.

$Al_xGa_{1-x}N$ layers grown by MOCVD on sapphire substrates have been tested using the surface acoustic wave (SAW) and guided optical wave (GOW) techniques. The transmission characteristics of the two-port SAW filter have been measured by the network analyzer.Time gating technique has been used in order to eliminate the spurious signal caused by the electromagnetic feed-through between the input and output transducers. For the layer with x=0.36 and thickness 0.6 μm, the transmission loss was 37.5 dB at 343 MHz.

This losses are of the same order as for GaN films of similar thickness,and they are smaller than those measured for thinner (about 0.4 μm) comparable AlGaN films. The one-port measurements of the S11 parameter of the SAW transducer yielded the electromechanical coupling coefficient value $K^2 = 0.028$ %, which is close to K^2 for comparable GaN films. The GOW technique was employed to measure the layer thickness and refractive indices. The values of the latter for the ordinary and extraordinary polarizations respectively were 2.23 and 2.259 for the 0.59 μm thickness. The guided mode propagation tracks have been investigated using the CCD imaging technique. The measured GOW attenuation was 6.6 dB/cm, 10.5 dB/cm, and 22.5 dB/cm for TE_0, TE_1, and TM_0 modes, respectively. This attenuation is comparable to that we measured in GaN by the same technique. Hence, our results show that the properties of AlGaN with relatively high molar fraction of Al (x=0.36) that determine SAW and GOW propagation are similar to those for GaN films.

SESSION C7: PROCESSING, GROWTH, DEVICES

Chairs: Jen-Inn Chyi and Jung Han
Thursday Afternoon, April 24, 2003
Golden Gate A2 (Marriott)

1:30 PM C7.1
EFFECTS OF HYDROGEN AND DRY ETCHING ON ZnO. Kelly Ip, M.E. Overberg, K.W. Baik, Y.W. Heo, D.P. Norton, S.J. Pearton, Univ of Florida, Dept of Material Science and Engineering, Gainesville, FL; C.E. Stutz, AFRL/MLPS, Wright-Patterson AFB, OH; D.C. Look, Wright State Univ, Semiconductor Research Center, Dayton, OH; B. Luo and F. Ren, Univ of Florida, Dept of Chemical Engineering, Gainesville, FL; S.O. Kucheyev, C. Jagadish, J.S. Williams, Australian National Univ, Canberra, AUSTRALIA; R.G. Wilson, Stevenson Ranch, CA; J.M. Zavada, US Army Research Office, Reseach Triangle Park, NC.

Bulk, single-crystal ZnO was etched in Cl_2/Ar and $CH_4/H_2/Ar$ Inductively Coupled Plasmas as a function of ion impact energy. For $CH_4/H_2/Ar$, the etch rate (R) increases with ion energy (E) as predicted from a model of ion enhanced sputtering by a collision-cascade process, $R \propto (E^{0.5}\ ?E_{TH}{}^{0.5})$, where the threshold energy, E_{TH}, is ~96eV. Bandedge photoluminescence intensity decreases with incident ion energy in both chemistries, with a 70% decrease even for low energies (~116eV). Surface roughness is also a function of ion energy with a minimum at ∝250eV, where Auger Electron Spectroscopy shows there is no measurable change in near-surface stoichiometry from that of unetched control samples. Hydrogen incorporation depths of >25 mm were obtained in bulk, single-crystal ZnO during exposure to ^2H plasmas for 0.5h at 300°C, producing an estimated diffusivity of $\propto 8\times10^{-10}$ cm^2/Vs at this temperature. The activation energy for diffusion was 0.17±0.12 eV, indicating an interstitial mechanism. Subsequent annealing at 500-600°C was sufficient to evolve all of the hydrogen out of the ZnO, at least to the sensitivity of Secondary Ion Mass Spectrometry ($<5\times10^{15}$ cm^{-3}). The thermal stability of hydrogen retention is slightly greater when the hydrogen is incorporated by direct implantation relative to plasma exposure, due to trapping at residual damage in the former case.

1:45 PM C7.2
LARGE AREA 6H- AND 4H-SiC PHOTOCONDUCTIVE SWITCHING DEVICES FOR USE IN HIGH POWER APPLICATIONS. S. Dogan[a], F. Yun, Department of Electrical Engineering, Virginia Commonwealth University, Richmond, VA; C.B. Roberts, Tech Explore LLC, Oxford, OH; J. Parish, AFRL/PRPE, Wright-Patterson AFB, OH; D. Huang, Department of Electrical Engineering, Virginia Commonwealth University, Richmond, VA; R.E. Myers, S.E. Saddow, Electrical Engineering Dept., Nanomaterials and Nanomanufacturing Research Center, USF, Tampa, FL; B. Ganguly, AFRL/PRPE, Wright-Patterson AFB, OH; and H. Morkoç, Department of Electrical Engineering, Virginia Commonwealth University, Richmond, VA. [a]Also with: Ataturk University, Faculty of Art & Science, Department of Physics, Erzurum, TURKEY.

Silicon carbide is a wide band gap semiconductor suitable for high-power, high-voltage devices and it has excellent properties for use in Photoconductive Semiconductor Switches (PCSS). PCSS were fabricated in planar structures on high resistivity 6H- and 4H-SiC and tested at DC Bias voltages up to 1000 V. The gap spacing between the electrodes is 1 mm. The average on-state resistance and the ratio of on-state to off-state currents were about 20 ohms and 3×10^{11}, respectively. The typical maximum switch current at 1000 V is about 49.36 A. Photoconductivity pulse widths for all applied voltages were 8-10 ns. These excellent results are in part due to removal of the surface damage by high temperature H etching and surface preparation. Atomic Force Microscopy images revealed that very good surface morphology, atomic layer flatness and large step width were achieved.

2:00 PM C7.3
CURRENT MAPPING IN EPITAXIAL GaN FILMS BY CONDUCTIVE ATOMIC FORCE MICROSCOPE. A.A. Pomarico, D. Huang, J. Dickinson, A.A. Baski, Department of Electrical Engineering and The Physics Department, Virginia Commonwealth Univ., Richmond, VA; R. Cingolani, NNL National Nanotechnology Laboratory of INFM, Universita di Lecce, Lecce, ITALY; and H. Morkoç, Department of Electrical Engineering and The Physics Department, Virginia Commonwealth Univ., Richmond, VA; R. Molnar, MIT, Lincoln Laboratory, Lexington, MA.

The electrical characteristics of GaN are at the moment the subject of a vast amount of research, as the reverse-bias leakage current in GaN-based electronic devices remains the main obstacle in their use for FET applications. A recently developed, powerful technique for the study of the electrical properties of semiconductor materials is the conductive-atomic force microscopy (C-AFM). By simultaneously mapping the topography and the current distribution, C-AFM allows to establish a direct correlation of a sample location with its electrical properties, which makes this technique very useful to identify and investigate localized current paths. In this study, conductive atomic force microscopy was used to image the conduction properties of GaN epitaxial layers on a microscopic scale. Three types of GaN films, n-type with etched pits, as grown n-type with truncated pyramids, and Zn-doped high resistivity with etched pits, were investigated. We found that a large and relatively stable local current was mainly observed from the walls of the etched pits in the n-type films, under negative sample bias of a few volts corresponding the forward bias of the metal tip/semiconductor junction. The local current from the walls of the truncated pyramids quickly decayed with time. For the Zn-doped high resistivity sample, under both positive and negative bias, the local current is much lower. The results show that the crystallographic planes that are tilted with respect to the c-plane have a much higher conductivity than the remaining parts of the sample surface.

2:15 PM C7.4
GaN EPITAXIAL GROWTH BY MOLECULAR BEAM EPITAXY UTILIZING AlGaN BUFFER LAYER WITH NANOTUBES. F. Yun, L. He, X. Liu, M.A. Reshchikov, and H. Morkoç, Department of Electrical Engineering and Physics Department, Virginia Commonwealth University, Richmond, VA; J. Jasinski and Z. Liliental-Weber, Materials Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA.

For application in electronic devices such as field effect transistors, high-quality GaN epilayers by MBE is essential. While selective and lateral overgrowth has been successfully incorporated for GaN MOCVD growth, the case in MBE is not well investigated. Recently, there has been some effort in growing GaN on nanopatterned substrate for defect reduction. In this work, we report the growth and characterization of GaN thin films on top of porous templates of AlGaN. It is believed that the use of ternary alloy as a buffer layer would be beneficial for reducing lattice and thermal mismatch, while the porous structure of the AlGaN surface would presumably enhance the lateral overgrowth of GaN in order to rid of the threading dislocations along the growth direction. AlGaN films (0.6-1.0 μm in thickness) were grown by MBE using rf-plasma nitrogen source under metal-rich condition. Within the Al composition range of 0.5-0.6, open-end nanotubes were formed at the surface of AlGaN films with a density of $\sim 6\times10^9$ cm^{-2} and a size ranging from 10 to 20 nm. These nanotubes, observed within ~300 nm of the surface, served as an porous AlGaN template for re-growth of GaN epilayers. GaN epilayers grown to different thickness and with different III/V ratio by MBE were studied for their microstructure. For a typical AlGaN buffer layer with dislocation density of $1\text{-}3\times10^{10}$ cm^{-2} near its surface, the overlaying GaN layers with thickness ranging from 0.1 μm to $\sim 2\mu$m were grown and analyzed by TEM for dislocation density. The GaN layer started with hexagonal islands on the porous AlGaN and began to coalesce at about 0.1 μm thickness. At a thickness of ~0.4 μm and above, the dislocation density has shown to be reduced to about 10^9 cm^{-2}, with screw component dislocation density in the low 10^8 cm^{-2}, and edge component dislocation density in the high 10^8 cm^{-2}. This may suggest that the distribution among different types of threading dislocations has been transformed from the AlGaN buffer to the GaN epilayers. Namely, the AlGaN buffer has a similar density for all types of dislocations (screw, edge, and mixed), while the GaN epilayer shows more dislocations with edge component (edge and mixed) than those with screw component (screw and mixed). The microstructure of the GaN epilayer and the porous template of AlGaN buffer layer were also studied by high-resolution X-ray diffraction (rocking curves) and tri-axis reciprocal space map, to correlate the crystalline quality data with microstructural results for various growth with different GaN thickness and other growth parameters. LT Photoluminescence is employed to access the evolution of optical quality of the GaN epilayer.

2:30 PM C7.5

GROWTH OF InN EPITAXIAL LAYERS BY PULSED ATOMIC LAYER EPITAXY. Qhalid Fareed, Rakesh Jain, Remis Gaska, Sensor Electronic Technology, Inc., Columbia, SC; Gintautas Tamulaitis, Ibrahim Yilmaz, Sergey Rumyantsev, Michael Shur, Department of ECE and CIE, Rensselaer Polytechnic Institute, Troy, NY; Asif Khan, Department of EE, University of South Carolina, Columbia, SC.

High quality InN layers were grown on a 2-3 micron thick GaN templates deposited on sapphire substrates. The layers were grown by conventional and pulsed metalorganic vapor phase epitaxy method. In the conventional MOCVD method, In and N sources were ON during the entire growth procedure. However, in the pulsed MOCVD method, In and N sources were alternately pulsed to get better control of V/III ratio. The epitaxial layers showed excellent surface morphology with no In droplets in both modes of growth. X-ray rocking curve and X-ray reciprocal space mapping were carried out on both the samples. The XRD showed the high crystal quality of InN material. Typical XRD peak along (0001) orientation was observed confirming the wurtzite type structure. No cubic phase components were observed. The InN layers grown by conventional MOCVD technique showed the carrier concentration close to 10^{19} cm^{-3} and mobility 100 cm^2/Vs. In the layers grown by pulsed method the measured carrier concentration was 1.5×10^{19} cm^{-3} and the Hall mobility was 30 cm^2/Vs. The calculations of low field mobility that account for polar optical, ionized impurity, and acoustic scattering show that this relatively low value of mobility is caused by compensation. We will also report on room temperature and low temperature photoluminescence data and on the comparative studies of GaN and InN low frequency noise that allow us to characterize the potential of these films for applications in MESFET and HEMT devices.

3:15 PM C7.6

INTEGRATED OPTICAL PUMPING OF RUBY SUBSTRATES BY InGaN LED GROWN ON Cr:SAPPHIRE. Andrew Oberhofer, John Muth, John Roberts, and Salah Bedair, ECE Dept, North Carolina State University, NC; Mason Reed, Materials Engineering Dept, North Carolina State University, NC.

The emission spectra of blue and green emitting III-V nitride materials overlap the absorption bands of Chromium doped sapphire. Thus, III-V nitride structures have the potential to be efficient optical pumps of the Cr doped sapphire substrates on which they are deposited. We have grown high quality epitaxial layers of III-V nitride materials on Cr:Sapphire and Ti:Sapphire substrates and fabricated InGaN LED structures. In this work, multiple quantum wells were grown with the active layer consisting of 5 periods of $In_{0.15}Ga_{0.85}N$/GaN, in which the InGaN layers are 3.0 nm and the GaN barriers are 7.4 nm. Electroluminescence of these devices showed red emission at 694 nm from the Cr^{3+} in the sapphire subtrate matrix in addition to the LED electroluminescence at 420 nm, producing a two color light emitter.

3:30 PM C7.7

GROWTH of GaN(0001) FILMS WITH ZnO BUFFER ON Si(111) AND Si(100) SUBSTRATES. O. Kryliouk, K.C. Kim, T. Anderson, Chemical Engineering, University of Florida, Gainesville, FL; D. Craciun, V. Craciun, R.K. Singh, Materials Science and Engineering, University of Florida, Gainesville, FL.

The desire for large area films and substrates for device fabrications and the possibility of integration of well established Si electronics with III-V based photonics devices has renewed the interest in using Si substrates for GaN growth. Si is one of the most promising substrate materials due to its many advantages such as large size, high quality and low cost. Because of a large lattice mismatch and difference in the thermal expansion coefficient of GaN and Si, direct deposition results in polycrystalline films. Therefore, a proper buffer layer or special substrate treatment procedure is required. We have investigated the use of ZnO buffer layers for the growth of high quality GaN films on Si substrates. ZnO films of various thicknesses have been grown by the pulsed laser deposition (PLD) technique. The deposition of single crystal wurtzitic GaN (0001) films was achieved by low-pressure MOVPE on Si(111), Si(100) and c-Al_2O_3 substrates in the temperature range of 560 to 850°C. TEGa and NH_3 were used as precursors. The grown structures were characterized by XRD, AES, XPS, SEM, TEM, AFM, Raman spectroscopy and ellipsometry to determine the optimal growth conditions. It is shown that the growth conditions, substrate preparation procedure and ZnO buffer layer thickness played an important role on GaN film quality. Results on the effect of ZnO/Si substrate polarity, oxygen and zinc faces, on the quality of GaN epitaxial layer will be presented. These results show that ZnO/Si is a promising substrate for the growth of high quality GaN films.

3:45 PM C7.8

THE GROWTH AND CHARACTERISTIC OF ZnO FILMS GROWN BY LASER MOLECULAR BEAM EPITAXY. Chiung-Chi Tsai, Hung-Yu Lin, Wen-Feng Hsieh, Chen-Shiung Chang, Institute of Electro-Optical Engineering, National Chiao-Tung University, Hsinchu, TAIWAN, R.O.C.

The growth and characteristic of ZnO films grown by laser molecular beam epitaxy ZnO, a wide band-gap material, have recently received great interest due to its large binding energy (60 meV) and lasing mechanism. Several growth technologies have been demonstrated for the growth of ZnO films such as molecular-beam epitaxy (MBE), chemical vapor deposition (CVD), pulse-laser deposition (PLD). Among these methods, PLD has an advantage of achieving high-quality crystalline films with a relatively high-growth rate (> 1gm) at a low temperature. However, several studies have shown that good quality ZnO films can be obtained by using appropriate oxygen pressure, temperature, and one additional buffer layer. Fewer studies have been done on the growth under a ultra-low pressure($< 2 \times 10^{-8}$ torr). In this study, we investigate the growth of ZnO films on c-face sapphire under a ultra-low pressure (without flowing any oxygen) by PLD in a laser molecular-beam epitaxial system (LMBE). After the growth, these ZnO samples show only the $(0\ 0\ \gamma)$ (γ =2,4) planes in the XRD(θ-2θ). The θ-2θ scan shows that these ZnO films are highly c-axis oriented. The full width at half maximum (FWHM) of the double crystal X-ray diffraction (DCXRD) is around 320 arcsec. The transmittance of the optimized ZnO film in the visible region is above 98 %. Photoluminescence spectra show only one band edge emission at 3.4eV. The hall measurement shows a mobility and the carrier concentration of 13 cm^2/Vs and 1.78×10^{17} /cm^3, respectively. The low mobility can be attributed to the electron scattering at the grain boundaries. However, the FWHM data of DCXRD and the relatively low carrier concentration show the good crystal quality of the oxygen-free ZnO films.

4:00 PM C7.9

MODULATION OF ENERGY BAND GAP OF ZnO THIN FILMS GROWN BY PULSED LASER DEPOSITION. Sang Yeol Lee, Yuan Li, Quanxi Jia, MST-STC, Los Alamos National Laboratory, Los Alamos, NM.

ZnO thin film could be used as an optoelectronic device due to its wide bandgap. Multilayers of ZnO-based thin films have been fabricated by pulsed laser deposition. Energy bandgap of ZnO thin films has been modulated by using multilayer structures with ZnMgO and ZnCdO. The structural properties of ZnO-based multilayer structure have been also examined systematically depending on layer thicknesses. ZnMgO and ZnCdO thin films also characterized and compared with the multilayer structures. Structural, electrical and optical properties of multilayered ZnO-based thin films will be presented.

4:15 PM C7.10

THE DEVICE-GRADE ZnO FILMS PREPARED BY RADIO-FREQUENCY MAGNETRON SPUTTERING. Yoichiro Aya, Kouichi Nakahata, Masao Isomura, Kenichiro Wakisaka and Koji Nishio, Sanyo Electric Co., Ltd., Osaka, JAPAN.

Zinc oxide film (ZnO) is well known as a transparent and conductive oxide material, and recent investigations reveal that this material can be used as a wide band gap semiconductor. However, the electrical properties of ZnO usually show n-type conduction with relatively high conductivity due to oxygen vacancies. In this report, we investigated the control of oxygen vacancies to achieve semiconductor behavior in ZnO, and *successfully fabricated a ZnO thin film transistor (TFT) with 7 orders of on/off ratio.* ZnO samples were deposited on glass substrates using the radio-frequency (RF) magnetron sputtering method. The target was non-doped ZnO (99.99%). The sputtering gases were Ar with O2 and the flow rate ratio (O2/(O2+Ar)) was changed from 0 to 100%. The crystallinity and electrical properties were evaluated by X-ray diffraction (XRD) and Hall effect measurement, respectively. The conductivity of ZnO is reduced *from 10-2 to 10-9 (S/cm)-1 when O2/(O2+Ar) is increased from 0% to 25%*, and above 25%, it remains around 10-9 (S/cm)-1. This result indicates that the oxygen in the sputtering gases reduces the oxygen vacancies and the conductivity effectively decreases. *The optical transmission of all samples is maintained above 80%* in the wavelength range of 400 nm to 2000 nm, suggesting that transparent electronic devices can be achieved with ZnO. *The ZnO films have (200) crystal orientation, which is enhanced by increasing O2/(O2+Ar).* Using the optimized ZnO, a bottom gate type TFT was realized with an SiN gate insulator, and our ZnO films proved to have sufficient properties for semiconductor devices. These results indicate that device-grade semiconductor ZnO films can be prepared by using the RF magnetron sputtering method, which is suitable for low-cost, large-area production. We believe that this ZnO is a promising material for achieving fully transparent, low-cost, large-area electronic devices.

4:30 PM C7.11

QUANTUM-CONFINED STARK EFFECT IN WIDE-GAP NITRIDE-BASED QUANTUM STRUCTURES.

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We investigate the role of quantum-confined Stark effect due to built-in electrostatic field on photoluminescence (PL) properties of wide-gap (>3.2 eV) GaN/AlGaN multiple quantum wells (MQWs) deposited on sapphire substrates with different crystallographic surfaces. MQWs were grown by metalorganic chemical vapor deposition on 1-μm-thick GaN buffer layer which was grown on (0001) C-plane, $(11\bar{2}0)$ A-plane or $(1\bar{1}02)$ R-plane sapphire substrates under identical growth conditions. XRD analysis has showed that quantum structures fabricated on R-plane sapphire substrates have A-plane orientation whereas those on C- and A-plane sapphire substrates have both C-plane faces. These two orientations of nitride-based layers determined sufficiently different PL properties. The samples were excited with intense excimer laser pulses (τ = 8 ns, P = 0.001-1 MW/cm^2). PL intensity of A-plane MQWs at low excitation (10 kW/cm^2) was about 100 times higher that that of C-plane MQWs, however PL intensity becomes close in both cases under high (~1MW/cm^2) excitation. Besides, it was observed strong (up to 250 meV) excitation-induced blushift of emission maximum in the samples with C-plane faces, whereas it was no spectral shift in A-plane structures. The theoretical analysis of PL spectra of those structures and comparison with experimental data revealed formation of strong (up to ~1.7 MV/cm) built-in electrostatic field due to spontaneous polarization and piezoelectric field in MQWs grown on C-and A-plane sapphire, whereas identical structures grown on R-plane sapphire showed features of non-polar layers. The PL dynamics with increase of excitation we explain by screening of built-in electrostatic field due to photo-injected carriers. The internal electrostatic field-free quantum structures grown on R-plane sapphire may be promising for ultraviolet region optoelectronic applications due to higher emission intensity and stable spectral parameters.

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GADOLINIUM-DOPED YTTRIUM OXIDE ULTRAVIOLET EMITTING MATERIALS.

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The development of semiconductor based ultraviolet (UV) light sources is of critical importance for miniaturized ultraviolet light sources which have application in biological agent detection, non-line-of-sight covert communications, water purification, equipment/personnel decontamination, and white light generation. To this end, we are investigating gadolinium-doped wide band gap oxide materials as high field electroluminescent materials. Gadolinium is known to radiate in the ultra-violet region at ~312nm and 275nm due to intra-band 4f transitions when suitably doped in oxide host materials. Thin film materials of Y2O3:Gd have been rf-magnetron sputter deposited via a combinatorial sputtering process and the optical (PL and CL), chemical (AES), and microstructural (XRD and SEM) properties of the thin films have been thoroughly characterized. In this paper we will give a brief overview of the high field device architecture. The combinatorial sputtering process will be described and the optical properties of the Y2O3:Gd thin films will be correlated to the chemical and microstructural properties.