SYMPOSIUM K
Materials and Devices for Optoelectronics and Photonics
April 2 – 5, 2002

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*Invited paper
1300 PM K1.3
PROGRESS IN THE PREPARATION OF ALUMINUM NITRIDE SUBSTRATES FROM BULK CRYSTALS. J. Carlos Rojo, Crystal IS, Inc. Latham, NY.

Wide bandgap semiconductor devices, based on AlN, will dominate several optical and electronic technologies in the areas of short wavelength emission and detection or high-power, high-frequency microwave devices. However, the nitride semiconductor industry has not been able to fulfill the expectations of the community, due to the lack of optoelectronic and electronic devices so far. The lack of a high-quality bulk nitride substrate has been pointed out as one of the chief factors contributing to the absence of a mature III-nitride technology. The use of commercially available foreign substrates such as silicon carbide and sapphire has been demonstrated to have serious problems. To overcome these problems there are many efforts worldwide to grow bulk crystals of gallium nitride (GaN) and aluminum nitride (AlN). Some applications would benefit more from bulk GaN, AlN has also received attention as a candidate for III-nitride epitaxy applications due to its close lattice match, minimal differential thermal expansion, and high thermal conductivity compared to GaN. In addition, AlN is a desirable substrate than GaN for device structures that require Al-rich nitride epitaxial layers such as solar-blind UV detectors, UV light sources, and high-power microwave devices. The continuous demonstration by Crystal IS of larger and better single-crystal boules using the sublimation-recrystallization growth technique has greatly increased the prospect of a commercially available 2-inch diameter bulk nitride substrate in the next few years. Currently, boules 1.5 cm in diameter and several cm in length, with density of dislocation below 10^6 cm^-2 and with a thermal conductivity exceeding 3 W/cmK, have been reported. The current state-of-the-art and key issues regarding the growth and surface preparation of bulk AlN substrates will be reviewed. Also, extensive epitaxial results on bulk AlN substrates along several crystallographic directions will be discussed.

2600 PM K1.2

In the paper, we report the results of the investigation of the spectral emission of the inverted pyramid defects of hybrid vapor phase epitaxy (HVPE) grown GaN sample using a confocal microscope imaging and microphotoluminescence (micro-PL) system. The GaN sample was grown on the sapphire substrate. The inverted pyramid defect of a single-crystalline quality surface has a hexagonal facets of about 5.13 μm wide. The sample is placed between top and bottom microscopes with GaN material facing downward to the pump laser. The pump laser is irradiated through the bottom microscope. The signal is collected and focused to the top microscope. Therefore, the observed spectrum is from the emission of the GaN surface defect. The spatial dependence of PL emission spectrum from inside to outside of the pyramid defect was measured. The emission spectrum from the center of the hexagonal structure shows a peak around 370 nm. The emission peak of spectrum gradually blueshifted as the position moving toward the outside of the hexagonal structure where the peak emission wavelength shifted to about 372.5 nm. Since the pyramid defect is believed to be created as result of the stress release of the threading dislocation, the spatial blue shift in the emission spectrum outside the defect center seems reasonable. We also observed an additional peak at 380 nm near the center which could be originated from the threading dislocation associated with the pyramid defect. The spatial blue shift in the emission spectrum outside the defect center seems reasonable.

3:15 PM K1.5
DISLOCATION REDUCTION WITH QUANTUM DOTS IN GaN GROWN ON SAPPHIRE SUBSTRATES BY MOLECULAR BEAM EPITAXY. D.J. Smith, Arizona State University, Tempe, AZ, D. Hung, M.A. Reschikov, F. Yun, T. King, and H. Morok, Virginia Commonwealth University, Richmond, VA; C.W. Litton, Air Force Research Laboratories (AFRL/MLPS), Wright Patterson AFB, OH.

III-nitride semiconductors have a wide range of applications in blue/UV light emitters and detectors, and high power amplifiers. They are most commonly grown on foreign substrates such as sapphire. However, the large difference in lattice constant between the III-nitrides and sapphire substrate, and a lack of common stacking order in high defect densities in the epilayers. The typical threading density in a 1 μm thick GaN film grown directly on sapphire substrate is on the order of 10^10 cm^-2 or higher. In this presentation, we report a new dislocation reduction method utilizing a stack of quantum dots (QDs) in GaN grown on sapphire substrates by molecular beam epitaxy. The GaN films were grown on GaN/AlN buffer layers containing multiple QDs and were characterized by x-ray diffraction, photoluminescence, atomic force microscopy, and transmission electron microscopy. The density of the dislocations in the films was determined by defect detection wet chemical etching and atomic force microscopy. It was found that the insertion of a set of multiple GaN QD layers in the buffer layer effectively reduced the density of the dislocations in the epitaxial layers. As compared to a density of ~10^11 cm^-2, a density of ~3x10^7 cm^-2 was demonstrated in the GaN films grown on AIN buffer layer. Transmission electron microscopy observations showed disruption of the threading dislocations by the QD layers. Experimental details will be presented and the possible macroscopic mechanisms of the dislocation reduction by the application of the QD layers will be discussed.
Due to a wide energy band gap, GaN and AlGaN are well suited for the fabrication of ultraviolet (UV) sensors, particularly of visible-blind and solar-blind photodetectors. Piezoelectric effects in these materials make them promising for surface acoustic wave (SAW) device applications. We made use of this unique combination of the material properties and developed UV sensor based on GaN SAW oscillator. A key advantage of this device is that the output data is obtained in the form of a radio signal, which makes it very attractive for remote sensing applications. The oscillator uses a GaN-on-nitride SAW delay line coupled to a feedback loop of a broad bandwidth amplifier. The oscillator frequency is in the range from 200 to 300 MHz. Illumination of the GaN surface by UV light leads to the change in the oscillator frequency: it is decreased due to the interaction between piezoelectric fields of the SAW and photo-generated carriers. The spectral characteristics of the SAW oscillator, however, showed a large visible/UV rejection ratio, which makes these devices promising for the development of visible-blind remote sensor. However, the observed optimization of the photodiode is harmful for visible-blind operation and must be eliminated. We observed and studied the changes in the device response to UV illumination (around 365 nm) by an artificial Xenon lamp and natural (the Sun) source. The spectral width for the Sun light remained almost the same as for the dark signal, whereas it was much broader for the illumination using a Xenon lamp. We attribute the differences in the line widths to the different noise spectra of the artificial and natural UV sources. Based on this result, we demonstrated the possibilities of identifying artificial UV sources on the background of Sun light.

3:45 PM K1.7
UV EMISSION MECHANISMS IN QUANTUM NANOALLOYING.
Ali Kim, C.-C. Chen, G. Simin, M. Asl Khan, Hongzhe Yang, C.-Y. Yu, and S. H. Chae,
Dept. of Electrical Engineering, Columbia, SC, G. Simin, M. Asl Khan
Korea Advanced Institute of Science and Technology, Dep. of Information and Communications, Korea.

Solid-state white-light emitters require efficient pumping sources in the ultraviolet (UV) region of 250-350 nm. Nitride-based alloys such as AlGaN have been used for the preparation of quantum nanoalloys. However, the radiative recombination properties and mechanisms (especially, in quantum nanoalloys) are not yet systematically analyzed. We present the results of experiments on the excitation and emission of photoluminescence (PL) of quantum nanoalloys (QNA) and quantum dot (QD) AlGaN QNAs with a novel pulsed metalorganic chemical vapor deposition (MOCVD). The samples were excited by an excimer laser (A = 193 nm, t = 8 ns) for quantum nanoalloy strong pumping or a picosecond laser (A = 320 nm, t = 10 ps) for time-resolved PL measurements. The CDQ array and time-correlated single photon counting system were used for PL registration. The experiments were carried out in a wide temperature range from 10 to 300 K. The quantum nanoalloys demonstrated strong UV emission. The PL spectra and PL kinetics analysis in epilayers of different composition and QMOS under different excitation conditions and temperatures showed that localized states due to alloy fluctuations and/or intermixing play a significant role in radiative recombination in both AlGaN QNAs and AlGaN QD. A clear excitation-induced blueshift was observed. It is attributed to the filling of band-tail states and for screening of built-in electric fields. We have demonstrated that a pulsed MOCVD can be used for growing of the high quality quantum nanoalloys for UV emitters with strong spontaneous emission.

4:00 PM K1.8
METAL-ORGANIC CHEMICAL VAPOR DEPOSITION OF QUANTUM ANANTIONAL GAN MULTIPLE QUANTUM WELL STRUCTURES FOR DEEP ULTRAVIOLET EMISSORS. W. Chen, M. Asl Khan, M. Gao, C.-Y. Yu, and L. L. Chang, 
Department of Electrical Engineering, Columbia, SC.

UV nitrides are of great interest for application to blue and ultraviolet (UV) light-emitting diodes (LEDs) and laser diodes (LDs) due to their appropriate wide direct band gap. Nitride based deep UV emitters with the wavelength below 340 nm require the use of high Al content. AlGaN has been used as the active region of the device. The use of AlGaN, however, has been shown to lead to a severe degradation of the device properties. We are therefore exploring quantum AlGaN/GaN nanolayers for the active layer of multiple quantum wells (MQW) in UV emitters. We have developed an efficient metalorganic chemical vapor deposition (MOCVD) technique, a pulsed atomic layer etch process (PALE), and a pulsed MOCVD (PMOCVD) method to grow high quality MQWs for UV light emitters. The excitation-dependent transmittance (PL) spectroscopy technique shows that the samples grown by PALE process have low density of band tail states and exhibit an intense UV band-to-band emission. This behavior is highly promising for UV LEDs application because it leads to the emission of high-quality UV emitters. The AlGaN/GaN LED structure grown using PALE and a pulsed MOCVD process exhibit higher band to band states and show very strong room-temperature (RT) light due to the recombination of carriers (presumably excitons) localized at these tail states. Therefore samples grown by the pulsed MOCVD process would be ideal candidates for the UV LED application. Finally, the deep UV LEDs with emission wavelength of 305-340 nm based on quantum nanoalloys grown by both growth processes have been demonstrated.

SESSION K2: SOLAR LIGHTING
Chair: Leo J. Schoenwalder
Wednesday, April 3, 2002
Nob Hill C/D (Marriott)

8:30 AM K2.1
MATERIALS FOR SOLAR LIGHTING.
C. G. Johnson, Lawrence Berkeley National Laboratory, Berkeley, CA, J. Simmons, Sandia National Laboratory, Albuquerque, NM.

Dramatic improvement in the efficiency of inorganic and organic light emitting diodes (LEDs and OLEDs) within the last decade has made these devices viable future energy efficient replacements for conventional light sources. However, both technologies must overcome major technical barriers, requiring significant advances in material science, technology, and device processing. Attention will be given to two material systems: inorganic technology associated with the following major areas of research: 1) material synthesis, 2) device development, 3) device and defect physics, and 4) packaging. The discussion on material synthesis will emphasize the need for further development of component materials, including substrates and electrodes, necessary for improving device performance. The process technology associated with the LEDs and OLEDs is very different, but in both cases it is a factor limiting device performance. Improvements in process control and methodology are expected to lead to additional benefits of higher yield, greater reliability and lower costs. Since reliability and performance are critical to these devices, an understanding of the basic physics of the devices and device failure mechanisms is necessary to effectively improve the product. The discussion will highlight some of the more basic material science problems remaining to be solved. In addition, consideration will be given to packaging technology and the need for the development of novel materials and geometries to increase the efficiency and reliability of the devices. The discussion will emphasize the performance criteria necessary to meet lighting applications, in order to illustrate the gap between current status and market expectations for future products.

9:00 AM K2.2
NEW CHARGE-TRANSPORT MATERIALS FOR HIGH EFFICIENCY OLEDs.
V. L. Adomovich, Steven R. Cordes, Mark E. Thompson, University of Southern California, Department of Chemistry, Los Angeles, CA, Brian W. Ondrascik, Stephen R. Fontana, Center for Photonics and Optoelectronics Materials, New Mexico Tech.

High efficiency phosphorescent organic light emitting diodes (OLEDs) require charge-transporting materials utilized in hole-blocking layers (HBL) or electron-blocking layers (EBL) to confine excitons within a luminescent layer. Carrier blockers dramatically increase the quantum efficiency of the device and keep emission spectrum pure by preventing emission either from the electron-transistor or from the hole-transistor materials. The present work describes a novel approach for hole-blocking layer design as well as introduces some new inorganic-organic hybrid materials. We use crystalline/polymer complexes as hole-blocking materials. Complexes of this type are more stable towards oxidation and reduction, have high Tg values and make excellent glassy films. Moreover, the HOMO and LUMO levels of the materials can be easily tuned with suitable metal and ligand combinations. We have prepared OLEDs using bis(2,4,6-tris(carbazolylphenyl)-pyridyl-N-C2)iridium(I) hexafluorophosphate (FlrPc) in a HBL as a neat film or doped into a wide gap matrix. In host-guest configuration, the deep HOMO level of both matrix and dopant prevents the transport of holes to the ETL whereas the relatively shallow LUMO level of the dopant is favorable for electron conduction and injection. The new HBLs were tested in phosphorescent OLEDs with blue [FlrPc] and green [tris-(8-quinolinylphenyl)iridium(I)] emitters in 44:14:23:29 [8-hexylquinoline:N,N-dicyanobiphenyl (CHP) host] host oocophenyl cyclomettrene (OCPOT) and various sulfonyl compounds were used in hole-blocking matrices. FlrPc was used both as blue phosphorescent emitter in CHP and as an electron dopant in OCPOT and sexiphenyl. The device with a neat FlrPc HBL performed better than BCP control device (max quantum efficiency 41% vs 27%). The device with OCPOT FlrPc HBL is...
8:15 AM K2.3
INFLUENCE OF DEFECTS ON CURRENT TRANSPORT IN GaN/InGaN MULTIPLE QUANTUM WELL LIGHT EMITTING DIODES

We have compared the electrical characteristics and optical properties of GaN/InGaN multiple quantum wells [MQW] light emitting diodes [LEDs] fabricated from commercial epitaxial wafers. It appears that there is an essential link between material quality and the mechanism of current transport through the wide-bandgap p-n junction. Tunneling behavior dominates through all injection regimes in the devices with high-density defects which act as deep-level carrier traps. However, in a high gain LED device, the injection current is only a major contributor at low forward biases. At moderate biases, temperature dependent diffusion-recombination current has been identified with an ideality factor of 1.6. Light output has been found to follow a power law, i.e. I ∝ V 1.6 in all devices. In the high quality LEDs, nonradiative recombination centers are saturated at current densities as low as 1.4 x 10^6 A/cm², which is two orders of magnitude lower than that in high efficiency GaAs-based LEDs. This low saturation level indicates that only a small portion of the defects in III-V nitride materials are nonradiative in nature.

9:30 AM K2.4
ELECTRICAL PROPERTIES AND LUMINESCENCE SPECTRA OF LIGHT-EMITTING DIODES WITH INGaN/ GaN QUANTUM WELLS. Alexander E. Yamanouchi, S.S. Manzkin, M.V. Lomonosov Moscow State University, Moscow, Russia; Yu. Masyukhin, A.B. Wattman, Moscow State Institute of Steel and Alloys, Moscow, Russia; N. Gardner, W. Goetz, M. Misra, S. Stockman, Lumileds Lighting, San Jose, CA.

Charge distributions N(z) and electroluminescence spectra of light-emitting diodes [LEDs] based on AlGaN/GaN p-n heterostructures with multiple InGaN quantum wells [MQW] [1] were studied. N(z) was determined using the capacitance-voltage (CV) method. The GaN barriers in the MQW were doped with Si donors. Acceptor and donor concentrations near the p-n junction are approximately N ∝ 1 x 10^16 cm⁻² and N ∝ 3 x 10^17 cm⁻². Function N(z) on the side of the junction has a periodic maximum and minimum corresponding to the barrier doping and the presence of QWs. It is shown that the dynamic capacitance method can be applied to the study of doped MQWs. Shifts of spectral maxima with current for these LEDs are comparatively low (3-12 meV for blue LEDs and 25-50 meV for green ones). These shifts for green LEDs with non-doped MQWs studied previously were higher, up to 150 meV. This behavior is explained by screening of p-n junctions in wells by electrons from donors in doped barriers [1]. [1] N. Gardner, C. Kocot, W. Goetz et al. 4th Intern. Conf. on Nitride Semicond., Denver, July 2001, Book of Abstr. P. 38, PM B6.1.

SESSION K3: NITRIDES—CHARACTERIZATION AND PROCESSING
Chair: J. Carlos Rojo
Wednesday, April 3, 2002
Nab Hill C/D (Merriweather)

10:15 AM K3.1
MICROSTRUCTURE OF GaN AND InGaN FILMS GROWN BY MOVCD ON GaN Template
J. Jasinski, Z. Lichtensteger, Lawrence Berkeley National Laboratory, Berkeley, CA; D. Hwang, M.A. Reschikov, F. Yun, H. Morkoc, Virginia Commonwealth University, Richmond, VA; C. Sone, S.S. Park, K.Y. Lee, Samsung Advanced Institute of Technology, Suwon, KOREA.

InGaN/GaN heterostructures are used as active layers in nitride based light emitting devices. Although bright light emitting devices, and lasers from visible to violet region have been fabricated, the growth of high quality GaN films and the understanding of the microstructures are still not well understood. Here we report the results of transmission electron microscopy (TEM), x-ray diffraction (XRD) and photoluminescence (PL) from GaN and InGaN films grown on high quality and freestanding GaN templates which remove much of the complications resulting from severe lattice mismatch and complications associated with heterolayers on sapphire, SiC and other substrates. The GaN templates were grown by hydride vapor phase epitaxy on c-plane sapphire substrates and separated from the substrates by laser lift-off. They were then mechanically polished, dry-etched, and finally etched in molten KOH. A nominally undoped 1.8 μm GaN layer was first grown on the template followed by a 30-nm InGaN quantum well film by MOVCD. The In mole fraction x of the InGaN quantum well layer was estimated to be 0.13 from XRD and PL spectra. The PL peak at 3.018 and 3.474 eV with peak widths of 36 and 63 meV were identified at 15 K from the InGaN and GaN layers. The InGaN/GaN heterostructure investigated showed the films have the same Ga-polarity as the substrate. The TEM images with various diffraction conditions showed a high quality of the epilayers with a low density of threading dislocations (~10^4 cm⁻²). The threading dislocations originate from the GaN template and some of them bend at the InGaN/GaN interface. In addition, some dislocation loops, mostly on the template side, were observed. The preliminary high-resolution electron microscopy studies suggest that the InGaN quantum well film contains two well-separated layers. The first quantum well layer near the InGaN/GaN interface has a thickness of 10 nm and the second layer near the surface has a thickness of 24 nm. The lattice constant of the first layer in the c-direction is about 0.1% larger than that of the GaN layer. The lattice constant of the second InGaN quantum well is even larger (about 0.3%). The results indicate that the two well-separated layers, runaway relaxation due to the increase in the InGaN quantum well thickness, but is more likely related to the phase-separation [1,2] or the change in the growth mode [3] when the InGaN quantum well film with a critical composition of x=0.12 was grown. [1] L. Gargiulo, O. Ambacher, M. Stutzman, and C. Maksy, F. Scholz, and J. Off, Appl. Phys. Lett. 76, 577 (2000). [2] Z. Lichtensteger, W. Benemann, and J. Wambarth, J.Z. Domagala, J. Bardow, E.P. Perez, J.C. Roberts, and S.M. Bednar, J. Electr. Mater. 30, 439 (2001). [3] N. Grandjean and J. Mansies, Appl. Phys. Lett. 72, 1078 (1998).

10:45 AM K3.2
BOWING PARAMETER OF AlGaN/GaN L. He, F. Yun, M.A. Reschikov, T. King, M. Zafar Iqbal, D. Huang, H. Morkoc, Virginia Commonwealth University, Richmond, VA; S. Novik, Evans East, East Windsor, NJ.

The quality of AlGaN/GaN heterostructures is a key to the performance of light emitters, detectors, and modulation-doped field-effect transistors. AlGaN/GaN heterostructures are used to improve together with polarization charges and polarization-induced barrier height, depend on the Al composition. Precise determination of the Al composition from the bandgap requires knowledge of the bowing parameter, which suffers from the large dispersion in the bowing parameter up to date. This is mainly due to the scatter of samples by different growth techniques, limits of specific characterization techniques, and lack of awareness of the spatial distribution of Al composition. In this paper, a variety of characterization techniques have been employed to address this problem. Four different techniques, including secondary ion mass spectroscopy, high-resolution X-ray diffraction rocking curves, Auger Electron Spectroscopy and Rutherford Backscattering were used to determine the Al composition. Energy bandgaps of AlGaN/GaN films were determined by photoluminescence and reflectance measurements. The set of AlGaN/GaN films were grown by plasma-assisted MBE on c-plane sapphire substrates with the insertion of a thin AlN buffer covering a wide range of Al compositions from x=0.13 to x=0.74. The high quality of the AlGaN/GaN films was evidenced by the narrow linewidth of [102] peak of X-ray rocking curves. The data were analyzed to suggest the appropriate bowing parameter relaxed. The results indicate that the bandgaps of the materials to the alloy composition of AlGaN/GaN from one binary extreme to the other. The aforementioned results as well as possible for the cause of the dispersion in previously reported bowing parameters (in the range of 0.4 to 1.1 eV) will be addressed.

11:00 AM K3.3
LUMINESCENCE ENERGY AND CARRIER LIFETIME AS A FUNCTION OF APPLIED BIAxIAL STRAIN IN GaN QUANTUM WELL STRUCTURES. Norio A. Shiguro, Henning Friek, Eike R. Weber, Materials Science Division, Lawrence Berkeley National Laboratory and University of California at Berkeley, Berkeley, CA; Nathan F. Gardner, Werner K. Gütz, Lumileds Lighting, Silico, CA.

InGaAs based light emitting devices demonstrate excellent luminescent properties and have great potential in lighting applications. Though these devices are already produced on an industrial scale, the nature of their radiative transition is still not well understood. In particular, the role of the huge (>1 MV/cm), built-in electric field in these transitions is still under debate. We study the photoluminescence (PL) and time-resolved PL (TRPL) of metallocorganic chemical vapour deposition (MOVCD)-grown InGaN quantum well (QW) structures as a function of applied biaxial strain to determine the dependences of the transition energies and carrier lifetime to the built-in electric field. We find that the luminescence energy redshifts or blueshifts, depending on the sample. The shift in luminescence energy is well described by a single, newly introduced parameter L0, representing the effective separation of electrons and holes participating in the luminescence transition. Strong carrier separation due to the built-in electric field corresponds to a blueshift and L0.
equal to the QW width, Lw, whereas negligible carrier separation corresponds to a redshift and L, equal to 0. We also find that the carrier lifetime decreases with applied light indicating a significant reduction of the effective electron-hole (e-h) separation achieved by the strained-field-induced reduction in the well thickness. We use this method to evaluate the effective e-h separation in several structures with varying thickness, indium composition, and doping. We find that the e-h separation increases with increasing QW thickness and with increasing indium content. Finally, despite the reduced radiative transition rate associated with the carrier separation, our structures exhibit efficient luminescence, which is indicative of non-radiative recombination. This suggests that while the carriers are separated along the direction of the electric field, they are localized in the perpendicular direction such that they are protected from non-radiative centers associated with the high density of threading dislocations in the structure.

11:15 AM K3.3
A CHEMICAL PILOT OF GaP: PLASMA ETCHING AGAINST NaOH WET ETCHING TO DETERMINE POLARITY. Maria Lascialfo, Maria-Michele Gianagregorio, Pio Capezzuto, Giovanni Bruno, Plasma Chemistry Research Center, CNR, Bari, ITALY; Gun Anusongkong, W. Alan Doohittle, April S. Brown, Georgia Institute of Technology, School of Electrical and Computer Engineering, Microelectronics Research Center, Atlanta, GA.

In the last decade, GaN has received large attention for its use in optoelectronic, and high power/temperature electronic devices. GaN is suitable for applications such as UV detectors, ultraviolet-blue LEDs and lasers. Moreover, GaN and high-temperature and thermal conductivity are suitable for high power/temperature modulation doped FETs. Nevertheless, being non-centrosymmetric due to its wurtzite structure, GaN films show the phenomenon of poling, i.e., the spontaneous polarization and the Gao's (or [0001]-direction). Spontaneous polarization and piezoelectric poling depend on the film polarity, which needs to be known and controlled particularly in modulation doped FETs. In fact, it is well known that Ga- and N-polarity yield GaN films with completely different morphological, optical, photochromic and electrical properties. In this contribution, we present a new highly selective process based on Raman remote plasma etching to determine GaN film polarity. The peculiarity of this process is that it allows to distinguish also films with the same polarity but characterized by a different density of inversion domains [ID]. This selectivity to IDs is not allowed by the conventional method of NaOH wet etching used to determine polarity. Data by Kelvin probe force microscopy (KPFM), X-ray photoelectron spectroscopy (XPS) and of Spectroscopic ellipsometry (SE) are presented and discussed in order to correlate the chemistry of GaN surface modification induced by both NaOH wet etching and RHCos dry etching to the film polarity and IDs. GaN films with different polarity and IDs grown by MBE using a multistep (substrate nitridation-buff growth-annealing-bulk growth) process have been analysed. Therefore, the polarity is also discussed in relation to different growth parameters such as substrate nitridation and GaN/AlN buffers in order to achieve a better control of film properties.

11:30 AM K3.5
THE ELECTRICAL AND OPTICAL CHARACTERISTICS OF ISOELECTRONIC AL-DOPED GaN FILMS GROWN BY METAL-ORGANIC CHEMICAL VAPOR DEPOSITION (MOCVD). Jee-Heon Lee, Hyoung-Bok Lee, Sung-Ho Hahn, Yong-Hyun Lee, and Jong-Hee Lee, The School of Electronic and Electrical Engineering, Kyounggook National University, KOREA; Sung-Bum Bae, Kyo-Suk Lee, Electronics and Telecommunications Research Institute, KOREA.

In regard to the film quality, it has been reported that with the advent of isoelectronic impurity (In or As), the optical and electrical properties of GaN film could be effectively improved. We investigated the first isoelectronic Al-doping effects on GaN film grown by metalorganic chemical vapor deposition (MOCVD). Al-doped GaN samples were grown for different TMAI flow rates of 3, 6, 11, and 30 sccm/min and then their material properties were compared with those of undoped GaN sample. With increasing the TMAI flow rate, the electron mobility was greatly increased from 130 to 510 cm²/Vs, although unintentional background concentration was slightly increased in accordance with increasing TMAI flow. The effect of Al-isoelectronic doping on the optical properties of GaN was also investigated by room temperature photoluminescence (PL). As the TMAI flow rate was increased, the band-to-band recombination peak intensity of Al-doped GaN was increased up to two order larger than that of undoped GaN, pointing that Al doping greatly enhances radiative recombination with suppressing non-radiative transitions. X-ray rocking curve of Al-doped GaN films showed no significant difference, although TMAI flow rate was increased in this condition. In summary, the first isoelectronic Al doping effects was studied on MOCVD grown GaN films. Proper Al-doping improved electrical and optical properties of GaN films and hence an optimized isoelectronic Al-doping would greatly enhance the GaN based device performances.

11:45 AM K3.6
EFFECT OF ANNEALING CONDITIONS OF P GaN ON OH/JIC CONTACT USING Ni/Pt/Au METALLIZATION. Chen-Fu Chu, C.C. Yu, H.C. Cheng, F.I. Liu, C.F. Lin, S.C. Weng, Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, TAIWAN.

We report the effect of different annealing conditions of p-GaN on new metallization scheme using Ni/Pt/Au. The undoped p-GaN samples were grown on (0001) sapphire substrate by metalorganic chemical vapor deposition (MOCVD). The first set of p-GaN samples were thermally annealed at an external furnace at 800°C for 30 minutes. The second set of p-GaN samples were annealed in situ inside the MOCVD reactor at 800°C for 30 minutes. The carrier concentrations of these two sets of samples were both about 10^{17} cm^{-2}. These two sets of p-GaN samples were deposited with the same Ni/Pt/Au metallization contact and then annealed at 550°C in oxygen environment. For the first set of samples, the specific contact resistance has a value of 1.1 x 10^{-4} Ω.cm². While the second set of samples has a much higher resistance value of about 3.3 x 10^{-1} Ω.cm². The different in the ohmic contact resistance for these two sets of GaN samples were investigated by the secondary ion mass spectroscopy. For the first set of samples, a clear evidence of the outdiffusion and interdiffusion of Ga, Pt, and Au in the metal layers and GaN layer boundary was observed suggesting the possibility of formation of Ga-Pt-Au reaction products between the metal layers and GaN. For the second set of samples, there was no evidence of the outdiffusion and interdiffusion of Pt, and Au into the GaN layer. In addition, the content of Pt in the second set samples was less than that of the first set sample. These results suggest that the formation of intermetallic compounds such as Ni-Pt-Au or Ni-Pt is beneficial to the formation of p-type ohmic contact. And the external annealing could modify the GaN is a preferable process for achieving the low ohmic contact resistance.
Narrow gap nitride alloys, such as GaNAs, are very promising candidates for a variety of applications including 1.3μm light emitters and solar cells. One challenge is achieving long wavelength (>1.3μm) GaInNAs alloys. We have developed a new structure using GaInNAsSb quantum wells (QWs) with strain compensating GaNAs or GaNAsSb barriers. The material for this work was grown by solid source MBE with a CuBe substrate. With GaNAsSb source, we are able to grow samples with nine GaInNAs QWs (63mK WQ thickness), which is 20% higher in the growth and performance of both high efficiency long wavelength multiple quantum well [MQW] GaInNAs ridge-waveguide lasers and VCSELs as well as the remaining challenges will be presented.

2:00 PM k4.2
ON THE ORIGIN OF LIGHT EMISSION IN GaNP. L.A. Burschke, G. Yu. Rudko, W.M. Chen, Linkoping Univ, Linkoping; Sweden; H.P. Xin and C.W. Tsai, Univ of California, La Jolla, CA.

Incorporation of nitrogen in GaP has been reported to have a pronounced effect on the band structure leading to a large bowing in band-gap energy. It is also expected to cause a non-linear transformation from an indirect to a direct band-gap leading to much increased efficiency of light emission in the GaNP alloy, desirable for optoelectronic applications. Though a strong effect of the N incorporation on the near-band edge emission of GaNP has been observed, our understanding of its exact physical origin, in particular the mechanism for light emission, is far from complete. The aim of this work is to provide experimental evidence, from temperature-dependent photoconductance [PL] and photocurrent measurements that will shed light on the origin of the light emission in GaNP. Both thick GaNP epilayers (with thickness 0.5 to 0.75 μm) and 7% of GaNP grown on ZnTe (001) multiple quantum wells [MQW] structures were studied, with N concentration up to 4%. The PL emission in both structures is shown to be dominated by optical transitions within deep states likely related to N clusters. With increasing N concentration these states show shifts to lower energy, consistent with the band gap of the alloy and thus optically inactive, leading to the apparent red shift of the PL maximum position. On the other hand, band-to-band recombination in the alloy remains predominantly nonradiative presumably due to the presence of a large number of competing recombination channels.

2:15 PM k4.3
ON STRAIN RELAXATION IN THIN FILMS OF InGaAs AND THE DILUTE NITRIDE InGaAsN. M. Advincula, J.H. Schmid, T. Tiedje* Department of Physics and Astronomy, University of British Columbia, "also Department of Electrical and Computer Engineering, Vancouver, Canada; A. Koveshnikov, A. Chichibabin, V. Finik, K.L. Kiewang Department of Physics, Simon Fraser University, Burnaby, CANADA.

The dilute nitride-arsenide compound semiconductors GaNAs, InGaNAs and In,Ga,NAs, are promising new semiconductor alloys for the fabrication of next generation optoelectronic devices. In particular, they are candidates for use in the active region of...
tested for their doping efficiency in the metastable material system. Additionally, the electronic properties have been correlated to the single dopant. Interstitially hydrogenated Te (from diethyl tellurium) and Mg (from dicyclopentadienyl magnesium) were used as p-type dopants. Electric measurements to determine the concentrations for the two growth parameters have been performed and show comparable high carrier mobilities for both, n- and p-type dopants. The achieved doping level can be as high as 1019 for n- and p-type dopants, respectively. Photon luminescence (PL) measurements on the n-type dopant indicate the type of doping. These measurements will be discussed in dependence on the doping element. First devices have been successfully grown using this n- and p-doped quaternary material.

3:45 PM Kd.7
INVESTIGATION OF GREEN EMITTING MONOLITHIC II-VI VERTICAL CAVITY SURFACE EMITTING LASER (VCSEL) 

H-VI-based vertical cavity surface emitting laser (VCSEL) are expected to increase the lifetime of time-grown laser because of the low threshold current density connected with the small resonator volume. Furthermore, the use of quantum dots (QDs) as the active region should lead to a high stability of the device against degradation. Recent results show that stacks of self-assembled CdSe QDs provide a sufficiently high gain for lasing activity at 550 nm and can be used for active material in electrically pumped emitters operating at room temperature [1]. In order to achieve the goal of an electrically pumped VCSEL, monolithic microcavities with both ZnCdSe quantum wells (QWs) and CdSe QDs have been grown and are investigated with regard to their optical and electrical properties. The Distributed Bragg Reflectors (DBRs), which form bottom and top mirror of the microcavity, consist of lattice matched ZnCdSe as the high refractive index material and strain compensated ZnSe/MgZnSe superlattices (SLs) as the low index material. The use of short-period ZnSe/MgZnSe SLs allows the growth of high quality MgZnSe in zincblende crystal structure and is an approach to reduce the serial optical resistance of doped DBR mirrors because of the resulting formation of minibands. In order to find an optimized design for the VCSEL structures, the serial electrical resistance of doped DBRs has been measured in dependence of the SL period and the thickness ratio of the ZnSe and MgZnSe layers in the SL. Furthermore, temperature-dependent optical pumping experiments have been performed for VCSELs with QWs and QDs as active layers in order to investigate the coupling between excitons and photons in the microcavity. [1] M. Klode, T. Pausch, R. Kroemer and D. Hommel, Electr. Lett. 37, 1119 (2001).

4:00 PM Kd.8
LATERAL COMPONIMENT MODULATION IN InAs$_x$/AlAs$_{1-x}$ SUPERLATTICE
H. Hentsch, D. Hommel, University of Bremen, Germany.

Semiconductor lateral superlattices or quantum wells are promising for high efficient solar cells and polarized light emitters and detectors. This lateral structure can be formed spontaneously during the growth of III-V ternary semiconductor alloy films via lateral decomposition or lateral composition modulation. One way to manipulate this self-assembled lateral structure is to grow short-period vertical superlattice. The out-of-phase morphological undulations of the two strained ultrathin component layers of the vertical superlattice lead to effectively to an overall composition modulation in the lateral direction. Here, we present a quantitative structural study of such a laterally modulated structure formed in an [InAs]$_x$/[AlAs]$_{1-x}$ [n, m < 2] short-period vertical superlattice by means of synchrotron x-ray diffraction and grazing-incidence small-angle x-ray scattering. We determined not only the lateral modulation wavelength but also the modulation amplitude. We also determined the interface morphology of the short-period vertical superlattice, which has an impact on the composition modulation and an amplitude of less than 1.5%. The relation between the composition modulation and the interface undulation is discussed quantitatively.

SESSION K5: OPTICAL WAVEGUIDES
Chair: Keith Wayne Goosen
Thursday Morning, April 4, 2002
Nob Hill C/D (Marriott)

8:30 AM K5.1
OPTICAL WAVEGUIDES, CMOS-COMPATIBLE PROCESSING AND MATERIALS FOR MICROPHOTONICS. Peter D. Persans, Nianm Agarwala, Shun Pong, Joel Plawsky, Center for Integrated Electronics, Rensselaer Polytechnic Institute, Troy, NY.

One of the practical problems for deployment of optical interconnects on computer chips and boards is the need to turn and/or wavelength-select optical beams in the small spaces consistent with upper level CMOS wiring, which has pitch of a few microns. The theoretical optical interconnects using reflective or SI optical interconnects should also be consistent with level thickness of a few microns or less. In this talk we review recent progress in microphotonic waveguides and address limitations imposed by incorporation of waveguides onto chips using materials and processes compatible with the CMOS backend.

9:00 AM K5.2
CHALCOGENIC MATERIALS FOR ACTIVE WAVEGUIDE DEVICES. Michele L. Oustrad, Michael L. Steigerwald, James J. Krajewski, Dave L. Tang, and Yin-luen Wong, Agere Systems, Murray Hill, NJ.

The success of the phase change memory effect in chalcogenide (Ge$_2$Sb$_2$Te$_5$) thin films for optical read-write CDs has sparked renewed interest in this class of materials for numerous optical and electronic memory applications. Our research effort focuses upon two major goals: [1] to understand the electrical phase change effect for low-power nonvolatile memories and [2] to explore the feasibility of active waveguide devices using a variant of this memory technology. Although Ge$_2$Sb$_2$Te$_5$ is still a material of choice in rewritable CDs, this material does not appear to be best suited for other optical and electronic applications. For this reason, we are investigating pulsed electronic and optical switching and measuring optical properties on a wide variety of chalcogenide materials to determine the switching behavior and morphology of these films appears to be strongly correlated to the electrode and barrier materials used in confining the chalcogenide material. Annealing and quenching studies in reducing and oxidizing environments on planar and geometrically confined devices are used to determine the effect of temperature cycling on reversible switching behavior, current-voltage characteristics, and optical properties, such as optical absorption and band-gap.

Transmission electron microscopy and optical microscopy are used to monitor the microstructure and macrostructure evolution from amorphous to crystalline films, to determine the extent of phase segregation, and to correlate the film structure to the observed switching behavior. Reversible switching from some Ge$_2$Sb$_2$Te$_5$-related materials has been observed on a variety of electrode materials. For active optical waveguide applications, the optical absorption and band-gap have been measured as a function of composition for the Ge$_3$Te$_5$ and Sb$_2$Te$_3$ materials system (Ge$_2$Sb$_2$Te$_5$) and Ge$_2$Sb$_2$Te$_5$ (Sb$_2$Te$_3$)$_x$. Some members of the Ge$_2$Sb$_2$Te$_5$ (Sb$_2$Te$_3$)$_x$ family of compositions exhibit the phase change memory effect. These results will be discussed as well as some interesting interactions between chalcogenide glasses and barrier and electrode materials as observed from a variety of analytical techniques, including XPS, AFM, and SEM.

9:15 AM K5.3
LAYER GROWTH OF HIGH-QUALITY BaSb0.4Mn0.6 USING LIQUID PHASE EPITAXY. D. B seesomporn and M. Pollnau, Institute of Applied Physics, Department of Microtechnology, Swiss Federal Institute of Technology, Lausanne, SWITZERLAND.

Single-crystalline host materials doped with transition-metal ions are of high interest for applications as tunable lasers. Mn$_6$A4 ions exhibit broadband luminescence, however, Mn$_6$A4-doped crystals or waveguide structures could not be grown in sufficient quality. The active material has to be free of inclusions or defects larger than 1/10, with 1/10 wavelength of the propagating beam. In addition, the interface between active layer and substrate must be optically flat to receive low-loss guiding properties. The growth temperature of BaSb$_{0.4}$Mn$_{0.6}$ is limited by the decomposition of BaSb$_{0.4}$ at 1500°C, its phase transition above 1000°C, and especially the chemical reduction of the manganese dopant from Mn$_6$A4 to Mn$_{0.4}$A$_{5.6}$ above 620°C. Therefore, the growth of BaSb$_{0.4}$Mn$_{0.6}$ from a solution at lower temperatures is the most suitable method. Liquid phase growth is close to the thermodynamic equilibrium and enables us to grow high-quality layers. First, we prepared undoped BaSb$_{0.4}$ crystals of 10 x 5 x 1 mm3 in a, b, and c-direction, respectively, using the flux method with LiCl as solvent. Subsequently, growth of high-quality undoped BaSb$_{0.4}$ was performed by liquid phase epitaxy (LPE), using the additive ternary CaCl$_2$KCl-NaCl solution. We obtained crystalline layers free of inclusions, grown in the Frank-Van Der Merve mode (layer-by-layer growth). Finally, layers of BaSb$_{0.4}$Mn$_{0.6}$ were fabricated with thicknesses up to 150 μm, at growth rates of 3 μm/h and temperatures of 500-580°C. The thickness was controllable with a precision of ±0.1 μm. The Mn$_{0.4}$ concentration in the doped layer was up to 1 mol. %.
with respect to SiOx. In collaboration with the University of Hamburg, absorption and emission spectra were measured, which confirmed that the magnetic ion incorporation was incorporated in the layer solely by its second oxidation state. Room-temperature broadband luminescence in the wavelength range 850-1100 nm was observed.

**9:30 AM K6.4**

**HIGH INDEX CONTRAST AIo x Ga1-x OAS GRatings BURIED in GaAs/AlGaAs WAVElGIDEs**


We report the successful fabrication of high index contrast optical grating made of AlOx, and GaAs buried in GaAs/AlGaAs waveguides. Due to the high index contrast of 3.4 for GaAs and 1.6 for AlOx, photon dispersion in semiconductor waveguides can be modified much stronger than it is possible with materials currently used for buried gratings. This will allow fabrication of DFB lasers with improved temperature stability and reduced sensitivity to optical feedback and novel optoelectronic devices based on photonic bandgap materials. The choice of materials for the grating is compatible with the emerging technologies for making long wavelength active devices on GaAs substrates by using InGaAs quantum wells or InGaAs quantum dots. Central to the fabrication of these structures is an in-situ thermal chlorine etch carried out at a substrate temperature of 200°C and a Cl2 pressure of 1 x 10^-4 mbar in a UHV processing chamber attached to a molecular beam epitaxy system. This in-situ etch is used to transfer a surface grating on a 150 nm thick GaAs cap layer into a buried 50 nm thick AlAs layer. Real time measurements of the specular reflectivity of the sample as a function of the etch time and control of the etch depth with a precision of approximately 20 nm without including any etch stop layers. After the etch the sample can be transferred into the growth chamber for overgrowth of the AlAs grating without exposing to air thus avoiding oxidation of the AlAs that would make such regrowth impossible. After regrowth the AlAs can be oxidized to AlOx by exposure to hot water vapor. We present results of measurements of the optical and electrical properties of waveguides containing high index contrast gratings and InGaAs quantum wells.

**SESSION K6: OPTICAL INTERCONNECTIONS**

**Chair Peter D. Persans**

Thursday Morning, April 4, 2002

Nob Hill C/D (Marriott)

**10:45 AM K6.2**

**HETEROGENEOUS INTEGRATION OF PHOTONIC AND ELECTRONIC CHIPS**

Keith Gossen, Arakliit, Monroe Township, NJ.

Integration of photonic material, which is primarily III-V based, onto electronic chips, which are primarily silicon based, may be accomplished by a variety of techniques including, e.g., heteroepitaxy, thin-film transfer, or chip bonding. Any technique must accomplish a pristine electrical (both contacts), mechanical, and thermal interface between the two devices. A further requirement is that the optical signal be facilitated out of the assembly, usually to optical fiber, in a manner consistent with good packaging techniques. The optical requirement can be further complicated if the optical signal is at 850 nm, which is typical for short distance communication, and the only available wavelength at which vassal arrays have been robustly demonstrated, since both silicon and GaAs are opaque at that wavelength. These techniques will be discussed and demonstrated on the technique of flip-chip bonding followed by substrate removal, which facilitates 850 nm operation.

**11:45 AM K6.5**

**INTERFACIAL GAS DESORPTION AND DIFFUSION DURING THE LOW THERMAL STRESS FUSION OF III-V MATERIALS TO SILICON**

Phil Magee, Paul K. Yu, University of California at San Diego, Dept. of Electrical and Computer Engineering, La Jolla, CA.

Low Thermal Stress (LTS) wafer-fusion methods allow the use of larger substrates without the so-called thermal mismatch complications found when wafer-fusing materials with differing thermal expansion coefficients. Furthermore, LTS fusion has been co-cured with the excellent dark-current levels of very low dark-current Si-In x Ga1-x As p-n photodiodes[1]. However, LTS processes face a different obstacle: the appearance of gas bubbles trapped between the thinned layer of material and the thicker GaAs substrates showed differential quantum efficiencies of 0.14 and threshold current densities of 1.708 A/cm². This comparative data agree with our previous microlens fabricated, thin-film lifetime in GaAs grown on Ge/Si/Si substrates. A number of GaAs/Ge/Si integration issues including thermal expansion mismatches, facet mirror curvatures on on-axis Si substrates and Ge wafer bonding between InGaAs have been overcome. Recent results will be presented device lifetime and reduce threshold current via defect-resistant strained InGaAs quantum well and improved contact geometries will be discussed.
substrate, here InGaN (P) and Si respectively. This study investigated the temperature dependence of the appearance of gas at the interface, the concentration of this gas and the resulting bonding state of the interface. Two separate temperature regimes were observed where gas generation and out-diffusion differed, likely according to the gas released from the wafer surfaces at the interface. Afterwards, out-diffusion of the gases at room temperature indicated a qualitatively different interfacial bonding character for samples which had been heated into the higher T regime versus those kept in the lower T regime. Utilizing this critical information, and addressing any system of thermally mismatched bonded materials, a simple method was designed and used to produce wafer-scale InGaN (P) on-Si material, without the use of trenches or liquid mediated bonding techniques. This material was used to fabricate Si-Ga InGaN Avalanche Photodetectors with the bonding interface at the center of the device active region [2]. Fabrication methods and unexpected observations of gas description and bubble formation made during the study will be discussed.


TUTORIAL
ST K: OPTOELECTRONIC DEVICES FOR COMMUNICATIONS
Thursday, April 4, 2002
1:15 p.m. - 4:15 p.m.
Nob Hill C/D (Merriott)

The dramatic advances in the technologies for electronic integrated circuits over the past several decades are widely known. Less well known are the even more dramatic advances in the technology and understanding of optoelectronic devices particularly those intended for use in optical communication systems. This tutorial will review the main developments in optoelectronic devices (semiconductor lasers and optical detectors) and the various microfabricated optical components (waveguides, diffractive/diffractive optics and micromechanical devices that have defined our present optical communications infrastructure and that are defining future generations of optical communication systems. The tutorial will begin with an overview of the basic laser diode and high-speed optical detectors. The laser diode is a semiconductor device in which light is generated by recombination of carriers. The high-speed optical detector is a device that converts light into electrical signals. These devices are used in a wide variety of applications, including optical communication systems, optical fiber communications, and optical data storage.

The precise control of microfabrication will be illustrated by the MEMS-based quantum layer used for many years in high-performance semiconductor lasers and in more recent optoelectronic devices. Integrated structures including the basic optical devices and diffractive/diffractive elements will be reviewed. Surface emitting optical sources, providing system architecture options not possible with in-plane emitting sources, will be discussed using the examples of VCSEL arrays, detector arrays, and modular array switching components. Wavelength division multiplexing (the optical analog of the familiar use of frequency division multiplexing for electronic communication systems) has greatly expanded the capabilities of optical communication systems, allowing several optical channels to simultaneously pass through a common optical fiber. Wavelength tunable lasers and detectors, critical elements in such wavelength division multiplexed (WDM) systems, will be described. Throughout the discussions of the topics above, the performance characteristics of the devices, from the perspective of the performance objectives of an optical communication system, will be presented. Long distance optical networks are cost effective despite a high cost for the transmitter and receiver optoelectronic components due to the very high data rates that can be transmitted over a single optical fiber. As the costs of optoelectronics have decreased, the benefits of optical communications can perhaps be applied to shorter distance optical networks (e.g., LANs). The presentation will include examples of contemporary systems for both cases.

Instructor:
S.K. Tewksbury, Seewon Institute of Technology

SESSION K7: POSTER SESSION
NITRIDES AND OTHER WIDE BANDGAP SEMICONDUCTORS
Chair Shin Lien Chang
Thursday Evening, April 4, 2002
8:00 PM
Salon 1-7 (Merriott)

K7.1 STRUCTURAL AND OPTICAL PROPERTIES OF STRAINED GALLIUM NITRIDE NANOWIRES. Hee Won Soo, Seung Yong Bae, Jeonghee Park, Department of Chemistry, Korea University, Jochiwon, KOREA; Hyun Kyung Kang, College of Engineering Science, Hanyang University, Anam, KOREA; Kwang Soo Park, Sung Kyun, Department of Electrical Engineering, Korea University, Seoul, KOREA.

Gallium nitride nanowires are synthesized on silicon substrates by chemical vapor deposition reaction of silicon tetrachloride and gallium nitride powder mixture with ammonia at 1220-1370 °C. Iron and iron oxide nanoparticles are used as a catalyst. The diameters of the nanowires are uniform at 25 nm and the length is in the range 240 μm. The nanowires exhibit highly crystalline wurite structure with a few stacking faults. A careful examination into x-ray diffraction and Raman scattering data reveals that the separation of neighboring lattice planes parallel to the growth direction in the gallium nitride nanowires is larger than that in silicon substrate bulk. On the basis of our experimental results, we suggest that the nanowires are under compressive biaxial stresses in the inward radial direction which induce tensile uniaxial stresses in the growth direction. In the temperature-dependent photoluminescence (PL) spectrum of the nanowires, a strong broad PL band was observed in the energy range of 2.3-3.6 eV. The broad PL band could originate from the recombination of bound excitons. The various stresses experienced by the nanowires would result in the wide-distributed PL energy position and the strong room-temperature PL intensity.

K7.2 OPTICAL AND DEFECT STRUCTURE CHARACTERIZATION OF Mg-DOPED GaN FILM GROWN BY MEBEAL ORGANIC CHEMICAL VAPOR PHASE DEPOSITION. H.F. Hong and J.J. Choi, Institute of Electronic Engineering, National Central University, TAIWAN, ROC.

P-type Mg-doped GaN epitaxial films were characterized by photoluminescence (PL) measurement, X-ray diffractometer, secondary ion-mass spectroscopy (SIMS) and Hall effect. The epitaxial films were grown by MBE on the Si(001) substrate at the growth temperature of 750°C. The PL measurement was performed at room temperature with an excitation wavelength of 325 nm. The optical properties of the samples were characterized by photoconductivity measurements. The defect density was determined by second harmonic generation (SHG) measurements. The PL spectra were recorded in the range 200-350 nm. The defect structure of the film was investigated by X-ray diffraction (XRD) technique. The high-resolution transmission electron microscopy (HRTEM) was used to examine the quality of the epitaxial film. The results show that the Mg-doped GaN film is of high quality and the PL properties are affected by the Mg doping concentration.
defects. Meanwhile, the spectra at room temperature for others showed band edge emissions having yellow luminescence at about 580 nm. So, it could be seen that the Al$_{50}$Ga$_{50}$N (150 nm)/AIN/CdA with suitable thickness related to growth time of AIN play an important role for improving the crystallinity and optical properties of GaN/Si[111] heteroepitaxy without any defects such as pits and cracks over the whole layer by reducing the thermal coefficient and lattice mismatch between GaN and Si.

**K7.4**

**THE ROLE OF THIN ALN BUFFER LAYER IN ALGaN$_{x}$N/GAN HETEROSTRUCTURES HAVING HIGH X FROM 0.35 TO 0.5.**

Chung-Ho Lee, In-Seok Seo, Hae-Kyoung Ahn, Jee-Song Yeon, Byung-Jun Byun, Chonbuk National University, School of Advanced Material Engineering, Cheonju, SOUTH KOREA; Yong-Jo Park, Samsung Advanced Institute of Technology (SAIT), Suwon, SOUTH KOREA.

We have studied the role of thin AlN buffer layer of 20 nm thickness grown between GaN and AlGaN$_{x}$N in AlGaN$_{x}$N/GaN heterostructures having high x from 0.35 to 0.5. After growing the AlN buffer layer of 20 nm thickness on GaN/Si(001) epitaxy, the AlGaN$_{x}$N layers of 1.0 µm thickness were grown at 1070°C with increasing the flow rate of TMAl. The measured Al mole fraction of AlGaN$_{x}$N layers from each TCD rocking curve were 0.35, 0.37, 0.45 and 0.5, respectively. As the incorporation rate of Al in AlGaN$_{x}$N increases, the crystallinity becomes better. The surface morphologies observed by AFM of the AlGaN$_{x}$N layers were grown on thin AlN buffer layers showed that the RMS values become lower with the increase of x. This behavior is very similar with the data of TCD measurement. However, the crystallinity and surface morphology of AlGaN$_{x}$N/GaN heterostructures grown without thin AlN buffer layers between AlGaN$_{x}$N and GaN become generally worse with the increase of x. The resistivities of Al$_{0.48}$Ga$_{0.52}$N, Al$_{0.38}$Ga$_{0.62}$N, Al$_{0.28}$Ga$_{0.72}$N, Al$_{0.2}$Ga$_{0.8}$N and Al$_{0.15}$Ga$_{0.85}$N measured by four point probe method are 13.5, 18.1, 31.7 and 36.2 Ωcm, respectively. The resistivity increases with the rising of x in spite of the good crystallinity and the excellent surface morphology. It is obvious that the increase of resistivity resulted from the rise of intrinsic AlGaN$_{x}$N resistance with the increase of x independent of crystallinity and surface morphology. So, it can be concluded that the thin AlN buffer layer of 20 nm thickness between AlGaN$_{x}$N and GaN play an important role for improving the quality of AlGaN$_{x}$N/GaN heterostructures grown with the increase of x by reducing the thermal coefficient and lattice mismatch between the both layers.

**K7.5**

**CONTROL OF POLARITY FOR GaN/AlGaN/GaN FILMS GROWN ON (0001) SAPPHIRE Y.S. Park, H.C. Jun, H.S. Lee, S.M. Yi, S.Y. Jung, J.H. Na, T.W. Kang, Dongduk University, Quantum-Functional Semiconductor Research Center, Seoul, KOREA; J.E. Oh, C.S. Kim, Hanyang University, Center for Electronic Materials and Components, School of Electrical and Computer Engineering, Ansan, KOREA.

GaN/AlGaN/GaN heterostructures with N- and Ga-polarity are grown on sapphire (0001) substrates by using Al metal layer by plasma assisted molecular epitaxy (PMBE) in order to study the formation of the two-dimensional electron gases (2DEGs) with a certain polarization. Carrier concentration profiles in the GaIN/AlGaN/GaN heterostructures are evaluated by V-profile measurements in order to determine the polarity of the films and the location of the 2DEG inside the heterostructure. By depositing a thin Al metal layer before growing of AlN buffer layer, we are able to change the polarity from N to Ga polarity. We discuss the growth mechanism of a GaN phase structure by reflection high energy electron diffraction (RHEED).

**K7.6**

**LAYER-BY-LAYER GROWTH OF GaN FILMS ON SAPPHIRE BY LOW-TEMPERATURE CYCLIC DEPOSITION / NITROGEN RF PLASMA.**

P. Sanguino, M. Niehan, S. Koyoum, L.V. Mele, R. Schwarz, Dechanting de Frais, Instituto Superior Técnico, Lisbon, PORTUGAL; H. Alves, B.K. Meyer, Justus-Liebig-University, Giessen, GERMANY.

Recently we have proposed a new layer-by-layer method for deposition of group-III nitrides from elemental precursors (Ga, N) [1]. This technique is based on a two-step cyclic process, which alternates Pulsed Laser Deposition (PLD) of a limited thickness and nitrogen plasma treatment. In this work, we proceed on the development of this flexible cyclic deposition technique and study the influence of the power and time duration of the 1 mbar nitrogen RF plasma on the GaN thin films. The layers are deposited on pre-nitrided sapphire (0001) substrates at low deposition temperatures (300°C to 500°C) to minimize reevaporation. The GaN thin films thus obtained are compared with simple PLD GaN films in terms of deposition rate, layer morphology, nitrogen incorporation and crystalline quality. Optical transmission spectra, X-ray diffraction and atomic force microscopy are the elected tools to characterize and compare the deposited films. [1] S. Koyoum, P. Mele, R. Schwarck, L. Niehan, Layer-by-Layer Deposition of Group-III Nitrides By Two Step Cyclic Process, presented at E-MRS Spring Meeting (2001), Strasbourg, France. To be published in Materials Science & Engineering.

**K7.7**

**THE PROPERTIES OF CLEAVED MIRROR AND OPTICAL THIN FILM USED IN BLUE LASER DIODE FABRICATION.**

Jeong-Hoon Yi, LG Electronics Institute of Technology, Seoul, KOREA.

The natural single cleavage plane process developed and will be discussed as the optimal condition including the simple one. We have found key parameter for the successful cleaving is scribing angle, and the rest is depending on good lapping process, proper mounting, lapping direction, passing time, and finally careful demounting and also proper machine. We use thick wafer 200 to 1250um automatic sourc, demounting and refurnished by Leu Rahn Technik Lams company in Germany. We have also rms 125um model but the refurbished one was better for the cleavage, faster and stronger, which helps good cleavage of GaN LD grown on sapphire wafer. Just simple variable is angle only depending on the wafer thickness. We apply thin films SiNx during Process, SiO$_2$ and TiO$_2$ after making mirror to modify characteristic of the mirror. We found that the desired mirror is reliable and applicable for LD fabrication.

**K7.8**

**ETCHING OF GaN AND InGaN LASER STRUCTURE USING INDUCTIVELY COUPLED Plasma.**

Hung Wen Huang, C.C. Yu, J.Y. Tsai, T.H. Hsieh, C.F. Chu, C.F. Lin and S.C. Wang, Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan, REPUBLIC OF CHINA.

Dry-etching of GaN based material and laser structure was investigated in Ni mask using inductively coupled plasma (ICP) reactive ion etching system with Cl$_2$/Ar plasma source. For etching of n-GaN, the etch rate and surface roughness are studied as a function of ICP power, rf chuck power, and chamber pressure. The highest etching rate of 1300 Å/min for n-GaN was achieved at 30mTorr, 300W ICP, 100W rf chamber power using Cl$_2$/Ar (10% 25 secm) gas mixture. The surface roughness is dependent on rf chuck power and chamber pressure, and shows a low root-mean-square roughness value of 1nm at 50 W rf chuck power. The scanning electron microscopy data shows the etching surface of n-GaN has a very smooth profile with sharp vertical sidewall for all etching conditions. For etching of InGaN laser structure using high Cl2 ratio (Cl2/Ar = 50/20 secm) and low chamber pressure 5 mTorr, a smooth mirror-like facet of InGaN laser diode structure can be obtained.

**K7.9**

**DEPENDENCE OF optical and Structural PROPERTIES OF GaN and number of well of In$_{x}$Ga$_{1-x}$N QUANTUM WELL STRUCTURES.**

Hwan-Kuk Yuh, E. Yoon, Chonbuk National University, School of Materials Science and Engineering, Seoul, KOREA; Sung Kee Shee, Jack B. Lam, Chiel Kying Choi, Gordon H. Guiner, Gil Hae Park, Seon Joe Hoeung, Jin Joo Song, Oklahoma State University, Center for Laser and Photonics Research, Stillwater, OK.

III-V nitrides and their alloys have recently emerged as a strategic material system for the design and manufacture of light emitting diodes (LEDs) and devices for high power and high frequency. To develop high performance LEDs, it is essential to optimize several critical parameters, such as In composition, well width, and number of wells. We systematically studied the dependence of structural and optical properties of the number of wells. High quality In$_{x}$Ga$_{1-x}$N/In$_{y}$Ga$_{1-y}$N quantum well (QW) structures of different well widths were grown by metal organic chemical vapor deposition and analyzed by high resolution x-ray diffraction (HRXRD), atomic force microscopy (AFM), low excitation density photoluminescence (PL), high excitation density pulsed PL, and PL excitation (PLE). HRXRD and PLE showed that the average in concentration of all the samples is almost the same. However, the low excitation PL peak initially blueshifts, and then redshifts as the number of wells increases. These PL peak shifts are considerably different from the results of other researchers. HRXRD reciprocal space mapping and high excitation pulsed PL strongly suggest that this microscale peak shift is mainly due to potential fluctuations, rather than the photonic effect. AFM images correlate with the PL full width at half maximum, showing that the degree of potential fluctuations varies with the dislocation density which can be affected by growth interlayer of deposition and the accumulated strain energy. In addition, the PL intensity and stimulated emission of the samples strongly indicate that an appropriate degree of indium composition fluctuation improves the optical properties of InGaN QW devices.
K7.10
INTERPLAY OF DEFECTS, MICROSTRUCTURES AND SURFACE STOICHIOMETRY DURING PLASMA PROCESSING
OF GaN. A. Raman, Institute of Materials Research and Engineering, SINGAPORE; S. Tripathy, S.J. Chua, Dept of Electrical and Computer Engineering, National University of Singapore, SINGAPORE

Despite technological advances, the generation and electronic properties of defects in GaN layers and their effects on device performance are still unclear. In the present study, optical properties of the dry etched pattern of GaN are investigated using x-ray micro-PL and micro-Raman scattering. The damage introduced by inductively coupled plasma etching was assessed and improvement of the optical properties was observed during post etch annealing. Defect-induced Raman scattering from etched GaN shows impurity induced local vibrational modes. Luminescence bands in the low temperature PL spectra show that the formation of vacancy-impurity complexes during plasma processing. Based on the results of temperature-dependent Raman scattering, the observed changes of the phonon properties of GaN can be associated with electronic and vibronic scattering mechanisms of defects. The reconstruction and stoichiometry of the dry etched surface have been analyzed by x-ray photoelectron spectroscopy (XPS). Atomic force microscopy (AFM) technique is employed to investigate the microstructures resulting from dry processing. Formation of nano-whiskers, cracks, pits, and surface inhomogeneities on the dry etched surface would lead to subsequent changes in the metal contact resistivity.

K7.11
HIGH PRESSURE ANNEALING OF GALLIUM NITRIDE FILMS ON SAPPHIRE. F. Kelly, R. Chodell, M. Overberg, M. Ollinger, V. Craciun, R. Abboudachin, R.K. Singh, Department of Materials Science & Engineering, University of Florida, Gainesville, FL.

Gallium Nitride (GaN) is an attractive material for optoelectronic applications because it has a wide direct bandgap, a large breakdown field strength, and good thermal conductivity. Annealing of GaN films is a necessary step in the fabrication of GaN-based devices to remove ion-implantation damage and promote dopant atoms to substitutional lattice sites to electrically activate them. Annealing, however, is complicated by the high temperature of GaN growth and the electronic properties of GaN at temperatures in excess of 800°C, as much higher temperatures are needed to anneal extended defects out. In an effort to circumvent this, weathers with a micro-length, commercially-grown [MOCVD] film of GaN on sapphire is grown at high-pressure and high-temperature conditions (Inpress) at various temperatures (900°C - 1200°C). This was done under pressure greater than 40 kbar to prevent the GaN films from thermally decomposing. These films were characterized by x-ray diffraction to determine the effect of the impurities on the electronic behavior of the films and assess any improvement in defect density, crystalline quality. Auger electron spectroscopy was performed to provide a measure of the nitrogen loss in the non-surface region, and X-ray diffraction was performed to observe any microstructural changes in the films upon annealing. Hall measurements were performed on the films after annealing to investigate the effect of the impurities on resistivity and mobility. Scanning electron microscopy and atomic force microscopy images were also obtained from the films after annealing and roughness measurements of the films before and after annealing are compared. The work represents the first time that annealing of direct bandgap materials has been reported. It is believed that high pressure impurities in the Inpress may be used to improve electrical and optical properties of GaN films.

K7.12
STRUCTURAL AND OPTICAL PROPERTIES OF InGaN/GaN MULTIPLE QUANTUM WELL STRUCTURES WITH DIFFERENT WIDE WIDTHS. Young-Hoon Kim*, Chang-Soo Kim*, Sun-Kyu No*, Jin-Young Leem**, Kyeong-Hun Lim**, Byung-Sung O* and Jiy P* Song*, Korea Research Institute of Standards and Science, Taejon, KOREA; 3Semiconductor Physics Research Center and Department of Semiconductor Science and Technology, Chonbuk National University, Chonju, KOREA; 4Department of Physics, Chonbuk National University, Taejon, KOREA; 5Samsung Industrial Corporation, Sungnam, KOREA.

The structural and the optical properties of InGaN/GaN multiple quantum well (MQW) have been investigated using XRD [high resolution X-ray diffraction] and I(V) (photoluminescence). For the samples the barrier width was kept constant at 7 nm and the well widths were varied, 1, 3, 5, 8, 10 nm. For the structural characterization, XRD, high resolution XRD (HRXRD) and TEM was performed on the GaN (0002) reflections, and reciprocal space mapping (RSM) around GaN (1015) lattice points were employed. The average strain of the MQW increased as the well width increased. The MQW of a 2.0 nm well width experienced lattice relaxation and the crystallinity of the sample was poor compared to that of the other samples. MQWs with well widths of 1.5, 3.0 and 4.5 nm, however, maintained lattice coherency with the GaN layer underneath, and the undoped well thickness for lattice relaxation of the MQW used in the study was 6.0 nm. The PL spectra showed that the relative intensity of the sample with a 6.0 nm well width was lower than for the others, a fact consistent with the X-ray results. The emission wavelength is considered to be affected by factors related to lattice relaxation of the epilayer. As the well width increased, the transition energy, which was influenced by the piezoelectric field, showed a red shift.

K7.13
OPTICAL AND STRUCTURAL STUDIES OF InGaN LAYERS AND GaN/GaNP TIPS ON MO CVD. Suk Hyun Jin, Junho Seo, Kyuhason Lee, Hwang Corp, Taejon, KOREA; Hesseok Lee, Kevin Park, Optronix, Taejon, KOREA; Chang-Soo Kim, KIHSS, Taejon, KOREA.

InGaN device quality films and their related heterostructures play an important role in the development of nitride devices. InGaN growth needs to be performed at much lower temperatures than GaN growth, due to the lower dissociation temperature of InN. Furthermore, decomposition of ammonia becomes less efficient with decreasing temperature due to high kinetic barrier for breaking N-H bonds and InGaN growth needs high NH3/TMIn ratio. We investigated the optical and structural properties of InGaN bulk layers and InGaN/InGaN MQWs using thermally precracked ion sputtered metalorganic chemical vapor deposition (MOCVD) system. The temperature range for this study was 650 - 700°C. In a low NH3 flow rate condition, InGaN layers grown on the surface of GaN/MOCVD layer in conventional MOCVD system, but it disappeared in TIPS-MOCVD system. An improvement of In mole fraction in InGaN could be achieved even in low NH3 flow. As the NH3 flow rate and the InGaN growth temperature decreased, In mole fraction was effectively reduced by NH3 precracker. The quality of InGaN/GaN MQWs was evaluated with photoluminescence, high-resolution x-ray, and transmission electron microscopy.

K7.14
OPTICAL CHARACTERISTICS OF InGaN/GaN MULTIPLE QUANTUM WELL STRUCTURES. Jeong-Ho Kim, Jong-Hak Won, Soo-Young Park, Sunyoung Electronics Co., Photonic Device Lab, Sunwon, KOREA; Hoon Sung, Choi, In-Hoon Choi, Koen Univ, Dept of Materials Science, Seoul, KOREA.

The optical properties of InGaN/GaN multiple quantum wells (MQW) grown on sapphire by metalorganic chemical vapor deposition were investigated under various growth conditions. The well-defined X-ray diffraction (XRD) satellite peaks of InGaN/GaN MQWs were achieved under the optimal growth conditions. The photoluminescence (PL) and electroluminescence (EL) of InGaN/GaN MQWs have been measured and investigated at different growth temperatures and indium compositions. From the PL of the InGaN/GaN MQWs, a noticeable blue shift was observed in higher excitation power. This result is attributable to the localization of excitons at potential fluctuations due to InGaN phase separation that forms indium-rich precipitates in InGaN layers. The defects in the GaN layers were also investigated by using high-resolution transmission electron microscopy.

K7.15
TRANSMISSION ELECTRON MICROSCOPY STUDIES OF ELECTRICAL ACTIVE GaN/GaN INTERFACES OBTAINED BY WAFER BONDING. J. Jasinski, Z. Liliental-Al schem, Materials Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA; S. Monteith, E. Hu, Materials Department, University of California, Santa Barbara, CA.

Wafer bonding is a well recognized method of semiconductor integration. It has been successfully applied to a number of lattice mismatched heterostructures devices. Rapid development in research and application of GaN and related materials has resulted in increased interest in possible integration of GaN with other semiconductors, among which GaAs plays a very important role. Successful wafer bonding of these two materials would allow integration of GaNs and GaN-based optoelectronic devices. A GaN/GaN interface combines the high breakdown electric field of GaN with the high mobility of GaNs, which are ideal characteristics for transistors and other electronic devices. Very promising attempts, to apply direct wafer bonding, to create an electrically active GaN/GaN interface have recently been reported [1]. In this paper we present transmission electron microscopy studies of these same interfaces. Our studies indicate that most of the interface area, except for a large number of small “features” present at the interface, was wide spaced and only a very thin layer (thickness about 1-2 nm) of residual oxide, as confirmed by x-ray study, was present at the interface. A dislocation network was observed at the interface in the
K7.16
HIGHLY-ORIENTED ZnO THIN FILMS GROWN ON Si SUBSTRATE BY METAL-ORGANIC CHEMICAL VAPOR DEPOSITION METHOD. Hyoun-woo Kim, Kwangsook Kim, Jung Ho Lee, Inha Univ., School of Materials Sci. and Eng., Incheon, KOREA.

There has been much attention to the epitaxial growth and optical characteristics of ZnO films for short-wavelength photonic device applications. In addition, ZnO can be grown at low temperature, hundreds of degrees lower than gallium nitride, which enables the growth of ZnO on silicon and glass substrates. We have grown ZnO layers on Si and SiO₂/Si substrates using metal-organic chemical vapor deposition (MOCVD). We reveal that growth temperature and flow rates were main factors affecting the crystallinity and surface smoothness. We found that the films were strongly correlated as the growth temperature of 300-400°C X-ray diffraction. AAFM. XTEM were utilized for materials characterizations. The photoluminescence spectra were obtained at room temperature and analyzed. (This work was supported by grant No. 2011-003-2 from the University Research Program of the Ministry of Information and Communication).

K7.17
EFFECT OF Si DOPING ON PROPERTIES OF ZnO THIN FILMS BY PULSED LASER DEPOSITION. Hong Seong Kang, Jeong Seok Kang, Seong Sik Pang, Eun Sub Shim, and Song Yeol Lee.

ZnO thin films have been deposited on various substrates by pulsed laser deposition. And then, Si has been doped on ZnO thin film. After Si doping, films were investigated on optical, structural, and electrical properties. To improve effect of Si doping, films have been annealed at various temperatures. The optical and structural properties of Si-doped ZnO thin films were characterized by PL (photoluminescence) and XRD (X-ray diffraction) method respectively. Electrical properties were measured by van der Pauw Hall measurements.

K7.18
EXAMINATION OF N INCORPORATION INTO GaNAs. Vincenzo Lozzi, Vincent Granik, Wentao Hu, Seth Bank, James S. Harris, Stanford University, Dept of Electrical Engineering and Dept of Materials Science and Engineering, Stanford, CA; Nan Yao, Princeton University, Princeton Materials Institute, Princeton, NJ.

Gaₐ₋₀.₅₄Inₓₐ₋₀.₅₄Nₓ (x=0.75, y=0.02-0.03) is a novel semiconductor material system for realizing quantum-well based optoelectronic devices on GaN that operate at the telecommunication wavelengths of 1.3 to 1.5 µm. Evidence suggests that the site-specific incorporation of N into this material during molecular beam epitaxy (MBE) growth and subsequent rapid thermal annealing (RTA) strongly influences the electronic properties (band gap, band offsets, effective masses, etc.). For example, small amounts of N should reduce the band gap, and peak photoluminescence intensity is observed to increase and blue-shift after RTA. Direct determination of how N incorporates in terms of coordination with Ga and In, interstitial site occupancy, and N clustering as grown very difficult. Yet, an understanding of the N incorporation and its connection to the non-intuitive electronic properties exhibited by GaInNAs is important for developing precise control over growth and annealing conditions to control the material properties desired. Optoelectronic properties. Experimental investigation of the local bonding environments of N before and after annealing was conducted using a variety of techniques. Samples consisted of binary InGaN quantum wells grown between GaN barriers on GaN substrates. An rf plasma was used as the N source. Rutherford backscattering (RBS) experiments on the MBE-grown material show a significant amount of interstitial N, which decreases after annealing. Secondary ion mass spectroscopy (SIMS) suggests preferential out-diffusion of N as. In from the QWs. To investigate the coordination of N group V lattice sites before and after annealing, electron energy loss spectroscopy (EELS) was used. The next-edge fine structure of EELS of N-containing InGaN quantum wells is sensitive to variations in N nearest-neighbor configurations. Ab-initio simulations of the ELNES spectra, which are proportional to the partial local density of 2p excited states of N, were used for the interpretation of the EELS data.

SESSION K8: POSTER SESSION
QUANTUM DOTS, QUANTUM WELLS, AND SELF-ASSEMBLED STRUCTURES
Chair: Yong-Hang Zhang
Thursday, April 4, 2002
8:00 PM
Salon 1-7 (Morriscott)

K8.1
CARBON NANOTUBE DEPOSITION USING HELICON Plasma CVT AT LOW TEMPERATURE. Masanori Murayama, Takuro Yagi, Keiji Inoue, Ichiro Suito, SONY Corporation, Atsugi, Kanagawa, JAPAN.

Carbon nanotubes are considered to be promising material for field emission displays. Preparation of highly purified carbon nanotubes in large quantity, well-aligned nanotubes, and low temperature syntheses are prerequisites for this application. In order to use glasses for the field-emission display cathode, it is necessary to reduce the growth temperature to below 600°C. Helicon Plasma-enhanced CVD (HPECVD) has been used to deposit nanotubes at temperatures from 400°C to 500°C. The helicon plasma source is the one of the high-density plasma sources and is promising for low temperature carbon nanotube deposition. RF bias was also applied to the substrate holder to control the ion bombardment. A Ni film was used as a catalyst to reduce the activation energy of the nanotube growth. A mixture of methane and hydrogen gas was used as the carbon source. To analyze the structure of the nanotubes, SEM, TEM and Raman were used. Vertically aligned carbon nanotubes were obtained selectively on the Ni catalyst from the SEM observation. The growth of the carbon nanotube revealed that source gases were decomposed with the high-density plasma and the ion bombardment worked to grow the carbon nanotube. Field emission measurements were performed with a diode structure. The turn-on voltage was about 7V/µm.

K8.2
MICRO-RAMAN SCATTERING IN SELF-ASSEMBLED InAs and InP QUANTUM DOTS. S. Tripathy, S.J. Chun, Center for Optoelectronics, National University of Singapore, Singapore, SINGAPORE; Ben Zhong Wang, Institute of Materials Research and Engineering, SINGAPORE.

Using Raman spectroscopy, vibrational properties of InAs and InP quantum dots have been investigated. Self-organized quantum dots of InAs and InP were grown on GaAs, InP, and GaP substrates by metal organic chemical vapor deposition (MOCVD) and were characterized by photoluminescence (PL), polarized micro-Raman scattering, and atomic force microscopy (AFM). Optical properties of InAs and InP quantum dots under different growth conditions have been studied. There is a clear correlation between the observation of quantum dots by AFM and a phonon mode at an energy few wavenumbers above the TO and LO phonon energy for thick InAs and InP layers. In the case of quantum dots grown on intermediate buffer layer, two-mode behavior of phonons is observed and attributed to the interdiffusion of In and Ga at the interface. Microscopic interface modes revealed contribution from the wetting layer. The strain calculated for InAs/GaAs and InP/GaP dots, satisfactorily explains the stress-induced frequency shifts obtained for the interface InGaAs and InGaP modes. The effects of size of quantum dots on the phonon modes are also investigated.

K8.3
NONLINEAR OPTICAL PROPERTIES OF PLASMA ENHANCED CHEMICAL VAPOUR DEPOSITION GROWN SILICON. Michael J. Prockash, M. Cavigli, Z. Galarneau, L. Pavesi, INFN and Dipartimento di Fisica, Universita di Trento, Trento, ITALY; F. Ascani CNR-IMETF, Catania, ITALY; G. Francia and F. Pirolo, INFN and Dipartimento di Fisica, Universita di Catania, Catania, ITALY.

We present a systematic study on the nonlinear optical properties of silicon nanocrystals (SiNCs) grown by plasma enhanced chemical vapor deposition (PECVD). The sign and magnitude of both real and imaginary parts of third-order nonlinear susceptibility of SiNCs are measured by Z-scan method. While the closed aperture Z-scan reveals a sign of positive nonlinearity, the open aperture measurements suggests nonlinearity absorption-based effects. Absolute values of third-order nonlinear susceptibility are in the order of 10⁻⁹ esu and show systematic correlation with the SiNC size, due to quantum confinement related effects. A systematic study on third order nonlinear process was made using different pumping wavelengths to
study the nonlinear dispersion. The measurements of second order nonlinear coefficients are also attempted via second harmonic generation measurements and preliminary results are presented.

K8.4 PHOTOLUMINESCENCE AND TIME-RESOLVED PHOTO-
LUMINESCENCE STUDIES OF SELF-ASSEMBLED InAs
QUANTUM DOTS. Xinhui Zhang, Jianrong Dong, Soo Jin Chan,
Institute of Materials Research & Engineering, SINGAPORE.

In the past several years there has been a surge of interest in self-assembled quantum dots (QDs) fabricated by Stranski-Krastanov (SK) growth due to their importance in device applications and in understanding the fundamental physics of zero-dimensional (0D) systems. In this paper, we conduct photoluminescence (PL) and time-resolved PL studies of self-assembled InAs/GaAs quantum dots (QDs) grown by metal organic chemical vapor deposition. A reduction in the emission linewidth with increasing temperature is observed at low temperature range and the linewidth at higher temperature. It is also observed that the variation of PL peak energy with temperature does not follow Varshini's equation. Additionally, it is found that the PL decay time of QDs increases with emission wavelength and the PL spectra red shift with the time evolution. We found that the behavior of PL and time resolved PL can be explained in terms of thermal redistribution of carriers and carrier transfer between laterally coupled quantum dots, either through the GaAs barrier or through the wetting layer.

K8.5 OPTICAL SPECTRA OF InAs/GaAs QUANTUM DOT ARRAYS
UNDER INDENTATION. LT.H. Johnson, R. Rose, University of Illinois at Urbana-Champaign, Dept of Mechanical and Industrial Engineering, Urbana, IL.

A computational model is used to predict the effect of externally applied stress on the optical absorption spectrum of a self-assembled InAs/GaAs quantum dot array. The optical properties are computed from the spectrum of electron and hole states found for the ensemble, containing approximately 30 individual dots of different sizes and shapes. The energies and wave functions in the spectrum are computed using a strain-modified kp Hamiltonian approach, the spectrum includes electron and hole states associated with individual dots, in addition to some delocalized states associated with coupled dots as well as the wetting layer. By modeling the entire ensemble of dots simultaneously, it is possible to consider the effect of an entire strain field superimposed by inducing the sample with the near-field scanning optical microscope (NSOM) tip used to illuminate the dots and detect their emission. To do so, the linear elastic indentation strain field is determined analytically and accounted for in the Schrodinger equation using deformation potential theory, as is the nonuniform misfit strain due to quantum dot self-assembly. The absorption peaks of the individual dots and the ensemble are shown to shift as a function of indentation depth. Results of the calculations compare favorably to recent experimental data.

SESSION K9: POSTER SESSION
MATERIALS, PROCESSING, AND CHARACTERIZATION
Chair: Hong Q. Hou
Thursday Evening, April 4, 2002
8:00 PM
Salon 1-7 (Merriott)

K9.1 DYNAMIC RESPONSE OF NON-PINELED AMORPHOUS
SILICON BASED IMAGE SENSORS. M. Fernandez, Yu. Vygovenko
and M. Vieira, Electronics Telecommunications and Computer Dept.,
ISEL, Lisbon, PORTUGAL.

Large area hydrogenated amorphous silicon p-i-n structures with low
conductivity doped layers were proposed as single element image
sensors. The image acquisition technique consists in using a
modulated light beam to scan the sensor active area and recording the
photocurrent in each scanning position. This work is focused on the
analysis of the dynamic behaviour of this type of sensor and to infer
some sensor parameters like maximum scanning speed, from which
depends the maximum achievable frame rate. In order to evaluate the
sensor response to a time varying light excitation the sensor was
locally illuminated with a focussed chopped light source and the
generated photocurrent was measured under different load conditions.
Results show that the sensor is mainly capacitive and a signal rise
rate of approximately 100 μs was measured under 1 kΩ load.
Capacitive behaviour was expected as also performed in order to
evaluate the change in capacitance with uniform illumination.
A model for the sensor was created from the experimental data and
this model was used to simulate the dynamic behavior of the sensor. The
simulation results obtained are in good agreement with the experimental
ones. As conclusion one can expect a trade off between the frame rate and the number of pixels. A frame rate higher than 10
fps was achieved for 100x100 pixels readout without a significant
degradation in the image quality.

K9.2 SPRAY PYROLYSIS SEEDING FOLLOWED BY CHEMICAL
BATH DEPOSITION OF HIGHLY ORIENTED CdS FILMS.
S. Watanabe and P. Mackerey, Laboratory for Advanced
Materials Science and Technology (LAMAS-T) Dpt. of Physics,
University of South Florida, Tampa, FL; S. Aheylath, M.G.M. Muss,
Industrial Technology Institute, Colombo, SRI LANKA.

Films of cadmium sulfide are used in a variety of photonic applications including solar cell devices. Based on the optical and electrical properties, n-doped polycrystalline CdS is the most compatible substrate material that can be used in CdTe and CdS/CdSe solar cells. Electrical properties of CdS films are sensitive to the method of preparation. To minimize carrier recombination losses at grain boundaries it is desirable to grow CdS films with large grains in a columnar structure. One of the widely used inexpensive methods for large area growth of CdS films is chemical bath deposition. Cadmium sulfide films that were deposited on glass substrates by chemical bath deposition, where aqueous solutions that contain CdCl₂ and thiouren were used, show poor crystal structure. In this paper, we report the improvements made on film orientation and grain growth by a process where seed crystals of CdS were formed on glass substrates prior to chemical bath deposition. A solution containing CdCl₂, thiouren, ammonium hydroxide and ethanol was sprayed on to the substrate at 25°C using an ultrasonic nebulizer. The size of the seed crystals were controlled by the concentration of CdCl₂ and thiouren in the spray solution while the density was controlled by the time of spray. X-ray analysis showed a significant improvement in the orientation of the chemical bath deposited films on seeded glass substrates. Columnar growth of large grains is visible in cross-sectional SEM micrographs of CdS films deposited on seeded substrates. The effect of the seed crystal size and density on CdS film morphology, orientation, grains size, as well as optical and electrical properties will be discussed.

K9.3 ELECTRICAL PROPERTIES OF BETA-BRONDISILICIDE/
GERMANIUM HETEROJUNCTIONS. Takashi Fujita, Yoshihiro
Kokubun, Ishinomaki Senshu Univ, Scl of Science and Engineering,
Ishinomaki, Miyagi, JAPAN.

The electrical properties of heterojunctions of polycrystalline films of beta-brondisilicide grown on n-type single-crystal germanium are investigated. The heterojunctions have been prepared by co-sputtering of iron and silicon with thickness of 1 μm on germanium substrate followed by thermal annealing. The samples are prepared over various chemical compositions and annealing temperature. The dark current-voltage and capacitance-voltage characteristics of these devices were measured. The samples showed rectifying behavior in both characteristics in current-voltage characteristics measurement. However, a large reverse leakage current and low breakdown voltage were observed. The results are consistent with that in the case of beta-brondisilicide/germanium heterojunctions, reported previously. It was suggested that the high density of trap levels existed on the interface and those levels induce the inadequate electrical properties of the samples as well as in the case of beta-brondisilicide/germanium junctions. The properties of the heterojunctions will be discussed in comparison with beta-brondisilicide/germanium heterojunctions.

K9.4 GROWTH OF InTS: AS THE ADVANCED MATERIAL FOR
LONG WAVELENGTH APPLICATION. D.B. Gadkari, Department of
Physics, Mithibai College, Mumbai, INDIA; K.B. Jal and P.
Shankariram, Department of Physics, University of Mumbai, Mumbai,
INDIA; S.S. Chandawarkar and B.M. Arora, Condensed Matter &
Material Science, Mumbai, Mumbai, INDIA.

The use HgCdTe in the fabrication of infrared sensitive imaging
arrays and detector technology is becoming useful, but the growth of
bulk single crystal ingots of HgCdTe remains a topic of interest to the
community growth. For long wavelengths and for focal plane
arrays the dominant material is HgCdTe. However, the growth of
monocrystalline HgCdTe is difficult due to the weakly bound II-VI
compound and uniform band-gap. It is also very expensive to the
compositional. An alternate material to the HgCdTe would be InTeS, which will significantly reduce the III-V application, low cost and
optimal performance. Therefore, the II-V alloy InTeS holds much
promise as suitable alternate materials to HgCdTe. An indigenous
system in vertical directional solidification (VDS) technique has been
evaluated for the growth of the semiconductor crystals. Bulk
crystals of II-VI compound were grown without using seed by VDS
method. XRD, EDAX, EMPA and FTIR-Transmission, Hall

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measurement and etching were used to characterize the wafer. Our experiment observation was found to closely agree with the prediction of the model. 

Ko. 5
76° MULTI WAFER PLANETARY REACTOR(5) AS USED FOR P-HET AND HBT APPLICATIONS Jochen Heldfeld, Thomas Schwinger, Michael Jung, Michael Kolb, Michael Heukel, Holger Jurgensen, Aixtron AG, Germany

The AIXTRON Planetary Reactor is proven to grow extreme uniform films together with a highly efficient utilization of the precursors. The novel reactor in 76° configuration is based on the proven AIXTRON Planetary Reactor, which in its 6º configuration, is already qualified for the production of InP-based HBTs for 40 GHz backbone data transmission amplifiers. We investigated the growth and doping of AlGaAs and GaInP which are prominent materials in GaAs-based HEMTs and HBTs. Table 1 shows adjusted doping levels in the 76º configuration established by Hall-effect measurements and homogeneities measured in a Leaighton sheet resistivity meter in GaAs and AlGaAs layers. Wafer-to-wafer homogeneities were found to be in the range of ±0.4 % for n-type and ±0.7 % for p-type GaAs. Tab. 1: On-wafer homogeneity of doping concentration for selected material systems.

<table>
<thead>
<tr>
<th>Material</th>
<th>doping level [cm⁻²]</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaAs</td>
<td>n = 3·10¹⁹</td>
<td>1.54%</td>
</tr>
<tr>
<td>A₀₂GaAs</td>
<td>n = 1·10¹⁷</td>
<td>1.26%</td>
</tr>
<tr>
<td>GaInP</td>
<td>n = 1·10¹⁴</td>
<td>3%</td>
</tr>
</tbody>
</table>

GaInP layers grown in this configuration exhibited a standard deviation of the Ga concentration of 0.05% resulting in a wavelength standard deviation of 2 nm. The thickness homogeneity on-wafer was 0.05%. Al₀₂GaAs layers exhibited a standard deviation of 0.05% in the As-composition and a thickness standard deviation of 0.17% for layers of roughly 2 μm thickness. Unique uniform temperature distribution on-wafer as well as from wafer-to-wafer of better than ±1°C determined by pyrometer temperature measurement was shown. In addition we will present modelling results and additional experimental data on wafer-to-wafer and on wafer thickness homogeneities and compositions of AlGaAs, GaInP and GaAs which prove the qualification of the 76° configuration for the large scale production of p-HETs and HBTs.

Ko. 6

Luminescences on Crystalline-Si epitaxial layers grown on (110) Si substrates by rapid thermal chemical vapor deposition have been investigated. Before the growth, the substrate was recrystallized with implanted Si was used to improve the characterization of Si-epitaxy. Epitaxial layers have been grown at 950°C and Si⁺ to a dose of 5·10¹⁵ cm⁻² and subsequently annealed in a conventional furnace at 1100°C for 1 hour. The growth temperature and the thickness are about 500°C and 700 nm, respectively. The crystallinity of the Si layer has been confirmed by transmission electron microscopy (TEM) and double crystal rocking curve (DCRC), and the strain of Si-epitaxial layers is investigated via the Raman spectroscopy. Photoluminescence (PL) and cathodoluminescence (CL) have been used to study structural and optical properties of Si epitaxial layers grown on the Si⁺-implanted (110) Si substrate. For comparison, we have prepared the annealed substrate without an implantation, and the implanted substrate before annealing, respectively. In Si⁺ implanted samples, the PL and CL spectrum have been measured at 570 nm and 574 nm, respectively. Especially, it is confirmed that these peaks might be responsible for the Si crystalline layers from the photo shift dependence of the incident power and the measuring temperature. The crystallinity of the Si layer was determined by the cathodoluminescence of the epilayer on the implanted substrate will be evaluated.

Ko. 7
ARSENIDE-PHOSPHIDE INTERFACE FORMATION DURING MOVPE OF INDIUM GALLIUM ARSENIDE/INDIUM PHOSPHIDE. Connie Li, Daniel Law, Lien Li, Shen Vaiduke, and Robert Hicks, University of California, Los Angeles, Dept of Chemical Engineering, Los Angeles, CA.

Interface formation during the MOVPE of InGaAs/InP has been studied on the atomic scale using scanning tunneling microscopy and other surface science techniques. It is known that the interface formed by depositing indium gallium arsenide on indium phosphide can be sharp or diffuse depending on the growth procedures employed. We have found that the exchange of arsenic with phosphorus is limited to the first three bilayers below the surface, providing that the substrate temperature is kept at or below 500 degrees C, or the length of exposure is limited to a few seconds. The surface structures produced on the arsenic-exchanged films have been characterized in detail. At decreasing temperatures and increasing pressures of the group V source (e.g., arsine), the AsInP (001) surface exhibits the following reconstructions: (4x2), alpha[2x2](4x2), beta[2x2](4x2), and distorted (1x4). The corresponding coverages of group V atoms are 0.25, 0.50, 0.75, 1.00 and 1.50 monolayers, respectively. Below 500 degrees C, these reconstructions are generated on surfaces that exhibit a roughness of no more than 5 to 6 atomic layers. By contrast, long exposures of indium phosphide to arsine above 500 degrees C, causes a thick InAsP film to grow on the substrate. This film undergoes strain relaxation with the formation of three-dimensional, faceted microcrystals. The implications of these results for the formation of InGaAs/InP heterostructures will be discussed at the meeting.

Ko. 8
STRUCTURE-SENSITIVE OXIDATION OF THE INDIUM PHOSPHIDE (001) SURFACES. Ganggui Chen, Shen V. Vaidue, Daniel C. Law, and Robert F. Hicks, Dept. of Chemical Engineering, University of California, Los Angeles, CA.

The properties of oxide-semiconductor interfaces significantly affect the performance of indium phosphide-based electronic and photonic devices. In this study, indium phosphide films were grown on InP (001) substrates by metalorganic chemical vapor deposition (MOCVD). Then the samples were transferred to an ultrahigh vacuum system, and annealed at 623 and 723 K to produce the (2x1) and (2x1) reconstructions with phosphorus coverages of 1.0 and 1.05 ML, respectively. These structures were exposed to unexcited molecular oxygen, and the oxygen adsorption was characterized by X-ray photoelectron spectroscopy (XPS), reflectance difference spectroscopy (RDS) and low energy electron diffraction (LEED). At 298 K and above, the In-rich InP (001) surface rapidly oxidizes upon exposure to O₂. The oxygen dissociatively chemisorbs onto the (2x1) surface, inserting into the In-P back bonds and the In-In dimer bonds. By contrast, the P-rich (2x1) reconstruction does not absorb O₂ up to 5·10⁵ cm⁻² at 298 K. Above 433 K, the (2x1) becomes reactive with oxygen inserting into both the In-P back bonds and the In-In dimer bonds. Based on these results, we conclude that the oxidation of indium phosphide (001) is highly structure-sensitive. This means that the oxide-semiconductor interface formed on InP devices can vary widely depending on the process history.

Ko. 9
OPTICAL PROPERTIES OF SnS₂, Sn₃S₄C₂, AND Sn₃S₄Br SINGLE CRYSTALS. Choong-Lee Lee, Sung-Kyung Na, Dept. of Physics, Sunchon, KOREA

Sn₂S₃, Sn₃S₄C₂, and Sn₃S₄Br single crystals were grown by the chemical transport reaction method by using iodine as a transport agent. High purity (9N) constituent elements were used as starting materials. Transparent layered single crystals (a typical dimension of 1×1 (6x2) mm²) with golden yellow color were grown. The grown Sn₂S₃, Sn₃S₄C₂, and Sn₃S₄Br single crystals were metal-insensitive. The single crystals were crystallized in a hexagonal structure with lattice constants a = 3.627Å and c = 5.882Å for Sn₂S₃, b = 3.649Å and c = 5.895Å for Sn₃S₄C₂, and a = 3.675Å and c = 5.844Å for Sn₃S₄Br. Direct and indirect energy band gaps at 6K were found to be 2.51eV and 2.348eV for Sn₂S₃, 2.508eV and 2.346eV for Sn₃S₄C₂, and 2.595eV and 2.345eV for Sn₃S₄Br. Temperature dependence of the direct and indirect energy band gap was well fitted by the Varshni equation,

E_g(T) = E_g(0) - \frac{\beta T^2}{T^2 + \alpha^2}

Coefficients for the direct energy band gap were found to be E_g(0) = 2.51eV, α = 1.861·10⁻⁷ eV/K, and β = 1.087 K for Sn₂S₃, E_g(0) = 2.496eV, α = 8.921·10⁻⁷ eV/K, and β = 1.28K for Sn₃S₄C₂, and E_g(0) = 2.502eV, α = 6.930·10⁻⁷ eV/K, and β = 1.34K for Sn₃S₄Br. Coefficients for the indirect energy band gap were found to be E_g(0) = 2.54eV, α = 7.541·10⁻⁷ eV/K, and β = 0.88K for Sn₂S₃, E_g(0) =
K9.10 FORMATION OF TiSb2 AND TiSb2S3 THIN FILMS BY HEATING BiSb2S3-TiS2 AND Sb2S3-TiS2 THIN FILMS. Veronica Barrella, Joao Caamaño, M.T.S. Nair, P.C. Nair, Universidad Nacional Autonoma de Mexico, Centro de Investigacion en Energia, Tempico, Morelos, MEXICO.

TiSb2 and TiSb2S3 are semiconductors with reported band gaps of 0.40 eV and 1.69 eV, respectively, and are considered among non-linear materials. In this work we present a method to produce thin film coatings of these semiconductors on glass substrates by heating coatings of TiS2 deposited on BiSb2S3 or Sb2S3 thin films at 300°C in nitrogen. The chemical bath deposition technique, which is suitable for coating the inside or outside of substrates of any geometry, is employed for the deposition of the different multilayer thin films. The coating bath mixtures were prepared with hexamethane nitrate, triethanolamine and thionocarbamide for BiSb2S3, antimony trichloride and thiosulfate for Sb2S3, and thallium sulfate, sodium citrate, sodium hydroxide and thiourea for TiS2. X-ray diffraction studies confirmed the formation of the ternary compounds. The ternary compounds were deposited multilayer thin film stacks of 0.2 to 0.5 mm thickness. Optical characteristics are analyzed from the transmittance and reflectance data and the electrical characteristics from the dark current, photo current, and diode measurements. We present that it is possible to form solid solutions of the type Ti/Bi/Sb/Si/Sb with tailored properties by heating Sb2S3-Bi2S3-TiS2 layers.


Enhancement in the performances of optoelectronic devices such as LEDs, photodetectors, and photovoltaic energy conversion cells, by utilizing doped and thinned III-V compound semiconductor substrates is of high technological significance. Establishing reliable wafer processing strategies is key to the large-scale deployment of such high performance devices. In particular, damage-free thinning of compound semiconductors is of technical challenge. This presentation will focus on the beneficial effects of using ultrathin substrates for various applications, while describing the key results on successful wafer thinning of III-V compounds. Critical issues such as surface roughness and mechanical damage will be addressed. Atomic force microscopic analysis of wafer surfaces after various thinning processes will be compared. Novel device structures enabled by ultrathin substrates will be presented.

K9.12 PREPARATION OF THE CuAlS2 - CuAlTe2 SEMICONDUCTING ALLOYS. Elena Alih, Ole G. Kjekshus, Institute of Physics of Skids and Semiconductors,inskis BELARUS, Klaus Bente, Gerd Kunzmann, Leipzig Univ., Institut fir Mineralogie, Kristalllographie und Materialwissenschaft, Leipzig, GERMANY.

The LiHVL2 (where L=Cu, Ag, III-Al, Ga, In; VI-S, Se, Te) ternary semiconductors show various interesting physical properties according to the combination of the constituent elements. These chalcogenide semiconductors can be used as candidates for application in photovoltaics, optoelectronics and devices for transferring and processing of information. The CuAlS2 and CuAlTe2 semiconductors belong to these compounds. They were grown as large single crystals, and their alloys two methods were developed. One of them was the two-zone vertical method using elements of 99.999% (copper) and 99.999% (manganese) purity. The samples were sealed in evacuated double quartz ampoules and then placed into a hot furnace. The crucible from BN with the metallic components was kept in hot zone where the temperature was high above 2600°C that is the melting point of corresponding alloys. The temperature of cold zone was increased gradually to meet metallic components with selenium and tellurium. The second method was the sintering of alloys from the powders of previously obtained CuAlS2 and CuAlTe2 compounds. The procedure of photoluminescent spectra of the samples was measured by using the 325nm line of a He-Cd laser as an excitation source. Emission peaks were observed at 2.21 eV and 1.79 eV for 

K9.13 TXX PHASE DIAGRAM OF THE CuAlS2 - AlS2 QUASINARY SYSTEM. Herya V. Korzak, Ruslan R. Miroshnichenko, Institute of Physics of Solids and Semiconductors,inskis BELARUS; Klaus Bente, Gerd Kunzmann, Leipzig Univ., Institut fir Kristalllographie und Materialwissenschaft, Leipzig, GERMANY.

In recent years growing interest has been shown to complex semiconducting compounds LiHVL2 (where L=Cu, Ag, III-Al, Ga, In; VI-S, Se, Te). These chalcogenide semiconductors are considered to be possible candidates for application in photovoltaics, optoelectronics and devices for transferring and processing of information. The CuAlS2 semiconductor is one of these compounds and has a wide direct gap of 3.5 eV making it suitable for the use as window material for solar cells. CuAlS2 has been studied largely but there is not much information about its region of homogeneity in the literature. This compound is crystallized in a tetragonal system - AlS2 group of compounds that may be divided into equal parts (the CuAlS2 and CuxS1-xAlS2 systems). The aims of this paper are (i) the preparation of the CuAlS2 - AlS2 system and (ii) the construction of a Txx-phase diagram by differential thermal analysis and X-ray diffraction. To obtain the CuAlS2 and AlS2 compounds and their alloys the method of melting of the constituent elements of 99.995% purity (aluminum and copper) and 99.995% purity (sulfur) was used. The samples were sealed in evacuated double quartz ampoules and then placed into an electric furnace. The crucible from BN with the elemental components was heated to the temperature higher about 2830°C that is the melting point of corresponding alloys. The phase equilibria in the CuAlS2 - AlS2 system were investigated by means of X-ray diffraction and differential thermal analysis. It was discovered only the formation of CuAlS2 compound in this system. CuAlS2 has the peritectic character of melting with the temperature 1393K. The melting point was 1268K for AlS2 and 1413 K for CuAlS2. The Txx-phase diagram of the CuAlS2 - AlS2 system has the eutectics at 0.88 mole part of AlS2 and 1268K. The region of formation of solid solutions on AlS2 side does not exceed 0.05 mole part of AlS2 at the room temperature.

K10 CHARACTERIZATION OF ROOM-TEMPERATURE FERROMAGNETIC Co-Zn-Al O. Shaoqian Yung, Siims T. Huns, A.B. Pchomov, C.Y. Wong, Magnetic Innovation Center [MAGIC], Material Characterization and Preparation Facility [MCPP], The Free University of Hong Kong, University of Technology, Clear Water Bay, Kowloon, HONG KONG.

Wide gap diluted magnetic semiconductors (DMS) have been proposed for applications in magneto-optical devices. However there are very few reports of DMS which are magnetic at room temperature [1]. In this work we describe synthesis and characterization of transparent Co-doped ZnO DMS films, prepared by a single step sputtering deposition. The films are ferromagnetic at room temperature. Targets composed of Co metal and Zn metal were prepared by sputtering at 100°C for about 10 hours. The films were deposited on glass substrates by RF sputtering at a base pressure of 10-6 Torr. The Ar pressure during sputtering was 2 mTorr. The films were characterized by X-ray diffraction (XRD) and X-ray photoemission spectroscopy (XPS). Optical transparency was measured on UV/VIS spectrometer, and magnetic properties on a Quantum Design MPMS SQUID. XRD patterns show the wurtzite structure similar to ZnO with the [002] preferential texture. Both XRD and XPS show absence of pure Co in the samples, but paramagnetic ZnCo2O4 is present in small quantity. The films are transparent (having light green color) in a wide optical wavelength range up to 1000 nm (the maximum temperature used in the experiments). The value of spontaneous magnetization at 300 K is about 4.7 emu/cm3. Optical transparency spectrum shift with external applied magnetic fields have also been observed at room temperature. A proposed magnetic origin in our experiments was discussed [1].

K9.15 MATERIAL ISSUES IN THE LAYERS REQUIRED FOR INTEGRATED MAGNETO-OPTICAL ISOLATORS.
Lin J. Cruz-Rivera, Sung-Yeob Sung, Jesse Casasola, Martin R. Marrero-Cruz, and Bethanie J.H. Stauffer, University of Minnesota, Dept. of Electrical Engineering, Minneapolis, MN.

The development of integrated optical isolators is critical to the functional integration of optical devices and systems. This work will primarily focus on methodology to grow, by a semiconducting-compatible process, the critical active material in monolithically integrated magneto-optical isolators; yttrium iron garnet (YIG: Fe_{0.25}). By using the radio frequency (RF) sputtering was used to grow YIG on MgO, which is promising buffer layer material for optical devices. By thermally isolating the samples during growth, films crystallized in-situ without the use of a substrate heater.

Further optimization includes post deposition processing, such as low temperature anneal. We have shown previously that fully amorphous as-deposited samples could be crystallized well below the sintering temperature of YIG (~800°C). The samples grown here with YIG nuclei already observed in the as-deposited films require lower temperature anneals to allow the nuclei to grow without compromising a low thermal budget for the system. Other isolator key components have also been successfully fabricated and will be discussed. Optical cladding layers deposited with YIG films have been grown through plasma enhanced chemical vapor deposition (PECVD) and a thin film permanent magnet for biasing has been grown and optimized.

K9.16 NOVEL ORGANIC, POLYMERIC MATERIALS FOR ELECTRONICS APPLICATIONS.
Ran W. Salunk, Mary J. Spencer, William L. DeMann, Douglas J. Guerrero, Brewer Science Inc., Rolla, MO.

Novel organic polymeric materials and processes of depositing thin films on electronics substrates by chemical vapor deposition (CVD) have been developed and the lithographic behavior of photoreist coated over these CVD films at deep ultraviolet (DUV) wavelength has been evaluated. The specific monomers synthesized for DUV applications include [2-5](4)-naphthalene, 1,4-phenylcyclohexane, and the derivatives which showed remarkable film uniformity on flat wafers and conformality over structured topography wafers, upon polymerization by CVD. The chemical, physical and optical properties of the deposited films have been characterized by measuring parameters such as thickness uniformity, solubility, conformality, adhesion to semiconductor substrates, ultraviolet-visible spectra, optical density, optical constants, defectivity, and resist compatibility. Scanning electron microscopy (SEM) photos of cross-sectioned patterned wafers showed vertical profiles with no footing, standing waves or undercut. Resist profiles down to 0.1 μm dense lines and 0.08 μm isolated lines were achieved in initial tests. CVD etchings achieved 96-100% conformal films, which is a substantial improvement over commercial spin-on polymeric systems. The light absorbing layers have high optical density at 248 nm and are therefore capable materials for DUV lithography applications. CVD is a potentially useful technology to extend lithography for sub-0.15 μm devices. These films have potential applications in microelectronics, optoelectronics and photonics.

K9.17 PHOTOLUMINESCENCE OF NANO SCALE ZnS:Ms PHOSPHOR POWDERS.
S.H. Hsu*, Li-Gann Chen, Chi-Shyang Huang, F.S. Jung*, S.J. Chung*, and Y.K. Su*; "Department of Materials Science and Engineering, National Cheng Kung University, Taiwan, TAIWAN, R.O.C.; Department of Electro-Optic Engineering, National Taiwan Institute of Tech, Taipei, TAIWAN, R.O.C.; Department of Electrical Engineering, National Cheng Kung University, Tainan, TAIWAN, R.O.C.

Nano-scale ZnS:Ms phosphor powders were synthesized by solid state calcination, solvothermal, and microemulsion methods respectively. The processing parameters such as particle size distribution, chemical composition, morphology, etc. are characterized by DTA/TGA, XRD, FTIR, SEM, TEM, and BET. All the nano-scale YAG powders were heat treated below 800°C. Both TEM and XRD results of these nano-scale YAG powders show high degree of crystalline structure. Photoluminescence (PL) characterization shown that the nano-scale ZnS:Ms phosphor powders has a higher intensity of luminescence than that of sub-micro sized sample. The effect of different Ms doping level on the PL intensity shows a maximum at x ~ 0.01 to 0.1. The effect of particle size on the PL intensity will also be reported. Supported by NSC-93-2216-E-006-030.

K9.18 ANALYSIS OF THE VALENCE BAND SPLITTING BY FOURIER TRANSFORMATION OF PHOTOELECTROPHORESIS SPECTRA.
J.S. Huang, G.S. Cheng, C.W. Kuo, and Y.T. Lu, Dept. of Physics, National Cheng Kung University, Tainan, TAIWAN.

For an In structure, the strong electric field in the intrinsic layer gives rise to level splitting (~20 meV) between heavy hole (HH) and light hole (LH). This causes inaccuracy in the traditional scaling Fourier analysis of photoelectron distribution (PED) in In. In this work, we present a novel technique to obtain valence-band split from the Fourier spectrum of PED for GaAs and InAlAs. A line-convolution of PEDs of HH and LH is adopted as a trial function. Besides two linear coefficients, the band gaps for HH and LH are treated as adjustable parameters. We develop an efficient algorithm for fitting the trial function to the PED spectrum in Fourier space. The field induced splits thus found for PEDs performed under various pump beam intensities are in good agreement with a theoretical calculation using three-band strained Hamiltonian.

K9.19 ORGANIC PHOTOVOLTAIC DIODES WITH EL LIGHT EMISSIONS FROM INTERFACE. D. Farn*, B. Chu*, W.L. Li*, Z.R. Hong*, H.Z. Wei*, C.S. Lee*, and S.T. Lee*, "Laboratory of the Exalted State Processes, Chinese Academy of Sciences, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, CHINA; Department of Physics and Materials Sciences, City University of Hong Kong, CHINA.

A series of organic photovoltaic (PV) cells in which the electron acceptor and are guludinobilithoether, beta-phosphonothioylindole (GDBM)2thi and donor N,N' diethyl-N,N' bis(3methoxysilylpropyl)-1,1'-diphenyl-4,4'-diamine (TPD) were fabricated. The PV diodes can show EL emissions from the interface between TPD and Gd-complex. Open circuit voltage (Voc) of 3.2 V was obtained due to efficient exciton dissociation near the interface between Gd with TPD and TPD, and while 5.0 V was biased the diodes can give yellow which is only from the interface because the yellow band deflected from that from TPD, and Gd-complex is not emitted. We also observed that energy conversion efficiency was significantly improved by inserting an ultrathin mixed layer of Gd-complex and TPD into between TPD and Gd-complex; /ITOTPD/TPD:Gd-complex/Ag. So we can demonstrate that photovoltaic diodes of the diodes should be associated with interface state between the two organic layers, that is exciplex formation resulted from the interface.

K9.20 SYNTHESIS AND PHYSICAL PROPERTIES OF HYBRIDS ORGANIC AND INORGANIC CONTAINING DYES OR RARE EARTH IONS. Trung Kim An, Pham thi Minh Chau, Nguyen Truong Oanh, Tran Thuy Huong, Nguyen Thanh Huong, Le Quoc Minh, Institute of Materials Science, National Centre for Natural Science and Technology of Vietnam, Hanoi, VIETNAM.

The hybrid matrix obtained by the sol-gel method from tetraethoxysilane, which blended different polymers. The dyes are Rhodamin6G, Coumarin 540 and the RE ions as Eu3+, Er3+ which were embedded in these matrices. The optical properties such as absorption, luminescence spectrum and lifetime were investigated. The Eu and Er transitions in visible and infrared regions, the influence of dyes, Eu, Er concentration, temperature condition to optical properties and their application in optoelectronic and photonics will be studied.
wave-guides have functions similar to the ones of their analog fiber optic (EDFAs) but they are much more compact. As a consequence, they require higher Erbium concentrations. However, the raising of fluorescence by the increase of Er concentration has a cut-off due to the strengthening of the ion-ion interaction that reduces the Er fluorescence intensity and lifetime. The sol-gel technique allows the incorporation of high Erbium concentrations in glasses that allow obtaining fulldense film at lower temperature than those possible by other methods. In this work, (Au, Er3+) doped (Pbo4·As2O3) (Zn0.5As0.5)0.5 glass wave-guides have been prepared by sol-gel processing using multilayer spin-coating deposition on silica glasses. The aim was to reinforce the fluorescence intensity by: a) resonant phenomena between Er3+ and Au nanocrystallite, and b) dielectric effect of the matrix. The gold quantum dots were synthesized in micellar reaction by photoreduction from HAuCl4 by anchoring sol-gel compatible modifiers on their surfaces. GI X-ray diffraction, TEM, ellipsometry, FT-IR and Raman spectroscopy were used to characterize the structure, nanostructure and residual OH contents. The KKpropagation losses were measured at 633 nm and the (Au, Er3+) fluorescence was investigated at different wavelengths.

**K9.22**
**DEPOSITION OF OPTOELECTRONIC POLYSILANE FILMS USING CVD**

John P. Lock and Karen K. Gleason, Massachusetts Institute of Technology, Dept of Chemical Engineering, Cambridge, MA

Polysilane has many potential optoelectronic applications, including flexible blue light emitting devices, photochemistry, and photonic chip components. Plasma Enhanced Chemical Vapor Deposition (PECVD) employs high energy ions to initiate polymerization processes resulting in the growth of polysilane thin films. This PECVD method circumvents the difficulty of dissolving conventional polysilane, which is required to prepare films by the conventional hot methods. Fourier Transform Infrared Spectroscopy (FTIR) indicates the presence of Si(Ch1), Si(Ch2), and Si-H bonding environments and also detects the presence of oxygen contamination in the films. Selective use of X-ray Photoelectron Spectroscopy (XPS) and solid state Nuclear Magnetic Resonance (NMR) Spectroscopy in quantifying the FTIR results. Variable Angle Spectroscopic Ellipsometry (VASE) provides nondestructive measurements of film thickness, refractive index, surface roughness and film composition. These spectra also indicate good resemblance to conventionally polymerized polysilane powders that were obtained commercially. Ultraviolet observatory spectroscopy reveals that the polysilane materials are transparent in the visible region of the spectrum, but are strongly absorbing between 250 and 300 nm. The films fluorescence under ultraviolet light and the collection of photoluminescence spectra is underway.

**SESSION 10: UNIQUE MATERIALS, PROCESSING, AND CHARACTERIZATION**

Chair: Dieter Bimberg and Anupam Mathur

Friday Morning, April 5, 2002

**Nab Hill C/D (Marriott)**

**8:30 AM **

**K10.1**

**SUPPRESSION OF BULK DEFORMANTS IN ANTIMONIDE SUPERLATTICE INFRARED PHOTODIODES**


While the intrinsic physical properties of ideal antimonide superlattices (ASL) indicate that they should significantly outperform mercury cadmium telluride (MCT) based infrared photodiodes for low dark current applications in the long and very long wave-infrared (LWIR and VLWIR), this potential has not yet been fully realized. Even though measured Auger and tunneling rates in ASLs are reduced as predicted, overall carrier lifetimes remain much shorter, and dark currents much higher than expected. The large carrier losses are the result of defects in the ASL structure, with contributions from bulk defects and surface channels along the mesa sidewalls, and also a component that is believed to be due to midgap states. We have investigated the correlation between the evolution of bulk defects and MBE growth parameters. Interferometric and cross-sectional transmission electron microscopy (XTEM) of ASLs have shown that many bulk defects originate at the epilattice interface and are amplified during growth. The generation of these defects is strongly influenced by a number of growth variables including substrate preparation, substrate orientation, oxide removal procedure, growth temperature and MBE flux composition. The dependence of defect evolution on these factors is investigated systematically in a series of sequential and side by side growths to isolate individual mechanisms and identify them using structural and compositional techniques. We also discuss factors that underlie the nature of point defects in ASLs, through deep level transient spectroscopy (DLTS), and the characteristics of devices exposed to non-ionizing radiation to introduce a controlled density of dopant defects. We also present results suggesting the role of the active layers so as to increase the absorption and reduce the leakage.

**9:00 AM**

K10.2

**RELAXED InAs layers GROWN ON STEP GRADED InAsP BUFFERS BY SOLID SOURCE MBE.**

Mantu K. Hidajat, Yong Lin, Cecilia L. Andere, Pyush M. Saini, Steven A. Myers, The Ohio State University, Dept of Electrical Engineering, Columbus, OH; D.M. Wilt, NASA-Glenn Research Center, Photovoltaics and Environment Branch, Cleveland, OH.

InAsP alloys are receiving attention for infrared optoelectronic applications due to the wide range of infrared bandgap energies. For applications involving infrared energy conversion, the electronic quality and structural properties of bulk, relaxed InAsP layers having specific bandgap energies are critical to enable good device performance. However, little information is available concerning the dependence of bulk electronic and structural property correlations on InAsP composition. This paper presents a systematic study of structural and electronic properties of strain-relaxed InAsP layers grown on step-graded InAsP buffers on InP, for As mole fraction of 0.65, 0.30 and 0.34 using solid source molecular beam epitaxy. An optimized In ratio of 7.1 for InAsP growth was determined by first monitoring the mobility of InP layers as a function of P:In ratio. To achieve the range of targeted InAsP compositions, the As:In ratio was then adjusted accordingly while maintaining a P:In ratio of 7.1, and photoluminescence curves were obtained for a growth temperature of 480°C. Using this information, 1.5 microns thick, n-type InAsP films were grown on step-graded InAsP buffers. New complete relaxation of final overlayers, determined by high-resolution X-ray diffraction, were found after the composition with well-developed surface crosshatch morphology, indicating the effectiveness of the InAsP graded buffer in achieving controlled strain relaxation. The carrier concentration, mobility, and Si donor activation energy for each InAsP composition were determined using temperature dependent Hall measurements. At a constant electron concentration of 1x10^17 cm^-2 300 K carrier mobilities increased from 1745 to 2300 cm^2/V-sec with As mole fraction increasing from 0.65 to 0.34. Electrochemical C-V profiling confirmed that a uniform doping concentration was achieved for each film. Complete details of the structural and electrical properties of relaxed InAsP layer will be discussed and correlated to growth parameters.

**9:15 AM**

**K10.3**

**OPTICAL PROPERTIES OF PLANAR CHIRAL META-MATERIALS.**

A. Potts, A. Papakostas, D.M. Bagnall, University of Southampton, Dept of Electronic and Computer Eng, Highfield, Southampton, UNITED KINGDOM; N.I. Zheludev, H.J. Coles, University of Southampton, Dept of Physics and Astronomy, Highfield, Southampton, UNITED KINGDOM; B. Greef, University of Southampton, Dept of Chemistry, Highfield, Southampton, UNITED KINGDOM.

Chirality is a fundamental property of nature, underpinning many chemical and biological reactions and processes necessary to life. It is also of potential importance in the engineering of opto-electronic properties in photonic structures. Interest in this area has grown since it was recently shown how structures with both negative permittivity and negative permeability can be engineered in non-magnetic materials [1,2]. Such metamaterials have several unusual properties not found in nature, including negative angles of refraction and phase velocities. More recently, theoretical attention has turned to metamaterials that are also sensitive to different polarizations of light. Until now, no experimental work has been undertaken on metamaterials in the visible or infrared parts of the electromagnetic spectrum, even though such materials might potentially have many applications in areas such as optical communications and quantum cryptography. We have therefore fabricated planar chiral meta-materials with critical dimensions in the sub-micron regime that do indeed interact with light in the visible and infrared parts of the spectrum. These structures have been found to exhibit novel and unpredicted optical responses when illuminated with both linearly and circularly polarized light. Their responses are also size and geometry dependent, thus allowing their properties to be tailored to the wavelengths of interest. The simplicity of these structures, coupled with their versatility, promises to open up new opportunities and applications for photoelectronic devices in the future. [1] J.B. Pendry, A.J. Holden, W.J. Stewert and I. Youngs, Phys. Rev. Lett. 76, 24773 (1996), [2] J.B. Pendry, A.J. Holden, D.J. Robbins and W.J. Stewert, IEEE Trans. Microwave Theory Tech. 47 4785 (1998).
9:15 AM K10.4
Transferred to K12

9:30 AM K10.5
WATER-BINDED Ge/Si HETEROSTRUCTURES FOR PHOTOVOLTAIC APPLICATIONS. James M. Zahrer, Chang-Geun Ahn, Harry A. Atwater, Caltech, Dept. of Applied Physics, Pasadena, CA; Charles Chu, Peter Iles, Tesar Inc., City of Industry, CA.

Film transfer of Ge onto Si substrates through wafer bonding and layer transfer is being explored as a means of cost and weight reduction of triple-junction compound solar cells. Additionally, wafer bonding is being investigated as a method of improving flexibility of materials selection to allow band gap optimization in solar cell design. We have successfully used direct wafer bonding along with hydrogen-induced layer splitting of Ge to bond and transfer single crystal Ge(100) films to Si(100) substrates without using a metallic bonding layer. Ge substrate with a band gap of 1.8 eV at 77K were transferred to Si(100) from 600-700 nm thick films on the order of 1 cm² for Ge/Si. Hydrophilic surface passivation and less than 5nm rms surface roughness as measured by contact mode AFM along with ~7 MPA bond initiation pressure are suitable surface conditions for reversible room temperature bonding of Ge/Si to occur. Layer splitting is induced by a thermal cycle up to 250°C under 2.5 MPA normal pressure immediately followed by a thermal cycle up to 450°C under 0.5 MPA normal pressure leaving a transferred layer with 0.20 nm surface roughness. Electrical measurements indicate chunky-LV characteristics for Ge p+ substrates bonded to Si p+ substrates with ~1.2 Ω cm² resistance, sufficient to allow low-loss power extraction through band-to-band interfacial minority carrier current. Such structures have been grown on Ge/Si heterostructures. These devices exhibit photoluminescence intensity and photoluminescence decay lifetime in the GaAs top contact region and photoluminescence intensity in the GaAs active region that are comparable to devices grown on bulk Ge substrates. Future work will focus on surface preparation techniques to enhance the optical properties of GaAs grown on Ge/Si heterostructures. GaAs optical performance will be measured by time resolved photoluminescence in grown GaAs/AlGaAs double heterostructures tailored to give optimal minority carrier lifetimes and allow independent determination of the minority carrier lifetime and surface recombination velocity in the GaAs. [1] Additionally, the threading dislocation density will be analyzed with TEM analysis for the GaAs grown structures.


10:15 AM K10.6
ROOM TEMPERATURE ULTRAVIOLET NANOSERS. Huaqin Yan, Peidong Yang, Univ. of California,Berkeley, Berkeley, CA.

ZnO nanowires were successfully synthesized by a simple vapor transport and condensation process. Room temperature ultraviolet low-loss behavior has been demonstrated in these single crystalline ZnO nanowires. Given in a preferred direction <0001>, these wide band-gap semiconductor nanowires form natural resonance cavities with diameters varying from 20 to 150 nm and lengths up to 40 μm. Under a combination of cold plasmonic and focused ion beam action was observed at a near-UV wavelength of 385 nm with emission line width <0.3 nm. Doping experiments were also carried out to modify the bandgap of ZnO nanowires to make tunable wavelength nanolasers. These room temperature UV nanolasers can be used for high-density information storage and microanalysis.

10:30 AM K10.7
BIOMETRIC SYSTEM BASED ON ONE SINGLE LARGE AREA Si:C P-I-N PHOTODIODE. M Vieira, M Fernandes, A Fantoni, P.Louro, R. Schwarz, Electronics Telecommunications and Computer Dept., ISEL, Lisbon, PORTUGAL.

Based on the Linear Scanned Photodiode (LSP) image sensor we present an optical fingerprint reader for biometric authentication. The device configuration and the scanning system are optimised for this specific purpose. The output of the fingerprint scanner is a rectangular array of pixels, representing the fingerprint image on glass surface in front of the capture device. The reflected light coming from the glass is projected onto the active surface of the sensing element (large area Si:C p-i-n photodiode). The image is converted directly into electrical signal at the output of the LSP as fingerprint reader. In this work the main emphasis will be put on the influence of the doped layers (doping level), carbon content of the active layer (photovoltage, defect density, temperature dependence, thickness), and the device performance (transfer functions, sensor dynamic range, resolution, linearity, responsivity, response time).

The scanning technique for fingerprint acquisition is improved and the effects of the probe beam size, wavelength and flux, the scan time and modulation frequency on image quality and resolution will be analysed under different electrical bias. An optical model of the image acquisition process is presented and supported by a two dimensional simulation. Results show that a trade-off between read-out parameters (fingerprint scanner) and the biometric sensing element structure (p-i-n structure) are needed to minimize the cross talk between the fingerprint ridges and the fingerprint valleys. The performance of the capture device is enhanced by a tight control of image brightness and applied electrical bias. In the heterostructures with wide band gap low conductivity doped layers the user-specific information is detected with a good contrast while the resolution of the sensor is around 20 μm. A further increase in the contrast is achieved by slightly reverse biasing the sensor with a sensitivity of 6.5 μV/cm² and a flux range of two orders of magnitude.

10:45 AM K10.8
EPITAXIAL GROWTH OF ZnO ON Si[111] USING AlN AS A BUFFER LAYER. C. Jin, Asafatwot Awiari, A. Klot, M. Zhou, J. Noraian, Department of Materials Science & Engineering, North Carolina State University, Raleigh, NC.

ZnO (hexagonal Wurtzite structure) is a promising material for optical, electrical and laser applications. Because of its higher exciton binding energy, it is considered to be a better alternative for GaN. The optical quality of ZnO has been realized on sulphur substrates, but for integration with silicon microelectronic devices, it is desirable to grow ZnO on silicon. Recently we have succeeded in depositing epitaxial ZnO(0001) films on Si[111] substrate using a pulsed laser deposition technique. We used a thin layer of AlN as buffer layer. These films were characterized using x-ray diffraction, high resolution transmission electron microscopy (HRTEM) and electrical resistivity measurements. X-ray diffraction and HRTEM results show the epitaxial growth with 30° rotation in the basal plane. We present structure-property correlations of ZnO/AlN/Si[111] thin film heterostructures.

11:00 AM K10.9
SYNCHROTRON RADIATION PHOTOMISSION STUDY OF SURFACE CLEANING CHEMISTRY OF InP(100) BY HYDROGEN PEROXIDE BASED SOLUTIONS. Yun Sun, Piero Peronetti, William E. Spicer, Stanford Synchrotron Radiation Lab, Stanford, CA; Zhi Liu, Dept. of Physics, Stanford Univ, Stanford, CA; Francisco Mendoza, Department of Electric Engineering, Stanford Univ, Stanford, CA.

InP is an important semiconductor in many applications. A clean InP surface is normally critical for the performance of the InP-based devices. The chemical cleaning methods for GaAs(100) surface has been studied extensively and many effective cleaning techniques have been developed. Since InP is a very similar material to GaAs, a lot of chemical cleaning techniques for GaAs(100) were applied to InP(100) surface in previous work. However, the chemistry for InP might be different enough from GaAs that these techniques may not be effective. This work is concentrated on hydrogen peroxide based solutions proven to work on GaAs(100) surface, and synchrotron radiation photoelectron spectroscopy is used to study the chemical species on the surface at different stages. It is found that ammonium - hydrogen peroxide solution does not work at all because ammonium can dissolve Ga on surface. But nitric acid - hydrogen peroxide solutions leave the InP(100) surface with more than 0.5 monolayer of oxide, which can not be removed completely by vacuum annealing, while the GaAs(100) surface is left with two monolayers of elemental As, which can be removed by vacuum annealing to give a clean GaAs(100) surface. The possible explanation for the difference is explained by different chemical properties of elemental between P and As, and between In and Ga. The form of oxide on InP(100) surface after the chemical etching is identified as phosphorus and its transformation to metaphosphate when annealed is suggested and supported by chemical shifts of P2p, In4d core levels as well as valence band spectra. A second step to remove the oxide from InP(100) surface is then used and a clean InP(100) surface can be obtained.

11:15 AM K10.10
SENSITIZED PHOTOLUMINESCENCE OF RARE EARTH IONS DOPED INTO MESOPOROUS TITANIA THIN FILMS. Karen L. Findell, Department of Chemistry and Biochemistry, University of California, Santa Barbara, CA; Michael H. Burt, Department of Chemistry and Biochemistry, University of California, Santa Barbara, CA; Galen D. Stucky, Department of Chemistry and Biochemistry, University of California, Santa Barbara, CA.

High concentrations of rare earth ions have been incorporated into self-assembled mesoporous titania thin films to form a new, photoluminescent material, which operates via efficient energy transfer from the titania to the rare earth ions. The structure of the mesoporous material is composed of a cubic network of pores with a wall made of 1-3 nm amorphous titania crystallites surrounded by gassy amorphous titania. This material is synthesized via a one step, sol-gel
route using amphiphilic block copolymers, and the incorporation of rare earth ions during the synthesis does not affect the mesoscopic ordering. Since the rare earth elements generally have low absorption cross sections, the titania nanocrystals can be used to sensitize these ions via energy transfer. In a film doped with europium [111] ions, irradiation of the titania within its band gap produces the bright red photoluminescence observed in the film, and direct excitation of the europium produces no observable emission from the film.

11:30 AM K10.11

Lithium niobate (LiNbO₃) is known as a technologically important material for non-linear photonic components and electro-optical modulators. Although lithium niobate has been extensively studied in the bulk form, very few reports exist on the structure of LiNbO₃ thin films or epitaxial heterostructures. We present the results of the structural studies of the LiNbO₃ thin films grown by atmospheric pressure chemical vapor deposition at low temperature from alkoxide precursors, followed by high temperature post-growth annealing. The films fabricated on sapphire and LiNbO₃ single crystal substrates under the same processing and annealing conditions exhibited strikingly different microstructure, which is explained in terms of high LiNbO₃ self-diffusivity. Epitaxial single-crystalline films of about 1 μm thickness with the dislocation density less than 10⁶ cm⁻² (as determined by transmission electron microscopy, TEM) were fabricated on [0001] LiNbO₃. The LiNbO₃ layers formed on the [0001] sapphire substrates were found to be polycrystalline with the average grain size of about 1 μm. The formation of a ~200 nm-thick epitaxial LiAlO₂ interlayer at the LiNbO₃/sapphire interface, observed by TEM, is explained by high lithium ion diffusivity and tendency to form complex oxides/all oxides with other metals. We have also found the presence of small (about 100 nm size) second-phase inclusions in the LiNbO₃ layer grown on sapphire. The energy dispersive x-ray analysis showed the presence of excess oxygen in the inclusions as compared to the bulk of the LiNbO₃ film, indicating the different LiNbO₃ O-phase or, possibly, a niobium oxide. TEM revealed no second phase inclusions associated with the LiNbO₃ grain boundaries or the LiNbO₃/LiAlO₂ interface. The results of the structural studies are correlated with the growth parameters and chemical/compositional analysis data.

11:45 AM K10.12
NANOISLANDS AND NANOHOLES BY MOLECULAR BEAM EPITAXIAL GROWTH AND ATOMICALLY PRECISE IN SITU ETCHING. Swati Krawitz, Rudeeun Songmuang, and Oliver G. Schmidt, Max-Planck-Institut für Festkörperforschung, Stuttgart, GERMANY.

Extremely homogeneous arrays of nanocylinders and nanoholes are fabricated using molecular beam epitaxial growth and in situ etching. Self-organization mechanisms resulting in the high aspect ratios of ~5% are grown using a low indium growth rate on GaAs (001) substrate. If these nanocylinders are capped with GaAs at low temperature (470°C), strong room temperature emission at 1.3 μm with a linewidth of 22 meV from the island etching GaAs surface of capped InAs nanocylinders with AsₓBrᵧ. The nanocylinders have a depth of 5-6 nm and the lateral size is 50-60 nm in the [110] direction. We appoint the formation of nanocylinders to a pronounced selectivity of the AsₓBrᵧ to local strain fields. The holes can be filled with InAs again such that a flat surface is recovered. The etched and regrown structures show intense photoluminescence at room temperature.

SESSION K11: QUANTUM DOTS AND QUANTUM WELLS
Chair: Katherine Dovidenko and John E. Cunningham
Friday Afternoon, April 5, 2002
Nab Hill C/D (Marriott)

1:30 PM K11.3
INFRARED CAPPED GaAs (001)/InAs QUANTUM DOT INFRARED PHOTODETECTORS WITH UNDOPED ACTIVE REGION. Z.H. Chen, E.T. Kim, M. Ho, and A. Madhukar, University of Southern California, Departments of Materials Science and Physics, Los Angeles, CA; Z. Ye, and J.C. Campbell, The University of Texas at Austin, Microelectronics Research Center, Department of Electrical Engineering, Austin, TX.

Epitaxial self-assembled semiconductor quantum dots are attractive candidates for mid and long wavelength (3-14 μm) photodetectors. We report on normal incidence n-type quantum dot infrared photodetectors (QDIPs) with undoped active region (n-in-n configuration) consisting of GaAs capped GaAs (001) InAs QDIPs. The QDIPs were grown on GaAs (001) p-type substrates at a growth rate of 0.1 Å/s. The QDIPs were fabricated using conventional photolithography and in situ etching. The InAs QD dot density, as well as the structure and thickness of the QDIPs were characterized using atomic force microscopy and cross-sectional transmission electron microscopy. The InAs QDs embedded in the n-in-n QDIP structures have been...
comprehensively characterized using photoluminescence (PL), PL excitation, and FTIR based inter- and intra-band photocurrent spectroscopy. The QDs of infrared detectors have been realized using bound-to-bound intraband transitions of the In$_{0.15}$Ga$_{0.85}$As capped GaAs(100)/InAs QDs: (i) QDIPs with photoreponse wavelength of ~8.5 µm, and (ii) bias-controlled tunable two color (~8.5 and ~9.9 µm) QDIPs. The ~8.5 µm QDIPs are based on a set of five layers of 2.0 and 2.5 monolayer InAs QDs, respectively. Two types of QDs with different size/shape existing in a single QD layer and between different QD layers account for the observed two-color, bias, dark current, and detectivity of these QDIPs will be presented. At 77 K, the two color QDIPs show an intraband peak detectivity of 5.3x10$^9$ cm$^2$/Hz$^{1/2}$/W at ~5.0 µm and of 7.5x10$^9$ cm$^2$/Hz$^{1/2}$/W at ~10.0 µm. Approaches to improving detectivity are underway and will be discussed.

2:30 PM K11.4 A COMPARATIVE STUDY OF AN InP QUANTUM DOT LASER AND A GaP QUANTUM WELL LASER Y. M. Ahn and O. G. Schmidt, Max-Planck-Institut für Festkörperphysik, Stuttgart, GERMANY.

Recently we reported the first room-temperature injection laser, based upon self-assembled InP quantum dots [1]. In this contribution the lasing characteristics of InP quantum dot (QDs) are compared with a comparatively strained Ga$_{0.5}$In$_{0.5}$P quantum well (QW), grown by solid source molecular beam epitaxy under equivalent conditions, which both emit near the same wavelength. Our comparison is suitable to study the fundamentally different charge carrier population mechanisms and laser properties of QDs and QWs. Both devices exhibited room temperature lasing at threshold current densities of ~1.8 kA/cm$^2$ at a wavelength of 920 nm for the QD structure and 3.9 kA/cm$^2$ at 741 nm for the QW structure. For $T <$ 80 K both devices have threshold current densities smaller than that for QW lasers, which expressively increase with temperature. The QD device has an improved characteristic temperature compared with the QW device. At low temperatures the QD device exhibits lasing from excited states and changes to ground state lasing for $T >$ 200 K, whereas the QW device lases from the ground state for all temperatures. We attribute this effect to an extreme nonequilibrium population of the QDs at low temperatures whereas at higher temperatures thermal coupling of charge carriers provides effective filling of those dots with low ground state energies. At $T = 8$ K the PL spectrum of the QW structure shows a narrow linewidth of 11 meV compared to a much broader linewidth (21 meV) of the QD structure. Temperature dependent electroreflectance measurements reveal that the spontaneous linewidth of the QDs is less temperature dependent than the linewidth of the QW, agreeing well with the improved temperature stability of the threshold current density of the QD lasers. References [1] Y. M. Ahn, O. G. Schmidt, and K. Eberl, Appl. Phys. Lett. 76, 3430 (2000).

3:15 PM K11.5 DEFECT FREE IN-SITU ELECTRIC FIELDS IN QUANTUM DOT LASER STRUCTURES GROWN BY METAL ORGANIC CHEMICAL VAPOR DEPOSITION Adrijana Pascovic, Massimo De Vittorio, Giuseppe Merucci, M. Teresa Todaro, Sergio De Rinaldis, Roberto Cingolani, National Nanotechnology Laboratory of INFM, Dep. Ing. Innovation, University of Lecce, Lecce, ITALY.

In the last years great effort has been dedicated to the study and fabrication of optical electronic devices containing InGaAs quantum dot (QD) structures as active layers, for 1.3 microns operation. However, even if room temperature lasers emitting in the 1.3 microns region have been recently fabricated by Molecular Beam Epitaxy (MBE), long-wavelength lasing in QD laser structures grown by metalorganic chemical vapor deposition (MOCVD) has not been reported so far, and very few works have shown emission wavelength at 1.3 microns in QDs fabricated by MOCVD. By means of systematic studies carried out on 60% (50%) quantum dot (QD) structures, we are currently able to demonstrate that the combination of different electric fields in such structures dramatically blue shifts the emission wavelength even though the photoluminescence occurs at the expected value of 1.3 microns at room temperature. By comparing photoluminescence (PL), electroluminescence (EL) and photocurrent (PC) measurements in InGaAs QD structures emitting between 1.28 microns and 1.4 microns ($3000$ K), we demonstrate that the electric field associated to the built-in dipole field, directed from the substrate to the QDs (with the substrate at the higher potential than the QDs), and the device junction field (when parallel to the dipole field) lead to the depletion of the ground state. As a consequence, structures grown on n-type GaAs substrates exhibit electroluminescence only from the excited states (whereas the photoluminescence comes from the ground level). Instead, by growing the same device structure on p-type GaAs substrates, i.e. by reversing the direction of the built-in electric field of the device, the effect of the permanent dipole is strongly reduced and allowing us to achieve a designed wavelength of 1.3 microns at 3000 K, coincident to the PL emission. The consequence on the achievement of efficient lasing in the spectral region of interest for optical transmission will be illustrated.

3:30 PM K11.6 TIME RESOLVED STUDIES OF PROTON IRRADIATED QUANTUM DOTS. A. A. Menousek, Royal Instutute of Technology, Dept of Microelectronics and Information Technology, Kista, SWEDEN; R. Leon, Jet Propulsion Laboratory, California Inst of Technology, Pasadena, CA; C. Lob, Cambridge Univ, Cavendish Laboratory, Cambridge, UNITED KINGDOM; B. Mangels, W. Taylor, California State Univ, Dept of Physics and Astronomy, Los Angeles, CA.

Proton irradiation induces structural defects and creates carrier-trapping centers in semiconductors. First studies of steady-state optical properties of proton-irradiated quantum dot (QD) structures and QD lasers showed that the QDs are much more resistant to proton irradiation than bulk semiconductors or quantum wells (QW). In the present work we extend those investigations by studying carrier dynamics in irradiated QD structures. To get a better insight on the irradiation influence on the carrier dynamics in the QDs, we investigated a number of different QD structures, differing in material (InGaAs/GaAs and InAs/GaAs), dot density, substrate orientation and irradiation dose. Carrier dynamics was measured by time-resolved photoluminescence (PL). For comparison, similar measurements were performed on InGaAs QWs. We find that carrier lifetimes in QDs are much less affected by proton irradiation than the QWs. For example, the 80 K carrier lifetimes in [311]B QDs decrease from 2.2 ns for the unirradiated sample to 1.4 ns for the sample with the highest proton dose of 3.5x10$^{16}$ cm$^{-2}$, compared to a 0.4 ns for the QW. Moreover, we were able to observe some increase in the QD PL intensity in the low-dose samples with small irradiation doses compared to the unirradiated samples. These observations are explained taking into account that, unlike in QWs, carriers in the QDs are not mobile, and their lifetime is reduced only by the defects created inside the dots. The electrons in the QWs, on the other hand, can easily find a radiation-induced trap and be removed from the conduction band. Enhancement of the PL intensity at moderate radiation doses suggests a more effective carrier transfer from the wetting layer into the QDs. This may occur due to an additional channel of carrier trapping via irradiation-induced defects.


Semiconductor nanocrystals possess unique optical and electronic properties due to size quantization effect on the nanometer scale. Such nanoparticles (NPs) are usually capped with organic molecules to prevent chemical and electrical properties. Surface modification of CdSe nanoparticles with various electron donating linear and dendritic ligands. In addition to various linear modifiers with monofunctional ligands, also multifunctional poly(alkanamide) (PAAM) dendrimers carrying different numbers of linear polyamidamine chains and covalently linked TOPO/TOP caps were achieved through a CdSe/polyamine interface. The modified CdSe nanocrystals were characterized using NMR, UV-visible absorption, photoluminescence (PL) and TEM. It was found that both absorption and PL spectral characteristics change instantaneously as a function of composition. UV/Vis absorption and PL of such CdSe/PAAM and CdSe/Linear systems were studied during a two months period as a function of time. The ligand composition, PAAM derivatives with only secondary and tertiary amines provided a better protection for the nanocrystal than those with primary amines.

4:00 PM K11.8 DEFECT FREE InGaAs-BASED STRAIN BALANCED MQW GROWN ON VIRTUAL SUBSTRATE BY METALLORGANIC CHEMICAL VAPOR DEPOSITION. Adriana Passovic, Roberto Cingolani, National Nanotechnology Laboratory of INFM, Dept. Ing. Innovation, University of Lecce, Lecce, ITALY; Massimo Muzzi, Mauro Lomonaco, Stefano Tundo, IEM CNR, Lecce, ITALY; Laura Lanuznari, Giorgoro Salvini, CNR IMEPE Spec, Parmi, ITALY; Keith Farnham, Imperial College, Dept of Exp. Solid State Physics, London, UNITED KINGDOM.

Strained heterostructures are currently used for a large variety of micro-electronic devices, including high efficiency photovoltaic cells. InGaAs/GaAs strain balanced MQWs have recently been the subject
of extensive studies, both for solar and thermophotovoltaic applications, due to the possibility to extend the cell absorption edge to lower energies respect to the lattice mismatch limitation. In this work we will describe a novel system for photovoltaic applications which combines InGaAs based strain-balanced MQW with a "virtual substrate", designed to extend the absorption edge of the photovoltaic devices to about 1 eV. The virtual substrate is designed by properly choosing a sequence of InGaAs layers having different In content, in order to obtain the desired lattice parameter at the topmost layer and to confine at the most deep interfaces the misfit dislocations, well away from the QW active region. On the basis of this design, we have grown, by metalorganic chemical vapor deposition, a series of InGaAs p-i-n junctions deposited on different virtual substrates and containing a strain balanced MQW in the intrinsic region. In all the samples the virtual substrates were proved to be successful to grow zero net strain MQW and to confine defects at the buffer/substrate interface. Transmission electron microscopy observation shown that, apart from the surface undulations caused by the non homogeneous strain field induced by the confined dislocations, no defects propagate from the strain accommodating layers to the active region. The total density of threading dislocations reaching the surface was found to be less than 10³⁵/cm². The misfit dislocation network, however, results in marked cross-hatched morphology that was found to affect the lateral strain distribution in the whole structure. The lateral thickness modulation of the MQW results from step-bunching at the cross-hatched valleys.