SYMPOSIUM K

Materials and Devices for Optoelectronics and Photonics

April 2 – 5, 2002

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* Invited paper

SESSION K1: NITRIDES—EPITAXY AND SUBSTRATES

Chairs: Zuzanna Liliental-Weber and Remis Gaska
Tuesday Afternoon, April 2, 2002
Nob Hill C/D (Marriott)

1:30 PM *K1.1
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 III-nitride, will dramatically recast several opto-electronics and electronics technologies in the areas of short wavelength emission and detection or high-power, high-frequency microwave devices. However, the nitride semiconductor device industry has not been able to fulfill the expectations of a new generation of cost-effective opto-electronic 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 those problems there are many efforts worldwide to grow bulk crystals of gallium nitride (GaN) and aluminum nitride (AlN). While 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 more 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-recondensation 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 10^4 cm^{-2} and with a thermal conductivity exceeding 3 W/cm-K, 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.

2:00 PM K1.2
MICRO-PHOTOLUMINESCENCE OF V-SHAPE INVERTED PYRAMID IN HVPE GROWN GaN FILM. Chao-Kuei Lee, Yi-Bean Chen, Shu-Chen Chang, S.C. Wang, and Ci-Ling Pan, National Chiao-Tung University, Institute of Electro-Optical Engineering, Hsinchu, TAIWAN, R.O.C.

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 microscopic imaging and micro photoluminescence (micro-PL) system. The GaN sample was grown on the sapphire substrate. The inverted pyramid defect created in the GaN surface has hexagonal facets with opening 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 from 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 379.1 nm. The emission peak of spectrum gradually blue-shifted as the position moving toward the outside of the hexagonal structure where the peak emission wavelength shifted to around 373.5 nm. Since the pyramid defect is believed to be created as result of the stress release of the threading dislocation defect, the spatial blue shift in the emission spectrum outside the defect center seems reasonable. We also observed an additional peak at 386.7 nm near the center which could be originated from the threading dislocation itself because the peak was not observed in other positions. This result further suggests the possible origin of the formation of inverted pyramid defect.

2:15 PM K1.3
GROWTH OF GaN ON POROUS SiC SUBSTRATES BY MBE. C.K. Inoki, T.S. Kuan, Univ at Albany, SUNY, Dept of Physics, Albany, NY; C.D. Lee, A. Sagar, R.M. Feenstra, Carnegie Mellon Univ, Dept of Physics, Pittsburgh, PA.

We have explored the growth of GaN on porous SiC substrates by plasma-assisted molecular beam epitaxy. The growth process on porous surfaces may resemble that of lateral epitaxy overgrowth (LEO) on a nano-scale. We have grown GaN on porous SiC using standard growth parameters optimized for non-porous substrates. The porous 4H-SiC or 6H-SiC produced by anodic etching contains elongated and tilted pores and a thin (<20 nm) skin layer at the surface. This layer was partially removed prior to the growth by H-etching, exposing more pores on the surface. Cross-sectional electron microscopy observations indicate that the growth initiates from the surface areas between pores, and the exposed pores tend to generate defects and trap Ga droplets. Nevertheless, the GaN layers grown on porous substrates still contain slightly fewer dislocations than layers grown on non-porous substrates, as observed by plan-view TEM. The dislocation reduction may be achieved by the increased GaN surface roughness during the early stage of growth on the porous surface. Dislocations are observed to bend toward recessed dimples at the top surface and annihilate each other. Another advantage of a porous template is its ability to relax more mechanical stress induced by the lattice and thermal mismatch between the overgrown film and substrate materials. Electron diffraction indicates fully relaxed GaN layers on porous substrates as compared to about 85% relaxation on non-porous substrates. Our finite element analysis also suggests that pores in SiC are effective in relieving thermal mismatch stress arising during cooling from growth to room temperature.

2:30 PM K1.4
PHOTOLUMINESCENCE OF GaN GROWN BY MOLECULAR BEAM EPITAXY ON FREESTANDING GaN TEMPLATE. M.A. Reshchikov, D. Huang, F. Yun, L. He, H. Morkoç, Dept of Electrical Engineering and Physics, Virginia Commonwealth Univ, Richmond, VA; D.C. Reynolds, Wright State Univ, Dayton, OH; S.S. Park, K.Y. Lee, Samsung Advanced Institute of Technology, Suwon, KOREA.

We studied photoluminescence (PL) of GaN layer grown by molecular beam epitaxy on a freestanding and high quality GaN template. The layer was grown under Ga rich conditions using RF plasma source for nitrogen to a thickness of about 1 micron. The PL spectra from both the epilayer and the substrate contain a plethora of very sharp peaks related to excitonic transitions. We identified the main peaks in the PL spectrum. Taking advantage of the observation of donor bound exciton peaks and their associated two-electron satellites, we have determined the binding energies of two distinct shallow donors very accurately (28.8 and 32.6 meV), which are attributed to Si and O, respectively. The PL spectra involved also weak emissions due to shallow donor-shallow acceptor transitions with the main peak at 3.26 eV and a broadband peaking at about 2.5 eV (green band). We relate the green emission to a point defect involving a gallium vacancy.

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. Huang, M.A. Reshchikov, F. Yun, T. King, and H. Morkoç, 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 result in high defect densities in the epilayers. The typical dislocation density in a 1 μm GaN film grown on AlN buffer or directly on sapphire substrate is on the order of 10^9 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 delineation 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 $\sim 10^{10}$ cm^{-2} in typical GaN films grown on AlN buffer layer, a density of $\sim 3x10^7$ cm^{-2} was demonstrated in the GaN films grown with quantum dot layers. Transmission electron microscopy observations showed disruption of the threading dislocations by the QD layers. Experimental details will be presented and the possible microscopic mechanisms of the dislocation reduction by the application of the QD layers will be discussed.

3:30 PM K1.6
REMOTE UV SENSOR BASED ON GALLIUM NITRIDE SURFACE ACOUSTIC WAVE OSCILLATOR. Remis Gaska, Sensor Electronic Technology Inc, Latham, NY; Daumantas Ciplys, Michael Shur, Serguey Rumyantsev, Rensselaer Polytechnic Institute, Dept of ECSE and CIE, Troy, NY; Romualdas Rimeika, Albertas Sereika, Vilnius University, Dept of Radiophysics, Vilnius, LITHUANIA; Jingwei Yang, Asif Khan, University of South Carolina, Dept of EE, Columbia, SC.

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-sapphire SAW delay line connected to a feedback loop of a broadband 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 respons showed large visible/UV rejection ratio, which make these devices promising for the development of visible-blind remote sensor. However, the observed optical quenching of the photoconductivity is harmful for visible-blind operation and must be eliminated. We observed and studied the differences in the device response to UV illumination (around 365 nm) by artificial (Xenon lamp) and natural (the Sun) source. The rf spectral line 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 QUATERNARY AlInGaN EPILAYERS AND MULTIPLE QUANTUM WELLS. Mee-Yi Ryu, C.Q. Chen, E. Kuokstis, J.W. Yang, G. Simin, M. Asif Khan, Univ of South Carolina, Dept of Electrical Engineering, Columbia, SC; G.G. Sim, P.W. Yu, Kwangju Institute of Science and Technology, Dept of Information and Communications, Kwangju, KOREA.

Solid-state-white-light emitters require efficient pumping sources in the ultraviolet (UV) region of 250-350 nm. Nitride-based alloys such as $Al_xGa_{1-x}N$ and relatively new quaternary $Al_xIn_yGa_{1-x-y}N$ are among the most prospective candidates for the active parts of these UV devices due to their appropriate wide direct band gap. However, the radiative recombination properties and mechanisms (especially, in quaternary alloys) are not yet systematically analyzed. We present the results on investigation and analysis of photoluminescence (PL) dynamics of quaternary AlInGaN epilayers and AlInGaN/AlInGaN multiple quantum wells (MQWs) grown by a novel pulsed metal-organic chemical vapor deposition (MOCVD). The samples were excited by an excimer laser (λ=193 nm, τ=8 ns) for quasistationary strong pumping or picosecond laser ((λ=270 nm, τ=3 ps) for time-resolved PL measurements. The CCD 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 quaternary compounds demonstrated strong UV emission. The PL spectra and PL kinetics analysis in epilayers of different composition and MQWs under different excitation conditions and temperatures showed that localized states due to alloy fluctuations and/or interface roughness (in MQWs) play a significant role in radiative recombination. In both AlInGaN epilayers and MQWs a clear excitation-induced blueshift was observed. It is attributed to the filling of band-tail states and/or screening of built-in electric fields. We have demonstrated that a pulsed MOCVD can be used for growing of the high quality quaternary materials for UV emitters with strong spontaneous emission.

4:00 PM K1.8
METALORGANIC CHEMICAL VAPOR DEPOSITION OF QUARTERARY AlInGaN MULTIPLE QUANTUM WELL STRUCTURES FOR DEEP ULTRAVIOLET EMITTERS.
J.W. Yang, C.Q. Chen, J.P. Zhang, Q. Fareed, H.M. Wang, M.Y. Ryu, E. Kuokstis, G. Simin, M. Asif Khan, Department of Electrical Engineering, University of South Carolina, Columbia, SC.

III-V 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 bandgap. Nitride based deep UV emitters with the wavelength below 340 nm require the use of high Al content AlGaN or quaternary AlInGaN layers in the active region of device. The use of AlGaN, however, has been shown to lead to a severe degradation of the device properties. We are therefore exploring quaternary AlInGaN layers for the active layer of multiple quantum wells (MQW) in UV LEDs. We used two different metalorganic chemical vapor deposition (MOCVD) techniques: a pulsed atomic layer epitaxy (PALE) process and a pulsed MOCVD (PMOCVD) method to grow high quality MQWs for UV light emitters. The excitation-dependent photoluminescence (PL) spectroscopy 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 LDs application because it leads to the highest values of optical gain. The AlInGaN layers grown by a pulsed MOCVD process exhibit higher band tail states and show very strong room temperature (PL) due to the recombination of carriers (presumably excitons) localized at these tail states. Therefore samples grown by the pulsed MOCVD would be ideal candidate for the UV LED application. Finally, the deep UV LEDs with the emission wavelength of 305 - 340 nm based on quaternary MQWs grown by both growth processes have been demonstrated.

SESSION K2: SOLID-STATE LIGHTING
Chair: Leo J. Schowalter
Wednesday Morning, April 3, 2002
Nob Hill C/D (Marriott)

8:30 AM *K2.1
MATERIALS FOR SOLID STATE LIGHTING. S.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 current light sources. However, both technologies must overcome major technical barriers, requiring significant advances in material science, before this goal can be achieved. Attention will be given to each technology associated with the following major areas of material research: 1) material synthesis, 2) process 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 one 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 efficiencies 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 product.

9:00 AM K2.2
NEW CHARGE-CARRIER BLOCKING MATERIALS FOR HIGH EFFICIENCY OLEDS. Vadim I. Adamovich, Steven R. Cordero, Mark E. Thompson, University of Southern California, Department of Chemistry, Los Angeles, CA; Brian W. D'Andrade, Stephen R. Forrest, Center for Photonics and Optoelectronic Materials (POEM), Department of Electrical Engineering and the Princeton Materials Institute, Princeton University, Princeton, NJ.

High efficiency phosphorescent organic light emitting devices (OLEDs) require carrier-blocking 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-transporter or from the hole-transporter materials. The present work describes a novel approach for hole-blocking material design as well as introduces some new electron-blocking materials. We use cyclometalated complexes as hole-blocking materials. Complexes of this type are more stable toward both oxidation and reduction, have high Tg values and make excellent glassy films. Moreover, the HOMO and LUMO levels of the metal complexes can be easily tuned with suitable metal and ligand combinations. We have prepared OLEDs using bis(2-(4,6-difluoro-phenyl) pyridyl-N,C2$'$)iridium(III) picolinate (FIrPic) 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 a 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 (FIrPic) and green (tris-iridium phenylpirydine, Irppy) emitters in a 4,4$'$-N,N$'$-dicarbazole biphenyl (CBP) host. Ooctaphenyl cyclooctatetraene (OPCOT) and various sexiphenyl compounds were used as hole-blocking matrices. FIrPic was used both as a blue phosphorescent emitter (in CBP) and as an electron conducting dopant in OPCOT and sexiphenyl. The device with a neat FIrPic HBL performed better than BCP control device (max. quantum efficiency 4.1% vs 2.7%); the device with OPCOT:FIrPic HBL is comparable; and the devices with sexiphenyl:FIrPic HBL is more efficient than a standard BCP HBL OLED. OLEDs with electron-blockers will also be presented. The effect of an EBL on the device efficiency and EL spectrum will be demonstrated

9:15 AM K2.3
INFLUENCE OF DEFECTS ON CURRENT TRANSPORT IN GaN/InGaN MULTIPLE QUANTUM WELL LIGHT EMITTING DIODES. X.A. Cao, E.B. Stokes, S.F. LoBoeuf, P. Sandvik, J. Kretchmer, D. Walker, GE CRD, Niskayuna, NY.

We have compared the electrical characteristics and optical properties of GaN/InGaN multiple quantum wells (MQWs) 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 throughout all injection regimes in the devices with high-density defects which act as deep-level carrier traps. However, in a high quality LED diode, tunneling 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. $L \propto I^m$ in all devices. In the high quality LEDs, nonradiative recombination centers are saturated at current densities as low as 1.4×10^{-2} A/cm^2, 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. Yunovich, S.S. Mamakin, M.V. Lomonosov Moscow State University, Dept. of Physics, Moscow, RUSSIA; F.I. Manyakhin, A.B. Wattana, 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 estimated using the dynamic capacitance (C-V) method. The GaN barriers in the MQW were doped with Si donors. Acceptor and donor concentrations near the p-n-junction were approximately N > 1x10^{19} cm^{-3} $\gg$ ND > (3-10)x10^{17} cm^{-3}). Function N(z) on the n-type side of the junction have periodic maxima and minima corresponding to barrier doping and the presence of QWs. It is shown that 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 20-50 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 piezoelectric fields 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 Abst. P. 38, PM B6.1.

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

10:15 AM *K3.1
MICROSTRUCTURE OF GaN AND $In_xGa_{1-x}N$ FILMS GROWN BY MOCVD ON GaN TEMPLATES. J. Jasinski, Z. Liliental-Weber, Lawrence Berkeley National Laboratory, Berkeley, CA; D. Huang, M.A. Reshchikov, F. Yun, H. Morkoç, Virginia Commonwealth University, Richmond, VA; C. Sone, S.S. Park, K.Y. Lee, Samsung Advanced Institute of Technology, Suwon, KOREA.

$In_xGa_{1-x}N$/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 $In_xGa_{1-x}N$ 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 $In_xGa_{1-x}N$ films grown on very high quality and freestanding GaN templates which remove much of the complications resulting from severe lattice mismatch and complications associated with heteroepitaxy on sapphire, SiC and other substrates used. 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 1.0 μm GaN layer was first grown on the template followed by a ~30 nm $In_xGa_{1-x}N$ film by MOCVD. The In mole fraction x of the $In_xGa_{1-x}N$ layer was estimated to be 0.12 from XRD and PL spectra. The PL peaks at 3.018 and 3.474 eV with peak widths of 36 and 6.3 meV were identified at 15 K from the $In_xGa_{1-x}N$ and GaN layers. The convergent beam electron diffraction investigation showed the films to 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 (~10^6 cm^{-2}). The threading dislocations originate from the GaN template and some of them bend at the $In_xGa_{1-x}N$/GaN interface. In addition, some dislocation loops, mostly on the template side, were observed. The preliminary high-resolution electron microscopy studies suggest that the $In_xGa_{1-x}N$ film contains two well-defined layers. The first layer near the $In_xGa_{1-x}N$/GaN interface has a thickness of 10 nm and the second layer near the sample surface has a thickness of 24 nm. The lattice constant of the first layer in the c-direction is about 2% larger than that of the GaN layer. The lattice constant of the second $In_xGa_{1-x}N$ is even larger (about 3%). The results indicate that the two-layer structure is not due to the strain relaxation due to the increase in the $In_xGa_{1-x}N$ thickness, but is more likely related to the phase-separation [1,2] or the change in the growth mode [3] when the $In_xGa_{1-x}N$ film with a critical composition of x~0.12 was grown. [1] L. Gorgens, O. Ambacher, M. Stutzmann, and C. Miskys, F. Scholz, and J. Off, Appl. Phys. Lett. 76, 577 (2000). [2] Z. Liliental-Weber, M. Benamara and J. Washburn, J.Z. Domagala and J. Bak-Misiuk, E.L. Piner, J.C. Roberts and S.M. Bedair, J. Electr. Mater. 30, 439 (2001). [3] N. Grandjean and J. Massies, Appl. Phys. Lett. 72, 1078 (1998).

10:45 AM K3.2
BOWING PARAMETER OF $Al_xGa_{1-x}N$. L. He, F. Yun, M.A. Reshchikov, T. King, M. Zafar Iqbal, D. Huang, H. Morkoç, Virginia Commonwealth Univ, Richmond, VA; S. Novak, Evans East, East Windsor, NJ.

The quality of $Al_xGa_{1-x}N$/GaN heterostructures is key to the performance of light emitters, detectors, and modulation-doped field-effect transistors. $Al_xGa_{1-x}N$/GaN interface band offset, 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 a large dispersion in the literature 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 $Al_xGa_{1-x}N$ films were determined by photoluminescence and reflectance measurements. The set of $Al_xGa_{1-x}N$ samples 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 $Al_xGa_{1-x}N$ films was evidenced by the narrow linewidth of [002] peak of X-ray rocking curves. The data were analyzed to suggest the appropriate bowing parameter relating the bandgaps of the materials to the alloy composition of $Al_xGa_{1-x}N$ from one binary extreme to the other. The aforementioned results as well as the possible cause for 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 InGaN QUANTUM WELL STRUCTURES. Noad A. Shapiro, Henning Feick, Eicke R. Weber, Materials Science Division, Lawrence Berkeley National Laboratory and University of California at Berkeley, Berkeley, CA; Nathan F. Gardner, Werner K. Götz, LumiLeds Lighting, San Jose, CA.

InGaN based light emitting devices demonstrate excellent luminescence 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 (>1MV/cm), built-in electric field in these transitions is still under debate. We study the photoluminescence (PL) and time-resolved PL (TRPL) of metal-organic chemical vapour deposition (MOCVD)-grown InGaN quantum-well (QW) structures as a function of applied biaxial strain to determine the dependence of the radiative transition on the built-in electric field. We find that the luminescence either redshifts or blueshifts, depending on the sample. The shift in luminescence energy is well described by a single, newly introduced parameter L_r, 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 L_r

equal to the QW width, L_w, whereas negligible carrier separation corresponds to a redshift and L_r equal to 0. We also find that the carrier lifetime decreases with applied strain, indicating a significant reduction of the effective electron-hole (e-h) separation achieved by the strain-induced field-reduction in the well. We use this method to evaluate the effective e-h separation in several structures with varying thickness, indium QW 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 and a low non-radiative recombination rate. 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 K3.4
A CHEMICAL PERSPECTIVE OF GaN POLARITY: H-ATOMS PLASMA DRY ETCHING AGAINST NaOH WET ETCHING TO DETERMINE POLARITY. Maria Losurdo, MariaMichela Giangregorio, Pio Capezzuto, Giovanni Bruno, Plasma Chemistry Research Center-CNR, Bari, ITALY; Gon Namkoong, W. Alan Doolittle, April S. Brown, Georgia Institute of Technology, School of Electrical and Computer Engineering, Microelectronic 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 laser diodes. Moreover, GaNs good electron mobility and thermal conductivity are suitable for high power/temperature modulation doped FETs. Nevertheless, being non-centro-symmetric due to its wurtzitic structure, GaN films show the phenomenon of polarity, i.e., GaN could be Ga-polar ([0001] direction) or N-polar ([000-1] direction). Spontaneous polarization and piezoelectric polarization 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, stability, photoluminescence and electrical properties. In this contribution, we present a new highly selective process based on H-atom 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 (IDs). 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 H-atoms dry etching to the film polarity and IDs. GaN films with different polarity and IDs grown by MBE using a multistep (substrate nitridation-buffer growth-annealing-bulk growth) process have been analysed. Therefore, the film 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 CHARACTERISICS OF ISOELECTRIONIC Al-DOPED GaN FILMS GROWN BY METALORGANIC CHEMICAL VAPOR DEPOSTION.
Jae-Hoon Lee, Jong-Hyun Kim, Hyun-Min Ko, Ki-Yeol Park, Myoung-Bok Lee, Sung-Ho Hahm, Yong-Hyun Lee, and Jung-Hee Lee, The School of Electronic and Electrical Engineering, Kyungpook National University, KOREA; Sung-Bum Bae, Kyu-Suk Lee, Electronics and Telecommunications Research Institute, KOREA.

In regard to the film quality, it has been reported that with the adding 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 metalorgnic chemical vapor depostion (MOCVD). Al-doped GaN samples were grown at four different TMAl folw rates of 3, 6, 10, and 30 umol/min and then their material properties were compared with those of undoped GaN sample. With increasing the TMAl flow rate, the electron mobility was greatly increased from 130 to 510 cm^2/Vs, although unintentional background concentration was slightly increased in accordance with increasing TMAl flow. The effect of Al-isoelectronic doping on the optical properties of GaN was also investigated by room temperature photoluminescence (PL). As the TMAl flow rate was increased, 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 undoped and Al-doped GaN films did not showed any significant difference, although TMAl 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 improves optical and electrical 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 OHMIC CONTACT USING Ni/Pd/Au METALLIZATION. Chen-Fu Chu, C.C. Yu, H.C. Cheng, F.I. Lai, C.F. Lin, S.C. Wang, 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/Pd/Au. The Mg-doped 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 after the MOCVD growth. 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 $10^{17}cm^{-3}$. These two sets of p-GaN samples were deposited with the same Ni/Pd/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 1.1×10^{-4} $\Omega\cdot cm^2$. While the second set of samples has a much higher resistance value of about 3.3×10^{-1} $\Omega\cdot cm^2$. 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 samples, A clear evidence of the outdiffusion and interdiffusion of Ga, Pd, and Au in the metal layers and GaN layer boundary was observed suggesting the possible formation of Ga-Pd-Au reaction products between the metal layers and GaN. For the second set samples, there was no evidence of the outdiffusion and interdiffusion of Pd, and Au into the GaN layer. In addition, the content of oxygen in the second set samples was less than in that of the first set sample. These results suggest that the formation of eutectics or intermetallic compounds such as Ni-Pd-Au or Ni-Pd are beneficial to the formation of p-type ohmic contact. And the external annealing of the p-GaN is a preferable process for achieving the low ohmic contact resistance.

SESSION K4: NITRIDING TRADITIONAL III-V SEMICONDUCTORS

Chairs: Hadis Morkoc and James Harris
Wednesday Afternoon, April 3, 2002
Nob Hill C/D (Marriott)

1:30 PM *K4.1
GaInNAs, A NEW MATERIAL IN THE QUEST FOR COMMUNICATIONS LASERS. James S. Harris Jr., Solid States and Photonics Laboratory, Stanford University, Stanford, CA.

One of the major limitations for rapid expansion of optical metro area networks (MANs) is the availability of low cost, directly modulated 1.3-1.55μm single mode lasers for transmitters. A second is expanding the accessible fiber bandwidth, which will require high power pump lasers for Raman amplifiers. These are two rather dramatically different requirements that InGaAsP, the existing long wavelength technology has been unable to adequately address. The limitations are fundamental, not technological. There has been a major push to find suitable solutions to these problems and at least six approaches have been pursued over the past five years. Recent research has shown that GaInNAs lattice matched to GaAs has both a suitable bandgap energy and prospective characteristics, including low threshold current density, high temperature CW operation and high T_o in the wavelength range of 1.1μm to 1.3μm. These results suggest that GaInNAs will be the winning technology in this derby. I will review some of the requirements which must be met for the above applications, the successes to date and the challenges which remain to make this a viable technology for next generation high speed optical networks.
The first and most obvious challenge is high-speed access from the desktop to the fiber backbone. This will require low cost, single mode, 1.3 or 1.55μm lasers which can be directly modulated at >10 Gbps and operate over a significant temperature range (-10 to 85°C) with moderate power (>10mW). While 1.3μm GaInNAs VCSELs have been demonstrated, there are still challenges in realizing the desired threshold currents, differential efficiency, power and operating temperature range. Control of the blue shift with annealing and use of GaNAs barriers in the quantum well structure is still being investigated. Also, because of the higher free carrier absorption, p-mirror design is particularly critical and C-doping is essential. Finally, inter-cavity vs. through the mirror electrical contacts and their roll for high-speed devices are still an issue. The successes to date and possible solutions to the above issues will be addressed.
The second challenge is to open up the entire 1.3-1.6μm low loss wavelength region of fibers using Raman amplifiers. To design a

Raman amplifier for the 1.3-1.55μm range, a suitable high power pump source with a broad selection of emission wavelengths is required. One of the major challenges is achieving longer 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 RF plasma source. With GaNAs barriers, we are able to grow samples with nine GaInNAs QWs (63nm QW thickness), which is well above the critical thickness. By adding small amount of Sb, we were able to incorporate up to 46% indium with total active layer thickness of 21nm and avoid 3-D nucleation. Progress 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. I.A. Buyanova, G.Yu. Rudko, W.M. Chen, Linkoping Univ, Linkoping, SWEDEN; H.P. Xin and C.W. Tu, 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 huge bowing in band-gap energy. It is also expected to cause a N-induced 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 photoluminescence (PL) and absorption measurements, that will shed light on the origin of the light emission in GaNP. Both thick GaNP epilayers (with a thickness of 0.25 to 0.75 μm) and 7-period GaNP/GaP (70Å/200Å) multiple quantum well (MQW) structures were studied, with N composition 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 composition these states are shown to become resonant with conduction band 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 non-radiative presumably due to the presence of a large number of competing recombination channels.

2:15 PM K4.3
COMPARISON OF STRAIN RELAXATION IN THIN FILMS OF InGaAs AND THE DILUTE NITRIDE InGaAsN. M. Adamcyk, J.H. Schmid, T. Tiedje[a] Department of Physics and Astronomy, University of British Columbia, [a]also Department of Electrical and Computer Engineering, Vancouver, CANADA; A. Koveshnikov, A. Chahboun, V. Fink, K.L. Kavanagh Department of Physics, Simon Fraser University, Burnaby, CANADA.

The dilute nitride-arsenide compound semiconductors GaN_xAs_{1-x} and $In_yGa_{1-y}N_xAs_{1-x}$ 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 coolerless GaAs-based lasers emitting at 1.3 μm. In this paper, we compare the strain relaxation of $In_{0.08}Ga_{0.92}As$ and $In_{0.12}Ga_{0.88}As_{0.99}N_{0.01}$ epitaxial thin films grown by elemental source MBE. The films studied in this work were designed to have the same compressive misfit strain, namely 0.618 $\pm$ 0.017%, and the same final thickness of 600 nm. The strain state was determined in real time by in situ substrate curvature measurements, and by ex situ symmetric and asymmetric x-ray diffraction rocking curves and plan view transmission electron microscopy. For substrate temperatures of 400 and 450°C, we find an identical critical thickness, 250 nm, for both the nitride and the non-nitride films. However, we observe a slower rate of strain relaxation and a higher residual strain in the InGaAsN (54% relaxed) compared to the InGaAs (66% relaxed). We attribute the slower rate of strain relaxation to the presence of nitrogen interstitials in the InGaAsN epilayers and/or to the higher nitrogen bond strengths. Both these factors will slow down dislocation glide processes thereby impeding the dislocation formation. For a particular composition, we detected no effect of the substrate temperature from 400 to 450°C on the amount of relaxation present in the films. Similar comparisons carried out on dilute nitride material having higher compressive strain, will also be presented.

2:30 PM K4.4
ION-CUT-SYNTHESIS OF NARROW GAP NITRIDE ALLOYS. X. Weng, S. Clarke, W. Ye, and R.S. Goldman, Dept. of Materials Science and Engineering; V. Rotberg, Dept. of Nuclear Engineering and Radiological Sciences; J. Holt, J. Sipowska, and A. Francis, Dept. of Chemistry; A. Daniel and R. Clarke, Dept. of Physics, University of Michigan, Ann Arbor, MI.

Narrow gap nitride alloys, such as GaInNAs, are very promising candidates for a variety of applications including 1.3μm light emitters and high performance multi-junction solar cells. However, due to the large size difference between As and N, the miscibility of GaInNAs on the anion sublattice is limited. In principle, ion implantation allows for the introduction of atoms beyond their solubility limit. In addition, ion-cut, a layer splitting process using ion implantation followed by annealing, has been used recently for the integration of dissimilar materials. We are exploring a novel method, *ion-cut-synthesis*, in which the synthesis and cleavage of the GaInNAs layers occur simultaneously. Using a variety of implantation and rapid thermal annealing conditions, we have implanted N ions into both GaAs and InAs. High-resolution transmission electron microscopy (TEM) indicates the formation of crystalline GaN-rich nanostructures surrounded by disordered matrices. These nanostructures show significant photoluminescence in the near-infrared range, which may be due to the incorporation of a small amount of As in GaN, or due to strain-induced band gap narrowing of a GaN-rich cluster [1]. We find that both the size and volume fraction of the nanostructures increase with annealing temperature. Furthermore, a layer containing a high density of nanostructures may be cleaved from the substrate by 850°C annealing, providing a new opportunity for the integration of these nanostructures with a variety of substrates. Cross-sectional TEM reveals a series of cavities between the cleaved layer and substrate, suggesting that nitrogen bubbles at the interface provide the cleavage force. We will discuss the mechanisms of nanostructure coarsening and layer cleavage, as well as correlations between their optical and structural properties. [1] R.S. Goldman et al., Appl. Phys. Lett. 69, 3698 (1996), J. Electr. Mater. 26, 1342 (1997).

3:15 PM K4.5
HIGH INTENSITY 1.3-1.6μ LUMINESCENCE FROM MBE GROWN GaInNAsSb. Vincent Gambin, Wonill Ha, Mark Wistey, James Harris, Stanford University, Electrical Engineering, Stanford, CA; Seongsin Kim, Agilent Technologies, San Jose, CA.

GaInNAs grown on GaAs substrates has been found to optically emit at wavelengths longer than previously possible on GaAs and may be promising as an active region for use in 1.3 and 1.55μm optoelectronic devices. Adding small amounts of nitrogen to InGaAs pushes emission to even longer wavelengths and offsets the In lattice mismatch. Nitride-arsenide alloys were grown by elemental source MBE using a nitrogen RF plasma cell. High nitrogen content materials grown at low temperatures do not initially exhibit strong optical emission. The defects generated during the growth are a source for non-radiative recombination and diminish photoluminescence. By rapid thermal annealing the material after growth, defects are removed from the active region and the crystal quality of the GaInNAs films significantly improves. However during anneal nitrogen diffuses out from the quantum well and blue-shifts optical emission. Two techniques were investigated to expand the feasible emission wavelengths for this material system. GaNAs barriers between GaInNAs quantum wells reduce the blue shift due to nitrogen out-diffusion and can be designed to strain compensate highly compressive GaInNAs. Sb present during GaInNAs growth has been thought to act as a surfactant and improve photoluminescence. With the addition of Sb, we have observed a sharp intensity increase with high In samples past 1.3μm and found it not only acts as a surfactant but it is a significant alloy constituent further red-shifting the optical emission. Increasing In and N in materials with PL over 1.3μm normally drops optical intensity, however using Sb we can maintain high PL intensity out to 1.6μm. Since Sb in GaAs is compressively strained, there is further need for GaNAs strain compensating barriers for applications in multiple quantum well, high-intensity devices. Towards this goal, we have grown GaInNAsSb multiple quantum well devices on GaAs that exhibit high intensity optical emission across the 1.3-1.6μm wavelength range

3:30 PM K4.6
P- AND N-TYPE DOPING OF (GaIn)(NAs) BULK LAYERS GROWN BY MOVPE. Kerstin Volz, Joerg Koch, Wolfgang Stolz, Philipps University Marburg, Materials Science Center, Marburg, GERMANY.

(GaIn)(NAs) bulk films have been successfully grown under non equilibrium conditions by metal organic vapour phase epitaxy (MOVPE). Due to the large bandgap bowing in this metastable material system for low concentrations of nitrogen, it is possible to reach bandgap energies in the range of 1 eV already for low N contents. These films can be grown lattice matched to GaAs substrates. Hence, the novel quaternary material system could serve as 1 eV material in GaAs based multijunction solar cells. Theoretical calculations predict quantum efficiencies of up to 38% (AM0) for these devices. The metastable material system can be grown as bulk layers on GaAs at low temperatures by MOVPE with high structural quality as will be shown by X-ray diffraction and transmission electron microscopy. In the present study, various dopant precursors have been tested for their doping efficiency in the metastable material system. Additionally, the electronic properties have been correlated to the single dopants. Si (from ditertiarybutyl silane) and Te (from diethyl tellurium) are used as n-type dopants, while Zn (from diethyl zinc) and Mg (from dicyclopentadienyl magnesium) were used as p-dopants. Electric measurements to determine the carrier concentrations for the single dopants in dependence on the growth parameters have been performed and show comparable high carrier mobilities for both, n- and p-type dopnats. The achieved doping level can be as high as 1019 for n- and p-type dopants, respectively. Photoluminescence (PL) measurements show a strong dependence of the PL intensity on 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 K4.7
INVESTIGATION OF GREEN EMITTING MONOLITHIC II-VI VERTICAL CAVITY SURFACE EMITTING LASER. C. Kruse, G. Alexe, R. Kroeger, H. Heinke, D. Hommel, S. Ulrich, P. Michler, J. Gutowski, Institute of Solid State Physics, University of Bremen, GERMANY.

II-VI-based vertical cavity surface emitting laser (VCSEL) are expected to increase the lifetime of blue-green lasers 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 560 nm and can be used as the active material in electrically pumped edge-emitters operating at room temperature [1]. In order to achieve the goal of an electrically pumped VCSEL, monolithic microcavities with both ZnCdSSe 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 ZnSSe as the high refractive index material and strain compensated ZnSe/MgS superlattices (SLs) as the low index material. The use of short-period ZnSe/MgS SLs allows the growth of high quality MgS in zincblende crystal structure and is an approach to reduce the serial electrical 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 MgS 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. Klude, T. Passow, R. Kroeger and D. Hommel, Electr. Lett. 37, 1119 (2001).

4:00 PM K4.8
LATERAL COMPOSITION MODULATION IN $(InAs)_n/(AlAs)_m$ SHORT-PERIOD VERTICAL SUPERLATTICES STUDIED BY X-RAY DIFFRACTION. Jianhua Li, Simon Moss, Univ of Houston, Dept of Physics, Houston, TX; Vaclav Holy, Masaryk Univ, Dept of Solid State Physics, Brno, CZECH REPUBLIC; Yong Zhang, Angelo Mascarenhas, NREL, Golden, CO; David Follstaedt, SNL, Albuquerque, NM.

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 manuipulate this self-assembled lateral structure is to grow short-period vertical superlattice. The out-of-phase morphological undulations of the two strained ultra-thin component layers of the vertical superlattice lead to effectively an overall composition modulation in the lateral direction. Here, we present a quantitative structural study of such a laterally modulated structure formed in an $(InAs)_n/(AlAs)_m$ $(n, m < 2)$ short-period vertical superlattice by means of coplanar and grazing-incidence 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 the same wavelength as that of the composition modulation and an amplitude of less than 1.5 Å. The relation between the composition modulation and the interface undulation is discussed quantitatively.

SESSION K5: OPTICAL WAVEGUIDES
Chair: Keith Wayne Goossen
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, Navnit Agarwal, Shom Ponoth, 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 thickness of optical interconnect layers 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 back-end.

9:00 AM K5.2
CHALCOGENIDE MATERIALS FOR ACTIVE WAVEGUIDE DEVICES. Michele L. Ostraat, Michael L. Steigerwald, James J. Krajewski, Dave V. Lang, and Yiu-huen Wong, Agere Systems, Murray Hill, NJ.

The success of the phase change memory effect in chalcogenide ($Ge_2Sb_2Te_5$) 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 $Ge_2Sb_2Te_5$ is the material of choice in read-write CDs, this material does not appear to be best suited for other optical and electronic memory applications. For this reason, we are investigating pulsed electronic and optical switching and measuring optical properties on a wide variety of chalcogenide materials. 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 micro- and nanostructured 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 $Ge_2Sb_2Te_5$-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 Se-Te and S-Te variant of the $Ge_2Sb_2Te_5$ materials system ($Ge_2Sb_2(Te_{1-x}Se_x)_5$ and $Ge_2Sb_2(Te_{1-x}S_x)_5$). Some members of the $Ge_2Sb_2(Te_{1-x}Se_x)_5$ family of compositions exhibit the phase change memory effect. These results will be discussed as well as some interesting interactions between chalcogenide glass films 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 BaSO4:MN6+ USING LIQUID PHASE EPITAXY. D. Ehrentraut and M. Pollnau, Institute of Applied Optics, 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. Mn6+ ions exhibit broadband luminescence, however, Mn6+-doped crystals or waveguide structures could as yet not be grown in sufficient quality. The active material has to be free of inclusions or defects larger than $\lambda/10$, with λ, the 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 BaSO4:Mn6+ is limited by the decomposition of BaSO4 at 1590°C, its phase transition above 1010°C, and especially the chemical reduction of the manganese dopant from Mn6+ to Mn5+ above 620°C. Therefore, the growth of BaSO4:Mn6+ from a solution at lower temperatures is the most suitable method. Liquid phase growth is close to the thermodynamic equilibrium and has enabled us to grow high-quality layers. First, we prepared undoped BaSO4 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 BaSO4 was performed by liquid phase epitaxy (LPE), using the additive ternary CsCl-KCl-NaCl solution. We obtained crystalline layers free of inclusions, grown in the Frank-Van der Merwe mode (layer-by-layer growth). Finally, layers of BaSO4:Mn6+ were fabricated with thicknesses up to 150 μm, at growth rates of 3 m/h and temperatures of 500-580°C. The thickness was controllable with a precision of ± 0.1 μm. The Mn6+ concentration in the doped layer was up to 1 mol.%

with respect to S6+. In collaboration with the University of Hamburg, absorption and emission spectra were measured, which confirmed that the manganese ion was incorporated in the layer solely in its sextavalent oxidation state. Room-temperature broadband luminescence in the wavelength range 850-1600 nm was observed.

9:30 AM K5.4
HIGH INDEX CONTRAST AlO_x/GaAs GRATINGS BURIED IN GaAs/AlGaAs WAVEGUIDES. J.H. Schmid, M. Adamcyk, A. Ballestad, S. Tixier, M. Whitwick, T. Tiedje, Univ of British Columbia, Vancouver, CANADA.

We report the successful fabrication of high index contrast optical gratings made of AlO_x and GaAs buried in GaAs/AlGaAs waveguides. Due to the high index contrast of 3.4 for GaAs and 1.6 for AlO_x, 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 InGaNAs 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 Cl_2 pressure of 1×10^{-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 during the etch allow for 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 intermediate exposure to air thus avoiding oxidation of the AlAs that would make successful regrowth impossible. After regrowth the AlAs can be oxidized to AlO_x 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 InGaNAs quantum wells.

SESSION K6: OPTICAL INTERCONNECTS
Chair: Peter D. Persans
Thursday Morning, April 4, 2002
Nob Hill C/D (Marriott)

10:15 AM *K6.1
HETEROGENEOUS INTEGRATION OF PHOTONIC AND ELECTRONIC CHIPS. Keith Goossen, Aralight, 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 flip-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 consistant with good packaging techiques. 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 standard wavelength at which vcsel arrays have been robustly demonstrated, since both silicon and GaAs are opaque at that wavelength. These techniques will be discussed and data presented on the technique of flip-chip bonding followed by substrate removal, which facilitates 850 nm operation.

10:45 AM *K6.2
ROOM TEMPERATURE CW GaAs/AlGaAs QUANTUM WELL LASERS ON Si. Michael Groenert, Christopher Leitz, Arthur Pitera, Vicky Yang, Eugene Fitzgerald, MIT, Dept of Materials Science and Engineering, Cambridge, MA; Harry Lee, Rajeev Ram, MIT, Dept of Electrical Engineering, Cambridge, MA.

$Al_xGa_{(1-x)}As$/GaAs quantum well lasers have been demonstrated via organometallic chemical vapor deposition (OMCVD) on relaxed graded $Ge/Ge_xSi_{(1-x)}$ virtual substrates on Si. Relaxed graded $Ge/Ge_xSi_{(1-x)}$ buffer layers on Si offer a novel platform for direct monolithic integration of III-V optoelectronic devices with high-speed SiGe- and Si-based electronics. Despite un-optimized laser structures demonstrating high series resistance and large threshold current densities, measured surface threading dislocation densities as low as 2×10^6 cm^{-2} enabled cw room-temperature lasing at a wavelength of 858nm. The laser structures are oxide-stripe gain-guided devices with differential quantum efficiencies of 0.16 and threshold current densities of 1550 A/cm^2. Identical devices grown on commercial GaAs substrates showed differential quantum efficiencies of 0.14 and threshold current densities of 1700 A/cm^2. This comparative data agrees with our previous measurements of near-bulk minority carrier lifetimes in GaAs grown on Ge/GeSi/Si substrates. A number of GaAs/Ge/Si integration issues including thermal expansion mismatch, facet mirror cleaving on offcut Si substrates and Ge autododping behavior in GaAs have been overcome. Recent work to extend device lifetime and reduce threshold current via defect-resistant strained $In_xGa_{(1-x)}As$ quantum wells and improved contact geometries will be discussed.

11:15 AM K6.3
PERFORMANCE AND RELIABILITY OF A MEMS-BASED TUNABLE OPTICAL FILTER OPERATING IN THE 1565 NM-1525 NM WAVELENGTH RANGE. T.S. Sriram, Ben Strauss, Seth Pappas, Arvind Baliga, Themistoclis Parodos, Alain Jean, Douglas Dietz, Peidong Wang, Nortel Networks, CoreTek Division, Wilmington, MA.

This paper describes the results of extensive performance and reliability characterization of a silicon-based surface micro-machined tunable optical filter. The device comprises a high-finesse Fabry-Perot etalon with one flat and one curved dielectric mirror. The curved mirror is mounted on an electrostatically actuated silicon nitride membrane tethered to the substrate using silicon nitride posts. A voltage applied to the membrane allows the device to be tuned by adjusting the length of the cavity. The device is coupled optically to an input and an output single mode fiber inside a hermetic package. Extensive performance characterization (over operating temperature range) was performed on the packaged device. Parameters characterized included tuning characteristics, insertion loss, filter line-width, side mode suppression ratio and polarization dependent loss. Reliability testing was performed by subjecting the MEMS structure to a very large number of actuations at an elevated temperature both inside the package and on a test board. The MEMS structure was found to be extremely robust, running trillions of actuations without failures. Package level reliability testing conforming to Telcordia standards indicated that key device parameters including insertion loss, filter line-width and tuning characteristics did not change measurably over the duration of the test.

11:30 AM K6.4
LANTHANIDE(III)-DOPED NANOPARTICLES THAT EMIT IN THE NEAR INFRARED. Frank C.J.M. van Veggel, Gerald A. Hebbink, Jan W. Stouwdam, University of Twente, Lab. of Supramolecular Chemistry and Technology and MESA Research Institute, Enschede, THE NETHERLANDS.

Luminescent nanoparticles currently attract a great deal of interest as components in LEDs, displays, biological essays, optoelectronic devices with nanometer dimensions, and as light source in zero-threshold lasers. Our interest is in particular to use these materials in (polymer-based) lasers and optical amplifiers and integrate them with polymer-based components for telecommunication. In particular the optical window between 1300 and 1600 nm is important. Here we report the synthesis and optical properties of LaPO4, GdPO4, YPO4, LuPO4, and LaF3 doped with Er(3+), Nd(3+), Pr(3+) that emit in the near infrared. The synthesis followed a wet chemical approach, which led to redispersable nanoparticle with diameters in the range of 5-8 nm. The Er(3+)-doped material shows luminescence around 1550 nm with lifetimes up to 2.3 ms. The Nd(3+)-doped material shows the typical lines at 880, 1069, and 1330 nm, with lifetimes in 100-150 microsecond range. The Pr(3+)-doped material has various emissions in the visible region, but also an emission between 1400 and 1500 nm, with a lifetime of several microseconds. The combined emission of these three lanthanide ions cover the complete range of 1300 to 1600 nm, thus giving the potential of a compact broad-band polymer-based optical amplifier. The processability of these materials was proven by incorporating them in a thin PMMA layer on quartz and measuring the optical properties, which were not significantly altered.

11:45 AM K6.5
INTERFACIAL GAS DESORPTION AND DIFFUSION DURING THE LOW THERMAL STRESS FUSION OF III/V MATERIALS TO SILICON. Phil Mages, 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 credited with the excellent dark-current levels of very low dark-current $Si\text{-}In_{.53}Ga_{.47}As$ p-i-n photodetectors[1]. However, LTS processes face a different obstacle–the appearance of gas bubbles trapped between the thinned layer of material and the thicker substrate, here InGaAs(P) and Si respectively. This study investigated the temperature dependence of the appearance of gas at the interface, the out-diffusion of that 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. Afterward, 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 low 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 InGaAs(P)-on-Si material, without the use of trenches or liquid mediated bonding techniques. This material was used to fabricate Si-$In_{.53}Ga_{.47}As$ Avalanche Photodetectors with the bonding interface at the center of the device active region[2]. Fabrication methods and unexpected observations of gas desorption and bubble formation made during the study will be discussed.

[1] B.F. Levine et al., App. Physics Lett. 75 (14), 4 Oct 1999. [2] Y. Kang et al., LEOS IEEE Annual Meeting, La Jolla, CA, 15 Nov 2001.

TUTORIAL

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

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 optoeletronic devices (semiconductor lasers and optical detectors) and the various microfabricated optical components (waveguides, diffractive/refractive 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 ingenuity seen in the application of diverse semiconductor materials to achieve desired devices will be illustrated by the rich set of binary, ternary, and quaternary compound semiconductors used, along with their characteristics impacting communication systems design. The precise control of microfabrication will be illustrated by the MBE-grown quantum layers used for many years in high-performance semiconductor lasers and in more recent optoelectronic devices. Integrated structures including the basic optical device and refractive/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 mirror 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, Stevens Institute of Technology

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

K7.1
STRUCTURAL AND OPTICAL PROPERTIES OF STRAINED GALLIUM NITRIDE NANOWIRES. Hee Won Seo, Seung Yong Bae, Jeunghee Park, Department of Chemistry, Korea University, Jochiwon, KOREA; Hyunik Yang, College of Engineering Science, Hanyang University, Ansan, KOREA; Kwang Soo Park, Sangsig Kim, Department of Electrical Engineering, Korea University, Seoul, KOREA.

Gallium nitride nanowires are synthesized on silicon substrates by chemical vapor deposition using thermal reaction of gallium metal and gallium nitride powder mixture with ammonia at 1220-1370 K. Iron and iron oxide nanoparticles are used as a catalyst. The diameters of the nanowires are uniform as 25 nm and the length is in the range 20-40 micrometer. The nanowires exhibit highly crystalline wurtzite 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 shorter than that in gallium nitride 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 2.9-3.6 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 METALORGANIC CHEMICAL VAPOR PHASE DEPOSITION. H.F. Hong and J.I. Chyi, Institude 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) inthis work. The epitaxial layers were grown by OMVPE in the temperature range between 950°C and 1120°C. From the PL spectral responeses at room temperature, it was found that the epitaxial sample deposited at 1000°C had the hightest PL peak intensity. Based upon the low-temperature (9K to 15K) PL measurements, the conduction-band-edge-to-acceptor level (C-A) and donor-acceptor (D-A) pair emissions are the dominant luminescence mechanisms in the PL spectral responses. Therically, the C-A luminescence intensity could be enhanced if the measured temperature increased, since bound exiton near the donor level (ED) will be thermally-excited into the conduction band. However, we only observed that PL peaks were blue-shifted, while the C-A emission intensity remained nearly unchange. It was believed that this phenomenon was owing to the interplay between two Mg-realted trapping centers as the temperature increases. From X-ray diffracted data in this work, the epitaxial sample depiosited at 1120 hace the narrowest FWHM diffraction pattern, along with the hightest degree of lattice mismatch.The screw and edge dislocation density also reported.

K7.3
GROWTH CHARACTERISTICS OF GaN/Si(111) EPITAXIAL LAYERS GROWN USING $Al_{0.1}Ga_{0.9}N$/AlN CILs. Cheul-Ro Lee, Seong-Hwan Jang, Seung-Jae Lee, Jeong-Mo Yeon, Oh-Yeon Lee, Chonbuk National Univ, School of Advanced Materials Engineering, Chonju, SOUTH KOREA.

The characteristics of AlN nucleation layer which is one layer of $Al_{0.1}Ga_{0.9}N$/AlN CILs were investigated with the various growth time ranging from 15 to 30 minutes. The surface morphologies observed by AFM of the AlN layers which were grown on Si(111) showed that the size of islands and RMS values become larger and lower with the increase of the growth time until 25 min. However, the surface morphology of AlN/Si(111) layer grown during 30 min showed that the size and the RMS become smaller and higher compared with them of AlN/Si(111) layer grown during 25 min. The surface morphologies observed by SEM of the GaN epitaxial layers which were grown on $Al_{0.1}Ga_{0.9}N$(150 nm)/AlN CILs showed that the number of thermal etch pits and cracks on surfaces were abruptly decreased with the increase of the growth time until 25 min. However, the surface morphology of GaN/Si(111) epitaxy which was grown on $Al_{0.1}Ga_{0.9}N$(150 nm)/AlN(30 min) CIL showed that the number of them was increased again. And also, the GaN/Si(111) epitaxy which was grown on $Al_{0.1}Ga_{0.9}N$(150 nm)/AlN(25 min) CIL showed the highest quality having the FWHM of about 1157 arcsec of the DCXRD for the (0002) diffraction. Photoluminescence spectrum at room temperature for GaN/Si(111) epitaxy grown on $Al_{0.1}Ga_{0.9}N$(150 nm)/AlN(25 min) CIL showed a sharp band edge emission at 364 nm, which especially doesn't have yellow luminescence related to various defects. Meanwhile, the spectra at room temperature for others showed band edge emissions having yellow luminescence at about 580 nm. So, it can be concluded that the $Al_{0.1}Ga_{0.9}N$(150 nm)/AlN CILs having suitable thickness related to growth time of AlN play an important role for improving the crystallinities and optical properties of GaN/Si(111) heteroepitaxy without any defects such as pits and cracks over the surface by reducing the thermal coefficient and lattice mismatch between GaN and Si.

K7.4
THE ROLE OF THIN AlN BUFFER LAYER IN $Al_xGa_{1-x}N$/GaN HETEROSTRUCTURES HAVING HIGH X FROM 0.35 TO 0.5.
Cheul-Ro Lee, In-Seok Seo, Haeng-Keun Ahn, Jeong-Mo Yeon, Byong-Jun Baik, Chonbuk National Univ, School of Advanced Material Engineering, Chonju, 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 $Al_xGa_{1-x}N$ in $Al_xGa_{1-x}N$/GaN heterostructures having high x from 0.35 to 0.5. After growing the AlN buffer layer of 20 nm thickness on GaN/Sap.(0001) epitaxy, the $Al_xGa_{1-x}N$ layers of 1.0 μm thickness were grown at 1070°C with increasing the flow rate of TMA. The measured Al mole fraction of $Al_xGa_{1-x}N$ layers from each TCD rocking curve are 0.35, 0.37, 0.45 and 0.5, respectively. As the incorporation rate of Al in $Al_xGa_{1-x}N$ increases, the crystallinity becomes better. The surface morphologies observed by AFM of the $Al_xGa_{1-x}N$ layers which 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 $Al_xGa_{1-x}N$/GaN heterostructures grown without thin AlN buffer layers between $Al_xGa_{1-x}N$ and GaN become generally worse with the increase of x. The resisitivities of $Al_{0.35}Ga_{0.65}N$, $Al_{0.37}Ga_{0.63}N$, $Al_{0.45}Ga_{0.55}N$ and $Al_{0.5}Ga_{0.5}N$ measured by four point probe method are 13.5, 18.1, 31.7 and 36.2 MΩ·cm, respectively. The resisitivity increases with the raising of x in spite of the good crystallinity and the excellent surface morphology. It is obvious that the increases of resisitivity resulted from the rise of intrinsic $Al_xGa_{1-x}N$ 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 $Al_xGa_{1-x}N$ and GaN play an important role for improving the quality of $Al_xGa_{1-x}N$/GaN heterostructures grown with the increase of x by reducing the thermal coefficient and lattice mismatch between the both.

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. Si, Y.S. Jung, J.H. Na, T.W. Kang, Dongguk Univ, Quantum-functional Semiconductor Research Center, Seoul, KOREA; J.E. Oh, C.S. Kim, Hanyang Univ, 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 (PIMBE) in order to study the formation of two-dimensional electron gases(2DEGs) with a certain polarization. Carrier concentration profiles in the GaN/AlGaN/GaN heterostructures are evaluated by C-V profiling 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 Ga phase structure by reflection high energy electron diffraction (RHEED).

K7.6
LAYER-BY-LAYER GROWTH OF GaN FILMS ON SAPPHIRE BY LOW-TEMPERATURE CYCLIC PULSED LASER DEPOSITION / NITROGEN RF PLASMA.
P. Sanguino, M. Niehus, S. Koynov, L.V. Melo, R. Schwarz, Departamento de Física, Instituto Superior Técnico, Lisboa, PORTUGAL; H. Alves, B.K. Meyer, Justus-Liebeg-University, Giessen, GERMANY.

Recently we have proposed a new layer-by-layer method for deposition of group-III nitrides from elemental precursors (Ga, N2) [1]. This technique is based on a two-step cyclic process, which alternates Pulsed Laser Deposition (PLD), of a liquid gallium target 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-nitridated sapphire (0001) substrates at low deposition temperatures (300°C to 500°C) to minimise reevaporation. The cyclic GaN thin films thus obtained are compared with simple PLD GaN films in what respects to deposition rate, surface morphology, nitrogen incorporation and crystalline quality. Optical transmission spectra, x-ray diffraction and atomic force microscopy are the elected tools used to characterise and compare the deposited films. [1] S. Koynov, P. Sanguino, M. Niehus, L.V. Melo, R. Schwarz, 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 simple cleavage process developed and will be discussed the optimal condition including lapping process. We've found key parameter for the successful cleavage is scribing angle, and the rest is depending on good lapping process, proper mounting, lapping direction, pausing time, and finally careful de-mounting and also proper machine. We use suss ra-120 automatic scriber modified and refurbished by Lein Raum Technik Lans company in Germany. We also have ra-120M 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 Si_3N_4 during Process, SiO_2 and TiO_2 after making mirror to modify characteristic of the mirror. We found that the cleaved mirror is reliable and applicable for LD fabrication.

K7.8
DRY ETCHING OF GaN AND InGaN LASER STRUCTURE USING INDUCTIVELY COUPLED PLASMA.
Hung Wen Huang, C.C. Yu, J.Y. Tsai, T.H. Hsueh, C.F. Chu, C.F. Lin and S.C. Wang, Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan, REPUBLIC OF CHINA.

Drying 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 rates and surface roughness are studied as function of ICP power, rf chuck power, and chamber pressure. The highest etching rate of 10300 Å/min for n-GaN was achieved at 30mTorr, 300W ICP, 100W rf chuck power using Cl_2/Ar (= 10/25 sccm) gas mixtures. The surface roughness was dependent of rf chuck power and chamber pressure, and shows a low root-mean-square roughness value of about 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 Cl_2 ratio (Cl_2/Ar = 50/20 sccm) and low chamber pressure 5 mTorr, a smooth mirror-like facet of InGaN laser diode structure can was obtained.

K7.9
DEPENDENCE OF OPTICAL AND STRUCTURAL PROPERTIES ON THE NUMBER OF WELLS OF $In_xGa_{1-x}N/In_yGa_{1-y}N$ QUANTUM WELL STRUCTURES.
Hwan-Kuk Yuh, E. Yoon, Seoul National Univ, School of Materials Science and Engineering, Seoul, KOREA; Sang Kee Shee, Jack B. Lam, Chan Kyung Choi, Gordon H. Gainer, Gil Han Park, Seon Joo Hwang, Jin Joo Song, Oklahoma State Univ, 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 on the number of wells. High quality $In_xGa_{1-x}N/In_yGa_{1-y}N$ 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 anomalous peak shift is mainly due to potential fluctuations, rather than the piezoelectric field. 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 interruption, the deposition of strained layers, 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. Ramam, 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 properties are still unclear. In the present study, optical properties of the dry etched pattern of GaN are investigated using uv-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 defect evolution and 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. Chodelka, M. Overberg, M. Ollinger, V. Craciun, R. Abbaschian, 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 tendency of GaN to chemically dissociate at temperatures in excess of 800C, as much higher temperatures are needed to anneal extended defects out. In an effort to circumvent this, wafers with a 1 micron-thick, commercially-grown (MOCVD) film of GaN on sapphire were annealed in a novel high-pressure system (Isopress) at various temperatures (900C - 1300C). This was done under a pressure greater than 40 kbar to prevent the GaN films from thermally dissociating. These films were characterized by cathodoluminescence spectroscopy to investigate the effect of the anneals on the emission behavior of the films and assess any improvement in defect density or crystalline quality. Auger electron spectroscopy was performed to provide a measure of the nitrogen loss in the near-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 anneals on resistivity and carrier 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. This work represents the first time that results of annealing of direct bandgap materials in the Isopress have been reported. It shows some promise that high pressure anneals in the Isopress may be used to improve electrical and optical properties of GaN films.

K7.12
STRUCTURAL AND OPTICAL PROPERTIES OF InGaN/GaN MULTI-QUANTUM WELL STRUCTURES WITH DIFFERENT WELL WIDTHS. Young-Hoon Kim[a,c], Chang-Soo Kim[a], Sam-Kyu Noh[a], Jae-Young Leem[a], Kee-Young Lim[b], Byung-Sung O[c] and Jay P. Song[d]; [a]Materials Evaluation Center, Korea Research Institute of Standards and Science, Taejon, KOREA; [b]Semiconductor Physics Reasearch Center and Department of Semiconductor Science and Technology, Chonbuk National University, Chonju, KOREA; [c]Department of Physics, Chungnam National University, Taejon, KOREA; [d]SongJee Industrial Corporation, Sungnam, KOREA.

The structural and the optical properties of 10-period $In_{0.15}Ga_{0.85}N$/GaN multiple quantum wells(MQWs) have been investigated using HRXRD(high resolution X-ray diffraction) and PL(photoluminescence). For the samples the barrier width was kept constant, 7.5 nm and the well widths were varied, 1.5, 3.0, 4.5, 6.0 nm. For the structural characterization, $\omega/2\theta$-scans and ω-scans for GaN (0002) reflections, and reciprocal space mapping(RSM) around GaN($10\bar{1}5$) lattice points were employed. The average strain of the MQW increased as the well width increased. The MQW of a 6.0 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 epilayers underneath, and the critical well thickness for lattice relaxation of the MQWs used in the study was 6.0 nm. The PL spectra showed that the relative emission 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 intensity, therefore, is considered to be affected by the defects due 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/InGaN MQWs USING TPIS-MOCVD. Sunwoon Kim, Junho Seo, Kyuhan Lee, Hanvac Corp. Taejon, KOREA; Haeseok Lee, Kevin Park, Optronix, Taejon, KOREA; Chang-Soo Kim, KRISS, Taejon, KOREA.

InGaN device quality films and their related heterostures play a critical 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 NH_3/TMIn ratio. We investigated the optical and structural properties of InGaN bulk layers and GaN/InGaN MQWs using thermally precracked ion supplied metalorganic chemical vapor deposition (TPIS-MOCVD) system. The temperature range for this study was 660 - 760°C. In a low NH_3 flow rate condition, In metal droplet appeared on the surface of InGaN layer in conventional MOCVD system, but it dissappeared in TPIS-MOCVD system. An increasement of In mole fraction in InGaN could be achieved even in low NH_3 flow. As the NH_3 flow rate and the InGaN growth temperature decreased, In metal droplet was more effectively reduced by NH_3 precracker. The quality of InGaN/GaN MQWs was evaluated with photoluminescence, high resolution x-ray, and transmission electron microscope.

K7.14
OPTICAL CHARACTERICS OF InGaN/GaN MULTIPLE QUANTUM WELL STRUCTURES. Je Won Kim, Jong-Hak Won, Soo Young Park, Samsung Electro-Mechanics Co., Photonic Device Lab, Suwon, KOREA; Hoon Sang Choi, In-Hoon Choi, Korea Univ, Dept of Materials Science, Seoul, KOREA.

The optical properties of InGaN/GaN multiple quantum wells (MQWs) 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 at higher excitation power. This result is attributed to the localization of excitons at potential fluctuations due to the InGaN phase separation that forms indium-rich precipitates in InGaN layers. The defects in the InGaN layers were also investigated by using high-resolution transmission electron microscopy.

K7.15
TRANSMISSION ELECTRON MICROSCOPY STUDIES OF ELECTRICAL ACTIVE GaAs/GaN INTERFACES OBTAINED BY WAFER BONDING. J. Jasinski, Z. Liliental-Weber, 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 heterostructure 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 GaAs and GaN based optoelectronic devices. A GaAs/GaN interface combines also the high breakdown voltage of GaN with the high mobility of GaAs, which are ideal characteristics for transistors and other electronic devices. Very promising attempts, to apply direct wafer bonding, to create an electrically active GaAs/GaN interface have recently been reported [1,2]. 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 "cavities" present at the interface, was well-bonded and only a very thin layer (of thickness about 1-2 nm) of residual oxide, as confirmed by an x-ray study, was present at the interface. A dislocation network was observed at the interface in the well-bonded areas. The "cavities" at the interface were very asymmetric. They were almost entirely on the GaAs side and their in-plane shapes were elongated in the [110] GaAs direction. Their in-plane sizes ranged from tens of nanometers to tens of micrometers. [1] S.E. Monteith, L.S. McCarthy, S.K. Mathis-Yu, H. Marchand, U.K. Mishra, J.S. Speck, S.P. Den Baars, and E.L. Hu, "Wafer fusion of GaAs/GaN heterostructures", Proc. Elec. Mat. Conf. (2000). [2] S.E. Monteith, J. Jasinski, A. Huntington, A. Stonas, L. Coldren, S. Den Baars, Z. Liliental-Weber, U. Mishra, and E. Hu, "GaAs/GaN diodes wafer-fused at 500°C", Proc. Elec. Mat. Conf. (2001).

K7.16
HIGHLY-ORIENTED ZnO THIN FILMS GROWN ON Si SUBSTRATE BY THE METAL ORGANIC CHEMICAL VAPOR DEPOSITION METHOD. Hyoun-woo Kim, Kwangsik 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 characterization of ZnO 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 SiO_2/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 c-oriented at the growth temperature of 300-600° X-ray diffraction, AFM, SEM were utilized for materials characterizations. The photoluminescence spectra were obtained at room temperature and analyzed. (This work was supported by grant No. 2001-070-2 from the University Basic 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 Sang 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 GaInNAs. Vincenzo Lordi, Vincent Gambin, Wonill Ha, 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.

$Ga_xIn_{1-x}N_yAs_{1-y}$ (x∼0.75, y∼0.02-0.03) is a novel semiconductor material system for realizing quantum-well based optoelectronic devices on GaAs that operate at the telecommunications wavelengths of 1.3 to 1.55 μm. Evidence suggests that the site-specific incorporation of N into this material during molecular beam epitaxial (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 sharply 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–has proven 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 produce material with appropriate N content and 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 biaxially compressed GaInNAs quantum wells grown between GaAs barriers, on GaAs 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 *vs.* In from the QWs. To investigate the coordination of N on group V lattice sites before and after annealing, electron energy loss spectroscopy (EELS) was used. The near-edge fine structure (ELNES) of N-K edge EELS spectra 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 Evening, April 4, 2002
8:00 PM
Salon 1-7 (Marriott)

K8.1
CARBON NANOTUBE DEPOSITION USING HELICON PLASMA CVD AT LOW TEMPERATURE. Masamazu Muroyama, Takao Yagi, Kouji Inoue, Ichiro Saito, SONY Corporation, Atugi, Kanagawa, JAPAN.

Carbon nanotubes are considered to be a promising material for field emission displays. Preparation of highly purified carbon nanotubes in large quantity, well-aligned nanotubes, and low temperature synthesis 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 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 diameter of the carbon nanotube was in the range of 40-80nm. The length could be controlled with the deposition time. In the HRTEM observation, the graphite sheets were stacked along the Ni catalyst on the top of each nanotube. The results of Helicon and RF power dependence on the carbon nanotube growth 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. Chua, Center for Optoelectronics, National University of Singapore, SINGAPORE; Benzhong 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 the quantum dots on the phonon modes are also investigated.

K8.3
NONLINEAR OPTICAL PROPERTIES OF PLASMA ENHANCED CHEMICAL VAPOUR DEPOSITION GROWN SILICON NANOCRYSTALS. G. Vijaya Prakash, M. Cazzanelli, Z. Gaburro, L. Pavesi, INFM and Dipartimento di Fisica, Universita di Trento, Trento, ITALY; F. Iacona CNR-IMETEM, Catania, ITALY; G. Franzo and F. Priolo, INFM and Dipartimento di Fisica, Universita di Catania, Catania, ITALY.

We present a systematic study on the nonlinear optical properties of Silicon nanocrystals (Si-nc) grown by plasma enhanced chemical vapour deposition (PECVD). The sign and magnitude of both real and imaginary parts of third-order nonlinear susceptibility of Si-nc are measured by Z-scan method. While the closed aperture Z-scan reveals a sign of positive nonlinearity, the open aperture measurements suggests a nonlinear absorption coefficients. Absolute values of of third-order nonlinear susceptibility are in the order of 10-9 esu and show systematic correlation with the Si-nc 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 proposed.

K8.4
PHOTOLUMINESCENCE AND TIME-RESOLVED PHOTO-LUMINESCENCE STUDIES OF SELF-ASSEMBLED InAs QUANTUM DOTS. Xinhai Zhang, Jianrong Dong, Soo Jin Chua, 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 are studied. A reduction in the emission linewidth with increasing temperature is observed at low temperature range and an increase in the linewidth at higher temperature. It is also observed that the variation of PL peak energy with temperature does not follow Varshni'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 behaviors 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. H.T. Johnson, R. Bose, 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 strain 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 k-p Hamiltonian approach; the spectrum includes confined 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 elastic strain field superimposed by indenting 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 mismatch 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 calculation 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 (Marriott)

K9.1
DYNAMIC RESPONSE OF NON-PIXELED AMORPHOUS SILICON BASED IMAGE SENSORS. M. Fernandes, Yu. Vygranenko 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 photoresponse in each scanning position. This work is focused on the analysis of the dynamic behavior 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 focused 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 time of approximately 100 μs was measured under a 1 kΩ load. Capacitance-Voltage measurements where 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. Witanachchi, and P. Mukherjee, Laboratory for Advanced Materials Science and Technology (LAMSAT), Department of Physics, University of South Florida, Tampa, FL; S. Abeylath, M.G.M.U. Ismail, 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 collector material that can be used in CdTe and $CuInSe_2$ solar cells. Electrical properties of CdS films are very 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 CdCl and thiourea 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 CdCl, thiourea, ammonium hydroxide and ethanol was sprayed on to the substrate at 250°C using an ultrasonic nebulizer. The size of the seed crystals were controlled by the concentration of CdCl and thiourea 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, grain size, as well as optical and electrical properties will be discussed.

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

The electrical properties of heterojunctions of polycrystalline films of beta-irondisilicide 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 those devices were measured. The samples showed rectifying characteristics in current-voltage characteristics measurement. However, a large reverse leakage current and low breakdown voltage were observed. The result is consistent with that in the case of beta-irondisilicide/silicon 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-irondisilicide/silicon junction. The properties of the junctions will be discussed by comparison with beta-irondisilicide/ silicon heterojunctions.

K9.4
GROWTH OF InTlSb AS THE ADVANCED MATERIAL FOR LONG WAVELENGTH APPLICATION. D.B. Gadkari, Department of Physics, Mithibai College, Mumbai, INDIA; K.B. Lal and P. Shashidharan, Department of Physics, Unversity of Mumbai, Mumbia, INDIA; S.S. Chandvankar and B.M. Arora, Condensed Matter & Material Science, 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 crystal growth community. For long wavelengths and for focal plane arrays, the dominant material is HgCdTe. However, the growth of mono-crystalline HgCdTe is difficult due to the weakly bound II-VI compound and uniform band-gap. It is also very sensitive to the composition. An alternate material to the HgCdTe would be InTlSb, which will significantly benefit the IR application, low cost and optimal performance. Therefore, the III-V alloy InTlSb holds much promise as suitable alternate materials to HgCdTe. An indigenous system as vertical directional solidification (VDS) technique has been employed for the growth of the bulk semiconductor crystals. Bulk crystallites of III-V compound were grown without using seed by VDS method. XRD, EDAX, EMPA and FTIR-Transmission, Hall measurement and etching were used to characterize the wafers. Our experiment observation was found to closely agree with the prediction of the modeled InTlSb growth. We have discussed the principle problems in the growth of InTlSb and explained the methods to circumvent these problems. We have discussed the problem of crystalline quality, the generation of low angle grain boundary, twin boundary and high dislocation densities. The microscopic conducted phases were characterized with an electron microprobe. FTIR-Transmissions were obtained for the analysis of energy dependence near the band edge. Based on our calculation, we predict that the absorption 0.1 eV gap InTlSb will be nearly as good as that in 0.1 eV gap HgCdTe. This prediction, in addition to the other properties of InTlSb alloys, make them plausible candidate for infrared focal plane array application.

K9.5

7x6" MULTI WAFER PLANETARY REACTOR(R) AS USED FOR P-HEMT AND HBT APPLICATIONS. Jochen Hofeldt, Thomas Schmitt, Martin Dauelsberg, Michael Volk, Micheal Bremser, Michael Heuken, Holger Juergensen, Aixtron AG, GERMANY.

The AIXTRON Planetary Reactors® are proven to grow extremely uniform films together with a highly efficient utilization of the precursors. The novel reactor in 7x6" configuration is based on the proven AIXTRON Planetary Reactor®, which, in its 5x4" configuration, is already qualified for the production of InP-based HBTs for 40 GBit/s backbone data transmission amplifiers. We investigated the growth and doping of (Al)GaAs and GaInP which are prominent materials in GaAs-based HEMT and HBT. Tab. 1 shows adjusted doping levels in the 7x6" configuration established by Hall-effect measurements and homogeneities measured in a Lehighton sheet resistance mapper 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 homogeneities of doping concentration for selected material systems.

Material	doping level [cm^{-3}]	standard deviation
GaAs	$n = 8 \cdot 10^{17}$	1.24%
	$p = 3 \cdot 10^{19}$	1.1%
$Al_{0.3}GaAs$	$n = 1 \cdot 10^{17}$	1.26%
GaInP	$n = 1 \cdot 10^{18}$	3%

GaInP layers grown in this configuration exhibited a standard deviation of the Ga concentration of 0.75% resulting in a wavelength standard deviation of 2 nm. The thickness homogeneity on-wafer was 0.5%. $Al_{0.3}GaAs$ layers exhibited a standard deviation of 0.5% in the Al-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 pyrometric temperature measurement will be 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 7x6" configuration for the large scale production of p-HEMTs and HBTs.

K9.6

CATHODOLUMINESCENCE AND PHOTOLUMINESCENCE OF CRYSTALINE SILICON-EPILAYER GROWN ON Si^+-IMPLANTED $(1\bar{1}02)$ SAPPHIRE. C.J. Park, Y.H. Kwon, T.W. Kang, C.Y. Hong, H.Y. Cho, QSRC and Dept of Physics, Dongguk Univ, KOREA; S.-H. Choi, Dept of Physics, Kyung Hee Univ, KOREA; R.G. Elliman Dept. of Electronic Materials Engineering, Australian National University, AUSTRALIA.

Luminescences on Crystalline-Si epilayers grown on (1102) sapphire substrates by rapid thermal chemical vapor deposition have been investigated. Before the growth, the sapphire substrates recrystallized with implanted Si were used to improve the characterization of Si-epilayers. Sapphire substrates have been implanted with 30 keV Si^+ to a dose of $5\times10^{15}cm^{-2}$ and subsequently annealed in a conventional furnace at 1100°C for 1 hour. The growth temperature and the thickness are about 900°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-epilayers is investigated the Raman spectroscopy. Photoluminescence (PL) and cathodoluminescence (CL) have been used to study structural and optical properties of Si-epilayers grown on the Si^+-implanted (1102) sapphire substrates. For a comparision, we have prepared the annealed substrate without an implantation, and the implanted substrate before annealing, respectively. In Si^+ implanted samples, the PL and CL spectra have dominant peaks at about 570 nm and 574 nm, respectively. Especially, it is confirmed that these peaks might be resposible for nano-crystalline Si from the blue shifts dependent of the incident power and the measuring temperature. In addition, the crystalline quality of the epilayer on the implanted substrate will be evaluated.

K9.7

ARSENIDE-PHOSPHIDE INTERFACE FORMATION DURING MOVPE OF INDIUM GALLIUM ARSENIDE/INDIUM PHOSPHIDE. Connie Li, Daniel Law, Lian Li, Sven Visbeck, 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 obtained 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, provided 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 As:InP (001) surface exhibits the following reconstructions: (4x2), alpha2(2x4), beta2(2x4), (2x1) and disordered (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 nanocrystals. The implication of these results for the formation of InGaAs/InP heterojunctions will be described at the meeting.

K9.8

STRUCTURE-SENSITIVE OXIDATION OF THE INDIUM PHOSPHIDE (001) SURFACES. Gangyi Chen, Sven B. Visbeck, 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 (2×1) and $\delta(2\times4)$ reconstructions with phosphorus coverages of 1.0 and 0.125 ML, respectively. These structures were exposed to unexcited molecular oxygen, and the reaction 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 O_2. The oxygen dissociatively chemisorbs onto the $\delta(2\times4)$, inserting into the In-P back bonds and the In-In dimer bonds. By contrast, the P-rich (2×1) reconstruction does not absorb O_2 up to 5×10^5 L at 298 K. Above 453 K, the (2×1) becomes reactive with oxygen inserting into both the In-P back bonds and the phosphorus 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.

K9.9

OPTICAL PROPERTIES OF SnS_2, SnS_2:Cd, AND SnS_2:Sb SINGLE CRYSTALS. Choong-Il Lee, Suncheon Natl Univ, Dept of Physics, Suncheon, KOREA.

SnS_2, SnS_2:Cd, and SnS_2:Sb single crystals were grown by the chemical transport reaction method by using iodine as a transport agent. High purity(6N) constituent elements were used as starting materials. Transparent layered single crystals (a typical dimension of $12x10x0.2mm^3$) with golden yellow color were grown. The grown SnS_2, SnS_2:Cd, and SnS_2:Sb single crystals were metal-excessive. The single crystals were crystallized in a hexagonal structure with lattice constants a = 3.637Å and c = 5.882Å for SnS_2, a = 3.649Å and c = 5.892Å for SnS_2:Cd, and a = 3.675Å and c = 5.784Å for SnS_2:Sb. Direct and indirect energy band gaps at 6K were found to be 2.511eV and 2.348eV for SnS_2, 2.503eV and 2.343eV for SnS_2:Cd, and 2.505eV and 2.345eV for SnS_2:Sb. Temperature dependence of the direct and indirect energy band gap was well fitted by the Varshni equation,

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

Coefficients for the direct energy band gap were found to be $E_g(0)$ = 2.511eV, α = -1.86x10^{-3}eV/K, and β = -1087K for SnS_2, $E_g(0)$ = 2.499eV, α = -8.92x10^{-4}eV/K, and β = -128K for SnS_2:Cd, and $E_g(0)$ = 2.502eV, α = -6.92x10^{-4}eV/K, and β = -134K for SnS_2:Sb. Coefficients for the indirect energy band gap were found to be $E_g(0)$ = 2.342eV, α = -7.54x10^{-4}eV/K, and β = 88K for SnS_2, $E_g(0)$ =

2.338eV, α = -7.71x10^{-4}eV/K, and β = 79K for SnS_2:Cd, and $E_g(0)$ = 2.339eV, α = -6.82x10^{-4}eV/K, and β = -84K for SnS_2:Sb. Photoluminescence (PL) spectra of the single crystals were measured by using the 325nm-line of a He-Cd laser as an excitation source. Emission peaks were observed at 2.214eV and 1.794eV for SnS_2, 2.214eV and 1.838eV for SnS_2:Cd, and 2.214eV and 1.822eV for SnS_2:Sb. These emission peaks were analyzed to be originated from donor-acceptor pair recombination.
This work was supported by Korean Research Foundation Grant (KRF-2001-015-DP0162).

K9.10
FORMATION OF $TlBiS_2$ AND $TlSbS_2$ THIN FILMS BY HEATING Bi_2S_3-Tl_2S AND Sb_2S_3-Tl_2S THIN FILMS. Veronica Estrella, Jose Campos, M.T.S. Nair, P.K. Nair, Universidad Nacional Autónoma de México, Centro de Investigación en Energía, Temixco, Morelos, MEXICO.

$TlBiS_2$ and $TlSbS_2$ 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 Tl_2S deposited on Bi_2S_3 or Sb_2S_3 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 constituted by bismuth nitrate, triethanolamine and thioacetamide for Bi_2S_3; antimony trichloride and thiosulfate for Sb_2S_3; and thallium nitrate, sodium citrate, sodium hydroxide and thiourea for Tl_2S. X-ray diffraction studies confirmed the formation of the ternary compounds in the sequentially deposited multilayer thin film stacks of 0.2 to 0.5 mm thickness. Optical characteristics are analyzed from the transmittance and reflectance spectral data and the electrical characteristics from the dark current, photo current, and dielectric measurements. We present that it is also possible to form solid solutions of the type $Tl(Bi/Sb)S_2$ with tailored properties by heating Sb_2S_3-Bi_2S_3-Tl_2S layers.

K9.11
ULTRA-THIN III-V SUBSTRATES FOR ENHANCING THE PERFORMANCE OF OPTOELECTRONIC DEVICES.
K. Juliet Vogel, Partha S. Dutta, Department of Electrical, Computer and Systems Engineering, Rensselaer Polytechnic Institute, Troy, NY.

Enhancement in the performances of optoelectronic devices such as LEDs, photodetectors, and photovoltaic energy conversion cells, by utilizing bonded and thinned III-V compound semiconducting 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 ultra-thin substrates for various applications, while describing the key results on successful wafer thinning of III-V compounds. Critical issues such as surface roughness and sub-surface damage will be addressed. Atomic force microscopic analysis of wafer surfaces after various thinning processes will be compared. Novel device structures enabled by ultra-thin substrates will be presented.

K9.12
PREPARATION OF THE $CuAlSe_2$ - $CuAlTe_2$ SEMICONDUCTING ALLOYS. Barys V. Korzun, Elena A. Fadeeva, Oleg V. Ignatenko, Institute of Physics of Solids and Semiconductors, Minsk, BELARUS; Klaus Bente, Gerd Kommichau, Leipzig Univ, Institut fuer Mineralogie, Kristallographie und Materialwissenschaft, Leipzig, GERMANY.

The I-III-VI_2 (where I-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 chalcopyrite semiconductors are considered to be possible candidates for application in photovoltaics, optoelectronics and devices for transferring and processing of information. The $CuAlSe_2$ and $CuAlTe_2$ semiconductors belong to these compounds and have wide direct gap making them suitable for the use in optical filters and as window material for solar cells. The aims of this paper are (i) the preparation of alloys of the $CuAlSe_2$ $CuAlTe_2$ system and (ii) the construction of T-x phase diagram by differential thermal analysis and X-ray powder diffraction. To obtain the $CuAlSe_2$ and $CuAlTe_2$ ternary compounds and their alloys two methods were developed. One of them was the two zone vertical method using elements of 99,999% (copper) and 99,9999% purity (aluminium, selenium, tellurium). The charges were sealed in evacuated double quartz ampoules and then placed into electric furnace. The crucible from BN with the metallic components was kept in hot zone where the temperature was higher above 20-30K that the melting point of the corresponding alloys. The temperature of cold zone was increased gradually to react metallic components with selenium and tellurium. The second method was the sintering of alloys from the powders of previously obtained $CuAlSe_2$ and $CuAlTe_2$ compounds. The procedure was similar to the above-described one. The phase equilibriums in the $CuAlSe_2$ - $CuAlTe_2$ system were investigated by means of X-ray powder diffraction and differential thermal analysis. The carried investigations showed the formation of solid solutions in the complete range of compositions. All of alloys are single-phase and crystallize in the chalcopyrite structure. The lattice constants obey the Vegards law and change from (5,597±0,005) Å for a and (10,98±0,01) Å for c to (5,964±0,005) Å for a and (11,78±0,01) Å for c for $CuAlSe_2$ and $CuAlTe_2$, respectively. The thermograms have only one thermal effect corresponding to the melting. The melting point was 1363K for $CuAlSe_2$ and 1241K for $CuAlTe_2$.

K9.13
T-x PHASE DIAGRAM OF THE $CuAlS_2$ - Al_2S_3 QUASIBINARY SYSTEM. Barys V. Korzun, Ruslan R. Mianzelen, Institute of Physics of Solids and Semiconductors, Minsk, BELARUS; Klaus Bente, Gerd Kommichau, Leipzig Univ, Institut fuer Mineralogie, Kristallographie und Materialwissenschaft, Leipzig, GERMANY.

In recent years growing interest has been shown to complex semiconducting compounds I-III-VI_2 (where I-Cu, Ag; III-Al, Ga, In; VI-S, Se, Te). These chalcopyrite semiconductors are considered to be possible candidates for application in photovoltaics, optoelectronics and devices for transferring and processing of information. The $CuAlS_2$ 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. $CuAlS_2$ has been studied largely but there is not the information about its region of homogeneity in the literature. This compound is crystallized in the Cu_2S - Al_2S_3 quasibinary system that may be divided into equal parts (the Cu_2S - $CuAlS_2$ and $CuAlS_2$ - Al_2S_3 systems). The aims of this paper are (i) the preparation of alloys of the $CuAlS_2$ - Al_2S_3 system and (ii) the construction of T-x phase diagram by differential thermal analysis and X-ray diffraction. To obtain the $CuAlS_2$ and Al_2S_3 compounds and their alloys the method of melting of the constituent elements of 99,999% (copper) and 99,9999% purity (aluminium, sulfur) was used. The charges were sealed in evacuated double quartz ampoules and then placed into electric furnace. The crucible from BN with the elementary components was heated to the temperature higher above 20-30 K that the melting point of corresponding alloys. The phase equilibriums in the $CuAlS_2$ - Al_2S_3 system were investigated by means of X-ray diffraction and differential thermal analysis. It was discovered only the formation of $CuAl_5S_8$ compound in this system. $CuAl_5S_8$ has the peritectic character of melting with the temperature 1363K. The melting point was 1268K for Al_2S_3 and 1493 K for $CuAlS_2$. The T-x phase diagram of the $CuAlS_2$ - Al_2S_3 system has the eutectics at 0,88 molar part of Al_2S_3 and 1263K. The region of formation of solid solutions on Al_2S_3 side does not exceed 0,05 molar part of Al_2S_3 at the room temperature.

K9.14
CHARACTERIZATION OF ROOM-TEMPERATURE FERROMAGNETIC $Co_xZn_{1-x}O$. Shaoguang Yang, Silas T. Hung, A.B. Pakhomov, C.Y. Wong, Magnetic Innovation Center (MAGIC), Material Characterisation and Preparation Facility (MCPF), The Hong Kong University of Science and 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 Cobalt oxide and Zinc oxide were prepared by annealing at 1000°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 20 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 System. 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 $ZnCo_2O_4$ is present in small quantity. The films are transparent (having light green color) in a wide optical wavelength range, with adsorption edge at around 450 nm, and several local adsorption maximum corresponding to Co^{2+} ions. Measurements of magnetic hysteresis loops and magnetization as a function of temperature show ferromagnetic behavior at least up to 350 K (the maximum temperature used in the experiments). The value of spontaneous magnetization at 300 K is about 4.7 emu/cm^3. Optical transparency spectrum shift with external applied magnetic fields have also been observed at room temperature. A proposed model on our experimental observations will be discussed.
[1] K. Ueda, H. Taata and T. Kawai, Appl. Phys. Lett. 79, 988 (2001).

K9.15
MATERIALS ISSUES IN THE LAYERS REQUIRED FOR INTEGRATED MAGNETO-OPTICAL ISOLATORS.
Luis J. Cruz-Rivera, Sang-Yeob Sung, Jessie Cassada, Mariza R. Marrero-Cruz, and Bethanie J.H. Stadler, 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 elucidate a methodology to grow, by a semiconductor compatible process, the critical active material in monolithically integrated magneto-optical isolators; yttrium iron garnet (YIG: $Y_3Fe_5O_{12}$). Reactive 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. However, as processing pressure increased, the crystallization of the YIG films decreased. The Y:Fe ratio and oxygen content were identified as critical factors to prevent secondary phases from developing in the films. Low forward powers (lower limit of 12.3 W/cm^2) grew YIG nuclei in an amorphous matrix and the number of these nuclei increased with increasing forward power. At powers exceeding $19W/cm^2$ film cracking occurred. The films with YIG had strong in-plane magnetizations with small coercive fields. The chemical, structural, optical, and magneto-optical properties of the resulting films have been studied by various techniques including vibrating sample magnetometry (VSM), energy dispersive X-ray spectroscopy (EDX), X-ray diffraction (XRD), and Faraday rotation. Further optimization includes post deposition processing, such as low temperature anneals. 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 present 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 compatible 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.
Ram W. Sabnis, Mary J. Spencer, William L. DiMenna, 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 photoresist coated over these CVD films at deep ultraviolet (DUV) wavelength has been evaluated. The specific monomers synthesized for DUV applications include [2.2](1,4)-naphthalenophane, [2.2](9,10)-anthracenophane and their 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 microscope (SEM) photos of cross-sectioned patterned wafers showed verticle profiles with no footing, standing waves or undercut. Resist profiles down to 0.10 μm dense lines and 0.09 μm isolated lines were achieved in initial tests. CVD coatings generated 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:Mn PHOSPHOR POWDERS.
H.S. Hsu[a], In-Gann Chen[a], Chii-Shyang Hwang[a], F.S. Juang[b], S.J. Chang[c], and Y.K. Su[c]; [a]Department of Materials Science and Engineering, National Cheng Kung University, Tainan, TAIWAN, R.O.C; [b]Department of Electro-Optics Engineering, National Huwei Inst. of Tech, Huwei, Yunlin, TAIWAN, R.O.C.; [c]Department of Electrical Engineer, National Cheng Kung University, Tainan, TAIWAN, R.O.C.

Nano-scale ZnS:Mn phosphor powders were synthesized by solid state calcination, solvothermal, and microemusion methods respectively. The processing parameters such as particle size distribution, chemical composition, crystalline structure, 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:Mn phosphor powders has a higher intensity of luminescence than that of sub-micro sized sample. The effect of different Mn 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 reported. Supported by NSC-90-2215-E-006-030

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

For an SIN 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 photoreflectance (PR). In this work, we present a novel technique to obtain valence-band split from the Fourier spectrum of PR for GaAs and InAlAs. A linear combination of FKOs of HH and LH is adopted as a trial function. Besides two linear coefficients, the band gaps for HH and LH are also treated as adjusted parameters. We develop an efficient algorithm for fitting the trial function to the PR spectrum in Fourier space. The field induced splits thus found for PRs performed under various pump beam intensities are in good agreement with a theoretic calculation using three-band strained Hamiltonian.

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

A series of organic photovoltaic (PV) cells in which the electron acceptor and are gadolinium(dibenzoylmethanato)$_3$(batho-phenanthroline) [Gd(DBM)$_3$bath] and donor N,N′-diphenyl-N,N′bis(3-methylphenyl)-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(V_{oc}) of 3.2 V was obtained due to efficient exciton dissociation near the interface between Gd(DBM)$_3$bath and TPD, and while 5-10V was biased the diodes can given yellow which is only from the interface because the yellow band deferred from that from TPD, and Gd-complex is not emitted. We also observed that energy conversion efficiency was significantly improved by insetting an ultrathin mixed layer of Gd-complex and TPD into between TPD and Gd-complex, /ITOTPD/TPD:Gd-complex/ Gd-complex/Mg:Ag. So we can demonstrate that photovoltaic effects 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.
Tran Kim An, Pham thi Minh Chau, Nguyen Trong Oanh, Tran Thu 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 tetraethoxysilan, in which blended different polymers. The dyes are Rhodamin 6G, Coumarin 540 and the RE ions as Eu3+, Er3+ which were embedded in these matrices. The optical properties such as Raman scattering, infrared absorption, fluorescence, photoluminescent excitation spectra and lifetime were investigated. The Eu and Er transitions in visible and infrared regions, the influence of dyes, Eu, Er concentration, technology condition to optical properties and their application in optoelectronic and photonics will be studied.

K9.21
(Au Er^+)-DOPED PLZT WAVE-GUIDES PREPARED BY SOL-GEL PROCESSING.
Nora Pellegri, Oscar de Sanctis, Laboratorio de Materiales Cermicos, FCEIyA, IFIR, UNR, Rosario, ARGENTINA; Agustin Frattini, Area Fisica, FCByF, UNR, Rosario, ARGENTINA; Rui de Almeida, INESC, Lisboa, PORTUGAL.

The pseudocubic crystal structure of the 9/65/35 PLZT becomes a high optical transparent material throughout the visible spectrum from 0.5 μm to the near infrared at 6.5 μm. PLZT films are good candidates for wave-guides owing to their high index refraction (≈2.5) and low-temperature synthesis. On the other hand, Er^{3+} - doped wave-guides are fabricated for integrated optic amplifiers. These

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 larger concentrations of active optical agent and obtaining full-dense film at lower temperature than those possible by other methods In this work, (Au, Er^{3+}) - doped ($Pb_{0.91}La_{0.09}$)($Zr_{0.65}Ti_{0.35}$)O_3 planar wave-guides have been prepared by sol-gel processing using multilayer spin-coating deposition on silica glass. The aim was to reinforce the fluorescence intensity by: a) resonant phenomena between Er^{3+} and Au nanoparticle, and b) dielectric effect of the matrix. The gold quantum dots were synthesized in micellar reactors by photoreaction and isolation from media by anchoring sol-gel-compatible modifiers on their surfaces. GI X-ray diffraction, TEM, elipsometry, FT-IR and Raman spectroscopy were used to characterize the structure, nanostructure anf residual OH contents. The optical propagation losses were measured at 633 nm and the (Au, Er^{3+}) 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, photovoltaics, and photonic chip components. Plasma Enhanced Chemical Vapor Deposition (PECVD) employing a variety of organic-substituted silane precursors resulted in the growth of polysilane thin films. This PECVD method circumvents the difficult task of dissolving conventional polysilane, which is required to prepare thin films by solution-based methods. Fourier Transform Infrared Spectroscopy (FTIR) indicates the presence of Si-$(CH_3)_x$, Si-$(C_6H_6)_x$, 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 aids in quantifying the FTIR results. Variable Angle Spectroscopic Ellipsometry (VASE) provides nondestructive measurements of film thickness, roughness, and refractive index. Growth rates in excess of 1000 Å per minute were achieved for films with a refractive index of greater than 1.6. Both the FTIR and VASE measurements show that the PECVD polysilane films are stable to oxidation at ambient conditions. These spectra also indicate good resemblance to conventionally polymerized polysilane powders that were obtained commercially. Ultraviolet/visible spectroscopy reveals that the polysilane materials are transparent in the visible region of the spectrum, but are strongly absorbing between 250 and 280 nm. The films fluoresce under ultraviolet light and the collection of photoluminescence spectra is underway.

SESSION K10: UNIQUE MATERIALS, PROCESSING, AND CHARACTERIZATION

Chairs: Dieter Bimberg and Anupam Madhukar
Friday Morning, April 5, 2002
Nob Hill C/D (Marriott)

8:30 AM *K10.1
SUPPRESSION OF BULK DEFECTS IN ANTIMONIDE SUPERLATTICE INFRARED PHOTODIODES. E.H. Aifer, E.M. Jackson, B.R. Bennett, I. Vurgaftman, J.R. Meyer, G.G. Jernigan, Naval Research Laboratory, Washington, DC; M. Goldenberg, SFA Inc., Largo, MD.

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 large 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. Interrupted growth studies and cross-sectional transmission electron microscopy (XTEM) of ASLs have shown that many large bulk defects originate at the epi-substrate 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 probes. We also discuss recent efforts to understand 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 dislocations. Theoretical simulations suggest strategies for redesigning the active layers so as to increase the absorption and reduce the leakage.

9:00 AM K10.2
RELAXED InAsP LAYERS GROWN ON STEP GRADED InAsP BUFFERS BY SOLID SOURCE MBE. Mantu K. Hudait, Yong Lin, Carrie L. Andre, Piyush M. Sinha, Steven A. Ringel, 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 0.05, 0.20 and 0.34 using solid source molecular beam epitaxy. An optimum P:In ratio of 7:1 for the 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 calibration curves were obtained for a growth temperature of 480°C. Using this information, 1.5 μm thick Si-doped, n-type InAsP films were grown on step-graded InAsP buffers. Near complete relaxation of final overlayers, determined by high-resolution X-ray diffraction, were found for each composition with well developed surfaced crosshatch morphology, indicating the effectiveness of the InAsP graded buffers 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^{-3} 300 K carrier mobilities increased from 1745 to 2300 cm^2/V-sec with As mole fraction increasing from 0.05 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 Electronics and Computer Science, Highfield, Southampton, UNITED KINGDOM; N.I. Zheludev, H.J. Coles, University of Southampton, Dept of Physics and Astronomy, Highfield, Southampton, UNITED KINGDOM; R. 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 for 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 meta-materials have several unusual properties not found in nature, including negative angles of refraction and phase velocities. More recently, theoretical attention has turned to meta-materials that are also sensitive to different polarization states of light. Until now, no experimental work has been undertaken on meta-materials in the visible or infra-red parts of the electromagnetic spectrum, even though such materials would potentially have many applications in areas such as optical communications and quantum cryptography. We have now fabricated planar chiral meta-materials with critical dimensions in the sub-micron regime that do indeed interact with light in the visible and infra-red 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, thereby allowing their properties to be tailored to the particular wavelength of interest. The simplicity of these structures, coupled with their versatility, promises to open up new opportunities and applications for opto-electronic devices in the future. [1] J.B. Pendry, A.J. Holden, W.J. Stewart and I. Youngs, Phys. Rev. Lett. 76 4773 (1996). [2] J.B. Pendry, A.J. Holden, D.J. Robbins and W.J. Stewart, IEEE Trans. Microwave Theory Tech. 47 4785 (1998).

9:15 AM K10.4
Transferred to K9.22

9:30 AM K10.5
WAFER BONDED Ge/Si HETEROSTRUCTURES FOR PHOTOVOLTAIC APPLICATIONS. James M. Zahler, Chang-Geun Ahn, Harry A. Atwater, Caltech, Dept. of Applied Physics, Pasadena, CA; Charles Chu, Peter Iles, Tecstar 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 can be used as a means 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 substrates with $1x10^{17}$ cm^{-2} H^+ at 80 keV were used to transfer 600-700 nm thick films on the order of 1 cm^2 for Ge/Si. Hydrophobic surface passivation and less than 1nm rms surface roughness as measured by contact mode AFM along with $\sim$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 10-20 nm surface roughness. Electrical measurements indicate ohmic I-V characteristics for Ge p^+ substrates bonded to Si p^+ substrates with $<0.2\ \Omega\ cm^{-2}$ resistance, sufficient to allow low-loss power extraction through backside contacts. Triple junction solar cell 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 GaInP 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.

1. Sieg, R., *et al.*, Appl. Phys. Lett. **73**, 3111 (1998).

10:15 AM K10.6
ROOM TEMPERATURE ULTRAVIOLET NANOLASERS. Haoquan Yan, Peidong Yang, Univ of Calfornia-Berkeley, Berkeley, CA.

ZnO nanowires were successfully synthesized by a simple vapor transport and condensation process. Room temperature ultraviolet lasing behavior has been demonstrated in these single crystalline ZnO nanowires. Grown 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 um. Under optical excitation, surface-emitting lasing 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 a-SiC:H P-I-N PHOTODIODE. M. Vieira, M. Fernandes, A. Fantoni, P. Louro, R. Schwarz, Electronics Telecommunications and Computer Dept., ISEL, Lisboa, PORTUGAL.

Based on the Laser 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. A laser light illuminates the fingerprint placed on a 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 a-SiC:H p-i-n photodiode). The image is converted directly into a proportional electric current using 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 (photosensitivity, defect density, temperature dependence, thickness) on the device performance (transfer functions, sensitivity, dynamic range, resolution, linearity, responsivity, response time). The scanning technique for fingerprint acquisition will be improved and the effects of the probe beam size, wavelength and flux, the scan time and modulation frequency on image contrast 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 $\mu W\cdot cm^{-2}$ 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, Ashutosh Tiwari, A. Kvit, H. Zhou, J. Narayan, 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 epitaxial growth of ZnO has been realized on sapphire 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 a buffer medium. These films were characterized using x-ray diffraction, high resolution transmission electron microscopy (HRTEM) and electrical resistivity measurements. X-ray diffraction and HRTEM results showed 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 PHOTOEMISSION STUDY OF SURFACE CLEANING CHEMISTRY OF InP(100) BY HYDROGEN PEROXIDE BASED SOLUTIONS. Yun Sun, Piero Pianetta, William E. Spicer, Stanford Synchrotron Radiation Lab, Stanford, CA; Zhi Liu, Dept of Physics, Stanford Univ, Stanford, CA; Francisco Machuca, Department of Electric Engineering, Stanford Univ, Stanford, CA.

InP is an important semiconductor in many applications. A clean starting 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 oxide but not In oxide. The sulfuric 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 more than two monolayers of elemental As, which can be removed by vacuum annealing to give a clean GaAs(100) surface. The underlying reason 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 phosphate 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. Frindell, Department of Chemistry and Biochemistry, University of California, Santa Barbara, CA; Michael H. Bartl, 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 walls made of 1-3 nm anatase nanocrystallites surrounded by glassy 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 (III) ions, irradiation of the titania within its band gap produces the bright red photoluminescence characteristic of europium, whereas direct excitation of the europium produces no observable emission from the films.

11:30 AM K10.11
STRUCTURAL STUDIES OF THE CVD GROWN $LiNbO_3$ FILMS. K. Dovidenko, K.A. Dunn, S. Oktyabrsky, School of Nanosciences and Engineering, UAlbany Institute for Materials, University at Albany-SUNY, Albany, NY; V. Joshkin, Focused Research, Inc., Middleton, WI; D. Saulys, L. McCaughan, T.F. Kuech, Materials Research Science and Engineering Center, UW-Madison, Madison, WI.

Lithium niobate ($LiNbO_3$) 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 $LiNbO_3$ thin films or epitaxial heterostructures. We present the results of the structural studies of the $LiNbO_3$ 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 $LiNbO_3$ single crystal substrates under the same processing and annealing conditions exhibited strikingly different microstructure, which is explained in terms of high $LiNbO_3$ self-diffusivity. Epitaxial single crystalline films of about 1 μm thickness with the dislocation density less than 10^6 cm^{-2} (as determined by transmission electron microscopy, TEM) were fabricated on (0001) $LiNbO_3$. The $LiNbO_3$ 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 $\sim$200 nm-thick epitaxial $LiAl_5O_8$ interlayer at the $LiNbO_3$/sapphire interface, observed by TEM, is explained by high lithium ion diffusivity and tendency to form complex oxides/alloys with other metals. We have also found the presence of small (about 100 nm size) second-phase inclusions in the $LiNbO_3$ 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 $LiNbO_3$ film, indicating the different Li-Nb-O phase or, possibly, a niobium oxide. TEM revealed no second phase inclusions associated with the $LiNbO_3$ grain boundaries or the $LiNbO_3/LiAl_5O_8$ 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. Suwit Kiravittaya, Rudeesun Songmuang, and Oliver G. Schmidt, Max-Planck-Institut für Festkörperforschung, Stuttgart, GERMANY.

Extremely homogeneous arrays of nanoislands and nanoholes are fabricated using molecular beam epitaxy growth and in situ etching. Self-assembled InAs nanoislands with height fluctuations of $\pm$5% were grown using a low indium growth rate on GaAs (001) substrate. If these nanoislands 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 islands is observed. A homogeneous array of nanoholes is fabricated by in situ etching the GaAs surface of capped InAs nanoislands with $AsBr_3$. The nanoholes have a depth of 5-6 nm and the lateral size is 50-60 nm in the [110] direction. We appoint the formation of nanoholes to a pronounced selectivity of the $AsBr_3$ 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

Chairs: Katharine Dovidenko and John E. Cunningham
Friday Afternoon, April 5, 2002
Nob Hill C/D (Marriott)

1:30 PM *K11.1
QUANTUM DOTS, LASERS AND AMPLIFIERS. Dieter Bimberg, Institut für Festkörperphysik, Technische Universität Berlin, Berlin, GERMANY.

Universal self organisation on surfaces of semiconductor upon deposition of a few monolayers of a diffeent non-lattice-matched material lead to the formation of quantum dots. Their electronic and optical properties are closer to those of atoms than of solids (1). Two decades ago it was predicted that QD lasers should be superior to classical lasers eg by showing lower tranparency current. First such QD lasers were created by us in 1993. Today we have indeed demonstrated a record low threshold current for infinite length of $6A/cm^2$ per dot layer at 1.16 μm, high-power of 4W, an internal quantum efficiency of 98%, and an internal loss below 1.5 cm^{-1}. Relaxation oscillations indicate the potential for cut-off frequencies larger than 10 GHz. GaAs-based QD-lasers emitting at 1.3 μm with Jth=$70A/cm^2$ show a cw output power of 3 W and single transverse mode operation up to 300 mW. We presented the first GaAs (wavelength tunable) VCSEL based on QDs operating at 1.3 μm with a cw output power of more than 0.7 mW at 25 C and a maximum efficiency of 50%. Thus GaAs-lasers can now replace InP-based ones at least in the range up to 1.3 μm. First results demonstrate the potential of QD-lasers to cover also the range up to 1.55μm. Semiconductor Optical Amplifiers based on QDs show gain recovery times as short as 70 fs, much faster than QW-based ones, indicating the potential of QDs for a completely novel class of devices with large commercial importance for multi-tera bit metropolitan area networks. Unusually long phase relaxation times of excitons in QDs of more than 600 ps make QDs presently the best candidates as backbone of optical computers. First promising results to use alternative nontoxic MOCVD precursors in the growth of QD-based heterostructures will be reported. *in cooperation with N.N. Ledentsov, J. Lott, V. Ustinov, R. Sellin, C. Ribbat. P. Borri, J. Hvam, U. Woggon, F. Hopfer and others (1) D. Bimberg, M. Grundmann, N.N. Ledentsov: Quantum Dot Heterostructures, J. Wiley, Chichester 1999.

2:00 PM K11.2
ELECTROMAGNETIC AND MECHANICAL INTERACTIONS IN NEAR-FIELD SPECTROSCOPY OF SINGLE SEMICONDUCTOR QUANTUM DOTS. A.M. Mintairov, J.L. Merz, University of Notre Dame, Dept. of Electrical Engineering, Notre Dame, IN; A.S. Vlasov, P.A. Plagnov, I.S. Tarasov, D.A. Vinokurov, Ioffe Physico-Technical Institute, RAS, St. Petersburg, RUSSIA; V. Tokranov, S. Oktyabrsky, UAlbany Institute for Materials, University at Albany-SUNY, Albany, NY.

We present the results of a study of low-temperature photo-luminescence spectra of self-organized InP/GaInP (base 100 nm, density 10^8 cm^{-2}) and InAs/GaAs(AlAs) (base 9-18 nm, density 1-10*10^{10} cm^{-2}) quantum dots (QDs) using near-field scanning optical microscopy. The spectra of single QDs were measured for fiber tips having aperture diameters of 70-500 nm and throughput 10^{-4}-10^{-1}. The spectra were measured at 5K in collection-illumination mode using 5-500 μW of 514.5 nm excitation. A magnetic field up to 10T was used to measure Zeeman splitting and diamagnetic shift of the single QD emission lines in polarized near-field spectra. In the present paper we discuss the effects of the tip-to-surface distance (z) on the emission spectra of single QDs. We found that the emission intensity as a function of z from a single QD is described well by the electromagnetic theory of light diffraction from a subwavelength aperture and we used these measurements to evaluate the effective aperture size. We observed a small ($\sim$0.5 meV) red shift of the single QD emission lines as the tip approached the sample surface (z=0-500 nm), which results from the electromagnetic interaction of the metallic coating of the tip with the QD excitonic transition. We studied the effect on QD emission of the pressure (0-10 kbar) produced by pushing the tip against the sample surface ($z<0$). We found that the pressure-induced blue shift of the single QD emission line depends strongly on the position of the QD from tip center and that this shift exceeds 100 and 10 meV for InP and InAs QDs, respectively. For some QDs we observed an order of magnitude increase of the emission intensity under the applied pressure. These effects will be further evaluated. DARPA/ONR grant N00014-01-1-0658 and the W.M. Keck Foundation have supported this work.

2:15 PM K11.3
InGaAs 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.

Epitaxical 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 photo-detectors (QDIPs) with undoped active region (n-i-n configuration) comprising InGaAs capped GaAs(001)/InAs QDs. The QDIP samples were grown on GaAs(001)$\pm$0.1° substrates via solid source molecular beam epitaxy. The InAs QD size, density, as well as the structure and defect density of QDIPs were characterized using atomic force microscope and cross-sectional transmission electron microscope. The InAs QDs embedded in the n-i-n QDIP structures have been comprehensively characterized using photoluminescence (PL), PL excitation, and FTIR based inter- and intra-band photocurrent spectroscopy. Two types of infrared photodetectors have been realized utilizing bound-to-bound intraband transitions of the $In_{0.15}Ga_{0.85}As$ capped GaAs(001)/InAs QDs: i) QDIPs with photoresponse wavelength of ~8.5 μm, and ii) bias-controlled tunable two color (~5.6 and ~10 μm) QDIPs. The ~8.5 μm and two-color QDIPs are based on a stack 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 behavior. The responsivity, dark current, and detectivity of these QDIPs will be presented. At 77 K, the two color QDIPs show an intraband peak detectivity of 5.3×10^{9}cmHz$^{1/2}$/W at ~5.6 μm and of 7.3×10^{8}cmHz$^{1/2}$/W at ~10 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 GaInP QUANTUM WELL LASER. Y.M. Manz and O.G. Schmidt, Max-Planck-Institut für Festkörperforschung, 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 dots (QDs) are compared with a compressively strained $Ga_{20}In_{80}P$ quantum well (QW), grown by solid source molecular beam epitaxy under equivalent conditions, which both emit at nearly 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 exhibit ground state lasing at room temperature with threshold current densities of 1.8 kA/cm^2 at a wavelength of 732 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 100 A/cm^2, which exponentially 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 quantum dots. Temperature dependent electroluminescence 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 laser. References [1] Y.M. Manz, O.G. Schmidt, and K. Eberl, Appl. Phys. Lett. 76, 3343 (2000).

3:15 PM K11.5
EFFECT OF BUILT-IN ELECTRIC FIELDS IN QUANTUM DOT LASER STRUCTURES GROWN BY METAL ORGANIC CHEMICAL VAPOR DEPOSITION. Adriana Passaseo, Massimo De Vittorio, Giuseppe Maruccio, M. Teresa Todaro, Sergio De Rinaldis, Roberto Cingolani, National Nanotechnology Laboratory of INFM, Dept. Ing. Innovazione, University of Lecce, Lecce, ITALY.

In the last years great effort has been dedicated to the study and fabrication of optoelectronic 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 InGaAs/GaAs (In 50%) quantum dot electroluminescent devices, we will show 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 (at 300 K), we demonstrate that the electric field associated to the built-in dipole in the dots, directed from the base of the dots to their apex, 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, thus allowing us to obtain EL emission at the designed wavelength of 1.3 microns at 300 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. S. Marcinkevicius, Royal Inst of Technology, Dept of Microelectronics and Information Technology, Kista, SWEDEN; R. Leon, Jet Propulsion Laboratory, California Inst of Technology, Pasadena, CA; C. Lobo, Cambridge Univ, Cavendish Laboratory, Cambridge, UNITED KINGDOM; B. Magness, 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 irradiation than bulk semiconductors or quantum wells (QW). In the present work we extend these investigations by studying carrier dynamics in irradiated QD structures. To get a general picture 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 InAlAs/AlGaAs), dot density, substrate orientation and irradiation dose. Carrier dynamics was measured by time-resolved photoluminescence (PL). For comparison, similar measurements were performed on thin 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 3.5×10^{13} cm^{-2}, compared to a ~20-fold decrease for the QW. Moreover, we observe some increase in the QD PL intensity in the low-density samples with small irradiation doses as 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.

3:45 PM K11.7
SURFACE MODIFICATION OF CdSe NANOCRYSTALS WITH LINEAR AND DENDRITIC ORGANIC LIGANDS: STABILITY AND OPTICAL PROPERTIES. Chunxin Zhang, Lajos Balogh, The University of Michigan, Center for Biologic Nanotechnology, Ann Arbor, MI; Stephen O'Brien, Dept of Applied Physics; Louis E. Brus, Nicholas J. Turro, Dept of Chemistry, Columbia University, New York, NY.

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 provide chemical and electric passivation. Surface modification of NPs is an important issue because the properties of absorbed molecules modify the stability of the NPs, influence their optical properties and control their compatibility with the actual environment. Here we describe the 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(amidoamine) (PAMAM) dendrimers carrying different numbers of amine sites and hydrophobic aliphatic chains were used. Complete exchange of the original TOPO/TOP caps was achieved through a CdSe/pyridine intermediate. 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/PAMAM and CdSe/Linear systems were studied during a two months period as a function of time and ligand composition. PAMAM derivatives with only secondary and tertiary amines provided a better protection for the nanocrystals 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 Passaseo, Roberto Cingolani, National Nanotechnology Laboratory of INFM, Dept. Ing. Innovazione, University of Lecce, Lecce, ITALY; Massimo Mazzer, Mauro Lomascolo, Stefania Tundo, IME-CNR, Lecce, ITALY; Laura Lazzarini, Giancarlo Salviati, CNR-MASPEC, Parma, ITALY; Keit Barnham, 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 metallorganic 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 1*E5/cm^2. 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.