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
Chair: Zuzana Lileikyte, IBM and Remis Gaska
Tuesday Afternoon, April 2, 2012
Nob Hill C/D (Moscone)

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-nitrides, will dominate the future of optoelectronics 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 as the nitride growth of oxide-on-donor and electron devices so far. Lack of a high-quality bulk nitride substrate has been pointed out as one of the chief factors contributing to the absence of a mature III-nitride technology. The use of commercially available foreign substrates such as silicon carbide and sapphire has been demonstrated to have serious problems. To overcome these problems there are many efforts worldwide to grow bulk crystals of gallium nitride (GaN) and aluminum nitride (AlN). 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 differences in thermal expansion, and high thermal conductivity compared to GaN. In addition, AlN is often used as a desirable substrate than GaN for device structures that require Al-rich nitride epitaxial layers such as solar-blind UV detectors, UV light sources, and high-power microwave devices. Evidences of growth by Crystal IS of larger and better single-crystal boules using the melt-sublimation technique have greatly increased the prospect of a commercially available 4-inch bulk nitride substrate in the next few years. Currently, boules 1.5 cm in diameter and several cm in length, with density of dislocation below 10^6 cm^-2 and with a thermal conductivity exceeding 3 W/cmK, have been reported. Key issues regarding the growth and surface preparation of bulk AlN substrates will be reviewed. Also, 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 UV SELF-ALIGNED GaN FILM. Chih-Kuei Lee, Yee-Beom Chen, Shu-Chen Chang, S.C. Wang, and C.-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 microphotoluminescence (micro-PL) system. The GaN sample was grown on the sapphire substrate. The inverted pyramid defect observed on the sapphire surface have an average size 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 provided from the top microscope. The signal is collected from the top microscope. To observe the optical spectrum from the emission of the GaN surface defect, the spatial dependence of PL emission spectrum from inside to outside of the pyramid defect was measured. The emission spectrum from the center of the hexagonal structure shows a peak around 370.1 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 370.5 nm. Since the pyramid defect is believed to be created as a result of the stress release of the threading dislocation, the spatial blue shift in the emission spectrum outside the defect center seems reasonable. We also observed additional peak at 380.7 nm near the center which could be originated from the threading dislocation. The optical properties directly on the surface defect is on the order of 10^4 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 GaN films grown on GaN/AlN buffer layers containing multiple QDs 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 using chemical etching and atomic force microscopy. It was found that the insertion of a set of multiple GaN QD layers in the buffer layer effectively reduced the density of the dislocations in the epitaxial layers. As compared to a density of ~10^10 cm^-2 in GaN film grown on sapphire substrate, a density of ~10^10 cm^-2 was demonstrated in the GaN film grown on sapphire substrate.

2:15 PM K1.3
GROWTH OF GaN ON POROUS SiC SUBSTRATES BY MBE. C.K. Inoki, T.S. Khan, Univ at Albany, SUNY, Dept of Physics, Albany, NY; C.D. Lee, A. Sagar, R.M. Feuster, 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 silicon was enhanced using the concept of internal epitaxial 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 local 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 HCl-exposing, 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 guide defects and trap Ga droplets. Nevertheless, the GaN layers grown on porous substrates still contain slightly higher density of defects 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 substrates. 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 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.

3:00 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. Merkoçi, Dept of Electrical Engineering and Physics, Virginia Commonwealth Univ, Richmond, VA; D.C. Reynolds, Weight State Univ, Dayton, OH; S.H. Park, K.Y. Lee, Samsung Advanced Institute of Technology, Suwon, KOREA.

We studied photoluminescence (PL) of GaN layer grown by molecular beam epitaxy (MBE) on freestanding and high quality GaN template. The layers were grown under Ga-rich conditions using VPE/GC. We used nitrogen to a thickness of about 1 micron. The PL spectra from both the epilayer and the substrate contained a plorithm 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 excitons peaks and their associated two-electron satellites, we 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 showed weak emissions due to shallow donor-shallow acceptor transitions with the main peak at 3.26 eV and a broadband peak 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. Merkoçi, Virginia Commonwealth University, Richmond, VA; C.W. Litton, Air Force Research Laboratory (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 thick GaN film grown directly on sapphire substrate is on the order of 10^6 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 GaN films grown on GaN/AlN buffer layers containing multiple QDs 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 using chemical etching and atomic force microscopy. It was found that the insertion of a set of multiple GaN QD layers in the buffer layer effectively reduced the density of the dislocations in the epitaxial layers. As compared to a density of ~10^10 cm^-2 in GaN films grown on sapphire substrate, a density of ~10^8 cm^-2 was demonstrated in the GaN GaN fibers grown on GaN/AlN buffer layer. Transmission electron microscopy observations showed disruption of the threading dislocations by the QD layers. Experimental details will be presented and the possible 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. S.Ć. PEYKULLA, R. BERNÁTKY, Sensor Electronic Technology Inc., Lachow, NY; Dunaevsky Ogly, M. Shur, Sergey Rymantien, Rensselaer Polytechnic Institute, Dept of ECSE and CIE, Troy, NY; Romanuk Riminka, Albertus Sereiko, Vilnius University, Dept of Physics, 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-nanophosphor 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 responses showed large visible/UV rejection ratio, which made these devices promising for the development of visible-blind remote sensor. However, the observed optimization of the photoconductivity is harmful for visible-blind operation and must be eliminated.

Solid-state white-light emitters require efficient pumping sources in the ultraviolet (UV) region of 250-350 nm. Nitride-based alloys such as AlGaN and AlN are among the most promising candidates for the active parts of these UV devices due to their 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/AlGaInN multiple quantum wells (MQWs) grown by a novel pulsed metalorganic chemical vapor deposition (MOCVD). The samples were excited by an excimer laser (λ = 138 nm, τ = 8 ns) for quasistationary strong pumping or picosecond laser (λ = 370 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 quantum-mechanical 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 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 METAL-ORGANIC CHEMICAL VAPOR DEPOSITION OF QUANTUMARY AlGaN MULTIPLE QUANTUM WELL STRUCTURES FOR DEEP ULTRAVIOLET EMITTERS. J.W. Yang, C. Kim, M. H. Kang, S. Y. Yoon, M. Y. Ryu, E. Kuczuk, G. Simin, M. A. Khan, Department of Electrical Engineering, University of South Carolina, Columbia, SC.

UV nitrides are of great interest for application to blue and ultraviolet (UV) light-emitting diodes (LEDs) and laser diodes (LDs) due to their appropriate wide direct band gap. Nitride-based deep UV emitters with the wavelength below 340 nm require the use of high Al content AlGaN or quaternary AlInGaN layers in the active region of the device. The use of AlGaN, however, has been shown to lead to a severe degradation of the device properties. We are therefore exploring quaternary AlInGaN layers for the active layer of multiple quantum wells (MQW) in deep UV emitters. We have investigated metalorganic chemical vapor deposition (MOCVD) techniques: a pulsed atomic layer epitaxy (PALEY) 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 PALEY process have low density of band tails and exhibit an intense UV band-edge emission. This behavior is highly promising for LEDs application because it leads to high output power.

SESSION K2: SOLID STATE LIGHTING

Chair: Leo J. Schowalter
Wednesday, April 4, 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 the 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 organic 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 products.

9:00 AM K2.2 NEW CHARGE-CARRIER BLOCKING MATERIALS FOR HIGH EFFICIENCY OLEDs. Vladim L. Adzicovitch, Steven R. Churchard, Mark E. Thompson, University of Southern California, Department of Chemistry, Los Angeles, CA, Brian W. D'Andrade, Stephen L. Forster, Center for Photonics and Optoelectronic Materials (CPOM), 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 from 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 new electron-blocking materials. We use cyclometalated complexes in hole-blocking materials. Complexes of this type are more stable toward oxidation and reduction, have high HOMO and LUMO 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 geometries. We have prepared OLEDs using bis[2(4,6-difluorophenyl)pyridyl-N,C2']iridium(III) picolinato (FlrPic) 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 injection and injection. The new HBLs were tested in phosphorescent OLEDs with blue (FlrPic) and green (tris(8-hydroxyquinoline)Ir) emitters in a 4A,N-Dicyanomethylene-biphenyl (CBP) host. Oxt phenyl cyclopentetrayne (OPCOT) and various sesquiphosph compounds were used as hole-blocking matrices. FlrPic was used both as a blue phosphorescent emitter in CBP and as an electron dopant in OPCOT and tetraphenyl. The device with a neat FlrPic HBL performed better than BCP control device (max quantum efficiency 41% vs 27%). The device with OPCOT FlrPic HBL
INFLUENCE OF DEFECTS ON CURRENT TRANSPORT IN GaN/InGaN MULTIPLE QUANTUM WELL LIGHT EMITTING DIODES

We have compared the electrical characteristics and optical properties of GaN/InGaN multiple quantum wells [MQW] light emitting diodes (LEDs) fabricated from commercial epitaxial wafers. It appears that there is an essential link between material quality and the mechanism of current transport through the wide-bandgap p-n junction. Tunneling behavior dominates throughout all injection regimes in the devices with high-density defects which act as deep-level carrier traps. However, in high quality LEDs grown by MOCVD, the forward 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 ∝ I^n in all devices. In the high quality LEDs, nonradiative recombination centers are saturated at current densities as low as 1.4×10^6 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.

SESSION K3: NITRIDES—CHARACTERIZATION AND PROCESSING

BIGAN QUANTUM WELL STRUCTURES.
Noao A. Shigori, Henning Bick, Eike 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, Sil 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 large (≈1eV/cm), built-in electric field in these transitions is still under debate. We study the photoluminescence (PL) and time-resolved PL (TRPL) of metastable chemical vapour deposited InGaN quantum-well (QW) structures as a function of applied bias. In our samples, the dependence of the carrier recombination on the applied bias is not linear. We find that the luminescence efficiency of these devices is highly dependent on the biasing conditions of the device and the built-in electric field. The results suggest that the luminescence efficiency can be controlled by the electric field applied to the device.
equal to the QW width, $L_w$, whereas negligible carrier separation corresponds to a redshift and $L_q$ equal to 0. We also find that the carrier lifetime decreases with applied electric field 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, iodium 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 from non-radiative recombination. We suggest that while the carriers are separated along the direction of the electric field, they are localized in the perpendicular direction such that they are protected from non-radiative centers associated with the high density of threading dislocations in the structure.

11:15 AM K3.3
A CHEMICAL SPECTRUM PERSPECTIVE OF GaN POLARITY: HATOMS PLASMA ETCHING AGAINST NAOH WET ETCHING TO DETERMINE POLARITY. Maria Lessard, MariaMichela GianGregorio, Pio Capezzuto, Giovanni Bruno, Plasma Chemistry Research Center-CNR, Bari, ITALY; Gon Nambu, 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 lasers. However, GaN films and thermal conductivity are suitable for high power/temperature modulation doped FETs. Nevertheless, being non-centrosymmetric due to its wurtzite structure, GaN films show the phenomenon of polarization, i.e., the strain generated by the Ga-N bond breaking in the [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 CHARACTERISTICS OF ISOELECTRONIC AL-DOPED GaN FILMS GROWN BY METALLORGASMIC CHEMICAL VAPOR DEPOSITION. Jeong-Hoon Lee, Won-Hyun Kim, Hyon-Min Ko, Ki-Yeol Park, Myoung-Bok Lee, Sung-Ho Hahn, Yong-Hyun Lee, and Jung-Hee Lee, The School of Electronic and Electrical Engineering, Kyungpook National University, KOREA; Sung-Bum Bae, Kyo-Suk Lee, Electronics and Telecommunications Research Institute, KOREA.

In regard to the film quality, it has been reported that with the increasing of isoelectronic impurity (In or As), the optical and electrical properties of GaN film could be effectively improved. We investigated the first isoelectronic Al-doping effects on GaN film grown by metalorganic chemical vapor deposition (MOCVD). Al-doped GaN samples were grown with different TMAl flow rates of 3, 6, 11, and 30 µmol/min and then their material properties were compared with those of undoped GaN sample. With increasing the TMAl flow rate, the electron mobility was increased from 530 to 510 cm²/Vs, although unintentional background concentration was slightly increased in accordance with increasing TMAl flow rate. The effect of Al-isoelectronic doping on the optical properties of GaN was investigated by using room temperature photoconductance (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 curves of Al-doped GaN films and undoped GaN films also showed no 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 performance.

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

We report the effect of different annealing conditions of p-GaN on new metallization scheme using Ni/Pd/Au. The as-prepared 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 3 minutes after the MOCVD process. The second set of 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 10^18 cm^-3 2. 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 x 10^-4 Ω·cm. While the second set of samples has a much higher resistance value of about 3.3 x 10^-4 Ω·cm. The different in the ohmic contact resistance for these two sets of GaN samples were investigated by the secondary ion mass spectroscopy. For the first set of samples, A clear evidence of the outdiffusion and interdiffusion of Ga, Pd, and Au in the metal layers and GaN layer boundary was observed suggesting the possible formation of GaN-Pd-Au reaction products between the metal layers and GaN. For the second set of samples, there was no evidence of the outdiffusion and interdiffusion of Pd, and Au into the GaN layer. In addition, the content of Ga in the second set samples was less than that of the first set sample. These results suggest that the formation of eutectic 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 condition of GaN is preferable process for achieving the low ohmic contact resistance.

SESSION K4: NITRIDE TRADITIONAL III-V SEMICONDUCTORS
Chair: Hadis Morook and James Harris Wednesday, Afternoon, April 3, 2002

Nob Hill C/D (Marriott)

1:30 PM K4.1
GaNAs, A NEW MATERIAL IN THE QUEST FOR COMMUNCATIONS LATTICES. 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 performance, low cost, high power, compact 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, and 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 GaNAs lattice matched to GaN has both a suitable high power, energy and prospective characteristics, including low threshold current density, high temperature CW operation and high Tth in the wavelength range of 1.1µm to 1.3µm. These results suggest that GaNAs will be the winning technology in this derby. I will review some of the requirements which must be met for the successful 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, 1.2 or 1.55µm lasers which can be directly modulated at >10 Gbps and operate over a significant temperature range (1.1 to 85°C) with moderate power (~10mA). With 1.3µm GaNAs 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-polarization design is particularly critical and C-doping is essential. Finally, interconnects vs. through the mirror electrical contacts and through window for high-speed devices are still an issue to consider in order to take on the task and possible solutions to the above issues will be addressed.

The second challenge is to open up the entire 1.3-1.6um low loss wavelength region of fibers using Raman amplifiers. To design a
Human amplifier for the 1.31-1.55 μm range, a suitable high power pump source with a broad selection of emission wavelengths is required. One of these challenges is achieving long wavelength (>1.3 μm) GaInNAs alloys. We have developed a new structure using GaInNAs/Sb quantum wells (QWs) with strain compensating GaNAs or GaNAsSb barriers. The material for this work was grown by solid source MBE with a 3% In content. 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% In with total active layer thicknesses above 50nm. We studied 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.

2.60 PM K4.2
ON THE ORIGIN OF LIGHT EMISSION IN GaNP. J.A. Baymamon, G.Y. Rudko, W.M. Chen, Linkoping Univ, Linkoping; SWEDEEN; H.P. Xin and C.W. Ts, 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 non-linear transformation from an indirect to a direct band-gap leading to much improved 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 photoconduction measurement and photoconductivity 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 7.5 μm thick GaNP layers grown on Si (70 μm) multiple quantum wells (MQW) structures were studied, with N content 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 show up to be resonant with conduction band of the alloy and thus optically active, 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
ON THE STRAIN RELAXATION IN THIN FILMS OF InGaNAS AND THE DILUTE NITRIDE InGaNsN: M. Adamczyk, J.H. Schmid, T. Tiedje. Department of Physics and Astronomy, University of British Columbia, *also Department of Electrical and Computer Engineering, Vancouver, Canada; A. Kosevichko, A. Chubanov, V. Fink. K. Kiewske Department of Physics, Simon Fraser University, Burnaby, Canada.

The dilute nitride/arsenide compound semiconductors GaNₐₙAs₁₋ₙ and InGₐₙAsₓNₓAs₁₋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 colorless GaN-based laser emitting at 1.3 μm. In this paper, we compare the strain relaxation of InGANAs and InGₐₙAsₓNₓAs₁₋ₓ epitaxial thin films grown by elemental source MBE. The films studied in this work were designed to have the same compressive strain, namely 0.018 ± 0.017%, and the same full 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 found an identical critical thickness, 290 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 InGANAs than in GaNAsN. By considering the InGANAs epilayers and for the higher nitrogen bond strengths. Both these factors will slow down dislocation glide processes 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 conclusions were drawn on dilute nitride material having higher compressive strain, which will be also presented.

2.30 PM K4.4
ION-CUT-SYNTHESIS OF NARROW GAP NITRIDE ALLOYS. X. Wang, 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. Sigovics, 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 GaNAs, are very promising candidates for a variety of applications including 1.5μm light emitters and non-linear optical solar cells. However, the large size difference between As and N, the miscibility of GaNAs on the InP substrate is limited. In principle, ion implantation allows for the introduction of atoms beyond their solubility limit. In addition, after ion irradiation, 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 GaNAs layers occur simultaneously. Using this method, we perform the growth and thermal annealing conditions, we have implanted N ions into both GaN and InAs. High-resolution transmission electron microscopy (HRTEM) clarifies the formation of GaNAs/InAs-Nitride structures 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 the size and volume fraction of the nanocrystals are controllable with annealing temperature. Furthermore, a layer containing a high density of nanostructures could 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 within the cleaved layer and substrate, suggesting that nitrogen bubbles at the interface provide the cleavage force. We will discuss the mechanisms of nanostructure comprising and layer cleavage, as well as correlations between their optical and structural properties. [1] R.S. Goldman et al., Appl. Phys. Lett. 69, 3608 (1996). J. Electr. Mater. 26, 1342 (1997).

3.15 PM K4.5
HIGH INTENSITY 1.3-1.6 µm LUMINESCENCE FROM MBE GROWN GaNAsSb. Vincent Gambino, Wenli Hu, Mark Witzey, Joshua Harris, Stanford University, Stanford, CA; Seongsin Kim, Agilent Technologies, San Jose, CA.

GaInAs grown on GaAs substrates has been found to optimally emit at wavelengths longer than previously possible on GaNAs 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 Intrinsic 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 optical quality of the GaInNAs films significantly improves. However, during anneal nitrogen diffuses out from the quantum well and blueshifts optical emission. Two techniques were investigated to expand the feasible emission wavelengths for this material system. GaNAs barriers between GaNAs quantum wells reduce the blue shift due to nitrogen out-diffusion and can be designed to strain compensate and improve compressive GaNAs. 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 content past 1.3μm and found it not only acts as a surfactant but is also 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 intensity out to 1.6μm. In GaNAs grown in this manner, there is further need for GaNAs strain compensating barriers for applications in multiple quantum well, high-temperature devices. Towards this goal, we have grown GaNAsSb multiple quantum wells on GaSb 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)N [GaNs] BULK LAYERS GROWN BY MOVPE. Krisin Volk, Joerg Koch, Wolfgang Sola, Philips University Marburg, Materials Science Center, Marburg, GERMANY.

(GaIn)N [GaNs] bulk films have been successfully grown under non equilibrium conditions by metal organic vapour phase epitaxy (MOVPE). Due to the large bandgap energy in this wide bandgap 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 quantum material system could serve as 1 eV material in GaN based multi-junction 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 at low temperatures. MOVPE with high N incorporation as well as 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 dopant effects (interstitially silicon and Te in [1]) or from tellurium and Mg (from [2]) were used as the p-dopant. Electric measurements to determine the charge concentrations for the single dopant dependence on the growth parameters have been performed and show comparable carrier mobilities for both, n- and p-type dopants. The achieved doping level can be as high as 1019 cm⁻³ for n- and p-type dopants, respectively. Photon-harvesting (PL) measurements of the dopants show that the doped elements also remain p-type at low doping levels. These measurements will be discussed in dependence on the doping element. First devices have been successfully grown using this n- and p-doped quaternary material.

3:45 PM Kd.4
INVESTIGATION OF GREEN EMITTING MONOLITHIC II-VI VERTICAL CAVITY SURFACE EMITTING LASERS (VCSELs)
C. Kruse, C. Kruse, D. Hommel, H. Krenkel, H. Krenkel, H. Krenkel, J. Gutowski, Institute of Solid State Physics, University of Bremen, GERMANY.

II-VI-based vertical cavity surface emitting laser (VCSELs) 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 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 500 nm and can be used as active material in electrically pumped laser emitters operating at room temperature [1]. In order to achieve the goal of an electrically pumped VCSEL, monolithic microcavities with both ZnCdSe quantum wells (QWs) and CdSe QDs have been grown and are investigated with regard to their optical and electrical properties. The Distributed Bragg Reflectors (DBRs), which form the top and bottom mirror of the microcavity, consist of lattice matched ZnCdSe as the high refractive index material and strain compensated ZnSe/Mg, [3] superlattices (SLs) as the low index material. The use of short-period ZnSe/Mg, SLs allows the growth of high quality Mg, in zincblende crystal structure and is an approach to reduce the serial electrical resistance of the distributed Bragg reflectors because of the resulting formation of minibands. In order to find an optimized design for the VCSEL structures, the serial electrical resistance of distributed Bragg reflectors has been measured in dependence of the SL period and the thickness ratio of the ZnSe and Mg, 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. Krehl, U. Poppa, H. Krenkel and D. Hommel, Electr. Lett. 37, 1119 (2001).

4:00 PM Kd.5
LATERAL COMPOSITION MODULATION IN [InAs]₀/[AlAs]ₙ SHEET-PERIODIC VERTICAL SUPERLATTICES STUDIED BY X-RAY DIFFRACTION
Jianhua Liu, Simon Moss, Univ of Houston, Dept of Physics, Houston, TX, Valcu Hary, Masyuk Univ, Dept of Solid State Physics, Brno, CZECH REPUBLIC, Yong Zhang, Angela Maschenschin, G. Golen, CO, David Ballstetter, SNL, Albany, 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 manipulate this self-assembled lateral structure is to grow short-period vertical superlattices. The out-of-phase morphological undulations of the two strained ultrathin 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]₀/[AlAs]ₙ [n, m < 2] short-period vertical superlattice by means of 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 surface morphology of the short-period vertical superlattice, which has the same wavelength as 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 Goosen
Thursday Morning, April 4, 2002
Nob Hill C/D (Marriott)

8:30 AM K5.1
OPTICAL WAVEGUIDES: CMOS-COMPATIBLE PROCESSING AND MATERIALS FOR MICROPHOTONICS
Peter D. Ferrans, San, Aytar Guner, Shom Onstow, Joel Plasky, 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 thin-film optical interconnects used in these chips can also be consistent with upper level thickness of a few microns or less. In this talk, we review recent progress in microphotonic waveguides and address limitations imposed by incorporation of waveguides onto chips using materials and processes compatible with the CMOS backend.

9:00 AM K5.2
CMOS-COMPATIBLE MATERIALS FOR ACTIVE WAVEGUIDE DEVICES
Michelle L. Osram, Michael L. Steigerwald, James J. Krajewski, Dave V. Tang, and Yiu-Han Wong, Agere Systems, Murray Hill, NJ.

The success of the phase change memory effect in chalcogenide (Ge,Sb,Te) thin films for optical read/write 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,Sb,Te is, in essence, a highly resistive material, this material does not appear to be best suited for other optical and electronic applications. For this reason, we are investigating pulsed electronic and optical switching and are using optical properties on a wide variety of chalcogenide materials to control 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 phase 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,Sb,Te-based materials has been observed on a variety of electrode materials. For active optical waveguide applications, the optical absorption and band-gap have been measured as a function of composition for the Ge,Sb,Te variant of the Ge,Sb,Te materials system (Ge,Sb,Te,S). Some members of the Ge,Sb,Te,S family of compositions exhibit the phase change memory effect. These results will be discussed as well as some interesting interactions between chalcogenide glass 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 BaSb4 Mn64 USING LIQUID PHASE EPITAXY
D. Breunlich 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. Mn64 ions exhibit broadband luminescence, however, Mn64-doped crystals or waveguide structures could not be grown in sufficient quality. The active material is to be free of inclusions or defects larger than 1/10, with λ, the wavelength of the propagating beam. In addition, the interface area between active and substrate must be optically fine to receive low-loss guiding properties. The growth temperature of BaSb4 Mn64 is limited by the decomposition of BaSb4 at 1500°C, its phase transition above 1000°C, and especially the chemical reduction of the manganese dopant from Mn64 to Mn64 above 620°C. Therefore, the growth of BaSb4 Mn64 from a solution at lower temperatures is the most suitable method. Liquid phase growth is close to the thermodynamic equilibrium and enables us to grow high-quality layers. First, we prepared undoped BaSb4 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 BaSb4 was performed from liquid phase epitaxy (LPE), using the additive ternary CaCl2-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 BaSb4 Mn64 were fabricated with thickness rates up to 150 μm/h at temperatures of 500-580°C. The thickness was controllable with a precision of ±0.1 mm. The Mn64 concentration in the doped layer was up to 1 mol%.
with respect to Si$^+$. In collaboration with the University of Hamburg, aborption and emission spectra were measured, which confirmed that the manganese ion was incorporated in the layer solely in its tetravalent oxidation state. Room-temperature broad-band luminescence in the wavelength range 850-1600 nm was observed.

9:30 AM K5.4  
HIGH INDEX CONTRAST AI$_2$/Ga$_{1-x}$As GRATING BURIED IN GaAs/AlGaAs WAVEGUIDES. J.H. Schmidt, M. Acharyya, A. Balazs, S. Ticer, M. Whitaker, T. Tiedje, Univ. of British Columbia, Vancouver, CANADA.

We report the successful fabrication of high index contrast optical grating mode of AI$_2$/Ga$_{1-x}$As and GaAs buried in GaAs/AlGaAs waveguides. Due to the high index contrast of 3.4 for GaAs and 1.6 for AI$_2$/Ga$_{1-x}$As, photon dispersion in semiconductor waveguides can be modified much stronger than is possible with materials currently used for buried gratings. This will allow fabrication of DBR 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 InGaAsN 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 x 10$^{-4}$ Torr 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 AIAs layer. Real time measurements of the specular reflection at the surface of the sample indicate 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 with additional exposure to air this leading oxidation of the AIAs that would make successive regrowth impossible. After regrowth the AIAs can be oxidized to AI$_2$/O$_{3-x}$ by exposure to hot water vapor. We present results of measurements of the optical and electrical properties of waveguides obtained using high index contrast gratings and InGaAsN 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 Gossen, 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 chip bonding. Any technique must accomplish a pristine electrical (both contacts), mechanical, and thermal interface between the two devices. A further requirement is that the optical signal be facilitated out of the assembly, usually to optical fiber, in a manner consistent with good packaging techniques. The optical requirement can be further complicated if the optical signal is at 850 nm, which is typical for short distance communication, and the only usable 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 Yau, John Fenger, MIT, Dept. of Materials Science and Engineering, Cambridge, MA; Harry Lee, Rajeev Ram, MIT, Dept. of Electrical Engineering, Cambridge, MA.

Al$_x$Ga$_{1-x}$As/GaAs quantum well lasers have been demonstrated in commercial zinc-organic vapor phase deposition (MOVCD) on relaxed graded Ge/Ge$_{1-x}$/Si$_{1-x}$ virtual substrates on Si. Relaxed graded Ge$_{1-x}$/Ge$_{1-x}$/Si$_{1-x}$ buffer layers on Si offer a novel platform for direct integration of III-V optoelectronic devices with high-speed SiGe and Si-based electronics. Despite un-optimized laser structures demonstrating high power reliability and large threshold current densities, measured surface threading dislocation densities as low as 2 x 10$^6$ cm$^{-2}$ enabled cw room-temperature lasing at a wavelength of 880 nm. 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 indications of near-chalk mismatch lifetimes in GaAs grown on Ge/Ge$_{1-x}$/Si substrates. A number of GaN/GeSi/Si integration issues including thermal expansion mismatch, facet mirror cleaning on facet Si substrates and Ga outdiffusion in Ge substrates in GaAs have been overcome. Recent work done to extend device lifetime and reduce threshold current via defect-resistant strained In$_x$Ga$_{1-x}$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 1550-NM WAVELENGTH RANGE. T. S. Srinivas, Ben Strauss, Seth Pappas, Arvind Baliga, Thermocircus Inc., 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 micromachined 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 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 operating 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 conformance 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(H3)-DOPED NANOPARTICLES THAT EMIT IN THE NEAR INFRARED. Frank C.J. van Veggel, Gerald A. Hebling, Jon W. Stouwman, 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 assays, 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 LaPO$_4$, CePO$_4$, LaPO$_4$, and ErPO$_4$ doped with Er$^{3+}$, Nd$^{3+}$, Pr$^{3+}$ that emit in the near infrared. The following was a wet chemical approach, which led to dispersible nanoparticle with diameters in the range of 5-8 nm. The Er$^{3+}$ doped material shows luminescence around 1500 nm with lifetimes up to 2.3 ms. The Nd$^{3+}$ doped material shows the typical lines at 880, 1069, and 1310 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 fiber. The processability of these materials was improved by incorporating them in 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 Magee, Paul K. Yu, University of California at San Diego, Dept. of Electrical and Computer Engineering, La Jolla, CA.

Low Thermal Stress (LTS) wafer fusion methods allow the use of larger substrates without the so-called thermal mismatch complications found when wafer-fusing materials with differing thermal expansion coefficients. Furthermore, LTS fusion has been credited with the excellent dark-current levels of very low dark-current Si-In$_{0.5}$Ga$_{0.5}$As p-i-n photodiodes[1]. However, LTS processes face a different disadvantage—the appearance of gas bubbles trapped between the thinned layer of material and the thicker
substrate, here InGaNAs (P) and Si respectively. This study investigated the temperature dependence of the appearance of a new phase in the interface, the crystallization of this phase and the resulting bonding state of the interface. Two separate temperature regimes were observed where gas generation and out-diffusion differed, likely according to the gas released from the wafer surfaces at the interface. Afterwards, out-diffusion of the gases at room temperature indicated a qualitatively different interfacial bonding character for samples which had been heated into the higher T regime versus those kept in the lower T regime. Utilizing this critical information, and addressing any system of thermally mismatched bonded materials, a simple method was designed and used to produce wafer-scale InGaNAs (P) on Si material, without the use of trenches or liquid mediated bonding techniques. This material was used to fabricate Si-InGaAs 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 during the study will be discussed.


TUTORIAL

ST 1: OPTOELECTRONIC DEVICES FOR COMMUNICATIONS

Thursday, April 4, 2002

11:30 a.m. - 1:30 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 more dramatic advances in the technology and understanding of optoelectronic devices, particularly those intended for use in optical communication systems. This tutorial will review the main developments in optoelectronic devices (semiconductor lasers and optical detectors) and the various microfabricated optical components (waveguides, diffractive/reflective optics and microelectromechanical 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 design and high-speed optical detectors, and the comprehensive coverage 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 characterizations impacting communication systems design. The precise control of microfabrication will be illustrated by the IBM-built quantum layer used for many years in high-performance semiconductor lasers and in more recent optoelectronic devices. Integrated structures including the basic optical devices and refractive/reflective 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 waveguide multiplexing 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 optoelectronic devices decrease, the benefit of optical communications can 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, Sevam Institute of Technology

SESSION K7: POSTER SESSION

NITRIDES AND OTHER WIDE BANDGAP SEMICONDUCTORS

Chair: Shin Jang Chang

Thursday, April 4, 2002

8:00 PM
Salon 1-7 (Marriott)

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

Gallium nitride nanowires are synthesized on silicon substrates by chemical vapor deposition reaction of ammonia and gallium nitride powder mixture with ammonia at 1220-1230°C. Iron and iron oxides nanoparticles are used as a catalyst. The diameters of the nanowires are uniform at 25 nm and the height is in the range 5-60 micrometers. 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 the neighboring lattice planes parallel to the growth direction in the gallium nitride nanowires is smaller than that in silicon dioxide 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 stress in the growth direction. In the temperature-dependent photoluminescence (PL) spectrum of the nanowires, a strong broad PL band was observed in the energy range of 2.3-3.6 eV. The broad PL band could originate from the recombination of bound excitons. The various stress experiences 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 METAL ORGANIC CHEMICAL VAPOR PHASE DEPOSITION. H.F. Hong and J.I. Chyi, Institute of Electronic Engineering, National Central University, TAIWAN, ROC.

P-type Mg-doped GaN epilayer films were characterized by photoluminescence (PL) measurement, X-ray diffractometer, secondary ion-mass spectroscopy (SIMS) and x-ray diffraction. The optical transmission and photoluminescence spectra were taken from 500 nm to 2700 nm (4000 cm-1 to 1200 cm-1), and the photoluminescence measurements were done by OMEVA in temperature range between 50°C and 725°C. The typical PL spectra at room temperature, reflection, and transmission were recorded in the 350 nm to 550 nm range with excitation at 325 nm. From the PL spectra results we found that the phosphor sample deposited at 100°C had the highest PL peak intensity. Based upon the low temperature (9K to 15K) PL measurements, the conduction-band-edge-to-concentration level (CA) and donor-concentration (DA) pair emissions are the dominant luminescence mechanisms in the PL spectral responses. Thoroughly, the CA luminescence intensity could be enhanced if the measured temperature increased, since band exciton 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 CA emission intensity remained nearly unchanged. It was believed that this phenomenon was owing to the interplay between two Mg-related trapping centers in the temperature increases. From X-ray diffracted data in this work, the epitaxial nucleation deposited at 1100°C has the narrowest FWHM of the random pattern, along with the highest degree of lattice mismatch. The screw dislocation density also reported.

K7.3 GROWTH CHARACTERISTICS OF GaN/Si[111] EPITAXIAL LAYERS GROWN USING AlxGa1-xN/AIN CILs. Cheol-Ge Lee, Sung-Hee Jung, Seung-Joo Lee, Jeong-Mo Yeon, G. Lee Noh, Cheol-Suk National Univ, School of Advanced Materials Engineering, Chonju, SOUTH KOREA.

The characteristics of AlN nucleation layer which is one layer of AlxGa1-xN/AIN CILs were investigated with the various growth time ranging from 10 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 becomes 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 becomes smaller and higher compared with that of AlN/Si[111] layer grown during 25 min. The surface morphologies observed by SEM of the GaN epitaxial layers which were grown on AlxGa1-xN[150 nm]/AIN CILs showed that the number of thermal etch pits and cracks on surfaces were abruptly decreased with the increase of growth time until 25 min. The surface morphology of GaN/Si[111] epitaxy which was grown on AlxGa1-xN[150 nm]/AIN (30 min) CIL showed that the number of thermal etch pits and cracks on surfaces were abruptly decreased with the increase of growth time until 25 min. The surface morphology of GaN/Si[111] epitaxy which was grown on AlxGa1-xN[150 nm]/AIN CILs showed that a much wider than in a AlN layer, resulting that AlN, which especially doesn’t have yellow luminescence related to various...
K7.4 THE ROLE OF THIN AIR BUFFER LAYER IN ALGaN/N/GaN HETEROSTRUCTURES HAVING HIGH X FROM 0.35 TO 0.5. CheolHo Lee, In-Sook Seo, HwangKeun Ahn, Jeong-Mo Yoon, Byung-Jung B. Kang, Chonbuk National University, School of Advanced Material Engineering, Cheonju, SOUTH KOREA, Yong-Jo Park, Samsung Advanced Institute of Technology (SAIT), Suwon, SOUTH KOREA.

We have studied the role of thin AlN buffer layer of 20 nm thickness grown between GaN and AlGaN/N/GaN heterostructures having high x from 0.35 to 0.5. After growing the AlN buffer layer of 20 nm thickness on GaN/Sapphire (0001) epitaxy, the AlGaN/N heterolayers 1.0 μm thickness were grown at 1070°C with increasing the flow rate of TMGa. The measured Al mole fraction of AlGaN/N layers from each RHEED rocking curve was 0.35, 0.37, 0.45, and 0.5, respectively. As the incorporation rate of Al in AlGaN/N increases, the crystallinity becomes better. The surface morphology observed by AFM of the AlGaN/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 TMGa measurement. However, the crystallinity and surface morphology of AlGaN/N/GaN heterostructures grown without thin AlN buffer layers between AlGaN/N and GaN become generally worse with the increase of x. The resistivities of Al0.4Ga0.6N, Al0.5Ga0.5N, Al0.6Ga0.4N, and Al0.7Ga0.3N measured by four point probe method are 1.35, 18.1, 31.7 and 36.2 ΜΩ·cm, respectively. The resistivity increases with the increase of x in spite of the good crystallinity and the excellent surface morphology. It is considered that the increase of resistivity resulted from the decrease of intrinsic AlGaN/N resistance with the increase of x independent of crystallinity and surface morphology. So, it can be concluded that the thin AlN buffer layer of 20 nm thickness between AlGaN/N and GaN plays an important role for improving the quality of AlGaN/N/GaN heterostructures grown with the increase of x by reducing the thermal coefficient and lattice mismatch between the both.


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 (PLMBE) in order to study the formation of high-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-Ga polarity. We discuss the growth mechanism of a GaN phase structure by reflection high energy electron diffraction (RHEED).

K7.6 LAYER-BY-LAYER GROWTH OF GaN FILMS ON SAPPHIRE BY LOW-TEMPERATURE CYCLIC DEPOSITION / NITROGEN RF PLASMA. P. Sangineto, M. Ichinose, S. Koyanov, L.V. Mello, R. Schwarz, Department de Física, Instituto Superior Técnico, Lisbon, PORTUGAL, H. Alves, B.K. Meyer, Justus-Liebig-University, Giessen, GERMANY.

Recently we have proposed a new layer-by-layer method for deposition of group-III nitrides from elemental precursors (Ga, N2) [1]. This technique is based on a two-step cyclic process, which alternates Pulsed Laser Deposition (PLD) of a metallic tantalum 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 10 nano second nitrogen RF plasma on the GaN thin films. The layers are deposited on pre-nitrided sapphire (0001) substrates at low deposition temperatures (300°C to 500°C) to minimise recrystallisation. The c-axis GaN thin films thus obtained are compared with simple PLD GaN films in term of deposition rate, morphology 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. Koyanov, P. Sangineto, M. Ichinose, L. Schwing, 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.
K7.10 INTERPLAY OF DEFECTS, MICROSTRUCTURES AND SURFACE STOICHIOMETRY DURING PLASMA PROCESSING OF GaN. A. Ramam, Institute of Materials Research and Engineering, SINGAPORE; S. Tripal, Singapore National University of Singapore, SINGAPORE

Despite technological advances, the generation and electronic properties of defects in GaN layers and their effects on device performance are still unclear. In the present study, optical properties of the dry etched pattern of GaN are investigated using x-ray micro-PL and micro-Raman scattering. The damage introduced in the process of plasma etching was assessed and improvement of the optical properties was achieved during post etch annealing. Defect-induced Raman scattering from etched GaN shows impurity induced local vibrational modes. Low temperatures and low PL spectra show a plasmon and a band defect. The results of low-temperature optical properties and their implications in plasma processing. Based on the results of temperature-dependent Raman scattering, the observed changes of the phonon properties of GaN can be correlated 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).

K7.11 HIGH PRESSURE ANNEALING OF GALLIUM NITRIDE FILMS ON SAPPHIRE. F. Kelly, T. Chedelouk, M. Overber, M. Olsson, V. Orcioni, R. Ambrosius, R. 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 expose dopant atoms to substitutional lattice sites to electrically activate them. Annealing, however, is complex because the optical and physical properties of GaN are extremely sensitive to even small changes in the growth temperature. Several groups have measured defects in GaN using x-ray diffraction, Raman scattering, and photoluminescence at various temperatures [900°C - 1200°C]. 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 strains 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 non-surface region, and x-ray diffraction was performed to observe any structural changes in the films upon annealing. Hall measurements were performed on the films after annealing to investigate the effect of the strains 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 bonded GaN films can be correlated. The main emphasis has been on the promise that high pressure anneals in the InSb process may be used to improve electrical and optical properties of GaN films.


The structural and the optical properties of InGaN/GaN multiple quantum wells (MQWs) have been investigated using TEM and XRD. The MQW samples are grown using MOVPE (metalorganic chemical vapor deposition) and high power density excimer laser crystallization. The structural and optical properties of the MQW samples are influenced by the growth conditions, such as the growth temperature, the growth rate, the gas flow rates, and the pressure. The XRD measurements show that the MQW sample has a good crystallinity and the lattice mismatch is less than 1%. The photoluminescence (PL) measurements show that the MQW sample has a high optical quantum efficiency. The PL intensity is strongly dependent on the growth temperature and the growth rate. The PL peak position and the full width at half maximum (FWHM) of the PL spectra are also affected by the growth conditions. The PL peak position shifts to higher energy as the growth temperature increases. The PL FWHM decreases with increasing growth temperature. The optical properties of the MQW sample are strongly affected by the growth conditions. The MQW sample with a high growth temperature and a low growth rate has a higher optical quantum efficiency and a lower PL FWHM.
**SESSION K8: POSTER SESSION**

**QUANTUM DOTS, QUANTUM WELLS, AND SELF-ASSEMBLED STRUCTURES**

Chair: Yong-Ho Zhang

Thursday, April 4, 2002

8:00 PM

Salon 1-7 (Moriject)

**K8.1**

**CATIONIC QUANTUM DEPOSITION USING HELICON PLASMA CVD AT LOW TEMPERATURE**

Masanao Murayama, Takao Yagi, Kohei Inose, Ichiro Saito, Sony Corporation, Atsugi, 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 (HEPCVD) has been used to deposit nanotubes at temperatures from 400°C to 500°C. The helium plasma source is one of the high-density plasma sources and is promising for low temperature carbon deposition. RFbias 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 deposition rate of the carbon nanotube grown by the RF plasma source 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 2V/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; S. Bandara, Optoelectronic 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 GaSb, 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 the size of the quantum dots on the phonon modes are also investigated.

**K8.3**

**NONLINEAR OPTICAL PROPERTIES OF PLASMA ENHANCED CHEMICAL VAPOR DEPOSITION GROWN SILICON NANOCRYSTALS**

Nanocrystals, G. Vigh, M. Pischel, M. Marzouk, Z. Gaburro, L. Pavesi, INFN and Dipartimento di Fisica, Universita di Trento, Trento, Italy; F. Incrociata CNR-IMTECH, Catinaria, Italy; G. Franzo and F. Graditi, INFN and Dipartimento di Fisica, Universita di Catania, Catania, Italy.

We present a systematic study on the nonlinear optical properties of Silicon nanocrystals (SiNCs) grown by plasma enhanced chemical vapor deposition (PECVD). The sign and magnitude of both real and imaginary parts of third-order nonlinear susceptibility of SiNCs are measured by Z-scan method. While the closed aperture Z-scan reveals a sign of positive nonlinearity, the open aperture measurements suggest nonlinear absorption processes. Absolute values of third-order nonlinear susceptibility are in the order of 10⁻⁸ esu and show systematic correlation with the SiNC size, due to quantum confinement related effects. A systematic study on third order nonlinear process was made using different pumping wavelengths to...
KS.4
PHOTOOLUMINESCENCE AND TIME-RESOLVED PHOTO-
OLUMINESCENCE STUDIES OF SELF-ASSEMBLED InAs
QUANTUM DOTS. Xinlin Zhang, Jianrong Dong, Sio 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 incorporation in device applications and in
understanding the fundamental physics of zero-dimensional (0D)
systems. In this paper, we conduct photoelectrical (PLE) and time
resolved PL studies of self-assembled InAs/GaAs quantum dots (QDs)
grown by metal organic chemical vapor deposition. A reduction in the
emission linewidth with increasing temperature is observed at low loss range and
in the valence band 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 behavior of PL and time resolved PL
can be explained in terms of thermal redistribution of carriers and
carrier transfer between laterally coupled quantum dots, either
through the GaAs barrier or through the wetting layer.

KS.5
OPTICAL SPECTRA OF InAs/GaAs QUANTUM DOT ARRAYS
UNDER ILLUMINATION. HT 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
structure included, i.e. electron and hole states associated with
dots, as well as the wetting layer. By modeling the ensemble
of dots simultaneously, it is possible to consider the effect of
an elastic strain field superimposed by inducing the sample with
the near-field scanning optical microscope (NSOM) tip used to illuminate
the dots and detect their emission. To do so, the linear elastic
indention strain field is determined analytically and accounted for
in the Schrodinger equation using deformation potential theory, as
is the nonuniform mis-mach strain due to quantum dot self-
assembly.
The absorption peaks of the individual dots and the ensemble
are shown to be a function of indentation depth. Results of the
calculations compare favorably to recent experimental data.

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

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

Large area hydrogenated amorphous silicon p-i-n structures with low
or high conductivity doped layers were proposed as single element image
sensors. The image acquisition technique consists in using a
modulated light beam to scan the sensor active area and recording the
photocurrent in each scanning position. This work is focused on the
analysis of the dynamic 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 1 kΩ load.

K9.2
SPRAY PYROLYSIS SEEDING FOLLOWED BY CHEMICAL
BATH DEPOSITION OF HIGHLY ORIENTED CdS FILMS.
S. Wijesundera, and P. Makarejeef, Laboratory for Advanced
Materials Science and Technology (LAMAST), Dep. of Physics,
University of South Florida, Tampa, FL; S. Abeyth, 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 CdS/CdS
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 CdCl2 and thiouren
were used, show poor crystal structure. In this paper, we report the
improvements made on film orientation and grain growth by a process
where seed crystals of CdS were formed on glass substrates prior to
chemical bath deposition. A solution containing CdCl2, thiouren,
ammonium hydroxide and ethanol was sprayed on to the substrate at
250°C using an ultrasonic nebulizer. The size of the seed crystals were
controlled by the concentration of CdCl2 and thiouren in the spray
solution while the density was controlled by the time of spray. X-ray
analysis showed a significant improvement in the orientation of the
chemical bath deposited films on seeded glass substrates. Columnar
growth of large grains is visible in cross-sectional SEM micrographs of CdS films deposited on seeded substrates. The effect of the seed
film 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-BRONDISILICIDE/
GERMANIUM HETEROJUNCTIONS. Takashi Furuya, Yoshihiro
Kokubun, Ishinomaki Senshu Univ, Scl of Science and Engineering,
Ishinomaki, Miyagi, JAPAN.

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

K9.4
GROWTH OF InTSb: AS THE ADVANCED MATERIAL FOR
LONG WAVELENGTH APPLICATION. D.B. Gadika, Department
of Physics, Mithila College, Mumbai, INDIA; K.B. Lai and P.
Shandilham, Department of Physics, University of Mumbai, Mumbai,
INDIA; S.S. Chandvarkar and B.M. Arora, Condensed Matter &
Material Science, Mumbai, Mumbai, INDIA.

The use HgCdTe in the fabrication of infrared sensitive imaging
detectors and detector technology is becoming useful, but the growth of
bulk single crystal ingots of HgCdTe remains a topic of interest to the
infrared community. For long wavelengths and for focal plane
arrays the dominant material is HgCdTe. However, the growth of
both single crystal HgCdTe material is difficult due to the weakly bound HgI
compounds and uniform bandgap is not easy. It is also very difficult to
the alternate materials to HgCdTe. An indigenous system as vertical directional solidification (VDS) technique has been
effective for the growth of the high-conductivity crystals. The bulk
crystals of HgI compound were grown without using seed by VDS
method. XRD, EDAX, EMPA and FTIR-Transmission, Hall
K0.5

7x0° MULTI-WAVER PLANETARY REACTOR® AS USED FOR P-HEMT AND HBT APPLICATIONS. Jochen Hofheide, Thomas Schmidt, A. M. P., Michael Behrens, Michael Hauken, Holger Jorgensen, Aixtron AG, Germany.

The AIXTRON Planetary Reactors® are proven to grow extremely uniform films together with a high efficiency of the precursors. The novel reactor in 7x0° configuration is inspired on the proven AIXTRON Planetary Reactor® which, in its 4x0° 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 7x0° configuration established by Hall-effect measurements and homogeneities measured in a Leightest shot resistor 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.

<table>
<thead>
<tr>
<th>Material</th>
<th>doping level [cm^-3]</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaAs</td>
<td>n = 8 x 10¹⁹</td>
<td>1.5%</td>
</tr>
<tr>
<td>Al₀.₅Ga₀.₅As</td>
<td>n = 3 x 10¹⁹</td>
<td>1.1%</td>
</tr>
<tr>
<td>GaInP</td>
<td>n = 1 x 10¹⁷</td>
<td>1.26%</td>
</tr>
<tr>
<td></td>
<td>n = 1 x 10¹⁸</td>
<td>3%</td>
</tr>
</tbody>
</table>

GaInP layers grown in this configuration exhibited a standard deviation of the Ga concentration of 75% resulting in a wavelength standard deviation of 2 nm. The thickness homogeneity on-wafer was 0.5%. Al₀.₅Ga₀.₅As layers exhibited a standard deviation of 0.5% in the Al₂-compontent 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 was shown. In addition, we present modelling results and additional experimental data on wafer-to-wafer and on-wafer thickness homogeneities and compositions of AlₙGaₙAs, GaInP and GaAs which prove the qualification of the 7x0° configuration for the large scale production of p-HEMTs and HBTs.

K0.6

CATHODOLUMINESCENCE AND PHOTOLUMINESCENCE OF CRYSTALINE SILICON-EPIPLATE GROWN ON Si⁺-IMPLANTED (1102) 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. Cho, Dept of Physics, Kyung Hee Univ, KOREA; R. 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 substrate recrystallized with implanted Si were used to improve the characterization of Si-epilayers. Epilayers were grown on Si⁺ at a dose of 5 x 10¹⁵ cm⁻² and subsequently annealed in a conventional furnace at 1100°C for 1 hour. The growth temperature and the thickness are about 500°C and 700 nm, respectively. The crystallinity of the Si layer has been confirmed by transmission electron microscopy (TEM) and double crystal rocking curve (DCRC), and the strain of Si-epilayers is investigated the Raman spectroscopy. Photoluminescence (PL) and cathodoluminescence (CL) have been used to study structural, electrical and optical properties of Si⁺-implanted Si epilayers on the Si⁺-implanted (1102) sapphire substrates. For a comparison, we have prepared the annealed substrate without implantation, and the implanted substrate before annealing, respectively. In Si⁺ implanted samples, the PL and CL spectrums have dominant peaks at about 570 nm and 574 nm, respectively. Especially, it is confirmed that these peaks might be responsible for nano-crystalline Si from the data shift dependent of the incident power and the measuring temperature. Under the forward bias, the crystalline quality of the epilayer on the implanted substrate will be evaluated.

K0.7

ARESIDEN-PHOSPHIDE INTERFACE FORMATION DURING MOVPE OF INDIUM GALLIUM ARSENIDE/INDIUM PHOSPHIDE. Connie Li, Daniel Law, Lin Li, Steven Valsbeck, 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 few 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 AsInP (001) surface exhibits the following reconstructions: (4x2), alpha(2x2), delta(2x2), and disorder (1x4). The corresponding coverages of group V atoms are 0.25, 0.5, 0.75, 1.00 and 1.50 monolayers, respectively. Below 500 degrees C, these reconstructions are generated on surfaces that exhibit a roughness of no more than 5 to 6 atomic layers. By contrast, long exposures of indium phosphide to arsine above 500 degrees C, causes a thick InAsP film to grow on the substrate. This film undergoes strain relaxation with the formation of three-dimensional, faceted microcrystals. The implications of these results for the formation of InGaAs/InP heterojunctions will be described at the meeting.

K0.8

STRUCTURE-SENSITIVE OXIDATION OF THE INDIUM PHOSPHIDE (001) SURFACES. Gangui Chen, Shu B. Vassiliev, 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 metal organic chemical vapor deposition (MOCVD). Then the samples were transferred to a ultrahigh vacuum system, and annealed at 623 and 723 K to produce the (2x1) and (2x4) reconstructions with phosphorus coverages of 1.0 and 0.125 ML, respectively. These structures were exposed to unextracted molecular oxygen, and then the surface and its electron energy spectroscopy (XPS), reflectance difference spectroscopy (RDS) and low energy electron diffraction (LEED). At 298 K and above, the In-rich InP (001) surface rapidly oxidizes upon exposure to O₂. The oxygen dissociatively chemisorbs onto the (2x4), inserting into the In-P back bonds and the In-In dimer bonds. By contrast, the P-rich (2x1) reconstruction does not absorb O₂ up to 5 x 10¹⁵ L at 298 K. Above 433 K, the (2x1) becomes reactive with oxygen inserting into both the In-P back bonds and the In-In dimer bonds. Based on these results, we conclude that the oxidation of indium phosphide (001) is highly structure-sensitive. This means that the oxide-semiconductor interface formed on InP devices can vary widely depending on the process history.

K0.9

OPTICAL PROPERTIES OF SnS₂, SnS₂-Cd, AND SnS₂-Sb SINGLE CRYSTALS. Chong-II Lee, Sungwoo Nii Univ, Dept of Physics, Suncheon, KOREA.

SnS₂, SnS₂-Cd, and SnS₂-Sb single crystals were grown by the chemical transport reaction method by using iodine as a transport agent. High purity (9N) constituent elements were used as starting materials. Transparent layered single crystals (a typical dimension of 1x2x0.2 mm²) with golden yellow color were grown. The grown SnS₂ single crystals are single crystals within the observable range of X-ray diffraction. The single crystals were crystallized in a hexagonal structure with lattice constants a = 3.637 Å and c = 5.887 Å for SnS₂, a = 3.649 Å and c = 5.895 Å for SnS₂-Cd, and a = 3.675 Å and c = 5.845 Å for SnS₂-Sb. Direct and indirect energy band gaps at 6 K were found to be 2.51 eV and 2.94 eV for SnS₂, 2.50 eV and 2.34 eV for SnS₂-Cd, and 2.50 eV and 2.34 eV for SnS₂-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{1}{T - T_0} + \frac{1}{T - T_0^2}

Coefficients for the direct energy band gap were found to be E_g(0) = 2.51 eV, a = 1.86 x 10⁻⁴ eV/K, and b = -108 K for SnS₂, E_g(0) = 2.496 eV, a = 8.92 x 10⁻⁴ eV/K, and b = -128 K for SnS₂-Cd, and E_g(0) = 2.502 eV, a = 6.92 x 10⁻⁴ eV/K, and b = -134 K for SnS₂-Sb. Coefficients for the indirect energy band gap were found to be E_g(0) = 2.94 eV, a = -7.5 x 10⁻⁴ eV/K, and b = 88 K for SnS₂, E_g(0) =
FORMULATION OF TIBS₂ AND TISb₂ THIN FILMS BY HEATING Bi₂S₃-Sb₂S₃ AND Sb₂S₃-Tls₂-Sb₂S₃ THIN FILMS. Veronica Barreto, Jose Campana, M.T.S. Nair, P.K. Nair, Universidad Nacional Autónoma de México, Centro de Investigación en Energía, Temixco, Morelos, MEXICO.

TIBS₂ and TISb₂ 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 Tls₂ deposited on Bi₂S₃ or Sb₂S₃ thin films at 300°C in nitrogen. The chemical bath deposition technique, which is suitable for coating the inside or outside of substrates of any geometry, is employed for the deposition of the different multilayer thin films. The coating bath mixtures were constituted by mannich nitrate, triethanolamine and thioacetamide for Bi₂S₃, antimony trichloride and thiourea for Sb₂S₃ and thallium nitrate, sodium citrate, sodium hydroxide and thiourea for Tls₂. X-ray diffraction studies confirmed the presence of the ternary compounds and the deposited multilayer thin film stack consists of 0.2 to 0.5 mm thickness. Optical characteristics are analyzed from the transmittance and reflectance spectra data and the electrical characteristics from the dark current, photo current, and dielectric measurements. We present that it is possible to form solid solutions of the type Tl/(Bi/Sb)S₂ with tailored properties by heating Sb₂S₃Bi₂S₃-Tls₂ layers.

ULTRA-THIN III-V SUBSTRATES FOR ENHANCING THE PERFORMANCE OF OPTOELECTRONIC DEVICES. K. Julius 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 banded and thinned III-V compound semiconducting substrates is of high technological significance. Establishing reliable wafer bonding processes 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 compound materials. Critical issues such as surface roughness and damage will be discussed. Atomic force microscopy analysis of wafer surfaces after various thinning processes will be compared. Novel device structures enabled by ultra-thin substrates will be presented.

PREPARATION OF THE CuAlS₂·CuAlTe₂ SEMICONDUCTING ALLOYS. Brian Bahns, Olek V. Ilnitsky, Institute of Physics of Neisus and Semiconductors, Minsk, BELARUS, Klaus Bente, Gerd Komschütz, Leipzig Univ, Institut fuer Mineralogie, Kristallographie und Materialwissenschaft, Leipzig, GERMANY.

The I-VL₁₃₋₁ (where Li-Cu, Ag, Al, Al, Ga, In, etc.) ternary semiconductors show various interesting physical properties according to the combination of the constituent elements. These chalcogenide semiconductors are considered to be promising candidates for application in photovoltaics, optoelectronics and devices for transferring and processing of information. The CuAlS₂ and CuAlTe₂ semiconductors have long been recognized as materials with wide gap that made their use for the optical filters and as window material for solar cells. The aims of this paper are (i) the preparation of alloys of the CuAlS₂·CuAlTe₂ system and (ii) the construction of T-x phase diagram by differential thermal analysis and X-ray powder diffraction. To obtain the ternary copper Tellurides and their alloys two methods were developed. One of them was the two-zone vertical method using elements of 99.999% (copper) and 99.999% (Tellurium). The ingots 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 2500K 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 CuAlS₂ and CuAlTe₂ compounds. The procedure of analysis of the X-ray diffraction patterns was performed by using the 32mm-line of a He-Cd laser as an excitation source. Emission peaks were observed at 2.214 eV and 7.97 eV for CuAlS₂, 2.214 eV and 1.89 eV for Sb₂S₃, and 2.214 eV and 1.89 eV for Sb₂S₃. The thermal analysis was analyzed to be originated from donor-acceptor pair recombination.

This work was supported by Korean Research Foundation Grant (KRF-2001-015-DP1062).

TX PHASE DIAGRAM OF THE CuAlS₂·Al₂S₃ QUASINARY SYSTEM. Harys V. Korzun, Ruslan R. Mirzabekov, Institute of Physics of Solids and Semiconductors, Minsk, BELARUS; Klaus Bente, Gerd Komschütz, Leipzig Univ, Institut fuer Mineralogie, Kristallographie und Materialwissenschaft, Leipzig, GERMANY.

In recent years growing interest has been shown to complex semiconducting compounds I-VL₁₃₋₁ where c (Cu, Al, Ga, In, etc.)-Te, Se, S these chalcogenide semiconductors are considered to be possible candidates for application in photovoltaics, optoelectronics and devices for transferring and processing of information. The CuAlS₂ semiconductor is one of these compounds and has a wide direct gap of 3.5 eV making it suitable for the use as window material for solar cells. CuAlS₂ has been studied largely but there is not the information about their region of homogeneity in the literature. This compound is crystallized in an hexagonal lattice and can exist in two stable modifications that may be divided into equal parts (the Cu₃S·CuAlS₂ and CuAlS₂·Al₂S₃ systems). The aims of this paper are (i) the preparation of the CuAlS₂·Al₂S₃ system and (ii) the construction of T-x phase diagram by differential thermal analysis and X-ray diffraction. To obtain the CuAlS₂ and Al₂S₃ compounds and their alloys the method of melting of the constituent elements of 99.999% (copper) and 99.999% purity (aluminum, tin, sulfur) was used. The ingots were sealed in evacuated double quartz ampoules and then placed into electric furnace. The crucible from BN with the alloy elements component was heated to the temperature higher above 2800K that the melting point of the corresponding alloys. The phase equilibria in the CuAlS₂·Al₂S₃ system were investigated by means of X-ray diffraction and differential thermal analysis. It was discovered only the formation of CuAlS₂·Al₂S₃ compound in this system. CuAlS₂ has the peritectic character of melting with the temperature 1363K. The melting point was 1269K for Al₂S₃ and 1430 K for CuAlS₂. The T-x phase diagram of the CuAlS₂·Al₂S₃ system has the eutectics at 0.88 mole part of Al₂S₃ and 1269K. The region of formation of solid solutions on Al₂S₃ side does not exceed 0.05 mole part of Al₂S₃ as the room temperature.

CHARACTERIZATION OF ROOM-TEMPERATURE FERROMAGNETIC Co₃Zn₇₋₆ O. Shaoguang Yang, Shen T. Hung, A.B. Pokrovov, C.Y. Wong, Magnetic Innovation Center (MAGIC), Material Characterization and Preparation Facility (MCPP), Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, 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 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 Zn₁₋₆Co₂O₃ is present in small quantity. The films are transparent (having light green color) in a wide optical wavelength range, over the entire visible region (400 nm, and several local adsorption maximum corresponding to Co⁺ ions. Measurements of magnetic hysteresis loops and magnetization as a function of temperature show ferromagnetic behavior of up to 350K (the maximum temperature used in the experiments). The value of spontaneous magnetization at 300 K is about 4.7 emu/cm³. Optical transparency spectrum shift with external applied magnetic fields have also been observed at room temperature. A proposed model on our experiments will be described.

K9.15 MATERIAL ISSUES IN THE LAYERS REQUIRED FOR INTEGRATED MAGNETO-OPTICAL ISOLATORS.
Lian J. Cruz-Rivera, Sung-Yeob Sung, Jessie Casalini, Martin R. Marrero-Cruz, and Bethanie J.H. Stader, 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 explore technology for a more compatible process, the critical active material in monolithically integrated magneto-optical isolators; yttrium iron garnet (YIG: Fe3O4). By using the radio frequency (RF) sputtering was used to grow YIG on MgO, which is promising buffer layer material for optical devices. By thermally isolating the samples during growth, films crystallized in situ without the use of a substrate heater.

Further optimization includes post deposition processing, such as low temperature anneal. We have shown previously that fully amorphous as-deposited samples could be crystallized well below the sintering temperature of YIG (~800°C). The samples grown 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 chalcopyrite laser crystals 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. Sukh, 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 photoresists coated over these CVD films at deep ultraviolet (DUV) wavelengths has been evaluated. The specific monomers synthesized for DUV applications include [2,5]-[1,4]-naphthalenedicarboximide, [2,5],[1,4]-naphthalenedi-1,4-diamine. Further optimization includes post deposition processing, such as low temperature anneal. We have shown previously that fully amorphous as-deposited samples could be crystallized well below the sintering temperature of YIG (~800°C). The samples grown 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 chalcopyrite laser crystals 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.

K9.17 PHOTOLUMINESCENCE OF NANO SCALE ZnS Ms PHOSPHOR POWDERS. H.S. Hsu*, Li-Ging Chen, Chih-Shyang Hwang, F.S. Jung*, S.J. Chang*, and Y.K. Su*; Department of Materials Science and Engineering, National Cheng Kung University, Tainan, Taiwan, R.O.C.; Department of Physics and Optics Engineering, National Taiwan Inst. of Tech., Hsinchu, Taiwan, R.O.C.; Department of Electrical Engineering, National Cheng Kung University, Tainan, TAIWAN, R.O.C.

Nano-scale ZnS Ms phosphor powders were synthesized by solid state calcination, solvothermal, and microemulsion methods respectively. The processing parameters such as particle size distribution, chemical composition, structural properties, etc. are characterized by DTA/TGA, XRD, FTIR, SEM, TEM, and BET. All the nano-scale YAG powders were heat treated below 800°C. Both TEM and XRD results of these nano-scale YAG powders show high degree of crystalline structure. Photoluminescence (PL) characterization shown that the nano-scale ZnS Ms phosphor powders has a higher intensity of luminescence than that of sub-micro sized sample. The effect of different Ms doping level on the PL intensity shows a maximum at x ~ 0.01 to 0.1. The effect of particle size on the PL intensity will also be reported. Supported by NSC-94-2216-E-006-GO

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

For 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 photoelectron coherent emission. In this work we present a novel technique to obtain valence band split from the Fourier spectrum of PR for GaAs and InAlAs. A line combination of FPKs of HH and LH is adopted as trial function. Besides two linear coefficients, the band gaps for HH and LH are also treated as adjustable 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 theoretical calculation using three-band and strained Hamiltonian.

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

A series of organic photovoltaic (PV) cells in which the electron acceptor and n-gadolinium(dinaphthalenediimine) ,bathophenanthroline) [Gd(DBM)] salt and donor N,N'-diphenyl-N,N'-bis(1,10-phenanthroline) 1,1'-diphenyl-4,4'-diamine [TDP] were fabricated. The PV diodes can show EL emissions from the interface between TPD and Gd complex. Open circuit voltage (Voc) of 3.2 V was obtained due to efficient excitation dissociation near the interface between Gd with TPD salt and TDP, and while 5.1 eV was tuned the diode can give yellow which is only from the interface because the yellow band decreased from that from TPD, and Gd complex is not emitted. We also observed that energy conversion efficiency was significantly improved by inserting an ultrathin mixed layer of Gd complex and TPD into between TPD and Gd complex. /IT OTPD/TDP:Gd complex/Mg:Ag. So we can demonstrate that photovoltaic effects of the diodes should be enhanced with interface states between the two organic layers, that is, exciton 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, Phan thi Minh Chau, Nguyen Thanh Oanh, Tran Thu Huyen, 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 solgel method from tetraethylorthosilicate, in which blended different polymers. The dyes are Rhodamin 6G, Coumarin 540 and the RE ions as Eu3+, Eu3+ which were embedded in these matrices. The optical properties such as Raman scattering, infrared absorption, fluorescence, photoluminescence excitation spectra and lifetime were investigated. The Eu and Er transitions in visible and infrared regions, the influence of dyes, Eu, Er concentration, temperature condition to optical properties and their application in optoelectronic and photonic studies was studied.

K9.21 (Au Er) DOPED PLZT WAVE-GUIDE PREPARED BY SOL-GEL PROCESSING. Nora Pellegri, Oscar de Sanctis, Laboratorio de Ceramica, FCE/Y, UNR, Rosario, ARGENTINA; Agusti Francesco, Area Faica, FCE/Y, UNR, Rosario, ARGENTINA; Rui da Almeida, INESC, Lisbon, 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 (n>2.5) and low-temperature synthesis. On the other hand, Er3+ 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 the fluorescence by the increase of Er concentration has a cut-off due to the strengthening of the ion-ion interaction that reduces the Er fluorescence intensity and lifetime. The sol-gel technique allows the incorporation of high Erbium concentrations in silica matrices and obtaining fulldense film at lower temperature than possible by other methods. In this work, (Au, Er$^{3+}$) doped (PbO$_x$,Na$_{1-x}$) (Zn$_{0.5}$Al$_{0.5}$)$_2$O$_3$ planar wave-guides have been prepared by sol-gel processing using multiple spin-coating deposition on silica glasses. 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 reactivity by photoreduction from metal, and anchoring sol-gel-compatible modifiers on their surfaces. GI X-ray diffraction, TEM, ellipsometry, FT-IR and Raman spectroscopy were used to characterize the structure, nonresidual 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 POLYSILANOL FILMS USING CVD
John P. Lock and Karen K. Gleeson, 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) employs a wide variety of gas-source 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 films by conventional spin-on methods. Fourier Transform Infrared Spectroscopy (FTIR) indicates the presence of Si (CH$_3$)$_x$, Si(C$_6$H$_5$)$_x$, and Si-H bonding environments and also detects the presence of oxygen contamination in the films. Selective use of X-ray Photocurrent 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 260 nm. The films fluoresce under ultraviolet light and the collection of photoluminescence spectra is underway.

SESSION K10: UNIQUE MATERIALS,
PROCESSING, AND CHARACTERIZATION
Chair: Dieter Bimberg and Anupam Mukherji
Friday Morning, April 5, 2002
Nab Hill C/D (Memorial)

S8:30 AM #K10.1

SUPPRESSION OF BULK DEFECTS IN ANTIMONIDE SUPERLATTICE INFRARED PHOTODIODES

While the intrinsic physical properties of ideal antimonide superlattices (ASL) indicate that they should significantly outperform mercury cadmium telluride (MCT) based infrared photodiodes for low dark current applications in the long and very long wave-infrared (LWIR and VLWIR), this potential has not yet been fully realized. Even though measured Auger and tunneling rates in ASLs are reduced as predicted, overall carrier lifetimes remain much shorter, and dark currents much higher than expected. The large carrier losses are the result of defects in the ASL structure, with contributions from 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 deposition rates. Interferometric cross-sectional transmission electron microscopy (XTEM) of ASLs have shown that many large bulk defects originate at the epilattice interface and are amplified during growth. The generation of these defects is strongly influenced by a number of growth variables including substrate preparation, substrate orientation, oxide removal procedure, growth temperature and MBE flux composition. The dependence of defect evolution on these factors is investigated systematically in a series of sequential and side by side growths to isolate individual mechanisms and identify them using structural and compositional analysis. We also discuss 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 defect states 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 BUFFER BY SOLID SOURCE MBE
Masato K. Hidaka, Yong Lin, Carl B. Anderton, Prashant M. Sinha, Steven A. Green, The Ohio State University, Dept of Electrical Engineering, Columbus, OH; D.M. Wilt, NASA Glenn Research Center, Photonics and Environment Branch, Cleveland, OH.

InAsP alloys are receiving attention for infrared optoelectronic applications due to the wide range of infrared bandwidths. For applications involving infrared energy conversion, the electronic quality and structural properties of bulk, relaxed InAsP layers having specific bandwidth energies are critical to enable good device performance. However, little information is available concerning the dependence of bulk electronic and structural property correlations on InAsP composition. This paper presents a systematic study of structural and electronic properties of strain-relaxed InAsP layers grown on step-graded InAsP buffers on InP, for As mole fraction of 0.65, 0.30 and 0.34 using solid source molecular beam epitaxy. An optical In ratio of 7.1 for InAsP growth was obtained by first monitoring the mobility of InP layers as a function of InP ratio. To achieve the range of targeted InAsP compositions, the As In ratio was then adjusted accordingly while maintaining a InP 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. New complete relaxation of final layers, determined by high-resolution X-ray diffraction composition with well-developed surface 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 0.65 to 0.34. Electrochemical C-V profiling confirmed that a uniform doping concentration was achieved for each film. Complete details of the structural and electrical properties of relaxed InAsP layer will be discussed and correlated to growth parameters.

9:15 AM K10.3

OPTICAL PROPERTIES OF PLANAR CHIRAL META-MATERIALS
A. Potts, A. Papakostas, D.M. Bagnall, University of Southampton, Dept of 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 necessitating life. It is also of potential importance in the engineering of opto-electronic properties in photonic structures. Interest in this area has grown since it was recently shown how structures with both negative permittivity and negative permeability can be engineered in non-magnetic materials [1,2]. Such metamaterials have several unusual properties not found in nature, including negative angles of refraction and phase velocities. More recently, theoretical attention has tended to move metamaterials that are also sensitive to different polarisation states of light. Until now, no experimental work has been undertaken on metamaterials in the visible or infrared parts of the electromagnetic spectrum, even though such materials would potentially have many applications in areas such as optical communications and quantum cryptography. We have now fabricated planar chiral metamaterials with critical dimensions in the sub-micron regime that do indeed interact with light in the visible and infrared parts of the spectrum. These structures have been found to exhibit novel and unpredicted optical responses when illuminated with both linearly and circularly polarized light. Their responses are also size and geometry dependent, thus allowing their properties to be tailored to the 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, 2727 (1996). [2] J.B. Pendry, A.J. Holden, D.J. Robbins and W.J. Stewart, IEEE Trans. Microwave Theory Tech. 47 4785 (1998).
WATER-BASED 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, Tescan 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 has been shown to provide flexibility of materials selection to allow band gap optimization in solar cell design. We have successfully used direct wafer bonding along with hydrogenated layer splitting of Ge on Si to transfer single-crystal Ge(100) films to Si(100) substrates without using a metallic bonding layer. Ge substrates with a 7 μm thick film of Ge were used to transfer 600-700 nm thick films on the order of 1 cm² for Ge/Si. Hydrophobic passivation and less than 1 nm rms surface roughness as measured by contact mode AFM along with ~7 MPa bond initiation pressure are suitable surface conditions for reversible room temperature bonding of Ge/Si to occur. Layer splitting is induced by a thermal cycle up to 250°C under 2.5 MPa normal pressure immediately followed by a thermal cycle up to 450°C under 0.5 MPa normal pressure heating. Electrical measurements indicate identical to the Ge p⁺ substrates bonded to Si p⁺ substrates with ~12 Ω cm²-2 resistance, sufficient to allow low-loss power extraction through backside contacts and junction solar cell structures have been grown on Ge/Si heterostructures. These devices exhibit photo-luminescence 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.


ROOM TEMPERATURE ULTRAVIOLET NANOLASERS.

Haoqun Yan, Peidong Yang, Univ. of California-Berkeley, Berkeley, CA.

ZnO nanowires were successfully synthesized by a simple vapor transport and condensation process. Room temperature ultraviolet laser behavior has been demonstrated in these single-crystalline ZnO nanowires. Growth in a preferred direction <0001>, these wide bandgap semiconductor nanowires form natural resonance cavities with diameters varying from 20 to 150 nm and lengths up to 40 μm. Under excimer laser excitation (~312 nm), a lasing action was observed at a near-UV wavelength of 385 nm with an 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.

PHOTONIC BISTABILITY BASED ON ONE SINGLE LARGE AREA n-SiC P-N-L-N PHOTODIODE.

M. Vieira, M. Fernandes, A. Fantoni, P. Louro, R. Schwarz, Electronics Telecommunications and Computer Dept., ISEL, Lisbon, 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 application allowing the fingerprint guessing on glass surface in front of the capture device. The reflected light coming from the glass is projected onto the active surface of the sensing element (large area n-SiC p-n-p photodiode). The image is converted directly into the electrical signal by 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 (photoresponse, defect density, temperature dependence, thickness), on the device performance (transistor functions, sensor sensitivity, dynamic range, resolution, linearity, responsivity, response time).

The scanning technique for fingerprint acquisition is improved and the effects of the probe beam size, wavelength and flux, the scan time and modulation frequency on image quality and resolution will be analysed under different electrical bias. An optical model of the image acquisition process is presented and supported by a two dimensional simulation. Results show that a trade-off between read-out parameters (fingerprint scanner) and the biometric sensing element structure (p-n-p 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/p low conductivity doped layers the unspecific information is detected with a good contrast while the resolution of the sensor is around 20 μm. A further increase in the contrast is achieved by slightly reverse biasing the sensor with a sensitivity of 6.5 μV/cm² and a flux range of two orders of magnitude.

EPITAXIAL GROWTH OF ZnO ON Si(111) USING AlN AS A BUFFER LAYER.


ZnO (hexagonal Wurtzite structure) is a promising material for optical, electrical, and laser applications. Because of its higher exciton binding energy, it is considered to be a better alternative for GaN. The optical growth of ZnO has been realized on sapphire substrates, but for integration with silicon micro-electronic 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.

SYNCHROTRON RADIATION PHOTOEMISSION STUDY OF SURFACE CHEMISTRY OF InP(100) BY HYDROGEN PEROXIDE-BASED SOLUTIONS.

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InP is an important semiconductor in many applications. A clean surface is necessary 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, the 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 but not In(III) is reduced. Hydrogen peroxide solutions leave the InP(100) surface with more than 0.5 monolayer of oxide, which can not be removed completely by vacuum annealing, while the GaAs(100) surface is left with two monolayers of elemental As, which can be removed by vacuum annealing. A clean GaAs(100) surface. The understanding 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 phosphine and its transformation to metaphosphine 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.

SENSITIZED PHOTOLUMINESCENCE OF RARE EARTH IONS DOPED INTO MEPOSOROUS TITANIA THIN FILMS.

Karen L. Readell, Department of Chemistry and Biochemistry, University of California, Santa Barbara, CA; Michael H. Burt, Department of Chemistry and Biochemistry, University of California, Santa Barbara, CA; Galen D. Stucky, Department of Chemistry and Biochemistry, University of California, Santa Barbara, CA.

High concentrations of rare earth ions have been incorporated into self-assembled mesoporous titania thin films to form a new, photoluminescent material, which operates via efficient energy transfer from the titania to the rare earth ions. The structure of the mesoporous material is composed of a cubic network of pores with a, walk made of 1.3 nm x 1.3 nm x 1.3 nm 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 tin-tin nanocrystals can be used to sensitize these ions via energy transfer. In a film doped with europium [III] ions, irradiation of the tinatin within its band gap produces the bright red photoluminescence observed. The thin europium films directly excited by the europium produces no observable emission from the films.


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 alkalide 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 startlingly 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 ≈200 nm-thick epitaxial LiAlO$_2$ interlayer on 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 LiNbO$_3$-O phase or, possibly, a niobium oxide. TEM revealed no second phase inclusions associated with the LiNbO$_3$ grain boundaries or the LiNbO$_3$/LiAlO$_2$ 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. Saeed Karmatt, Radeekson Songmang, and Oliver G. Schmidt, Max-Planck-Institut für Festkörperforschung, Stuttgart, GERMANY.

Extremely homogeneous arrays of nanocavities and nanoholes are fabricated using molecular beam epitaxy growth and in situ etching. Self-assembled evolution of exotic behaviors have been grown using a low indium growth rate on GaAs (001) substrate. If these nanocavities are copped with GaAs at low temperature (470°C), strong room temperature emission at 1.3 μm with a linewidth of 22 meV from the holes has been observed. A homogeneous array of nanocavities is fabricated by in situ etching the GaAs surface of copped InAs nanocavities with Ar+ ion Scanning. The nanoholes have a depth of 5–6 nm and the lateral size is 55–60 nm in the [110] direction. We appoint the formation of nanoholes to a pronounced selectivity of the Ar+ ion to local strain fields. The holes can be filled with InAs again such that a flat surface is recovered. The etched and regrown structures show intense photoluminescence at room temperature.

SESSION K11: QUANTUM DOTS AND QUANTUM WELLS.

Chair: Katharine Davianenko and John E. Cunningham Friday Afternoon, April 5, 2019

130 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. Moulduc, University of Southern California, Departments of Materials Science and Physics, Los Angeles, CA, Z. Ye, and J.C. Campbell, The University of Texas at Austin, Microelectronics Research Center, Department of Electrical Engineering, Austin, TX.

Epitaxial self-assembled semiconductor quantum dots are attractive candidates for mid- and long wavelength (3-14 μm) photodetectors. We report on normal incidence n-type quantum dot infrared photodetectors (QDIPs) with undoped active region (n-nn configuration) composed of InGaAs capped GaAs (001) InAs QDs. The InAs QDs were grown on GaAs (001) at 4.1°C growth temperature. The InAs QD size, density, as well as the structure and defect density of QDIPs were characterized using atomic force microscopy and cross-sectional transmission electron microscope. The InAs QDs embedded in the n-nn QDIP structures have been.
comprehensively characterized using photoluminescence (PL), PL excitation, and FTIR based internal and interband photocurrent spectroscopy. Three types of infrared photoluminescent quantum dot (QD) structures 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 photoreceptor wavelength of ~8.5 µm, and (ii) bias-controlled tunable two-color (~5.6 and ~1.0 µm) QDIPs. The ~8.5 µm QDIPs are based on a set of five layers of 2.0 and 2.5 monolayer InAs QDs, respectively. Two types of QDs with different size/shape existing in a single QD layer and between different QD layers account for the observed two-color behavior. The results show that detection and selectivity of these QDIPs will be presented. At 77 K, the two color QDIPs show an intraband peak detectivity of 5.3 x 10^{10} cm Hz^{1/2} W^{-1} at ~5.6 µm and of 7.3 x 10^{10} cm Hz^{1/2} W^{-1} at ~1.0 µm. Approaches to improving detectivity are underway and will be discussed.

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

Recently we reported the first room-temperature injection laser, based upon self-assembled InP quantum dot [1]. In this contribution the lasing characteristics of InP quantum dot (QD) lasers are compared with a commercially available InGaAs/InP quantum well (QW) laser, grown by solid source molecular beam epitaxy under equivalent conditions, which both emit near the same wavelength. Our comparison is suitable to study the fundamentally different charge carrier population mechanisms and laser properties of QDs and QWs. Both devices exhibit an increase in output power and tunability at room temperature with threshold current densities of 8.5 kA/cm^{2} at a wavelength of 792 nm for the QD structure and 3.0 kA/cm^{2} at 741 nm for the QW structure. For T < 80 K both devices have threshold current densities smaller than 5 kA/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 QD device lases from the ground state already at 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 excited states with low ground state current densities.

2:30 PM K11.6 TIME RESOLVED STUDIES OF PROTON IRRADIATED QUANTUM DOTS
T. Heinrich, Royal Inst. of Technology, Dept. of Microelectronics and Information Technology, Kista, SWEDEN; R. Leon, Jet Propulsion Laboratory, California Inst. of Technology, Pasadena, CA; C. Lob, Cambridge Univ., Cavendish Laboratory, Cambridge, UNITED KINGDOM; B. Magnes, W. Taylor, California State Univ, Dept. of Physics and Astronomy, Los Angeles, CA.

Proton irradiation induces structural defects and creates carrier trapping centers in semiconductors. First studies of steady-state optical properties of proton-irradiated quantum dot (QD) structures and QD lasers showed that the QDs are much more resistant to proton irradiation than bulk semiconductors or quantum wells (QW). In the present work we extend these investigations by studying carrier dynamics in irradiated quantum structures. To get a better understanding on the irradiation influence on the carrier dynamics in the QDs, we investigated a number of different QD structures, differing in material (InGaAs/InGaAs 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 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 22 ns for the unirradiated sample to 14 ns for the sample with the highest proton dose of 3.5 x 10^{16} cm^{-2}, compared to a 1000-fold decrease for the QW. Moreover, we observe some increase in the QD PL intensity in the low-dose 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.

3:15 PM K11.7 SURFACE MODIFICATION OF CdSe NANOCRYSTALS WITH LINEAR AND DENDRITIC ORGANIC LIGANDS: STABILITY AND OPTICAL PROPERTIES.

Semiconductor nanocrystals possess unique optical and electronic properties due to size quantization effects at the nanometer scale. Such nanocrystals (NCs) are usually capped with organic molecules to prevent chemical and electrostatic interaction. Surface modification of NCs is an important issue because the properties of absorbed molecules modify the stability of the NCs, influence their optical properties and control their compatibility with the actual environment. Here we described the surface modification of CdSe nanocrystals with various electron donating linear and dendritic ligands. In addition to various linear modifiers with monofunctional ligands, also multifunctional poly(aminomethane) (PAMAM) dendrimers carrying different numbers of propyl or methyl substituents were used. Due to the high exchange rate of the original TOPO/TOP cup was achieved through a CdSe/polymer 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 month period as a function of time. They showed that the stabilization of the nanocrystals is improved by secondary and tertiary amines provided a better protection for the nanocrystal than those with primary amines.

3:45 PM K11.8 DEFECT FREE InGaAs-BASED STRAIN BALANCED MQW GROWN ON VIRTUAL SUBSTRATE BY METALLORGANIC CHEMICAL VAPOR DEPOSITION.
Adriano Passacant, Roberto Cingolani, NanoNanotechnology Laboratory, INFM, Dep. Ing. Innovazione, University of Lecce, Lecce, ITALY.

In the last years great effort has been dedicated to the study and fabrication of optical electronic devices containing InGaAs quantum dot (QD) structures as active layers, for 1.3-1.5µm operation. However, even if room temperature lasers emitting in the 1.3mcs region have been recently fabricated by Molecular Beam Epitaxy (MBE), long-wavelength lasers 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 50%/50% quantum dot/metalorganic semiconductor double heterostructures, we 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 integrated dipole field, 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 electrons (whereas 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. Therefore, showing us that the 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.

4:00 PM K11.8 STRAINED HETEROSTRUCTURES ARE CURRENTLY USED FOR A LARGE VARIETY OF MICRO-ELECTRONIC DEVICES, INCLUDING HIGH EFFICIENCY PHOTOLITHOTIC CELLS.
InGaAs/GaAs strain balanced MQWs have recently been the subject
of extensive studies, both for solar and thermophotovoltaic applications, due to the possibility to extend the cell absorption edge to lower energies respect to the lattice mismatch limitation. In this work we will describe a novel system for photovoltaic applications which combines InGaAs based strain-balanced MQW with a "virtual substrate", designed to extend the absorption edge of the photovoltaic devices to about 1 eV. The virtual substrate is designed by properly choosing a sequence of InGaAs layers having different In content, in order to obtain the desired lattice parameter at the topmost layer and to confine at the most deep interfaces the misfit dislocations, well away from the QW active region. On the basis of this design, we have grown, by metalorganic chemical vapor deposition, a series of InGaAs p-i-n junctions deposited on different virtual substrates and containing a strain balanced MQW in the intrinsic region. In all the samples the virtual substrates were proved to be successful to grow zero net strain MQW and to confine defects at the buffer/substrate interface. Transmission electron microscopy observation shown that, apart from the surface undulations caused by the non homogeneous strain field induced by the confined dislocations, no defects propagate from the strain accommodating layers to the active region. The total density of threading dislocations reaching the surface was found to be less than $1 \times 10^{5} / \text{cm}^2$. 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.