SYMPOSIUM H

Progress in Semiconductor Materials for Optoelectronic Applications

November 26 – 29, 2001

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SESSION H1: LOW CONCENTRATION NITRIDE ALLOYS I
Chairs: Eric Daniel Jones and Satyen K. Deb
Monday Morning, November 26, 2001
Room 312 (Hynes)

NOTE EARLY START

8:00 AM H1.1
LUMINESCENCE CHARACTERISTICS OF InGaN-InP QUANTUM WELL STRUCTURES BY IMPURITY-FREE VACANCY DISORDERING. J. Zhao, X.D. Zhang, Y.C. Wang, J.C. Deng, Dept of Physics & Inst of Mat Sci, Tianjin Normal University, PR CHINA; Z.C. Feng, Axcel Photonics, Marlborough, MA; G. Xu, Department of Mat Sci & Engineering, McMaster University, Hamilton, CANADA.

In fabricating luminescence devices for integrated optoelectronic and photonic application, InGaAs-InP multiple quantum wells (MQWs) structures have attracted research interests. Post-tuning of optical band gap energy can be achieved from these MQW structures, which possess the advantage to avoid the complicated post growth processing. Several technical approaches have been explored to achieve this purpose, among which impurity-free vacancy disordering (IFVD) technique shows more promising because it can keep high crystal quality and low optical propagation loses as well as does not introduce free-carrier concentration. IFVD, utilizing a dielectric layer as Ga sink at elevated temperature, could result in the redistribution of Ga vacancies in MQW structures to enhance quantum wells intermixing and thus to enhance the luminescence. We have also employed SiO_2 and Si_3N_4 as well as spin on glass (SOG) as dielectric layer in IFVD of InGaAs/InP system, for the first time. In this paper, a systematic investigation on luminescent characteristics of InGaAs/InP MQW system using SiO, SiN and SOG as dielectric layers in IFVD is reported. Photoluminescence (PL) was measured by a Fourier transform near infrared (NIR) PL system at a varied temperature range of 10-300 K. Band gap blue shift of InGaAs/InP MQW structures by IFVD was found to vary with different dielectric layers and depend on the annealing temperature. These are due to the mechanism of quantum well intermixing, which was confirmed through the corresponding secondary ion mass spectroscopy (SIMS) measurements. Our results also show that the dielectric capped layer and rapid thermal annealing (RTA) could cause the quantum wells intermixing which results in the band gap blue shift. Optimum condition can be reached by suitable dielectric choice and annealing condition.

8:15 AM H1.2
SYNTHESIS, MICROSTRUCTURE, AND OPTICAL PROPERTIES OF (InGa)(AsN) NANOSTRUCTURES. X. Weng, S. Clarke, S. Kumar, and R.S. Goldman, Dept. of Materials Science and Engineering; V.H. Rotberg, Dept. of Nuclear Engineering and Radiological Sciences; S. Krishna and P.K. Bhattacharya, Dept. of Electrical Engineering and Computer Science; J. Holt, J. Sipowska, and A. Francis, Dept. of Chemistry; A. Daniel and R. Clarke, Dept. of Physics, University of Michigan, Ann Arbor, MI; J.C. Mabon, Frederick Seitz Materials Research Laboratory, University of Illinois, Urbana, IL.

Mixed anion nitride-arsenide compound semiconductor heterostructures are promising for devices with emission or detection wavelengths throughout the near infrared range. However, a consequence of the large N-As size difference is a predicted limited miscibility of (InGa)(AsN) on the anion sublattice, which leads to the formation of phase separation-induced alloy nanostructures [1,2]. We have examined the synthesis, microstructure, and optical properties of a new class of light-emitting (InGa)(AsN) nanostructures. Using a variety of implantation and rapid thermal annealing conditions, we have implanted N ions into both GaAs and InAs. For 50 keV N ion implanted GaAs and InAs substrates, high resolution cross-sectional transmission electron microscopy reveals ~5nm diameter amorphous nanostructures surrounded by crystalline matrices. For 100 keV N ion implanted GaAs epilayers, crystalline nanostructures surrounded by disordered matrices are apparent. Electron and x-ray diffraction indicate that these nanostructures possess symmetry and lattice parameters similar to that of cubic GaN. Significant photo-luminescence in the near infrared range is observed, and depth-dependent cathodoluminescence spectroscopy suggests that this peak is related to the GaN-rich nanostructures. The apparent lowering of the fundamental band gap 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 will discuss the mechanisms of formation and coarsening of these nanostructures, correlations between their optical and structural properties, and comparisons with similar alloys and nanostructures synthesized by reactive molecular beam epitaxy.
[1] R.S. Goldman et al., Appl. Phys. Lett. 69, 3698 (1996), J. Electr. Mater. 26, 1342 (1997). [2] H.P. Xin et al., Appl. Phys. Lett. 74, 2337 (1999).

8:30 AM *H1.3
ELECTRONIC AND OPTICAL ANOMALIES IN COMPLEX NITRIDE ALLOYS. Laurent Bellaiche, University of Arkansas, Physics Department, Fayetteville, AR.

The band-gaps of the random (Ga,In)(As,N) alloys lattice-matched to GaAs and InP have been calculated as a function of the nitrogen composition and as a function of pressure, by using a new pseudopotential technique. The calculations are in excellent agreement with the experimental results, which are only available for small nitrogen compositions. In particular, the calculations reproduce very well the large red-shift of the band gap with increasing nitrogen compositions. The band-gap of both lattice-matched systems is predicted to significantly decrease when further increasing the nitrogen content. As a result, the band-gap of both systems crosses very important technological spectral regions, and even closes for large-enough nitrogen compositions! Furthermore, long-range-ordering is found to drastically affect the optical and electronic properties of lattice-matched (Ga,In)(As,N) alloys. Other anomalies occurring in the Ga(As,P,N) complex nitride alloy will also be demonstrated. Discussion about the effects responsible for these unusual behaviors is provided.
Done in collaboration with A. Al-Yacoub (University of Arkansas), E.D. Jones and N.A. Modine (both at Sandia National Laboratories, Albuquerque).
Supported by ACS-PRF grant N 34892-G, the ORAU Ralph E. Powe Junior Faculty Enhancement Award and NSF grant DMR-0080054.

9:00 AM *H1.4
OPTICAL CHARACTERIZATION OF III-V-N ALLOYS.
I.A. Buyanova, W.M. Chen, N.Q. Thinh, G. Pozina, P.N. Hai, Linkoping University, Dept of Physics and Measurement Technology, Linkoping, SWEDEN; H.P. Xin, C.W. Tu, University of California at San Diego, Department of Electrical and Computer Engineering, La Jolla, CA.

Nitrogen containing III-V-V alloys, such as Ga(In)NAs and GaNP have in recent years emerged as a subject of considerable theoretical and experimental research interest, due to their very unique physical properties and a wide range of possible device applications. In this paper we review our recent results from optical characterization of MBE-grown III-V-N alloys with N content up to 4.5%, by employing photoluminescence (PL), PL excitation, and time-resolved PL spectroscopies as well as optically detected magnetic resonance (ODMR) and cyclotron resonance (ODCR) studies. The issues have been addressed include basic electronic properties of the alloys and key material-related problems relevant to optoelectronic device applications, such as identification of dominant recombination processes in the alloy, compositional dependence of the electron effective mass and band alignment in the heterostructures. The dominant PL mechanism has been determined as being due to recombination of excitons trapped by potential fluctuations of the bandedge, due to composition disorder and strain nonuniformity of the alloy. The estimated value of the localization potential is around 60 meV for the low-temperature grown GaNAs/GaAs structures and can be reduced by increasing growth temperature or using post-growth rapid thermal annealing (RTA). Efficient competing non-radiative recombination (NRR) channels located in the Ga(In)NAs layers have been found to be responsible for the observed rapid thermal quenching of the Ga(In)NAs-related emission. The introduction of NRR defects in the material can to some extent be suppressed either by increasing growth temperature or using RTA. The possible nature of NRR defects is studied by ODMR. From ODCR, effective mass of electrons in GaNAs has directly been determined providing an important parameter needed for fundamental understanding of the material and for the device design. The type I alignment in the GaNAs/GaAs heterostructures with low nitrogen composition has been proven by using three complimentary optical techniques.

9:30 AM H1.5
UNDERSTANDING THE CONDUCTION BAND MASS OF GaAsN. N.A. Modine, E.D. Jones, A.A. Allerman, S.R. Kurtz, Sandia National Laboratories, Albuquerque, NM.

Adding a small (up to 3%) amount of nitrogen to GaAs reduces the band gap dramatically (up to 30%). Since the band gap of GaN is roughly twice that of GaAs, this requires extreme deviation from the roughly linear dependence of band gap on concentration typically observed in semiconductor alloys. We will argue that this unusual behavior results primarily from the very low energy of the valence *s* orbital of nitrogen relative to the other group-V elements. Since the GaAsN conduction band experiences a 4 eV well at the location of each nitrogen atom, the conduction band edge shifts sharply downward as nitrogen is added to GaAs. Given the depth of the potential wells, one might expect the band edge states to be strongly localized on the nitrogen atoms, leading to flat bands and a high

mass. In contrast, both experiment and theory indicate that the conduction band mass of GaAsN is only moderately heavier than GaAs. We resolve this apparent conflict by identifying a strongly localized level below the bottom of the valence band. As previously observed in the dilute limit, orthogonality to such a hyperdeep level forces the excited state to extend significantly into the surrounding crystal. For more than a few tenths of a percent of nitrogen, the excited state wavefunctions centered on different nitrogen atoms overlap leading to a wide band with a modest mass. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

9:45 AM H1.6
CARRIER LOCALIZATION AND THE ORIGIN OF LUMINESCENCE IN CUBIC InGaN ALLOYS. P.R.C. Kent and Alex Zunger, National Renewable Laboratory, Golden, CO.

InGaN alloys exhibit numerous anomalous phenomena that have been interpreted as indicative of an unconventional electronic structure. Microscopy has also demonstrated the presence of substantial In-inhomogeneity (composition fluctuations) in current grown material. In this work, the electronic structure of cubic InGaN is investigated using large scale atomistic empirical pseudopotential calculations to determine the role of alloy composition fluctuations on the optical properties. We find that (i) strong hole localization exists even in the homogeneous random alloy, with a preferential localization along the (1,1,0) In-N-In-N-In chains, and (ii) even modest sized (<50 A) indium rich "quantum dots" provide substantial quantum confinement and readily reduce emission energies relative to the random alloy by 200-300 meV, depending on size and composition, consistent with current photoluminescence, microscopy and Raman data. The dual effects of alloy hole localization and localization of electrons and hole at intrinsic quantum dots are responsible for the emission characteristics of current grown InGaN alloys.

10:30 AM *H1.7
LOCALIZATION, DEFECT, AND TRANSPORT PROCESSES OF InGaAsN: A COMPARISON OF MBE AND MOCVD MATERIAL. Steven R. Kurtz, Sandia National Laboratories, Albuquerque, NM.

Addition of a small amount of nitrogen into GaAs radically lowers the bandgap, and InGaAsN alloys have been grown, lattice matched to GaAs, with bandgaps <1.0 eV. However, nitrogen incorporation has proven problematic, and device performance has not reached expectations, with radiative efficiencies and minority carrier diffusion lengths diminishing with increasing N concentration. Post-growth annealing has proven effective in increasing minority carrier lifetimes. Also, large alloy scattering rates shown to limit mobilities and optical linewidths may result in intrinsic localization. To address these issues, we examined the defect and transport properties of MBE-grown InGaAsN and compare the properties of the MBE-grown material with those of MOCVD-grown InGaAsN. From infrared spectra, we find that annealing promotes In-N bonding and Ga3InN cluster formation in MBE material similar to that reported in MOCVD material. In both MBE and MOCVD-grown annealed samples, temperature dependence of the mobility was characteristic of transport limited by large-scale ($\gg$ carrier mean free path) material inhomogeneities, similar to behavior observed in large-grain polycrystalline semiconductors. However, the minority carrier properties of MBE and MOCVD InGaAsN are dissimilar which indicates that some defects are unique to a particular growth process. From quantum efficiency measurements on solar cells with varying layer thicknesses, we find electron and hole diffusion lengths of 0.5 and 0.03 micron, respectively, for annealed MBE-grown material. Surprisingly, these diffusion lengths are reversed from those we have reported for MOCVD-grown InGaAsN (0.01 micron for electrons and 0.9 micron for holes). Both MBE and MOCVD material displayed shorter minority carrier diffusion lengths prior to annealing. (Work performed in collaboration with A.A. Allerman, J.F. Klem, R.M. Sieg, C.H. Seager, and E.D. Jones) Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the U.S. Dept. of Energy under contract DE-AC04-94AL85000.

11:00 AM H1.8
THE ROLE OF In AND Al IN THE INCORPORATION OF N In (Al,In)GaAsN GROWN BY METALORGANIC CHEMICAL VAPOR DEPOSITION. A.J. Ptak, Sarah Kurtz, J.F. Geisz and R.C. Reedy, National Renewable Energy Lab, Golden, CO.

InGaAsN, with potential uses in long-wavelength lasers and multijunction solar cells, has been studied intensely for a number of years. AlGaAsN is also potentially useful as a semiconductor laser material. It is known that the incorporation of N in the ternary alloy $GaAs_{1-x}N_x$ ($x \ll 1$) is highly dependent on the conditions of growth. The substrate temperature, V/III ratio, growth rates and precursors can each have a dramatic effect on the ultimate concentration of N in GaAs. Also, studies have shown that the addition of In to create a quaternary alloy can drastically decrease N levels. We have investigated the incorporation of N in GaAs as a function of the In content using two sources of nitrogen: nitrogen trifluoride (NF_3), which does not contain the potential p-type dopant carbon, and unsymmetric dimethylhydrazine (DMHy). Nitrogen from DMHy is shown to incorporate less efficiently than that from NF_3 when no indium is included. With the addition of indium, the nitrogen incorporation from DMHy decreased more dramatically than the nitrogen incorporation from NF_3. For example, using a growth rate of 2 μm/h, a growth temperature of 550°C, and an arsine pressure of 0.2 Torr, the addition of 3% indium (keeping all other growth conditions constant) reduced the nitrogen concentration from approximately 1.7% to 0.7% when DMHy was used, but had no measurable effect on the nitrogen concentration when NF_3 was used. Whereas indium reduces the nitrogen incorporation, the addition of aluminum to the alloys markedly increases the nitrogen incorporation. The details of the effects of indium and aluminum on the nitrogen incorporation and its dependence on various growth parameters will be reported.

11:15 AM H1.9
EFFECT OF H_2 ON NITROGEN INCORPORATION IN THE MOCVD GROWTH OF GaAsN. J.C. Roberts, B.F. Moody, P. Barletta, M.E. Aumer, S.F. LeBoeuf, J.M. Luther, and S.M. Bedair, N.C. State University, Dept. of ECE, Raleigh, NC.

GaAsN and InGaAsN are promising materials for long wavelength fiber communications and solar cell applications. Several difficulties are facing this material system such as poor material quality, high background doping and low nitrogen content (up to a few percent). In this work we will report on the effect of H_2 carrier gas on the nitrogen incorporation and the electrical and structural properties of $GaAs_{1-x}N_x$ ($0 \leq x \leq 0.08$) epitaxial films. GaAsN epitaxial films were grown by atmospheric pressure metalorganic chemical vapor deposition (MOCVD) on GaAs substrates using trimethylgallium (TMG), tertiarybutylarsine (TBA), and dimethylhydrazine (DMHy), with growth temperatures in the 575 - 600°C range. Growth conditions were adjusted so that N_2 was used both as the carrier gas through the organometallic (OM) bubblers and the push gas through the column III and V manifolds. The nitrogen content of the process gas stream reaching the substrates during the growth process can be decreased from 100% to ~40% with the controlled addition of H_2 to the manifold push gas. For optimum growth conditions and with 100% N_2 flow, $GaAs_{1-x}N_x$ with x = 0.08 was achieved, the highest reported by any CVD technique. By controlling the H_2 flow and maintaining the same OM partial pressures, the value of x can be controlled and reduced to ~1%. We have also found that the H_2 flow has dramatic effects on the optical, electrical, and structural properties of these GaAsN films. For example, the background carriers (p-type) can be controlled by H_2 flow and semi-insulating films can be achieved under optimized flow conditions. We will discuss the possible mechanisms responsible for the role of H_2 in reducing nitrogen content such as the formation of NH_x and site blocking. We will also report on several potential applications resulting from carefully controlling both the N content and background carrier concentration in GaAsN films.

11:30 AM H1.10
HIGH LUMINESCENCE EFFICIENCY FROM GaAsN LAYERS GROWN BY MBE WITH RF NITROGEN PLASMA SOURCE. V.M. Ustinov, B.V. Volovik, A.F. Tsatsul'nikov, Ioffe Physico-Technical Institute, St. Petersburg, RUSSIA; A.R. Kovsh, J.S. Wang, L. Wei, J.Y. Chi, Industrial Technology Research Institute, Hsinchu, TAIWAN ROC.

(In)GaAsN based heterostructures have been found to be promising candidates for the active region of 1.3 micron VCSELs. However, (In)GaAsN bulk layers and quantum wells usually demonstrate lower photoluminescence intensity than their nitrogen-free analogues. Defects associated with lower temperature growth and N-related defects due to plasma cell operation and possible nonuniform distribution of nitrogen enhance the non-radiative recombination in N-contained layers. We studied the photoluminescence intensity of GaAsN layers as a function of N content in MBE grown samples using rf-plasma source. Increasing the growth temperature to as high as 520C in combination with the increase in the growth rate allowed us to avoid any N-related defects up to 1.5% of nitrogen. Low-temperature-growth defects can be removed by post-growth annealing. We achieved the same radiative efficiency of GaAsN samples grown at 520C with that of reference layer of GaAs grown at 600C. Compositional fluctuations in GaAsN layers lead to characteristic S-shape of temperature dependence of photoluminescence peak position and this feature is the more pronounced the higher the amount of nitrogen in GaAsN. Annealing reduces compositional fluctuations in addition to the increase in the photoluminescence intensity. The results obtained are important for further improving the characteristics of InGaAsN lasers emitting at 1.3 micron.

11:45 AM H1.11
EFFECT OF RAPID THERMAL ANNEALING: RED AND BLUE SHIFT IN PHOTOLUMINESCENCE OF GaNAs GROWN BY RF PLASMA-ASSISTED MOLECULAR BEAM EPITAXY. W.K. Loke, S.F. Yoon, T.K. Ng, S.Z. Wang and W.J. Fan, Nanyang Technological University, Singapore, SINGAPORE.

Rapid thermal annealing (RTA) of 1000Å GaNAs films grown on (100) oriented GaAs substrate by RF plasma assisted solid-source molecular beam epitaxy was studied by low-temperature photoluminescence and high-resolution x-ray diffraction (HRXRD). Samples with nitrogen content of 1.3-2.17% have shown redshift range of 24.3-54.3 meV and blueshift range of 6.2-81.1 meV after performing RTA at 600-850°C for 10min. It is also shown that these samples have the highest photoluminescence efficiency (2.6-4.6 times higher than the as-grown sample) and minimum full width at half maximum (FWHM) of the GaNAs peak in HRXRD rocking curve for samples annealed at 700-750°C. Through reciprocal space mapping of all the samples using HRXRD, the 1000Å GaNAs as grown and annealed are shown to be of no lattice relaxation in the direction parallel to the growth surface. These results have significant implication on the growth and post-growth treatment of GaNAs and GaInNAs materials for high performance optoelectronics devices.

SESSION H2: LOW-CONCENTRATION NITRIDE ALLOYS II & PHOTOVOLTAICS
Chairs: Daniel J. Friedman and Salah M. Bedair
Monday Afternoon, November 26, 2001
Room 312 (Hynes)

NOTE EARLY START

1:00 PM *H2.1
HEAVILY NITROGEN DOPED GaAs, GaP AND RELATED SEMICONDUCTORS. Yong Zhang, National Renewable Energy Laboratory, Golden, CO.

An isolated nitrogen in GaAs is well known to form a resonant state above the GaAs conduction band edge. Nitrogen pairs are found to form either resonant or bound states, depending on their configurations. In addition to these nitrogen impurity states which appear at rather low nitrogen doping levels, deeper nitrogen related bound states have been observed at somewhat higher nitrogen doping level ($[N] > 10^{18}$ cm^{-3}). When the nitrogen concentration is further increased to above 0.1%, discrete optical transitions disappear and a large band gap reduction is observed. Similar situation also occurs for nitrogen doped GaP. The phenomenon observed in these III-V-N systems in fact shares a great similarity with the heavily n-type and p-type doped semiconductors, where the impurity band formation has been shown to be the origin for the band structure change under the situation of heavy doping. A systematic study of GaAsN and GaPN, using experimental techniques of photoluminescence, electro-reflectance, resonant Raman etc. in conjunction with theoretical modelling, has led to progress in understanding the evolution of these dilute nitride materials from the impurity limit of very dilute nitrogen doping to the limit of heavy nitrogen doping.

1:30 PM H2.2
ELECTROREFLECTANCE MEASUREMENTS OF NITROGEN INDUCED LEVELS IN DILUTE GaAs:N. J.D. Perkins, A. Mascarenhas, J.F. Geisz, D.J. Friedman, National Renewable Energy Lab., Golden, CO.

We report electroreflectance spectra between 1 and 4 eV for $GaAs_{1-x}N_x$ samples with $x < 3\%$. In addition to four intrinsic GaAs transitions, three nitrogen-induced optical transitions, E_+, $E_+ \Delta_0$ and E^*, were observed. The weak and heretofore unknown E^* transition was observed in four samples with 0.1 to 2.4% nitrogen and occurs 0.1 to 0.3 eV below the ~3 eV intrinsic E1 transition. Opposite to E_+, E^* decreases in energy with increasing nitrogen content. Furthermore, in the dilute limit, both E_+ and E^* appear to converge to the known conduction-band-resonant nitrogen-impurity level N_x.

1:45 PM *H2.3
1-eV SEMICONDUCTORS FOR MULTIJUNCTION SOLAR CELLS. J.M. Olson, J.F. Geisz, Sarah R. Kurtz, A.G. Norman, National Renewable Energy Laboratory, Golden, CO.

The GaInP/GaAs tandem cell has an energy conversion efficiency exceeding 30% (AM1.5G) and is now being produced in large volume for orbiting satellite power systems. Adding in series a third and fourth junction with band gaps of 1.0 eV and 0.7 eV, respectively, could boost the efficiency to over 40%. To reach this goal, the new junction materials should also be closely lattice matched to GaAs (and GaInP) and exhibit near-band-edge internal quantum efficiencies greater than 90%. Germanium is an obvious candidate for the fourth junction. Candidate 1-eV semiconductors include GaInAsN, GaAsSbN, BGaInAs, TlGaP, $ZnGeAs_2$, $CuInSe_2$, and GaAsGe. In this presentation, we compare and contrast the relative merits and disadvantages of these 1-eV materials. Issues of phase equilibria and minority-carrier diffusion length are emphasized. We also review the progress to date in this field and consider the prospect of reaching the goal of a 40% solar cell and the impact such a device might have on the world energy problem.

2:15 PM H2.4
NOVEL STRUCTURAL DEFECTS IN 1 eV GaInNAs ALLOYS GROWN AT HIGH TEMPERATURES. Andrew Norman, John Geisz, Mowafak Al-Jassim, Sarah Kurtz, National Renewable Energy Laboratory, Golden, CO.

GaInNAs alloys are attracting increasing interest for light emitters and multi-junction solar cells grown lattice matched on GaAs substrates. GaInNAs, containing 3% nitrogen, is a possible 1 eV bandgap material, lattice-matched to GaAs and Ge, for inclusion in increased-efficiency quadruple-junction solar cells. Presently its application is limited by poor minority carrier lifetimes, the origin of which is still unclear. We report here the observation of a novel type of structural defect in metal-organic vapor-phase epitaxy GaInNAs layers grown at 650°C using dimethylhydrazine as a nitrogen source. Layers grown under these conditions contain a high density of 'comet'-like defects. The heads of these defects consist of a cavity or inclusion that is associated with a high concentration of carbon and hydrogen as revealed by secondary ion mass spectrometry. The defect heads migrate during growth leaving behind a tail of different alloy composition that causes strain in the crystal. The 'comet' defects result in the generation of a high density of threading dislocations that are likely to be harmful to the electronic properties of the material. These defects may be eliminated by growth at lower temperatures, e.g., 550°C.

2:30 PM H2.5
InAsN GROWN BY PLASMA-ASSISTED GAS SOURCE MBE. Ding-Kang Shih, Hao-Hsiung Lin, and Tso-Yu Chu, National Taiwan University, Dept of Electrical Engineering, Taipei, TAIWAN, R.O.C.; T.R. Yang, National Taiwan Normal University, Dept of Physics, Taipei, TAIWAN, R.O.C.

The huge bowing effect on the band gap energy makes InAsN alloy a promising material for infrared applications. However, only very limited efforts were put on this materials because previous studies demonstrated problems of phase separation and immiscibility on the growth of InAsN with high nitrogen content. Nonetheless, there are no existing definitive results on the synthesis of this alloy. In this report, we have investigated InAsN bulk layers on InP substrates grown by gas source MBE with a RF plasma K-cell. The samples were grown at 460°C. The thickness is 2000 nm, and the N composition ranges from 0 to 2.8%. From DXRD measurement, it is clear that the diffraction peak of the InAsN samples shift closer to the InP substrate peak, compared with that of InAs sample. A dynamic simulation program, RADS, was used to determine the nitrogen composition of InAsN samples. The Hall results of the samples show that InAsN samples have higher residual carrier concentration than InAs sample, and the concentration increases as the N composition increases. The highest concentration can be up to $10^{19}/cm^3$. Possible origin of the high carrier concentration in InAsN sample is not quite clear at the moment. From the absorption measurement, it is found that the absorption edge of InAsN samples is always higher than that of InAs. This phenomenon is due to Burstein-Moss effect, caused by the residual carriers in InAsN samples. To deduce the 'real' band gap energy of our InAsN samples, the energy shift due to Burstein-Moss effect and the band gap narrowing effect are considered by using a self-consistent approach based on the band-anticrossing (BAC) model. After the correction, the 'real' band gap energy of InAsN samples decreases as N increases, follows the bowing effect normally. Results of detailed quantitative estimation on the band gap, bowing factor, the interaction potential (V_{MN}) and effective mass measurement of InAsN bulk layers grown on InP substrate will be presented.

2:45 PM H2.6
NATURE AND FORMATION OF NON-RADIATIVE DEFECTS IN GaNAs AND InGaAsN. W.M. Chen, N.Q. Thinh, I.A. Buyanova, P.N. Hai, Linkoping Univ, Dept of Physics, SWEDEN; H.P. Xin, C.W. Tu, Univ of California, Dept of Electrical and Computer Engineering, La Jolla, CA; W. Li, M. Pessa, Tampere Univ of Technol., Optoelectron. Res. Center, FINLAND.

N-containing III-V alloys, such as InGaAsN and GaNAs, are known to exhibit intriguing fundamental properties including giant bandgap bowing, that has attracted much interest in potential application for near infrared optoelectronic devices. Unfortunately, radiative efficiency of the alloys is known to degrade rapidly with N

incorporation largely attributed to the formation of competing non-radiative (NR) defects. However, very little is so far known about the nature of these defects and mechanism for their formation in the alloys. In this paper we shall present our recent results from optically detected magnetic resonance (ODMR) studies of grown-in non-radiative defects in GaNAs and InGaAsN as a function of growth and structural parameters. The samples studied include thick epilayers of GaNAs and InGaAsN, and GaNAs/GaAs multi-quantum wells (MQW), grown by gas-source MBE. In both alloys, two non-radiative defects have been detected. One of them exhibits characteristic hyperfine structure, arising from S=1/2 and I=3/2, which suggest a complex involving the As_{Ga} antisite as being the most likely candidate. The other non-radiative defect with an effective electronic spin S=1/2 gives rise to an isotropic ODMR signal with a g-value of 2.03. We demonstrate that the introduction rate of these defects increases with decreasing growth temperature and with increasing N composition, leading to an increasingly important role in carrier recombination and thus in degrading optical quality of the material. With a further increase in nitrogen composition to 4.5% in the GaNAs/GaAs MQW structures grown at low temperature, the ODMR signals start to decrease probably due to the introduction of other competing defects that overshadow the role of the studied defects in carrier recombination. Post-growth rapid thermal annealing can significantly suppress the influence of the studied non-radiative defects in both GaNAs and InGaAsN alloys, accompanied by a drastic improvement in the efficiency of light emission.

3:30 PM *H2.7
DEEP CENTERS AND THEIR CAPTURE BARRIERS IN MOCVD-GROWN GaN. D.K. Johnstone, Air Force Office of Scientific Research, Arlington, VA; M. Ahoujja, Y.K. Yeo, R.L. Hengehold, Air Force Institute of Technology, Wright-Patterson AFB, OH.

GaN and its related alloys are being widely developed for blue-ultraviolet emitting and detecting devices as well as high temperature, high power, and high frequency electronics. Despite the fast improvement in the growth of good quality GaN, a high concentration of deep level defects of yet unconfirmed origin are still found in GaN. For both optical and electronic devices, these deep carrier traps and/or recombination centers are very important and must therefore be understood. In the present work, deep level defects in GaN grown on sapphire substrates by metal organic chemical vapor deposition (MOCVD) have been investigated using Isothermal Capacitance Transient Spectroscopy (ICTS). Several deep level electron traps were characterized, obtaining the emission energy, concentration, and capture cross section from a fit of exponentials to the capacitance transients. ICTS was also used to reveal information about the capture kinetics involved in the traps found in GaN by measuring the amplitude of the capacitance transient at each temperature. At a reduced filling pulse where the traps were not saturated, several of them showed marked reduction in capacitance transient amplitude when compared to the transient amplitude measured under conditions where the filling pulse saturates the traps. This reduction in transient amplitude indicates that there is a barrier to carrier capture, in addition to the emission barrier. It has been found that several traps had capture barriers that were significant fractions of the emission energies ranging from 0.04 to 0.32 eV. These capture barriers may lead to persistent photoconductivity and reduced trapping. In this paper, deep level emission energies as well as capture barrier energies found in MOCVD-grown GaN will be discussed along with traps found in ion-implanted GaN and MBE-grown samples.

4:00 PM H2.8
NEAR-FIELD PHOTOLUMINESCENCE SPECTROSCOPY OF LOCALIZED STATES IN InGaAsN ALLOYS. A.M. Mintairov, J.L. Merz, T. Kosel, Notre Dame Univ, Dept of Electrical Engineering, Notre Dame, IN; P.A. Blagnov, V.M. Ustinov, A.S. Vlasov, Ioffe Physico-Technical Institute, RAS, St. Petersburg, RUSSIA; R. Csencsits, Argonne National Laboratory, Argonne, IL.

InGaAsN alloys have recently attracted considerable attention as promising materials for laser diodes in the 1.3-1.5 μm range as well as more efficient solar cells. Recent studies have shown that optical and transport properties of this material are dramatically affected by localized states, the nature of which are not yet fully clarified. In the present paper we used near-field scanning optical microscopy (NSOM) to observe the emission of single localized states in InGaAsN alloys and to study their temperature and magnetic field dependence. We studied $In_xGa_{1-x}As_{1-y}N_y$ (x$\sim$0.08, y$\sim$0.03) samples with thickness 0.2 μm grown by solid source MBE on (001) semi-insulating GaAs substrates at T=450°C. Photoluminescence (PL) NSOM spectra (excitation 514.5 nm and power density 10-1000 W/cm^2) were taken in collection-illumination mode using uncoated fiber tips. The spectra were measured at temperatures T=5-300 K and magnetic field strengths B=0-10 T. The spectral resolution was 0.5 meV. Far-field PL spectra of an $In_{0.08}Ga_{0.92}As_{0.97}N_{0.03}$ layer at 5 K consist of a single broad band with peak energy 1.088 eV and halfwidth (γ) of 20 meV. In the near-field PL spectra at 5K several ultranarrow (γ<0.5 meV) lines superimposed on this band have been observed. The intensity of the lines decreased with increasing temperature and they disappeared at T$\sim$65 K. We attribute each of these lines to the ground state emission of a single quantum dot-like N-rich cluster (localized state) and estimated the density of these clusters to be $\sim 5 \cdot 10^{13}$ cm^{-3}. We measured a value of the Zeeman splitting of a single cluster at 10 T of $\sim$1.5 meV. The lateral extent of the ground state wave function was estimated to be 2-7 nm from the measured values of the diamagnetic coefficient (2-15 μeV/T^2). The authors wish to acknowledge the NATO Science for Piece Program (grant SFP-972484).

4:15 PM H2.9
WAFER BONDING PROCESSES FOR ULTRAHIGH EFFICIENCY PHOTOVOLTAIC APPLICATIONS. James M. Zahler, Aditi S. Risbud, Chang-Geun Ahn, Harry A. Atwater, California Institute of Technology, Dept. of Applied Physics, Pasadena, CA; Charles Chu, Peter Iles, Tecstar Inc., City of Industry, CA.

Film transfer of Ge onto Si through wafer bonding and hydrogen-induced layer splitting is being explored as a means of cost and weight reduction of triple-junction compound solar cells. Additionally, wafer bonding can be used as a means of improving flexibility of materials selection to allow band gap optimization in solar cell design. A proposed four-junction cell design to achieve 40% cell efficiency can be created by utilizing InGaAlP/GaAs/Ge and InGaAsP/InGaAs/InP/Si lattice-mismatched heterostructures formed by wafer bonding and layer transfer to integrate both GaAs-compatible and InP-compatible III-V compounds to optimize the bandgaps in a tandem hetero-structure. We have successfully used direct wafer bonding along with hydrogen-induced layer splitting of Ge and InP to bond and transfer single crystal Ge (100) films and InP (100) films to Si (100) substrates without using a metallic bonding layer. Ge and InP wafers implanted with 1x10^{17} cm^{-2} H$^+$ at 80keV were used to transfer $\sim$700 nm thick films on the order of cm^2 for Ge/Si and mm^2 for InP/Si. Hydrophobic surface passivation and less than 1nm rms surface roughness as measured by contact mode AFM along with $\sim$1000 psi bond initiation pressure are suitable conditions for reversible room temperature bonding to occur for both Ge/Si and InP/Si heterostructures. Layer splitting is induced by a thermal cycle up to 350°C or greater leaving a transferred layer with 10-25 nm surface roughness. Electrical measurements indicate ohmic I-V characteristics for Ge p films bonded to Si p substrates with $\sim 40\Omega$ resistance following the breakdown of a non-ohmic interlayer. Triple-junction GaInP/GaAs/Ge solar cell structures have been grown by MOCVD on bonded Ge/Si heterostructures. These devices exhibit GaAs photoluminescence intensity and photoluminescence decay lifetime comparable to devices grown on bulk Ge substrates. Initial results for Ge/Si indicate that MBE Ge buffer layer growth reduces the surface roughness of the transferred layer by 80% and may improve the Ge surface quality for growth of III-V semiconductors. Future work will include TEM analysis of the Ge/Si and InP/Si interfaces along with analysis of the optical properties of III-V device structures grown on these heterostructure templates.

4:30 PM H2.10
FLEXIBLE, LIGHTWEIGHT, AND ALL-SOLID-STATE NANOCRYSTALLINE TITANIUM DIOXIDE - POLYMER SOLAR CELLS ON PLASTICS. Krishna C. Mandal, Anton Smirnov, D. Peramunage, and R. David Rauh, EIC Laboratories, Inc., MA.

A promising new type of solar cell on plastics has been fabricated and characterized at EIC Laboratories, Inc. This paper will describe various critical fabrication steps to develop for the first time these low-cost, large areas, stable all-solid-state nanocrystalline TiO_2 - polymer solar cells on plastics. A novel highly conducting polymer electrolyte and a low temperature, spray processed nanocrystalline TiO_2 layer on ITO coated plastics have been demonstrated as valuable active components, which enhance cost-effective productions. The photovoltaic performance of the fabricated solar cells of 5 cm^2 area shows reproducible efficiencies of 4.8% at 30 mW/cm^2. A thoroughly characterized 6.25 cm^2 prototype solar cell with AM1 efficiency $\geq$3.6% will also be demonstrated.

4:45 PM H2.11
RAMAN AND PHOTOLUMINESCENCE MAPPING OF MOVPE LATTICE MATCHED GaInP/GaAs HETEROSTRUCTURES. Giovanni Attolini, P. Fallini, Fabrizio Germini, Claudio Pelosi, Maspec-CNR Institute, Parma, ITALY; Oscar Martinez, Luis F. Sanz, Miguel A. Gonzalez, Juan Jimenez, Fisica de la Materia Condensada, ETSII, Valladolid, SPAIN.

Lattice matched GaInP/GaAs heterostructures present a big interest for light emitting and detector devices, solar cells and bipolar transistors. However, GaInP can appear under a Cu-Pt ordered phase that shrinks the band gap. In this ordered phase In and Ga occupy

alternate (-111) planes in the cation sublattice. On the other hand, ordered domains can appear, which are detrimental to the device performance. Composition changes can also induce changes of the properties similar to those produced by ordering. Composition and ordering can be studied by Raman spectroscopy and photo-luminescence. We present herein a study of lattice matched GaInP/GaAs heterostructures grown by MOVPE (Metal Organic Vapor Phase Epitaxy) grown on either undoped or Si-doped GaAs substrates. The Raman frequency of the LO (Longitudinal Optic) GaP-like phonon mode is insensitive to order and can be used to determine the composition with an accuracy better than 1 percent. The compositional homogeneity of the samples was studied, showing a maximum composition fluctuation of 1.5 percent in some of the samples, while the other presented very small composition fluctuations. Photoluminescence mapping was used to check the homogeneity of the samples. A correlation between the luminescence intensity and the band gap was obtained. These results are discussed in terms of order and composition fluctuations related to the growth conditions and the nature of the substrates.

SESSION H3: QUANTUM DOTS

Chairs: Yoon-Soo Park and Joe C. Campbell
Tuesday Morning, November 27, 2001
Room 312 (Hynes)

8:30 AM *H3.1
QUANTUM DOTS OF InAs/GaSb TYPE II SUPERLATTICE FOR INFRARED SENSING. Manijeh Razeghi, Northwestern University, Center for Quantum Devices, ECE Department, Evanston, IL.

Throughout the past years, significant progress has been made in type II (InAs/GaSb) photovoltaic detectors in both LWIR and VLWIR ranges. BLIP performance at 60K for 16um photovoltaic type II detectors has been successfully demonstrated for the first time. Detectors of cutoff wavelength up to 25um have been demonstrated at 77K. The great performance of single element detectors appeals us to lower dimensional structures for both higher temperature performance and possible wavelength tunability. Simple calculations show that quantum effect will show up when the lateral confinement is small enough. The variation of applied gate voltage will move the electron and the hole energy levels unevenly. The cut off wavelength of the superlattice will vary accordingly. Auger recombination will also decrease and higher temperature operation becomes possible. In this talk, the latest results will be discussed.

9:00 AM *H3.2
QUANTUM DOT LONG WAVELENGTH DETECTORS. Pallab Bhattacharya, Sanjay Krishna and Adrienne Stiff, University of Michigan, Dept of Electrical Engineering & Computer Science, Ann Arbor, MI.

Quantum dot infrared photodetectors (QDIPs) have been widely investigated in the past few years for operation in the mid-infrared range of 3-20 μm. Two of the major advantages that QDIPS offer over the existing technologies are (i) normal incidence operation that eliminates the need for external gratings and optocouplers and (ii) high temperature operation which would eliminate the need for cooling systems presently used in quantum well infrared detectors (QWIPs) and mercury cadmium telluride (MCT) detectors and significantly decrease the operational costs. QDIPs are expected to perform better at higher temperature due to the increased intersubband relaxation time between the phonon-decoupled ground state and excited states that increases the probability of a photoexcited carrier getting collected as photocurrent. Moreover since the quantum dots are grown on the mature GaAs technology, they are essentially defect-free and do not suffer from the etch-pit densities and void defects that plague the present day MCT detectors.
In the past we have demonstrated normal incidence InAs/GaAs quantum detectors with D* $\sim$1e10cmHz$^{1/2}$/W$^{1/2}$ at T=40K. However the large dark current prevented operation at higher temperatures. Symmetrically and asymmetrically placed current blocking AlGaAs layers were introduced in the active region of the detector to decrease the dark current and increase the operating temperature of the devices. Using appropriate heterostructure engineering of the detectors, we have achieved reasonable operation till T-150K, with D*=1e10 cmHz$^{1/2}$/W$^{1/2}$ and R=2mA/W at T=100K with a peak response at $\lambda\sim4\mu$m (V_b=0.1V, T=78K). This is highest reported detectivity in quantum dot detectors and highest operating temperature for normally incident vertical QDIPs. The design of these detectors, their calibrated blackbody characterization and their performance will be discussed in detail in the talk.

9:30 AM H3.3
ENHANCED PHOTOLUMINESCENCE FROM LONG WAVELENGTH InAs QUANTUM DOTS EMBEDDED IN A GRADED InGaAs QUANTUM WELL. Liang Chen, Gabriela Stoleru, Dong Pan, Elias Towe, University of Virginia, Department of Electrical and Computer Engineering, Charlottesville, VA.

Three sets of self-organized InAs quantum dots (QDs) embedded in an external InGaAs quantum well were grown by solid source molecular beam epitaxy (MBE). By modifying Indium composition profile within quantum well region, its found the photoluminescence emission from quantum dots can be greatly enhanced with employing a graded InGaAs quantum well to surround QDs. We believe better material quality around QDs contributes to this enhancement. In addition to the PL enhancement, QDs in a graded QW structure still maintains the desired long wavelength emission (1.3 mm) requirement. This makes it an attractive alternative for long wavelength quantum dot lasers.

9:45 AM H3.4
A THEORETICAL STUDY OF STRUCTURAL DISORDER AND PHOTOLUMINESCENCE LINEWIDTH IN InGaAs/GaAs SELF ASSEMBLED QUANTUM DOTS. Yih-Yin Lin, Jasprit Singh, Univ of Michigan, Dept of Electrical Engineering and Computer Science, Ann Arbor, MI; Hongtao Jiang, Broadcom Corp, Irvine, CA.

The past few years have seen considerable efforts in growth and device applications of self-assembled quantum dots. However, the photoluminescence (PL) linewidth, which represents structural fluctuations in dot sizes, is still in the range of 30-50 meV. This large linewidth has deleterious effects on devices such as lasers based on self-assembled dots. In this paper we will examine the configuration-energy diagram of self-assembled dots and provide insight into the question: Is the PL linewidth limited by kinetic or thermodynamic considerations? Our formalism is based on: (1) an atomistic Monte Carlo method which allows us to find the minimum energy configuration and strain tensor as well as intermediate configurations of dots; (2) an 8-band $\mathbf{k} \bullet \mathbf{p}$ method to calculate the electronic spectra which is then used to obtain PL linewidth. We will present results on strain energy per unit cell for various distributions of InGaAs/GaAs quantum dots and relate them to published experimental results on PL and AFM studies. We find from our simulations that at present the published PL data suggests that kinetic effects limit the PL linewidths. This suggests that dot uniformity can be considerably improved in self-assembled structures.

10:30 AM *H3.5
DESIGN AND GROWTH OF InAs QUANTUM DOT SUPER-LATTICES FOR UNIPOLAR CURRENT EXCITATION. C. Cao, D.G. Deppe, and O.B. Shchekin, The University of Texas at Austin, Microelectronics Research Center, Austin, TX.

Quantum dot heterostructures can eliminate phonon emission and be used to create high efficiency spontaneous and stimulated mid-infrared sources. When phonon emission is eliminated, the electron relaxation through discrete electron levels can be greatly slowed to result only due to mid-infrared light emission. Although the AlAs/GaAs/InAs material system is very attractive for these types of light sources, the self-organized quantum dots must be carefully designed to provide efficient filling and emptying of the discrete electron levels. Emptying of the quantum dot energy levels is of particular concern, since the quantum dot energy levels generally reside below the GaAs bandedge. In this talk we discuss the design of InAs quantum dot hetero-structures, and present initial results of self-organized quantum dot heterostructures designed for unipolar current injection. We have characterized both InAlAs and InAs quantum dot heterostructures grown on AlAs/GaAs superlattices. Our best results have been obtained using InAs quantum dots grown directly on AlAs layers to obtain electron-hole emission at a wavelength shorter than 0.96 μm. The quantum dots are grown at relatively low temperature to obtain small sizes with large energy separations between the discrete levels. Miniband blocking layers are designed to obtain emptying of the ground quantum dot states using InGaAs quantum wells. Current-voltage and light emission characteristics from the heterostructures will be presented in the talk. The prospects of microcavity emission from such structures will also be discussed.

11:00 AM H3.6
ELECTROLUMINESCENCE OF CdS NANOPARTICLES ON Si. Eih-Zhe Liang, Ching-Fuh Lin, Sheng-Ming Shih, Graduate Institute of Electro-Optical Engineering and Wei-Fang Su, Department of MS&E, National Taiwan University, Taipei, TAIWAN.

Low-dimensional structures like quantum dots (QDs) are attractive for light emission due to the significant enhancement in the density of states for increasing the probability of light emission. However, the epitaxially grown QDs are very selective on the substrate, making Si wafer not suitable for QDs and limiting the integration of QD devices with ULSI based on Si. In contrast, nanoparticles formed by chemical

methods are more flexible. They can be applied on almost any substrates. In this work, we report the applications of CdS nanoparticles on Si substrate. Electroluminescence (EL) can be easily achieved by quantum tunneling of carriers into the nanoparticles, showing a promising way to monolithically integrate functions provided by nanoparticles and conventional integrated circuitry based on Si. The nanoparticles are small, the total surface is large, compared to usual bulk materials. Therefore, in addition to quantum states, the surface or impurity states, mostly formed at the surface of the nanoparticles, could be useful for light emission. Our study shows that the EL spectrum of CdS nanoparticles is strongly influenced by the surrounding material and processing steps. Depending on the processing steps, the EL has two peaks. One is at 515 nm, corresponding to the band-edge emission from the CdS material. The other at 570 nm is due to the impurity states caused by the oxygen ions in the CdS. With the surrounded oxide, the light emission due to the impurity states could be stronger than the band-edge emission from the CdS material, demonstrating another use of nanoparticles in addition to quantum states provided by the low-dimensional structures.

11:15 AM H3.7
RABI FLOPPING AND QUANTUM INTERFERENCE IN SELF ASSEMBLED QUANTUM DOTS. H. Htoon, D. Kulik, C.K. Shih, Department of Physics, University of Texas at Austin, Austin TX; O. Baklenov, A.L. Holmes Jr., Department of Electrical and Computer Engineering, University of Texas at Austin, Austin TX; T. Takagahara, Department of Electronics and Information Science, Kyoto Institute of Technology, JAPAN.

Self-assembled semiconductor quantum dots are considered to be one of the key material systems for quantum computation and quantum information processing. This technological motivation intensifies the recent investigations on coherent phenomena in semiconductor quantum dots. One of the most striking manifestations of quantum coherence in atomic world is the Rabi flopping. Here we report a new type of quantum interference phenomena resulted from the emergence of Rabi flopping under strong excitation condition in a mesoscopic SAQD. In our experiment, we resonantly excite an excited state of a QD with pico-second pulse pairs. At low excitation intensity, the time integrated PL intensity of the exciton ground state shows sinusoidal oscillations with respect to the time separation of the pulse pair. Envelopes of maximums and minimums of the oscillations show symmetric exponential decay reflecting the quantum decoherence of the excited states. When excitation power density becomes strong enough for the creation of excitonic dressed states (Rabi splitting), seemingly irregular oscillation patterns appear in contrast to the regular sinusoidal oscillation patterns at low excitation power. The decay of maximum and minimum envelope also become asymmetric. These features are in agreement with the recent theoretical prediction [1]. [1] T. Takagahara, QELS 2001, Technical Digest-Postconference Ed, TOPS Vo 57, pp19 (2001)

11:30 AM H3.8
EFFICIENT InAs QUANTUM DOTS IN AlAs/GaAs SHORT PERIOD SUPERLATTICES: STRUCTURE, OPTICAL CHARACTERISTICS AND LASER DIODES. Vadim Tokranov, M. Yakimov, A. Katsnelson, K. Dovidenko, R. Todt, S. Oktyabrsky, U Albany Institute for Materials, University at Albany - SUNY, Albany, NY.

With a goal of the development of the active medium for laser diodes operating at elevated temperatures, we have studied the influence of 2 monolayers (ML) AlAs under- and overlayers on the formation of self-assembled InAs quantum dots (QDs) using transmission electron microscopy (TEM), atomic force microscopy (AFM) and photo-luminescence (PL). Single sheets of InAs QDs with 1.9 - 2.4 ML average coverage were grown on GaAs(001) substrate by molecular beam epitaxy using As_2 at 0.05 ML/sec growth rate at 475°C growth temperature inside a 2ML/8ML- AlAs/GaAs short-period superlattice with various combinations of under- and overlayers. We have found from TEM and AFM measurements, that InAs QDs with GaAs underlayer and 2ML AlAs overlayer exhibit the lowest QD surface density of $4.2 \bullet 10^{10}$ cm^{-2} and the largest QD lateral size of about 19nm as compared to the other combinations of cladding layers. This InAs QD ensemble has also shown the highest room temperature PL intensity with a peak at 1.21μm and the narrowest linewidth, 34meV. The correlation of the TEM and PL results indicated the suppression of the excitation transfer in the high-efficiency QD systems reducing the effective rate of nonradiative carrier recombination at room and elevated temperatures. The optical properties of the QD structures were also compared with those of InGaAs quantum well (QW) structures generally used as a laser active medium. The QD samples with 2ML AlAs overlayer exhibited 10 times higher room temperature PL efficiency than QW at 1W/cm^2 excitation level. Thermal quenching of the PL intensity from 77K to 420K was found to be 30 for QDs vs. 5000 for QW. Fabricated edge-emitting lasers using InAs QDs with AlAs overlayer demonstrated a weaker thermal dependence of CW threshold current density than QW lasers for the temperatures up to 100°C.

SESSION H4: INFRARED DETECTORS
Chair: Daniel K. Johnstone
Tuesday Afternoon, November 27, 2001
Room 312 (Hynes)

NOTE EARLY START

1:00 PM *H4.1
QUANTUM WELL INFRARED PHOTODETECTORS FOR IR IMAGING APPLICATIONS. Sheng S. Li, Dept. of Electrical and Computer Engineering, University of Florida, Gainseville, FL.

Recent advances in III-V semiconductor quantum well infrared photodecectors (QWIPs) technology have led to the rapid development of large format high performance focal plane arrays (FPAs) for mid- and long-wavelength (MW/LW) infrared (IR) imaging applications. The basic physics, device structures, and characteristics of a wide variety of GaAs/AlGaAs and InGaAs/AlGaAs QWIPs will be depicted. In addition, multi-color QWIPs using multiple stacks and asymmetrical coupled quantum well structures for MW/LW/VLW IR detection will be discussed. Finally, applications of QWIPs for IR FPA imaging applications will also be presented in this talk.

1:30 PM *H4.2
A BOWTIE ANTENNA COUPLED TUNABLE PHOTON-ASSISTED TUNNELING DOUBLE QUANTUM WELL (DQW) THz DETECTOR. Majid Khodier, Christos Christodoulou, The University of New Mexico, EECE Dept., Albuquerque, NM; Jerry Simmons, Sandia National Laboratories, Albuquerque, NM.

The integration of a bowtie antenna with a double quantum well device to enhance the detection of THz (or Far Infrared) radiation is investigated in this paper. The concept of THz detection, based on photon-assisted tunneling (PAT) between the two electron layers in a double quantum well (DQW) heterostructure, will be explained. The device has the possibility of having multiple and significant advantages over existing photodetectors. The advantages of such photodetector include a narrowband detectivity whose resonant photon energy can easily be tuned with a surface gate voltage and/or source-drain bias. The range of wavelengths, which can be detected, is quite broad since it is determined by the relative energies of the two lowest energy subbands in the quantum wells. By fabricating the structure in material systems with large conduction band offsets, sensitivities at wavelengths in the 8 μm range out to sub-millimeter waves should be attainable. Finally, because the photon-assisted transition is between two 2D layers, the phase-space of allowed transitions is greatly restricted, and dark current due to thermal excitations is expected to be tremendously reduced. This unique situation could result in a great reduction in cooling requirements over conventional detectors and possibly even allowing room temperature operation. Since the device area is very small, which is required to achieve fast response, it is not efficient in collecting THz radiation, and a mechanism to efficiently couple THz radiation to the device is needed. To take advantage of the electrical tunability of the detector, a bowtie antenna is integrated with the DQW detector to couple THz radiation to the device because of its broadband characteristic and compatibility with the device fabrication process. The detector has many applications, ranging from chemical and biological agents detection to astrophysical applications. Simulation as well as detailed experimental results of the antenna obtained to this point will be presented.

2:00 PM H4.3
FAST ROOM TEMPERATURE DETECTION OF STATE OF CIRCULAR POLARIZATION OF TERAHERTZ RADIATION. Sergey D. Ganichev, Hermann Ketterl, Wilhelm Prettl, Institut fuer Experimentelle und Angewandte Physik, University of Regensburg, GERMANY.

We report on a room temperature detector which allows to determine and monitor the state of polarization of terahertz radiation with picosecond temporal resolution. The detector is based on the circular photogalvanic effect recently observed in GaAs/AlGaAs quantum wells [1]. The circular photogalvanic effect yields in response to ellyptically polarized radiation a current signal proportional to the degree of circular polarization $P_{circ} = (|E^2_{+|} - |E^2_{-|})/(|E^2_{|} + |E^2_{-|})$ where E_+ and E_- are the amplitudes of left and right handed circularly polarized radiation, respectively. The peak current signal occurs in unbiased samples for circular polarization, vanishes at linear polarization and changes sign by switching the helicity from right-handed to left-handed. The detector consists of (113)A MBE grown p-GaAs/AlGaAs quantum wells structure. The surface density

of carriers is $2 \cdot 10^{11}\,cm^{-2}$. Ohmic contact have been alloyed on opposite edges of the $5\times5\,mm^2$ samples along $[1\bar{1}0]$ crystallographic direction. The response has been measured in the wavelength range bewtween 35 μm and 280 μm at normal incidence of the radiation on the sample.

[1] S.D. Ganichev, H. Ketterl, W. Prettl, E.L. Ivchenko, L.E. Vorobjev, Appl. Phys. Lett. **77**, 3146 (2000).

2:15 PM H4.4

PbTe FLASH EVAPORATION on Si <100> SUBSTRATES for HETEROJUNCTION INFRARED DETECTORS. Sonia Guimarães, Instituto de Aeronáutica e Espaćo, Divisão de Materiais, São José dos Campos, SP, BRAZIL; Sabrina de C.F.F. da Silva, João M.K. de Assis, Faculdade de Engenharia Química de Lorena, Lorena, SP, BRAZIL.

This work is to present results of flash evaporation of PbTe directly over single crystal Si substrates, in order to produce heterojunction infrared detectors (HIRD). The evaporation was performed on modified JEOL vacuum equipment, model JEE4B(a), working with vaccum pressure around 10^{-5} torr, using diffusion pump. The HIRDs obtained with this method presented the same detectivity values (D*) obtained by HIRDs made with Hot Wall Epitaxial System (HWES)(b), in which PbTe epitaxial layers were grown directly over the same Si substrates, where an ionic pump was used to maintain 10^{-7} torr as vacuum pressure. The best results, were obtained with PbTe epilayers grown with Molecular Beam Epitaxial (MBE) method(c) directly over Si substrates, where the vacuum pressure is around 10^{-9} torr, also using a ionic pump. The advantage of growing over Si is that the HIRD performs at room temperature. The detectivity values of HIRDs obtained with methods (a) and (b) were $D^* \approx 4{,}8 \times 10^5\ cm.Hz^{1/2}.W^{-1}$, and with method (c) $D^* \approx 6{,}7 \times 10^6\ cm.Hz^{1/2}.W^{-1}$. Different technologies, not very different results. The modification performed in the evaporator was to provide a sample heater system, which enable us to heat and control the Si substrates temperature till about 230°C. X-ray diffraction spectrum of these epilayers showed that they are single crystals layers. Scanning Electronic Microscopy (SEM) of them showed some surface defects, like cracks, and in some cases, they are not very flat. Consequently, if we can decrease these, defects, it will be possible to improve the detectivity values of the next HIRDs. The experimental procedures of this work have been made in order to reach these improvements, for example, changing Si substrate surface cleaning treatment, changing samples temperature during evaporation, varying Si wafers resistivity and crystal orientation.

2:30 PM H4.5

GaAs PHOTODETECTOR FOR X-RAY IMAGING. G.C. Sun[a], H. Samic[a,b], V. Donchev[a,c], J.C. Bourgoin[a]; [a]Université Pierre et Marie Curie, CNRS, Laboratoire des Milieux Dèsordonnś et Hètèrogènes, Paris, FRANCE; [b]University of Sarajevo, Department of Physics, Sarajevo, BOSNIA & HERTZEGOVINA; [c]Sofia University, Department of Condensed Matter Physics, Sofia, BULGARIA.

Imaging requires a pixel array on the semiconductor material to convert directly photons into electrons and collect them. In case of X-ray, the absence of optics implies the use of a large pixel size (typically 100 μm for medical imaging) and consequently of a large area material for which a microelectronic technology exist. In addition the material must be characterized by a large atomic number, to absorb the X-ray photons efficiently, and by a gap of about 1.5 eV to maximize the number of electrons created by a photon while keeping the noise low at room temperature. Only thick epitaxial GaAs can obey to all these requirements. Indeed no technology is available for CdTe, which exists only in small size, and bulk grown GaAs cannot be used because it contains defects in large and non-uniform concentration. We shall describe an economical, non-polluting, technique which we use to grow several hundred microns thick epitaxial GaAs layers, on two inches diameter wafers for the moment, in a matter of hour. We shall briefly describe the structural, optical and electronic characteristics of these layers which demonstrate that they have the potentialities necessary for imaging X-ray detectors. Pixelled $p^+/i/n^+$ structures have been developed and their performances for X-ray detection will be described. A charge collection efficiency of 60% has been obtained, using particles when only a small fraction of the 200 μm thick layer was depleted. The level of the residual doping, of the order of few $10^{14}cm^{-3}$, appears to be the limiting factor and a way to overcome this limitation will be proposed and data presented illustrating the feasibility of this method.

2:45 PM H4.6

LEAD TELLURIDE-BASED FAR-INFRARED PHOTO-DETECTORS – A PROMISING ALTERNATIVE TO DOPED Si AND Ge. Dmitriy Dolzhenko, Ivan Ivanchik, Dmitriy Khokhlov, Konstantin Kristovskiy, Moscow State Univ, Physics Dept, Moscow, RUSSIA.

Doping of the lead telluride and related alloys with the group III impurities results in an appearance of the unique physical features of a material, such as such as persistent photoresponse, enhanced responsive quantum efficiency (up to 100 photoelectrons/incident photon), radiation hardness and many others. We review the physical principles of operation of the photodetecting devices based on the group III-doped IV-VI including the possibilities of a fast quenching of the persistent photoresponse, construction of the focal-plane array, new readout technique, and others. Comparison of performance of the state of the art Ge(Ga) and Si(Sb) photodetectors with their lead telluride-based analogs shows that the responsivity of PbSnTe(In) photodetectors is by several orders of magnitude higher. High photoresponse is detected at the wavelength 116 microns in PbSnTe(In), and it is possible that the photoconductivity spectrum covers all the submillimeter wavelength range.

SESSION H5: INOVATIVE DEVICES

Chair: M. Omar Manasreh
Tuesday Afternoon, November 27, 2001
Room 312 (Hynes)

3:30 PM *H5.1

PROGRESS IN BLUE AND NEAR ULTRAVIOLET VERTICAL CAVITY EMITTERS. Arto V. Nurmikko, Division of Engineering, Brown University, Providence, RI; Jung Han, Department of Electrical Engineering, Yale University, New Haven, CT.

In this presentation we review recent progress in the device science and implementation of blue and near ultraviolet vertical cavity might emitters, based on InGaN/GaN quantum well heterostructures. Different strategies that employ combinations of dielectric and as-grown AlGaN multilayer high reflectors have been used to demonstrate continuous-wave room temperature optically pumped operation. For electrically injected diode devices, additional design criteria include the challenge of lateral current spreading due to low conductivity of p-GaN. This has been resolved by using highly transparent intracavity layers based either on indium-tin oxide or p /n InGaN/GaN tunnel junctions. Resonant cavity LEDs have been demonstrated in high injection regime, suggesting that such approaches can lead to short wavelength vertical cavity lasers.

4:00 PM H5.2

A NOVEL, NON-CONTACT, OPTICAL-BASED METHOD FOR THE CHARACTERIZATION OF CRITICAL DIMENSIONS IN OPTOELECTRONIC DEVICE STRUCTURES. Yiorgos Kostoulas, Chris Raymond, Mike Littau, Raj Mundhe, Accent Optical Technologies, Bend, OR.

In this work we present results on the characterization and metrology of optoelectronic devices using a novel non-contact, optical-based technique. The method is based on the analysis of light scattered/diffracted from a periodic pattern and allows for fast, accurate and repeatable measurement of critical device structures. The system is based on a single-wavelength light source (633 nm laser) and an angle of incidence which is varied between 0 and 47 degrees from the normal. The measurement spot on the sample covers a 60 mm x 85 mm target with a maximum pitch of 5 mm. The resulting diffraction data is fitted using first principles to yield information about the underlying structure. This process provides simultaneous information on a number of parameters about the optoelectronic device including critical dimensions, layer thickness, and side wall angle. We have used this method to characterize photolithography steppers by employing focus/exposure shoots (FEMs) on structures with critical dimensions ranging from 130 nm to 180 nm. We will be presenting this data together with a comparison between this method, a scanning electron microscope (SEM) and an atomic force microscope (AFM). Our results show critical dimension resolution of <1 nm, side-wall angle resolution of <0.1° and precision of <1 nm which is more than 10x better than the performance of a typical SEM. In conclusion, we present a novel, non-contact, optical diffraction-based method for measuring critical optoelectronic device characteristics. The method provides in a single measurement critical dimension and side-wall information at 10 times better precision and twice the speed of an SEM.

4:15 PM H5.3

OPTIMIZATION OF ILMENITE-HAEMATITE WIDE BANDGAP SEMICONDUCTING FILM FOR DEVICE APPLICATIONS. P. Padmini, S. Kotru, S. Surthi and R.K. Pandey, The University of Alabama, Dept. of Electrical and Computer Engineering, Tuscaloosa, AL; D.P. Young, Louisiana State University, Dept. of Physics and Astronomy, Baton Rouge, LA; D. Donnelly, Southwest Texas State University, San Marcos, TX.

Wide bandgap materials based on (1-x)$FeTiO_3$ .xFe_2O_3 are attractive for a variety of applications such as low voltage varistors, p-n junction diodes and high temperature electronics. The excellent radiation resistance properties of this system make them particularly suitable for applications in space and in nuclear reactors. This paper discusses the optimization of the growth of thin films by pulsed laser deposition. The films were deposited on single crystal MgO and sapphire substrates. The material can be made n or p type simply by varying the concentrations of Fe_2O_3. It is found that for $x<0.27$ the material is p type, whereas for x = 0.27 to 0.45 it exhibits an n-type behavior. The paper also discusses the temperature dependence of resistivity, dependence of resistivity and Seebeck coefficients on Fe_2O_3 concentrations and I-V characteristics of the p-n junction. Moreover the absorption and transmission behavior from inrared to visible region will also be discussed to identify possible optical applications.

4:30 PM H5.4
OPTICAL GAIN PERSPECTIVE OF SILICON NANOCRYSTALS.
P.G. Kik, M.J.A. de Dood, M.L. Brongersma, and A. Polman, FOM Institute for Atomic and Molecular Physics, Amsterdam, THE NETHERLANDS; Applied Physics, California Institute of Technology, CA.

Due to its indirect electronic bandgap, bulk silicon is an inefficient light emitter, and has therefore never been considered a useful material in active opto-electronic devices such as lasers or light emitting diodes. Silicon nanocrystals are considered to be more promising, because quantum-confined excitons can recombine with a relatively high rate and at high efficiency, provided that non-radiative quenching sites are passivated.
In this presentation we will review the basic requirements for a silicon nanocrystal-based laser or optical amplifier. We discuss various energy level schemes in silicon nanocrystals: the purely excitonic system, excitons coupled to surface states (dangling bonds, oxygen), and excitons coupled to impurities (erbium). We will then describe and compare experiments done in our lab and elsewhere to probe the exciton recombination mechanism in these three nanocrystal-based systems. We will describe limiting effects such as free carrier absorption, Auger quenching and inhomogeneous broadening.
Finally we demonstrate that a system based on Si nanocrystals coupled to erbium, if carefully designed, holds promise for laser operation at 1.53 μm. Erbium doped Si nanocrystal based optical waveguides were formed by Er and Si ion implantation into SiO_2. The increased refractive index due to the nanocrystals causes excellent confinement of an optical mode at 1.5 μm centered on the Er and nanocrystal doped region. Thus, this novel nanocomposite material is not only attractive as a sensitizer system, but also as a waveguide material. Transmission measurements reveal a clear Er related absorption of 2.7 dB/cm at 1.532 μm, corresponding to a cross section of $8x10^{-20}$ cm^2. The Si nanocrystals act as very efficient sensitizers for Er. Under high doping conditions (50 Er ions per nanocrystals) no pump-induced change in the Er related absorption is observed (λ=458 nm), which is ascribed to an Auger quenching effect. For very high pump powers, a broad absorption feature is observed, related to free carrier absorption.

4:45 PM H5.5
PARTIALLY OXIDIZED PHEMTS WITH IMPROVED POWER ADDED EFFICIENCY.
Can Zheng, Robert Coffie, James Champlain, Umesh Mishra, Department of Electrical and Computer Engineering, University of California at Santa Barbara, CA.

GaAs on insulator (GOI) MESFETs have demonstrated high power added efficiencies (PAE) and high output impedances due to the minimization of substrate leakage current. Extending the GOI technology to pHEMTs is of great interest since pHEMTs are widely used for low noise and high power applications in the microwave and millimeter wave frequency ranges. Double-side doped AlGaAs/GaAs/InGaAs pHEMT structures with a 150$\AA$ $In_{0.20}GaAs$ channel and a 500$\AA$ $Al_{0.98}GaAs$ oxidation layer underneath the channel were grown. Hall measurement showed a sheet charge density of $3.5x10^{12}/cm^2$ and a room temperature mobility of 6400 $cm^2/v{\bullet}sec$. 0.7μm gate length GOI pHEMTs were fabricated. Fully oxidized pHEMTs showed transconductance peaking as high as 50% due to impact ionization in the InGaAs channel, as well as charge loss up to 30% due to back depletion caused by defects at the oxide-semiconductor interface. Partial oxidation was investigated to solve these problems. The depth of the lateral wet oxidation of AlGaAs underneath the channel can be controlled by varying the distance from the oxidation mesa edge to the active region. A series of partially to fully oxidized pHEMTs were fabricated with the oxidation front extending from below the source edge to beyond the drain edge. It was found that the largest transconductance peaking and charge loss occurred for devices with a oxidation front extending underneath and beyond the gate region. Devices with the oxidation front stopped around the source edge showed flat transconductance curves and negligible charge loss. Improved PAEs as high as 55% have been achieved at 8 GHz, class AB bias condition, compared with a PAE of 32.5% for an unoxidized control sample on the same wafer and fabricated at the same time. The associated power gains were around 15 to 17 dB at a low V_{DS} bias of 3.5V.

SESSION H6: POSTER SESSION
Chairs: M. Omar Manasreh, Eric Daniel Jones, Daniel K. Johnstone, Daniel J. Friedman and Kent D. Choquette
Tuesday Evening, November 27, 2001
8:00 PM
Exhibition Hall D (Hynes)

H6.1
ENHANCING EFFECT OF NANOMETER SILICON ON 1.54-MICROMETER ELECTROLUMINESCENCE FROM ERBIUM-DOPED SILICON OXIDE.
G.G. Qin, Y. Chen, G.Z. Ran, F.C. Yuan, L. Dai, Peking Univ, Dept of Physics, Beijing, CHINA; Z.C. Ma, W.H. Zong, National Key Laboratory for ASIC, HSRI, Shijiazhuang, CHINA.

A SiO2:Si:Er film was deposited on a n -Si substrate using the magnetron sputtering technique, and electroluminescence (EL) was observed from the Au/SiO2:Si:Er/n -Si structure at room temperature under reverse biases, which were defined as that the n -Si substrate is biased positive, larger than 4V. The 1.54- mm EL intensity ratio of an Au/SiO2:Si:Er/n -Si LED with the SiO2:Si:Er film having an excess Si content of 20% to that of an Au/SiO2:Er /n -Si LED with the SiO2: Er film without any excess Si is as large as 8. While the 1.54 mm EL efficiency of the former is 6 times larger than that of the latter. We also deposited a nanoscale (SiO2:Er/Si/SiO2:Er) sandwich structure, in which the silicon layer between the two SiO2: Er barriers was 1.0-4.0 nm thick with an interval of 0.2 nm, on the n -Si substrate. EL from the Au/SiO2:Er/Si/SiO2:Er/n -Si structure was observed under reverse bias at room temperature. Each EL spectrum of the LEDs with Si layers having different thicknesses can be fitted by three Gaussian bands with fixed peak energies of 0.757 eV (1.64 mm), 0.806 eV (1.54 mm) and 0.860 eV (1.44 mm), and fixed full widths at half maximum of 0.052, 0.045 and 0.055 eV, respectively. The 1.54 mm peak was assigned to the Er3 luminescence. Among the LEDs with Si layers of various thicknesses, the 1.64, 1.54 and 1.44 mm EL intensities of the Au/SiO2:Er/Si/SiO2:Er/n -Si LED with a 1.6 nm Si layer attain maxima which are 22, 7.9 and 6.7 times larger than those of the Au/SiO2:Er/n -Si LED, respectively. The EL efficiencies of the former are 12, 4.5 and 3.8 times larger than those of the latter, respectively. Collectively, existence of both nanoscale Si clusters and layers can enhance markedly the 1.54- mm EL from Er-doped Si oxide.

H6.2
COMPLEX RESPONSE OF LOW DIMENSIONAL SYSTEMS IN A MAGNETIC FIELD: SPIN-FLIP RAMAN SCATTERING AND ANISOTROPIC EFFECTS IN NARROW-GAP QUANTUM WELLS.
V. López-Richard, G. Qiang-Hai, IFSC, Universidade de São Paulo, São Carlos, BRAZIL; C. Trallero-Giner, Dept Fisica Teorica, Universidad de La Habana, CUBA; G.E. Marques, Dept Fisica, UFSCar, São Carlos, BRAZIL.

Despite the great advances reached in understanding the properties of narrow-gap structures there are still many opened questions that deserve an accurate analysis. We have reported and explained interesting features concerning electronic and optical properties of narrow-gap semiconductor quantum wells, such as peculiar inversion of the effective Lande factor as a function of the magnetic field and strong effective mass dependence on the Landau level index, which are directly bound to their peculiar band structure. The relevance of the electronic band structure in the simulation of the system response related to spin excitations has also been stressed. However, many times these properties are clearly underestimated. The omission of interband mixing effects usually forces the introduction of quasiparticles in order to account for unexpected features of the system response, what we believe is some times misleading. We have proved, by taking the strong interband coupling into account, that inelastic light scattering by spin-density fluctuations is to be strong and, in the limit case of low transverse momentum, the scattering mediated by spin-flip transitions is the leading process. The anisotropic response to the incident light, as function of the incident angle, has been described and linked to the symmetry properties of the quasi-two dimensional plasma excitations. This point may help to understand the nature of spin-flip Raman scattering processes observed in quasi-two dimensional electron plasmas in the presence of a magnetic field. It is also shown that integer Landau filling factors can be associated to limit cases where the picture of the excitation spectrum changes drastically. The polarizability strength is modulated by the density of occupied states and this induced magnetic field

modulation certainly may be used to switch off chosen resonant transitions, adding an external control to a device.

H6.3
α,ω-DIAMINE ASSISTED ASSEMBLY OF CdSe NANOCRYSTALS. Jeunghoon Lee, Mathew Mathai, Faquir Jain, Fotios Papadimitrakopoulos, Nanomaterials Optoelectronics Laboratory (NOEL), Institute of Material Science, University of Connecticut, Storrs, CT.

Developing methodologies for controlling film thickness at the nanometer level while retaining morphological stability, high photoluminescence (PL) efficiency and carrier transport is of great importance for semiconductor applications of quantum dot nanocrystals. The layer-by-layer assembly of CdSe nanocrystals using ,-diamine fit all these requirements and has permitted their incorporation in organic light emitting diode as functional and emitting layer. This paper provides an in depth understanding of the growth mechanism, in conjunction with order. CdSe nanocrystals having different chemical passivating agent was assembled to investigate chemical interaction between the nanocrystal and organic molecules, which greatly influence optical properties of the nanocrystals such as PL efficiency. A variety of spectroscopic techniques in conjunction with quartz crystalline microbalance (QCM) were employed in order to illustrate various aspects of film properties associated with PL and EL efficiency.

H6.4
ELECTRICAL AND OPTICAL PROPERTIES OF $Zn_{1-x}(LiMg)_xO$ THIN FILMS. R.E. Melgarejo, M.S. Tomar, A. Hidalgo, Univ. Puerto Rico, Mayaguez, PR; A. Dixit, R.S. Katiyar, Univ. Puerto Rico, Phys. Dept., San Juan, PR.

Li and Mg doped ZnO thin films are of interest because of their possible ferroelectric and semiconducting behavior. We prepared thin films on various substrates by spin coating. Electrical and oprical properties of the films were investigated. Mg doped films improve the optical transmission and reduces the film resistance. Work supported by AFOSR

H6.5
THE ELECTROLUMINESCENCE AND PHOTOLUMINESCENCE STUDY OF SILICON-RICH-SILICON-OXIDE FABRICATED BY RF MAGNETRON SPUTTERING. T.G. Kim, H.S. Bae, S. Im, C.N. Whang, Institute of Physics and Applied Physics, and ASSRC, Yonsei University, Seoul, KOREA; Johan Sun, Jung H. Shin, Dept of Physics, Korea Advanced Institute of Science and Technology (KAIST), Taejon, KOREA; J.S. Yang, Photonics Center, Korea Institute of Science and Technology (KIST), Seoul, KOREA; J.S. Yun, J.H. Song, Advanced Analysis Center, Korea Institute of Science and Technology (KIST), Seoul, KOREA.

For the study of silicon luminescence, the Silicon-Rich-Silicon-Oxide(SRSO) films were deposited by rf magnetron sputtering. The base and working pressure were $5x10^{-7}$ and $4x10^{-3}$ Torr, respectively. As was confirmed by backscattering(BS), the thickness and Si content of SRSO films were 2000 Å and 42 at.%, respectively. Si, P, Ge and As Ion implantation with doses ranged from $5x10^{14}$ to $1x10^{16}$ were carried out to give damages to the films. As-deposited films were annealed at 500°C for 2 hr and 1100°C for 4 hr. subsequently. Implanted SRSO films were annealed at 800°C for 30 min and 900, 1000°C for 1 min subsequently. In order to measure electroluminescence (EL), the metal insulator semiconductor(MIS) structure was fabricated by HF etching and gold ohmic contact. EL was observed at forward bias from the sample annealed at 1100°C 4 hour annealed and hydrogenated. While, intense EL was observed at reverse bias from as-deposited and the 500°C annealed sample. It could be seen with naked eyes. It seems like that the EL from reverse bias is related with defects, and that from forward bias is related with nanocrystal. In addition, the PL spectra were measured to confirm the existence of nanocrystal. The broad peak centered at 450 nm related with defects was observed from the as-deposited and 500°C annealed sample. The broad peak related with defect was weakened and the peak related with nanocrystal was intensified after 1000°C 4 hour anneal and hydrogenation. The PL intensity of 110 keV Si implanted SRSO film was greater than that of 50 keV Si implanted SRSO films at the same dose. In case of Ge ion implantation, PL intensity closely depends on the dose. However, P ion implantation does not increase PL intensity as increasing the doses. It thus means that Ge ion implantation affects more sensitively to PL intensity than P ion implantation. Detail effects of ion implantation into PL and EL will be presented.

H6.6
DEPTH PROFILING OF SiC LATTICE DAMAGE USING MICRO-RAMAN SPECTROSCOPY. Iulia C. Muntele, Daryush Ila, Claudiu I. Muntele, Center for Irradiation of Materials, Alabama A&M University, Normal, AL; David B. Poker, Dale K. Hensley, Solid State Division, Oak Ridge National Laboratory, Oak Ridge, TN.

In device fabrication the ion implantation is usually the doping method of choice because it offers precise control over the spatial distribution and doping level using conventional masking techniques. Hot implantation of silicon carbide is a common practice aimed at reducing the damages incurred during the passage of ions through the material, reducing the needs for post-implantation annealing for crystalline lattice recovery. Although literature mentions that strong dynamical recovery has been achieved at temperatures as low as 200°C, an annealing temperature up to 1700°C is still necessary for an acceptable degree of lattice recovery, especially for Al-doped p-type silicon carbide. In order to predict a certain type of behavior of an electronic device, it is important to know the depth distribution of the residual damage present in the crystalline lattice, since the carrier trapping levels introduced in the band gap can significantly change the electric behavior. Techniques like Positron Annihilation Spectroscopy and Rutherford Backscattering/Channeling Spectrometry have been reported in the literature as good tools for this type of investigation. This paper is intended to present an all-optical approach of this problem, using a confocal micro-Raman spectrometer for depth analysis, along with an UV/Vis spectrometer for optical absorption measurements. Various samples of p-type (Al-doped) and n-type (N-doped) silicon carbide samples have been implanted with helium, oxygen, and aluminum at 2 MeV and fluences between 1015 and 1017 ions/cm^2 at both room temperature and 500°C, and then annealed at temperatures between 500 and 1000°C. Optical measurements were performed before and after each step. The paper will also present full details of the experimental procedure employed for damage depth profiling and quantitative results at any significant step during sample processing on all the samples mentioned here.

H6.7
OPTICAL AND STRUCTURAL CHARACTERIZATION OF THE QUATERNARY SEMICONDUCTOR COMPOUND $Sa^4_nIna^2_nZna^x_nMna^{1-x}_n$. Rosario Avila-Godoy, Adan Lopez-Rivera, Asiloe Mora-Rodriguez and Dwight R. Acosta[a], Universidad de Los Andes, Fac. de Ciencias, Merida, VENEZUELA; [a]Instituto de Fisica, UNAM, Mexico D.F., MEXICO.

The optical and structural properties of the semimagnetic and semiconductor family $Sa^4_nIna^2_nZna^x_nMna^{1-x}_n$ are studied in this work by at least two techniques: optical absorption and electron microscopy, to clarify their possible applications and to identify crystallographic and structural parameters when manganese atoms are introduced to the starting ternary semiconductor phase. It has been found that the quaternary compound accepts Mn concentrations up to x = 0.47, without alters its crystallographic starting phase. Our samples were grown by chemical transport method using iodine like transport agent. Analytical electron microscopy (eds) was used to determine the manganese concentration for the quaternary compound $Sa^4_nIna^2_nZna^x_nMna^{1-x}_n$ and values running from x = 0.0 up to x = 0.47 were observed. Optical absorption spectra were recorded between 400 and 900 nm, using a Spex monochromator with 0.75 m with a 1200 lines/mm diffraction grating and after plotting (αhν) versus hν, a straight line is obtained and from here using least square fitting methods the band gap was determined. Crystallographic studies were done from high resolution electron microscopy images obtanied in a JEOL 4000EX electron microscope and using the commercial CRISP computing program. Also convergent beam electron diffraction images were studied in order to precise the right crystallographic space group for different manganese concentrations. Several different polytype configuration were derived and identified from electron diffraction and high resolution electron micrographs. Since this semiconductor presents crystal defects, the atomic structures of extended defects, e.g. dislocations, stacking fault type, been studied by high-resolution transmission electron microscopy in this work.

H6.8
NEW APPROACH FOR THE DEPOSITION OF I/III/VI THIN FILMS. Jin-Ho Park, Mohammad Afzaal, Paul O'Brien, The Manchester Materials Science Centre and Dept. of Chemistry, Univ. of Manchester, Manchester, UNITED KINGDOM.

The ternary chalcopyrite semiconductor Cu(In,Ga)(Se,S)$_2$ is currently used as absorber layer in high efficiency thin film solar cells. In this study, various types of I/III/VI$_2$ (I = Cu, III = Ga or In, VI = S or Se) thin films ($CuGaS_2$, $CuInS_2$ and $CuInSe_2$) were prepared from a series of organometallic precursors, M[S(Se)CNMeR]$_n$ (M= Cu, In, Ga, R = alkyl) by aerosol-assisted chemical vapour deposition (AA-CVD). The precursors are very easy to synthesise by one-pot reaction and are air stable, which is favourable in comparison with metal alkyl compounds, MR_3 (M = In and Ga, R = alkyl), which are found to be pyphroic. The optimum growth temperature for the preparation of these films on various substrates (glass, GaAs and InP) was found to be above 400°C in terms of crystallinity, although deposition occurred at lower temperatures. The films have been

investigated using XRPD, SEM, EDS, XPS and AFM, as well as other material characterization techniques. SEM analyses show all films are micro-crystalline. XRPD results show evidence of the crystalline nature of these films. The results of this comprehensive study will be presented and discussed.

H6.9
VISIBLE PHOTOLUMINESCENCE OF NON-EQUILIBRIUM SILICA FILMS FABRICATED BY PULSED ION BEAM ABLATION. N. Kishimoto, Nanomaterials Laboratory, National Institute for Materials Science, Tsukuba, JAPAN; T.J. Renk, Sandia National Laboratories, Albuquerque, NM; M.O. Thompson, Cornell University Ithaca, NY.

Intense ion-beam ablation methods have demonstrated unique capabilities such as high-deposition rate with wide angular coverage, and non-equilibrium doping of immiscible elements. One possible application that takes advantage of these characteristics is the fabrication of luminescent films. The non-equilibrium nature favors efficient doping, but results in the formation of defect centers which may either directly attenuate or indirectly assist radiative recombination. In order to optimize the luminescence mechanism, it is required to study interactions between defect centers and doped elements. We focus on doping of rare-earth elements which may act as luminescent centers due to partially filled 4f shells. In order to pursue *blue* emission, we employ rare-earth elements of Gd, Tm and Er which have different fundamental transition energies. Pulsed ion-beam ablation was conducted on the 700 kV RHEPP-1 facility at Sandia National Laboratories. Silica glass and target metals were co-ablated by an intense carbon beam at 5-10 J/cm^2 and were directly deposited onto silica substrates. Photoluminescence (PL) was measured by a luminescence-lifetime detection system (Hamamatsu Photonics Co. Ltd.), which consisted of an N_2-laser for excitation (wavelength 337 nm, pulse width 300 ps) and a streak scope. Although the deposition rate was extremely high, the surface morphology observed by AFM indicated successful formation of continuous silica films. The PL spectra of the silica glasses moderately (*1%) doped with Gd, Tm and Er showed intense visible luminescence around 450 nm at room temperature. The spectra for the three elements were similar and covered a range from 370 nm to 600 nm. The lifetime is about 4 ns with a weak dependence on wavelength. The rare-earth doping increased optical absorption in the UV-Vis region. Heavy doping above ∼5% significantly increased the absorption, and eventually quenched the luminescence. The fundamental transition energies of Gd and Tm (and Er) ions are larger and smaller, respectively, than the photo-excitation of 337 nm. The similarity of PL spectra indicates that the main PL spectra do not arise from the 4f states but are associated with defect-solute agglomerates. Effects of SiO_x formation and dopant concentration on the PL will be presented.

H6.10
THZ-IMAGING: APPLICATION TO THE NONDESTRUCTIVE EVALUATION OF ENERGETIC MATERIAL COMPONENTS. Francesca Calgaro Montalenti, David J. Funk, Richard D. Averitt and Antoinette J. Taylor, Los Alamos National Laboratory, Los Alamos, NM.

The use of THz time-domain spectroscopy (THz-TDS) for imaging has recently attracted considerable interest, mainly due to the possible applications in several different scientific fields (such as biology, medicine, and material science). The technique offers the advantages of being cheap, safe, and non-invasive. Moreover, for relatively thin samples (a few millimeters), THz-TDS can achieve a spatial resolution on the order of a few hundred microns (or less). We have developed a transmission imaging system where the THz pulses are generated and detected by photoconductive semiconductor antennas excited with femtosecond laser pulses. The images are obtained by moving the sample on a two-axis stage and recording, pixel by pixel via a fast-scanner, the electric field transmitted through the sample. The image can be optimized using the signal amplitude, the signal phase, or the frequency spectrum of the radiation. We show how THz-imaging can be exploited for defect detection in different materials. In particular, we have examined machined samples of two plastic-bonded explosives, PBX 9501 (95% HMX/2.5% estane/2.5%BDNPA-F), and PBX 9502 (95% TATB/5% Kel-F 800), on which we report our results.

H6.11
COMPARISON OF $Al_xGa_{1-x}As$ OXIDATION IN MBE AND MOCVD GROWN SAMPLES. Y. Chen, A. Roshko, K.A. Bertness, National Institute of Standards and Technology; D. Readey, Colorado School of Mines; A.A. Allerman, Sandia National Laboratories; M. Tan, A. Tandon, Agilent Technologies.

AlGaAs native oxides are playing an increasingly important role in optoelectronic devices as current and optical confinement apertures in VCSELs and in DBRs. While many studies have investigated the influence of oxidation parameters on the oxidation kinetics, the effect of AlGaAs growth conditions on the oxidation rate has not been examined. In this study, the oxidation of $Al_xGa_{1-x}As$ (x=0.9 to 1.0) layers grown by both MBE and MOCVD in several different growth systems, has been investigated. Although the MBE-grown AlGaAs layers are pseudo-alloys rather than the random alloys grown by MOCVD, it was found that the MBE samples have oxidation kinetics almost identical to those of some MOCVD samples. However, large variations in the oxidation rates of MOCVD samples grown in different systems were found. All of the samples show the typical exponential dependence of oxidation rate on Al composition for x = 0.90 to 0.98 but the oxidation rate of pure AlAs layers was found to be lower than expected in MOCVD-grown samples. The role of growth parameters such as: temperature, III/V ratio, source material, rate, substrate orientation, and impurities will be discussed.

H6.12
HOLE CONCENTRATION VERSUS Mn FRACTION IN A DILUTED (Ga,Mn)As FERROMAGNETIC SEMICONDUCTOR. Raimundo R. dos Santos, Instituto de Física, UFRJ, Rio de Janeiro, RJ, BRAZIL; L.E. Oliveira, Instituto de Física "Gleb Wataghin", UNICAMP, Campinas, SP, BRAZIL; J. d'Albuquerque e Castro, Instituto de Física, UFRJ, Rio de Janeiro, RJ, BRAZIL.

Over the last few decades a considerable amount of work has been devoted to the understanding of the electronic, optical and transport properties of diluted magnetic semiconductors [1]. In particular, the discovery of ferromagnetism [2] in III-V Mn-based semiconductor compounds has opened the possibility of manupilating both charge and spin degrees of freedom combined with effects due to quantum confinement. Mn is a transition metal having five electrons in its 3d levels, and acts as an $S = 5/2$ local moment when incorporated into a GaAs matrix, besides being an acceptor generating free holes in the valence band due to the difference between Mn^{2+} and the cation Ga^{3+}. However, the density of free carriers (holes) largely differs from that of Mn sites. In this work, we address this issue by considering a mean-field theory in which the coupling between the localized Mn^{2+} moments is mediated by a gas of polarized free holes (with effective mass m^*) [4]. The hole concentration as a function of the fraction of Mn sites, x, is then given by

$$p \propto \left[\frac{T_c}{m^* J^2\, x}\right]^3,$$

where J is the free-hole/local-moment coupling, and T_c is the critical temperature. By fitting experimental data [3] for T_c and for the product $m^* J^2$, one may infer that the dependence of the hole concentration p with x can be traced back to the occurrence of the reentrant metal-insulator transition taking place in the hole gas.
[1] H. Ohno, Science **281**, 951 (1998); J. Magn. Magn. Mater. **200**, 110 (1999). [2] H. Ohno *et al.*, Phys. Rev. Lett. **68**, 2664 (1992); Appl. Phys. Lett. **69**, 363 (1996). [3] H. Ohno and F. Matsukura, Solid State Commun. **117**, 179 (2001). [4] J. König, H.-H. Lin, and A.H. MacDonald, cond-mat/0010471.

H6.13
PHOTOLUMINESCENCE FROM Er-IMPLANTED 4H AND 6H-SiC. Shin-ichiro Uekusa, Takayuki Goto, Meiji Univ, Kawasaki, Kanagawa, JAPAN.

Erbium (Er)-doped semiconductor is a potentiallly useful material for light-emitting devices in optical communication systems, since the intra-4f-shell transitions of Er ions cause sharp and temperature-stable luminescence in various host materials, 1.54 μm, which corresponds to the minimum absorption of silica-based optical fibers. Photoluminescence (PL) from Er^{3+} in Er-doped narrow band gap semiconductors [e.g., silicon (Si)] has been reported, but the PL is weak and difficult to observe at room temperature (RT). In this work, Er ions were implanted into 4H and 6H-silicon carbide (SiC) materials, which are useful host materials because they equip the wide band gap and improve the luminescence properties of Er^{3+} ions, and were characterized by PL measurements and Rutherford backscattering spectrometry channeling analysis. Er implantation energy was performed at 2MeV with a dose range of 1×10^{13}, 3×10^{13}, 1×10^{14}, cm^{-2} at R.T. Following the ion implantation, these sample were annealed at ranging from 1400°C to 1700°C for 40 minutes using a rapid thermal annealing. As to 4H-SiC, the optimum annealing temperature was 1600°C. PL intensity decreased at 1700°C, and the bandedge luminescence changed in relation to the luminescence of Er^{3+}. PL intensity of Er^{3+} may be due to the sublimation of Si atoms and the decrease in excitation volume of PL. The PL spectra were excited using the 325nm line of He-Cd laser at power of 20mW and were measured at temperatures ranging from 15K to 300K. Thermal quenching of the luminescence of Er^{3+} was suppressed further by using 4H and 6H-SiC with more wide band gap as a host material compared with 3C-SiC and their luminescences were observed at RT. From the excitation wavelength dependence, we

suggest that the transfer of the recombination energy of electron-hole pairs generated in SiC to the Er-4f-shell via the Auger effect causes the luminescence of Er^{3+} in SiC:Er.

H6.14
CORRELATION OF ERBIUM PHOTOLUMINESCENCE AND LATTICE LOCATION IN CARBON DOPED Si. Xiaotang Ren, Mengbing Huang, Dept. of Physics, Univ. at Albany-SUNY.

Doping erbium into Si is a promising method for realizing light emission from Si. It is known that impurities (e.g. carbon, oxygen) in Si can greatly influence luminescence from Er atoms. In this work, we report a study of carbon doping effects on Er lattice locations and photoluminescence. Ion channeling combined with Monte Carlo simulation has been utilized to determine the lattice location of Er atoms in Si. Incorporating carbon into Si was found to result in a conversion of Er lattice sites from the generally observed tetrahedral position to the hexagonal position. This structural modification of Er-related defects has been correlated with changes in Er luminescence, and may shed light on the nature of two luminescence components of Er with distinct time scale characteristics.

H6.15
OPTICAL PROPERTIES OF MgZnO ALLOYS. J.F. Muth, ECE Dept, NCSU, Raleigh, NC; C. Jin, A. Kvit, J. Narayan, Materials and Engineering Dept, NCSU, Raleigh, NC.

Alloying Mg with ZnO permits the band gap to be controlled between ~3.3 to ~8 eV. Materials with band gaps in this range have potential uses as ultraviolet light emitters and photodetectors. ZnO is wurtzite while MgO is cubic. With Pulsed Laser Deposition we have found that we can produce MgZnO alloys in both phases. The wurzite phase is grown on sapphire substrates while the cubic phase has been epitaxialy grown on both Sapphire and Silicon substrates through domain matching epitaxy.This potentially permits integration with silicon electronics on silicon substrates. The optical properties of cubic and wurtzite MgZnO will be presented. The excitonic binding energy of the MgZnO alloy is very large $>\sim 60$ meV which results in very bright photoluminescence and cathodoluminescence. Structural data is provided via high-resolution transmission electron microscopy.

H6.16
AVALANCHE BREAKDOWN IN NANOCRYSTALLINE SILICON HETEROSTRUCTURES. Andrew Verba, Igor Tcheslavsky, Kiev National Taras Shevchenko Univ, Dept of Radiophysics, Kiev, UKRAINE.

The dark and light I-V characteristics and spectral curves of planar Ni-porous Silicon- p-Si - Ni heterostructures have been studied. It is shown, the photogeneration in heterostructure occurs both in the region of thin porous silicon layer and p-Si base. The avalanche breakdown is observed in the heterostructure at applied voltage biases V>8-10 V and temperature T=77 K. The coefficient of multiplying at V=11 V achieves 60 (dark) and 200 (light) that is close for silicon n -p -i- p avalanche photodiodes.

H6.17
TIME-INTEGRATED AND TIME-RESOLVED PHOTO-LUMINESCENT PROPERTIES OF ZnO THIN FILMS GROWN ON Al_2O_3(00•1) USING METAL-ORGANIC VAPOR PHASE EPITAXY. S.W. Jung, W.I. Park, S.J. An, G.-C. Yi, Pohang Univ. of Science and Technology (POSTECH), Dept of MS&E, KOREA (SOUTH); S. Hong, T. Joo, Pohang Univ. of Science and Technology (POSTECH), Dept of Chemistry, KOREA (SOUTH).

There has been great interest in the growth and optical characterizations of ZnO thin films for ultraviolet (UV) photonic device applications. From the PL spectra, PL peaks associated with free excitons and stimulated emission in ZnO epilayers have been observed at room temperature, implying that an exciton-related recombination process can be utilized for optoelectronic devices. However, little research has been performed on the vapor phase epitaxial growth of ZnO thin films. In addition, the optical properties of high quality ZnO films grown by metal-organic vapor phase epitaxy (MOVPE) have rarely been studied. For PL measurements, high quality ZnO thin films were epitaxially grown on Al_2O_3(00•1) substrates using low pressure metal-organic vapor phase epitaxy. As-grown films exhibited dominant excitonic emissions and a very weak deep level emission. Temperature-dependent PL measurements were carried out in order to investigate the origins of near bandedge emission peaks. Furthermore, time-resolved PL measurements indicate that the lifetime of free excitons in the epilayers is in the range of 100-300 ps at room temperature, depending on film quality. From excitation power dependent PL spectra of ZnO films at room temperature, stimulated emission was observed at 3.19 eV. Their temporal behavior also will be discussed.

H6.18
CONTROL OF ZnO MORPHOLOGY BY MICROEMULSION-MEDIATED HYDROTHERMAL AND SOLVOTHERMAL SYNTHESIS. Lingdong Sun, Jun Zhang, Chunsheng Liao, Chunhua Yan, College of Chemistry and Molecular Engineering, Peking University, Beijing, PR CHINA.

The direct synthesis of inorganic material with diversiform morphologies (morphosynthesis) is a stimulating area of materials chemistry. It is apparent that the properties are liable to be tailored for effective morphology controlling. ZnO, as an exceptionally important material for applications in pigment, rubber additives, gas sensor, as well as optical applications, has been attracting both for fundamental and application studies. The reports of ZnO with different size and morphology emerged endlessly in order to fine-tune ZnO properties for special application. In this communication, ZnO with a rich variety of well-defined morphologies have been achieved by microemulsion-mediated hydrothermal or solvothermal synthesis, which can prepare materials with controlled morphology by only one step without calcination which may lead to the growth and aggregation of the particles. The influences of solvent, microemulsion composition, temperature, growth time as well as pH on the particle size and morphology of ZnO were investigated. It was revealed by the scanning electron microscope (SEM) and transmission electron microscope (TEM) images that the morphological feature of ZnO can be controlled as sphere-, twin tablet-, rod-, polyhedron-, round fluffy sphere-, snowflake- and flower-like, etc. XRD measurement showed that ZnO with different morphologies was the same as hexagonal structure, which was well consistent with electron diffraction (ED) characterization. The possible growth mechanism was afforded briefly. This communication not only provides promising candidates for materials science due to the importance of shape in relationship with materials, but also presents an effective route to synthesize the well-defined inorganic materials.

H6.19
INFLUENCE OF Er AND O DOSES ON Er-RELATED EMISSION IN $Al_{0.70}Ga_{0.30}As$:Er. S. Uekusa, T. Arai, Meiji Univ, Dept of Electrical and Electronic Engineering, School of Science and Technology, Kanagawa, JAPAN.

Erbium (Er)-doped semiconductors are of much interest as an application of optical emitting device at 1.54μm, which coincides with the wavelength of minimum loss in silica-based optical fiber. It is important for the Er-doped semiconductor to improve problems such as the rapid thermal quenching property of the Er-related emission of energy transition from the host semiconductor to intra-4f-shell of Er ions. Er ions with doses ranging from $1x10^{13}$ cm^{-2} to $1x10^{15}$ cm^{-2} were implanted into molecular beam epitaxy (MBE) grown $Al_{0.70}Ga_{0.30}As$ on GaAs substrates and were annealed for 10 min. at 800°C, using the proximitry cap method in a pure H_2 atmosphere. Photoluminescence (PL) intensity of Er-related emission around 1.54 μm was enhanced by co-implanted oxygen (O). The optimum dose of Er ion was $1x10^{14}$ cm^{-2} and O ion was $1x10^{15}$ cm^{-2}, respectively. Furthermore, from the temperature dependence of the PL intensity of sample implanted with the optimum dose, we estimated the values of E_1, E_2, and E_3, the activation energies in order to investigate the rapid thermal quenching of Er ion in $Al_{0.70}Ga_{0.30}As$. We found that PL intensity of Er-related emission, in addition to O dose, was enhanced approximately twenty two times at room temperature. And from the temperature dependence of the lifetime of the optimum dose of Er and O, the value of E_A (245meV), the activation energy for the decrease of the lifetime, was nearly equal to the value of E_3 (235meV). Based on the result, the decrease of the lifetime confirms that the radiative efficiency is low as compared with Er dose of $1x10^{14}$ cm^{-2} into $Al_{0.70}Ga_{0.30}As$, therefore we propose that rapid thermal quenching occurs at temperatures above 200 K due to the decrease of the radiative efficiency.

H6.20
AB INITIO STUDIES OF THE INFLUENCE OF 5- AND 6-ATOM RING TOPOLOGY ON THE OPTICAL PROPERTIES OF AMORPHOUS GERMANIUM AND GERMANIUM NITRIDE. R.M. Valladares, A.G. Calles, Depto. de Física, Fac. de Ciencias-UNAM, México, DF, MEXICO; M.A. Mc Nelis, México, DF, MEXICO; Ariel A. Valladares, IIM-UNAM, México, DF, MEXICO.

We simulate a-$Ge_{17-i}N_i$:H that contains 5-atom planar rings and a-$Ge_{21-i}N_i$:H that contains 6-atom boat-type rings where $i = 0, 1, 4$. The simulations were carried out using the DFT-LDA approximation included in the *DMol* code of MSI. We report calculations of the impurity levels and relate these to the size of the gap and to the optical absorption curves for each cluster. A comparison is made between the two a-GeN clusters studied to analyze the effect of the ring topology. This work is part of a program to understand the effect of ring topology on the interband transitions in group IV amorphous semiconductor materials pure and with nitrogen.

H6.21
OPTICAL AND SURFACE ANALYSIS OF DC-REACTIVE SPUTTERED AlN FILMS. A. Mahmood, Centro de Ciencias de la Materia Condensada-UNAM, Ensenada, BC, MEXICO; S. Muhl, Instituto de Investigaciones en Materiales-UNAM, MEXICO; J. Heiras, R. Machorro, Centro de Ciencias de la Materia Condensada-UNAM, Ensenada, BC, MEXICO; and E. Andrade, Instituto de Fisica-UNAM, MEXICO; F.F. Castillón, Departamento de Polímeros y Materiales-US, Sonora, MEXICO.

Aluminium nitride, AlN, is very attractive for many electronic and optoelectronic applications in the semiconductor industry. We report the preparation of AlN films by DC-reactive magnetron sputtering. To study the relation between the film properties and the preparation conditions the following range of deposition parameters have been used: substrate temperature from 200 to 700°C, working gas composition ratio of Ar/N_2 from 80/20 to 20/80, and plasma current from 0.2 to 0.50 Amperes. The dielectric function in the visible range, absorption spectra, and band gap have been studied by ellipsometry. We report a correlation between the deposition parameters and the optical properties of the films. Surface analysis is done by X-ray Photoelectron Spectroscopy (XPS) to find out the bonding nature and chemical states on the surface of the film. Rutherford backscattering analysis showed that films with composition close to the 1:1 stoichiometry could be produced even with nitrogen gas concentrations below 50%. The deposits have also been analysed using XRD, SEM, AFM and FTIR.

H6.22
STUDY OF POSSIBILITY TO CONTROL OPTICAL PROPERTIES OF ZGP CRYSTALS. A.W. Vere, The Crystal Consortium Ltd., Glasgow, UNITED KINGDOM; C.J. Flynn, DERA, Malvern, Worcs, UNITED KINGDOM; A.I. Gribenyukov, G.A. Verozubova, A.Yu. Trofimov, Inst. for Optical Monitoring, Tomsk, RUSSIA.

This contribution is a study of behavior of the defect-related optical absorption spectra of ZGP under post-growth thermal treatment and irradiation by fast (4 MeV) electrons. A level of optical absorption in as-grown crystals studied by us is determined by deep levels with energy position E=Ev 0.9 eV. Comparison of parameters of theoretical dependence of optical absorption cross-section and experimentally determined values of optical absorption coefficient shows that the optically active centers are donors. It is shown that post-growth thermal annealing allows to decrease the optical absorption coefficient at 2-4 times down to 0.1 cm^{-1}. No changes are observed in energy spectra of the defects under thermal treatment of ZGP crystals. Electron beam irradiation of ZGP provides a higher decrease in optical absorption at 2.0 mkm as compared with thermal annealing. It is also found significant changes in the energy spectra of the optically active centers: the deep level donors with E=Ev 0.9 eV disappear whereas defects with shallow levels of unknown nature occur. A dependence between the optimal electron dose for the maximum ZGP enlightenment and initial absorption of ZGP crystals is found. The optimal irradiation dose allows to reduce the absorption down to 0.01 cm^{-1} at 2 mkm. Post-irradiation annealing experiments reveal an effect of irreversible changes in absorption under the irradiation. This behavior is discussed in frames of model of interaction between the initial point defects and radiation ones.

H6.23
Abstract Withdrawn.

H6.24
Abstract Withdrawn.

H6.25
OPTICAL ABSORPTION OF INTERSUBBAND TRANSITIONS IN InGaAs/InAlAs MULTIPLE QUANTUM WELLS. Zachary Dios, Robert Koontz, Jing Chen, M.O. Manasreh, Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, NM; Mohamed Missous, Department of Electrical Engineering and Electronics, University of Manchester, Institute of Science and Technology, Manchester, UNITED KINGDOM.

$In_{0.52}Ga_{0.48}As$:Si/$In_{0.52}Al_{0.48}As$ multiple quantum wells (MQWs) grown on InP substrate by molecular beam epitaxial technique were investigated using Fourier-transform infrared and photoluminescence spectroscopies. Capacitance-Voltage and X-ray diffraction measurements were used to verify the good quality of the MQW structures. Hall effect measurements performed at 300 and 77K show the absence of freeze out at low temperatures, which is an indication of high quality MQW structures. Intersubband transitions in the MQWs were observed in structures with well widths ranging from 30 -75 . Unlike GaAs/AlGaAs MQWs, the optical spectra of InGaAs/InAlAs MQWs exhibit two transitions in samples with a well width of 75 . This is due to the fact that the conduction band offset of InGaAs/InAlAs MQWs is much larger than that of the GaAs/AlGaAs system. Comparison between the experimental results and theoretical calculations will be presented. The large conduction band offset in the InGaAs/InAlAs MQWs makes this system very attractive for optical communication in the 1.5 micron region.

H6.26
Transferred to H3.6.

H6.27
CALCULATIONS OF DIELECTRIC CONSTANT FOR QUATERNARY III-V SEMICONDUCTOR ALLOYS IN THE TRANSPARENT REGION AND ABOVE (0.2-4.0EV). M. Linnik and A. Christou, Department of Materials and Nuclear Engineering and Materials Research Science and Engineering Center, University of Maryland, College Park, MD.

The modeling of the spectral behavior of the refractive indices of the binary, ternary and quaternary III-V semiconductor alloys in the energy range from 0.2 to 4eV, including the transparent region, is presented. The extended model of interband transition contributions incorporates not only the fundamental absorption edge contribution to the dielectric function, but also contributions from higher energy and indirect transitions. It is demonstrated that indirect energy transitions must be included in the calculations of the complex dielectric function of the material in the transparent region. Indirect transitions from different critical points in the Brillouin zone are treated separately. The comparison between the theoretical refractive indices and the experimental data for AlGaAsSb, AlGaInAs, AlGaInP, GaInAsSb, and GaInPAs alloys is presented. These calculations have been applied to the design of Bragg mirrors with the highest refractive index contrast for heterostructure lasers.

H6.28
ANNEALING OF SOME II-IV-V_2 CRYSTALS IN THE VAPOR OF VOLATILE CONSTITUENTS. Valeriy G. Voevodin, Olga V. Voevodina, Svetlana A. Bereznaya, Zoya V. Korotchenko, Siberian Physico-Technical Inst., Tomsk, RUSSIA; Nils C. Fernelius, Jonathan T. Goldstein, Melvin C. Ohmer, Air Force Research Lab., Materials and Manufacturing Directorate, Wright-Patterson AFB, OH.

Experiments on annealing of $CdGeAs_2$-, $CdSnAs_2$- and $ZnGeP_2$-crystals in the vapor of volatile constituents were carried out. Conductivity and Hall effect measurements were performed to characterize the modification of electrical properties, caused by the interaction of the crystal with the gas phase during annealing. Literature data and the results of the present work are discussed based on the results of a quasi-chemical analysis. This yielded that the results of annealing depends essentially on both the conditions of the experiment and the initial imperfection of the crystal. The most probable native structural defects becoming apparent under the annealing were the following: for $CdSnAs_2$ - Sn_{Cd}, V_{As}; for $CdGeAs_2$ - V_{As}, V_{Cd}, Cd_{Ge}, Ge_{Cd}: for $CdSiAs_2$ - Si_{As}, V_{As}; for $CdSiP_2$ - V_{Cd}, V_P; for $ZnGeP_2$ - Zn_{Ge}, Ge_{Zn}, V_{Zn}, V_P; and for $ZnSnP_2$ - Zn_{Sn}, Sn_{Zn}, V_{Zn}, V_P.

H6.29
ELECTRICAL AND OPTICAL STUDIES ON SEMI-INSULATING ZnTe. S. Johnston, R.K. Ahrenkiel, National Renewable Energy Laboratory, Golden, CO; P. Banerji, S. Bhunia and D.N. Bose, Advanced Technology Centre, Indian Institute of Technology, Kharagpur INDIA.

ZnTe is II-VI compound semiconductor which is p-type when undoped, n-type doping being reported only recently. Semi-insulating (SI) ZnTe formed by compensation with donor impurities is of interest in nuclear particle detection and as a substrate for epitaxy of InAs and GaSb. SI - ZnTe single crystals were grown by the Bridgman technique by In doping of the melt. Although $\sim 10^{19}/cm^3$ In atoms were introduced,the amount incorporated was estimated to be $\sim 10^{17}/cm^3$. The direct band-edge at 300 K thus shifted from 2.26 eV to 2.06 eV. Resistivity and Hall effect studies at 300 K gave a resistivity of $5.74\times 10^7 \Omega\cdot cm$ with a hole concentration of $2.4\times 10^9/cm^3$ and hole mobility of 45.1 cm^2 / V.s Time-resolved photoconductivity (TRPC) studies were carried out with the incident laser wavelength varied from 555 nm (2.23 eV) to 592 nm (2.095 eV). The PC response was characterized by two decay times. With 555 nm illumination, the fast decay time was very short (5.45 μs) due to surface recombination,increasing to 36 μs at 592 nm characteristic of the bulk.The amplitude of the response was largest at 585 nm (2.12 eV) just above the band-gap of SI-ZnTe. Thermally stimulated current (TSC) measurements revealed 2 trap levels at depths of 0.202 - 0.222 eV and 0.412 - 0.419 eV.The former is due to the In donor while the latter may be attributed to the V_{Zn} - $In_{Zn}+$ complex. From the area under the curve, the concentration of traps was estimated to be 5×10^{17} / cm^3. Positron annihilation studies gave a life-time t_2 of 518.4 ps which could be assigned to the above V_{Zn} - $In_{Zn}+$ complex.

It was found that a short anneal of 3 min at 250°C was sufficient to revert the sample to a low resistivitystate thus indicating metastable behavior.

H6.30
RADIATIVE RECOMBINATION PROCESSES OF THERMAL DONORS IN SILICON. S. Pizzini, S. Binetti, E. Leoni, A. LeDonne, M. Acciarri, INFM and Dept of Materials Science, University of Milano-Bicocca, Milano, ITALY; A. Castaldini, A. Cavallini, INFM and Dept of Physics, University of Bologna, Bologna, ITALY.

There is a recent, renewed attention on the possible development of optical emitters compatible with silicon microelectronic technology and it has been recently shown that light emitting diodes could be manufactured on dislocated silicon, where dislocations were generated by plastical deformation or ion implantation [1]. In addition, we have already shown that oxygen precipitates emit light efficiently [2] and could be as well considered potential candidates for room temperature emitters. Among other potential sources of room temperature light emission, compatible with standard silicon-based ULSI technology, we have studied old thermal donors (OTD), as the origin of their luminescence is still matter of controversy and demands further investigation. Since their discovery, in fact, many studies have been devoted to their electrical and structural properties, but a lack of knowledge still exists concerning the physics of radiative and non-radiative recombination processes, whose knowledge is preliminary to the development of light emitters. In this work we discuss the results of a spectroscopy study of OTD using photoluminescence and Deep Level Transient Spectroscopy (DLTS) on standard Cz silicon samples and on carbon and nitrogen doped samples. We were able to show that their main optical activity, consists of a narrow band at 0.767 eV (P line), correlated to a transition from a shallow donor level of OTD to a deep level at 0.4 eV, which is tentatively associated to C-O complexes. As we have shown that the P line emission persists at room temperature, it opens new potentialities to silicon in optoelectronics applications. References [1] Wai Le Ng, M.A. Loutenco, R.M. Gwilliam, S. Ledain, G. Shao, K.P. Homewood Nature 410, (2001) 192 [2] S. Pizzini, S. Binetti, A. Le Donne, E. Leoni, M. Acciarri, G. Salviati, L. Lazzarini, Solid State Phenomena Vols 78-79 (2001) 57.

H6.31
ANNEALING EFFECT ON THE NONRADIATIVE CARRIER RECOMBINATION IN AlGaAs/GaAs INVESTIGATED BY A PIEZOELECTRIC PHOTOTHERMAL SPECTROSCOPY.
A. Fukuyama and Y. Akashi, Dept. of Applied Physics, Miyazaki University, JAPAN; T. Ikari, Dept. of Electrical and Electronic Engineering, Miyazaki University, JAPAN.

AlGaAs is widely used for quantum electronic devices such as light emitting diode (LED) and hetero bipolar transistor (HBT). Intrinsic deep defect levels in these materials are known to cause a degradation of such devices. They trap the free carriers, and thus high frequency response time and the light emitting efficiency of electronic devices are seriously influenced. Annealing process followed by an ion-implantation is a most important process in the device fabrication. Since this annealing process affects a formation and destruction of deep levels, it is very important to understand an annealing effect on the carrier generation and recombination properties through deep levels. The recombination process of carrier through deep level is mainly nonradiative recombination. Since it is very difficult to detect the nonradiative recombination process by the photoluminescence method, it becomes important to establish an alternative experimental technique to investigate such transitions. Piezoelectric photothermal (PPT) spectroscopy is a sensitive technique for investigating the thermal and electronic properties of semiconductors. Since, this technique also gives us useful information for the nonradiative transition through deep levels, the measurements were carried out for AlGaAs/GaAs heterostructure sample for investigating electron transitions especially at the interface. The PPT signal above the band-gap energy of GaAs substrate drastically decreased when the Si doped n-$Al_{0.2}Ga_{0.8}As$/GaAs was annealed at 815°C for 30 min. In the frequency dependence measurements, we observed that the signal is almost frequency independent below a critical frequency around 250 Hz. The signal, then, decreased with 1/f above the critical frequency. We also found that this critical frequency shifted to the lower frequency region by the annealing. Our experimental results are explained by assuming that the annealing generates a deep level in AlGaAs thin film region and this level effectively traps the photoexcited carriers. The change of the intensity and frequency dependence of the PPT signal by annealing is well explained by developing the two layer model for the photoacoustic signal generation mechanism to the present case for that the thermoelastic effect is dominant.

H6.32
OPTICALLY DETECTED MAGNETIC RESONANCE STUDIES OF HgTe/CdS CORE-SHELL NANOCRYSTALS. L. Fradkin, E. Lifshitz, Dept of Chemistry and Solid State Inst, Technion, Haifa, ISRAEL; A. Rogach, A. Echymüller, and H. Weller, Institute of Physical Chemistry, University of Hamburg, Hamburg, GERMANY.

HgTe nanocrystals (NCs) demonstrate near infrared luminescence with potential utilization in optical telecommunication. The quantum efficiency of this luminescence is governed by the quantum size effect and by the surface properties of the NCs. Recent study showed the possibility to synthesis a HgTe NC core, covered by an epitaxial shell of CdS. These new core-shell structures exhibit an enhanced luminescence intensity, however, they still present interface imperfections, which can act as electron and hole traps. Thus, the present study utilized an optically detected magnetic resonance spectroscopy for the investigation of the influence of the interface properties on the luminescence efficiency. In the ODMR method, one detects a change in the luminescence intensity (or a circular component) due to a magnetic resonance event at the excited state. The ODMR of the HgTe/CdS NCs, exhibit a dominated resonance band, centered at 0.4 Tesla (g=1.97) with FWHM of 0.05 Tesla. This band is overlapping a weak and broader background signal. The ODMR spectra were recorded under various laser excitation powers, microwave powers, optical orientation and circular polarized detection, and under various microwave modulation frequencies. The circular polarized examination suggested that the ODMR signal corresponds to excited state spin manifold of S=1, of strongly coupled electron and hole (each with S=1/2) by exchange interaction. The microwave modulation frequency dependence suggests slightly different spin-lattice relaxation for the electron and hole. The magnetic resonance events, are associated with flipping of electrons and holes spins, presumably trapped at the HgTe/CdS interface. Theoretical simulation of the resonance band, currently being done in our laboratory, should enable the chemical identification of the trapping sites. The dynamic properties of the spins, the radiative recombination time, and the spin-lattice relaxation time will be determined in the near future by the use time-resolved ODMR measurements.

H6.33
COMPUTER SIMULATION IN THE DESIGN AND ANALYSIS OF THERMO-PHOTO-VOLTAIC DEVICES. Richard W. Smith, Clint B. Geller, Richard Thomas, Ilmun Ju, Bechtel-Bettis Inc, West Mifflin, PA.

Multi-Scale computer simulation is being employed to analyze the performance and optimize the design of Monolithic Interconnected Modules (MIMs) for thermophotovoltaic (TPV) applications. Efforts are directed at modeling both the optical and electrical performance of the devices. The computational models utilized in this work include quantum mechanical analyses of semiconductor optical properties and electrical properties, such as carrier recombination rates, as functions of photon wavelength, dopant density and material composition. Also utilized are ray tracing codes that simulate photon scattering and absorption in complex optical cavities, finite difference hydrodynamic equation formulations for carrier transport analyses, and continuum level device performance modeling to understand the overall behavior of MIMs and facilitate automated optimization of design parameters. The optical and electronic simulations have been used to drive the development of MIM architecture and have had a substantial impact on device efficiency and total power density. Simulations incorporating advanced component concepts such as base dopant density gradients, filtered radiators and tandem diode cells promise further increases in performance.

H6.34
ON THE SCALING OF EXCITON AND IMPURITY BINDING ENERGIES AND THE VIRIAL THEOREM IN SEMICONDUCTOR QUANTUM WELLS AND QUANTUM-WELL WIRES. M. de Dios-Leyva, Dept. of Theoretical Physics, Univ. of Havana, Vedado, Havana, CUBA; L.E. Oliveira, Instituto de Física "Gleb Wataghin", UNICAMP, Campinas, SP, BRAZIL.

Recently, the scaling of the exciton binding energy in semiconductor quantum wells and quantum-well wires was numerically investigated by Rossi et al [1], who found that in the strong confinement limit the same potential-to-kinetic energy ratio holds for quite different wire cross sections and compositions, and claimed that a universal parameter would govern the scaling of the exciton binding energy with size. These findings were attributed to the existence of a constant (shape- and/or size-independent) virial theorem value, respectively, for wires and wells, and that its value was larger (= 4) for wires than (= 2) for wells. Zhang and Mascarenhas [2] reexamined the subject by calculating the exciton binding energies and the corresponding virial theorem value in quantum wells and quantum wires with infinite confinement barriers, and found that a shape-independent scaling rule does exist for wires, but argued that a virial theorem value being or not a constant is irrelevant. In particular, they found that the virial theorem value is not a constant for either wires or wells. In the present

work, the variational [3] and fractional-dimensional space approaches [4] are used in a thorough study of the virial theorem value and scaling of the shallow-donor binding energies versus quantum-sized donor Bohr radius in GaAs-(Ga,Al)As semiconductor quantum wells and quantum-well wires. In the case of the fractional-dimensional space approach, we have shown that, if the ground-state wave function may be approximated by a D-dimensional hydrogenic wave function, the virial theorem value equals 2 and the scaling rule for the donor binding energy versus Bohr radius is hyperbolic, both for GaAs-(Ga,Al)As wells and wires. In contrast, calculations within the variational scheme show that the scaling of the donor binding energies with quantum-sized Bohr radius is in general nonhyperbolic and that the virial theorem value is nonconstant. Moreover, calculations for the donor binding energies versus well widths or wire radii within both the fractional-dimensional and variational approaches indicate that any conclusion based on a given virial theorem value or donor (or exciton) energy versus Bohr radius scaling rule should be examined with caution. [1] F. Rossi, G. Goldoni, and E. Molinari, Phys. Rev. Lett. 78, 3527 (1997). [2] Y. Zhang and A. Mascarenhas, Phys. Rev. B 59, 2040 (1999). [3] L.E. Oliveira, Phys. Rev. B 38, 10641 (1988); J.W. Brown and H.N. Spector, J. Appl. Phys. 59, 1179 (1986). [4] H. Stillinger, J. Math. Phys. 18, 1224 (1977); P. Christol, P. Lefebvre, and H. Mathieu, J. Appl. Phys. 74, 5626 (1993); E.R. Gomez, A.M. Abiague, C.A.P. Leiva, M. de Dios-Leyva, and L.E. Oliveira, Phys. Rev. B 61, 13104 (2000).

H6.35
INTRA-MAGNETOEXCITON TRANSITIONS IN SEMI-CONDUCTOR QUANTUM WELLS. Z. Barticevic, Depto. de Física, Univ. Técnica Federico Santa María, Valparaíso, CHILE; M. Pacheco, Depto. de Física, Universidad de Santiago de Chile, Santiago, CHILE; C.A. Duque, Depto de Física, Universidad de Antioquia, Medellín, COLOMBIA; L.E. Oliveira, Instituto de Física "Gleb Wataghin", UNICAMP, Campinas, SP, BRAZIL.

Highly sensitive optically detected resonance experiments [1-3] have shown that magnetoexcitons in GaAs-(Ga,Al)As semiconductor quantum wells have discrete internal energy levels, with transition energies found in the far-infrared (terahertz) region. Here we are concerned with a theoretical study of the terahertz internal dynamics of light-hole and heavy-hole confined magnetoexcitons in GaAs-(Ga,Al)As quantum wells, under a magnetic field applied in the growth direction of the semiconductor heterostructure. The various magnetoexciton states are obtained in the effective-mass approximation by expanding the corresponding exciton-envelope wave functions in terms of appropriate Gaussian functions [4]. We use a parabolic dispersion for electrons, and assume the spin-orbit splitting to be large enough so that the interaction between $J = 3/2$ and $J = 1/2$ hole states may be disregarded. The electron and hole cyclotron resonances and internal dynamics of excitons are theoretically studied by exciting the allowed electron, hole and internal magnetoexcitonic transitions with far-infrared (terahertz) radiation. Theoretical results are obtained for both the intra-magnetoexciton transition energies and oscillator strengths associated with excitations from 1s - like to 2s -, 2p -, 3p -, and 4p - like magnetoexciton states, and from 2p to 2s like exciton states. Present results are in overall agreement with available optically detected resonance measurements [1-3] and clarifies a number of queries raised in previous theoretical [5] work. [1] J. Cerne, J. Kono, M.S. Sherwin, M. Sundaram, A.C. Gossard, and G.E.W. Bauer, Phys. Rev. Lett. 77, 1131 (1996); J. Kono, M.Y. Su, J. Cerne, M.S. Sherwin, S.J. Allen, Jr., T. Inoshita, T. Noda, and H. Sakaki, Physica B 249-251, 527 (1998). [2] H.A. Nickel, G.S. Herold, M.S. Salib, G. Kioseoglou, A. Petrou, B.D. McCombe, and D. Broido, Physica B 249-251, 598 (1998). [3] H.A. Nickel, G. Kioseoglou, T. Yeo, H.D. Cheong, A. Petrou, B.D. McCombe, D. Broido, K.K. Bajaj, and R.A. Lewis, Phys. Rev. B 62, 2773 (2000). [4] M. Pacheco, Z. Barticevic, and F. Claro, J. Phys. C 5, A393 (1993); Z. Barticevic, M. Pacheco, and F. Claro, Phys. Rev. B 51, 14414 (1995). [5] C.A. Duque, C.L. Beltran, A. Montes, N. Porras- Montenegro, and L.E. Oliveira, Phys. Rev. B 61, 9936 (2000).

H6.36
ELECTRON SCATTERING IN TWO–DIMENSIONAL DISORDERED HETEROSTRUCTURES. Ignacio Gómez, Enrique Diez, Francisco Domínguez-Adame, GISC, Departamento de Física de Materiales, Universidad Complutense, Madrid, SPAIN; Pedro Orellana, Departamento de Física, Universidad Católica del Norte, Antofagasta, CHILE.

The main aim of this work is to study electronic transport in disordered semiconductor heterostructures. In order to achieve this goal we solve the two–dimensional Schrödinger equation for electron scattering due to the presence of unintentional disorder at the interfaces. We carry out this task within the framework of a one–band effective–mass approximation that leads to the Ben Daniel–Duke Hamiltonian for the envelope function. Our model assumes open boundary conditions along the growth direction and periodic boundary conditions parallel to the heterojunctions. In such a way we can compute (by means of a transfer matrix formalism) the reflexion and transmission matrices that govern the channel mixing due to the interface roughness present in the sample. To characterize electron scattering by interface roughness, several models of disorder are introduced and studied numerically. The knowledge of the mixing matrices allows us to calculate quantities such as the conductance or the electric current, related to the electronic transport, in a more realistic fashion than previous one–dimensional models.

H6.37
EXCITON DIAMAGNETIC SHIFTS AND MAGNETIC FIELD LINEWIDTHS IN ORDERED AND DISORDERED InGaP ALLOYS. E.D. Jones, Sandia National Laboratories, Albuquerque, NM; K.K. Bajaj, G. Coli, Emory University, Atlanta, GA; Scott Crooker, NHMFL/LANL, Los Alamos, NM; Yong Zhang, A. Mascarenhas, J.M. Olsen NREL, Golden, CO.

We have measured the diamagnetic shifts and photoluminescence linewidths of excitonic transitions in ordered and disordered $In_{0.48}Ga_{0.52}P$ alloys lattice matched to GaAs as a function of magnetic field at 4 and 76K. The magnetic field ranged between 0 and 50T. We find that for a sample with a given order parameter, the diamagnetic shift and excitonic linewidth increase as a function of magnetic field. The observed variations of the diamagnetic shifts and excitonic linewidths with magnetic field in a completely disordered and partially ordered sample are considerably smaller than those calculated by Lee and Bajaj [J. Appl. Phys. 73, 1788 (1993)] using a free exciton model. For a given magnetic field, the value of the diamagnetic shifts is found to increase with increasing order. Furthermore, for all samples, the diamagnetic shifts at 76K are larger than their corresponding values at 4K. The experimental data suggest that the excitons are localized in completely disordered and weakly ordered samples and appear to be free for the most ordered sample. The effect of this observation on the measured magnetic field dependent excitonic linewidth will also be presented.

H6.38
FIELD EMISSION ENHANCEMENT OF DLC FILMS USING TRIPLE-JUNCTION TYPE EMISSION STRUCTURES. Namwoong Paik, Michael Martin, Daeil Kim and Steven Kim, Skion Corporation, Hoboken, NJ; Kie Moon Song, Department of Applied Physics, Konkuk University, Chungju, KOREA.

Negative electron affinity (NEA) of Diamond-like-Carbon (DLC) films make them favorable candidates for use in field emission displays (FED). It has been suggest that a triple junction type structure can enhance the field emission characteristics. A triple junction is the intersection of a semiconductor surface with a metal substrate in vacuum. In this study, filed emission enhancement in triple junction type structures was investigated. As a metal substrate, 5000 $\AA$ of Molybdenum films were deposited. Then, 3000-4000 $\AA$ of DLC film was deposited as a semiconductor material. Using a 248 nm KrF excimer laser at various fluencies, we removed the DLC layer and made circular triple junction features with diameters of 50 200 μm. the field emission characteristics such as I-V curves, turn on voltage and emission lifetime data were obtained from a diode type field emission measurement system. Overall results show significantly enhanced performance of field emission characteristics such as uniform emission over patterned areas, reduced turn on voltages and longer lifetimes.

H6.39
LUMINESCENCE OF QUASI-2DEG IN HETEROSTRUCTURES BASED ON PBS FILMS. Galina Khlyap, State Pedagogical Univ, Drogobych, UKRAINE.

The abstract deals with the problem of luminescence due to non-equilibrium charge carriers transfer between the quasi-2D electron system localized in the space-charge region of the heterostructures based on lead sulfide films (up to 3 mkm thickness) and zinc selenide substrates surrounded by the wide gap semiconductor region. The processes of electro- and photoluminescence are studied, the band diagram is proposed and the main parameters of the structure PbS/quasi-2DEG/ZnSe are calculated.

SESSION H7: LASERS AND MATERIALS

Chairs: Kent D. Choquette and Weng W. Chow
Wednesday Morning, November 28, 2001
Room 312 (Hynes)

8:30 AM *H7.1
GaInNAs MATERIAL PROPERTIES FOR LONG WAVELENGTH OPTO-ELECTRONIC DEVICES. Vincent Gambin, Wonill Ha, Mark Wistey, Sylvia Spruytte, James Harris, Stanford University, Electrical

Engineering, Stanford, CA; Seongsin Kim, Agilent Technologies, San Jose, CA.

Dilute nitrogen GaInNAs is a new promising material as an active region for use in 1.3 and 1.55 μm optoelectronic devices. Adding nitrogen to GaAs preserves its direct gap electronic structure, decreases the bandgap dramatically and shrinks the lattice constant. The addition of In complements GaNAs permitting even longer wavelength emission by offsetting the lattice mismatch and further reducing the bandgap. Epitaxial films were grown by elemental source MBE using a nitrogen r.f. plasma. In order to limit phase segregation, prevent In and N desorbtion, and improve crystal quality, substrate temperatures were kept low thereby incorporating much more nitrogen than thermodymically stable. Using Optical Emission Spectroscopy (OES) we have studied our plasma conditions observing the atomic to molecular ratio. We have also carefully measured the incorporation of nitrogen in GaAs under differing growth conditions. In an effort to improve optical properties a voltage bias across the aperture of the plasma source was used in order to reduce nitrogen ion damage in our films. It has been commonly observed that increasing the nitrogen content generally reduces the optical emission intensity. However non-radiative recombination defects are removed from the material during a post-growth anneal. The drawback to the anneal is that nitrogen out-diffuses from the quantum well and blue-shifts optical emission. We have observed this with SIMS profiles and XRD analysis. Using a modified active region structure we have decreased nitrogen out-diffusion reducing the luminescence blue-shift while still improving crystal quality. The growth consists of high nitrogen GaNAs barriers grown between lower nitrogen GaInNAs quantum wells. As an added benefit the nitride barriers strain compensates the compression in the high In content GaInNAs wells. We have observed high intensity photoluminescence using this design and have fabricated both edge emitters and VCSELs at and beyond 1.3 μm.

9:00 AM ***H7.2**

RECENT BALLISTIC ELECTRON EMISSION MICROSCOPY/ SPECTROSCOPY RESULTS IN SEMICONDUCTOR HETEROSTRUCTURES. Venkatesh Narayanamurti, Harvard University, Division of Engineering and Applied Sciences, Cambridge, MA.

In this talk, I would like to review the progress we made in the last few years on the ballistic electron emission microscopy (BEEM)/ spectroscopy of semiconductor heterostructures, in particular, phosphide-based quantum dot (QD) structures and dilute nitride semiconductors [1]. BEEM is a modified version of the STM, whose excellent nanometer scale lateral resolution is utilized to inject carriers directly into a single dot. By appropriate positioning of the STM tip, even a small difference in the spectroscopic properties corresponding to on-the-dot and off-the-dot can be distinguished without any ambiguity [2]. A resonant level, which accounts for the maximum carrier leakage from the self-assembled InP QDs in an AlInP double barrier heterostructure, is thus fingerprinted with the help of second-derivative BEEM spectra. Some of the latest results with AlGaInP barriers will also be discussed. Recently, dilute nitride semiconductors such as GaAs:N and GaP:N have attracted great deal of attention because of the giant bandgap reduction. However, none of the traditional characterization tools offered a convincing physical model to explain the phenomena of bandgap reduction. The evolution of the GaNAs and GaNP alloy band structure as a function of nitrogen concentration will be presented with the help of second-derivative BEEM spectra [3,4]. The similarities and the contrasts on the role of nitrogen in these two semiconductors will be discussed in detail. Finally, I will touch upon some of our recent work on wide bandgap semiconductors such as SiC and GaN [5]. 1. V. Narayanamurti, and M. Kozhevnikov, Physics Reports, 349/6, 447-514 (2001) 2. C.V. Reddy, V. Narayanamurti, J.H. Ryou, U. Chowdhury, and R.D. Dupuis, Appl. Phys. Lett., 77, 1167 (2000) 3. M. Kozhevnikov, V. Narayanamurti, et al, Phys. Rev. B, 61, R7861 (2000) 4. C.V. Reddy, V. Narayanamurti, H.P. Xin and C.W. Tu, presented in the 199th meeting of the Electrochemical society, held in Washington, D.C., during March 25-29, 2001 5. I. Shalish and V. Narayanamurti, Phys. Rev. B (in press).

9:30 AM H7.3

ANGLE-DEPENDENT PHOTOCURRENT SPECTROSCOPY OF OXIDE-APERTURED VERTICAL-CAVITY SURFACE-EMITTING LASERS DURING AGING. A. Jaeger, P.M. Petroff, T.D. Lowes.

VCSELs are important radiation sources for a number of applications such as optical interconnects and optical data storage. For achieving lasing conditions the active multiquantum well (MQW) region of a VCSEL is sandwiched between highly reflective mirrors. Therefore, nondestructive optical methods like luminescence spectroscopy are difficult to apply to VCSELs. The light emitted from the active region of the VCSEL is in the mirror stop band and is strongly modified by the mirror transmission. Thus, alternative methods are required to study the MQW transitions of VCSEL epitaxial layers. Here, we will show for the first time how angle-dependent photocurrent (PC) spectroscopy can be exploited for characterization of oxide-apertured VCSELs with lateral diameters of a few microns at room temperature including gradual aging processes as well as data on relevant layers of the complex multilayer structure. PC spectra measured with light under normal incidence exhibit strong peaks due to top mirror reflectance minima and barrier absorption. By changing the angle of incidence the top mirror features shift to higher photon energy while the excitonic transitions do not alter. Therefore, despite top mirror reflectance characteristics PC spectroscopy allows characterization of active region including multi quantum wells of VCSELs. Additionally, this new method is also well suited for an analysis of the aging process of these devices. Angle-dependent PC spectra reveal both the appearance of defect bands located in the intrinsic region of the VCSEL as well as modifications of the top mirror during operation of these devices.

9:45 AM H7.4

EXCITONIC DIAMAGNETIC SHIFTS AND MAGNETIC FIELD DEPENDENT LINEWIDTHS IN $Al_xGa_{1-x}As$ ALLOYS. K.K. Bajaj, G. Coli, Physics Department, Emory University, Atlanta, GA; J.L. Reno, E.D. Jones, Sandia National Laboratories, Albuquerque, NM.

We have measured both the diamagnetic shifts and the linewidths of excitonic transitions in $Al_xGa_{1-x}As$ alloys as a function of aluminum concentration and magnetic field at 1.4 K using photoluminescence spectroscopy. The aluminum composition in our samples ranged from 0 to 30% and magnetic field was varied from 0 to 13 tesla. The samples were grown on GaAs substrates oriented along [001] direction using molecular beam epitaxy at 590°C. We find that for a given value of alloy composition, both the diamagnetic shift and excitonic linewidth increase as a function of magnetic field. The observed variations of the diamagnetic shifts and excitonic linewidths with magnetic field are considerably smaller than those calculated by Lee and Bajaj [J. Appl. Phys. 73, 1788 (1993)] using a free exciton model. To explain our experimental data we propose that the excitons are localized in a very specific manner. To simulate exciton localization, we assume that the exciton reduced mass is increased and is obtained by using the alloy dependent heavy-hole mass along (001) direction. The calculated values of the variation of the diamagnetic shift and excitonic linewidth as a function of magnetic field obtained using this model agree very well with those reported here.

10:30 AM ***H7.5**

LASER GaIn IN TYPE-II QUANTUM WELLS. W.W. Chow, O. Blum, J. Klem, H.C. Schneider, Sandia National Laboratories, Albuquerque, NM.

Semiconductor gain media in the 1.3 to 1.5 micron wavelength range are currently under intense investigation, because of the important role of lasers in optical fiber communications. For vertical-cavity surface-emitting lasers (VCSELs), gain structures that can be epitaxially grown on GaAs substrates are of particular interest. One such system is the type-II GaAsSb/GaInAs/GaAs quantum-well structure. The defining feature of a type-II quantum well is the spatial separation of electron and hole confinement in the epitaxial growth direction. Because of the charge separation, a type-II quantum-well structure can exhibit interesting excitation-dependent optical behaviors due to the competing effects of quantum confinement, which separates the electron and hole distributions, and the resulting Coulomb attraction, which induces band distortions that have the opposite effect of increasing their overlap. This paper describes an investigation of the interplay of the above effects, which can lead to strong carrier density dependences in the oscillator strength and bandedge energies. Implications to laser operation, including the large blue shift of the gain peak with increasing injection current, and inhibition of spontaneous emission, will be discussed.

11:00 AM ***H7.6**

FABRICATION AND CHARACTERIZATION OF A SUBSTRATE-INDEPENDENT AMORPHOUS ALUMINUM-OXIDE DISTRIBUTED BRAGG REFLECTOR. K.Y. Cheng and K.C. Hsieh, Electrical and Computer Engineering Department, University of Illinois at Urbana-Champaign, Urbana, IL.

With the recent success of vertical cavity surface emitting lasers (VCSELs), interest in the fabrication of distributed Bragg reflectors (DBRs) has grown. The requirement of lattice matching to the host substrate places great limitations on the DBR materials used. In addition, the difference in the index of refraction between two semiconductor materials is often small necessitating a large number of pairs in the DBR mirror to achieve high reflectivities. Through the use of water-vapor-oxidation, (Al)GaAs/Al-oxide DBRs have been used successfully in VCSELs. Due to the large index difference between the GaAs and the oxide, a relatively small number of DBR pairs are sufficient for device operation. While these DBRs have

proved successful, their use is limited to heterostructures closely lattice-matched to GaAs substrates. In order to fabricate substrate-independent DBRs, a method of preparing amorphous native Al-oxide layers has been demonstrated. Using amorphous (Al,As) layers deposited by molecular beam epitaxy at very-low temperatures (~100°C), amorphous native oxides have been formed on various semiconductor substrates by wet oxidation at temperatures as low as 300°C. It was determined by Auger electron spectroscopy and transmission electron microscopy that alternating layers of polycrystalline GaAs(P) and amorphous (Al,As) can be deposited under controlled group V vapor pressures. Because these layers are not single crystal, they can be grown on any host lattice. After lateral wet oxidation, the polycrystalline GaAs(P) does not undergo any significant changes, while the amorphous (Al,As) becomes an amorphous Al-oxide. A large index step (>1) is realized between these two layers which makes it possible to fabricate a high efficiency DBR with few mirror pairs on GaAs, GaP, or InP based materials. Using this technique, efficient DBRs have been demonstrated in both visible (~0.5μm) and infrared (~1.55μm) ranges.

11:30 AM H7.7
NOVEL AlGaAs/CaF_2 SESAM DEVICE FOR ULTRASHORT PULSE GENERATION. S. Schön, L. Gallmann, M. Haiml, U. Keller, Swiss Federal Institute of Technology, Zurich, SWITZERLAND.

A novel ultrabroadband AlGaAs/CaF_2 semiconductor saturable absorber mirror (SESAM) covering the entire Ti:sapphire gain spectrum is demonstrated. In contrast to previous SESAMs of comparable bandwidth, this optoelectronic device can be monolithically grown and requires no post-growth processing. AlGaAs/CaF_2 multilayer stacks with GaAs saturable absorber for all-optical switching were grown using molecular beam epitaxy (MBE). The device quality of AlGaAs/CaF_2 Bragg mirrors grown on (100)-oriented GaAs substrates is degraded by the formation of cracks since both materials largely differ in their linear thermal expansion coefficient. However, crack formation is avoided when growing on (111)-oriented substrates since the relaxation of the thermal strain is supported by dislocation gliding in the CaF_2. GaAs heteroepitaxy on CaF_2 follows the Vollmer-Weber growth mode due to the low surface free energy of the fluoride. Thus, high defect concentrations can be generated at high growth temperatures allowing for ultrashort response times of the order of 100 to 500 fs. Such short response times together with the second time-constant in the picosecond range are prerequisite for the self-starting operation of the laser. AlGaAs/CaF_2 SESAMs have been grown consisting of a two-pair quarter-wavelength AlGaAs/CaF_2 Bragg mirror, a CaF_2 spacer and GaAs absorber layer. The measured saturated reflectivity and modulation depth of the device was 97.3% and 2.2%, respectively. The saturation fluence was measured to be 36 $\mu J/cm^2$, which is comparable to conventional small bandwidth SESAMs based on AlGaAs/AlAs. The fast time-constant of the nonlinear response was shorter than 150 fs. Laser pulses of 9.5 fs duration time have been generated in a standard Ti:sapphire cavity. A broader pulse spectrum with a transform limit of as short as 5.9 fs was measured showing the potential of the AlGaAs/CaF_2 SESAMs for sub-6 fs pulse generation.

11:45 AM H7.8
OPTICAL CHARACTERIZATION OF IV-VI MID-INFRARED VCSEL. Fanghai Zhao, Huizheng Wu, Tao Zheng, Sheena Narayanan and Zhisheng Shi, School of Electrical and Computer Engineering, University of Oklahoma, Norman, OK.

Mid infrared diode lasers are mainly used for trace-gas-sensing applications. Performance requirements that are not yet available include continuous wave (cw) operation at temperatures higher than thermoelectric cooler range, spectral purity, and reasonable output powers ($\geq$1 mW) with good beam quality. Recently, we have reported the first IV-VI compound semiconductor mid-infrared VCSELs that operate near room temperature. We also reported quantum well (QW) IV-VI VCSELs with very low threshold pump intensity. In this work, we will present optical measurement in designing and characterizing such IV-VI QW mid-infrared VCSELs. The VCSEL structures were grown on BaF_2 (111) substrate by MBE. Bottom and top mirrors were fabricated with 3-pair quarter-wave stack of $Pb_{0.97}Sr_{0.03}Se/BaF_2$ and $Pb_{0.85}Sr_{0.15}Se/BaF_2$ with 99% and 98%, reflectivity. The active layer consists of $\lambda/2$-cavity $PbSe/Pb_{0.97}Sr_{0.03}Se$ multiple QW structure. Refractive indices of PbSrSe layers are experimentally determined by the optical transmission measurement to design all $\lambda/2$ and $\lambda/4$ layers. Cavity resonance is determined by the reflection measurement. To optimize the VCSEL performance at a certain temperature, one needs to align the gain peak to the cavity resonance. Due to the large difference of refractive indices between the IV-VI QW layer (n ~4.7) and the BaF_2 substrate (n=1.46), photoluminescence (PL) signals were often merged with the interference fringes of the layer, which makes it very difficulty to determine the net gain peak. In this work, short pulse Nd-YAG laser at 1.06μm was used as a pump source. With relatively high peak pumping power, PL signals clearly showed amplified spontaneous emission (ASE) that significantly suppressed the interference fringes. Light emission energies and net gain of $PbSe/Pb_{0.97}Sr_{0.03}Se$ QW from 150K to 320K were determined. The ASE above room temperature suggests that Auger recombination does not limit IV-VI lasers operating above room temperature. 320K is the high limit of the temperature controller. The net gain at 320K is not saturated within the pumping range. Laser emission from QW VCSEL will also be presented.

SESSION H8: ANTIMONY-BASED DEVICES
Chairs: John D. Bruno and Steven R. Kurtz
Wednesday Afternoon, November 28, 2001
Room 312 (Hynes)

1:30 PM *H8.1
Sb-BASED MID-INFRARED DIODE LASERS. C. Mermelstein, M. Rattunde, J. Schmitz, S. Simanowski, R. Kiefer, M. Walther, and J. Wagner, Fraunhofer-Institut für Angewandte Festkörperphysik, Freiburg, GERMANY.

High performance mid-IR lasers are required for a variety of commercial and military applications. The (AlGaIn)(AsSb) materials system is particularly adequate for emission in the 2 to 5 μm wavelength range.
This talk reviews the physics and applications of GaSb-based diode lasers covering the 1.75-2.34 μm wavelength range. The active region of these lasers consists of GaInAsSb/AlGaAsSb quantum-well (QW)/barrier layers with different In and As contents in the QWs, grown by molecular beam epitaxy on n-GaSb substrates.
Devices with emission wavelength of 1.94 μm show a characteristic temperature of the threshold current as high as 179 K, power conversion efficiency of 29% and threshold current density at infinite cavity length of 121 A/cm^2. A low internal loss coefficient of 6 cm^{-1} and a high internal quantum efficiency of 77% have been obtained. CW output powers exceeding 1 W at 300 K have been achieved for broad area devices mounted p-side down. Far field profiles of the diode lasers have been measured and are found to be in good agreement with the calculated patterns. With ridge waveguide GaSb-based devices, tunable diode laser absorption spectroscopy (TDLAS) for the detection of methane at 2.34 μm has been demonstrated.

2:00 PM *H8.2
DEVELOPMENT OF HIGH-POWER, HIGH-EFFICIENCY TYPE-II INTERBAND CASCADE LASERS. J.D. Bruno, Rui Q. Yang, J.L. Bradshaw, J.T. Pham, and D.E. Wortman, Maxion Technologies, Inc., Hyattsville, MD.

Type-II interband cascade (IC) lasers take advantage of the broken-gap alignment in type-II quantum wells to reuse electrons for sequential photon emissions from serially connected active regions. In this presentation, we review our recent progress in InAs/GaInSb type-II IC lasers at emission wavelengths of 3-4μm.

2:30 PM H8.3
THIN FILMS OF ANTIMONY-TIN OXIDE AS COUNTER-ELECTRODES FOR PROTON-WORKING ELECTROCHROMIC DEVICES. Corinne Marcel, Negar Naghavi, Loic Dupont, Aline Rougier, Jean-Marie Tarascon, Laboratoire de Reactivite et de Chimie des Solides, Amiens, FRANCE.

Electrochromic devices are capable of persistent and reversible changes in color under a reversible electrochemical process. They are widely involved in optical technology, particularly in the field of display panels, antiglare car rear-view mirrors and "smart windows". We report here on thin films proton-working electrochromic devices based on the well-known tungsten oxide as the coloring electrode, and Antimony Tin Oxide (ATO) as the ion-storage counter-electrode. ATO materials with antimony doping contents ranging from 10 to 20 at.% ($Sn_{0.8}Sb_{0.2}O_2$) have been extensively studied as transparent conducting electrodes, catalysts and semiconductor gas sensors. We recently succeeded in preparing, by Pulsed Laser Deposition (PLD) technique, thin films having an apparent Sb solubility up to 70 at.% and showing unusual electrochromic properties. The films were first deposited at low temperature (200°C) under an oxygen pressure of 10^{-2} mbar, and annealed under the same pressure at an optimized temperature of 500°C. The latter step was mandatory to turn on their electrochromic properties. The structural properties of ATO films were characterized by X-ray diffraction and electron microscopy (SEM, TEM), while optical absorption measurements were carried out for a better understanding of the electrochromic mechanism in terms of energy band theory. Electrochromic behavior was studied by means of cyclic voltamperometry and chronoamperometry, both coupled with ex situ optical transmittance measurements in the visible range. The maximum proton-storage capacity was observed for ATO films containing 40-50 at.% Sb, while being quasi-neutral when switching

over a wide range of potentials. Those compositions were finally retained for the assembly of our WO_3/proton-electrolyte/ATO devices, whose performances will be reported.

2:45 PM H8.4
STRUCTURE OF Sb-TERMINATED InAs(001)-(2x4) AND (2x8) STUDIED USING SCANNING TUNNELING MICROSCOPY AND *AB INITIO* DENSITY FUNCTIONAL THEORY. William Barvosa-Carter and Jennifer J. Zinck, HRL Laboratories, LLC, Malibu, CA; and James Owen and Frank Grosse, HRL Laboratories, LLC and UCLA Department of Mathematics, Los Angeles, CA.

For many devices based on the 6.1Å system of III-V semiconductor materials (InAs, GaSb, and AlSb), the quality and bond-type of the interfaces between the constituent materials can significantly impact device performance. While work has been done to understand the structure of these interfaces after their formation, little is known about the atomic mechanisms involved. In this work, we study the structure of MBE-grown InAs(001)-(2x4) surfaces exposed to low Sb_2 fluxes by scanning tunneling microscopy (STM) and density functional theory (DFT). Experimentally, we observe an Sb-terminated $\alpha 2$(2x4) phase over a wide range of temperatures (400-510°C) for low Sb_2 flux (<0.1 ML/s), whereas temperature and As_2 flux must be carefully controlled to achieve the same As-terminated surface structure. Investigating group V dimer correlations between neighboring (2x4) cells reveals another significant difference: Whereas As top dimers are slightly anti-correlated, Sb-dimers tend to align along the dimer rows. Interestingly, this behavior is not easily predicted by DFT, and may involve correlated adsorption/desorption processes or intermediate surface phase formation. The structure of this (2x8) symmetry phase (as confirmed by STM and DFT) suggests furthermore a possible route to formation of the Sb-terminated (1x3) phase found at typical Sb_2 fluxes used during heterostructure growth. This work is supported by NSF and DARPA through the Virtual Integrated Prototyping Initiative and the NSF Industrial Postdoc Program. The DFT calculations were carried out using the FHI98MD simulation package [Bockstedte, Kley, Neugebauer, Scheffler, CPC 107, 187 (1997). http://www.fhi-berlin.mpg.de/th/fhi98md/].

3:30 PM *H8.5
InAs/AlSb UNIPOLAR QUANTUM CASCADE LIGHT EMITTING DEVICES. Carlo Sirtori, Cyrille Becker, Xavier Marcadet, Isabelle Prevot, Olivier Durand, Renato Bisaro, Thales Research and Technology, Orsay, FRANCE.

Quantum Cascade Lasers (QCL's) based on heterostructures are promising candidates for room temperature semiconductor laser operating in the mid-infrared (2 - 5μm). The basic unit of such devices is made from InAs/AlSb quantum wells nearly lattice matched on GaSb substrates. The very high conduction band discontinuity between these materials (~1.5eV) allows to design QCL's in a wavelength region difficult to access by the GaAs or InP based structures. It is well known that the structural and optical properties of the antimonide/arsenide interfaces strongly depend on the growth parameters and on the effusion cell shutter sequencing used to establish interface bond types. The potential of this materials system is thus closely related to the ability to control, characterise and improve the interface quality. Due to the numerous unknown structural parameters, they cannot be extracted unambiguously from only High Resolution X-ray Diffraction (HRXRD) measurements. We show that X-ray reflectometry (XRR) is a powerful complementary tool to extract individual layer thicknesses using only electronic densities as input parameters. We show that the amount of InSb deliberately incorporated between InAs and AlSb layers can be accurately determined from the combination of the two X-ray techniques. These latter structural parameters are investigated as a function of growth conditions and shutter sequencing. The associated optical properties are studied by photo-induced intersubband absorption. A strong e1e2 p-polarised intersubband absorption is observed with a full-width-at-half-maximum (FWHM) of 11meV at 77K showing good material quality. These results has allowed us to properly design InAs/AlSb quantum cascade light emitting devices in the 3 - 5μm wavelength window. Well-resolved Mid-Infrared (3.7 - 5.3μm) electroluminescence peaks are observed up to 300 K with FWHM ratio ($\Delta\lambda/\lambda$) around 8%. The emitted optical power is lower than predicted due to a non optimised electron injection into the active region.

4:00 PM H8.6
EFFECT OF MARANGONI CONVECTION ON InSb SINGLE CRYSTAL GROWTH BY HORIZONTAL BRIDGMAN METHOD. K. Kodera, A. Kinoshita, K. Arafune[a], Y. Nakae, A. Hirata, Dept. of Chemical Engineering, Waseda Univ., Tokyo, JAPAN. [a]Research Institute of Electronics, Shizuoka Univ., Hamamatsu, Shizuoka, JAPAN.

It is necessary to clarify the effect of Marangoni convection on single crystal growth from a melt in order to improve the crystal quality. In this study, effect of Marangoni convection on InSb single crystal growth by Horizontal Bridgman (HB) method was investigated. InSb single crystals were grown under different cooling rate conditions of -16.7 K/h, -8.3 K/h, and -5.0 K/h in a graphite crucible under flowing Ar-3%H_2 gas at atmospheric pressure. Average growth rates for each condition were 8.7 mm/h, 3.0 mm/h, and 2.0 mm/h. The length, the width and depth of the crucible were 48 mm, 10 mm, and 5 mm, respectively. Temperature gradient in the melt was kept 16.7 K/cm during the growth. The interface shaped planar for the 8.7 mm/h case, but concave for the 3.0 mm/h and 2.0 mm/h cases. The concavity for the 2.0 mm/h case was larger than that of the 3.0 mm/h case and increased with growing of the crystal. The fluctuation of the growth rate for 3.0 mm/h and 2.0 mm/h cases was larger than that of 8.7 mm/h case. The dependence of the concavity on the growth rate is caused by the correlation of the driving force of Marangoni convection and the growth rate. After growth, etch pit density (EPD) on the surface of the grown crystals were measured. EPD in the edge part was larger than that in the center part. The etch pits could be caused by the deviation of the growth plane from the growth direction. In conclusion, it was suggested that optimized growth rate in HB method should be determined by the correlation between Marangoni convection and the growth rate. This is because Marangoni convection has a large effect on the stability of the interface shape and growth rate for low growth rate conditions.

4:15 PM H8.7
EFFECTS OF INTERFACE STRUCTURE ON OPTICAL PROPERTIES OF InAs/GaSb/AlSb HETEROSTRUCTURES. Wayne H. Lau and Michael E. Flatté, Department of Physics and Astronomy, University of Iowa, Iowa City, IA.

Major improvements in operating temperature and output power for MWIR laser diodes have been achieved over the past few years through the use of thin layer InAs/GaSb/AlSb heterostructures. Concern has been expressed over the use of traditional envelope-function approaches (EFA) to calculate optical and electrical properties of these thin-layer heterostructures. Here we identify the dominant effects of thin-layer heterostructures not included in typical envelope-function approaches, and show how they may be naturally incorporated into EFA's. We show that the coupling of the heavy and light holes at the interface splits the intersubband absorption into two peaks. This will dramatically change the nature of the internal loss for laser diodes based on these active regions. The inclusion of the interface terms also allows EFA to provide a satisfactory explanation for the recent measured dependence of band gap on GaSb layer thickness in InAs/GaSb superlattices.

4:30 PM H8.8
ASYMMETRIC HYBRID Al(Ga)SbAs/InAs/Cd(Mg)Se HETEROSTRUCTURES FOR MID-IR LEDS AND LASERS. Sergey Ivanov, Sergey Sorokin, Konstantin Moiseev, Victor Soloviev, Valentin Kaygorodov, Yakov Terent'ev, Boris Meltzer, Alexey Semenov, Maia Mikhailova, Yuri Yakovlev and Petr Kop'ev, Ioffe Physico-Technical Institute of RAS, St. Petersburg, RUSSIA.

Fabrication of mid-infrared room temperature semiconductor laser diodes for the 3-5 μm spectral range is still a big challenge. A hole leakage from an active region of pure III-V laser structures due to the particular valence band line up of InAs usually used in the active region may hamper the achievement of a low threshold current and a high output power. To solve the problem of efficient hole confinement in InAs, taking a benefit of type I and type II band alignment, we propose a hybrid III-V/II-VI double heterostructure with large asymmetric band offsets in conduction (AlAsSb/InAs) and valence (InAs/CdMgSe) bands, as a basic element of a new mid-IR laser structure design. In this case AlAsSb and CdMgSe form a strong type II heterojunction, while InAs layer interfaces are of type I. The hybrid $p-i-n$ diode heterostructures grown pseudomorphically by MBE on p^+-InAs(001) substrate with Cl-doped n-Cd(Mg)Se layers on top exhibit an intense long-wavelength electroluminescence (EL) at 3.12 μm (300K) in both pulse and quasi-cw regimes. A II-VI MBE growth initiation with a thin ZnTe buffer layer prior to the CdMgSe deposition results in a dramatic reduction of defect density originating at the II-VI/III-V interface, as demonstrated by transmission electron microscopy. A less than 10 times reduction of EL intensity from 77 to 300K indicates an efficient carrier confinement in the InAs active layer due to high potential barriers in conduction and valence bands, estimated as ΔE_C = 1.28 eV and ΔE_V = 1.6 eV, as well as high optical and electrical quality of the III-V/II-VI interface. An increase in a pumping current results in a super-linear raising the EL intensity. The type of band line up at the coherent InAs/$Cd_{1-x}Mg_xSe$ interface is discussed for $0 \leq x \leq 0.2$, using experimental data and theoretical estimation within a model-solid theory.

4:45 PM H8.9
GROWTH CHARACTERISTICS OF LASER-PULSE DEPOSITED

InSb LAYERS ON NaCl-TYPE SUBSTRATES. A.G. Alexanian, N.S. Aramyan, K.E. Avdjian, A.S. Yeremyan, A.M. Khachatryan, and L.A. Matevosyan, Institute of Radiophysics & Electronics of National Ac. Sci. of Armenia, Dept of Semiconductor Electronics, Ashtarak, ARMENIA.

Features of growth mechanism of ultra thin ($\leq$ 30 nm) InSb layers laser-deposited on NaCl-type dielectric substrates with large lattice mismatch are discussed. The lattice parameters are measured for discrete growing InSb monolayers obtained on naturally split, as well as on treated surfaces of NaCl substrates. The dependence of lattice constant and resistivity of InSb layers on the layer thickness are represented. It is shown that InSb layers grown on both treated and untreated substrates are strained with the lattice parameter being reduced. As distinct from the case of naturally split substrate in case of treated substrate the dependence of resistivity on the thickness has a non monotonic behavior. It reaches a minimum at a certain thickness d_1 and a maximum at d_2. In our opinion the range of thickness $<d_1$ corresponds to the growth with strained lattice, while at $d>d_2$ the growth with dislocations occurs.

SESSION H9: POSTER SESSION
Chairs: M. Omar Manasreh, Eric Daniel Jones, Daniel K. Johnstone, Daniel J. Friedman and Kent D. Choquette
Wednesday Evening, November 28, 2001
8:00 PM
Exhibition Hall D (Hynes)

H9.1
CARBON-HYDROGEN COMPLEXES IN PROTON IRRADIATED $Al_xGa_{1-x}N$. Jing Chen, Qiaoying Zhou, and M.O. Manasreh, Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, NM; M. Pophristic and Ian T. Ferguson, EMCORE Corporation, Somerset, NJ; B.D. Weaver, Naval Research Lab, Washington, DC; Sergei Kucheyev and C. Jagadish, Department of Electronic Materials Engineering, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, AUSTRALIA.

Local vibrational modes (LVMs) of carbon-hydrogen complexes defects in proton irradiated $Al_xGa_{1-x}N$ thin film grown on sapphire by MOCVD were investigated using Fourier transform infrared spectroscopy. The spectra were measured at either 77 or 300K. Several Mg, Si-doped and un-doped samples with Al mole fraction ranging from 30% to 60% were investigated with 1.0 MeV proton irradiation over a irradiation dose range of (1.0-10.0)x10^{16} ions/cm^2. The C-H_n (n=1,2 or 3) LVMs exhibit five peaks in the spectra range of 2846-2963 cm^{-1} due to stretching symmetrical and asymmetrical vibrational modes. The C-H_n LVM frequencies are slightly different from those observed in GaN thin film. This is obviously due to the fact that Al atoms were added to the crystal and the atomic structure around C-H complexes is different. It is observed that LVMs intensities are increased as the irradiation dose is increased in Mg and Si doped AlGaN thin film in the entire irradiation dose range used in this study. On the other hand, the intensities of the C-H LVMs in the un-doped samples were increased and then start to decrease as the dose is increased above 5x10^{16} ions/cm^2. This behavior can be explained in terms of the dissociation of C-H complexes in the un-doped materials. However, in the doped materials, including thin films with carbon impurities, the hydrogen atoms (proton) seem to continue to form complexes without reaching the saturation stage. The results reported here provide useful information on the trapping of hydrogen and qualitatively provide information on the presence of impurities such as carbon and their concentration.

H9.2
EFFECTS OF ION BOMBARDING AND NITROGENATION ON THE PROPERTIES OF PHOTOVOLTAIC ORIENTED a-Cn_x THIN FILMS. Z.B. Zhou, R.Q. Cui, Q.J. Pang, C.J. Zhao Solar Energy Institute, Department of Physics, Shanghai Jiaotong University, Shanghai, CHINA.

Amorphous carbon nitride thin films were deposited by using a single ion beam sputtering process in argon and nitrogen sputtering gases. The thin films bombarded by energetic ions during deposition could be used as a novel photovoltaic material, which has been demonstrated in our previous work. The films were characterized with the techniques of Raman, spectroscopic ellipsometry and electron spin resonance spectrometer (ESR). The effects of the impact of ions to the growing thin films and nitrogenation on the microstructure, optical, electrical and photovoltaic properties were studied. Effective decreasing of the ESR defined defect density and valence electron density of state and increasing of SP^3/SP^2 rate were observed, which could be attributed to the increasement of the amount of ions impinging on the growing films. The nitrogenation in a-CN_x films can decrease the Tauc optical gap and electron spin resonance density; increase photon absorption coefficient of the films. They are 0.62-0.86eV and 10^6-10^4cm^{-1}, respectively.

H9.3
Abstract Withdrawn.

H9.4
DOPING PROFILES OF N-TYPE GaAs LAYERS GROWN ON Si SUBSTRATES BY THE CONFORMAL METHOD. A.M. Ardila, Departamento de Física, Facultad de Ciencias, Universidad Nacional de Colombia, Ciudad Universitaria, Santa Fe de Bogot, COLOMBIA; O. Martínez, M. Avella, J. Jiménez, Física de la Materia Condensada, Facultad de Ciencias, Universidad de Valladolid, Valladolid, SPAIN; B. Gérard, THALES, Corporate Research Laboratory, Orsay, FRANCE; J. Napierala, E. Gil-Lafon, LASMEA UMR CNRS, Université Blaise Pascal, Les Cézeaux, Aubiére, FRANCE.

We study doping profiles in selectively Silicon doped GaAs layers grown by the conformal method. This growth technique allows to obtain GaAs on Silicon substrates with optoelectronic quality. The samples are laterally grown, and the selective doping with Silicon is carried out in such a way that doped stripes are intercalated with undoped ones. The study of the doping profiles was carried out by Cathodoluminescence (CL) and microRaman spectroscopy. Abrupt doping profiles were demonstrated by monochromatic CL images at either 830 nanometers, corresponding to the near-band edge emission, or near 1000 nanometers corresponding to the presence of Silicon related deep level complexes. The formation of these complexes reduces the doping efficiency and is detrimental for the carrier mobility. The deep level related bands can be observed between 900 and 1100 nanometers depending on the samples, evidencing the complex mechanism for Silicon incorporation at the growth temperature (700-750 Celsius degrees). Net doping concentrations and mobilities across the layers were determined from the analysis of the phonon-plasmon coupled modes in the microRaman spectra obtained with a lateral resolution better than 1 micrometer. The free electron distribution, the mobilities and their relation to the CL spectra are discussed in terms of the different Silicon configurations in the lattice.

H9.5
GALLIUM VACANCY IN GaSb STUDIED BY POSITRON LIFETIME SPECTROSCOPY AND PHOTOLUMINESCENCE. W.K. Mui, M.K. Lui, C.C. Ling, C.D. Beling, S. Fung, Department of Physics, The University of Hong Kong, Hong Kong, CHINA; K.W. Cheah, K.F. Li, Department of Physics, Hong Kong Baptist University, Hong Kong, CHINA; Y.W. Zhau, Material Science Centre, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, CHINA.

Positron lifetime technique and Photoluminescence (PL) was employed to study the vacancy type defects in p-type Zn-doped and undoped GaSb samples. In the positron lifetime study, Ga vacancy related defect was identified in these materials and it was found to anneal out at temperature of about 350°C. For the PL measurement on the as-grown undoped sample performed at 10K, a transient peak having a photon energy of about 777meV was observed. This transition peak was observed to disappear after the sample was annealed to 400°C. Our results is consistent with the general belief that the 777meV transition is related to the $V_{Ga}Ga_{Sb}$ defect, which is the proposed residual acceptor of GaSb.

H9.6
Abstract Withdrawn.

H9.7
CHARACTERIZATION OF LiInS2 AND LiInSe2 SINGLE CRYSTALS FOR NONLINEAR APPLICATIONS. Ludmila Isaenko, Alexander Yelisseyev, Sergei Lobanov, Julia Smirnova, Design & Technological Institute of Monocrystals, Novosibirsk, RUSSIA; Alexander Panich, Ben-Gurion University of the Negev, ISRAEL; Jean-Jacques Zondy, Observatory of Paris, FRANCE; Valentin Petrov, MB-Institute for Nonlinear Optics and Ultrafast Spectroscopy, Berlin, GERMANY; Guido Knippels, FOM-Institute for Plasma Physics, Nieuwegeln, THE NETHERLANDS.

Reasons of variations in different parameters were studied using optical spectroscopy, X-ray structural analysis and NMR for large single crystals of ternary chalcogenides LiInS2 and LiInSe2, which are considered as promising for nonlinear applications in the mid IR. Both compounds were found to crystallize in wurtzite-type pyroelectric structure (Pna21 space group) and demonstrate similar nonlinearity for each case, whereas point defects affect considerably their color, lattice parameters and phase-matching conditions. These crystals have maximum band gap among ternary sulfides and selenides, respectively, which results in low two-photon absorption and is important for

applications in OPO. Photoinduced absorption was investigated and minimized by composition adjusting. LiInSe2 crystals were found to have a 1.5 times higher nonlinearity and increased optical stability.

H9.8
OPTICAL CONSTANTS OF ANNEALED a-Si:H FROM TRANSMITTANCE AT NORMAL INCIDENCE. Atsutoshi Doi, Yoshiyuki Matsumoto, Kinki Univ, Dept of Electrical Engineering, Higashiosaka, Osaka, JAPAN.

Solid phase crystallization of amorphous silicon films deposited on glass substrates is potentially useful and has received considerable attention. However, little is known about changes in optical constants caused by the thermal annealing involved in crystallization. Changes in refractive index are most likely caused by a change of the network structure. We investigate the refractive index change at a photon energy of 1.4 eV, by analyzing interference fringes in transmitted light at normal incidence. The analysis is based on an iterative calculation of the fringe pattern. Thin a-Si:H films were deposited onto quartz substrate by PCVD using pure silane gas at temperatures between 150 and 300°C, a chamber pressure of 10 Pa, and rf power density 37 mW/cm^2. Measurements were made following isochronous annealing for 16 hours, at temperatures up to 1000°C. The refractive index shows different dependences on temperature in different ranges; the critical transition temperatures between these ranges are 240, 340, 450, 570, and 680°C. Since the hydrogen concentration obtained by FTIR measurement disappears at about 470°C, the lower three critical temperatures may be caused by a network change in a-Si:H film. A sharp decrease in the refractive index and increase of the absorption coefficient was observed at about 570°C. This is probably due to crystallization of a-Si. The narrow temperature range for high absorption implies the formation of nc-Si. A step increase of the DSC signal was observed at 674°C, indicating an increase of specific heat of the film at this temperature, which is close to the critical temperature of 680°C. These results demonstrate the value of transmittance analysis.

H9.9
A^3B^6-TYPE LAYERED CRYSTALS AS OPTOELECTRONIC MATERIALS. A.G. Kyazym-zade, V.M. Salmanov, G.I. Abutalibov, Baku State University, Baku, AZERBAIJAN.

The long-term researches carried out by us show, that A^3B^6-layered compounds, in particular Indium Selenide (InSe) and Gallium Selenide (GaSe) single crystals has a perspective materials for optoelectronic applications. Because of the weakness of interlayer bonds in the indicated crystals, frequently occur a casual shift and peeling of group of layers from each other, that result to the disorder of a structure. On the boundaries of the disordered areas and in dilatation interlayer space accumulate the numerous irregular impurities and defects which are centers of capture of major carriers. The capture of main carriers by these centers results to the appearance of a non-homogeneous of potential barrier. Due to it, the specific effects are observed in them, such as high-speed effect of switching, stimulation of conductivity by electrical field, residual and anomalous photoconductivity. It makes possible the producing of regulated elements of electrical, optical and spectral memory on the base of the indicated crystals. The use of diode structures on the base of the indicated crystals allows to expand functional possibilities of the indicated elements. The single crystals InSe and GaSe also can be used for producing of the optical filters of laser light in visible and close IR range of spectrum. The transmission of these crystals the certain frequency of laser light appropriate to the edge of fundamental absorption sharply depends on the temperature and on the applied electric field. It allows to produce the optical filters of laser light, transmission of which is operated by the temperature and electrical field. The use of solid solutions $GaSe_{1-x}S_x$ and $Ga_{1-x}In_xSe$ also allow to expand the working range of temperature and electrical field of the indicated elements.

H9.10
FIELD EFFECT CONTROLLED PHOTORESISTORS BASED ON CHEMICALLY DEPOSITED PbS FILMS. Lucian Pintilie, Eugenia Pentia, Ion Matei, Ioana Pintilie, National Institute of Materials Physics, Bucharest, ROMANIA.

MOS-like structures were obtained by chemical deposition of a polycrystalline PbS thin film on top of a silicon dioxide/Si substrate. Gold ohmic electrodes in coplanar configuration were subsequently deposited by vacuum evaporation on PbS surface (drain and source electrodes). The gate aluminum electrode was deposited on the back of the Si substrate. The dependence of the photoconductive signal, generated in the PbS film, on the gate voltage was studied for wavelengths ranging between 800 nm and 3000 nm at room temperature as well as at low temperatures. It was found that the relative variation of the signal could be as high as 50% for gate voltages ranging between -30 V and 30 V. Two possible mechanisms are proposed to explain the signal variation with the gate voltage: 1) Variation of the depleted region's thickness in the PbS film, that leads to a variation of the conduction channel's resistance (the reference resistance called, also, the dark resistance), 2) The possible variation of the majority carriers (holes) life-time due to the electron blocking at the PbS/oxide interface when positive gate voltages are applied on the back electrode. Integrated IR detectors with controlled sensitivity in the 800-3000 nm range can be manufactured at a relatively low cost using the PbS/oxide/Si MOS-like structure.

H9.11
PHOTO-STIMULATED REBUILDING OF STRUCTURE IN SEMICONDUCTORS. B.L. Oksengendler, S.S. Rashidova, N.N. Turaeva, I.M. Aripov, Institute of Polymer Chemistry and Physics Tashkent, UZBEKISTAN.

A strong electron-phonon interaction observed in semiconductors allows to realize a special kind of atomic rebuilding under photo-radiation of media. We consider three types of the defective structures: one-atomic, two-atomic ("dump-bell") and multi-atomic (kinks) ones. It is shown that an inversion effect of potential relief may be realized if there are non-equivalent neighboring positions of one-atomic and two-atomic defects. In this case photo-excitation of the electronic subsystems of these defects leads to the inversion of terms and consecutively athermal rebuilding of the defective structures. Yahn-Teller effect and psevdo-effect play a special role here. It is shown for kink-structures that photo-excitation of the electronic subsystems results in the alteration of the kink nonius and the successive exponentially strong decrease of the activation barrier. Especially effects of athermal atomic rebuilding of the U-negative defects are considerable.

H9.12
STRATEGIES FOR OHMIC CONTACT IN FABRICATION OF Ge/Si WAFER BONDED STRUCTURES. Chang-Geun Ahn, James M. Zahler, Harry A. Atwater, California Institute of Technology, Dept. of Applied Physics, Pasadena, CA; Charles Chu, Peter Iles, Tecstar Inc., City of Industry, CA.

Wafer bonding technology allows potential for integration of epitaxially incompatible optical materials with Si. We have successfully used hydrophobic direct wafer bonding along with hydrogen-induced layer splitting of Ge to transfer 700nm thick, (100) single-crystal Ge films to (100) Si substrates without using a metallic bonding layer. Compound triple-junction solar cells have been grown on the Ge/Si heterostructures with comparable photoluminescence to control structures grown on Ge bulk. However, a major technical challenge in utilizing layer transfer to integrate Si and optical materials is the formation of a low resistance ohmic contact at the bonding interface. In this paper we present results demonstrating successful ohmic contact formation at heavily doped but metal-free Ge/Si bonded interfaces and discuss characterization and improvement of the ohmic properties at the transferred Ge/Si interface. Ge/Si heterostructures are formed by bonding hydrophobically terminated, $1x10^{17}$ cm^{-2} 80keV H^+ implanted Ge to hydrophobically terminated Si under >1000 psi bond-initiation pressure at room temperature in an atmospheric ambient. Subsequent thermal processing in N_2 to 350°C initiates crack propagation along the H-profile peak concentration in the Ge transferring a ~700nm film. Electrical measurements of the bonded samples made from $\sim 1x10^{19}$ cm^{-3} Ga doped Ge and $\sim 1x10^{19}$ cm^{-3} B doped Si substrates indicate initially non-linear, asymmetric I-V characteristics with ~400Ω resistance at low voltage (-5V to 5V) that destructively breaks down during the first I-V cycle at high voltage (>5V) to leave a ~40Ω ohmic interface resistance after one I-V cycle. This high resistance and breakdown behavior may be caused by residual contaminants at the interface that form an insulating layer after bonding and annealing. Additionally, factors such as Ge/Si conduction band offset, lattice mismatch between Ge and Si crystals, and screw dislocation networks at the interface formed by azimuthal rotation of the wafers during bonding may also lead to interfacial surface states further contributing to the interface resistance. We will discuss surface cleaning and annealing techniques as a means of minimizing interfacial insulating layers, as well as various doping strategies – p Ge / p Si, p Ge / n Si, and n Ge / p Si – for making ohmic tunnel-junction contact at the bonding interface.

H9.13
CONTROLLED SURFACE MODIFICATION OF CdSe NANOCRYSTALS BY AMPHIPHILIC PAMAM DENDRIMERS. Lajos Balogh, Chunxin Zhang, Center for Biologic Nanotechnology, University of Michigan, Ann Arbor, MI; Stephen O'Brien, Dept of Applied Physics, Columbia University, New York, NY; Nicholas J. Turro, Louis E. Brus, Dept of Chemistry, Columbia University, New York, NY.

Controlled attachment of organic ligands onto nanoparticle surfaces is an important issue because surface bound ligands not only (a)

determine the stability of the nanoparticles, but (b) control their compatibility with the actual physical environment, and (c) influence their optical properties as well. Crystalline CdSe nanoparticles synthesized in TOPO/TOPSe were used as photonic materials in this study. First TOPO caps were exchanged to pyridine then binding of various tertiary, secondary and primary amines was explored. Then, terminal amine groups of poly(amidoamine) PAMAM dendrimers were partially and fully modified with hydrocarbon chains and successfully used as stable surface ligands. The resulting nanoparticle systems were characterized by proton, carbon, phosphorous and nitrogen NMR, AFM, TEM, absorption and photoluminescence spectroscopy. Crucial parameters of preparation, such as purity of chemicals, and major strategies of cap exchange using small molecules and macromolecular ligands will be discussed, as well as their effect on the photoluminescence intensity of the otherwise identical CdSe nanocrystallites.

H9.14
CATHODOLUMINESCENCE FROM ERBIUM OXIDE GROWN ON SILICON. Emilio Nogales, Bianchi Méndez, Javier Piqueras, Universidad Complutense de Madrid, Dpt. Física de Materiales, Madrid, SPAIN; Rodica Plugaru, Inst. of Microtechnology, Bucharest, ROMANIA; José A García, Universidad del País Vasco, Dpt. Física Aplicada II, Vizcaya, SPAIN; Tom J. Tate, Imperial College, Dpt. of Electrical and Electronic Engineering, London, UNITED KINGDOM.

Luminescence of erbium oxide layers grown on crystalline and amorphous silicon has been investigated by cathodoluminescence (CL) in the scanning electron microscope, and by photoluminescence (PL). Intense red and green CL bands due to intraionic Er^{3+} radiative transitions have been detected at room temperature. The red band is dominant in the spectra of crystalline silicon while green emission dominates in the case of amorphous samples. These results are explained in terms of the oxygen content in the substrate. The samples show a weak infrared CL emission. The visible bands are not, however, present in the PL spectra but broad infrared bands related to erbium ions and defects are present. Samples implanted with Er or with Er and O were investigated for comparison. Green and red CL bands are absent in all implanted samples which show the sharp PL emission at 1.54 μm, typical of Er^{3+} ions.

H9.15
TEM CHARACTERIZATION OF SELF-ASSEMBLY OF FRACTIONATED CADMIUM SELENIDE NANOPARTICLES. Dafei Kang, Hongwei Yang, Mark Aindow, Department of Metallurgy and Materials Engineering, Institute of Materials Science, University of Connecticut, Storrs, CT; Jeunghoon Lee, Fotios Papadimitra-kopoulos, Nanomaterials Optoelectronics Laboratory (NOEL), Institute of Materials Science, University of Connecticut, Storrs, CT.

Many proposed applications of semiconductor nanoparticles (quantum dots) depend on the ability to manipulate them into structures with well-organized order to utilize the collective properties. Self-assembly as a promising method to organize these nanoparticles can be achieved by exploiting the intrinsic interactions existing among them. In this paper the organically-capped cadmium selenide (CdSe) nanoparticles were synthesized using the colloidal chemistry approach. Nearly monodisperse samples of these nanoparticles were obtained by performing size-selective fractionation, the effectiveness of which was confirmed by data from UV-Vis spectrometry and size distribution evaluation of the nanoparticles using transmission electron microscope (TEM). Deposition of the fractionated CdSe nanoparticles onto proper substrates produced self-assembled CdSe superlattices which were characterized by applying both imaging and diffraction techniques of transmission electron microscope. Useful information was extracted from the self-assembled superlattice structures and the individual nanoparticles. Furthermore, TEM specimens prepared from mixtures of these CdSe nanoparticles of two different sizes were studied and the character of the structures produced was revealed.

H9.16
SIMULATIONS OF OPTOELECTRONIC PROPERTIES OF SELF-ASSEMBLED InAs/GaAs QUANTUM DOT ARRAYS. Harley T. Johnson, University of Illinois at Urbana-Champaign, Department of Mechanical and Industrial Engineering, Urbana, IL.

Ensemble optoelectronic properties of self-assembled InAs island quantum dot arrays on GaAs substrates are studied theoretically using a coupled morphology/electronic structure finite element approach. Results of a three-dimensional finite element model for the self-assembly process, capturing the nucleation, growth, and coarsening of a quantum dot array during deposition and annealing, are used as input into an electronic structure finite element calculation. Using a strain-modified $\mathbf{k}\cdot\mathbf{p}$ Hamiltonian formulation for single charge confinement, the energy levels and wave functions are calculated for the electron and hole states in the ensemble. The states include characteristic s-type, p-type, and d-type states in individual dots as well as delocalized states such as wetting layer states and multiple-dot states. Finally, the optical conductivity of the system, as a function of wavelength of incident light, is calculated by evaluating the relevant matrix elements for interband and intraband transitions between the calculated energy states. The results compare favorably to experimental spectroscopic data from the literature.

H9.17
HIGH-PERFORMANCE InAs/GaAs QUANTUM DOTS INFRARED PHOTODETECTOR WITH/WITHOUT $Al_{0.2}GA_{0.8}AS$ BLOCKING LAYERS. Zhengmao Ye, Joe C. Campbell, Microelectronics Research Center, The University of Texas at Austin, Austin, TX; Zhonghui Chen, O. Baklenov, E.T. Kim, I. Mukhametzhanov, J. Tie, and A. Madhukar, Departments of Materials Science and Physics, University of Southern California, Los Angeles, CA.

Infrared photodetectors have gained widespread attention due to their potential applications in both commercial and military areas. Compared with quantum well infrared photodetectors (QWIPs), self-assembled quantum dots infrared photodetectors (QDIPs) have the advantage that they have high absorption of normal-incident infrared radiation owing to three-dimensional carriers confinement in quantum dots. They also exhibit high responsivity and low dark current as a result of the long carrier capture and relaxation times. In this paper, we demonstrate two high-performance InAs/GaAs QDIPs. QDIP sample A was grown on a semi-insulating GaAs(001) substrate by solid-source molecular beam epitaxy (MBE). This QDIP sample consisted of five stacks of undoped InAs quantum dots sandwiched between heavily-doped GaAs layers. Sample B had the same structure as sample A except that $Al_{0.2}Ga_{0.8}As$ blocking layers were introduced between each quantum dot layer. FTIR measurements showed a peak photoresponse at wavelengths of 7.1μm and 6.2μm for samples A and B at 77K, respectively. The spectrum indicated that the photo-response was due to a band-to-band intersubband transition in the InAs quantum dots. The shift of the peak photoresponse suggests a change of the electronic states inside the quantum dots. The temperature dependence of the photoresponse will also be discussed. The dark current and noise of the sample were successfully reduced by over two orders of magnitude by the incorporation of the $Al_{0.2}Ga_{0.8}As$ blocking layers. The normal-incident peak responsivity was calibrated using a blackbody. The peak responsivities of sample A and sample B were 5mA/W at 0.1V bias and 5.5mA/V at 0.8V bias, respectively. The corresponding detectivities were 3×10^9 $cmHz^{1/2}/W$ and 2.8×10^9 $cmHz^{1/2}/W$, which are the highest detectivities reported for QDIPs at 77K.

H9.18
ORDERED BOUND EXCITONS IN GaP:N FOR ADVANCED OPTOELECTRONICS. Sergei L. Pyshkin, Institute of Applied Physics, Academy of Sciences, Kishinev, MOLDOVA.

Gallium Phosphide doped with nitrogen N or GaP:N is a unique object for generation, investigation and application of bound exciton system, which is mostly interesting at high density of excitons bound to ordered N-impurity superlattice. An investigation of long-time ordering of nitrogen atoms along P sites in 35 years ago grown GaP single crystals and related phenomena in N impurity-bound excitons is presented. It was shown that during this period impurity redistribution due to the respective substitution reaction with the energetic barrier 1.0-1.2 eV at room temperature and normal pressure leads to regular distribution of N along anion sites. High density excitons bound to N-impurity superlattice can be considered as an excitonic crystal like to an inverted alkali metal and consisting of a net of negatively charged heavy nuclei (N atom captured electron) which interacts with a free hole gas. Creation of this phase in long-time ordered crystals was recognized by specific dependences of luminescence and Raman scattering spectra on bound excitons density as well as by p-type photoconductivity of highly optically excited GaP:N compared to always n-type dark conductivity of these crystals. Methods of growth of GaP thin epitaxial films periodically doped with N atoms are proposed. Some non-linear optic phenomena, accumulation, conversion and transport of light energy as well as development of a new generation of optoelectronic devices on crystalline excitons have been discussed.

H9.19
CURRENT IMAGES OF CdSe COLLOIDAL NANODOTS BY CONDUCTIVE-TIP ATOMIC FORCE MICROSCOPY. Ichiro Tanaka, Eri Kawasaki, O. Ohtsuki, Wakayama Univ, Dept of Materials Sci & Chem, Wakayama, JAPAN; M. Hara, RIKEN Frontier, Wako, JAPAN; H. Asami, I. Kamiya, Mitsubishi Chemical Corp, Yokohama, JAPAN.

Colloidal nanodots have been of interest both from the fundamental and the applicational point of views because they exhibit nano-size or quantum effects. We have fabricated sub-monolayer thick films of CdSe colloidal nanodots in order to investigate electronic properties of

individual nanodots by conductive-tip atomic force microscopy (AFM). CdSe colloidal dots were dispersed in toluene at a concentration of 0.1 wt%, and spun coat on single crystalline Au (111) films evaporated on mica substrates. A monolayer of dodecanethiol molecules had been predeposited on the Au (111) surface to improve the adhesion of the colloidal dots. We have successfully observed isolated colloidal nanodots on the Au (111) surfaces by AFM operating in contact mode, and obtained topographic and current images simultaneously under appropriate bias voltages. In the current image, it is found that the dot regions have higher electric resistances, which we attribute to the tunneling resistance through the CdSe dots. In addition, we observed 10-nm scale electric inhomogeneity around the dots, which may correspond to the previously reported etch-pits of Au (111) surfaces formed during the deposition of dodecanethiol molecules.

H9.20

SHALLOW-DONOR STATES IN SPHERICAL QUANTUM DOTS WITH PARABOLIC CONFINEMENT. C.A. Duque, Depto de Física, Universidad de Antioquia, Medellín, COLOMBIA; N. Porras-Montenegro, Depto de Física, Universidad del Valle, Cali, COLOMBIA; M. de Dios-Leyva, Dept. of Theoretical Physics, Univ. of Havana, Vedado, Havana, CUBA; L.E. Oliveira, Instituto de Física "Gleb Wataghin", UNICAMP, Campinas, SP, BRAZIL.

Quantum-dot heterostructures are most studied both from the theoretical and experimental point of view due to the wide possibility of applications in electronic and optoelectronic devices. Such semiconductor nanostructures show interesting physical properties due to the extreme degree of confinement of electrons and holes, and the presence of impurities of course modify both the optical and transport properties of such nanostructures. For impurities in quantum dots, the ultimate goal is an artificial atom whose properties can be controlled through the material parameters and geometry. The evidence of the existence of a parabolic potential well in quantum wires and dots was reported in the literature [1], and a parabolic potential is often considered to be a good representation of the "barrier" potential in semiconductor quantum dots [2-3]. In the present work, the variational [3] and fractional-dimensional space approaches [4] are used in a thorough study of the binding energy of on-center shallow donors in spherical GaAs-Ga1-xAlxAs quantum dots with potential barriers taken either as rectangular or parabolic isotropic barriers. We define the parabolic potential so that it results in the same ground-state energy as for the spherical quantum dot of radius R and rectangular potential in the absence of the impurity. Calculations using the variational and fractional-dimensional approaches both for rectangular and parabolic potentials result in essentially the same on-center binding energies provided the dot radius is not too small. This indicates that both potentials are alike representations of the quantum-dot barrier potential for a radius R quantum dot provided the parabolic potential is defined as mentioned above. [1] K. Kash et al, Phys. Rev. Lett. 67, 1326 (1991); M. Sopanen et al, Appl. Phys. Lett. 66, 2364 (1995). [2] Z. Xiao, J. Zhu, and F. He, Superlatt. and Microstrut. 19, 137 (1996); C. Bose, J. Appl. Phys. 83, 3089 (1998); ibid., Physica E 4, 180 (1999). [3] G. Murillo and N.P. Montenegro, Phys. Stat. Sol. (b) 220, 187 (2000); N.P. Montenegro and S.T.P. Merchancano, Phys. Rev. B 46, 9780 (1992). [4] H. Stillinger, J. Math. Phys. 18, 1224 (1977); P. Christol, P. Lefebvre, and H. Mathieu, J. Appl. Phys. 74, 5626 (1993); E. Reyes-Gomez, A. Matos-Abiague, C.A. Perdomo-Leiva, M. de Dios-Leyva, and L.E. Oliveira, Phys. Rev. B 61, 13104 (2000).

H9.21

Abstract Withdrawn.

H9.22

ELECTRIC FIELD MODULATED OPTICAL STUDIES OF SINGLE DOPED AND UNDOPED II/VI SEMI-CONDUCTOR QUANTUM DOTS. Benjamin J. Gross, Michael Holman, Oksansa Cherniavsky, Kim T. Nguyen, David M. Adams, Columbia University, Dept of Chemistry, New York, NY.

Electric field modulated near-field scanning optical microscopy (NSOM), scanning confocal microscopy (SCM) and spectroscopy techniques are used to study the luminescence "on/off blinking" observed in single quantum dot systems. Large electric fields ($\sim 10^6$ V/cm) are generated over samples between a metalized NSOM probe and transparent conducting substrate. Under these conditions the electronic band structure of the particle as well as charge and energy transfer processes (to substrate or dopant respectively) are significantly modified. The kinetics of these processes can be inferred from the time resolved luminescence behavior and spectroscopy. These studies are performed on synthesized materials, which include CdSe, ZnSe, and ZnTe nanoparticles as both undoped and doped species.

H9.23

CONTINUOUS AND TIME RESOLVED OPTICALLY DETECTED MAGNETIC RESONANCE STUDIES OF InP NANOPARTICLES. L. Langof, E. Ehrenfreund, E. Lifshitz, Solid State Institute, Technion - Israel Institute of Technology, Haifa, ISRAEL; O.I. Micic, A.J. Nozik, National Renewable Laboratory, Golden, CO.

Carriers in small colloidal InP nanoparticles are in strong quantum confinement regime. The low temperature photoluminescence spectrum of InP nanoparticles is composed of an excitonic luminescence at high energies and a non-excitonic defect emission band at lower energies. HF etching of the nanoparticles reduces the defect emission and enhances the exciton process. In this work we apply optically detected magnetic resonance spectroscopy (ODMR) both in continuous wave and time resolved mode (TR-ODMR) to study the defect luminescence in InP nanoparticles. In the ODMR experiment, we monitor a change in a luminescence intensity (or circular polarized component), resulting from a magnetic resonance event at the excited state. The ODMR spectra of the InP samples were measured as a function of the laser power, microwave power, microwave modulation frequencies, and light polarization. The results show that the defect luminescence originates from weakly coupled electron-hole pair, where the electron is trapped at the surface by phosphorous vacancy, Vp, (S=1/2) and the hole is located at the valence band (S=3/2). Additionally, the results suggests that the non-etched samples are dominated by Vp at the surface. Those are mainly eliminated upon HF treatment, leaving behind small percent of Vp in the core of the nanoparticle. We also find the electron-hole exchange interaction from circular polarized ODMR measurements. The TR-ODMR measurement further clarifies the spin dynamics and characteristic of the magnetic sites. Fitting these measurements to the simulated response of the PL intensity to the square wave modulated microwave power revealed that the spin relaxation time and radiative lifetime of electron-hole pair in the nanoparticles are in the microseconds regime.

H9.24

AIRPLANE AND DROP EXPERIMENTS ON CRYSTALLIZATION OF $In_xGa_{1-x}Sb$ SEMICONDUCTOR UNDER DIFFERENT GRAVITY CONDITIONS. Krishnan Balakrishnan, Yasuhiro Hayakawa, Hideki Komatsu, Noriaki Murakami, Tetsuro Nakamura, Tadashi Kimura, Masashi Kumagawa, Research Institute of Electronics, Shizuoka University, Hamamatsu, JAPAN; Tetsuo Ozawa, Shizuoka Inst. Sci. Tech., Fukuroi, JAPAN; Yasunori Okano, Masafumi Miyazawa, Faculty of Eng., Shizuoka Univ., Hamamatsu, JAPAN; Sadik Dost, Univ. of Victoria, Victoria BC, CANADA; Le H. Dao, Univ. du Quebec, Verennes, Quebec, CANADA.

Fundamental studies on crystal growth and related processes done on technologically important materials like $In_xGa_{1-x}Sb$ under different gravity conditions provide important information which could help utilizing these materials better in the device oriented applications. We have made an attempt to systematically analyse the crystallization behavior of $In_xGa_{1-x}Sb$(x=0.05) under different gravity conditions by performing experiments in an air plane flying in parabolic trajectory and in a 150 m long drop tower under different gravity conditions, varying from microgravity (10^{-5}g) to normal gravity (1g). Czochralski grown polycrystalline InGaSb, cut into thin plates of dimensions 5x5x2-0.5 mm^3, were used as the starting materials. The melting and crystallization processes of InGaSb were recorded live by a high speed CCD camera. In the drop experiment, during the crystllization of InGaSb, spherical projections were found to appear and increase in size. The shapes of the projections were found to vary with the prevailing gravity conditions. It was also found the In composition varied with the time of crystallization. In a typical InGaSb sample, the bubble shaped crystal, formed first, was found to contain less amount of indium when compared with the indium composition of the crystal formed next. In the airplane experiment, many needle crystals of InGaSb resulted at 10^{-2}g. It was found that there were larger needle crystals in the 10^{-2}g processed sample compared with the normal gravity (1g) processed sample. This may be due to the reason that the heat transfer under the reduced condition is restricted to some extent as the convective forces are less active than those under the normal gravity.

H9.25

CURRENT-VOLTAGE AND CAPACITANCE-VOLTAGE CHARACTERISTICS OF nGaAs-nInSb HETEROJUNCTIONS OBTAINED BY LASER-PULSE DEPOSITION TECHNIQUE. Karapet E. Avdjian, Inst of Radiphysics & Electronics, AcSci of Armenia, Dept of Semiconductor Electronics, Ashtarak, ARMENIA.

Using laser pulse deposition technique, nGaAs-nInSb heterojunctions (HJs) are obtained. Their electrical properties are studied. The Current-Voltage characteristics show that obtained HJs possess rectifying properties. The rectification coefficient depends strongly on the doping level of GaAs substrate. The linear dependence of C^{-2} (V) curve in Capacitance-Voltage characteristics, as well as the change of photo-response sign with wavelength, indicates that the HJs have

abrupt interface, which is, to the best of our knowledge, a novel result for these HJ materials. The full number of interface states arising due to the lattice mismatch is determined which is in agreement with Hall measurements. Current-Voltage characteristics of obtained HJs are analogous to those of metal-semiconductor junction. Based on the obtained results the energy band diagrams of nGaAs-nInSb HJ is constructed taking into account the interface states.

H9.26
EFFECTS OF ELECTRIC FIELDS ON CATHODOLUMINESCENCE FROM II-VI QUANTUM WELL LIGHT EMITTING DIODES. A. Nikiforov, G.S. Cargill, III, Department of Materials Science and Engineering, Lehigh University, Bethlehem, PA; M.C. Tamargo, S.P. Guo[a], Department of Chemistry, City College-CUNY, New York, NY; Y.-C. Chen, Department of Physics, Hunter College, CUNY, New York, NY. [a]Present address: EMCORE Corporation, Somerset, NJ.

Structures made from lattice-matched quaternary II-VI alloys are expected to improve lifetimes of ZnSe-based quantum well (QW) light emitting devices (LEDs). Cathodoluminescence (CL) is being used to study degradation in these devices, e.g. whether it is localized and how it is affected by internal electrical fields. Effects of electrical bias on the luminescent properties of blue and green II-VI LEDs have been investigated. The LEDs are ZnCd(Mg)Se-based multilayer QW structures grown by molecular beam epitaxy (MBE). Wavelength and time-based CL scans were performed with different biasing conditions. Without bias, the wavelength CL scans show well resolved peaks from QW and cladding. Reverse bias decreases the CL intensity from QW peaks while cladding peaks are unaffected. Forward bias causes the disappearance of cladding peaks and shifts the QW peaks to smaller energies. In time-based CL scans without bias, the QW intensity increases initially and then remains constant. Forward bias leads to a rapid decay of the QW intensity. When the bias is switched off, the CL intensity increases to near its original, zero-bias level. Reverse bias causes the intensity to drop initially by 30-40%. Then, in contrast to the forward bias case, the QW intensity remains nearly constant. These observations are discussed in terms of carrier dynamics and recombination processes.

H9.27
GAS SOURCE MBE GROWTH AND CHARACTERIZATION OF TlInGaAs/InP DH STRUCTURES FOR TEMPERATURE-INDEPENDENT WAVELENGTH LD APPLICATION. Hajime Asahi, Hwe-Jae Lee, Akiko Mizobata, Kenta Konishi, Osamu Maeda, and Kumiko Asami, The Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka, JAPAN.

Wavelength division multiplexing (WDM) technology is very important for optical fiber communication systems to increase transport capacity, where the stability of the lasing wavelength of laser diodes (LDs) are very important. Recently, we proposed III-V quaternary semiconductors TlInGaP and TlInGaAs[1,2] to fabricate such temperature-stable lasing wavelength LDs. TlInGaP and TlInGaAs are expected to show the temperature-independent bandgap energy at certain compositions because it is an alloy of semiconductor, InGaP or InGaAs, and semimetal, TlP or TlAs[1,2]. In this paper, TlInGaAs/InP double heterostructures (DHs) were grown on (100) InP substrates by gas source MBE. The photoluminescence (PL) peak energy and its variation with temperature decreased with increasing Tl composition. For the DH with a Tl composition of 13%, the PL peak energy varied only slightly with temperature (-0.03 meV/K). This value corresponds to a wavelength variation of 0.04 nm/K and is much smaller than that of the lasing wavelength of InGaAsP/InP DFB LDs (0.1 nm/K). The TlInGaAs/InP light emitting diodes (LEDs) were fabricated. They were operated up to 610 K in the wavelength range of 1580 nm. The similar small temperature variation for the electroluminescence (EL) peak energy to that of PL peak energy was observed. For the DH LEDs with a Tl composition of 6% showed the small temperature variation of the EL peak energy (-0.09 meV/K). The result for the TlInGaAs/InP laser diodes will also be reported in the conference. References: [1] H. Asahi et al., Jpn. J. Appl. Phys. 35 (1996) L876. [2] H. Asahi, Compound Semicond. 2 (1996) 34.

H9.28
EFFECT OF THE Zn ATOMS DIFFUSION IN THE ACTIVE LAYER OF InGaAlP VISIBLE-LED INVESTIGATED BY A PIEZOELECTRIC PHOTOTHERMAL SPECTROSCOPY. R. Ohno, S. Sato, Y. Taiji, Dept of Electrical and Electronic Engineering, Miyazaki University, JAPAN; A. Fukuyama, Dept of Applied Physics, Miyazaki University, JAPAN; S. Shigetomi, Dept of Physics, Hukuoka Kurume University, JAPAN.

Recently, high-brightness operation from the orange to green region have been obtained for the InGaAlP LEDs using InAlP cladding layers and distributed Bragg reflectors (DBRs) grown by metal organic chemical-vapor deposition (MOCVD) method. But one of the problems in the InGaAlP LEDs is a degradation of light output power, which may be caused by the presence of Zn atoms diffused from Zn-doped InAlP cladding layer during the device manufacturing processes. Since a lifetime of the injected carriers in the active layer decreased with increasing Zn atoms, the diffused Zn was considered to create a not only shallow acceptor but also deep defect levels at the same time in the InGaAlP active layer. However, details have not been clear yet. In the case of such lattice defect-related deep levels, nonradiative processes may play an important role for the electron transition mechanisms. However, PL methods canft detect such nonradiative transitions. The great advantage of the Piezoelectric Photothermal Spectoroscopy (PPTS) is that it is a direct monitor of the nonradiative recombination processes of photoexcited electrons. Therefore, the temperature variations experiments of the PPTS were carried out to clarify the effect of diffused Zn atoms in InGaAlP active layer from the nonradiative transition point of view. We propose here a band structure model for the nonradiative electron transition pathways to explain our results. The effect of DBRs, carrier diffusion between the layer and carrier drift by the presence of the electric field in the interface regions are also taken into account. We then found that deep defect level generated by the Zn atoms diffusion play an important role for the degradation of the LEDs.

H9.29
Abstract Withdrawn.

H9.30
STRATEGIES FOR DIRECT MONOLITHIC INTEGRATION OF $Al_xGa_{(1-x)}As/In_xGa_{(1-x)}As$ LEDS AND LASERS ON Ge/GeSi/Si SUBSTRATES VIA RELAXED GRADED $Ge_xSi_{(1-x)}$ BUFFER LAYERS. Michael Groenert, Vicky Yang, Matthew Currie, Christopher Leitz, and Eugene Fitzgerald, MIT, Dept of Materials Science and Engineering, Cambridge, MA.

Experiments with the direct transfer of proven GaAs-based devices onto $Ge/Ge_xSi_{(1-x)}/Si$ virtual substrates have shown the importance of a number of material issues in addition to the GaAs/Ge/Si lattice mismatch. The difference in the thermal expansion coefficients of GaAs, Ge and Si has been previously recognized as a source of tensile strain and microcracking in thin GaAs films on Si. We have investigated the effects of built-in compression as a compensation mechanism, and how deliberately compressed layers near the GaAs/Ge interface will affect the growth of defect-resistant $In_xGa_{(1-x)}As/GaAs$ strained quantum well structures on Ge virtual substrates. The cross-hatch surface roughness that characterizes low-mismatch relaxed graded buffer layers can increase optical scattering in GaAs-based waveguides grown on Ge/GeSi/Si substrates. Optical absorption from mode leakage into the Ge virtual substrate can also be a significant source of waveguide loss. Ge virtual substrates can lead to autodoping affects during GaAs growth, with surface exchange mechanisms carrying Ge impurities into the active regions of the GaAs device structures and causing high free-carrier absorption losses. The quantitative effects of all of these factors will be discussed, and strategies for dealing with them using proper cladding design and a deliberate low-temperature cycling step to halt Ge/Ga surface exchange after GaAs growth initiation will be detailed. Making use of these strategies, optimized $Al_xGa_{(1-x)}As/GaAs$ and $In_xGa_{(1-x)}As/GaAs$ LED and laser structures have been grown on Ge/GeSi/Si virtual substrates using atmospheric-pressure organometallic chemical vapor deposition (OMCVD), and these devices have been characterized and compared with identical structures grown on standard GaAs, Ge, and Si substrates.

H9.31
TRANSFER OF III-V MATERIALS ONTO SILICON BY WAFER BONDING AND ION BEAM INDUCED LAYER SPLITTING. Xiaotang Ren, Jie Zhu and Mengbing Huang, Dept. of Physics, Univ. at Albany-SUNY, Albany, NY.

We investigated materials issues related to the transfer of III-V optical materials onto Si as a solution for achieving hybrid integration of III-V optical devices, e.g. vertical cavity surface emitting lasers (VCSELs), onto silicon wafers. Our approach relies on wafer bonding and ion beam induced layer splitting techniques. To ensure that the III-V optical devices are defect free after being transferred onto Si, implantation masks were used for protection of active device regions during ion beam processes. We have demonstrated that both the implanted region (without devices) and the unimplanted region (with devices) on a 3" GaAs wafer can be simultaneously transferred onto a 3" Si wafer, depending on the ratio of areas between these two regions. The interfacial structures of bonding wafers, and the optical/electrical properties of III-V thin films transferred onto Si, are examined in details.

H9.32
CVD DIAMOND THIN FILMS FOR ALPHA PARTICLE

DETECTOR APPLICATION. S.G. Wang, Q. Zhang, S.F. Yoon, J. Ahn, B. Gan, D.J. Yang, Rusli, Nanyang Technological University, School of Electrical & Electronic Engineering, Microelectronics Centre, Singapore, SINGAPORE; A.A. Bettiol, T. Osipowicz, F. Watt, The National University of Singapore, Department of Physics, Research Center for Nuclear Microscopy, SINGAPORE.

Diamond has high radiate hardness, good thermal conductivity, wide band gap and fast charge collection. Its combination of such unique properties makes it an attractive material for radiation detection applications. In this paper, CVD diamond thin films for alpha particle detector application has been studied. Alpha particle detectors were fabricated based on mechanically polished freestanding diamond thin films deposited by HFCVD technique. Coplanar and sandwich electrical contacts patterned using lift-off technology were applied to the sides of diamond thin film detectors to provide spatial resolution. The detector collection efficiency was mapped using ion-beam-induced charge microscopy technique. The effects of coplanar and sandwich electrical contacts on collection efficiency has also been compared and analyzed.

H9.33
CHEMICAL BATH DEPOSITION OF INDIUM SULFIDE THIN FILMS. Kuvasani Govender, David Smyth-Boyle, Iain P. O'Hare, and Paul O'Brien, Department of Chemistry, University of Manchester, Manchester, UNITED KINGDOM.

Recently there has been much effort towards replacing cadmium containing compounds in solar cells, due to their toxicity, with more benign materials. We have investigated a number of materials as alternatives for buffer layers in chalcopyrite based solar cells. Of particular interest is the group III-VI semiconductor indium sulfide(In2S3), which has been associated with device efficiencies of 15.7 %. In the present study, we have investigated the low temperature solution deposition of In2S3. We have identified the conditions necessary for the deposition of pristine thin films on glass substrates. The composition and material properties of the films have been characterised using a range of optical and structural techniques. Results are systemised by computer modelling of the solutions used in the deposition process.

H9.34
CHARACTERIZATION AND FABRICATION OF OPTICAL DEVICES ON SiGe VIRTUAL SUBSTRATES. Vicky Yang, Michael Groenert, Steve Ting, Mayank Bulsara, Matthew Currie, Christopher Leitz, Arthur Pitera, Gianni Taraschi, Zhi-Yuan Cheng, Eugene Fitzgerald.

The monolithic integration of optoelectronic devices on Si can be realized through the utilization of SiGe virtual substrates that are only 0.07% lattice mismatched to GaAs. We have measured and compared the luminescent efficiencies of $In_{0.2}Ga_{0.8}As$ quantum well structures grown on various substrates by atmospheric MOCVD, including SiGe, GaAs, Si, and Ge. Quantitative cathodoluminescence was used to compare the luminescent efficiency of the quantum wells and TEM was used to characterize dislocation densities. Our results show that the InGaAs quantum wells grown on GaAs substrates have the highest luminescent efficiencies and the smallest dislocation densities. Interestingly, InGaAs quantuam wells grown on SiGe virtual substrates out-performs those on Ge substrates, both in terms of luminescent efficiency and dislocation density. This difference is attributed to the thermal expansion coefficients (α). The SiGe virtual substrate has a smaller α, which helps minimize compressive strain in the quantum well during the temperature drop. Consequently, fewer misfit dislocations are created between the quantum well and cladding interfaces. These misfits can greatly affect the luminescence efficiency since they can act as recombination sites. With the SiGe virtual substrate, we were also able to monolithically integrate GaAs-based optical links on Si. The optical link consists of a LED as the emitter and a PIN diode as the detector. A vertical-coupling scheme was utilized to couple devices with the $Al_{0.15}Ga_{0.85}As$ waveguide. With this coupling scheme, no re-growth steps were required. Waveguides of lengths varying from 10 μm to 1 cm were fabricated and exhibited loss of approximately 144 dB/cm. Waveguides of various geometries were also fabricated, including Y-junctions and bends. We have observed a decrease in detector response with increasing waveguide length and Y-junction angle. Despite the early nature of these non-optimized prototypes, these optical links are the first monolithic on-chip optical links fabricated on Si.

H9.35
MID-INFRARED PHOTONIC-CRYSTAL DISTRIBUTED-FEEDBACK LASER WITH ENHANCED SPECTRAL PURITY AND BEAM QUALITY. W.W. Bewley, C.L. Felix, I. Vurgaftman, R.E. Bartolo, J.R. Lindle, J.R. Meyer, Naval Research Laboratory, Washington, DC; H. Lee (now with AOI, Sugar Land, TX) and R.U. Martinelli, Sarnoff Corp., Princeton, NJ.

A gain-guided semiconductor laser patterned with a two-dimensional photonic-crystal distributed-feedback (PCDFB) grating can potentially operate in a single mode to stripes as wide as several hundred μm. The enhancement in the spatial coherence and spectral purity is due to the presence of three distinct diffraction processes, one of which guides the beam down a stripe tilted with respect to the facets [as in an angled-grating distributed-feedback (α-DFB) laser] while the other two provide DFB-like distributed feedback from the counter-propagating beam. The advantages of the PCDFB configuration over the 1D DFB and α-DFB structures are expected to be particularly pronounced in cases where either the linewidth enhancement factor or the internal loss is relatively high, as in current mid-infrared lasers. We report a PCDFB laser with an antimonide type-II "W" active region. Optical lithography and dry etching were used to pattern a second-order rectangular lattice with a tan(20°) aspect ratio and a 20° tilt with respect to the facet normal. The devices were tested using pulsed optical pumping with a Gaussian stripe that had the same tilt as the grating. The PCDFB emission switched between two lasing lines at λ = 4.59 and 4.70 μm as the peak of the gain spectrum was tuned by varying the temperature. The width of the emission line (7-10 nm) was considerably narrower than for Fabry-Perot and α-DFB lasers fabricated from the same wafer. Whereas both PCDFB and α-DFB have diffraction-limited beam quality for a stripe width of 50 μm, the PCDFB exhibits a substantially smaller etendue for wider stripes. For example, at a pump-stripe width of 200 μm the PCDFB beam quality estimated from measured far-field and simulated near-field profiles was 5.9 mm-mr (4 times the diffraction limit), a factor of 5 improvement over the α-DFB laser.

H9.36
SUPER-LUMINESCENCE PROPERTIES OF MID-INFRARED LIGHT EMITTING DIODES FOR GAS DETECTION. A. Krier, V. Sherstnev, Physics Department, Lancaster University, Lancaster, UNITED KINGDOM.

The mid-infrared spectral range contains the strong fundamental molecular absorption bands of a number of combustible and atmospheric pollutant gases. Currently, infrared gas detection techniques based on optical absorption are becoming increasingly popular as they are the only ones which are truly gas specific, and therefore reliable, for gas sensor instrumentation. Consequently, there has been much research into providing suitable monochromatic sources, such that a number of mid-infrared light-emitting diodes (LEDs) operating at different target wavelengths have now been realised. However, non-radiative recombination together with poor optical extraction has so far limited the practical application of mid-infrared LEDs in gas sensor instrumentation. In this work we report on the superluminescence of InAs and InAsSb based light-emitting diodes, operating at 3.3 um and 4.6um, suitable for methane and carbon monoxide gas detection respectively. The sources are mesa-etched LEDs with a ring contact design which produces a circular waveguide due to current crowding effects. An optical whispering gallery (or circulating) mode which is generated near the perimeter of the mesa as the injection level is increased is thought to be responsible for the mid-infrared superluminescence. Surface and edge emission from each of the LEDs at the two different wavelengths was examined and compared. The behaviour of the superluminescence with current and temperature was also investigated. A strong current tuning of the superluminescence emission was obtained at 4K resulting in a blue shift of 180nm. Spectral line narrowing characteristic of superluminescence was readily obtained and the output of these diodes was found to be greater than that of analogous diodes of a non-circular configuration. A pulsed optical output power in excess of 2 mW at room temperature was obtained, making these emitters suitable for use in cost-effective instruments for environmental monitoring.

H9.37
THIRD ORDER MODE OPTICALLY PUMPED SEMI-CONDUCTOR LASER FOR AN INTEGRATED TWIN PHOTON SOURCE IN QUANTUM OPTICS. N.G. Semaltianos, A. De Rossi, V. Berger, B. Vinter, E. Chirlias, V. Ortiz, Thales (ex Thomson-CSF), Laboratoire Central de Recherches, Domaine de Corbeville, Orsay, FRANCE.

One of the main purposes in quantum cryptography or nonlinear optics is to fabricate new semiconductor laser structures in which parametric fluorescence (PF) can be obtained in the same structure used for lasing thus resulting in a highly compact twin photon source. III-V semiconductors and especially GaAs are very interesting materials for waveguided nonlinear frequency conversion due to their highly nonlinear susceptibility and the possibility to integrate quantum well (QW) sources and nonlinear interactions. However they are not birefringent and thus alternative phase matching schemes must be found. In this paper we exploit the scheme of modal phase

matching where by a careful design of a multilayer waveguide in a material grown by molecular beam epitaxy (MBE) the effective indices of two different modes i and j can satisfy the condition: $n_{eff,i}(\omega_p)=n_{eff,j}(\omega_s)$ where ω_p is the pump frequency and $\omega_s=\omega_p/2$ is the frequency of the twin down generated photons. We have designed and grown by MBE a laser sample structure consisting of an AlGaAs QW separated from a carrier generation layer (G) by a barrier layer (B). Theoretical calculations of the refractive index profile of the structure show that due to the B layer the waveguided laser mode is a third order (i=2) at 775 nm and thus efficient phase matched PF towards 1.55 μm photons on the fundamental mode (j=0) can be obtained. By using photoluminescence spectroscopy we have fully characterized this laser structure. We demonstrate stimulated emission from the sample at room temperature upon pumping at 532 nm with a pulsed Nd:YAG laser, with more than 50% efficiency of recombination of the carriers in the QW as compared to the G layer. At low temperatures the population is also first inverted in the QW. Barlike samples were optically pumped transversely and almost 100% of the output radiation was collected with a microscope objective lens. Laser power threshold and peak position were measured versus cavity length and sample temperature. By carefully measuring the far field angular distribution of the laser radiation on the horizontal plane we demonstrate lasing from the sample to be on the third order mode in agreement with the theoretical simulations.

H9.38

ON THE OPTICAL MEMORY OF A THIN-FILM pInSb-nCdTe HETEROJUNCTION OBTAINED BY LASER PULSED DEPOSITION. Arik G. Alexanian, Nikolay S. Aramyan, Arsham S. Yeremyan, Lenrik A. Matevossian, Ashot M. Khachatrian, Inst of Radiophysics & Electronics, Nat. Academy of Science of Armenia, Dept of Semiconductor Electronics, Ashtarak, ARMENIA; Romen P. Grigoryan, Yerevan Physics Institute, Yerevan, ARMENIA.

Thin film pInSb-nCdTe heterojunctions (HJs) were produced using the laser-pulse deposition technique and their photoelectric properties were studied for various thickness of the CdTe layer at nitrogen temperature and under a background radiation the photo-emf for which was around 1.5 mV. At radiative excitation of the HJ a photo-emf is observed, which persists after the excitation is turned off. The optical memory (OM) effect is observed in an idling regime and in a wide spectral range: (0.37-1.37) μm with "recording" (0.37-0.75) μm, (0.75-1.37) μm, and "clearing" (0.575-0.75) μm sub-regions. The maximal OM signal is observed at 0.575 μm while the minimal signal is at 0.768 μm. In the spectral dependence of the OM signal at direct and reverse scanning of monochromatic radiation incident on the HJ an hysteresis is observed which is evident for the OM effect. The temporal dependence of OM signal at 0.575 μm and at various intensities of the radiation source is studied, where an effect of saturation is clearly observed, and the time during which the OM signal reaches up the saturation, depends strongly on the incident light flow power and decreases drastically as it increases. The external bias applied to the HJ enhances the OM on 2 orders over its value in the idling regime. The OM signal persists for a time period no less than 10^5 sec, either with or without the external bias. The actually obtained values of "recording" sensitivity and the "recording" time are 0.66 $\mu J/mm^2$ and 10−4 sec., respectively. As the thickness of CdTe layer increases to the value d=0.45 μm, the OM signal reaches its maximal value. It is shown that the investigated HJ possess the property of integration of the radiation.

H9.39

STOICHIOMETRY CHANGES BY SELECTIVE VACANCY FORMATION ON (110) SURFACES OF III-V SEMICONDUCTORS: INFLUENCE OF ELECTRONIC EFFECTS. Ph. Ebert, U. Semmler, M. Simon, K. Urban, Institut fuer Festkoerperforschung, Forschungszentrum Juelich GmbH, GERMANY.

The extent to which point defects can influence the properties of a semiconductor depends not only on the electronic structure of the defects, but also very sensitively on their concentrations. Therefore, it is highly desirable to determine the factors governing the formation of defects. Although most semiconductor devices are grown under kinetic rather than equilibrium conditions, most works focussed on the thermal equilibrium concentrations of defects rather than on the barrier heights for the formation of defects. We investigated the kinetics of thermal formation of anion vacancies and the subsequent stoichiometry changes on (110) cleavage surfaces of III-V semiconductors by scanning tunneling microscopy. We found that the rate of spontaneous formation of monovacancies depends very sensitively on the doping of the underlying semiconductor and the concentration of surface vacancies. It is shown that the position of the Fermi energy at the surface is the major electronic influence on the energy barrier height for the vacancy formation. We found barrier heights in the range of 1.1 to 1.3 eV for GaAs and InP. The physical factors affecting the vacancy formation and the surface stoichiometry are discussed in detail.

H9.40

QUANTITATIVE SECONDARY ION MASS SPECTROMETRY (SIMS) OF III-V MATERIALS. P. Van Lierde, C. Tian, R. Hockett, Evans Analytical Group, Sunnyvale, CA.

Secondary ion mass spectrometry (SIMS) provides direct methods to characterize the chemical composition of III-V materials at major, minor and trace level concentrations as a function of layer depth[1]. SIMS employs keV primary ions to sputter the surface and sensitive mass spectrometry techniques to mass analyze and detect sputtered secondary ions which are characteristic of the sample composition. In-depth compositional analysis of these materials by SIMS relies on a number of its unique features including: 1.) keV primary ion sputtering yielding nanometer depth resolutions 2.) the use of MCs detection techniques for quantifying major and minor constituents and 3.) ion implant standards for quantifying trace constituents like dopants and impurities. Nanometer depth resolution in SIMS sputtering provides accurate detection of diffusion of dopants, impurities and major constituents. MCs refers to the detection of "molecular" ions of an element (M) and the Cs primary beam. MCs minimizes SIMS matrix effects in analysis for major and minor constituents, thus providing good quantification. This paper will present an extensive SIMS study of $Al_xGa_{1-x}As$ structures with four different x values. MCs (M=Al, Ga) data will be presented for the accurate determination of major and minor components. Rutherford backscattering spectrometry and x-ray diffraction data were cross-correlated with the MCs results. Three specimens with different x values were ion implanted with H, C, O, Mg, Si, Zn and Se to study quantification of trace levels. Where appropriate, SIMS data acquired on a double focusing instrument (CAMECA IMS-4f) and a quadrupole instrument (PHI ADEPT 1010) will be compared. We will also discuss our efforts to improve analysis precision for p and n-type dopants in AlGaAs which currently is ±3% (1 sigma). 1. P.K. Chu in Encyclopedia of Materials Characterization, Eds. C.R. Brundle, C.A. Evans, Jr. and S. Wilson, Butterworth-Heinnemann, Boston, MA. 1992.

H9.41

PREPARATION OF CdS/ZnO CORE/SHELL STRUCTURED NANOMATERIALS BY HYDROTHERMAL METHOD. Ling-Dong Sun, Chun-Hua Yan, Jun Zhang, Chun-Sheng Liao, Peking Univ, Beijing, CHINA.

Nanosized materials have attracted much consideration in recent years because of the unique properties different very much from the corresponding bulks. And nanosized semiconductors have potential applications especially on novel luminescent materials. Many preparation methods have been afforded to improve the quantum efficiency. The most successful method is inorganic shell modification, both anionic and cationic sites, are modified by the inorganic shell layer and the surface traps are removed. The luminescence efficiency also benefits from the shell and the stability is also improved. We reported on the formation of CdS and CdS/ZnO complex nanoparticles by hydrothermal method, which $Cd{-}SCH_2CH(NH_2)COO$- and $Zn(OH)_4{}^{2-}$ are designed as the precursors to produce CdS and ZnO capped CdS nanoparticles effectively by controlling pH and reaction conditions which is easy to process. Compared to CdS nanoparticles, the band-gap emission of CdS/ZnO was greatly improved, that means the capping layer of ZnO modified the nanoparticle surface and reduced the surface defects effectively. Band edge emission increased with pH, and reached its maximum at pH=13, then decreased rapidly. Comparison of XPS of the prepared CdS with the bulk, the appearance of $Cd3d_{5/2}$ at 406.2 eV and S2p at 162.69 eV indicate the formation of CdS. For the CdS/ZnO nanoparticles, the appearance of $Cd3d_{5/2}$ at 404.7 eV, S2p at 160.99 eV, $Zn2p_{3/2}$ at 1021.45 eV and O1s at 530.45 eV confirmed the existence of Cd, S, Zn and O. TEM image indicates spherical particles with diameter of 20 nm and electron diffraction pattern exhibited hexagonal structure of CdS/ZnO. The particle size will increase with the reaction temperature and time, but the structure kept as well. It is difficult to distinguish ZnO because of the thin capping layer and similar structures of Cd^{2+} and Zn^{2+} ions.

H9.42

ENGINEERING OF QUASI-PHASE-MATCHED STRUCTURES IN LITHIUM NIOBATE CRYSTALS. Edvard Kokanyan, Vahan Babajanyan, Gagik Demirkhanyan, Institute for Physical Research National Academy of Sciences of Armenia, Ashtarak, ARMENIA.

Quasi-phase-matched structures with controlled periodicity were engineered in the lithium niobate crystals doped with various rare earth (Er, Nd, Yb) as well as transition metal (Cr, Hf) impurities directly during the growth process by the Czochralski technique. The controlled modulation of 4-50 micron wide domains was possible. The formation of periodic structures were related with rotation induced growth striations during off-centered growth and with an influence of

a periodic electric current applied to the crystal-melt system during the growth process on the effective distribution coefficient of impurities and main components of lithium niobate system. The modulation of domain lengths in the crystal were controlled by the program changes of the values of the pulling rate/rotation rate relation during the off-centered growth as well as the frequency of the periodic electrical current during the growth under the applied electrical field. The obtained crystals were investigated by the scanning electron microscopy and quasi-phase-matching second harmonic generation technique.

H9.43
DEVELOPMENT OF CHROMIUM DOPED II-VI COMPOUNDS FOR IR LASER APPLICATIONS. Vladimir Kasiyan, Zinovi Dashevsky, Stanley Rotman, Roni Shneck, Departments of Material Engineering and Electrical Engineering, Ben-Gurion University of the Negev, Beer Sheva, ISRAEL.

Recently, efficient room temperature lasing in the mid-IR (1.5-3 μm) spectral region has been demonstrated with Cr doped II-VI semiconductors. Strong luminescence in these doped semiconductors originates from internal transitions in the $3d$ orbitals of the transition metal dopants. We present electrical and optical measurements obtained with single crystals of CdSe and ZnSe, doped with chromium from a gas source over a wide temperature range (500-1000°C) and annealed in liquid metals (Cd and Zn). This process offers many possibilities for the variation of impurity and intrinsic defects. The structure determined by X-ray diffraction and Hall mobility demonstrates the low defect concentration of the doped crystals; the mobility in CdSe doped with Cr reaches 9000 cm^2/Vs at 80 K. The impurity absorption coefficient is 10-30 cm^{-1} up to 3 μm which increases with increasing impurity concentration. The states of the Cr ions in both compounds are analyzed based on photoconductivity and luminescence measurements. The analysis enables further optimization of the doped materials for IR laser application.

H9.44
LATERAL WET OXIDATION OF MBE-GROWN SHORT PERIOD AlGaAs SUPERLATTICES. René Todt, Katharine Dovidenko, Alexei Katsnelson, Vadim Tokranov, Michael Yakimov, Serge Oktyabrsky, UAlbany Institute for Materials, State University of New York at Albany, Albany, NY.

Short period superlattices are of great technological importance in MBE growth of optoelectronic device structures: (i) they provide enhanced control over the composition, (ii) digital alloys of a wide variety of compositions can be grown without changing the effusion cell temperatures, and (iii) superlattice structures also grow smoother as compared to alloys. The recently developed lateral wet oxidation technique is an advanced method to form current and optical apertures in vertical-cavity surface-emitting lasers and light-emitting diodes. As the wet oxidation process of AlGaAs depends strongly on the Al composition, a precise control over the composition of the layer to be oxidized is crucial for reproducible oxidations. Therefore, the wet oxidation process of MBE-grown 100 nm thick $AlAs/Al_{0.6}Ga_{0.4}As$ short period superlattices was investigated. The equivalent composition of the studied $Al_xGa_{1-x}As$ superlattices was ranging from x = 0.90 to x = 0.98. The superlattice layers consisted of periods of 1 monolayer of $Al_{0.6}Ga_{0.4}As$ and 3 to 19 monolayers of AlAs, depending on the equivalent composition of the superlattice. Oxidations were carried out at 350°C, 400°C and 450°C in a wet nitrogen atmosphere. We have found that the oxidation rates of digital alloys are higher than those of alloys with the equivalent Al composition and the difference in the oxidation rates depends on the coarseness of the digital alloy. Engineered multilayer structures were used for measuring the refractive index of oxidized digital alloys with an equivalent composition of x = 0.98 and for hydrogen profiling using a ^{15}N-induced nuclear reaction.

H9.45
EFFECT OF Zn-DOPING IN AN ACTIVE LAYER OF InGaAlP LIGHT-EMITTING DIODE INVESTIGATED BY A PHOTO-LUMINESCENCE MEASUREMENT. S. Sigetomi, Dept. of Physics, Kurume Univ., Kurume; A. Fukuyama and Y. Akashi, Dept. of Applied Physics; R. Ohno, Y. Taiji, and T. Ikari, Dept. of Electrical and Electronic Engineering, Miyazaki Univ., Miyazaki, JAPAN.

Since InGaAlP can be structurally lattice matched to GaAs, this is a promising III-V compound semiconductor in light-emitting diodes (LEDs). High-brightness operation from orange to green region was obtained with InAlP cladding layers and distributed Bragg reflectors grown by metal organic chemical-vapor deposition method. But one of the serious problems is that the luminescence efficiency decreases with increasing Zn unexpectedly introduced in the InGaAlP active layer. It is considered that the Zn atom diffused from Zn-doped cladding layer creates not only a shallow acceptor but also a deep defect level at the same time in the active layer. However, details have not been clear yet. The near-infrared photoluminescence (PL) measurements of InGaAlP LEDs with Zn-doped and not intentionally doped $In_{0.5}(Ga_{0.72}Al_{0.28})_{0.5}P$ active layer were carried out from 77 to 297 K to clarify an effect of Zn-doping. Three PL peaks at 2.170 (A), 2.034 (B), and 1.506 (C) eV were observed for the not intentionally doped sample at 84 K. A- and C-peaks are due to band-gap luminescence of active layer and GaAs substrate, respectively. In the Zn-doped sample, the A-peak intensity decreases and another peak at 2.139 eV (D) appears instead of B-peak. This D-peak is considered to be a Zn acceptor in InGaAlP with the activation energy of 40-50 meV. Present experimental results show that Zn atom plays an important role for the luminescence efficiency of the LED (A-peak intensity). It is considered that Zn atom forms a complex deep defect level together with unknown level associated with B-peak, and the formation of such complex decrease the intensity of B-peak by Zn-doping. A decrease of the A-peak intensity can also be explained by considering that Zn complex deep defect level traps a photoexited electron nonradiatively. We propose a model for electron transition pathways in the InGaAlP active layer.

SESSION H10: RADIATION DETECTORS AND EFFECTS

Chairs: Brad D. Weaver and Chennupati Jagadish
Thursday Morning, November 29, 2001
Room 312 (Hynes)

8:30 AM *H10.1
HIGH ENERGY NUCLEAR RADIATION EFFECTS ON GaAs THIN FILMS, QUANTUM WELL INFRARED PHOTO DETECTORS AND QUANTUM WELL LIGHT EMITTING DIODES. S.M. Khanna, Defence Research Establishment Ottawa, Ottawa, ON, CANADA.

Nuclear radiation effects on GaAs epitaxial thin films, quantum infrared photo detectors (QWIP) and quantum well light emitting diodes (QW LED) will be reviewed briefly. MOCVD and MBE GaAs n and p type thin films with doping levels ranging from unintentional doping to 10^{18} cm^{-3} were investigated for radiation effects due to a variety of nuclear particles including protons (1 - 500 MeV), neutrons, electrons, gamma rays, alpha particles, light and heavy ions (up to GeV energy range) with fluence in the range of 10^9 to 10^{16} cm^{-2}. GaAs thin films were studied through optical measurements including low temperature spectral photoluminescence, transport measurements including carrier density, mobility and carrier lifetime and deep level transient spectroscopic studies. Effects of radiation on QWIPs and QW LEDs were examined through measurements of device characteristics, device spectral response and operability, light emission and noise studies. In general, the photoluminescence and transport characteristics of GaAs deteriorated with radiation due to radiation-induced defects. New radiation-induced spectral structures have been identified in GaAs thin film photoluminescence spectra. In general, the radiation effects in GaAs thin films increased with fluence and correlated well with the non-ionizing energy loss (NIEL) component of the incident beam energy over most of the energy range. Based on spectral response, QWIPs were observed to be quite radiation hard and ideal for space applications. QW LEDs were observed to be more radiation susceptible than QWIPs but were harder than conventional diffused GaAs LEDs or double heterostucture LEDs. Degradation of light emission from QW LEDs on irradiation with protons in 1 - 500 MeV energy range will be compared with NIEL component of the incident beam energy.

9:00 AM *H10.2
SPACE RADIATION EFFECTS IN ADVANCED SOLAR CELL MATERIALS AND DEVICES. Robert J. Walters, U.S. Naval Research Laboratory, Washington, DC.

This invited talk will give a brief tutorial on the effects of the space radiation environment on the electrical properties of advanced photovoltaic materials and devices. Solar cells are the basis of nearly all spacecraft power systems. The rapidly burgeoning space market for commercial communications as well as military and scientific applications is driving rapid development of new solar cell technologies to provide increased power. In particular, the concept of mulitjunciton solar cells, where the concept of bandgap engineering is employed by layering several semiconductor junctions in a monolithic stack, has rapidly matured, attaining record, one-sun, air-mass-zero efficiencies close to 30%. However, for these advanced technologies to operate efficiently in space, they must by resistant to the harsh space radiation environment. This presentation will begin with a discussion of the basic mechanisms for radiation damage in solar materials. The talk will then describe the physics of multijunction solar cells and show how these advanced devices respond to radiation exposure. In keeping with the general symposium theme, the presentation will focus on the InGaAs and related material systems.

9:30 AM H10.3
CARRIER RECOMBINATION AND INTRADOT RELAXATION IN InGaAs/GaAs QUANTUM DOT STRUCTURES WITH RADIATION DEFECTS. N.A. Sobolev, A. Cavaco, M.C. Carmo, Dept of Physics, Univ of Aveiro, PORTUGAL; H. Born, A. Hoffmann, R. Heitz, D. Bimberg, Inst of Solid State Physics, Technical Univ, Berlin, GERMANY; M. Grundmann, Inst for Exp Physics II, Univ of Leipzig, GERMANY.

Tunneling of captured charge carriers off the high-lying states in the quantum dots (QDs) to neighboring defects in the barrier material has been considered to cause the absence of the phonon bottleneck in the carrier intradot relaxation [1]. However, the existence of this mechanism has never been proved experimentally. The most obvious way to check it is to vary the defect concentration in a sample and to investigate resulting changes in the time-resolved photoluminescence (TRPL) kinetics. We report a study of the influence of electron and proton irradiation on the TRPL of InGaAs/GaAs QD and QW structures. The TRPL measurements reveal a shortening of the rise and decay times in both the QWs and QDs, but the behavior of both the types of samples is qualitatively different. The transients prior to irradiation can be fitted with single values of the rise and decay time (τ_r and τ_d, respectively). After irradiation, in the QWs the PL kinetics still can be fitted with single (reduced) values of τ_r and τ_d. Both values are reduced obviously due to the shortening of the carrier diffusion length in the barrier and increasing non-radiative recombination in the QW, respectively, caused by the radiation-induced defects. However, in the QD samples the PL decay can only be described by at least two different τ_d values, one being characteristic of the as-grown sample and another (shorter) one that almost does not change with irradiation dose. We tentatively ascribe this shorter PL decay time constant to the capture of carriers confined in the QDs by defects inside or immediately adjacent to the QDs. Since not all QDs in a sample are disturbed by defects, the slow decay component is still observed even after irradiation. Two-beam experiments with variable delay between the beams are in progress.
[1] P.C. Sercel, Phys. Rev. B 51, 14532 (1995).

9:45 AM H10.4
THERMAL ANNEALING EFFECT ON LOCAL VIBRATIONAL MODES OF CARBON-HYDROGEN COMPLEXES IN PROTON IRRADIATED $Al_xGa_{1-x}N$. Jing Chen, Qiaoying Zhou and M.O. Manasreh, Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, NM; M. Pophristic and Ian T. Ferguson, EMCORE Corporation, Somerset, NJ; B.D. Weaver, Naval Research Lab, Washington, DC; Sergei Kucheyev and C. Jagadish, Department of Electronic Materials Engineering, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, AUSTRALIA.

Thermal annealing effects on carbon-hydrogen complexes defects in $Al_xGa_{1-x}N$ thin film grown on sapphire by MOCVD have been investigated using Fourier transform infrared spectroscopy. The carbon-hydrogen complexes in $Al_xGa_{1-x}N$, formed either during growth or by proton irradiation, exhibits five local vibrational modes (LVMs) in the spectral region of 2846-2963 cm^{-1} due to the symmetric and asymmetric vibrational stretching modes of C-H in CH_n (n=1-3) defect complexes. The LVMs were almost thermally depleted after annealing the irradiated un-doped, Si-doped and Mg-doped samples at annealing temperature (T_a) higher than 500°C. A turning point annealing temperature is found around 300°C for un-irradiated Mg-doped sample, below which the total integrated area of the C-H LVMs continued to increase with increasing annealing temperature and reach the maximum value around 300°C. At $T_a >$ 300°C, the total integrated area of the C-H LVMs starts to decrease and the C-H complexes seem to be completely depleted at $T_a >$ 700°C. However, the aging of the sample annealed at $T_a > 500$°C shows obvious recovery of C-H LVMs. The recovery of C-H LVMs in the annealed sample could be due to the fact that hydrogen remains inside the thin film after the dissociation of C-H complexes. These hydrogen atoms diffuse back and recombine again with carbon atom to form C-H complexes. The aging effect is performed in a period of 2-10 days at each temperature above 500°C.

10:30 AM *H10.5
IRRADIATION EFFECTS IN SPACE SOLAR CELLS MADE OF MULTIPLE ABSORBERS. Manuel J. Romero, Mowafak M. Al-Jassim, National Renewable Energy Laboratory, Golden, CO; Robert J. Walters, Scott R. Messenger, Geoffrey P. Summers, Naval Research Laboratory, Washington, DC.

The state-of-the-art communication satellites for global coverage systems are demanding solar cells with higher power density due to the expanding volume of data for transfer and processing. These satellite systems are in orbits in or near the proton radiation belts, which extend from 2,000 to 10,000 km of altitude (MEO: Medium-Earth Orbit). Radiation effects can be very severe in these orbits and high efficiency solar cells with minimal degradation under cosmic particle bombardment are required. III-Vs cells are the most desirable in space photovoltaics due to their superior radiation resistance. The most commonly used approach to high efficiency is the use of multiple III-V absorbers to cover most of the solar spectrum. Indeed, high efficiency space cells based on dual junction $In_{0.51}Ga_{0.49}P$/GaAs and multijunctions $In_{0.51}Ga_{0.49}P$/GaAs/Ge are already in production by several manufacturers. These monolithic cells consist of several single-junctions (SJ) of different spectral sensitivity connected in series. On the other hand, recent efforts have been made to increase the efficiency by the use of quantum wells as intermediate level that absorbs additional lower energy photons. The insertion of a multiple quantum well (MQW) in the depletion of a SJ cell extends the sensitivity of the cell to the solar spectrum. In this work the irradiation effects on these solar cells, made of multiple absorbers, are investigated by beam injection methods. Such characterization techniques are capable of spatially resolving the radiation damage induced in the different absorbers. In multijunction cells, some of the critical issues are the radiation-induced disordering in InGaP which limits the use of order-related band engineering, interconnecting junctions, impurities in the absorbers and buffer-layer engineering when needed. The radiation damage of MQW and their impact on the response of quantum well solar cells (QWSCs) is also studied.

11:00 AM *H10.6
ION IMPLANTATION INDUCED INTERDIFFUSION IN QUANTUM WELLS FOR OPTOELECTRONIC DEVICE INTEGRATION. L. Fu, H.H. Tan, M.I. Cohen and C. Jagadish, Department of Electronic Materials Engineering, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, ACT, AUSTRALIA; L.V. Dao and M. Gal School of Physics, University of New South Wales, Sydney, NSW, AUSTRALIA; Na Li, Ning Li, X. Liu, W. Lu and S.C. Shen, Shanghai Institute of Technical Physics, Chinese Academy of Science, Shanghai, CHINA.

Quantum well intermixing has drawn considerable interest in recent years for integration of optoelectronic devices. Impurity induced disordering and impurity free vacancy disordering have been widely used to modify shape of the quantum wells, in turn their electrical and optical properties. Ion implantation induced intermixing has been used to tune the emission wavelength of quantum wells. In this paper, we will give an overview of issues associated with implantation induced intermixing in GaAs/AlGaAs and InGaAs/AlGaAs quantum wells and apply this technique to tune the emission wavelength of quantum well lasers. Intermixing has been used to tune the detection wavelength of quantum well infrared photodetectors. Combination of implantation induced intermixing and wet oxidation has been used to tune the distributed Bragg reflection resonators.

11:30 AM H10.7
ION BEAM ENHANCED INTERMIXING EFFECTS ON InAs QUANTUM DOTS. Jie Zhu, Myo Thaik and Mengbing Huang, Dept. of Physics, Univ. of Albany-SUNY, Albany, NY.

Self-assembled quantum dots (QDs) have attracted significant attention because of their potential applications in novel optoelectronic devices. In this work, we examined radiation effects induced by ion beams on InAs self-assembled quantum dots. Molecular beam epitaxially grown InAs QD samples with coverage of 1.7-2.4 monolayers were irradiated with 1.0 MeV proton beams to doses between 1e12 and 1e15 /cm^2. Thermal annealing of QD samples was conducted at temperatures of 300-600°C. The structural information as well as the optical properties of QDs were obtained using ion scattering, transmission microscope and photoluminescence (PL) spectroscopy. A redshift in emitted wavelength from the QDs subjected to ion beam radiation was observed to progressively increase with irradiated ion doses. The results are discussed in terms of defect enhanced intermixing between InAs QDs and their hosting crystals.

11:45 AM H10.8
THE INFLUENCE OF ANNEALING TEMPERATURE AND DOPING ON THE RED/NEAR-INFRARED LUMINESCENCE OF ION IMPLANTED SiO_2: nc-Si. David Tetelbaum, Vladimir Burdov, Sergey Trushin, Alexey Mikhailov, Physico-Technical Research Institute of Nizhnii Novgorod State University, Nizhnii Novgorod, RUSSIA; Dmitry Revin, Dariya Gaponova, Institute of Physics for Microstructures, Nizhnii Novgorod, RUSSIA.

The SiO_2: nc-Si produced by Si^+ ion implantation is one of the more promising light-emitting at room temperature materials for the Si-based optoelectronics. The important task is an optimization of the regimes of their production, the clearance of their luminescence mechanisms and the study of the silicon nanocrystal (quantum dot) formation processes. The system was formed by ion implantation of 150 keV Si^+ ions into thermal SiO_2/Si films with subsequent

high-temperature annealing (800 - 1100°C). Previously, we have both experimentally and theoretically investigated the dependence of the formation of Si nanocrystals on the dose and have shown the lack of influence of donor impurity on the radiative transition energies. There have been suggested and experimentally proved the mechanisms of photoluminescence intensity increase at doping by phosphorus, and also the intensity reduction at the implantation of boron. At present, for completeness of the physical description of the rise and the evolution of nanocrystal system, there are carried out the experiments on influence of the annealing temperature on the dose dependence character of photoluminescence spectra. The interesting peculiarity is found out, namely, decrease of the dose at which the highest photoluminescence intensity (i.e. maximal concentration of nano-crystals) is achieved with increase of the annealing temperature. A model based on the consideration of the decomposition of supersaturated solid solution is proposed. The theoretically obtained activation character of the nanocrystal concentration dependence on annealing temperature explains the experimental data. The influence of the annealing temperature on the phosphorus-related change of the photoluminescence intensity is studied too. The theoretical consideration of electron energy spectra and the calculation of corresponding wave functions for quantum dots with arbitrarily placed shallow donor impurity within it is carried out. The real Si band structure and finite height of energy barrier nc-Si/SiO_2 are taken into account. This work is supported by RFBR (grants No. 00-02-17488, No. 01-02-06399, and No. 01-02-06397).

SESSION H11: GROWTH, MATERIALS, AND DOPING

Chairs: Robert M. Biefeld and Jerry M. Olson
Thursday Afternoon, November 29, 2001
Room 312 (Hynes)

1:30 PM *H11.1

GROWTH OF $In_xGa_{1-x}As$ ELO AND BRIDGE LAYERS WITH HIGH INDIUM COMPOSITIONS ON COMPOSITION COVERTED InAs PATTERNED SUBSTRATES. Krishnan Balakrishnan, Susumu Iida, Masashi Kumagawa, Yasuhiro Hayakawa, Research Institute of Electronics, Shizuoka University, Hamamatsu, JAPAN.

$In_xGa_{1-x}As$ semiconductors are used for the fabrication of optoelectronic devices such as detectors, thermo-photo-voltaic cells etc. in the near-IR region. Due to non-availability of lattice matched substrates, it is extremely difficult to grow $In_xGa_{1-x}As$ layers with high In compositions. This problem could be overcome to a great extent by using composition converted InAs substrates. In this study, $In_xGa_{1-x}As$ (x=0.8) layers have been prepared by the composition conversion of InAs substrates and subsequently the ELO and bridge layers have been grown on the composition converted substrates by LPE. Due to this, the problem of lattice mismatch between the substrate and the epilayer was effectively overcome and the process became virtually a homoepitaxial growth. Three different types of (111)B InAs patterned substrates, namely, trenchless substrate, trench substrate and trench substrate with SiN_x film deposition on the trench bottom were used. The composition conversion of InAs substrates was done for 30 min and subsequently InGaAs epilayers were grown. The composition conversion process was found to have taken place deep into the InAs substrate. Ga got incorporated into InAs substrate and the excess In got segregated out. The surface and the cross-section of the composition converted layer were found to be considerably rough by the SEM and AFM observations. The ELO layers grown on these composition converted substrates were relatively smoother. In addition, the EPD was low for the ELO layers. Trench substrates of InAs substrates were employed to grow InGaAs bridge layers. However, clean bridge layers did not form. This was due to very active nucleation from the trench bottom as the composition converted substrates were rough and this promoted nucleation from the trench bottom. The clean bridge layers with low EPD could be successfully formed by using the composition converted InAs trench substrates with SiN_x deposition at the trench bottom. The In compositions of the ELO and bridge layers were found to be uniform by EPMA.

2:00 PM H11.2

PHOTO-ASSISTED MOVPE GROWTH OF ZnMgS ON (100) Si. Angel Rodriguez, Jeremy Shattuck, Xiaoguang Zhang, Peng Li, Faquir Jain, John Ayers, Univ of Connecticut, Dept of Electrical and Computer Science Engineering, Storrs, CT; David Parent, San Jose State Univ, Dept of Electrical Engineering, San Jose, CA.

This paper presentsfor the first time photo-assisted Metalorganic vapor phase epitaxial (MOVPE) growth of ZnMgS on Si (100) substrates. II-VI materials such as ZnCdSe have been used and proposed in the implementation of laser diodes emitting in the red through blue spectrum. An application for this material system includes flat panel displays, which has the advantage of enabling the realization of transistor drivers in the silicon substrate. Another application includes higher efficiency solar cells. The growth was done using dimethylzinc (DMZn), dimethylselenide (DMSe) bismethylcyclo-pentadienyl-magnesium ($(MeCP)_22Mg$), and diethylsulfhide (DES) as zinc, selenium, magnesium, and sulfur precursors. The use of a ZnSe buffer was grown prior to the ZnMgS layer. Epitaxial characterization by X-ray Photoelectron Spectroscopy (XPS), and low - angle X-ray Diffraction (XRD) results are presented. The reactant mole fractions for the ZnMgS layers were 10^{-4} (DMZn), 4 x 10^{-4} (DES) and 1.8 - 7.4 x 10^{-6} ($(MeCP)_2Mg$). Mg incorporation is estimated to vary from 0 to 36 percent. The epitaxial nature of the ZnMgS layers has been verified using the low-angle X-ray diffraction eliminating any interference from the Si substrate. It can be shown with this technique that the change in the ZnMgS peak position changes from 27.35 degrees to 26.5 degrees with an increase in Mg incorporation, compared with a Si control sample peak at 27.4 degrees. XRD results obtained have been verified with XPS data. Chlorine doping of the ZnMgS layer was also studied. Concentrations up to 3 x 10^{15} cm^{-3} were observed in the ZnMgS layer. Results of the n (ZnMgS:Cl) - p (Si) diodes fabricated are also presented.

2:15 PM H11.3

PREPARATION OF β-$FeSi_2$ FILMS BY REACTIVE DEPOSITION EPITAXY. Y. Fukuzawa[a], H.L. Shen[a], S.N. Wang[a], N. Otogawa[a], H. Tanoue[a,b], Y. Makita[a,b], Y. Nakayama[a]; [a]Japan Science and Technology Corporation, (TCI), Tsukuba, Ibaraki, JAPAN; [b]National Institute of Advanced Industrial Science and Technology, Photonics Research Institute, Tsukuba, Ibaraki, JAPAN.

β-$FeSi_2$ is one of the promising materials for applications in the fields of photovoltaics, optoelectronics, and thermoelectrics. Results on high quality β-$FeSi_2$ films have not been reported up to now. With aiming at fabrication of high efficiency, high responsibility and low cost optical detectors for 1.5μm wavelength, we have prepared β-$FeSi_2$ films by reactive deposition epitaxy. Fe layers were deposited on cleaned Si(100) substrates by an iron Knudsen cell in a MBE system at 10^{-9} Torr. The substrate was first kept at 850°C for 20 minutes to remove the native oxide layer at the substrate surface and then at 1000°C for 20 minutes to make the surface atomically flat. During Fe layer deposition, the substrate temperature was changed from room temperature to 900°C. The prepared β-$FeSi_2$ film thickness was about 200nm. XRD spectum measurement demonstrated that β-$FeSi_2$ film starts to form at a substrate temperature of 600°C, 100°C lower than that for deposition without substrate surface flatting. Increasing deposition rate from 0.06nm/s to 0.2nm/s increased the XRD intensity of the β-$FeSi_2$ films, meaning a better expitaxial growth. By annealing at 900°C in the same chamber just for several minutes, those ϵ-FeSi films formed at lower substrate temperatures were found to be transferred into β-$FeSi_2$ films successfully. Scanning electron microscopy observation revealed that high substrate temperature and high deposition rate could produce β-$FeSi_2$ films with large size grains of about 100nm and small grain boundary gaps, which is in good consistence with XRD results. Most importantly, β-$FeSi_2$ films transferred completely from ϵ-FeSi film with grain size of 30nm show grains as large as 300nm with very smooth surface, which is the best β-$FeSi_2$ film result to our knowledge.

2:30 PM H11.4

OPTICAL, VIBRATIONAL, AND STRUCTURAL PROPERTIES OF Ge-Sn ALLOYS GROWN ON Si BY UHV-CVD. Stefan Zollner, N.V. Edwards, Erika Duda, Motorola SPS, Process and Materials Characterization Laboratory, Mesa, AZ; John Tolle, Jennifer Taraci, M.R. McCartney, Jose Menendez, George Wolf, D.J. Smith, John Kouvetakis, Arizona State University, Tempe, AZ.

UHV-CVD growth based on reactions of a newly developed deuterium-stabilized Sn hydride with digermane produces Ge-Sn alloy semiconductors with tunable band gaps and potential applications in infrared optoelectronics. Metastable alloys of Ge-Sn are created on Si and exhibit unprecedented thermal stability and superior crystallinity despite the 17% lattice mismatch between the consituent elements Ge and Sn. The composition, crystal structure, electronic structure, and optical and vibrational properties are characterized by Rutherford backscattering, low-energy secondary ion mass spectrometry, high resolution transmission electron microscopy, x-ray diffraction, as well as Raman, ellipsometry, and infrared spectroscopies. Electron diffraction reveals monocrystalline and perfectly epitaxial layers with lattice constants intermediate to those of Ge and Sn. X-ray diffraction shows well defined (002) and (004) Bragg reflections corresponding to random GeSn alloys, and in-plane rocking curves of the (004) peak indicate a tightly aligned spread of the crystal mosaics. The Raman spectra show bands corresponding to Ge-Ge and Sn-Ge vibrations with frequencies consistent with random tetrahedral alloys. Resonance Raman spectra indicate a E_1 band gap reduction relative to Ge, consistent with a decrease of the E_2 critical point in the dielectric

function seen in spectroscopic ellipsometry. Infrared transmission spectra of the GeSn films on Si indicate an increase of the absorption with increasing Sn content, which is consistent with the expected decrease of the lowest direct band gap.

2:45 PM H11.5
PULSED LASER DEPOSITION AND CHARACTERIZATION OF $Zn_xMn_{1-x}O$ THIN FILMS. C. Jin, T.K. Nath, A. Kvit, D. Kumar, J. Muth, and J. Narayan, Department of Materials Science and Engineering and NSF Center for Advanced Materials and Smart Structures, North Carolina State University, Raleigh, NC.

High quality $Zn_xMn_{1-x}O$ thin films were grown on sapphire (0001) substrate by using pulsed laser deposition technique. This material is the first oxide in the wide materials class of so-called diluted magnetic semiconductors (DMS). The presence of localized magnetic ions in a semiconductor alloy leads to exchange interaction between the sp-band and the d-electrons of the Mn^{2+} that modifies the crystal band structure and semiconductor properties. The films with different Mn content were achieved by using targets with different MnO content varied from 1 to 30 at.%. The optimum substrate temperature for the growth of high quality films was found to be around 600-650°C. The structure of the films was characterized with x-ray diffraction and transmission electron microscope including STEM-Z and EELS techniques. The results show that $Zn_xMn_{1-x}O$ thin films have epitaxial single crystal quality. Strong epitaxial relationship was found to be (0001)ZnMnO ‖ (0001)sap and [01-10] ZnMnO ‖ [-12-10]sap that is a 30° rotation in the basal (0001) plane. The optical absorption spectra measured at room temperature show that the absorption edge shifts to higher energy side and the midgap absorption increases with increasing Mn content. Magnetic property measurements indicated a finite hysteresis in the M-H curves up to 300 K, indicating a ferromagnetic behavior. We present correlations between atomic structure/microstructure, optical and magnetic property measurements.

3:30 PM *H11.6
InP SELF-ASSEMBLED QUANTUM DOTS EMBEDDED IN InAlGaP GROWN BY METALORGANIC CHEMICAL VAPOR DEPOSITION. Russell D. Dupuis[a], Jae-Hyun Ryou[a], C.V. Reddy[b], Venkatesh Narayanamurti[b], David T. Mathes[c], Robert Hull[c], David A. Kellogg[d], Gabriel Walter[d], and Nick Holonyak, Jr.[d], [a]Microelectronics Research Center, The University of Texas at Austin, Austin, TX; [b]Gordon McKay Laboratory of Applied Science, Harvard University, Cambridge, MA; [c]Department of Materials Science and Engineering, The University of Virginia, Charlottesville, VA; [d]Center for Compound Semiconductor Microelectronics, The University of Illinois at Urbana-Champaign, Urbana, IL.

III-phosphide self-assembled quantum dot (SAQD or simply QD) structures offer the potential to realize injection lasers operating in the visible spectral region with improved performance characteristics such as low threshold current density, high characteristic temperature, and high differential gain. Also, SAQD growth can overcome the limitation of lattice matching between the substrate and the epitaxial active region due to the intrinsic nature of the growth mode. InP QDs have been grown and characterized on direct-bandgap In0.49Ga0.51P matrices by several research groups and on indirect-bandgap In0.49Al0.51P matrices by these authors. As expected, the growth characteristics and optical properties are different in these cases. In this study, we report the characteristics of InP SAQDs embedded in InAlGaP grown by low-pressure metalorganic chemical vapor deposition to make a complete bridge between two ternary systems. The InP QD growth studies are performed by altering growth temperatures and times and using various In0.49(AlxGa1-x)0.51P matrices (x=0.0, 0.3, 0.6, and 1.0). The morphology changes of the exposed SAQDs depend on the growth time and the matrix material, and are characterized by atomic force microscopy (AFM). Photoluminescence (PL) spectra were taken at 4K and 300K to determine the light-emitting characteristics of the InP/In0.49(AlxGa1-x)0.51P quantum-dot heterostructures (QDHs). 4K PL spectra from the InP SAQDs embedded in In0.49(AlxGa1-x)0.51P cladding layers exhibit PL emission in the visible orange and red spectral regions. We further study the InP/In0.49(AlxGa1-x)0.51P (x=0.6) SAQDs using ballistic electron emission microscopy (BEEM) techniques to determine the band structure of the dots. Also, transmission electron microscopy is used to characterize the microscopic material quality and morphology of the individual QD and the interfaces between SAQD and cladding layers. Furthermore, we report electrically and optically pumped 300K lasing from InP SAQDs at the shortest wavelength yet reported for III-P QDs.

4:00 PM H11.7
GROWTH DEFECTS IN ZGP CRYSTALS GROWN FROM MELT. G.A. Verozubova, A.I. Gribenyukov, V.V. Korotkova, Inst. for Optical Monitoring, Tomsk, RUSSIA; A.W. Vere, The Crystal Consortium Ltd., Glasgow, UNITED KINGDOM; C.J. Flynn, DERA, Malvern, UNITED KINGDOM.

ZGP is the most interesting material for nonlinear optics in IR region. The main problem to grow transparent uniform ZGP crystals is related to the presence of two readily volatile components, zinc and phosphorus, which easily form binary compounds from the vapor phase. Losses of these components during synthesis and growth result in deviation from stoichiometry and emergence of defects typical for doped crystals. Characterization of growth microscopic defects appearing during ZGP growth by Vertical Bridgman method is a purpose of this contribution. Growth striation and precipitation of second phases were revealed by optical microscopy. Growth striae have periods 5-10 mkm, 60-180 mkm, 250-600 mkm and are related to thermal instability in growth setup. The precipitates are found with higher deviation from stoichiometry. Visible in optical transmitted microscope they are integrated in lineage structures oriented perpendicular to the crystallisation front. The structures can be continuous or discontinuous and occur with concave interface. The precipitate diameter is varied from 5 to 10 mkm. TEM also shows a presence of micron and submicron precipitates. The first type of precipitates is apparently related to deviation from stoichiometry whereas the second one can be attributed to retrograde solidus of homogeneity range. It is found that the precipitates in the structures substantially decrease the optical transmittance due to "shadow" effect. There is a 5-10-fold increase in optical losses in all transparency range. For crystals with a low density of the above defects the optical losses do not exceed 0.1 cm-1 at 2 mkm and 0.05 at 3-8 mkm.

4:15 PM H11.8
EFFECTS OF As DOPING ON PROPERTIES OF ZnO FILMS. K.S. Huh, D.K. Hwang, K.H. Bang, M.K. Hong, D.H. Lee, and J.M. Myoung, Yonsei University, Dept. of Metallurgical Engineering, Seoul, KOREA; M.S. Oh, W.K. Choi, Thin Film Technology Research Center, Korea Institute of Science and Technology, Seoul, KOREA.

ZnO is naturally n-type semiconductor having a direct band gap of 3.37 eV at room temperature and the band gap energy can be controlled to 4 eV by doping impurities into ZnO. Because of optical properties similar or superior to GaN, there has been much interest of applications for short wavelength optical devices such as laser diodes (LDs). But for realization and development of optical devices, the formation of p-type ZnO films with high qualities is essential as well as high quality n-type ZnO films. There has been a large experimental efforts, but only few reports exit about p-type conduction. In this study, we investigated the possibility of p-type ZnO films by As doping. As-doped ZnO films were deposited on (100)-GaAs substrates by rf-magnetron sputtering and GaAs substrates were used as As doping source by diffusion into ZnO films. During the film deposition, the ambient gas pressure($Ar:O_2$=1:1) was maintained at 10 mTorr with substrate temperature of 25-450°C and rf-power of 100-200 W. SIMS profiles corresponding to As in depth distribution carried out and evidenced uniform distribution of As inside the films. This implies As doping by GaAs substrates is a good method for p-type ZnO film synthesis. In order to enhance As diffusion in the films, post annealing process at 500°C was employed for ZnO films grown at 350°C and 450°C. After annealing, the electrical properties of the films changed to a large degree and the quality of the films was improved. The photoluminescence (PL) and cathodoluminescence (CL) spectra were measured, and the observed optical band gap was 3.28 eV. Through CL imaging process, the uniform band edge emission was confirmed. XRD, SEM, AFM studies were also performed to investigate the crystalline properties of the deposited films.

4:30 PM H11.9
GROWTH OF THE SINGLE-CRYSTALLINE ZnO FILMS ON Si (111) SUBSTRATES BY PLASMA-ASSISTED MOLECULAR-BEAM EPITAXY. Mitsuaki Yano, Kazuto Koike, Takanori Tanite, Shigehiko Sasa, Masataka Inoue, Osaka Inst of Technology, Bio Venture Center, New Materials Research Center, Osaka, JAPAN.

We report the single crystal ZnO growth on Si (111) substrates by plasma-assisted molecular beam epitaxy using a CaF_2 buffer layer. Recently, wide and direct band-gap semiconductor ZnO has attracted much attention to the short-wavelength optical device applications. Although high-quality ZnO growth on Si substrates is a key issue to integrate these devices with electronic circuitry, single-crystalline ZnO growth on Si substrates has been difficult due to the inevitable oxidation of substrate surface by impinging oxygen radicals. In order to suppress the surface oxidation, we employed a thin CaF_2 layer as the buffer layer of ZnO growth. In this experiment, Si (111) substrates were chemically etched by a HF solution and cleaned at 800°C by irradiating hydrogen radicals in the growth chamber. Before ZnO growth, a thin CaF_2 layer was covered on the Si surface using the stoichiometric beam from a K-cell. After the subsequent growth of ZnO layer using oxygen radicals and a Zn beam, the samples were characterized by reflection high-energy electron diffraction, atomic

force microscopy, photoluminescence, and x-ray diffraction. The x-ray pole-figure measurement revealed that single-crystalline ZnO (0001) films without any rotational domains in the c-axis orientation were obtained. Other characterization techniques also revealed the superior quality of the ZnO films on Si (111) substrates, suggesting probable device applications of this heterosystem.