SYMPOSIUM B

Progress in Semiconductor Materials IV–Electronic and Optoelectronic Applications

November 29 - December 3, 2004

Chairs

Gail J. Brown
Sensor Materials Branch
AFRL/MLPS
Bldg. 651
3005 Hobson Way
WPAFB, OH 45433-7707
937-255-4474 x-3238

M. O. Manasreh
Dept. of Electrical Engineering
University of Arkansas
Fayetteville, AR 72701
479-575-6053

Claire Gmachl
Dept. of Electrical Engineering
Princeton University
Olden St.
Princeton, NJ 8544
609-258-7489

Robert M. Biefeld
Dept. 01126
Sandia National Laboratories
MS 0601
Albuquerque, NM 87185-0601
505-844-1556

Karl Unterrainer
Institute for Solid State Electronics
Technical University Vienna
Florag. 7
Vienna, A-1040 Austria
43-1-58801-36231

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* Invited paper

SESSION B1: Nanostructures I
Chairs: Omar Manasreh and Jens Tomm
Monday Afternoon, November 29, 2004
Constitution A (Sheraton)

1:30 PM B1.1
Luminescence Properties of InP Quantum Dots Coupled to an InGaP Quantum Well through a Thin InAlGaP Barrier. Russell D. Dupuis[1], Xuebing Zhang[1], Jae-Hyun Ryou[1], Gabriel Walter[2] and Nick Holonyak[2]; [1]School of ECE, Georgia Institute of Technology, Atlanta, Georgia; [2]Electrical Engineering Research Laboratory, Univ. of Illinois at Urbana-Champaign, Urbana, Illinois.

The temperature-dependent cathodoluminescence (CL) properties of (1) InP/InAlGaP QDs coupled with an InGaP QW through a thin InAlGaP barrier, (2) the InP QDs directly in the InGaP well, and (3) a reference sample InP/InAlGaP QDs were studied in our SEM fitted with an Oxford MonoCL system. With an increase in temperature, we found that the CL peak of the reference sample shows a large red shift as compared with the bandgap of InP bulk material. This large red shift is due to (1) the easier thermal activation of carriers out of smaller QDs and (2) the transfer of thermally activated carriers from small QDs to large ones. Within the temperature range studied, this red shift is much larger in DWELL but is much smaller, and in some temperature range, the energy of CL peak is independent on temperature in QW+QD. The larger red shift observed in DWELL is due to the fact that the QW surrounding the QDs helps the transfer of thermally activated carriers from small QDs to large ones. The temperature insensitive emission energy observed in QW+QD is caused by (1) thermalization of hot carriers in QW and (2) nonuniform tensile strain in QW created by the QDs on top of the QW. The growth of these structures will be described and the analysis of the luminescence will be presented.

1:45 PM B1.2
Atomic Force Microscopy and Spectroscopy of Self-assembled InAsSb Quantum Dots Grown on InP Substrates by MOCVD. Yongkun Sin[1], Hyun I. Kim[2] and Yueming Qiu[3]; [1]Electronics and Photonics Laboratory, The Aerospace Corporation, El Segundo, California; [2]Space Materials Laboratory, The Aerospace Corporation, El Segundo, California; [3]Jet Propulsion Laboratory, Pasadena, California.

InAsSb quantum dot (QD) lasers are promising light sources with emission wavelengths beyond 2μm as recently demonstrated. We report the first detailed atomic force microscope (AFM) characterization of both capped and uncapped self-assembled InAsSb quantum dots embedded in $In_{0.53}Ga_{0.47}As$ quantum wells. These quantum dot structures were grown on (100) InP substrates by metal organic chemical vapor deposition (MOCVD). Growth conditions were chosen to maximize photoluminescence intensity and to obtain high output powers from Fabry-Perot lasers with one stack of InAsSb QDs. Conductive AFM was employed to simultaneously study topography, current image, and current-voltage (I-V) characteristics from various $InAs_{1-y}Sb_y$ QDs with y varied between 0 and 0.2. Typical dot density was 4-5x10^{10}/cm^2 and dots were estimated to have a lateral dimension at the base of 40nm and a height of 2-5nm. I-V characteristics measured from individual InAsSb QDs will be compared to those from InAs QDs. Also reported will be electronic properties including the density of states and energy band gaps of InAsSb QDs with different dot sizes and Sb compositions.

2:00 PM B1.3
Quantum-Dot Molecules for Potential Applications in Terahertz Devices. Valeria Gabriela Stoleru[2,1], Debdas Pal[1] and Elias Towe[1]; [1]Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania; [2]Materials Science and Engineering, University of Delaware, Newark, Delaware.

There is a lack of compact and coherent solid-state radiation sources emitting in the Terahertz (THz) region of the electromagnetic spectrum (30-300 μm). These sources would play a key role in a wide range of applications that include remote sensing of chemical and biological agents, infrared counter measures, laser radar, pollution monitoring, molecular and solid-state spectroscopy, and noninvasive medical diagnostics The most common sources within this spectral range are gas lasers with cumbersome designs that consume a great deal of energy, but provide narrow spectral tuning. Terahertz quantum cascade lasers that make use of intraband radiative carrier transitions in quantum wells have already been demonstrated. It has been predicted theoretically that quantum dot-based THz radiation sources would be more efficient. The essential ingredient in quantum dot-based lasers is the predicted increase in electron lifetime at the excited levels due to the sharp atom-like confinement. This condition facilitates the appearance of intraband population inversion. Such radiation sources in the THz range can be created using molecules formed by pairs of coupled quantum dots. We study here the electronic and optical properties of quantum dot molecules in order to identify the necessary conditions for the development of new types of THz injection lasers based on intraband carrier transitions in quantum dot molecules. The properties of artificial quantum-dot molecules have not been extensively studied experimentally up to now. The structures studied in this work are grown by molecular beam epitaxy. Two (In,Ga)As quantum dot layers, separated by a thin GaAs layer form a quantum dot molecule. The energy level splitting in a quantum-dot molecule is a function of the spacer thickness, and varies from 150 meV to a few meV, as shown by our calculations. For quantum dots grown in our laboratory, high-resolution cross-sectional transmission electron microscopy (TEM) analysis shows that a spacer thickness of about 7 nm results in the formation of a quantum-dot molecule with a ground-state splitting energy of 10-12 meV; as a consequence, the photon energy lies in the THz range. We investigate the interband transitions using photoluminescence spectroscopy. The experimentally measured spectra agree with the theoretically calculated ones and prove the presence of symmetrically coupled quantum dots forming the molecule with the appropriate ground state splitting. These studies provide valuable information that is directly useful in achieving a better understanding of the physical effects involved in optical transitions in quantum-dot molecules, and in the development of new THz devices.

2:15 PM B1.4
Intersubband Transitions in In0.3Ga0.7As/GaAs Multiple Quantum Dots of Varying Dot-Sizes. Jie Liang[1], Omar Manasreh[1], Y. C. Chua[1], B. C. Passmore[1], E. A. Decuir[1], Zhiming Wang[2] and G. J. Salamo[2]; [1]Electrical Engineering, University of Arkansas, Fayetteville, Arkansas; [2]Physics, University of Arkansas, Fayetteville, Arkansas.

We investigate the optical absorption spectra of intersubband transitions in In0.3Ga0.7As/GaAs multiple quantum dots grown by molecular beam epitaxy. By varying the number of In0.3Ga0.7As monolayers deposited, a series of samples with varying dot sizes ranging from 10 - 50 monolayers were grown. The optical absorption of intersubband transitions from these samples was studied as a function of the quantum dot size. The quantum dots grown with size less than 15 monolayers or more than 50 monolayers did not yield any observable measurements of intersubband transition. This suggests that there exist a critical upper and lower limit of In0.3Ga0.7As quantum dots for infrared detectors. A wavelength range of 8.60 - 13.70 micron is achieved for structures grown with a range of 15 - 50 monolayers of In0.3Ga0.7As. The theoretical optical absorption line-shape of the intersubband transition was compared to the experimental measurements. We observed that the intersubband transitions of these samples take the form of a Lorentzian. It is noted however that the line-shape of the sample with 15 monolayers of In0.3Ga0.7As is asymmetrical which implies that the intersubband transition is bound to continuum.

2:30 PM *B1.5
(110) Quantum Dots: Growth, Single Dot Luminescence and Cleaved-Edge Alignment. Daniel Wasserman and S.A. Lyon; Electrical Engineering, Princeton University, Princeton, New Jersey.

InAs quantum dot growth has been recently demonstrated on (110) GaAs substrates[1]. Both the growth and characterization of these (110) quantum dots will be discussed. Dots grown on the (110) surface form with extremely low densities (3×10^8 QDs/cm^2), which makes single (110) quantum dots significantly less difficult to access than their (100) counterparts, both optically and electrically. A single-dot, fiber-coupled electroluminescent device was fabricated by standard optical lithography. Electroluminescence data from this device will be discussed, as well as work in progress to improve the device characteristics. Additionally, the ability to grow quantum dots on the (110) surface of GaAs allows for the growth of these nanostructures on the cleaved edges of GaAs samples. The cleaved GaAs samples used in this work incorporated strained InGaAs quantum wells of varying thicknesses and Indium content. Linear alignment of dots over the strained layers on the cleaved edges of these samples has been observed. Variations in dot size and density can be achieved by adjusting the structure of the overgrowth sample as well as the first-growth, cleaved, sample. Dots formed on (110) GaAs, thus, are of significant interest from both a quantum computing and quantum communication standpoint, due to the low density growth mode on (110) wafers and the ability to align these dots on the cleaved edges of first-growth samples, respectively. [1] D. Wasserman and S.A. Lyon, *Formation of self-assembled InAs quantum dots on (110) GaAs substrates*, Appl. Phys. Lett. **83**, p.5050 (2003)

3:30 PM *B1.6
The definition of multiple bandgaps in quantum-dot material by intermixing. Ann Catrina Bryce[1], John H. Marsh[2,1], Dan A. Yanson[2], Olek P. Kowalski[2] and Shin-Sung Kim[1]; [1]Electronics and Electrical Engineering, University of Glasgow, Glasgow, United

Kingdom; [2]Intense Photonics Ltd., Blantyre, United Kingdom.

Recent progress in the intermixing of InGaAs/GaAs quantum dot (QD) material will be presented. Quantum dot intermixing (QDI) allows the tuning of the energy bandgap in selected areas of the wafer or optoelectronic device, thus modifying its emission and absorption properties, in much the same way as in quantum well (QW) material. QDI has recently received increasing interest, as it combines bandgap engineering with the predicted advantages that quantum dots offer, such as low temperature-sensitivity of threshold current, high modulation frequency and low chirp. Dielectric-cap-based techniques, originally developed for QW structures, have been applied to the intermixing of InGaAs/GaAs/AlGaAs QD material with an emission wavelength of 1280 nm. Intermixing was achieved by sputtering a QDI-enhancing cap in some areas, and a QDI-suppressing cap in other areas, followed by a high-temperature anneal cycle. Extremely large bandgap blue-shifts of up to 250 nm have been obtained with an anneal temperature of 800 C. The shifts were measured from the photoluminescence (PL) spectra measured at 77 K. To be of use in many applications, QDI must be able to provide a multiplicity of bandgaps on a single substrate. Multiple bandgaps can be created by varying the thickness of the QDI-enhancing cap, repeating the anneal cycle several times, or varying the coverage density of QDI-enhancing features over that of QDI-suppressing ones. The latter approach, termed selective intermixing in selected areas (SISA), involves the deposition of QDI-enhancing patterns of various area fill factors, which, upon annealing, will cause different degrees of intermixing in the underlying regions. To demonstrate the SISA process in the QD material, patterns containing lines and squares of various sizes (3 - 100 microns) and area fill factors (5% - 95%) were defined. The wafer was then annealed at 725 C for 1 minute. As expected, the observed bandgap shifts increased with the fill factor, with a 5% coverage providing a minimum shift (0 - 10 nm) and 40% a maximum one (120 nm). At fill factors above 40%, the shifts appeared to saturate and even decrease slightly. The effect of the feature size and shape was not very pronounced, with larger features generating somewhat larger shifts. This may be due to the fabrication-related size shrinkage that will have the strongest effect on the fill factor of smaller features. The PL spectra measured from patterns of large-size features (20 microns or more) often had a lopsided shape and broader peak width, which may be attributed to the limited spatial resolution of the measurement probe. In summary, intermixing in InGaAs/GaAs QD material and the suitability of the SISA approach for the generation of a plurality of bandgaps on a single QD substrate has been demonstrated.

4:00 PM B1.7
Optical characterization of hierarchically self-assembled GaAs/AlGaAs quantum dots. Franco Marabelli[1], Armando Rastelli[2], Oliver Schmidt[2], Guillame Beaurin[1], Mario Geddo[3] and Giorgio Guizzetti[1]; [1]CNR-INFM and University of Pavia, Pavia, Italy; [2]Max-Plank-Institut fur Festkorperforschung, Stuttgart, Germany; [3]CNR-INFM Pavia and University of Parma, Parma, Italy.

Recently, a simple method to obtain 3D GaAs/AlGaAs quantum dots (QDs) via multi-step (hierarchical) self-assembly was applied [1]. First we create a template of Stranski-Krastanow (SK) grown InAs/GaAs(001) islands, which are "converted" into nanoholes on a GaAs surface by GaAs-overgrowth followed by in situ etching. Self-assembled nanoholes are then transferred to an AlGaAs surface, filled with GaAs and overgrown with AlGaAs. Because of the absence of sizeable intermixing, the QD morphology is given by the shape of the AlGaAs nanoholes, which we determine by scanning probe microscopy. The good size homogenity of the QDs results in photoluminescence (PL) linewidths as narrow as 11 meV. The optical characterization of a series of samples grown with different size parameters was performed by means of reflectance (R) down to T=15 K, photo- and thermo-reflectance (T>80 K) and by spectroscopic ellipsometry (at RT). Such measurements allow to check thickness and concentration of the barrier layers and to complete the study of the electronic states involved in the emission properties of QDs and Quantum-well (QW) levels. QW states were well identified and their energies and shift with the size parameters well agree with the PL data. The identification of QD states seems less straightforward in R measurements and deserves further investigation. [1] A. Rastelli et al., Phys. Rev. Lett. 92, 166104 (2004)

4:15 PM B1.8
Virtual Fabrication of Small Ga-As/P and In-As/P Clusters with Pre-Designed Electronic Pattern Structure.
Liudmila A. Pozhar[1], Alan T. Yeates[2], Frank Szmulowicz[3] and William C. Mitchel[3]; [1]Chemistry, Western Kentucky University, Bowling Green, Kentucky; [2]Polymer Materials Branch, Materials and Manufacturing Directorate, Air Force Research Lab, Wright-Patterson Air Force Base, Ohio; [3]Sensor Materials Branch, Materials and Manufacturing Directorate, Air Force Research Lab, Wright-Patterson Air Force Base, Ohio.

In various studies to date formation of small atomic clusters and their growth have been modeled numerically at conditions that have not involved any spatial restrictions. As a rule, the stoichiometry of small clusters is chosen to be the same as that of the corresponding bulk material and dangling bonds are tied up with hydrogen or other simpler atoms that may or may not be involved in the process of actual experimental synthesis of such small atomic clusters. The structure of the clusters is obtained by a minimization of the total cluster energy using the density functional theory (DFT), Hartree-Fock (HF), multi-configuration self-consistent field (MCSCF) and similar methods. The data on the cluster structure and stoichiometry so obtained provide an insight into various possibilities that may be realized at some ideal equilibrium conditions in "vacuum", and are very different from those of the corresponding bulk materials. However, they differ even more from those specific to small clusters of the corresponding atoms grown experimentally on surfaces or in confinement. The Nature offers many more options for sub-nanoscale materials design and manipulation of their properties then simply an unrestricted growth. In particular, one can grow atomic clusters in 3D confinement of sub-nanoscale pores and voids of solid membranes (such as precisely characterized pores of several atomic diameters in width specific to alumina and silica membranes), or on surfaces. Nucleation and growth of the small clusters in such cases are dramatically affected by the presence of the environment. Thus, the growth conditions can be manipulated with to obtain small clusters and/or sub-nanoscale heterostructure units and heterostructures with pre-designed electro-optic properties. In this study several pre-designed pyramidal clusters of Ga-As, Ga-P, In-As and In-P atoms are investigated by means of the Hartree-Fock-based, MCSCF method. In some cases the cluster form, stoichiometry and atomic bond lengths are pre-designed to reflect the influence of the growth environment. In other cases the environment is re-created explicitly. These calculations prove that the electronic energy level patterns and the direct optic transition energy can be manipulated to at least an order of magnitude by manipulations with the confinement conditions and stoichiometry of the clusters. For small stable clusters the optical transition energy decreases with an increase in the cluster size. However, this decrease is not "almost linear", as as is the case for the chain organic molecules reported recently. The major parameters defining the effects of the restricted cluster growth on the change in electronic properties include the ratios of the covalent radii of the various atoms in clusters and those of the "environment"/confinement.

4:30 PM B1.9
Thermal Stability of InGaAs Quantum Dots Under Large Temperature Transients. R. Rangarajan, V. C. Elarde and J. J. Coleman; Electrical and Computer Engineering, University of Illinois, Urbana, Illinois.

Photonic devices designed around quantum dots are likely to have a variety of desirable characteristics. However, the growth of quantum dots in the InAs/GaAs materials system is complicated by thermal instability, which can make it difficult to incorporate them into devices. At high temperatures, significant changes can occur in the quantum dot (QD) shape, size and composition, which affect their optical emission properties. Thermal stability is desirable because of the range of temperatures necessary to fabricate optimum photonic devices. We report here studies of the thermal stability of InGaAs quantum dots under large temperature transients, including rapid cooling to room temperature. Common to all samples studied in this work is a base structure, designed to be the lower half of a separate confinement heterostructure (SCH), grown on an n-type, (100) oriented, GaAs substrate using atmospheric pressure metal organic chemical vapor deposition (MOCVD). The base structure is a GaAs buffer layer with a 1μm $Al_{0.74}Ga_{0.26}As$ cladding layer, both grown at 800 C, and a 65 nm GaAs inner barrier layer grown at 625 C. The temperature is ramped down to 500 C for the deposition of the self-assembled dot layer (1.6 monolayers of $In_{0.7}Ga_{0.3}As$). The InGaAs quantum dots are capped with a 15 nm GaAs layer grown at 600 C. The control for this experiment is the base structure above cooled immediately to room temperature and removed from the reactor. For comparison, two other samples are considered. The first is simply allowed to remain at 600 C for 5 minutes. The second is cooled immediately to room temperature where it remains for 10 minutes. The temperature is then rapidly raised to 600 C where the sample remains for 5 minutes. The 5 minute time and 600 C temperature is chosen to correspond to the growth time and temperature for completion of an SCH device. Photoluminescence (PL) spectroscopy and atomic force microscopy (AFM) are used to analyze the effects of the temperature transitions. In this paper, we present data that confirm a remarkable improvement in the stability of quantum dots that have undergone the large temperature excursion to room temperature, as indicated by emission wavelength and linewidth, and physical evidence from AFM measurement. Other data on similar samples that have been subjected to additional heat treatment are outlined. Finally, we speculate on the mechanisms that are important in this process.

4:45 PM B1.10
X-ray Analysis of Strain and Composition in Self-Assembled InAs Nanowires in InAs/GaSb Superlattices. Jianhua Li, Donna W. Stokes, Santoshi L. Ammu and Simon Moss; Physics, University of Houston, Houston, Texas.

We have employed synchrotron x-ray diffraction to characterize the strain and composition in self-assembled InAs nanowire arrays in InAs/GaSb superlattices grown by molecular beam epitaxy on either GaSb (001) or AlSb (001) substrates with InSb interfacial bonds. Model calculations have been performed in order to extract quantitative structural information from the nanowires. We found that in the ordered InAs nanowire arrays, the InAs layers experience biaxial compressive strain rather than expected biaxial tensile strain. We show that this change in the strain state is because of atomic segregation and/or contamination during the growth. We have also measured another set of superlattices grown on InAs (001) templates with GaAs interfacial bonds, in which the InAs layers remain planar. We have determined that the InAs layers in these later samples have larger biaxial strain compared to the previous ones, although planar growth was preserved in them. We attribute these observed phenomena to the interaction between the misfit strain in the bulk layer and that at the interfaces.

SESSION B2: Poster Session
Chairs: Robert Biefeld, Gail Brown, Claire Gmachl, Omar Manasreh and Karl Unterrainer
Monday Evening, November 29, 2004
8:00 PM
Exhibition Hall D (Hynes)

B2.1
Structural and Optical Effects of Capping Layer Material and Growth Rate on the Properties of Self-Assembled InAs Quantum Dot Structures. Gabriel Pierce Agnello, Vadim Tokranov, Michael Yakimov, Matthew Lamberti, Yuegui Zheng and Serge Oktyabrsky; College of Nanoscale Science and Engineering, University at Albany - SUNY, Albany, New York.

In recent years, extensive research efforts on quantum dots (QDs) have lead to significant advances in various device applications including lasers[1], amplifiers and photodetectors. In order to develop nanoengineering methods to control electronic spectrum of self-assembled InAs QDs, we utilized atomic force microscopy (AFM), photoluminescence (PL) and TEM methods to investigate the effects of capping layer growth on the physical/chemical properties as well as the optical/electronic performance of QD device structures. Capping layer material choice (or its absence all together) will directly influence QD dimensions (size, height), and subsequently, will effect emission wavelength. We will report results of lateral size and height as well as QD densities of InAs QDs capped with approximately 2ML (monolayers) of AlAs or GaAs at growth rates of 0.06 ML/s and 0.11 ML/s determined via atomic force microscopy (AFM) analysis. The data will show that QDs capped with either material exhibit a reduced average lateral size as well as height, where these decreases are heavily dependent on growth rate for QDs capped with GaAs. The decrease in QD size is accompanied by an increase in QD density for AlAs capping and a decrease for GaAs capping. The above trends can be attributed to the freezing of the growth surface post AlAs growth which minimizes In redistribution on the growing surface as opposed to in the GaAs system where In loss from the QDs is more pronounced at the growth surface. Our AFM results are complemented by photoluminescence measurements, where the optical properties of capped versus non-capped QDs have been explored and direct correspondence between structural differences induced by capping and the electronic/optical properties of QDs is demonstrated. TEM with multislice image simulation has supported our AFM and PL observations of the intermixing of In with GaAs overlayer and revealed a significant alloying of the InAs wetting layer. 1 V. Tokranov, M. Yakimov, A. Katsnelson, M. Lamberti and S. Oktyabrsky, Enhanced thermal stability of laser diodes with shape-engineered quantum dot medium. Appl. Phys. Lett. 83, 833-5, 2003.

B2.2
Structural characterization of multilayered InGaAs-embedded InGaAs/GaAs quantum-dot structures. Kohki Mukai[1], Atsushi Nishimoto[1], Yoshiaki Nakata[2] and Mitsuru Sugawara[2]; [1]Grad. School of Engineering, Yokohama National University, Yokohama, Kanagawa, Japan; [2]Fujitsu Laboratories Ltd., Atsugi, Kanagawa, Japan.

We have performed structural characterization of multilayered InGaAs-embedded InGaAs/GaAs quantum-dot structures, utilizing high-resolution x-ray diffraction (XRD), transmission electron microscopy (TEM), and photoluminescence (PL) measurements. Samples were grown by molecular beam epitaxy. We prepared four types of samples where the number of quantum-dot layers varied from 1 to 4. The dots were partially buried in strained InGaAs layer for 1.3-um emission, and the dot layers were separated by GaAs spacer layers. The growth condition was common to the growth of multiple dot layers. These samples have the semiconductor laser structure, and the evaluation of the structure was done after p-type layers were removed by chemical etching. Cross-sectional micrograph images of samples were obtained by utilizing dark-field TEM, which is sensitive to composition so that the shape of dot superlattice was clearly observed. We found that the single dot volume in the first layer was nearly 30 % larger than that in other dot layers. Dot density in the first layer was 1.5   1.7 times that in other layers. The interval of dot layers was accurately estimated from the separation of satellite peaks in (004) Bragg reflection measured with four-crystal x-ray monochrometer system, and with the result, absolute dimensions of TEM images were determined. In the XRD spectra, the satellite peaks shift to the substrate peak as the number of dot layer was increased. Taking into account the structure observed by TEM, we performed simulations of the XRD spectra based on the dynamical diffraction theory. We succeeded to estimate composition of quantum dots in the samples. We found that the indium composition of dots in the first-grown dot layer was quite smaller than that in other dot layers while the dot size and composition were almost the same among the second to the fourth dot layers. We examined how the variation in structure appeared in PL spectra. Emission peak energy of both the ground and the first excited states showed blue shift as the number of dot layers was increased. However, the shift was less than 10 meV while the full width at half maximum of the peak was about 30 meV. The ground-state lasing was attained with the samples having multiple dot layers, but not with the sample having a single dot layer. These results indicate that we obtained high gain by multiplying dot layers even when dot size and composition varied among the layers. * This work is supported by the Support Center for Advanced Telecommunications Technology Research Foundation (SCAT).

B2.3
Vertical and in-plane electrical transport in InAs/InP semiconductor nanostructures. Klaus Orian Vicaro[1], Humberto Rodriguez Gutierrez[1], Jose Roberto R. Bortoleto[1], Luis Nieto Gonzalez[1], Antonio Augusto de Godoy von Zuben[1], Peter Alexander Schulz[1], Antonio Carlos Seabra[2] and Monica Alonso Cotta[1]; [1]IFGW, DFA, UNICAMP, Campinas, SP, Brazil; [2]EPUSP, LSI, USP, Sao Paulo, SP, Brazil.

In this work we use conductive atomic force microscopy (C-AFM) and electron-beam litographically-processed devices to investigate the electrical properties of InAs/InP semiconductors wires and dots. Spatially resolved current images and localized I-V curves are obtained with C-AFM technique (in a controlled atmosphere) and provide information about vertical transport across the nanostructure. The processed devices were used in order to access the in-plane conductance of a small assembly of nanostructures. On these devices, fluctuations on I-V curves at $\leq$20K are observed for mesa orientations both parallel and perpendicular to the wires long axis direction. At these low temperatures, the signature of random telegraph signals in the current behavior with time at constant applied voltage is observed. The energy values for the onset of current fluctuations correlate well with threshold voltages and barrier heights obtained from C-AFM I-V curves for individual nanostructures. A transition between conduction via the low dimensional nanostructures to the continuum associated to the wetting layer is observed with increasing temperature. These results suggest transport via hopping through localized states of quantum wires and dots.

B2.4
Structural investigation of InAs/InGaAs/InP nanostructures: origin and stability of nanowires. Luis Nieto Gonzalez[1], Humberto Rodriguez Gutierrez[1], Jose Roberto Bortoleto[1], Rogerio Magalhaes Paniago[2] and Monica Alonso Cotta[1]; [1]IFGW - DFA, UNICAMP, Campinas, SP, Brazil; [2]ICEx - DF, UFMG, Belo Horizonte, MG, Brazil.

Nanostructures of InAs in InGaAs and InP matrixes have received much attention in the last years. In this work we present results on the growth of InAs nanowires on InGaAs lattice-matched to (100) InP by Chemical Beam Epitaxy. InAs growth evolution was monitored in situ by Reflection High Energy Electron Diffraction. The influence of the InGaAs layers on the size and spatial distribution of the InAs NWr's was analyzed using Atomic Force Microscopy and High Resolution Transmission Electron Microscopy (HRTEM). The role of strain fields on stability and nanostructure self-organization was investigated by Grazing Incidence X-ray Diffraction (GIXD). We observed that the nanowire shape anisotropy is preserved for small deviations of the InGaAs lattice parameter with regard to InP (0.15 %), for relatively thick (up to 80nm) InGaAs buffer layers. However, for thicker buffer layers the nanowires are shorter, and a large number

of dots is observed on the surface. (HR)TEM measurements have shown a thicker InAs wetting layer for nanowires grown on InGaAs. The GIXD data shows that the anisotropic strain relaxation occurs for nanowires grown on thin InGaAs layers. However, the relation between the in-plane lattice parameters for the shorter nanowires, grown on thicker layers, is closer to that observed for the dots. These results show that a wire-dot transition analogous to that observed in InAs/InP occurs for InAs grown on InGaAs but the effect of an intrinsic interface anisotropy is stronger for InP than for InGaAs.

B2.5
Low-Frequency Oscillations of Photo-Current in Silicon with Quantum Dots. Eshquvat Ualshevich Arziqulov, Physics, Samarkand State University, Samarkand, Samarkand, Uzbekistan.

At the present time numerous types of instability in semiconductors are known. Particularly, the instabilities of electric current in silicon can be divided into two types. First type is infra-low ($10^{-3}-10$ Hz) oscillations of the current with great amplitude (up to 1 A); second type is oscillations with low amplitude ($10^{-3}\div10^{-7}$A) and with sonic frequency. The observed auto-oscillations are related primarily to presence of impurities in the bulk of semiconductor. Creation of quantum dots (QD) in crystalline semiconductors with use o ion implantation technology has been intensively developed at the latest times. In the current work we present experimental results on study of infra-low-frequency oscillations of photo-current in samples of crystalline silicon with QDs. The silicon samples with QDs consisting of manganese ions (Mn^{3+} and Mn^{4+}) were obtained by the ion implantation method. The implantation of ions was carried out on a polished surface of silicon plates of p-type with specific resistance r=10 Ohm*cm, at the energy of ions 40 keV with the implantation dose 10^{16} ion/cm^2. From these plates we cut the samples with dimensions 5x3x0.3 mm^3 and after that they were subjected to one-hour annealing in argon atmosphere in temperature interval 1000÷1200 0C. After the annealing the samples possessed the specific resistance of n-type of conductivity with r $\tilde{1}$05 Ohm·cm. When studying the volt-ampere characteristic (VAC) of the samples preliminary illuminated by integral light at the temperature T=77 K we observed nonlinear VAC; and after we reached a certain magnitude of electric field we observed spontaneous auto-oscillations of the electric current. At this the amplitude of oscillations approached $\tilde{8}$0 mA, frequency varied from 102 to 10 Hz, and the modulation coefficient approached $99.9\frac{0}{00}$ A mechanism of the observed auto-oscillations can be explained by transitions of types $Mn^{3+} - e^- \rightarrow Mn^{4+}$ or $Mn^{4+} + e^- \rightarrow Mn^{3+}$ under joint influence of temperature, illumination, and electric field.

B2.6
Lithography-free Fabrication of High Index Contrast, Extreme Aspect Ratio Semiconductor Structures. H. Fang[1], D.-J. Won[1], A. Sharan[1], T. Scheidematel[1], B. Jackson[1], Neil F. Baril[1], J. Badding[1], V. Gopalan[1], A. Amezcua[2] and P. Sazio[2]; [1]Materials Research Institute, Pennsylvania State University, University Park, Pennsylvania; [2]Optoelectronics Research Center, University of Southampton, Southampton, United Kingdom.

The miniaturization and integration of photonic devices will form the basis of future optical communications network systems design. To this end, we have recently developed a new technique to grow hundreds of highly ordered semiconductor wires in a silica matrix over extremely long lengths. In this presentation, we will show the optical characterization results of Ge and Si based photonic structures formed by this unique method. All experiments were performed with Spectral Physics Spitfire Regenerate Amplifier and OPA systems providing 130 fs laser pulses at 1.55 μm. Optical guiding, loss measurements, and nonlinear absorptive and refractive optical properties of these structures will be presented using techniques of self-phase modulation, four-wave mixing and transient absorption spectroscopy.

B2.7
Electric Field Enhancement of Dark Current Generation in Detectors. James Philip Lavine, Eastman Kodak Company, Rochester, New York.

The performance of detectors and sensors is degraded by dark current generation, which is due to defects and impurities in the materials. Electric fields enhance the generation from deep levels [1-3]. The calculated enhancements are of the order of 100 and 1000 for iron and gold in silicon, respectively, when the electric field is in the mid-e+05 V/cm range. The activation energy of the generation rate as a function of temperature, decreases from 0.75 to 0.5 eV for an iron-like level and from 0.66 to 0.40 eV for the gold acceptor level in silicon, when the electric field goes from 0.0 to 0.6 MV/cm. Many detectors collect a charge packet before they are read out, and the presence of charge decreases the electric field. Thus, the electric field enhancement varies with time, which may affect the apparent activation energy of the dark current generation. This work explores the electric field enhancement and its signature with temperature. Different expressions for the electric field enhancement are evaluated and the numerical results are compared with the available experimental data.
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B2.8
Longitudinal Modes in InAlGaAs/GaAs High-Power Laser Diodes. Omar Manasreh[1], S. C. Chua[1], Jens W. Tomm[2] and Brandon S. Passmore[1]; [1]Electrical Engineering, University of Arkansas, Fayetteville, Arkansas; [2]Max-Born-Institut, Berlin, Germany.

The emission from bias voltage driven In0.06Al0.08Ga0.86As/Ga0.7Al0.3As edge-emitting diode lasers is measured at 280 K using a high resolution Fourier-transform infrared spectrometer. The L-I characteristic curves show that a threshold current of 1.0 A was needed to reach the stimulated emission. The laser diode longitudinal modes were observed in high-resolution spectra (resolution of 0.05 cm-1). These spectra enable us to calculate the number of the longitudinal modes and the laser cavity length. The cavity length is obtained by taking the fast Fourier-transform of the high-resolution emission spectra. The cavity length obtained from this procedure is in good agreement with the measured cavity length of 0.9 mm

B2.9
Heterostructures with Strained InGaAs Quantum Wells for RCE Photodiode Applications in the 1.8-2μm Spectral Range. Jadwiga Zynek[1], Agata Jasik[1], Jaroslaw Gaca[1], Marek Wojcik[1], Wlodzimierz Strupinski[1], Jaroslaw Rutkowski[2] and Artur Wnuk[1]; [1]Institute of Electronic Materials Technology, Warsaw, Poland; [2]Military University of Technology, Warsaw, Poland.

Conventional photodetectors for the wavelengths longer than 1.7 μm exhibit high dark current densities at the room temperature. The solution providing improvement in the photodetector detectivity by decreasing the dark current, while maintaining the sufficiently high sensitivity, is employing the structure with a thin absorbing layer and a resonant cavity formed by two Bragg mirrors, so called resonant cavity enhanced photodetector (RCE). This concept has been used to fabricate a photodiode for 2 μm, based on InP and containing a thin, pseudomorphic, strained $In_{0.83}Ga_{0.17}As$ absorbing layer [1]. In this paper we present our work on the technology and characterization methods of RCE photodiode heterostructures with strained quantum wells designed for the 1.8 - 2 μm spectral range. The absorption region consists of a single or double quantum well formed by the layer system $InP/In_{0.53}Ga_{0.47}As/In_xGa_{1-x}As/In_{0.53}Ga_{0.47}As/InP$ ($0.65\leq x\leq 0.82$) and is placed inside the depletion region of a p-i-n junction based on InP. The employment of $In_{0.53}Ga_{0.47}As$ barriers enables us to shift the cutoff wavelength toward longer wavelengths. The heterostructures have been grown by LP MOCVD method under various conditions. Step barriers and compositionally graded barriers with composition gradient within a few monolayers have been obtained. Quantum wells of non-resonant structures have been investigated by spectral photoluminescence measurements, TEM image observations, high-resolution X-ray diffraction measurements with synchrotron source. Composition profiles have been determined by comparison of measured diffraction profiles with computed ones. This analysis has shown us how the growth conditions had influenced the composition profiles. After photodiode processing dark current densities below 10^{-6} A/cm^2 and quantum efficiencies above 1 % (even without bias) have been obtained. Quantum efficiency values achieved in our experiments are a good basis for the resonant cavity enhancement. They give evidence to an efficient collection of photogenerated carriers. Predispositions of epitaxial heterostructures with the resonant cavity to the RCE detection at a designed wavelength have been examined on wafers before processing using photoluminescence and reflectivity spectra measurements. The resonant cavity back mirror is made of $In_{0.53}Ga_{0.47}As/InP$ quarter-wave layer stack and the cavity front mirror, for the purposes of these measurements, is the native air/InP interface. When PL and reflectivity spectra have indicated that the resonance has occurred at longer wavelength than it had been designed, the resonance wavelength has been tuned by recess etching. Changes in the reflectivity spectrum and an enhancement of the PL intensity at the resonant wavelength have been monitored during successive etching.
1. S. Jourba et al., Proc. SPIE, v.3629, 307-318 (1999).

B2.10
Good Temperature Performances of 870nm Resonant-Cavity Light Emitting Diode (RCLED). Lih-Wen Laih[1], Rong-Mu Hong[1], Yi-Hao Wu[1], Yu-Hsiang Huang[1], Li-Hong Laih[2] and Jung-Lung Yu[2]; [1]Electronic Engineering, Ching Yun University, Jung-Li, Taiwan; [2]R&D Production, Millennium Communication Co.,

Ltd. No. 5-1, Kuan Fu S. Rd., Hsinchu, Taiwan.

IrDaA is a standard defined by IrDA consortium (Infrared Data Association). It specifies a way to wirelessly transfer data via infrared radiation. Primary use for IrDA is to link notebooks or various personal communicatators. However, even video cameras are equiped with an IrDA interface. IrDa devices communicate using 870nm IR-LED. Many CCD cameras are sensitive to this wavelength, too. In conventional 870nm LED, the maximun transmission rate is less than 50Mbps. In this paper, a higher transmission rate and good temperature performance of 870nm resonant cavity light emitting diode (RCLED) is investigated. The operation temperature is varied from 25 to 85 °C. The good temperature performance is caused by the offset of cavity resonance and optical gain. When the operature temperature increases, both the cavity resonance and optical gain shift to longer wavelength owing to the refractive index and bandgap temperature dependence, respectively. However, the optical shifts to longer wavelength faster than the cavity resonance, causing spectral misalignment betwen the cavity resonance and peak gain. An optimun offset of 10nm is used to obtain the good temperature performance. The device grown by metal-organic chemical vapor deposition (MOCVD) is consisted of n-distributed Bragg reflector (DBR), active region, p-DBR and ohmic contact layer. A high differential gain material of InGaAs/GaAs MQW is employed to obtain the high light output characteristics. The operation principle of RCLED is the light, which generated from the active region, resonated by the upper and downer DBR and emitting from the surface. By designing and simulation, the main reflected wavelength is design at 870nm. The DBR is consisted of high and low refractive index materials, which contain thickness of 1/4 wavelength, respectively. The high refractive index material is Al0.12Ga0.88As and low refractive index material is Al0.92Ga0.08As. In summary, two kinds of 870nm RCLEDs were investigated to obtain the optimum temperature performance. A 870nm RCLED with gain offset of 10nm shows the best temperature performance for IrDA applications.

B2.11

Electrical Measurement of Non-Radiative Recombination Lifetime in Blue Light Emitting Diodes. Roger Nana, Michael A. Awaah and Kalyan Kumar Das; Department of Electrical Engineering, Tuskegee University, Tuskegee, Alabama.

Gallium nitride based high intensity blue and ultraviolet light emitting diodes (LEDs) are being studied extensively by a number of research groups. These devices are normally fabricated in AlGaN/GaN/AlGaN or AlGaN/InGaN/AlGaN heteroepitaxial films grown either on sapphire or 6H SiC substrates. Operation of these LEDs is apparently insensitive to the high level of defects present in the material used for their fabrication. Understanding and control of the recombination processes in the devices are important for achieving improvements in the efficiency of operation. The non-radiative processes are expected to take place with the participation of deep-level states arising from crystallographic defects or contaminants present in the active region of the LEDs. Most of the reported studies in this area are based on optical measurement techniques. The present study involves the use of a simple electrical technique for the determination of recombination lifetime from injected carrier storage-time measurements. Current-voltage (I-V) and capacitance-voltage (C-V) measurements were also employed for a complete characterization and simulation of the diode structure. Approximate concentrations of deep-level states were extracted both from the I-V and C-V measurements. In order to determine the reverse recovery storage times the LEDs were driven with a rectangular signal with an amplitude of 6.0 V and a dc offset of 6 mV. Transition from forward to reverse bias state was obtained using a current-ramp switching. The ramp-rate was adjusted such that the magnitude of the maximum reverse current during the reverse recovery was the same as the magnitude of the forward current. Under these conditions the recombination lifetime, τ_r is given by 1.25t_s, where t_s is the observed storage time. A representative value for the recombination was obtained as 25 ns. The observed weak dependence of the capacitance on low biases was considered to be due to the presence of a high concentration of deep states in the active region of the diode. A concentration of 2×10^{17} cm^{-3} was estimated from the difference between the measured capacitance at a bias approaching 0 V, and the extrapolated capacitance for a linearly graded junction at the same bias. These diodes were highly non-ideal with ideality factor ranging from 3 to 8, indicating that the recombination process cannot be described by the Shockley-Read-Hall recombination statistics. However, logarithmic plots of the forward characteristics indicated space-charge limited current conduction through the active region of the diodes in the presence of deep-level states with an estimated concentration of 2×10^{17} cm^{-3} corresponding to states located 530 meV above the valence bandedge. These deep-level states introduce non-radiative recombination centers which that are expected to reduce the efficiency of the LEDs by effectively competing with radiative recombination paths.

B2.12

Impurity Dominant Layer Disordering of AlGaInP/GaInP Multi-Quantum Well Laser Diodes. Yong Bum Kwon[1], In Woo Kim[1], Jae Mok Yi[1], Chong Cook Kim[1] and Jung Ho Je[1]; [1]POSTECH, Pohang, South Korea; [2]SIFCOM UMR CNRS-ENSICAEN, Caen, France.

AlGaInP/GaInP multi-quantum well (MQW) systems with wide direct band gaps have been used for LDs and LEDs in the red to green light regions. Intermixing between the layers in the MQW superstructure is one of the important issues in LD devices. Various factors such as impurity induced layer disordering (IILD), vacancy enhanced disordering (VED) or thermal disordering (TD) are known to induce the intermixing of layers during the post-growing process of current blocking layer. In this study we investigated the layer disordering by comparatively studying the Zn doped and un-doped AlGaInP/GaInP MQW samples using synchrotron X-ray scattering and secondary ion mass spectroscopy (SIMS). From the GaAs[11l] scattering profiles, we observed no intermixing in as-grown samples. However, at an annealing temperature of 640°C, the intermixing occurred for Zn doped MQW, but not for un-doped MQW. These results suggest that the layer disordering is caused by IILD, not by VED or TD. SIMS results also support the disordering by IILD.

B2.13

Si integrated $BaTiO_3$electro-optic modulators. Il-Doo Kim, Ytshak Avrahami, Luciano Socci, Francisco Lopez-Royo and Harry L. Tuller; Microphotonics Center, MIT, Cambridge, Massachusetts.

$BaTiO_3$ (BT) has attracted a great deal of attention in recent years for its electro-optic (E-O) and piezo-electric properties. Its large E-O coefficient, for example, could enable the fabrication of highly miniaturized optical modulators for fiber optic based data transmission systems. The buffer layer between Si and $BaTiO_3$ plays a major role in determining the quality of the film and its optical properties. Films of $BaTiO_3$ were grown on MgO single crystal substrates using PLD (Pulsed Laser Deposition) and RF sputtering. Both approaches were able to achieve the highly preferred (001) orientation. Waveguides were formed by e-beam lithography using HSQ resist material. The measured propagation loss of $BaTiO_3$ ridge waveguides was 3 5 dB/cm in TE polarization. Measured electrooptic coefficients were approximately 100 pm/V, three times larger than the electrooptic coefficient r_{33} = 30.8 pm/V of single crystal $LiNbO_3$. $BaTiO_3$ films were also grown onto Si by PLD and sputtering. A variety of buffer layers, including MgO grown by Molecular Beam Epitaxy (MBE), were essential for achieving high quality $BaTiO_3$ films. Sputtered and PLD $BaTiO_3$ thin films on MgO buffered Si substrates also showed the highly preferred (001) orientation with surface roughness of less than 5.3 nm. The waveguide and electro-optic properties of $BaTiO_3$ films on optically buffered Si substrates will be reported and compared to results obtained on MgO single crystal substrates.

B2.14

Application of Low Temperature InP Wafer Bonding Towards Optical Add/Drop Multiplexer Realization. Arokiaraj Jesudoss, Vicknesh Sahmuganathan and Ramam Akkipeddi; Institute of Material Research and Engg., Singapore, Singapore.

A low temperature process for wafer bonding of InP to InP has been realized. In our approach a specific chemical cleaning and plasma treatment has enabled the wafers to adhere together at room temperature. A further higher temperature (220oC) treatment with pressure aids in the completion of the wafer bonding process. The method developed would attract much interest in various fields such as optical MEMS, III-V photonics, optical add/drop multiplexers (OADMs) and photonic band-gap crystals (PBGs). Our particular interest is in the development of OADMs using this low temperature wafer fusion process. A typical OADM structure consists of four ports each isolated from each other, with an overlap region at a particular junction [1]. Since the structure consists of all epitaxial layers with different compositions, this overlap region can be achieved by adopting wafer bonding process. Hence a strong need arises to develop a robust low temperature process for such an application. Initial results on the low temperature wafer fusion process are reported. The InP samples were cut from 2inch InP <100> wafers for the bonding experiments. The size of the samples used for bonding was 20mmX20mm. The samples underwent a thorough cleaning cycle comprising of acetone, methanol, DI rinse and HF etch. Latter the samples were subjected to an oxygen plasma for 2 minutes, with RIE and ICP at 200W and 500W respectively. The base pressure was maintained at 12mTorr. The samples were immersed in HF and brought together without exposing the sample to air. After removing from the HF bath the samples were left in the clean bench for further bonding. The bonding was carried out in a Karl Suss Bonder system with temperature in the range between 220 to 250 oC for 30 minutes

with the application of pressure (80N). After the bonding, the samples remained sandwiched and withstood the cleaving process. A more robust treatment was given to the samples by subjecting to ultrasonic agitation. This treatment indicated that the samples still adhered to each other by strong bonds between the interfaces. TEM micrograph of the bonded interface revealed the uniformity and smoothness of the interface. Clear evidence of the crystallographic orientation of the two InP wafers along the bonded interface was observed. In addition micro-Raman scattering (RS) for the first time was used to investigate the cleaved bonded interface. The cleaved surfaces were (110) and hence exhibited vibrational properties. The Raman spectrum showed signals corresponding to first-order and second-order disorder-activated surface phonons, which are signatures corresponding to clean semiconductor surfaces [2]. The results of the detailed investigations will be presented. References: [1] M. Raburn, B. Liu, Y. Okuno and J.E. Bowers., IEEE Photonics Technology Letters, Vol. 13, No.6, 2001 [2] K. Hinrichs, A., Schierhorn, P. Haier, E. Esser, W. Richter and J. Sahm., Physical Review Letters., 79,no.6, 1997

B2.15

Enhancement of Device Performance Using Stress Inducing HARP Dielectric Oxides. Nitin K. Ingle[1], Zheng Yuan[1], Reza Arghavani[1], Vikash Banthia[1], Cary Ching[1], Paul Gee[1], Klas Lilja[2], Shankar Venkataraman[1] and Ellie Yieh[1]; [1]Applied Materials, Santa Clara, California; [2]Mixed Technology Associates, Palo Alto, California.

Transistor scaling and the introduction of new materials may not be sufficient in satisfying device performance requirements following Moore's Law. Previous work has already been shown that device performance can be significantly enhanced by engineering strain in the channel region either by using SiGe technology or the deposition of a stress inducing nitride layer post silicidation. Development of an innovative new product, High Aspect Ratio Process (HARP^{tm}), to deposit dielectric oxides using TEOS-Ozone chemistry, now enables us to tune localized stresses in the channel region. In this work, we show that localized stresses can be induced using HARP oxide for shallow trench isolation and as pre-metal dielectric. These stresses lead to improvements in device performance. We also report on a new mechanism of stress magnification in the channel region via deposition of HARP oxide in the STI trench followed by an appropriate anneal step. Moreover, HARP technology enables STI and PMD gap-fill without voids and seams for aggressive geometries of sub-65nm design rules.

B2.16

Imaging the Evolution of GaAsN Film Growth.
N. G. Rudawski, X. Weng, H. A. McKay and R. S. Goldman; Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan.

GaAsN and GaInAsN alloys with a few percent nitrogen have potential applications in infrared laser diodes, high efficiency solar cells, and other electronic devices. However, as-grown materials often exhibit poor photoluminescence efficiencies and lower than expected carrier concentrations and mobilities. A few studies have suggested that control of N incorporation via ex-situ annealing or superlattice growth may lead to improved optical and electronic properties. In this work, we are exploring in-situ approaches to controlling the incorporation of N during the growth of GaAsN films. Therefore, we are using $in-situ$ scanning tunneling microscopy to image the evolution of GaAsN films grown by solid-source molecular beam epitaxy using a 10%N2/90%Ar or pure N_2 radio frequency plasma source, with As_2 or As_4, and a variety of substrate temperatures and As/Ga ratios. For GaAsN films grown at 580°C, isolated GaAsN domains are observed to nucleate on flat regions between [1-10] elongated holes on the GaAs surface. A nearly continuous layer is observed for 0.3 nm thick GaAsN films. Interestingly, 3% lattice dilation relative to GaAs is observed for 0.1-0.3 nm thick GaAsN films, suggesting significant incorporation of interstitial N in the earliest stages of growth. In the case of GaAsN films grown at 400°C, larger GaAsN islands are observed to nucleate on flat regions on the GaAs surface. In this case, 3% lattice contraction relative to GaAs is observed, consistent with significant substitutional incorporation of N. These results suggest that substitutional N incorporation is maximized for lower growth temperatures, consistent with recent ion-beam-studies of GaAsN films [1]. In addition, GaAsN films grown at lower temperatures exhibit among the highest room temperature electron mobilities in GaAsN reported to date [2]. Similar studies of GaInAsN film growth will also be presented. This work was supported in part by NSF, DOE, AFOSR, and TRW. [1] M. Reason, H.A. McKay, W. Ye, S. Hanson, R.S. Goldman, and V. Rotberg, submitted (2004). [2] H.A. McKay, M. Reason, X. Weng, B. Nickles, and R.S. Goldman, unpublished (2004).

B2.17

Raman scattering in InGaAsN/GaAs single quantum wells. Omar Manasreh[1], P. A. Grandt[1], A. E. Griffith[1], D. J. Friedman[2], S. Dogan[3] and D. Johnstone[3]; [1]Electrical Engineering, University of Arkansas, Fayetteville, Arkansas; [2]National Renewable Energy Laboratory, Golden, Colorado; [3]Department of Electrical Engineering, Virginia Commonwealth University, Richmond, Virginia.

Longitudinal optical phonon-plasmon coupled (LOPPC) mode can exist in polar semiconductor materials, which can be detected by Raman scattering technique. The LOPPC mode is investigated in a series of modulation Si-doped InGaAsN/GaN single quantum well samples. The doping level is on the order of mid-10î8cm-̂3. The Raman spectra were analyzed by fitting them with the dielectric contant function that containes both the phonons and plasmon contributions. The electrons concnetrations (n) and drift mobilities were extracted from the plasmon frequency (wp) and damping rate (g) rate, respectively. An empirical expression for the electron concentrationis determined as [n] {2.35x10î6(wm - 502)}cm-̂3, where wm is the peak of the upper frequency branch, L+, of the LOPPC mode measured in unit of cm-1. The mobility values were determined to be in the range of (70-250) cm2̂/(V.s), while the relaxation time (g-̂1) is found to be in the range of (2.0-9.0)x10-̂15s for all tested samples.

B2.18

Short-Period Strain-balanced $Ga_{1-x}As_xN$/InAs(N) Superlattices Lattice-matched to InP(001): a new material for 0.45-0.6 eV mid IR applications. Lekhnath Bhusal[1,2], Andenet Alemu[1] and Alex Freundlich[1]; [1]Texas Center for Superconductivity and Advanced Materials, University of Houston, Houston, Texas; [2]Physics department, University of Houston, Houston, Texas.

Recently, low nitrogen content InGaAsN and GaAsN alloys have attracted much attention for their unusual fundamental features as well as for their potential application in optoelectronics operating in the mid-infrared (1.6-2.0 microns) window. One of the most important consequences of N alloying of GaAs is a large red shift of band gap of the novel alloys. The bandgap can be further red shifted by tensilely straining a thin layer of GaAsN, provided the thickness of the layer is less than the critical thickness to avoid defects. In this work we have undertaken a theoretical investigation of the electronic structure of short period superlattices, composed of alternate ultra-thin layers of $Ga_{1-x}As_xN$ (biaxially tensile) and InAs (biaxially compressive) strained to InP (001) and a preliminary experimental data on the fabrication of these structures by chemical beam epitaxy (CBE) has been initiated. The theoretical study was limited to low practically achievable nitrogen (x<0.05) containing materials. Variation of band offsets between $Ga_{1-x}As_xN$/InAs for various nitrogen compositions was ventured in detail and its modification for different N contents were calculated for various valence and conduction sub-bands. Heavy holes and light holes are found to be in type-I and type-II band alignment configuration respectively over the range of the compositions of interest. A transfer matrix method under the envelope function approximation has been used to determine the transition energy from hole sub-bands to electron sub-bands in $(GaAsN)_n/(InAs)_m$ short period (where n,m<5 represent the number of monolayers (ML)) superlattices strained to InP (k_x=k_y=0). The study predicts the evolution of the electron and hole miniband levels and associated miniband widths for various thickness (1ML-5ML) and composition combinations. The transmission probability calculation of this new material system lattice matched to InP indicates the potential to obtain photon absorption/emission at energies in the 0.45-0.6 eV range and stressing the potential of the approach for mid IR applications. Finally preliminary experimental data on the development of these strain balanced heterostructures by RF plasma assisted CBE will be presented at the meeting.

B2.19

On the optical properties of Er and Yb-related emission in Yb co-implanted $Al_{0.70}Ga_{0.30}As$:Er. Tomoyuki Arai and Shin-ichiro Uekusa; Electrical and Electronic Engineering, Meiji University, Kawasaki, Kanagawa, Japan.

Erbium (Er)-doped semiconductors are of much interest as an Application of optical emitting device at 1.54 μm, 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 poor luminescence intensity and the rapid thermal quenching property of the Er-related emission of energy transition from the host semiconductor to intra-4f-shell of Er ions. So far, Er ions were co-implanted with impurities (Carbon, Oxygen, Nitrogen) into $Al_{0.70}Ga_{0.30}As$ substrates; we have realized the increase in intensity of Er intra-4f-shell luminescence. These substrates were grown un-doped $Al_{0.70}Ga_{0.30}As$ layer on GaAs (100) by Molecular Beam Epitaxy (MBE). In this work, we studied the transfer energy and the optical sensitization of $Al_{0.70}Ga_{0.30}As$:Er substrate with co-implanted Ytterbium (Yb) ions and studied the defect using PAS (Positron Annihilation Spectroscopy). Er implantation was carried out at 1MeV

with doses of 1 x 10^{13} cm^{-2} at RT. Yb^{3+} ions were co-implanted at energy of 1MeV with doses of 3 x 10^{12} cm^{-2}. After implanting the ions, these samples were thermal annealed at temperature of 800 °C for 10min by the face-to-face technique in hydrogen atmosphere. The influence of the introduction of Yb^{3+} ions on Er^{3+} luminescence in $Al_{0.70}Ga_{0.30}As$ was studied, using photoluminescence (PL), photoluminescence excitation (PLE) and selective photoluminescence (SPL) techniques. Co-implanted Yb^{3+} enhanced PL intensity of Er-related emission. Er-related main peak (1538.2 nm), in addition to Yb^{3+} dose, was enhanced approximately two times. The energy transfers from $^2F_{5/2}$ (the first excited state) $^2F_{7/2}$ (the grand excited state) of Yb^{3+} to $^4I_{11/2}$ (the second excited state) $^4I_{15/2}$ (the grand excited state) and $^4I_{15/2}$ (the first excited state) $^4I_{15/2}$ of Er^{3+} was observed. We report systematically the experimental results of PL, PLE, SPL and PAS.

B2.20

Annealing Effects of ZnO Nanorods on DC Inorganic Electroluminescent Device Characteristics. Shinya Sasaki, Hiroshi Miyashita, Takashi Kimpara, Tomomasa Satoh and Takashi Hirate; Electrical, Electronics and Information Engineering, Kanagawa University, Yokohama, Japan.

Recently, various microstructures of ZnO such as nanowire, nanorod, nanobelt, nanowall, etc. have been fabricated by vapor-liquid-solid (VLS) method, vapor-phase method, metal organic chemical vapor deposition, sol-gel process and so on. Our previous study has demonstrated that ZnO nanorods are highly promising materials as a buffer layer of inorganic electroluminescence (EL) devices that operate stably under DC voltage driving. The device structure is ITO/ZnS:Mn/ZnO nanorods/p-Si(111). In this paper we report on the annealing effects of ZnO nanorods on the device characteristics. ZnO nanorods was fabricated on a p-Si(111) substrate by a chemical vapor deposition combined with laser ablation to dope an impurity of Mn into ZnO. Metal Zn vapor and O_2 are used as precursors to synthesize a ZnO nanorods and N_2 is used as carrier gas. A Mn target was set near a substrate in a deposition chamber and ablated by a pulsed Nd:YAG laser beam (wavelength =1.064 μm, pulse width = 8 ns, frequency of laser = 10 shots/sec, energy = 0.12 J/shot) during growth of ZnO nanorods. Growth conditions were as follows. Growth temperature was 600 °C. Growth pressure was 40 Pa. O_2 flow rate was 1.5 SCCM. The laser-irradiated area was 0.13 mm^2 on the Mn target. Growth time was 15 min. ZnO nanorods with a flat tip were successfully grown. The height and diameter of ZnO nanorods was about 2 μm and 100 nm respectively. After the growth of ZnO nanorods, the substrate with ZnO nanorods was annealed at 400 °C in O_2 atmosphere. And then a ZnS:Mn layer of 1 μm in thickness was deposited on the ZnO nanorods layer by an electron beam deposition using a sintered composite material of ZnS and MnS as a source. ITO electrode of 2 mm in diameter was finally electron-beam-deposited. Mn concentration in ZnS:Mn films was analyzed by EDX and is about 0.5 at.%. DC current - voltage measurement was performed in positive voltages applied to a ITO electrode. The result of the device without annealing has showed a current density of 1.1 A/cm^2 at 200 V and the breakdown voltage of 300 V. The EL emission could not be obtained. On the other hand, the device with annealing has exhibited the higher impedance, the higher breakdown voltage(650 V), and the EL emission from the ZnS:Mn layer. The current density at 200 V was 3.9×10^{-2} A/cm^2. The EL emission from the inside of the ITO electrode was poor even at near the breakdown voltage. As to the edge area, however, the threshold voltage of the EL emission was 80 V, and the increase of the voltage has lead to the bright EL emission, for example, 30 cd/m^2 at 200 V and 250 cd/m^2 at 400 V.

B2.21

Zinc oxide quantum dot formation using low energy ion implantation. Iulia C. Muntele[1], Bopha Chhay[2], Paul Thevenard[2], Claudiu I. Muntele[1] and Daryush Ila[1]; [1]Physics, Alabama A&M University, Normal, Alabama; [2]Physics, Claude Bernard University, Lyon, France.

We used low energy zinc and oxygen co-implantation into silicon dioxide substrates followed by high-energy ion bombardment or thermal annealing for producing zinc oxide quantum dots. The implantation conditions were chosen such that the final distribution of zinc and oxygen had a constant concentration profile starting from the surface to a depth of 20 nm. The stoichiometry and depth distribution of zinc and oxygen were verified using Rutherford Backscattering Spectrometry (RBS). Optical measurements (optical absorption, FTIR, Raman, and fluorescence) were employed to characterize the bandgap and crystalline structure of the formed quantum dots during every step of the fabrication process. Using AFM surface scanning we observed a more refined structure than after thermal annealing.

B2.22

Fabrication of ZnO Coated ZnS:Mn2+ Nanoparticles. Shinji Ishizaki, Yusuke Kusakari and Masakazu Kobayashi; Laboratory for Material Science and Technology, Waseda University, Shinjuku Tokyo, Japan.

In recent years, the concern over doped semiconductor nanoparticles has been increased due to their unique optical properties and potential applications. Among those doped nanoparticles, ZnS:Mn2+ was widely focused, and fabricated using various methods. The coating of those doped-nanoparticles by various materials could result in the improvement of the optical property. In this study, ZnO coated ZnS:Mn2+ nanoparticles were fabricated and optical properties were evaluated. The fabrication of ZnS:Mn2+ nanoparticles was achieved using a physical milling method. The physical milling method would exhibit a great advantage in the simplicity of the fabrication method and the capability in the mass production. A planetary micro mill method was used in this study to break down the starting material (ZnS:Mn2+, powder, 6N purity) soaked in the solvent. X-ray powder diffraction (XRD) showed that the crystal structure was not affected by the milling while the diffraction peak broadening was observed. The average particle size estimated using the Debye-Scherrer equation could be lowered to about 9 nm by tuning the milling condition. Transmission electron microscope (TEM) was used to confirm the size distribution of nanoparticles, and well dispersed particles whose average size was similar to that obtained by the XRD measurement were clearly observed. The degrees of the dispersion as well as the mean size of the nanoparticles were varied by changing the solvent during the milling. A zinc compound and an alcohol were mixed under the existence of ZnS:Mn2+ nanoparticles to establish the core/shell structure. The core/shell structure was confirmed by the 2 dimensional mapping of the transmission electron microscope energy dispersive X-ray (TEM-EDX). The mapping image of Zn and oxygen from the nanoparticle were about 10 nm larger than that of sulfur. These result indicated that the thickness of the shell was about 5 nm. The UV-LED (400 nm) was irradiated to the solvent including the nanoparticles. The bright orange color luminescence originated from the Mn2+ was observed. The enhancement of the PL intensity was confirmed from the ZnS:Mn2+/ZnO core/shell nanoparticles. Various nanoparticles including CdSe and SrS were prepared by various methods. The improvements of the optical properties were observed from most of the core/shell structures. In conclusion, ZnO coating of ZnS:Mn2+ nanoparticles were performed, and optical properties were improved by the coating. This study was supported in part by Waseda University Open Research Center Projects, Waseda University Grant for Special Research Projects (Individual Research).

B2.23

Defect Structures in Undoped and Doped ZnO Films Studied by Solid State Diffusion. Haruki Ryoken[2,1], Isao Sakaguchi[1], Takeshi Ohgaki[1], Naoki Ohashi[1] and Hajime Haneda[1,2]; [1]National Institute for Materials Science, Tsukuba, Japan; [2]Kyusyu University, Fukuoka, Japan.

Zinc oxide is a candidate material for transparent electronics as well as short wavelength light emitting devices. For those applications controlling of defect structures is of great importance. For example, on the use of UV detectors, passivation of active defect is necessary to improve signal/noise (S/N) ratio of the sensor performance. Particularly, understanding and controlling of deep levels must be achieved. In order to elucidate the behavior of deep levels, solid state tracer diffusion is one of the appropriate way for detection and characterization of deep levels. Indeed, neutral deep donors are not active under ground state and are not detectable by electric characterization. In this study, we analyzed tracer diffusion behavior in ZnO thin films to understand defect structures in ZnO. The samples were prepared by pulse laser deposition technique. To modify defect concentration and structures, the films were prepared with various growth conditions. For example, we applied oxygen radical source to modify oxygen stoichiometry in the growing ZnO films. We examined ZnO single crystals of ZnO as well as sapphire. Diffusion behavior was investigated with tracer diffusion method using isotope oxygen with mass 18. Exchange reaction was induced by heating samples in 18-oxygen atmosphere. To reveal cation diffusion process, we also used cobalt, aluminum and magnesium as tracer to evaluate cation diffusion. The result of diffusion analyses indicated that oxygen radical irradiation made significant influence on defect structures in ZnO films prepared on sapphire substrate, while oxygen radical irradiation cause no significant change in defect structures for the films homoepitaxially grown on ZnO single crystalline substrate. Regarding cation diffusion, anomalous diffusion behavior was observed in both films and bulk ZnO crystals. Diffusion behavior of cations could not be explained by ordinary diffusion theories. This indicate that diffusion process of cations in ZnO includes defect reaction, such as association and dissociation of defects and diffusion associate propagation of internal strain.

B2.24

Defect Structures in ZnO Causing Visible Luminescence.
Naoki Ohashi[1], Yuguang Wang[3,1], Takashi Sekiguchi[1], Haruki Ryoken[2,1], Hiroyuki Taguchi[1], Takeshi Ohgaki[1], Takamasa Ishigaki[1] and Hajime Haneda[1,2]; [1]National Institute for Materials Science, Tsukuba, Japan; [2]Kyusyu University, Fukuoka, Japan; [3]JSPS, Tokyo, Japan.

Visible emission of ZnO is of great importance for cathodoluminescence applications as well as understanding of the defect structures in ZnO. In this study, we investigated blue-green, green and yellow luminescence of ZnO by preparation of ZnO bulk and films and characterizing their luminescence and electronic properties. Particularly, we used high power pulse laser to induce nonlinear effect in photoluminescence spectra. Hydrogen plasma treatment was applied to modify electronic state of defects by adding electron injected by hydrogen. Moreover, density functional theory was applied for prediction of local coordination structure and electronic state of defects in ZnO. It was clearly demonstrated that there are two kinds of green luminescence; they are blue-green luminescence of ZnO:Zn phosphor and green luminescence of ZnO doped with trivalent impurities. It was also indicated that the presence of deep donors, e.g., a donor level at 0.3 eV blow the conduction band, played an important role for the appearance of both blue-green and green emission by means of photoluminescence excitation measurements and PL under strong excitation. We assigned green emission of IIIa doped ZnO as D-A pair emission using zinc vacancy site, while the blue-green emission was suppressed by doping with acceptors. The result of DFT calculation will be presented at the conference site. This study was partly supported by NEDO, Japan and Futaba electronics memorial foundation, Japan.

B2.25

Electrical Properties of ZnO Thin Films Deposited by Pulsed Laser Deposition. Silvia P. Heluani[1], Gabriela Simonelli[1], Manuel Villafuerte[1], Gabriel Juarez[1], Alan Tirpak[2] and Gabriel Braunstein[2]; [1]Laboratorio de Fisica del Solido, Fac. de Ciencias Exactas y Tenologia, Universidad Nacional de Tucuman, Tucuman, Argentina; [2]Department of Physics, University of Central Florida, FL32816, Orlando, Florida.

Structural and electronic transport properties of polycrystalline ZnO thin films, prepared by pulsed laser deposition, have been investigated. The films were deposited on glass and Si_3N_4Si using O_2 and N_2 atmospheres. X-ray analysis of the films deposited on Si_3N_4Si revealed a c-axes orientation perpendicular to the substrate surface, in all cases. Hall effect and conductivity measurements revealed different electronic transport properties depending on the gas atmosphere used during deposition and the relative pressure of the gas. The ZnO deposited under relatively low O_2 pressure was n-type with resistivity $\sim 10^{-3}\Omega cm$, sheet resistance $\sim 170\Omega/square$, mobility $\sim 5cm^2/Vs$ and sheet Carrier Concentration $\sim 7 \cdot 10^{15}cm^{-2}$(all at room temperature). Films deposited under relatively high O_2 pressure were highly resistive. However, the resistivity decreased upon irradiation with ultraviolet light. The ZnO film deposited in N_2 atmosphere exhibited resistivity $\sim 1\ \Omega cm$, sheet resistance $\sim 4 \cdot 10^4\Omega/square$, mobility $\sim 10cm^2/Vs$ and sheet Carrier Concentration $\sim 5 \cdot 10^{12}cm^{-2}$ (all at room temperature). The carrier type of this sample could not be determined unambiguously. The variation of the resistivity with temperature (in the temperature range of 9-277K) in this last sample followed a Mott's law dependence, characteristic of variable range hopping in a disordered material. Similar temperature dependence of the resistivity were observed in other (prepared under different conditions and less conductive) samples irradiated with ultraviolet light. A detailed analysis of the experimental results, in terms of possible doping and compensation effects, as well as conduction mechanisms, will be presented.

B2.26

Growth and Characterization of ZnO Nanonails. Heewon Seo[1], Dake Wang[1], Yonhua Tzeng[2], Chin-Che Tin[1], Michael Bozack[1], John Williams[1] and Minseo Park[1]; [1]Department of Physics, Auburn University, Auburn, Alabama; [2]Department of Electrical and Computer Engineering, Auburn University, Auburn, Alabama.

Zinc oxide (ZnO) is an interesting material for short-wavelength optoelectronics due to its wide band gap. The nanostructures of ZnO are also intriguing since a variety of morphology can be obtained by employing a different processing parameter. In our laboratory, ZnO nanonails were successfully synthesized using thermal chemical vapor deposition. The morphology of the sample was studied using scanning electron microscopy. The shape of the nail head can be controlled from hexagon to quasi-circular shape. Numerical simulation and analytical calculation shows that the optical field confined in the head of the nanonail cavity exhibits unique characteristics. It also showed that the optical characteristics of the nanonails are strongly dependent on the shape and size of the nail head. These results indicate that a novel nanophotonic device can be fabricated by engineering the shape and size of the nail head. X-ray diffraction pattern, Raman spectra, and photoluminescence spectra of these materials will be presented. Optical characteristics of the nanonails as a function of the head shape are being investigated.

B2.27

Synthesis and Characterization of ZnO Nanoparticles.
Isi Umolu Abhulimen[1], Xiang-Bai Chen[2], John L. Morrison[2], Vijaya Kumar Rangari[3], Leah Bergman[2] and Kalyan Kumar Das[1]; [1]Department of Electrical Engineering, Tuskegee University, Tuskegee, Alabama; [2]Department of Physics, University of Idaho, Moscow, Idaho; [3]Center for Advanced Materials, Tuskegee University, Tuskegee, Alabama.

Zinc oxide, a semiconductor with a wide and direct band gap of 3.37 eV, is of great interest as an optoelectronic material (1). Study of ZnO nanoparticles are of particular interest since these particles exhibit chemical, physical and electrical properties not representative of the molecular or the bulk forms. In this paper, we report the application of a novel technique for the synthesis of ZnO nanoparticles and characteristics of the material produced. Nanoparticles of ZnO were synthesized using a sonochemical technique. Sonochemistry arises from an acoustic cavitation phenomenon, that is, the formation, growth and implosive collapse of bubbles in a liquid medim (2). The synthesis of ZnO nanoparticles were carried out as follows: 1g of zinc(II)acetate dihydrate (Aldrich 98+%), was dissolved in a mixture of 12.5 mL of N,N-dimethylformamide(DMF) and 112.5 mL of deionized distilled water in 125 mL round bottom flask.. This reaction mixture was irradiated with a high-intensity ultrasonic horn (Ti-horn, 20kHz, 100 W/cm^2) at room temperature for 3 hr. The product obtained was washed thoroughly with doubly distilled water and finally with absolute ethanol. Samples for scanning electronic microscopy (SEM) examination and ultraviolet photoluminescence (PL) were prepared from a suspension of the product in absolute ethanol. One drop of the ZnO suspension was used to spin-coat (speed of 1000 rpm) RCA cleaned sapphire substrates. The substrate was then dried by placing on a hotplate at a temperature of 96-100° C for 1min. This procedure was repeated 15 times. The samples were then studied using an SEM and PL. Roughly spherical particles of 160 nm in diameter and also agglomeration of particles were observed. The ultraviolet photoluminescence (PL) studies of the samples showed a strong PL intensity and a significant blue shift relative to the PL of the bulk. Shifts up to 170 meV were observed and attributed to a confinement effect. From model calculations the average particle size corresponding to the observed shift was found to be 4 nm. Additionally the linewidth of the PL of the nanoclusters was found to be of the order of 154 meV which is much broader in comparison to the bulk value of 66 meV. The large linewidth observed for these clusters will be discussed in terms of the size distribution and impurity broadening. (1) Q. Wan, K. Yu, T.H. Wang, C. Lin, Appl. Phys. Lett., 83, 2253 (2003). (2) R. Vijaya Kumar, Y. Diamant, and A. Gedanken, Chem. Mater., 12, 2301 (2000).

B2.28

Study of localized vibrational modes in 3d transition metal doped ZnO Ceramics and thin films. Neha Awasthi, Pijush Bhattacharya, B. Sundarakannan and Ram S. Katiyar; Physics, Univ of Puerto Rico, San Juan, Puerto Rico.

Semiconductors doped with transition metal elements are extensively investigated for their potential in dilute magnetic semiconductor (DMS) application. It has been experimentally demonstrated that the 3d transition metal atoms are soluble up to several mole fraction(0.35) in ZnO host, which made it a promising candidate for fabrication of DMS with high Curie temperature. Localized vibrational modes (LVM) were observed due to impurity doping such as N, Ga Sn, along with ZnO modes. The origin of these LVM is under investigation. In this study, LVM of V, Co and Mn doped ZnO ceramics, which were prepared using conventional ceramic processing. Thin films were fabricated on c-Al_2O_3 substrate using pulsed laser deposition technique and ceramic targets. The dopant concentration was varied between 1 to 10 mole percent in the targets. The substrate temperature was varied in the range of 700-800^{0}C with an oxygen partial pressure of 1 mTorr. The hexagonal structure of ZnO was retained with the transition metal doping as observed from the x-ray diffraction measurements. Raman spectroscopy showed LVM due to transition doping in ceramic and thin films. Raman scattering in V doped ZnO shows sharp and strong vibrational modes at 377.1 cm^{-1} 395.8 cm^{-1}, 438.2 cm^{-1}, 788.2 cm^{-1}, 808.3 cm^{-1} and 850.9 cm^{-1}. In the case of Co doped ZnO, these were observed at 464.9 cm^{-1} and 523.1 cm^{-1}; along with a lower wave number shift of modes at 202.4 cm^{-1} and 332.4 cm^{-1}. The intensity of these LVM increased with the increase in the dopant concentrations. The temperature variation of these localized vibrational modes will be presented and the origin of these local vibrational modes will be correlated with Photolumiscence

(PL) spectroscopy of the transition metal-doped ZnO ceramics and thin films.

B2.29
Intersubband Transition in GaN/AlGaN Multi Quantum Wells. Omar Manasreh[1], Eric A. Decuir[1], Y. C. Chua[1], B. S. Passmore[1], Jie Liang[1], Jinqiao Xie[2], Hadis Morkoc[2], A. Payne[3] and J. Ferguson[3]; [1]Electrical Engineering, University of Arkansas, Fayetteville, Arkansas; [2]Department of Electrical Engineering, Virginia Commonwealth University, Richmond, Virginia; [3]Department of Electrical Engineering, Georgia Institute of Technology, Richmond, Georgia.

Intersubband transitions (ISTs) in GaN/AlGaN Multi Quantum Wells (MQW) were investigated using an optical absorption technique. Several samples were grown by either Molecular Beam Epitaxy or Metal-Organic Chemical Vapor Deposition and were investigated using normal incidence, Brewster angle, and waveguide configurations. The waveguides were made by dicing each sample into 2 mm wide by 5 mm long pieces with two facets polished at 45 degrees such that the light propagates across its width. Preliminary results indicate that ISTs are observable in both Si-doped and undoped GaN/AlGaN MQWs. The source of charge carriers that undergo the ISTs in the undoped samples are explained as being due to the spontaneous polarization effect which exist in GaN/AlGaN heterojunctions. Scanning Electron Microscopy was used to scan the surface of several samples that either possessed or lacked ISTs. It was observed, at least in one case, that a sample with a large density of dislocations lacked the presence of ISTs. It was also noted that a sample containing a large density of voids also lacked ISTs. On the other hand, ISTs are observed in samples with lower dislocation densities.

B2.30
Performance and Reliability of AlGaN-based Deep Ultraviolet Lamps. Yuriy Bilenko[1], Jianping Zhang[1], Xuhong Hu[1], Alex Lunev[1], Jianyu Deng[1], Remis Gaska[1], Michael Shur[2] and Asif Khan[3]; [1]Sensor Electronic Technology, Columbia, South Carolina; [2]Rensselaer Polytechnic Institute, Troy, New York; [3]Department of Electrical Engineering, University of South Carolina, Columbia, South Carolina.

Existing and potential applications of deep ultraviolet LEDs such as biological agents detection, water and air sterilization and purification require both sufficient UV output power and device reliability. In this paper, we report on the performance and reliability of deep UV lamps (UVTOP) based on addressable 2x2 flip-chipped LED arrays mounted on TO-39 headers. The devices containing high quality AlGaN layers up to 70% of Al and emitting in the spectral range from 365 nm down to below 250 nm have been fabricated. The shortest wavelength measured to date was 247 nm, which is below 254 nm line of low-pressure mercury lamps. The devices exhibited large (more than two orders of magnitude) drop in output power with the wavelength decrease from 365 nm to 247 nm and few times reduction in the lifetime at the same current densities. The CW output power of 2x2 LED array lamps at 25 A/cm2 current density decreased from 1.2 mW for 340 nm lamps to 0.120 mW for 280 nm lamps. The lifetime of the lamps at these current densities decreased from 800 hours to 300 hours for 340 nm and 280 nm lamps, respectively. We performed detailed studies of the lamps under CW bias for up to 350 hours. The most dramatic changes in the output power fluctuations at room temperature were observed during the first 20-30 hours of operation, especially for shorter wavelength devices.

B2.31
Abstract Withdrawn

B2.32
Electrical and Dielectric Behavior of Pb(Mg1/4Ni1/4W1/2)O3 Ceramics. Adolfo Junior Franco, Matematica e Fisica, Universidade Catolica de Goias, Goiania-GO, Goias, Brazil.

In this study polycrystalline samples of Pb(Mg1/4Ni1/4W1/2)O3 have been prepared by a solid-state reaction in two routes: (1) starting materials been commercial powders and (2) powders obtained by combustion reaction of liquid solution of metallic nitrides and urea. X-ray data showed the formation of single-phase compound for both routes. Scanning electron microscopy (SEM) was used to evaluate the microstructures of sintered specimens. Dielectric constant and loss of both specimens as function of temperature at 10 kHz was investigated.

B2.33
Preparation and luminescent properties of SrS:Ce by addition of sulphur and co-activator in SrSO_4:Ce(SO_4).7H_2O by carbothermal reduction. P. Thiyagarajan[1,2], M. Kottaisamy[2], K. Sethupathi[1] and M.S.R. Rao[1,2,3]; [1]Department of Physics, IIT Madras, Chennai, India; [2]Materials Science Research Centre, IIT Madras, Chennai, India; [3]Department of Physics, University of Maryland, College Park, Maryland.

An efficient blue green emitting SrS:Ce has been prepared from SrSO4:Ce(SO4)2.4H2O by ecologically acceptable carbothermal reduction in the absence of hazardous H2S and CS2 environments. We have studied various factors like sulfur compensation, charge compensation and sulfur-charge compensation on the luminescent properties of SrS:Ce. For charge compensation, NH4Cl and NaCl were used. The material synthesized was characterized by XRD, Photoluminescence (PL) emission and excitation spectra, SEM and thermo gravimetric analysis (TGA). The feasibility of reduction reaction from SrSO4 to SrS prepared at 900oC for 5 h, was confirmed by X-ray diffraction study. The PL emission spectra show broad bright blue-green emission peaked at 483 and 540 nm corresponding to energy bands originating from 2T2g (5d) to 2F7/2, 2F5/2(4f) transitions at the fundamental absorption of host crystal lattice and Ce excitation. In order to study the enhancement of PL emission intensity, sulphur with various concentrations ranging from 0 to 30 mol% was used. These additions increase the PL emission intensity due to the doping of more cerium and the green emission at 540 nm is enhanced with respect to sulphur. Addition of sulphur enhances more Ce doping leading to a shift in the Ce3+ emission from blue to green. However, the addition of Sulfur along with Ammonium chloride and NaCl decreases the green emission intensity at 540 nm and enhances the blue emission at 483 nm upto 50% compared with the SrS:Ce prepared without any external addition of Sulfur and NH4Cl. The phosphor formed in the presence of sulphur was found to show an improved PL intensity. This is due to the removal of defects in the host lattice and perfect doping of Ce by complete reduction of Ce4+ to Ce3+ which leads to more radiative transition. The addition of NH4Cl without sulphur dramatically increases the PL intensity leading to a reduction in the effective positive charge created by Ce3+ ion substituted at the Sr2+ site. However, the combination of sulphur and NH4Cl suppresses the green emission at 540 nm and enhances the blue emission at 483 nm. This blue emission enhancement may be due to the increase in the crystal field symmetry. * also, at the Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD 20740, USA

B2.34
Properties of SnOX Films on Pet Substrate Prepared by Electron Cyclotron Resonance Metal Organic Chemical Vapor Deposition. Joong-Kee Lee, Bup-Ju Jeon and Yun-Seok Kim; Eco-Nano Research Center, KIST, Seoul, South Korea.

In general, transparent conducting oxide(TCO) films show 80% of optical transmittance in visible light region and about 2x10-4 ohm-cm of electrical resistivity when deposited on glass substrate under the optimized temperature conditions during the sputtering or post annealing treatment. Recently room temperature TCO deposition has attracted much attention in conductive electrodes in plastic thin film solar cells, flexible electronic devices and flat panel display. TCO in the form of thin films on a plastic substrate gives many advantages compared with those deposited on glass substrate due to lighter weight, smaller volume, lower cost and flexibility. For many of these applications, preparation of TCO film by use of a plastic substrate at low temperature, especially at room temperature, is limited due to its low thermal resistance and high thermal expansion. Recently we found that chemical vapor deposition at ambient temperature using organometallic precursors should be possible with the ECR(Electron Cyclotron Resonance) plasma The high efficiency in exciting the reactants in an ECR plasma allows the deposition of metallic oxide film at ambient temperature without thermal activation. The aim of this work was to test the ECR-MOCVD method for deposition at room temperature and to characterize the films prepared thereby. We also report the results of experiments designed to investigate the deposition of SnOx films from tetra-methyl tin(TMT) as a tin precursor in an Ar-O2-H2 atmosphere by using ECR microwave plasma. The structural and chemical analyses of the SnOx films were carried out and their electrical resistances and optical transmittance in a visible region were determined as a function of process parameters such as O2/TMT mole ratio, microwave power, magnet current, working pressure and deposition time.

SESSION B3: Nanostructures II
Chairs: Gregg Salamo and Daniel Wasserman
Tuesday Morning, November 30, 2004
Constitution A (Sheraton)

8:30 AM *B3.1
T-shaped quantum wire lasers with high uniformity. Hidefumi Akiyama, ISSP, University of Tokyo, Chiba, Japan.

High-quality T-shaped quantum-wire (T-wire) lasers are fabricated by cleaved-edge overgrowth with the molecular beam epitaxy on the

interface improved by a growth-interrupt high-temperature anneal [1]. We achieved ground state lasing in single-quantum-wire lasers (T < 60K) [2,3] as well as 20-quantum-wire lasers (T < 120K) [4] by optical pumping. The wires tend to lase in a single mode at energy with a relatively small shift. Lasing threshold of T-wires was lower than that of quantum wells formed in the same samples. Near field pattern of the T-wire laser shows a very good circular shape [5]. Micro-photoluminescence (PL) and PL excitation (PLE) spectroscopy at 4K reveals unprecedented high quality of the wires, and structures of one-dimensional (1-D) free excitons and 1-D continuum states [6]. Transmission experiments have shown that modal absorption at 1D exciton peak at 4 K is fairly large (90/cm for a single T-wire) [7]. At high pumping levels, PL at 4K evolves from a sharp free exciton peak to a red-shifted PL band with symmetric broadening. The lasing energy is about 5 meV below the free exciton, and is on the red-shifted broad PL band. The evolution of this PL band suggests formation of Coulomb-correlated electron-hole plasma [3,4]. Recent measurements of gain spectra via the Cassidy's method (a modified method of the Hakki-Paoli method) strongly support this assignment [8]. It is concluded that origin of the laser gain is the 1D electron-hole plasma with strong Coulomb correlations. Additional experiment of PL and PLE spectroscopy for a modulation-doped single quantum wire with a gate to tune 1-D electron density [9] has shown various features (charged excitons, band-gap renormalization, Fermi edge singularity, and so on) to be related to many-body optical response of 1D carriers. All experimental results on doped and undoped T-wires seems to indicate importance of Coulomb interactions among carriers. [1] M. Yoshita et al., JJAP 40, L252 (2001); APL 81, 49 (2002); J. W. Oh et al., APL 82, 1709 (2003). [2] Y. Hayamizu et al., APL 81, 4937 (2002). [3] M. Yoshita et al., ICPS2004. [4] H. Akiyama et al., PRB 67, 041302(R) (2003). [5] Y. Takahashi et al., APL 83, 4089 (2003). [6] H. Itoh et al., APL 83, 2043 (2003); H. Akiyama et al., APL 82, 379 (2003). [7] Y. Takahashi et al., QELS2004. [8] Y. Hayamizu et al., ICPS2004. [9] T. Ihara et al., ICPS2004; H. Akiyama et al., SSC 122, 169 (2002).

9:00 AM B3.2
Coulomb Blockade and Andreev Reflections in Superconductor-Coupled Semiconducting Nanowires.
Yong-Joo Doh[1], S. De Franceschi[1], L. P. Kouwenhoven[1], A. Roest[1,2], E. P. A. M. Bakkers[2], L. F. Feiner[2] and J. A. van Dam[1]; [1]Kavli Institute of Nanoscience, Delft University of Technology, Delft, Netherlands; [2]Inorganic Materials & Processing, Philips Research Laboratories, Eindhoven, Netherlands.

We have studied the electronic transport properties of InP and InAs semiconducting nanowires contacted with superconducting electrodes. Our nanowires are grown using vapor-liquid-solid technique using Au nanoparticles as catalysts. The diameter of nanowires ranges from 40 nm to 80 nm. After deposition of nanowires on p-type Si wafer with 250-nm-thick surface oxide, superconducting contacts of Ti(10 nm)/Al(120 nm) bilayer are defined by standard e-beam lithography. The electrode spacing between source and drain contacts is varied from 100 nm to 3 μm. For the case of InP nanowire devices, the normal state resistance ranges from 4 kΩ to 1 MΩ at T = 2 K. Below superconducting transition temperature T_c = 1.1 K, our every InP device shows a suppression of zero-bias conductance. Particularly for the highly resistive device, the I(V) characteristics shows distinctive negative differential resistance, caused by BCS singularity of superconducting electrodes. The InAs nanowire devices, however, show clear enhancement of zero-bias conductance below T_c. Our typical specific contact resistance between InAs nanowires and superconducting electrodes is about 1.0×10^{-7} Ωcm^2. The enhanced zero-bias conductance and sub-gap structures can be explained by Andreev reflection at the interface between InAs nanowire and superconducting electrode. For the low resistive InAs devices with a normal state resistance below 1 kohm, we have observed clear supercurrent branch in their I(V) curves below Tc. The respective critical currents range from 15 nA to 140 nA at T = 30 mK. Its temperature and magnetic field dependences, as well as the gate effects, are discussed from the viewpoint of Josephson field effect transistor.

9:15 AM *B3.3
Optical and Magneto-Optical Processes in Carbon Nanotubes. Junichiro Kono, Electrical & Computer Engineering, Rice University, Houston, Texas.

The recent success in preparing individually-suspended single-walled carbon nanotubes (SWNTs) in aqueous solution has opened up the possibilities to perform spectroscpy of nanotubes of specific chiralities, allowing us to explore the intrinsic optical properties of these truly 1-D systems. This talk will describe our recent optical, magneto-optical, and ultrafast optical studies of such unbundled SWNTs. After briefly reviewing the unique band structure and basic optical properties of semiconducting SWNTs, I will describe two recent experiments: 1) using magneto-absorption, magneto-photoluminescence, and magneto-photoluminescence-excitation spectroscopies at high magnetic fields, we have detected the optical signatures of the Aharonov-Bohm phase [1], predicted more than 10 years ago [2], and 2) using pump-probe spectroscopy, we have detected previously-unobserved, long-lived photo-carriers with lasting polarization memory, especially when the nanotubes were excited resonantly [3,4]. This work was carried out in collaboration with Gordana Ostojic, Sasa Zaric, Yusuke Hashimoto, Ajit Srivastava, Jonah Shaver, Valerie Moore, Michael Strano, Robert Hauge, Richard Smalley, and Xing Wei. We thank the Robert A. Welch Foundation (No. C-1509), the Texas Advanced Technology Program (No. 003604-0001-2001), and the National Science Foundation (No. DMR-0134058) for support. 1. S. Zaric, G. N. Ostojic, J. Kono, J. Shaver, V. C. Moore, M. S. Strano, R. H. Hauge, R. E. Smalley, and X. Wei, "Optical Signatures of the Aharonov-Bohm Phase in Single-Walled Carbon Nanotubes," Science 304, 1129 (2004). 2. H. Ajiki and T. Ando, J. Phys. Soc. Jpn. 62, 1255 (1993). 3. G. N. Ostojic, S. Zaric, J. Kono, M. S. Strano, V. C. Moore, R. H. Hauge, and R. E. Smalley, "Interband Recombination Dynamics of Resonantly-Excited Single-Walled Carbon Nanotubes," Physical Review Letters 92, 117402 (2004). 4. Y. Hashimoto, A. Srivastava, J. Shaver, G. N. Ostojic, S. Zaric, V. C. Moore, R. H. Hauge, R. E. Smalley, and J. Kono, "Long-Lived Dilute Photocarriers in Individually-Suspended Single-Walled Carbon Nanotubes," in: Quantum Electronics and Laser Science Conference, OSA Technical Digest (Optical Society of America, Washington DC, 2004), IPDB4.

10:15 AM *B3.4
Quantum Dots for Optoelectronic Device Applications. K. Stewart, P. Lever, S. Barik, S. Mokkapati, J. Wong-Leung, L. Fu, M. Buda, H. H. Tan and Chennupati Jagadish; Department of Electronic Materials Engineering, Australian National University, Canberra, Australian Capital Territory, Australia.

Semiconductor quantum dots (QDs) based on the self-organized Stranski-Krastanov growth mode has found applications in a multitude of optoelectronic devices such as lasers, modulators and photodetectors. These devices have improved characteristics due to the unique electrical and optical properties resulting from the 3-dimensional confinement of carriers in the QDs leading to delta-function like density of states. However, there are still many challenges associated with the growth of these QDs, especially by Metal Organic Chemical Vapor Deposition (MOCVD). In comparison to MBE, MOCVD process is carried out at higher temperatures and the main implication to QDs is their coalescence/evaporation leading to large/highly non-uniform dots with dislocations. Furthermore, it is extremely difficult to obtain device quality In(Ga)As QDs grown on GaAs substrates. The emission wavelength of these QDs are still limited to less than 1.3μm, just short of the wavelength range of interest in long-haul optical communication systems. InAs QDs grown on InP substrates on the other hand tends to form dashes rather than dots and also suffers from the effect of As/P interdiffusion. In this talk, we will present our MOCVD results of the growth parameters that affect the formation of QDs for both In(Ga)As dots grown on GaAs and InP substrates. Ridge waveguide In(Ga)As/GaAs quantum dot lasers diodes are then designed and fabricated. These devices show some interesting properties such as built-in electric field of the QDs and gain saturation behavior. Preliminary results on quantum dot infrared photodetectors will also be discussed, particularly in relation to the stacking of a large numbers of QD layers and its implications on device performance. By growing these QDs on InP substrates and using a very thin layer of GaAs to minimize the As/P interdiffusion, we are able to form good quality dots that emit at 1.55μm. Finally, we will present our results on selective area growth of these QDs, whereby we are able to spatially control their size and emission wavelength. This is a promising technique for the fabrication of quantum dot-based optoelectronic integrated circuits.

10:45 AM B3.5
Superfluorescence of Ion Beam Synthesized Dense Packed Embedded CdSe Nanoclusters. Helmut Karl, Ingo Grosshans, Peter Huber and Bernd Stritzker; Institut fuer Physik, Univ. Augsburg, D-86135 Augsburg, Germany.

Dense packed embedded colloidal semiconductor quantum dot (QD) layers with a multimodal size distribution are representing new types of QD solids. Their optical and electronic properties are modified due to possible dipol-dipol interaction and tunneling. In this work sequential high dose ion implantation of Cd and Se and subsequent thermal treatment is used to synthesize QD assemblies with the required above mentioned structural properties in the surface near region of 500 nm thick thermally grown SiO_2 on Silicon. We used cw photoluminescence and Raman spectroscopy to study interband transitions and optical phonon modes at low temperatures as a function of stoichiometry and annealing conditions. In these embedded QD assemblies of mixed size distribution we measure exponential increase of the PL-intensity with increasing laser excitation power

(varied from 100 nW to 1 mW). The exponents measured are maximal for dose ratios of Cd:Se after implantation between 0.8 and 1.0. The blues shift of the fluorescence peak is smaller than expected from XRD and high-resolution transmission electron microscopy (TEM) measurements, this discrepancy will be discussed in context with electronic energy transfer between QDs of different size.

11:00 AM B3.6
Synthesis of highly photoluminescent CdTe nanocrystals and their incorporation into glass matrices. Norio Murase and Chunliang Li; National Institute of Advanced Industrial Science & Technology, Ikeda, Japan.

Colloidal preparations of nanocrystals have attracted much attention because of their size-dependent excitonic emissions. We have focused on the preparations in water because of their simplicity and advantages for a usage of versatile sol-gel reactions when incorporating them into glass matrices. CdTe is one of the most typical nanocrystals prepared in aqueous solution. Thioglycolic acid (TGA) is normally used as a surfactant for the preparation. We found out the extent of the surfactant upon preparation play an important role for the emission efficiency. The lower the extent, the more the emission efficiency becomes if the nanocrystals are not precipitated. When the molar ratio against Cd2+ is 1.54, the emission efficiency of red region becomes over 60% relative to quinine in sulfuric acid solution. It has been reported that the same system gives an efficiency of ca. 3% when the ratio is 2.43. Since the similar results were found in aqueous synthesis of ZnSe, the reason is under consideration from a context of the equilibrium between ionic concentration in solution phase and particles having a certain radius. As far as the nanocrystals are in solution phase, they are not suitable for applications. Therefore we have encapsulated them into glass matrices by using a sol-gel processing. Since the CdTe nanocrystals stabilized by TGA has a negative charge, an alkoxide having an amino group (aminopropyl trimethoxysilane, APS) was selected. For the encapsulation, addition of Cd2+ and TGA into hydrolyzed APS is crucial for maintaining the surface properties of CdTe. This is explained as well by an equilibrium between nanocrystals and the surrounding matrix. When prepared carefully, the glass having an emission efficiency more than 40% was obtained. The prepared glass was very transparent and fragile like a cover glass. The emission efficiency was maintained at least more than a half year. It is therefore fair to expect that the glass can easily be used for phosphors excited by UV-LEDs. This study was supported by the Nano-Glass Project of the Nanotechnology Materials Program, sponsored by the New Energy and Industrial Technology Development Organization, Japan.

11:15 AM B3.7
Synthesis of Monodisperse Lead Chalocogenides Nanocrystals in Octadecene. William W. Yu, Joshua C. Falkner and Vicki L. Colvin; Department of Chemistry, Rice University, Houston, Texas.

Monodisperse lead chalocogenides nanocrystals with wide size ranges have been successfully synthesized in octadecene. The as-prepared lead chalocogenides semiconductor nanocrystals have very narrow size distributions (less than 10%) without any post-synthetic size selection. High resolution transmission electron microscopy (TEM), electron diffraction and x-ray diffraction show that the nanocrystalline particles are single domains of rock-salt lead chalocogenides.

11:30 AM B3.8
The General Synthesis of Nanostructured V/VI Semiconductors. Paul Christian and Paul O'Brien; Chemistry, University of Manchester, Manchester, United Kingdom.

Semiconductors in the V/Vi series have band gaps ranging from 2.2eV for Sb2S3 to 0.21eV for Bi2Te3 spanning the range seen from conventional mid to narrow band gab materials to semi-metals. These materials, especially those with narrower band gaps, demonstrate thermo-electric properties and are used in Peltier devices. There are examples in the literature of the synthesis of several of these materials in a nanostructured form, however the reactions often rely on highly toxic reagents, especially in the case of tellurium containing materials. Further more there are no general routes applicable to all three chalcogenides. In this paper we describe a general method for the synthesis of chalcogenide V/VI nanomaterials by the reaction of acetate salts with the corresponding chalcogenide under reflux conditions in longchain alkyl amines, typically octylamine and dodecylamine. The effect of temperature and capping agent on the morphology and ordering of the final product are discussed and in particular the synthesis of Bi2S3 nanorods, Bi2Se3 and Bi2Te3 nanowafers and Sb2Se3 nanowires will be discussed.

11:45 AM B3.9
A Designed Molecular Precursor Approach for the Synthesis of Ternary II-II'-VI Nanomaterials. Marty W. DeGroot and John F. Corrigan; Department of Chemistry, The University of Western Ontario, London, Ontario, Canada.

While the development of molecular routes to binary II-VI semiconductor nanomaterials continues to be a burgeoning pursuit, entry into ternary II-II'-VI nanomaterials has been hindered by the relative lack of suitable precursors to their formation. This is despite the fact that these materials offer the advantage of controlling physical and chemical properties both by changing particle size and composition. Our research efforts have led to the development of a molecular precursor route for the synthesis of II-II'-VI nanomaterials. The principle of this designed approach is focused on the synthesis of a series of complexes $[L_nM(ESiMe_3)_2]$ (M = Zn, Cd; E = S, Se, Te; L = tmeda, 3,5-lutidine) where the preformed metal-chalcogen bond affords the potential to deliver 'ME2' units in nanocluster synthesis. The use of $(tmeda)Zn(ESiMe_3)_2$ has led to the synthesis of the nanocluster molecules $[(tmeda)_5Zn_5Cd_{11}E_{13}(EPh)_6]$ (E = Se, Te). Of particular relevance from a structural standpoint is the retention of the '$(tmeda)ZnE_2$' unit of the precursors upon elimination of the $-SiMe_3$ moieties. The non-lability of the chelating tmeda ligands at low temperatures restricts the 'ZnE_2' components to the cluster surface. The precursor molecules can therefore be utilized as capping agents in ternary nanocluster synthesis. The consequence is the formation of clusters with a CdE core surrounded by a layer of ZnE and these clusters can be regarded as the molecular limits of core/shell nanoparticles. In contrast, the lability of the 3,5-lutidine ligands of $(3,5\text{-lutidine})_2Zn(ESiMe_3)_2$ (E = Se, Te) affords access to nanocluster molecules $[Zn_xCd_{10-x}E_4(EPh)_{12}(PPr_3)_4]$ (x = 2.0-2.6) where Zn and Cd centers are intimately mixed within the cluster core. Comparison of the absorption spectra of these clusters demonstrates a distinct shift to higher energy of the first excitonic transition with increasing Zn content. The outlined approach has also been extended to the synthesis of larger II-II'-VI colloids where precise control of the Zn/Cd ratio results in a series of nanoparticles whose absorption and emission properties can easily be tuned. Furthermore, thermolysis of the nanocluster molecules described above in coordinating amine solvent affords size control of these ternary materials while maintaining the metal ion composition observed in the clusters.

SESSION B4: Emitters, Materials, and Devices I
Chairs: Mariano Troccoli and Karl Unterrainer
Tuesday Afternoon, November 30, 2004
Constitution A (Sheraton)

1:30 PM B4.1
Ultrashort Pulse Generation with Semiconductor Modelocked Lasers Using Saturable Absorbers Based on Intersubband transitions in GaN/AlGaN Quantum Wells. Farhan Rana, Faisal Razi Ahmad, Paul George, Jahan Dawlaty and Wiiliam Joseph Schaff; Electrical and Computer, Cornell University, Ithaca, New York.

We will show that saturable absorbers based on intersubband transitions in GaN/AlGaN quantum wells can be used to generate highly stable, sub-50 fs duration, high energy (> 100 pJ) optical pulses with semiconductor modelocked lasers. Typical pulse widths obtained with semiconductor modelocked lasers are around several picoseconds and typical pulse energies are generally less than 1 pJ. Radically new ideas are needed to enable semiconductor modelocked lasers to produce high energy ultrashort pulses. We will present such an idea in this talk that is based on the ultrafast (sub-100 fs) intersubband electron relaxation times in GaN/AlGaN quantum wells. The pulse shaping mechanism in semiconductor modelocked lasers is a combination of dynamic gain saturation and dynamic loss saturation (slow-saturable-absorber modelocking). This mechanism suffers from poor stability. In fast-saturable-absorber modelocking the pulse width is larger than the relaxation time of the absorber [2]. Fast absorber modelocking can provide improved pulse stability over a wide range of parameter values and can also produce shorter and higher energy pulses compared to slow absorber modelocking [2]. Very recently, intersubband optical transitions at wavelengths ranging from 1.1 um to 1.9 um have been realized by us (and by several other groups) in GaN/AlGaN and GaN/AlN multiple quantum well structures [3]. The ultrafast intersubband electron relaxation rates open up the possibility for realizing ultrafast-saturable-absorber modelocking in semiconductor lasers for the first time. We will present theoretical and experimental results that demonstrate that intersubband saturable absorbers can be used with semiconductor modelocked lasers to generate stable sub-50 fs optical pulses with energies exceeding 100 pJs. We will also show that detuned intersubband saturable absorbers can be used to realize an artificial Kerr-like non-linearity that is eight orders of magnitude stronger than that in optical fibers. This non-linearity can be used to generate optical novel soliton-like pulses in semiconductor lasers. Preliminary experimental results on intersubband saturable absorbers consisting of GaN/AlGaN/AlN quantum wells grown on AlGaN buffer layers on Sapphire substrates will be presented that demonstrate low pulse saturation energies

(<200 fJ) and ultrafast relaxation times (<150 fs). Quantum well and buffer layer designs geared towards strain minimization and a corresponding reduction in the polarization field will be discussed. Integrated optical waveguide designs for optimal performance will also be presented. 1.H. A. Haus, IEEE J. Quantum Electronics, vol. 11, 736-746 (1975). 2.H. A. Haus, J. Appl. Phys., vol. 46, 3049-3058 (1975). 3.K. Kushino, A. Kikuchi, H. Kanzawa, T. Tachibana, Appl. Phys. Letts., vol. 81, 1234-1236 (2002).

1:45 PM B4.2
Internal Photoemission Electro-Optic 400 meV Up-Conversion in a Phosphide-Based Heterostructure.
Marissa Olson[1], Venkatesh Narayanamurti[1] and J. M. Olson[2]; [1]Harvard University, Cambridge, Massachusetts; [2]National Renewable Energy Laboratory, Golden, Colorado.

We improve [1] on the arsenide-based internal photoemission optical up-conversion by using a GaInP quantum well with Al Ga InP cladding. The device uses a Au Schottky contact to inject photoexcited electrons into the asymmetric p+ i n heterostructure. A forward bias across the device is required for ohmic injection of holes into the GaInP quantum well, where the photoexcited electrons are confined. Both the cladding (AlGaInP) and well exhibit partial ordering, which is evident in the luminescence spectra at 77K. The device achieves up-conversion of photon energy from 820nm (1.51eV)to 650nm. [1] 'Room temperature electro-optic up-conversion via internal photoemission,' K.J. Russell, I. Appelbaum, H. Temkin, C.H. Perry, V. Narayanamurti, M.P. Hanson and A.C. Gossard, Applied Physics Letters, Vol. 82, No.18, 2960 (May, 2003).

2:00 PM B4.3
A Theoretical Study of Quantum Dash Lasers. J. H. Wei[1,2] and Kwok Sum Chan[1]; [1]Physics and Materials Science, City University of Hong Kong, Hong Kong, Hong Kong; [2]Physics, Shangdong University, Shangdong, China.

Self-assembled semiconductor nano-structures have received considerable attention for applications in photonics. Recently growth of self-assembled nano-structures on InP substrates led to the discovery of quantum dash structures with emission wavelengths around 1.5 micron, which are useful for optical communication. Quantum dashes are self-assembled wire-like nano-structures with significant size fluctuation. Although their growth mechanism is not clearly understood, quantum dashes can now be used to fabricate lasers with attractive features such as low threshold current, broad gain spectrum and high wavelength stability. It is therefore necessary to understand the optical gain of quantum dashes. The objective of the present study is to understand the effects of size fluctuation on the optical properties of quantum dash lasers. We have modeled the band structure and the optical properties of the quantum dash structures using the effective mass theory and density matrix theory. The effects of size fluctuation on the gain, differential gain, linewidth enhancement factor and chirp of quantum dash lasers are analyzed in terms of the structural parameters and materials properties. The effects of the dash dimensions and size fluctuation on the energy levels, densities of states and Fermi energies will be discussed. Special features in the optical properties are interpreted in terms of these characteristics. The dependence of the peak gain on the carrier densities, recombination current and size fluctuation is determined. It is found that a small size fluctuation (about 5% of average dimension) can destroy the one-dimensional characteristic of quantum dashes and the quantum dash structure behaves like a quantum well system. This high sensitivity to size fluctuation is due to a relatively large width. Energy splitting due to quantum confinement along the width is so small that small fluctuation of the height can destroy the 1-D characteristics. In general, size fluctuation reduces the peak gain, leading to significant increase in threshold currents. However, with a high packing density, quantum dashes can provide sufficient high gain with low threshold current for realistic applications (200-300 A/cm2 for a typical threshold gain of 1000cm-1). The differential gain, linewidth enhancement factor and chirp are also modified significantly by size fluctuation for a fixed carrier density. In this presentation, we will analyze these optical parameters for various injection levels and discuss strategies for optimizing the efficiency and dynamical characteristics of quantum dash lasers. Acknowledgement: The work described above was fully supported by a grant from CityU (Project No. 7001460)

2:15 PM *B4.4
Spectroscopic Analysis of External Stresses in Semiconductor Quantum-Well Materials. Jens W. Tomm[1], Mark L. Biermann[2], Omar M. Manasreh[3], B. S. Passmore[3], Axel Gerhardt[1] and Tien Q. Tran[1]; [1]Nonlinear processes in special laser systems, Max Born Institute Berlin, Berlin, Berlin, Germany; [2]Department of Physics and Astronomy, Eastern Kentucky University, Richmond, KY 40475, Kentucky; [3]Department of Electrical Engineering, University of Arkansas, Fayetteville, AR 72701, Arkansas.

Semiconductor structures such as quantum-wells are frequently designed as strained systems. The built-in strain is created during epitaxial growth and is caused by the lattice mismatch between different semiconductor materials. During its fabrication (processing, packaging) and operation a quantum-well device such as a semiconductor laser might experience additional stress of known as well as of arbitrary symmetry. We refer to these as external stresses, which result in an additional strain contribution. We present an approach for built-in strained quantum wells (which also holds for bulk material) that allows for the quantification of external stresses if they are of known symmetry. For special cases, however, even conclusions with regard of the symmetry of the additional stresses become possible. The approach is based on two main steps, namely the theoretical calculation of the strain-sensitivity of the spectral positions of the relevant quantum-confined optical transitions within the particular quantum-well, as well as the spatially resolved measurement of at least a substantial part of the optical transition sequence within the quantum-well. The experimental technique mainly applied is micro-photocurrent spectroscopy, which allows for the measurement of the spectral positions of the optical transition sequence within the quantum-well of a packaged commercial device with a spatial resolution of about 30 micrometer. InAlGaAs/GaAlAs/GaAs high-power lasers serve as the model species. A first set of experiments is performed to check theory. Thus we apply various stress geometries, such as hydrostatic, biaxial and uniaxial, to devices and compare the measured result with the calculated one. Furthermore, we show how the application of cyclic external stress (up to 2 million cycles) impacts the band structure by creating defects which cause band-gap renormalization within the quantum-wells. A second set of experiments uses our theoretical and experimental results in order to analyze high-power laser structures quantitatively. In particular the case of external stress along the <110>-direction, which corresponds to the facet orientation of real devices, is considered. We show strain profiles along the facets of devices. Furthermore, strain profiles along grooves, which are involved into the device architecture, are determined and discussed. Summarizing, we present a concerted approach for strain analysis in semiconductor materials and devices. This approach is applicable to all kinds of semiconductor materials and spectroscopic techniques, which employ the electronic band-structure of the material, such as photoluminescence, photoreflection, photocurrent, and transmittance. Finally, cross-calibration with established 'strain-analytical tools' such as Raman-spectroscopy is provided, too.

3:15 PM *B4.5
Photonic Crystal Vertical Cavity Surface Emitting Lasers.
Kent Choquette, University of Illinois Urbana-Champaign, Urbana, Illinois.

Operation of a vertical cavity surface-emitting laser (VCSEL) in the fundamental mode is important for numerous applications. Photonic crystal confinement is a method of introducing a controlled lateral index change into a VCSEL cavity through the addition of a periodic pattern of holes in the top distributed Bragg reflector. This is a robust and reliable technology for achieving operation in the fundamental lateral mode. We have developed a fabrication technique that can be implemented as a post-process step. A silicon dioxide dielectric mask is first deposited on a fabricated VCSEL. The dielectric layer is selectively removed with focused ion beam etching to define the photonic crystal pattern. The holes are subsequently etched with inductively coupled plasma reactive ion etching. The photonic crystal structure we examine contains a triangular array of circular air holes of varying lattice constant surrounding a central lasing region where a single air hole is absent. Single mode operation is achieved in the altered device through a combination of index guiding and mode-selective loss. For holes etched too shallow, there is insufficient index contrast to confine the light within the central region and the oxide aperture is able to produce a higher order lasing mode. For deeper holes not penetrating the active region, the index guiding is sufficient to eliminate all modes but the fundamental and achieve adequate confinement within the central region. Within this regime of allowed single mode operation, we have examined the dependence of the oxide aperture size on output power. We find a wide parameter range which leads to single fundamental mode operation, and have acheived greater than 3 mW of output power. We also show that coupling between adjacent defects in a photonic lattice is possible, enabling coherent 2-dimesional arrays. Previously, coherent 2-dimensional arrays have been fabricated by using mirror reflectivity modulation, or cavity or phase modifications in order to achieve coupling between adjacent elements in vertical structures. Using an array of defects within a photonic crystal pattern implies the lasing array is wholly contained within the same unpixelated gain area. Examining 1x2 and 2x2 arrays, we have demonstrated out-of-phase coupling for the coherent photonic crystal arrays.

3:45 PM B4.6
Vertical-Cavity Surface-Emitting Lasers with cw-Emission at Long Wavelengths of 6-8 Microns. Gunther Springholz[1], Thomas Schwarzl[1], Jens Fuerst[2], Michaela Boeberl[1], Harald Pascher[2] and Wolfgang Heiss[1]; [1]Institut fuer Halbleiterphysik, University of Linz, Linz, Austria; [2]Institut fuer Experimentalphysik, University of Bayreuth, Bayreuth, Germany.

Coherent optical emitters for the mid-infrared are extremely useful for highly sensitive molecular gas detection and analysis. For such devices, the narrow gap lead salt semiconductors are well suited because of their favorable band structure and low non-radiative Auger recombination losses. In this work, we present the first realization of vertical cavity surface emitting lasers (VCSELs) for wavelengths longer than 6 micrometers. The VCSELs, grown by molecular beam epitaxy, consist of a high finesse microcavity structure with highly efficient EuSe/PbEuSe Bragg mirrors and PbSe as active region. As a function of the optical cavity design the VCSEL structures, pumped by a CO laser, show strong laser emission at 6.5 to 7.9 μm, with ultra-narrow linewidths and a very small beam divergence. The threshold pump power is below 60 mW at operation temperatures up to 110K, and the maximum output power is 5 mW in cw mode and 25 W in pulsed mode.

4:00 PM B4.7
Experimental Demonstration of the Slow Group Velocity of Light in Two-Dimensional Coupled Photonic Crystal Microcavity Arrays. Hatice Altug and Jelena Vuckovic; Applied Physics, Stanford University, Stanford, California.

Small group velocity is crucial in variety of applications, ranging from optical delay components and low-threshold lasers, to study of nonlinear optics. Although photonic crystals can be employed to achieve slow group velocities at band edges, this effect is limited to a very narrow range of wavevectors in one particular direction. Moreover, the shape of an optical pulse propagating through such structure is distorted due to the large group velocity dispersion. In this talk, we present the first experimental demonstration of such structures with a measured group velocity below 0.008c. We will also describe our work on design, fabrication, and experimental setup. 2D CPCRA's are constructed by periodically modifying holes of a square lattice photonic crystal, for example, every third lattice hole in both x and y directions can be removed. This structure can be viewed as a 2D array of single-defect photonic crystal cavities formed by removing a single air hole. When cavities are tiled together, coupled cavity bands form and the structure supports three types of coupled modes similar to isolated single defect cavity (dipole, monopole, and quadrupole)[7]. We have experimentally studied up to half of the GX and GM direction. We have particularly obtained band diagram for coupled dipole and quadrupole band, which offers interesting application opportunities. The dipole bands are linearly polarized and can be used for laser applications where polarization control is preferred. We have experimentally observed group velocity less than 0.008c for dipole band in GX direction. Quadrupole radiates equally in the four GM (diagonal) directions and its radiation pattern has four-fold symmetry; which implies that the mode couples equally to all of its four neighbors in a particular lattice direction (e.g., GM or GX). The lack of preferential coupling directions, a good lateral confinement (high Q-factor), and a non-degeneracy of this mode lead to a single flat coupled-quadrupole band in all crystal directions In the talk, we will discuss our work on their applications (e.g., as low-threshold lasers with increased output powers, sensors and polarization properties).

4:15 PM B4.8
Time Reversal of Light with Linear Optics and Modulators. Mehmet Fatih Yanik and Shanhui Fan; Stanford University, Stanford, California.

The capability to reverse a wave in time has profound scientific and technological implications, including detection through random media, adaptive optics, sub-wavelength focusing, and dispersion compensation. We introduce a new physical process that can perform a complete time reversal operation on any electromagnetic pulse using only small refractive index modulations and linear optical elements. No nonlinear multi-photon effects such as four-wave mixing are required, and no knowledge of the time-dependent phase or amplitude of the light is necessary. The introduced process can be implemented on-chip with standard semiconductor materials. Furthermore, the same process can be used to compress or expand the spectrum of electromagnetic waves while completely preserving the coherent information. We exhibit the time-reversal process by first-principles simulations of microcavity complexes in photonic crystals. We show that dynamic photonic crystals, which can be constructed in any material system where index can be tuned slightly ($dn/n < 10^{-4}$), can be designed to perform sophisticated information processing tasks such as time reversal and pulse stopping, and may thus provide a common platform for on-chip optical information processing.

4:30 PM B4.9
Whispering Gallery Mode Lasing from a Semiconductor Nanocrystal / Microsphere Resonator Composite. Preston T. Snee, YinThai Chan, Rebecca Somers, Daniel G. Nocera and Moungi G. Bawendi; Chemistry, MIT, Cambridge, Massachusetts.

Semiconductor cadmium selenide nanocrystals (NCs) are attractive as lasing media given their photostability, spectrally narrow gain profiles, color-tunability and ease of chemical processing. However, the short biexcitonic (laser) lifetime of CdSe NC's creates difficulties in the development of a laser device using this material. We have developed a facile and robust method of incorporating colloidally synthesized CdSe/CdZnS NCs onto the surface of micron-sized silica or polystyrene microspheres by depositing a NC / titania or silica sol onto the microsphere substrate via a spin-coating process. This fabrication technique does not rely on expensive lithographic patterning techniques and the NCs do not suffer from the known photostability problems of organic laser dyes. Stable room temperature Whispering Gallery mode (WGM) lasing was observed when individual microspheres were optically pumped. Simultaneous lasing from both biexcitonic and multiexcitonic states has also been observed at higher pump intensities. Applications in non-linear sensing using these devices will also be discussed.

4:45 PM B4.10
Tunable Nanocrystal Blue Lasers. YinThai Chan, Jonathan S. Steckel, Preston T. Snee, Justin M. Hodgkiss, Jean-Michel Caruge, Daniel G. Nocera and Moungi G. Bawendi; Chemistry, MIT, Cambridge, Massachusetts.

Although stimulated emission in CdSe and CdSe/ZnS core-shell nanocrystals have recently been demonstrated, lasing at blue wavelengths has been more difficult to achieve due to highly efficient Auger relaxation processes that become dominant as the nanocrystal size decreases. We present here the incorporation of high quality CdS/ZnS core-shell nancrystals into a thin film of silica, which upon optical excitation, exhibits amplified spontaneous emission in the blue. We further incorporate the CdS/ZnS nanocrystals into a spherical microcavity, obtaining room temperature lasing. The emission wavelengths can be tuned by varying the size of the nanocrystals, affording access to a range of blue wavelengths. The threshold behavior, gain and lifetime dynamics will be discussed and compared with the more widely studied CdSe/ZnS nanocrystals.

SESSION B5: Emitters, Materials, and Devices II
Chairs: Hidefumi Akiyama and Junichiro Kono
Wednesday Morning, December 1, 2004
Constitution A (Sheraton)

8:30 AM *B5.1
Quantum Cascade Lasers and Photonic Crystal Technology: Surface-Emitting Microlasers. Raffaele Colombelli[1] and Mariano Troccoli[2]; [1]Institut d'Electronique Fondamentale, Universite Paris-Sud, Orsay, 91405, France; [2]Harvard University, Cambridge, Massachusetts.

Electronic- and photonic-band engineering are combined in a single device, i.e. a photonic-crystal quantum cascade laser emitting at $\approx 8\mu$m wavelength. The combination of size reduction and vertical emission can be interesting for gas sensing applications, as well as more fundamental studies. Recent results on photonic crystal quantum cascade (QC) microlasers will be presented. In this novel approach a photonic crystal lattice is incorporated - through a deep semiconductor etch - within a QC heterostructure. This technique allowed to develop a photonic-crystal injection laser emitting on a band-edge mode [1]. The device employs a two-dimensional distributed feedback effect, but at the same time - thanks to the high-index contrast photonic crystal employed - it is miniaturized compared to standard QC devices [2]. Since their invention in 1994 quantum cascade lasers have rapidly established themselves as the leading tunable coherent semiconductor source in the mid-infrared range of the electromagnetic spectrum. However, due to the transverse magnetic polarization of intersubband transitions, QC lasers cannot be designed as conventional vertically emitting lasers. An additional benefit of our approach is in fact direct surface emission. The two-dimensional photonic crystal forms a micro-resonator that simultaneously provides feedback for laser action, and diffracts the light vertically from the surface of the semiconductor chip [1,3]. The combination of size reduction, vertical emission, and lithographic tailorability of the emission properties enabled by the use of a high-index contrast photonic crystal resonant cavity can be interesting for applications in the mid/far-infrared ranges of the electromagnetic spectrum. In addition, the use of electrical pumping in these devices opens up another dimension of control for fundamental studies of

photonic crystal and surface plasmon structures in linear, non-linear, and near-field optics. [1] R. Colombelli, K. Srinivasan, M. Troccoli, O. Painter, C. Gmachl, D. M. Tennant, A. M. Sergent, D. L. Sivco, A. Y. Cho, and F. Capasso, "Quantum Cascade Surface-Emitting Photonic-Crystal Laser", Science **302**, 1374 (2003). [2] R. Colombelli, K. Srinivasan, M. Troccoli, O. Painter, C. Gmachl, D. M. Tennant, A. M. Sergent, D. L. Sivco, A. Y. Cho, and F. Capasso, "Fabrication technologies for quantum cascade photonic-crystal microlasers", IOP Nanotechnology **15**, 675 (2004). [3] K. Srinivasan, R. Colombelli , M. Troccoli, O. Painter, C. Gmachl, D. M. Tennant, A. M. Sergent, D. L. Sivco, A. Y. Cho, and F. Capasso "Lasing mode pattern of a quantum cascade photonic crystal surface-emitting microcavity laser", Appl. Phys. Lett. (in press).

9:00 AM B5.2
Processing of Deeply etched GaAs/AlGaAs quantum cascade lasers with DBR mirrors. Sebastian Golka, Christian Pfluegl, Werner Schrenk and Gottfried Strasser; Institute for Solid State Electronics, TU-Vienna, Vienna, Austria.

Substrate based planar Photonic Crystals (PhCs) for mid-infrared wavelengths are expected to greatly enhance optical performance of quantum cascade devices being a very convenient model system due to their low electric surface recombination losses. Furthermore the strong diffractive properties of PhC are important for vertical light emission, PhC in-plane refractive properties are wanted for lasing threshold reduction and single mode operation. In fabrication of such devices deep etching becomes crucial in preventing leakage of the optical mode into the substrate. Subsequent process challenges caused by high aspect ratios have to be overcome. In a first step we focused on tightly guided rib waveguide lasers with Distributed Bragg Reflectors (DBRs). We employ SiCl4/N2 based reactive ion etching with inductively coupled plasma to etch 13 microns deep gratings with a = 2.9 microns into GaAs. A 70:1 selectivity to the mask material Si3N4 is observed as well as little or no trenching at sidewalls and Al containing epitaxial layers. The inhibition of underetch becomes the most important issue and could be completely suppressed in a process window at low DC bias and low chamber pressure. EDX spectra measured on cleaved as etched samples show that sidewall passivation is provided for by a thin Si containing layer that is simultaneously formed with etching of GaAs on the bottom of the trench. The layer is then chemically inert to the chlorine based chemistry in the plasma. Electrical top contacts to laser ridges have to be bridged from the bond pads to the laser ridge since the height difference is too large to be overcome by thick image reversal resists. Mode selection is obtained for a rib laser with bridged contacts that uses deep DBRs at 10 microns wavelength.

9:15 AM B5.3
Optimization of 9 μm Quantum-Cascade Lasers for Room-Temperature Continuous-Wave Operation.
Thierry Aellen, Mattias Beck, Marcella Giovaninni and Jerome Faist; Physics Institute, University of Neuchatel, Neuchatel, Switzerland.

Continuous-wave (cw) operation of mid-infrared quantum-cascade (QC) lasers at room temperature is the result of recent progresses of designs and technology. In the present work, the lasing dependence on both doping concentration and injection barrier widths is investigated in order to optimize the laser performance. Laser structures designed for emission around 9 μm were grown by molecular beam epitaxy (MBE) with different doping concentration from consecutive runs. Fabry-Pérot (FP) lasers ridges exhibit a decrease of both threshold current and negative differential resistance while lowering the doping concentration. Performances depend on a trade-off between low threshold current and dynamical range. Comparison with growth runs made in sequence guarantees a similar MBE chamber quality. Indeed, as observed experimentally, current-voltage characteristics of lasers coming from growth runs temporally separated show strong differences. Structures based on 4-quantum wells, two phonons extraction, with different injection barrier thicknesses are also studied to explore the design optimization opportunity. As a result, at room temperature and 1.5% duty cycle, FP lasers with the thicker injection barrier (35 $\AA$ width) have a threshold current density of 2.1 kA/cm^2, which is lower than the lasers with a 30 $\AA$ barrier width (3.1 kA/cm^2). On the other hand, both lasers exhibit similar maximal optical peak power of 500 mW. Single-mode distributed feedback (DFB) lasers were then fabricated on the 35 $\AA$ injection barrier layer by standard lithography processes. We present cw operation at -48C for such devices mounted junction-up without back-facet coating. The device performances yield a threshold current of 1.4 A and a maximal optical power of 1 mW for a 3 mm-long and 12 μm-wide device. High resolution spectroscopy will benefit of these improvements for non-cryogenic applications. Free space optical data link will also be possible using Peltier-cooled cw QC lasers. On this side, we present recent results of high-frequency modulation up to 1GHz on Peltier cooler (-10C). The device used in this experiment is a FP, junction-down mounted, buried-heterostructure and back facet coated laser.

9:30 AM B5.4
Continuous-Wave Single-Mode Bound-to-Continuum Quantum-Cascade Lasers on TE-cooler at 5.4 μm.
Stephane Blaser[1], Lubos Hvozdara[1], Yargo Bonetti[1], Antoine Muller[1], Marcella Giovannini[2] and Jerome Faist[2]; [1]Alpes Lasers SA, Neuchatel, Switzerland; [2]Physics Institute, University of Neuchatel, Neuchatel, Switzerland.

State of the art mid-IR applications are often limited by the source power or radiance, the choice of available wavelengths, the linewidth, the size or the supply needs. System integrators using quantum cascade lasers (QCL) technology commercially available have access to pulsed devices exhibiting thermo-electrically cooled operation with radiance several orders of magnitude higher than conventional sources in a wavelength range spanning from 4 to 16 microns. The presently available performances cover a large span of applications, from chemical sensing to illumination and ranging. High-resolution spectroscopy requires tunable single-frequency light sources with very narrow linewidth (< 3.5 MHz), which can be achieved using QC lasers in continuous-wave (cw) operation. Such performances can be obtained using commercial cryogenic devices but for the price of cooling and size. Room-temperature cw operation of multimode QC lasers has been demonstrated around 9.1 μm, 5.6 μm and 6 μm. A single-mode cw operation on TE-cooler was reported only recently at λ 9μm up to 260K. We report the realization of a single-frequency distributed-feedback (DFB) QC laser with cw operation on a TE-cooler up to -5C at a frequency of ν 1840 cm-1, corresponding to a wavelength of 5.4 μm. The active region of the laser is based on a bound-to-continuum design, and the fabrication of the devices on molecular beam epitaxy (MBE) growth of strain-compensated (0.5%) InGaAs/InAlAs layers on an n-doped InP substrate. The DFB grating is holographically defined and wet etched in the upper InGaAs waveguide layer, whereas the InP top cladding is grown afterwards by metal organic vapor phase epitaxy (MOVPE). Processing is done using standard lithography in a ridge waveguide with a back facet high-reflection coating, and mounting is done junction-up. A 3 mm-long, 14 mm-wide, DFB QC laser emits up to 19 mW at -35C with a threshold current of 1.05 A, corresponding to a threshold current density of 2.5 kA/cm^2. The threshold current increases up to 1.44 A for the maximum cw operating temperature of -15C. A single-mode emission is observed over the entire investigated temperature and current ranges, with a side-mode suppression ratio (SMSR) > 25 dB and with a full width at half maximum (FWHM) narrower than 0.125 cm^{-1} limited by spectrometer resolution. The monomode emission spectra between -35 and -15C reveal a tuning range between 1843.75 and 1835.25 cm^{-1}, i.e. over 8.5 cm^{-1} or 0.46%. Another ridge (3 mm-long, 12 mm-wide) reaches the maximum operating temperature of -5C with similar output performances. The spectral measurements allow deducing a thermal resistance R_{th} of the device (or a specific thermal conductance G_{th}) from the variation of the emission frequency as a function of the temperature of the active region T_{act}. We find values of R_{th} = 6.6 K/W, corresponding to G_{th} = 359.8 W/Kcm^2, with a tuning coefficient $\beta = (1/\nu)\ (\Delta\nu/\Delta T)$ = -9.50 10^{-5} K^{-1}.

9:45 AM B5.5
THz Quantum Cascade Lasers: Magnetic Field Effects and Waveguide Properties. Juraj Darmo[1], Vincas Tamousiunas[1], Josef Kroell[1], Thomas Mueller[1], Gottfried Strasser[1], Karl Unterrainer[1], Raffaele Colombelli[2], Claire Gmachl[2], Frederico Capasso[2], K. West[2] and Loren N. Pfeiffer[2]; [1]Inst. fuer Photonik und ZMNS, Technische Universitaet Wien, Vienna, Austria; [2]Lucent Technologies, Murray Hill, New Jersey.

Terahertz quantum-cascade lasers (QCLs) are coherent sources of far-infrared radiation based on semiconductor heterostructures. Further improvement of the THz QCLs is a challenge for several reasons related to the intersubband population dynamics and to the waveguide properties. Electron-electron and interface roughness scattering represent the main scattering mechanisms at low temperatures in this range of intersubband energies. A strong magnetic field, applied perpendicularly to the superlattice planes, leads to an additional quantization of the in-plane electronic motion and creates a discrete ladder of Landau levels for each subband, which leads to a modification of the density of states and subsequently - of the scattering properties. The emission intensity of our THz QCL versus magnetic field shows clearly the influence of the reduced dimensionality. With increasing magnetic field the intensity shows an increase of the emission power and the threshold is decreased [1]. This effect is attributed to the reduced dimensionality which changes the phase space for elastic scattering processes. Lasing is completely suppressed for certain magnetic fields for which the magneto-intersubband resonance condition is met. In addition to the active region the properties of the waveguide are very important for the performance of the THz-QCL. The doping in active region and in

the contact layers cause quite significant free carrier absorption. We use THz time-domain spectroscopy to determine the waveguide absorption. [1] V. Tamosiunas, R. Zobl, J. Ulrich, K. Unterrainer, R. Colombelli, C. Gmachl, F. Capasso, K. West, L. Pfeiffer, Appl. Phys. Lett., 83, 3873 (2003).

10:30 AM *B5.6

THz Quantum Cascade Lasers. John Reno, Department 1123, Sandia National Laboratories, Albuquerque, New Mexico.

Terahertz (1-10 THz, or 4-40 meV, or 30-300 μm) frequencies are among the most underdeveloped electromagnetic spectra, even though their potential applications are promising for spectroscopy in chemistry and biology, astrophysics, plasma diagnostics, remote atmospheric sensing and imaging, noninvasive inspection of semiconductor wafers, and communications. This underdevelopment is primarily due to the lack of coherent solid-state THz sources that can provide high radiation intensities (greater than a milliwatt). The THz frequency falls between two other frequency ranges in which conventional semiconductor devices have been well developed. One is the microwave and millimeter-wave frequency range, and the other is the near-infrared and optical frequency range. The frequency range between these two bands, the frequency range of 1-10 THz, has been inaccessible for conventional semiconductor devices. We report our development of terahertz (THz) quantum cascade lasers (QCLs) based on two novel features. First, the depopulation of the lower radiative level is achieved through resonant longitudinal optical (LO) phonon scattering. This depopulation mechanism is robust at high temperatures and high injection levels. In contrast to infrared QCLs that also use LO-phonon scattering for depopulation, in our THz lasers the selectivity of the depopulation scattering is achieved through a combination of resonant tunneling and LO-phonon scattering, hence the term resonant phonon. This resonant-phonon scheme allows a highly selective depopulation of the lower radiative level with a subpicosecond lifetime, while maintaining a relatively long upper level lifetime (>5 picoseconds) that is due to upper-to-ground-state scattering. The second feature of our lasers is that mode confinement is achieved by using a novel double-sided metal-metal waveguide, which yields an essentially unity mode confinement factor and therefore a low total cavity loss at THz frequencies. Based on these two unique features, we have achieved some record performance, including but not limited to: the highest pulsed operating temperature of 137 K, the highest CW operating temperature of 97 K, and the longest wavelength of 141 μm (corresponding to 2.1 THz) without the assistance of a magnetic field. In addition to presenting our laser results, this talk will look at the design and growth considerations that must be taken into account to successfully produce THz QCL. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

11:00 AM B5.7

Mid-Infrared Intersubband Absorption of Carbon-Doped AlGaAs/GaAs Quantum Wells. Oana Malis[1], Claire Gmachl[2], Loren N. Pfeiffer[1] and K. W. West[1]; [1]Lucent Technologies, Murray Hill, New Jersey; [2]Dept. of Electrical Engineering, Princeton University, Princeton, New Jersey.

The intersubband hole transitions have not been studied as extensively as the intersubband electron transitions mostly due to the complexity of the valence band and the technological difficulties involved in p-type doping. However, the properties of hole intersubband transitions make them interesting for several light emitting and detecting devices. In particular they have the potential to extend the mid-infrared operating range of AlGaAs/GaAs quantum cascade lasers (QCLs). As a first step towards a hole QCL, we have studied bound-to-bound intersubband absorption of p-doped AlGaAs/GaAs isolated quantum wells (QW) and coupled superlattices. In order to reach a wide mid-infrared spectral range, GaAs wells with digitally-alloyed high Al composition (57%) AlGaAs barriers were grown by MBE on (100) GaAs substrates. Using a novel solid C source, the structures were modulation doped with hole densities of $1\text{-}2{\cdot}10^{12}/cm^2$. This C-doping method has been proven to produce extremely high hole mobility in low-density two-dimensional hole gases. The absorption measurements were made in the multipass waveguide geometry at temperatures from 5 to 300 K. As expected, the spectra display strong absorption features in the p-polarization due to the intersubband heavy-hole transitions and weaker features in the s-polarization likely due to the heavy-to-light hole transitions. The heavy hole absorption peak shifts from 6 μm to 11.5 μm when the QW width increases from 25.5 $\AA$ to 45.3 $\AA$. The energy of the heavy hole transitions was compared with calculations of a 6-band $\mathbf{k}{\cdot}\mathbf{p}$ model. The digital AlGaAs alloy consisting of a short period superlattice of pure GaAs and AlAs layers strongly influences the position of the quantized levels within the GaAs well, effectively increasing the height of the valence band offset. The theoretical calculations taking into account the full band structure reproduce the experimental findings but the agreement degrades with increasing QW width. The progress towards designing a hole quantum cascade emitter will also be discussed.

11:15 AM B5.8

Zener Tunneling of Light in an Optical Superlattice. Mher Ghulinyan[1], Lorenzo Pavesi[1], Claudio J. Oton[2], Costanza Toninelli[3] and Diederik S. Wiersma[3]; [1]Physics Department, University of Trento and INFM, Povo (TN), Italy; [2]Departamento de Fisica Basica, University of La Laguna, Tenerife, Spain; [3]INFM and European Laboratory for Nonlinear Spectroscopy, Florence, Italy.

We report on the first observation of Zener tunneling of light waves in transmission measurements performed on an optical superlattice made of free-standing porous silicon. The one dimensional structure is designed in a way that two photonic minibands are formed. A controlled linear optical path gradient along the light propagation direction tilts the photonic band structure, in analogy to the tilted energy bands of an electronic superlattice exposed to static electric field. A constant optical path condition through the structure provides a flat miniband situation, while the introduction of a refractive index gradient tilts the band structure. In the latter case, an optical Wannier-Stark ladder of localized modes is obtained, and the overall transmission of the superlattice falls down to 2%. Over a certain gradient value, at which the two tilted minibands couple within the extension of the structure, a resonant tunneling channel through the optical superlattice lifts up, resulting in an enhanced transmission peak of 44% in the middle of the minigap. This is a direct consequence of delocalization of optical Wannier-Stark states due to the coupling of two minibands. Ultrafast time resolved transmission experiments were performed: excitation of the Wannier-Stark states causes the appearance of photonic Bloch oscillations, which are strongly damped when Zener tunneling modes are excited. The observed phenomenon is the optical analogue of Zener breakdown in semiconductor superlattices

11:30 AM B5.9

Dispersion Engineering of Three-Dimensional Silicon Photonic Crystals: Fabrication and Applications. Sriram Venkataraman, Garrett Schneider, Janusz Murakowski, Shouyan Shi and Dennis W. Prather; Electrical Engineering, University of Delaware, Newark, Delaware.

The 2003 ITRS roadmap suggests that the most difficult interconnect challenges in the near term include the rapid introduction of interconnect processes compatible with device roadmaps, coupled with fine dimensional control and providing good mechanical stability and thermal budget.The continued push towards finer geometries, higher frequencies and larger chip sizes increasingly exposes the disparity between interconnect needs and projected interconnect performance. Further, the interconnect technologies should be able to meet performance requirements and manufacturing targets by leveraging low-cost conventional mass fabrication techniques and provide solutions to address global wiring scaling issues. The economies of scaling achieved by extending Moore's Law have lead to the dominance of silicon in the microelectronics industry; conversely only modest progress in silicon-based optoelectronic circuits has been achieved in recent decades. One of the other major obstacles to the realization of silicon microphotonics is chip-scale optical interconnects due to incompatibility of optical device materials and disparate integration scales with electronic devices and ICs. Photonic crystals (PhCs), the optical analogues to electronic semiconductors, are expected to be the elementary building blocks of future generation of opto-electronic devices, due to the performance enhancement they provide in terms of emission control, guiding, and dispersion engineering, combining dense integration and high-speed processing. While 3D photonic crystals have recently been fabricated using layer-by-layer fabrication, interferometric and two-photon volumetric lithography, and self-assembly techniques at various length scales, the challenges of disorder, size-dispersion effects, high complexity of multi-step processes, tight alignment tolerances, long turnaround times, and incompatibility with an integrated photonics platform amenable to mass fabrication, leave the scope for new ideas for their fabrication open. In this paper, we propose a method for the fabrication of three-dimensional (3D) photonic-crystal structures using conventional planar silicon micromachining. The method utilizes a single planar etch mask coupled with time-multiplexed, sidewall-passivating, deep anisotropic reactive-ion etching, to create an array of spherical voids with three-dimensional symmetry. Finally using this fabrication method, we propose a buried silicon optical interconnect technology, the sub-surface silicon optical bus (S3B) with the ability to meet the challenges cited earlier by the semiconductor roadmap, specifically process compatibility and mass fabrication. Our approach towards this demonstration is by engineering the dispersion properties of embedded silicon three-dimensional photonic crystals to create sub-micron routing channels and control light. Preliminary

results are presented that demonstrate the feasibility of the approach.

11:45 AM B5.10
N-type Delta Doping for High-Performance, High-Purity Silicon Imaging Arrays. Michael Hoenk[1], Jordana Bandaru[1], Shouleh Nikzad[1] and Stephen E. Holland[2]; [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California; [2]Lawrence Berkeley National Laboratory, Berkeley, California.

We have developed a process for growing delta-doped epitaxial silicon with $>10^{14}cm^{-2}$ antimony at temperatures compatible with fully-processed silicon devices (i.e., below 450 C). We have used this process to successfully grow delta-doped contacts on the back surface of fully-processed, high-purity charge-coupled devices (CCDs), enabling imaging at full depletion with high resolution, high sensitivity, and broadband response. High purity silicon arrays, under development at LBNL for extended infrared response, can be fully depleted up to a thickness of few hundred microns with the application of a modest voltage. Full depletion enables high-resolution imaging, while greater device thickness extends the spectral response farther into the infrared (i.e., $200\mu m$ devices are capable of detecting wavelengths up to $1\mu m$ with high efficiency, limited by low absorption near the silicon bandgap energy). However, full depletion also makes these devices particularly susceptible to surface effects. In particular, surface states at the back surface of an unpassivated, fully-depleted device cause an unacceptably high leakage current. The back electrode of high purity devices must therefore perform a dual function: providing a conductive surface for the applied bias, and passivating the surface to prevent excess dark current. Back surface electrodes thicker than a few atomic layers will prevent the detection of shallow-penetrating ionizing radiation, such ultraviolet photons and low-energy particles (e.g., electrons < 1 keV). Delta doping the silicon back surface provides a conductive electrode less than 5nm thick, which enables full depletion and passivates the back surface for low dark current. Consequently, delta-doped, high-purity silicon CCDs can detect ultraviolet light and low-energy particles that would otherwise be absorbed in the back surface contact. Sb-doped silicon has been grown by MBE at low temperatures (< 450 C) on fully processed and metallized high purity PIN diode arrays and CCDs. The first successful images have been taken with the Sb doped CCDs. High resolution, low leakage current and excellent uniformity have been achieved. We will discuss the effects of surface preparation, temperature, Sb dose, and thickness on the leakage current and quantum efficiency of these detectors.

SESSION B6: Infrared Detectors and Materials
Chairs: Gail Brown and Nibir Dhar
Wednesday Afternoon, December 1, 2004
Constitution A (Sheraton)

1:30 PM *B6.1
InAs/GaSb Superlattices for Mid-IR Detection: Growth, Characterization, and Modelling. Frank Szmulowicz[2,1], Heather Haugan[2], Gail J. Brown[2] and Krishnamurthy Mahalingam[2]; [1]University of Dayton Research Institute, Dayton, Ohio; [2]Materials & Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB 45433-7707, Ohio.

We have grown several series of InAs/GaSb superlattices by molecular beam epitaxy with precisely calibrated growth rates. The superlattice parameters such as the InAs and GaSb layer widths were varied in order to produce a device with an optimum mid-infrared photoresponse and a sharpest photoresponse cut-off. The effect of design parameters on the photoresponse cut-off are explained by a nonperturbative, modified envelope function approximation (EFA) calculation that includes the interface coupling of heavy, light, and spin-orbit holes resulting from the in-plane asymmetry at InAs/GaSb interfaces. Interface effects on the EFA-calculated band structure are manifested by large band splittings and avoided crossings. The physics of these effects has been modeled analytically in several important limits . Very good agreement was found between experimental results and theory on several sets of SLs (both MWIR and LWIR) with symmetric InSb-like interfaces and mixed GaAs- and InSb-like interface. We explain the band gaps as a function of GaSb and InAs widths in terms of variations of the heavy-hole and conduction band bandwidths. Therefore, a consistent application of the EFA method with the inclusion of well established IF effects provides useful physical insights and possesses good predictive capacity in the design of NCA SLs.

2:00 PM B6.2
Correlation Between Photoreflectance Spectra and Electrical Characteristics of InP/GaAsSb Double Heterojunction Bipolar Transistors. Hiroki Sugiyama[1], Yasuhiro Oda[1], Haruki Yokoyama[1], Masahiro Uchida[2], Noriyuki Watanabe[2] and Takashi Kobayashi[1]; [1]NTT Photonics Laboratories, Atsugi-shi, Japan; [2]NTT Advanced Technology Corporation, Atsugi-shi, Japan.

InP/GaAsSb double heterojunction bipolar transistors (HBTs) have recently attracted much attention because the type II (staggered) band alignment of this heterostructure enables the use of InP as a collector layer without current blocking effect. Excellent device characteristics have been demonstrated using these HBTs [1]. As these HBTs move from research to the production phase, nondestructive diagnosis of the quality of epitaxial layers becomes critical. Photoreflectance (PR) spectroscopy is a useful method for the nondestructive characterization of HBT wafers at room temperature because it is sensitive to the built-in electric fields and crystal quality at the heterointerfaces. However, few PR studies of InP/GaAsSb HBTs have been reported [2]. In this paper, we present PR spectroscopy of InP/GaAsSb HBT wafers and discuss the correlation between the PR spectra and electrical characteristics of devices. We found that the amplitude of Franz-Keldysh oscillations (FKOs) in the PR spectra is related to the amount of recombination current at the emitter-base (E/B) heterojunctions. We also found that the use of InAlP emitter suppresses the recombination at E/B heterojunctions thereby improving the electrical characteristics of devices. InP/GaAsSb HBTs were grown by metal-organic vapor phase epitaxy. The layer structure of the HBTs was n^+-InGaAs cap/n-InP/p^+-GaAsSb C-doped base/undoped InP collector/n^+-InGaAs and InP subcollector. We also prepared InP/InGaAs HBTs, and InP/GaAsSb HBTs with a pseudomorphic InAlP emitter for comparison. PR measurements were performed at room temperature using a conventional setup. The origin of FKOs in the PR spectra was identified by step etching of the samples. In order to measure current-voltage characteristics, HBT devices were fabricated by conventional processes. PR spectra showed FKOs from the emitter layer in the InP/GaAsSb HBT wafers with low recombination forward current at the E/B heterojunction. In contrast, when recombination current was dominant at the E/B heterojunction, we could not observe FKOs from the emitter. These results indicate that PR signal amplitude from the emitter reflects the crystal quality of E/B heterojunction. We found that the PR signal amplitude of our InP/GaAsSb HBTs was usually quite smaller than that of InP/InGaAs HBTs, though the PR measurement conditions and crystal quality of the InP emitter and collector were almost the same. We attribute the small PR amplitudes in the InP/GaAsSb HBTs to more significant recombination at InP/GaAsSb interfaces than at InP/InGaAs interfaces. In order to avoid recombination at type-II interfaces, we employed pseudomorphic InAlP as the emitter in the GaAsSb-base HBTs. PR spectra and current-voltage characteristics of E/B heterojunctions confirmed the suppression of the recombination at InAlP/GaAsSb heterojunctions. [1] M. Dvorak *etal.* IEEE Electron Device Letters **22**, 361 (2001). [2] C. Bru-Chevallier *etal.* Thin Solid Films **450**, 151 (2004).

2:15 PM B6.3
Roughness Analysis of Ion Beam Processed GaSb and InSb Surfaces. K. Krishnaswami[1], D. B. Fenner[2], S. R. Vangala[1], C. Santeufemio[1], M. Grzesik[1] and W. D. Goodhue[1]; [1]Photonics Center, Dept. of Physics, University of Massachusetts, Lowell, Massachusetts; [2]Dept. of Physics, University of Connecticut, Storrs, Connecticut.

High-quality GaSb and InSb substrates with minimal surface roughness and thin, uniform oxide layers are critical for developing low-power, epitaxy-based, electronic and optoelectronic devices. Ion beam processing techniques of gas-cluster ion beam (GCIB) and bromine ion-beam assisted etching (Br-IBAE) were investigated as to their potential for engineering the substrate surfaces for applications in the areas of molecular beam epitaxial (MBE) growth and ohmic contact formation. Residual surface roughness is a key metric for evaluating wafer quality. Images of pre- and post-processed surfaces were obtained using atomic force microscopy (AFM) and these were statistically analyzed to characterize the surface roughness properties. Height correlation functions and power spectral-density distributions of GaSb (100) surfaces before and after various GCIB processes showed random fractal characteristics, with fractal Hurst exponents (H) ranging from 0.8 to 1.0 and correlation lengths from 8 to 13 nm. The analysis indicated an increase in correlation length with an increase in cluster-ion beam energy. GaSb surfaces processed with Br-IBAE often exhibited characteristics of mound roughness with correlation lengths ranging from 60 to 200 nm. Br-IBAE processed InSb (111) surfaces were found to have nanoscale tips that were largely removed by the GCIB process producing surfaces with characteristics of mound roughness. Roughness characteristics of epitaxial layers grown on GCIB and Br-IBAE prepared GaSb (100) surfaces will also be reported and compared to the initial surfaces.

2:30 PM *B6.4
Fast, Tunable, THz Detector Based on a Double-Quantum-Well, Field-Effect Transistor. Michael C. Wanke[1], Mark Lee[1], X. G. Peralta[3,2], S. J. Allen[2], J. L. Reno[1] and J. A.

Simmons[1]; [1]Photonic Microsystems Technologies, Sandia National Labs, Albuquerque, New Mexico; [2]Physics Department, U.C. Santa Barbara, Santa Barbara, California; [3]Duke University, Durham, North Carolina.

We have demonstrated that double quantum well field-effect transistors with grating gates can operate as THz detectors. Early measurements explored voltage tunable terahertz photoconductivity exhibiting a relatively narrow linewidth of 15 GHz, and confirmed that the resonant frequency is determined by the 2-dimensional magneto-plasma oscillations of the composite structure. Biased appropriately, the structure can also operate as a broadband bolometer with higher sensitivity even at temperatures above 77K. Heterodyne measurements indicate that both modes of operation (plasmon resonant and bolometric) are fast with 3 dB bandwidths of approximately 700 MHz and greater than 1.5 GHz, respectively. Thus the detector can act as a spectrometer-on-a-chip both as a direct detector with low resolution or as a mixer with high resolution. I will present our most recent developments towards revealing the physical mechanism(s) and improving the device performance, in terms of speed, sensitivity and operation temperature. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

3:30 PM *B6.5
Enhancement of CuPt Ordering in GaInP Using Sb.
J. M. Olson, W. E. McMahon and A. G. Norman; National Renewable Energy Laboratory, Golden, Colorado.

During the MOCVD growth of GaInP, Ga and In cations on the (001)surface tend to order leading to the well known CuPt ordering in the bulk. This ordering causes a red shift of the band gap energy and is a complex function of growth variables including temperature, rate, P-source pressure, substrate orientation and the presence of foreign species on the surface. In particular the presence of trace quantities of Sb in the gas phase ($Sb/P < 10^{-5}$) is known to affect the degree of order in GaInP and the usual effect is to destroy or preclude the surface ordering. In this paper we show that under certain conditions, Sb can actually cause an increase in the degree of order. This has important implications with regards to the various models that have been proposed to explain ordering in III-V alloys. This and other aspects of the problem are presented and discussed.

4:00 PM B6.6
Absorption Analysis of Lateral Compositionally Modulated InAs/GaSb Superlattices.
Julia C. Wickett, Donna W. Stokes, Jianhua H. Li, Santoshi L. Ammu and Simon C. Moss; Department of Physics, University of Houston, Houston, Texas.

The effects of lateral composition modulation (LCM) in $(InAs)_{13}/(GaSb)_{13}$ superlattices on the optical response of the material have been investigated by infrared absorption and double crystal x-ray diffraction (XRD). Superlattice samples were grown by molecular beam epitaxy (MBE) on GaSb (001) substrates with InSb interfacial bonds on either a GaSb or AlSb buffer layer. From the XRD analysis, we have determined that the cross contamination of As and Sb into the GaSb and InAs layers, respectively, affects the strain state of the layers with respect to the growth template (GaSb or AlSb buffer). The InAs(Sb) layers grown on GaSb (001) template are under compressive strain, rather than expected tensile strain (expected for layers with nominally InAs), and those on AlSb (001) buffer are under significantly reduced tensile strain (expected for nominally InAs layers grown on AlSb). The changes in the strain state of the layers, appears to be significant in the optical response of the sample. Optical absorption measurements were taken on the samples at 77 and 300 K using a Bruker Fourier Transform Infrared Spectrometer (FTIR) and were compared with that of an $(InAs)_{13}/(GaSb)_{13}$ superlattice with no LCM. Note that the sample with no LCM was grown with As_2 and those with LCM were grown employing As_4. The samples were designed with a cutoff wavelength of 8 μm. In the sample with no modulation, the cutoff wavelength was 8 μm and the transitions involving the heavy- and light-hole bands in the GaSb hole quantum well and the electron subbands of the InAs electron quantum well were easily identified. For the LCM samples grown on GaSb template, identification of the hole and electron subband transitions were not clear and different cutoff wavelengths were observed for each sample. However, for the sample grown on the AlSb buffer, optical transitions were clearly identifiable. The Sb cross contamination in the InAs layers leading to the reduced tensile strain state, puts the system into a strain state similar to that of the samples with no LCM, therefore the transitions are observable. The AlSb buffer, which preserves the optical quality of the sample, may be a key component in employing these LCM samples for optical applications.

4:15 PM B6.7
Bandgap Tuning of InAs/GaSb Type-II Superlattices for Mid-Infrared Detection.
Heather J. Haugan, Frank Szmulowicz, Gail J. Brown, Krishnamurthy Mahalingam and Larry Grazulis; Materials & Manufacturing Directorate, Air Force Research Laboratory (AFRL), Wright-Patterson AFB, Ohio.

The superlattice (SL) parameters of a 40 period InAs/GaSb SL structure were varied around the 20.5 Å InAs/24 Å GaSb design in order to produce a device with an optimum mid-infrared photoresponse and a sharpest photoresponse cut-off. The samples for this study were grown by molecular beam epitaxy with precisely calibrated growth rates. Varying individual layer width around the nominal design, we were able to systematically change the photoresponse cut-off wavelength between 4.36 to 3.45 μm by decreasing the InAs width from 23.5 to 17.5 Å, and between 4.55 to 4.03 μm by increasing the GaSb width from 18 to 27 Å. Therefore, the cut-off changes faster with decreasing InAs rather than increasing GaSb width. However, increasing GaSb width more effectively enhances the sharpness of photoresponse near band edge. The effect of design parameters on the photoresponse cut-off and other effects are explained by a nonperturbative, modified envelope function approximation (EFA) calculation that includes the interface coupling of heavy, light, and spin-orbit holes resulting from the in-plane asymmetry at InAs/GaSb interfaces. Using the modified EFA model, the SL design at fixed period of 44.5 Å was adjusted for the optimum performance.

4:30 PM B6.8
Improved Performance of GaSb-Based MIR Photodetectors through Electrochemical Passivation in Sulphur Containing Solutions.
Anna Piotrowska[1], Ewa Papis[1], Krystyna Golaszewska[1], Radoslaw Lukasiewicz[1], Tadeusz T. Piotrowski[1], Renata Kruszka[1], Andrzej Kudla[1], Jaroslaw Rutkowski[2], Jacek Szade[3], Antoni Winiarski[3] and Marta Aleszkiewicz[4]; [1]Institute of Electron Technology, Warsaw, Poland; [2]Institute of Physics, Military Academy of Technology, Warsaw, Poland; [3]Institute of Physics, University of Silesia, Katowice, Poland; [4]Institute of Physics, PAS, Warsaw, Poland.

GaSb-based semiconductor alloys are well recognized for their potential applications in MIR optoelectronics and thermophotovoltaics. The implementation of these materials, however, has been hampered by an inability to reproducibly control their surface properties. In search for appropriate passivating coatings the surface treatment in sulphur containing solutions has recently received much attention. In this work the formation of passivating coatings on GaSb, InGaAsSb (E_G = 0.52 eV), and AlGaAsSb (E_G = 1.25 eV) surfaces via electrochemical treatment in sulphur containing electrolytes has been investigated and the effect of sulphur passivation of mesa side walls on the electro-optical characteristics of GaSb/InGaAsSb/AlGaAsSb photodiodes operating in the 1.9 - 2.3 μm has been analyzed. The long-term stability of the surface passivation was of particular concern. $(NH_4)_2S$, Na_2S, and $(NH_2)_2CS$ have been chosen as sulphur sources in either aqueous or C_3H_7OH solutions. Potentiometric and iodometric analyses have been performed to determine the total sulphur content, the total sulphide and reactive sulphide concentrations in electrolytes under investigation. Electrochemical processing has been carried out at the current density in the range 1.6×10^{-2} - 35 mA/cm^2 for 15 - 30 min at RT. Variable Angle Spectroscopic Ellipsometry (VASE) provided information on thickness, refractive index and dielectric function of superficial layers. The chemistry of the passivating coatings was analyzed by XPS, surface morphology was examined by AFM and optical microscopy with Nomarski contrast. Characterization of GaSb/InGaAsSb/AlGaAsSb device structures involved measurements of photodiode dark current and spectral response. The net result of our experiments is that two procedures can be used for effective passivation of GaSb-based surfaces. Specifically, electrochemical treatment in $(NH_4)_2S$ aqueous solution (pH = 9.1, j = 4 mA/cm^2) allows obtaining 300 nm thick sulphide coatings, while passivation in Na_2S alcoholic solution (pH = 11.0, j = 2 mA/cm^2) produces 100 nm thick sulphide layers. These coatings when applied to surface passivation of GaSb/InGaAsSb/AlGaAsSb photodiodes enables reducing their dark current by factor of 5 and increasing the zero-bias resistance by factor of 4. As a result devices characterized by the detectivity of 1.5-2x10^{10} cmHz$^{1/2}$/W and dark current density of 10 mA/cm^2 at -0.5 V bias have been fabricated and their long-term stability has been proven. This research is partially supported by the State Committee for Scientific Research under the grant 3 T11B 009 26.

4:45 PM B6.9
High Speed Ge Photodetectors on Si Platform for GHz Optical Communications in C+L Bands.
Jifeng Liu[1], Douglas D. Cannon[1], Samerkhae Jongthammanurak[1], David T. Danielson[1], John Yasaitis[2], Kazumi Wada[1], Jurgen Michel[1] and Lionel C. Kimerling[1]; [1]Materials Science and Engineering, Massachusetts Institute of

Technology, Cambridge, Massachusetts; [2]Analog Devices, Inc., Cambridge, Massachusetts.

Near infrared (NIR) photodetectors are indispensable devices in optical communications to convert optical signals into electronic ones. III-V semiconductors such as InGaAs are currently used as photodetectors in telecommunications, but these devices are not compatible with Si CMOS technology and require growth on InP or GaAs substrates, which leads to much higher costs. In this paper, we present a Si-CMOS compatible, high speed, high responsivity Ge p-i-n photodetector selectively grown on Si platform that covers the whole C band and a large part of the L band for high capacity optical communications. Highly smooth Ge epitaxial layers with a root mean square roughness of 0.7nm were selectively grown directly on Si windows opened up on SiO2 via a two step growth, where a 60nm pure Ge buffer layer was grown at 335°C followed by a high temperature growth at 700°C to deposit approximately 1.7 μm of Ge. The material was then subjected to 1 hour annealing at 900°C to remove 99% of the threading dislocations. Making use of the thermal mismatch between the Ge epitaxial layer and the Si substrate, a 0.18% in-plane tensile strain was introduced into the Ge layer, reducing the direct bandgap of Ge from 0.801eV to 0.774eV and extending the effective photodetection range up to 1600nm. A p-i-n diode was fabricated from this tensile strained Ge epitaxial material with fully Si-CMOS compatible processes. The device shows a 3dB frequency of 2.5GHz, mainly limited by the RC delay. The transit time limited bandwidth was measured to be as large as 20GHz. At a reverse bias of -2V the responsivity of the device at 1310nm, 1550nm and 1600nm are 0.72A/W, 0.40A/W and 0.10A/W, respectively, which can be further increased by 45% with antireflection coating. The responsivities at 1310nm and 1550nm are comparable to the InGaAs photodetectors currently used in optical communications. With high quality selectively grown Ge epitaxial layers and adequate device design, the responsivity of the device at 0 bias is still over 96% of that at -2V, which is promising for high signal-to-noise ratio, low power consumption operations. Unlike InGaAs photodiodes, the presented device is fully compatible with Si CMOS technology, which enables monolithically integrated photodiodes with Si circuitry.

SESSION B7: Electronic Materials and Devices
Chairs: Robert Biefeld and Michael Wanke
Thursday Morning, December 2, 2004
Constitution A (Sheraton)

8:30 AM B7.1
A New All-Diamond Heterostructure Diode. Dieter M. Gruen[1], Oliver A. Williams[2], Erhard Kohn[3], T. Zimmerman[3] and M. Kubovic[3]; [1]Materials Science Division, Argonne National Laboratory, Argonne, Illinois; [2]Center for Nanoscale Materials, Argonne National Laboratory, Argonne, Illinois; [3]Dept of Electron Devices and Circuits, University of Ulm, Ulm, Germany.

Diamond's potential as an electronic material has been difficult to achieve primarily because an appropriate n-type dopant has been lacking. The development and characterization of ultrananocrystalline diamond (UNCD) films composed of 3-5nm randomly oriented crystallites (1,2) may contribute to the realization of this goal. The semiconducting properties of boron doped p-type diamond have been known for a very long time. Much less well known is the fact that films of UNCD can be rendered highly electrically conducting (up to 100 (ohmcm-1)) by the addition of nitrogen to the synthesis gas. Such films display semimetallic properties with very low activation energies (3). Hall and Seebeck effect measurements prove the n-type nature of the conductivity with carrier concentrations reaching levels of 10+21cm-3 and mobilities in the range 1-3/cm2V-1s-1 (4). Tight-binding density functional calculations based on the incorporation of nitrogen into the ubiquitous high energy, high angle, twist grain boundaries of the material provide the theoretical basis for the plethora of energy levels introduced into the bandgap of diamond by the rehybridization of the carbon atoms that knit the crystallites together at the grain boundaries (5). The ready availability of both n and p-type diamond led us to construct an all-diamond heterostructure diode by depositing an n-type UNCD film onto a lightly boron doped depletion layer grown epitaxially on a highly boron doped contact layer which in turn was epitaxially grown on a Ib single crystal of diamond.The diode shows 10-11 orders of magnitude rectification with substantial currents at ambient temperature and stable, reversible performance at temperatures in excess of 1000 degrees Centigrade. The diode performance characteristics are currently being optimized and efforts are underway further to explore extensions of the results described above to other unipolar as well as bipolar diamond electronic devices. (1) D. M. Gruen, US Patent #5,209,916, filed Nov. 25,1991 (2) D. M. Gruen, Ann. Rev. Mat. Science,1999 29:211 (3) S. Bhattacharya et al., Appl. Phys. Lett., 2001 79:1441 (4) O. A. Williams et al., Appl. Phys. Lett., 2004 (submitted) (5) P. Zapol et al., Phys. Rev. B 2002 65: *Work performed under the auspices of the US Department of Energy, BES-Materials Sciences under Contract W-31-109-ENG-38

8:45 AM B7.2
High Quality MPCVD Epitaxial Diamond Film for Power Device Application. Jie Yang[1,2], Weixiao Huang[3], T. P. Chow[3] and James E. Butler[1]; [1]Gas/Surface Dynamics Section, Naval Research Laboratory, Washington DC, District of Columbia; [2]NOVA research Inc., Alexandraia, Virginia; [3]Rensselaer Polytechnic Institute, Troy, New York.

As a wide bandgap (5.47eV) semiconductor material, single crystal diamond has high electron mobility (reportedly between 2000 and 4400 cm2̂V-̂1s-̂1), high electron saturation velocity (2x107̂ cms-̂1), high breakdown voltage (>107̂ Vcm-̂1), and high thermal conductivity (>21 Wcm-̂1K-̂1). Diamond-based semiconductor devices offer the potential of operation at high voltages, power levels, temperatures and under extreme radiation conditions. In this work, we present our effort to grow high quality homo-epitaxial diamond films on (100)-single crystal diamond substrates by microwave plasma chemical vapor deposition (MPCVD). The growth rate can vary from 0.01 to 100 micrometers per hour, depending on growth conditions, doping, and quality; and using a lift-off process, free-standing homo-epi films with remarkably low p-type doping (from 1x101̂4 to 1x101̂7 cm-̂3) and exceptionally low compensation 1x101̂3 cm-̂3 have been made. Vertical and lateral structure high voltage diamond Schottky rectifiers have been built for frequency-dependent capacitance-voltage (C-V), and current-voltage (I-V) measurements. A breakdown voltage of 8kV at 100um distance and 12.4 kV at 300um distance is recorded for lateral structure devices without ohmic contact (back to back Schottky contacts), while an unoptimized vertical device with an Ohmic contact has demonstrated a forward voltage drop of 7V at 100 A/cm2̂ in a device that can only block 600V.

9:00 AM B7.3
Superconductivity in heavily B-doped CVD Diamond Thin film. Kensaku Kobayashi[1], Tidai Takenouchi[1], Yoshihiko Takano[2], Masanori Nagao[2], Isao Sakaguchi[2], Minoru Tachiki[2], Takeshi Hatano[2], Guofang Zhong[1], Hitoshi Umezawa[1] and Hiroshi Kawarada[1]; [1]School of Science and Engeering, Waseda university, Tokyo, Japan; [2]National Institute for Materials Science, Tokyo, Japan.

Diamond has always been adored as a jewel. Even more fascinating is its outstanding physical properties; it is the hardest material known in the world with the highest thermal conductivity. Meanwhile, when we turn to its electrical properties, diamond is a rather featureless electrical insulator. However, with boron doping, it becomes a p-type semiconductor, with boron acting as a charge acceptor [1-2]. Therefore the recent news of superconductivity in heavily borondoped diamond synthesized by high pressure sintering was received with considerable surprise [3]. Opening up new possibilities for diamond-based electrical devices, a systematic investigation of these phenomena clearly needs to be achieved. Here we show unambiguous evidence of superconductivity in heavily boron-doped diamond thin film .The heavily boron-doped diamond thin film (polycrystalline diamond) was deposited on a silicon (001) substrate using microwave plasma assisted chemical vapor deposition (MPCVD) method . CH4 and H2 were used for the reactant gas . Boron doping was carried out by mixing trimethylboron (TMB) in the reactant gas . The transport properties were measured between room temperature and 1.7K. With decreasing temperature , the resistivity initially decreases slightly but increases gradually below 200K. The resistivity began to drop at around 7.4K which corresponds to the onset of a superconducting transition, and dropped to zero at around 4.2K (Tc offset) in the absence of the field. This value is higher than the reported one in ref(3) and well above helium liquid temperature. This finding establishes the superconductivity to be a universal property of borondoped diamond, demonstrating that device application is indeed a feasible challenge. [1]Collins, A.T.&Williams, W.S.The nature of the acceptor centre in semiconducting diamond.J.Phys.C.4 1789-1800 (1971) [2]Chrenko,R.M.Boron, the Dominant acceptor in semiconducting diamond.Phys.Rev.B7 4560-4567 (1973) [3]Ekimov,E.A. et al . Superconductivity in diamond. Nature, 428, 542 - 545(2004).

9:15 AM B7.4
Diffusion Length of Minority Carriers in Sulfur-Doped Microcrystalline and Nanocrystalline Diamond using the Photo-Grating Technique. Fabrice Piazza[1], Aurora Jimenez[1], Guillermo Nery[1], Luis F. Fonseca[1] and Gerardo Morell[2]; [1]Dept of Physics, University of Puerto Rico, San Juan, Puerto Rico; [2]Dept of Physical Sciences, University of Puerto Rico, San Juan, PR, Puerto Rico.

Diamond is a promising wide band gap semiconductor with a strong potential for high-power high-temperature electronics. There is also

great interest in reproducibly obtaining n-type diamond in connection to applications requiring massive electron transport, especially those involving field electron emission and photoemission, which will be enabled by n-type diamond. We recently succeeded in making n-type diamond by sulfur doping [S. Gupta, B.R. Weiner, G. Morell, Applied Physics Letters 83, 491, 2003]. Now we are employing the steady-state photocarrier grating technique to measure the photoconductivity and ambipolar diffusion length of carriers in sulfur-doped microcrystalline diamond (μc-D:S) and nanocrystalline diamond (n-D:S) thin films synthesized by hot-filament chemical vapor deposition (HFCVD). The films are grown using methane (CH4), hydrogen (H2) and hydrogen sulfide (H2S) gas feedstocks. The process parameters such as substrate temperature and concentration of hydrogen sulfide are systematically varied while the methane concentration is fixed at 0.3 and 2 % for μc-D:S and n-D:S, respectively, to study the corresponding variation on the nanostructure and electronic properties. The nanostructure is analyzed using scanning electron microscopy, atomic force microscopy, X-ray diffraction analysis, X-ray photoelectron spectroscopy, Auger electron spectroscopy, and visible and UV Raman spectroscopy. The results are employed to elucidate the mechanism of n-type conductivity in these sulfur-doped diamond films.

9:30 AM B7.5
Low-Energy Electron Microscopy Study of SiGe Film Relaxation on Ultra-Thin Silicon-on-Insulator. Bin Yang, Michelle M. Roberts, Chanan Euaruksakul, Don E. Savage and Max G. Lagally; University of Wisconsin-Madison, Madison, Wisconsin.

Devices involving films with compressive or tensile strain and built on silicon-on-insulator (SOI) in some cases are and others soon will be reality for CMOS. The channel carrier mobility can be improved by reduction of dislocations in such films. In efforts to understand and perhaps control dislocation formation and motion at complex multiple-interface systems, we use low-energy electron microscopy (LEEM) to compare strain relaxation of SiGe thin films grown on thin SOI and bulk Si substrates. 50nm Si0.95Ge0.05 films are grown on a hybrid substrate composed of a pattern of thin SOI and bulk Si mesas, created from SOI by etching selected regions down to the Si handle wafer. The regions are both large enough so edge effects can be neglected in dislocation behavior and film relaxation, and far enough apart so one type does not affect the other. Using this substrate, we are able to demonstrate dislocation formation under identical conditions for both substrates, avoiding critiques that differing thermal, stress, or environmental conditions may affect the results. On bulk Si, the critical thickness for Si0.95Ge0.05 is greater than 50nm and this film is therefore thermodynamically stable. We confirm dislocations forming in the SiGe film on thin SOI, at densities lower than any other technique is capable of showing, with nearly none forming in the bulk-Si regions. Also, on thin SOI misfits are much longer than for dislocations that form above the critical thickness on bulk Si. These results agree with recent models of dislocation core spreading at the Si/oxide interface [1]. Our LEEM observations suggest, however, that the dislocation line tension is reduced, but not removed, by the buried oxide. Our observations have direct implications for the fabrication of strained layer devices on SOI substrates. Supported by NSF [1] E. M. Rehder, C. K. Inoki, T. S. Kuan, and T. F. Kuech, JAP 94, 7892 (2003)

9:45 AM B7.6
Nucleation and Growth Issues of Atomic Layer Deposited HfO2 on HF Last, NH3 and O3 Surface Preparations Using Hf[N(CH3)C2H5]4 + O3 AND HfCl4 + H2O.
Paul Daniel Kirsch[1], Jim Gutt[1], Sundar Gopalan[1], Hong-Jyh Li[1], Jeff Peterson[1], Patrick Lysaght[1], Mark I. Gardner[1], Michael C. Chudzik[2], Qi Wang[3], Jinhong Shin[3], Darren Gay[3], John G. Ekerdt[3], Nan Lu[4] and Dim-Lee Kwong[4]; [1]Front End Processes (FEP), International Sematech, Austin, Texas; [2]IBM Microelectronics, Hopewell Junction, New York; [3]Texas Materials Institute, The University of Texas at Austin, Austin, Texas; [4]Department of Electrical and Computer Engineering, The University of Texas at Austin, Austin, Texas.

Atomic layer deposited (ALD) HfO2 films have been grown using two precursor sets Hf[N(CH3)C2H5]4 + O3 and HfCl4 + H2O. Films were studied as a function of cycle number on HF last, NH3 and ozone surface preparations. Hf[N(CH3)C2H5]4 + O3 films were characterized with Rutherford backscattering (RBS), low energy ion scattering (LEIS), X-ray photoelectron spectroscopy (XPS) and transmission electron microscopy (TEM). This materials analysis is then correlated with electrical results from metal oxide semiconductor (MOS) capacitors. RBS indicates that ALD with Hf[N(CH3)C2H5]4 and O3 proceeds similarly on the three surfaces, including HF last. Specifically, RBS indicates a small incubation period, a fractional coverage/cycle = 0.20 and a small increase in growth rate near 25 cycles for the three surfaces. According to LEIS, 25 cycles are needed to fully quench the Si signal from a HF last surface, indicating surface coverage at that point. Consistent with RBS and LEIS, XPS suggests that two different near surface regimes exist during ALD growth. One surface is heterogeneous (SiOx and HfOx) below 25 cycles and the second is a homogeneous surface (HfOx) above 25 cycles. After 5 cycles, XPS shows the O 1s peak position is intermediate to Si-O and Hf-O at 531.7 eV, but by 25 cycles, the O 1s peak position shifts to 531.0 eV indicative of Hf-O bonding. The O 1s peak position does not change beyond 25 cycles suggesting that a homogeneous film is formed in the near surface region. High resolution TEM and low magnification TEM suggest that smooth, continuous films near 2.5 nm are feasible. Capacitor results as a function of ALD cycle show EOT scaling below 1.0 nm. Because RBS shows fractional coverage/cycle = 0.20 and LEIS shows 25 cycles are needed to cover the surface, we suggest some three-dimensional growth does occur with Hf[N(CH3)C2H5]4 + O3 before the substrate is completely covered. The independence of RBS Hf coverage to surface preparation is attributed to surface oxidation during the first O3 half cycle. LEIS, RBS, and XPS results for Hf[N(CH3)C2H5]4 + O3 will be compared with those for HfCl4 + H2O. Additionally, a non-contact technique using deposited thermalized ions is applied to the film growth mode for Hf[N(CH3)C2H5]4 + O3 and HfCl4 + H2O.

10:30 AM *B7.7
Prospect for III-Nitride Heterojunction MOSFET Structures and Devices. M.A.L. Johnson[1], D.W. Barlage[2] and W.D. Braddock[3]; [1]Material Science and Engineering, North Carolina State University, Raleigh, North Carolina; [2]Electrical and Computer Engineering, North Carolina State University, Raleigh, North Carolina; [3]OSEMI Inc., Rochester, Minnesota.

The development of heterojunction field effect transistors (HFET) for high-frequency and high-power electronics has been an area of active semiconductor materials research in recent years as a key enabling technology for applications ranging from wireless communications to power distribution. III-Nitride semiconductors are a leading candidate for fulfilling the material requirements of these devices based on the combination of large bandgap energy, high thermal conductivity, high electron mobility and saturated electron velocity. While III-Nitride HFETs have demonstrated remarkable advances, serious materials related limitations still exist, primarily related to charge states and trapping effects at the semiconductor surface. Several groups have investigated solutions such as the deposition of dielectric passivation layers and asymmetric field-plate gate geometries for controlling the influence of trap states near the gate-drain region of the metal/semiconductor FET interface. Recently, we have demonstrated a metal-oxide semiconductor FET (MOSFET) with a substantially unpinned interface which is capable of establishing substantial charge accumulation under the gate. These III-Nitride MOSFETs may be designed to operate in either depletion mode or enhancement mode. GaN/InGaN heterojunction MOSFETs exhibit enhancement mode peak transconductance at gate voltages Vg>+5V, corresponding to energy greater than the bandgap of the underlying semiconductor which provides strong evidence of an unpinned MOS interface. Additionally III-Nitride MOSFETs eliminate the need for field plate gate structures as the electric field geometry in the gate-drain region changes limiting the tunneling of charge to unfilled surface states. In depletion mode, low-rf dispersion InGaN/GaN MOSFETs exhibit excellent microwave performance with ft = 8GHz for optically defined gates dimensions. The development of a compound semiconductor MOSFET has been a 40 year scientific challenge and the demonstration of such a device represents a milestone for the materials research community. In this paper, we will review the history of compound semiconductor MOSFET development and overlaying these developments with recent advances in the III-Nitride materials and device research. With the fundamentally different crystal symmetry for III-Nitrides relative to all other compound semiconductors and the epitaxial deposition of gate-oxides such as Gadolinium Gallium Oxide (GGO), the convergence of these two technologies opens the possibility for dramatically improved devices for use at microwave and mm-wave frequencies as well as power MOSFET rectifiers. We will benchmark initial III-Nitride MOSFETs results relative to competing electronic devices in providing a roadmap for advancement. Additionally, we will identify key materials related research issues which are expected to impact the ongoing scientific development of III-Nitride MOSFETs.

11:00 AM B7.8
High Temperature Capping Materials for Dopant Activation in SiC Based Devices. Shiva Hullavarad[1], R. D. Vispute[1], K. Jones[2], M. Ervin[2] and T. Venkatesan[1]; [1]Center for Superconductivity Research, University of Maryland, College Park, Maryland; [2]Army Research Laboratory, Adelphi, Maryland.

Silicon Carbide (SiC) is a wide band-gap semiconductor highly suitable for high temperature, high power devices. However, the high resistance of Ohmic contacts to p-type SiC has limited their application. Through selective implantation, the SiC is doped with Al and Al/C so that p-type regions exist only where the Ohmic contacts will be made, which in theory provides for a better contact with lower

resistance. The high temperature implant annealing requires a capping procedure used to restrict surface-damaging silicon evaporation; however, the surface stoichiometry changes and the surface deteriorates at such temperatures, rendering it useless in device fabrication. Capping SiC with the temperature resistant material AlN protects its stoichiometry at these extreme temperatures. An alternative material for capping, WC, also shows promising physical properties for high-temperature processes. In this study we deposit AlN, TaC, BN and WC as capping materials for SiC based power devices. The surface morphology of the cap materials is studied before and after annealing. Also the etching process to get rid of the cap materials after annealing is studied by chemical method and reactive ion etching methods. The etch rates for these cap materials is developed.

11:15 AM B7.9
Effects of Metal Gate Thickness on the Electrical Characteristics of Hafnium Silicate MOSFETs.
Hye-Lan Lee, Hag-Ju Cho, Seong Geon Park, Hong Bae Park, Taek Soo Jeon, Beom Jun Jin, Sang Bom Kang, Yu Gyun Shin, U In Chung and Joo Tae Moon; Samsung Electronics Co.,Ltd., Yongin, South Korea.

High-k gate dielectrics have been intensively studied as a replacement for the conventional SiO2 dielectric having a serious gate leakage problem for future applications. Furthermore, metal gates with suitable workfunctions are expected to resolve many problems of high-k gate dielectric MOSFET such as poly-depletion and fermi-level pinning. In this study, TaN was evaluated as a metal gate for hafnium-silicate (HfSiO) MOSFETs. In particular, the effects of TaN thickness on both electrical characteristics of MOSFETs and reaction between TaN and poly-Si gate upon post annealing were investigated. 30-100Å thick TaN films were deposited by CVD method with TAIMATA precursor at 500°C, and followed by poly-Si deposition at 620°C by low pressure CVD. A standard CMOS integration process was used to fabricate HfSiO MOSFETs. It was found that the poly depletion was eliminated by TaN metal gate, and EOT was reduced as the film thickness was decreased. HfSiON-MOSFET with TaN metal gate exhibited 30% higher drain current compared to poly-Si gate, which can be explained by reduced EOT and improved mobility. In addition, threshold voltage (Vth) was reduced by 300mV in P-MOSFET with 100Å TaN gate. On the other hand, Vth reduction was altered depending on the the thickness of TaN. When 30Å-thick TaN gate was used, Vth was reduced by only 150mV compared to poly-Si. It was attributed to the different thermal reaction between TaN and poly-Si or high-k as evidenced by X-ray photoelectron spectroscopy (XPS). Therefore, the thickness of TaN is an important factor for engineering the threshold voltage of MOSFETs with high-k gate dielectric and metal gate.

11:30 AM B7.10
Ab-Initio Calculation of Electron Mobilities in Ultrathin SOI MOSFETs.
Matthew H. Evans[1,2], John D. Joannopoulos[1] and Sokrates T. Pantelides[2,3]; [1]Dept. of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]Dept. of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee; [3]Solid State Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Ultrathin silicon-on-insulator (SOI) technology has emerged as a key candidate for sub-100nm gate length CMOS devices. Recent experiments have characterized MOSFETs with silicon channels as thin as 1nm (four atomic layers of silicon), and found them to be well-behaved electrically. Quantum effects are crucial to the electron transport in such devices, and the penetration of the electron wavefunction into the gate oxide introduces important new scattering mechanims. We introduce here a novel method for ab-initio calculation of electron mobilities in ultrathin SOI channels, including surface roughness and defect scattering. The electronic structure and scattering potentials are calculated with density functional theory in the local density approximation (DFT-LDA), and the mobility is calculated through Green's functions. The method requires little computational effort beyond that of the DFT-LDA calculations, and allows the calculation of temperature and carrier concentration dependent mobilities. Since the silicon-oxide interface is treated at the atomic-scale, the mobility contributions of different defects (e.g. suboxide bonds, oxide protrusions) and impurities (e.g. nitrogen, hydrogen) can be calculated separately, giving a precise physical picture of channel electron transport.

11:45 AM B7.11
Nickel-Silicide Workfunction Tuning Study In Metal-Gate CMOS Applications.
Jun Yuan, Jason Woo and Grant Pan; Electrical Engineering Department, University of California, Los Angeles, Los Angeles, California.

Full silicidation of polysilicon gate is very promising in the nanoscaled MOSFET due to the reduced gate resistance and poly-depletion-effects. Nickel-silicide is an excellent candidate because of its low silicidation temperature and no linewidth dependence of resistance. However, the proper work-function (WF) is needed for both NMOS and PMOS. In this paper, the WF tuning for Nickel-silicide on oxide is studied in details, including anneal temperature/time and Arsenic (As) doping segregation effects. The same flatband voltage was obtained for Ni-silicide formed with 450C@ 5 30mins, and the extracted WF is 4.71 eV, which is close to the mid-gap, and RBS analysis shows that it is mono-Ni-silicide layer close to the oxide interface. However, 450C@1min annealed Ni-silicide has lower WF, and RBS analysis reveals that the Ni-silicide layer close to oxide is silicon-riched due to the insufficient silicidation. High temperature annealed Ni-silicide (600C 800C) has higher WF, and RBS reveals that the Ni:Si >1 in this Ni-silicide. Pre-As doped polysilicon is observed to effectively change the WF of the subsequently formed Ni-silicide, and SIMS analysis demonstrates that As doping segregation at the oxide interface after Ni-silicidation is the root cause. The WF of Ni-silicide is overall reduced when the As dose is increased. When the As dose is increased to 5e15cm-2, the WF shift of Ni-silicide (450C@5 30mins) can be as high as 0.25eV (actually this WF shift begins to saturate when As dose is getting to 2.5e15cm-2), but the WF shift of Ni-silicide (450C@1min) increases all of the way to 0.35eV. It is also the first time to report that the Ni-silicide WF modulation from As segregation is related with the As pre-activation temperature, low annealing temperature results in less WF shift, the just-implanted As (without activation) has negligible effect on the WF shift of Ni-silicide.

SESSION B8: ZnO I
Chairs: Jagadish Chennupati and Takafumi Yao
Thursday Afternoon, December 2, 2004
Constitution A (Sheraton)

1:30 PM B8.1
Nanodevices using Single ZnO Nanowire.
Young-Woo Heo[1], Byoung Sam Kang[2], L.C. Tien[1], Yongwook Kwon[1], J.R. La Roche[2], B. P. Gila[1], F. Ren[2], S. J. Pearton[1] and D. P. Norton[1]; [1]Materials Science and Engineering, University of Florida, Gainesville, Florida; [2]Chemical Engineering, University of Florida, Gainesville, Florida.

Single ZnO nanowire devices, including Pt Schottky diodes and metal-oxide semiconductor field effect transistors (MOSFETs), were fabricated using nanowires grown on Au-coated Al2O3 substrates by catalyst-driven site selective Molecular Beam Epitaxy. Al/Pt/Au metals are used for ohmic contacts of ZnO nanowire. Gate oxide of MOSFETs is amorphous (Ce, Tb)MgAl11O19 with 50nm thickness. The Pt Schottky diodes exhibit excellent ideality factors of 1.1 at 25°C and very low (1.5x10 -10A , equivalent to 2.35 A.cm-2, at -10V) reverse currents. The nanowire diodes show a strong photoresponse, with the current-voltage characteristics becoming Ohmic under ultra-violet(UV) illumination(366nm light). When measured in the dark at 25°C, the depletion-mode transistors exhibit good saturation behavior, a threshold voltage of -3V and a maximum transconductance of order 0.3 mS/mm. Under ultra-violet (366nm) illumination, the drain-source current increase by approximately a factor of 5 and the maximum transconductance is 5 mS/mm. ZnO nanowire depletion mode MOSFETs show excellent pinch-off and saturation characteristics and a strong UV photoresponse. The ZnO nanowires appear to be promising vehicles for functional nano-devive fabrication.

1:45 PM B8.2
Fabrication and Electrical Characteristics of High Performance ZnO Nanorod Field Effect Transistors.
Won Il Park[1], Cyu-Chul Yi[1], Myung-Ho Bae[2] and Hu-Jong Lee[2]; [1]Materials Science and Engineering, Pohang University of Science and Technology (POSTECH), Pohang, Gyeongbuk, South Korea; [2]Physics, POSTECH, Pohang, South Korea.

ZnO semiconductor nanowires and nanorods are attractive components for nanometer scale electronic and photonic device applications. Recently, a wide variety of nanodevices including ultraviolet photodetectors, Schottky diodes, and light emitting device arrays have been fabricated utilizing ZnO nanorods (nanowires). In particular, a field effect transistor (FET), one of the most fundamental and important electronic components, has been fabricated using a ZnO nanobelt. However, electrical characteristics of the ZnO-based nanodevice were much poorer than those of epitaxial thin film devices, presumably due to poor contacts between the nanowires and source-drain electrodes and undesirable surface effects. Hence, a transconductance and a switching current ON/OFF ratio of the ZnO FET were as low as a few nS and 100, respectively. However, we recently fabricated high performance ZnO nanorod FETs exhibiting high mobility over 1000 cm^2/Vs, transconductance of 1.9 μS, and a large turn-ON/OFF ratio of 10^4-10^5. ZnO nanorod FETs were fabricated by using high quality ZnO nanorods and e-beam

lithography. Single crystal ZnO nanorods were prepared on Si or sapphire substrates using catalyst-free metal-organic vapor phase epitaxy (MOVPE), and then dispersed on SiO_2/Si. A silicon oxide layer was employed as an insulating gate oxide layer on a heavily doped n-type silicon substrate. Good ohmic contacts were made on the nanorod ends. ZnO nanorod FETs exhibited good electrical characteristics, high mobility over 1000 cm^2/Vs, and a large turn-ON/OFF ratio of 10^4-10^5 with a maximum ON state current of 7.5 μA. High performance nanoscale FETs obtained in this study show the feasibility of semiconductor oxide based nanorods for electronic nanodevice applications.

2:00 PM B8.3
Patterned Growth of ZnO Nanowire Arrays: Preparation, Electrical and Spatial Resolved Luminescence Characterizations. Hong Jin Fan[1], Woo Lee[1], Kornelius Nielsch[1], Margit Zacharias[1], Frank Bertram[2], Armin Dadgar[2], Juergen Christen[2] and Alois Krost[2]; [1]Max Planck Institute of Microstructure Physics, Halle, Germany; [2]Institute of Experimental Physics, Otto-von-Guericke-University, Magdeburg, Germany.

We report the successful large-scale patterned growth of ZnO nanowire arrays on doped GaN/Si substrates by combining substrate micro-/nano-patterning and the vapor-liquid-solid (VLS) growth process. In a first step, ordered catalytic Au dot arrays on the substrates were obtained by using a membrane of ordered nanoholes as shadow mask for Au thermal evaporation. This novel type of shadow mask was obtained from an electrochemical duplication process of a macroporous Si or porous alumina membrane. Subsequent growth of ZnO via a VLS epitaxial process results in vertically-aligned and ordered ZnO nanowires. The diameter and separation of the nanowires are adjustable by using shadow mask with different hole size and inter-hole distances. The microscopic correlation of structural and optical properties of the ZnO nanowires was realized by scanning cathodoluminescence spectroscopy. Carrier transport property through the n-ZnO/p-GaN heterojunction nanowire arrays has been investigated with the I-V characteristics and electroluminescence. In addition, the electrical and optical properties of individual nanowires will be shown.

2:15 PM B8.4
Preparation and Characterization of Ultraviolet Light Emitting ZnO Nanoparticles. Yuntao Li[1], Richard D. Yang[2], Hung-Jue Sue[1], Nobuo Miyatake[3] and Riichi Nishimura[3]; [1]Department of Mechanical Engineering, Texas A&M University, College Station, Texas; [2]Department of Chemistry, Texas A&M University, College Station, Texas; [3]KANEKA Texas Corporation, Pasadena, Texas.

A new, versatile and simple approach is utilized to obtain highly concentrated ZnO nanoparticles with narrow size distribution in the size range from 2 to 5 nm. Various hydroxide and alcohol mixtures, such as KOH, NaOH, LiOH, methanol, ethanol and isopropanol, can also be utilized to form ZnO nanoparticles successfully by this method. The particle growth is found to be pH, reaction time and temperature dependent. Furthermore, the dry powders of ZnO nanoparticles prepared show a strong blue-shifted near-band-edge ultraviolet emission, and the size and size distribution of the particles did not change much during solvent evaporation. Raman spectra show ZnO $E_2^{(2)}$(TO) phonon mode and other vibration modes are attributed to the acetate group. The CO stretching mode in the Raman spectra is red-shifted to 1401 cm^{-1}, indicating a strong adsorption of the ligand onto ZnO surfaces. The adsorption removes oxygen vacancies from the surface and eliminates the impurity-induced green luminescence from the nanoparticles.

2:30 PM *B8.5
ZnO Spintronics and Nanowire Devices. David P. Norton[1], Young-Woo Heo[1], L. C. Tien[1], M. P. Ivill[1], Y. Li[1], Byoung Sam Kang[2], Fan Ren[2], J. Kelly[3], A. F. Hebard[3] and Stephen Pearton[1]; [1]MSE, University of Florida, Gainesville, Florida; [2]Chemical Engineering, University of Florida, Gainesville, Florida; [3]Physics, University of Florida, Gainesville, Florida.

ZnO is a very promising material for spintronics applications, with many groups reporting room temperature ferromagnetism in films doped with transition metals during growth or by ion implantation. In films doped with Mn during PLD, we find an inverse correlation between magnetization and electron density as controlled by Sn doping. The saturation magnetization and coercivity of the implanted single-phase films were both strong functions of the initial anneal temperature, suggesting that carrier concentration alone cannot account for the magnetic properties of ZnO:Mn and factors such as crystalline quality and residual defects play a role. Plausible mechanisms for the ferromagnetism include the bound magnetic polaron model or exchange is mediated by carriers in a spin-spilt impurity band derived from extended donor orbitals. We will also review progress in ZnO nanowires. The large surface area of nanorods makes them attractive for gas and chemical sensing, and the ability to control their nucleation sites makes them candidates for micro-lasers or memory arrays. Single ZnO nanowire depletion-mode metal-oxide semiconductor field effect transistors exhibit good saturation behavior, threshold voltage of -3V and a maximum transconductance of 0.3 mS/mm .Under UV illumination, the drain-source current increased by approximately a factor of 5 and the maximum transconductance was 5 mS/mm. The channel mobility is estimated to be 3 cm2 /V.s, comparable to that for thin film ZnO enhancement mode MOSFETs and the on/off ratio was 25 in the dark and 125 under UV illumination. Pt Schottky diodes exhibit excellent ideality factors of 1.1 at 25 C , very low reverse currents and a strong photoresponse, with only a minor component with long decay times thought to originate from surface states. In the temperature range from 25-150 C, the resistivity of nanorods treated in H2 at 400 C prior to measurement showed an activation energy of 0.089 eV and was insensitive to the ambient used . By contrast, the conductivity of nanorods not treated in H2 was sensitive to trace concentrations of gases in the measurement ambient even at room temperature, demonstrating their potential as gas sensors.

3:30 PM *B8.6
Electrical and Optical Properties of n-Type and p-Type ZnO. David C. Look[1,2] and Bruce B. Claflin[1,2]; [1]Semiconductor Research Center, Wright State University, Dayton, Ohio; [2]Materials and Manufacturing Directorate, Air Force Research Laboratory, Dayton, Ohio.

In recent years, ZnO has been proposed for new electronic and optoelectronic devices, such as transparent transistors and UV light-emitting diodes (LEDs). Successful realization of these devices will require a detailed understanding of the materials. Undoped ZnO is nearly always n-type, and excellent bulk material can be grown from the vapor phase (VP), with typical room-temperature resistivity $\approx$ 0.3 Ω-cm, mobility $\approx$ 225 cm^2/V-s, and carrier concentration n $\approx$ 1 x 10^{17} cm^{-3}. Two shallow donors are often seen, with activation energies of 30 $-$ 40 meV, and 60 $-$ 70 meV, respectively. The shallowest of these is thought to be interstitial H, and the deeper one, probably substitutional Al or some other Group III element. The dominant acceptor in the VP-grown material is the Zn vacancy V_{Zn}, although N_O is also present, at even higher concentrations. However, it is likely that N_O is passivated with H. Strong donor-bound-exciton (D^0X) photoluminescence peaks are observed at 3.357 (I9), 3.360 (I6), and 3.363 eV (I4). Associated two-electron satellite lines are also present. The identity of I9 is controversial, while I6 and I4 are probably due to Al and H, respectively. Attempts to produce p-type ZnO have usually involved doping with N, because it should readily substitute for O and not distort the lattice significantly. From temperature-dependent Hall-effect measurements on an MBE-grown, p-type, homoepitaxial layer with [N] $\approx$ 10^{19} cm^{-3}, an acceptor activation energy E_A of about 90 meV has been measured. From simple screening considerations, the energy of an isolated N_O acceptor would then be about 130 - 150 meV. Besides N, the dopants P, As, and Sb have also been successfully used to make p-type ZnO. This is somewhat surprising, because these elements have ionic radii much larger than that of O. In the case of As, a recent theoretical study has suggested that the relevant acceptor is not the simple substitutional impurity As_O, but a rather complicated impurity-defect complex, As_{Zn}-$2V_{Zn}$. This complex is predicted to have a relatively low formation energy, and an acceptor ionization energy of about 150 meV, both of which are consistent with the sparse experimental data available so far. Photoluminescence measurements in p-type ZnO, heavily doped with acceptors, give broader and weaker lines than those in n-type ZnO. Often the D^0X lines spectral features at 3.357 and 3.367 eV are emphasized, and a new line appears at 3.31 eV. This new line seems to have either A^0X or D^0-A^0 character, but its identity is uncertain. Possible compensating centers in p-type ZnO include the donors H, V_O, and Zn_I, with H also serving as a passivating center. If H indeed passivates the acceptor dopants during the growth process, then the deleterious compensating centers may not be generated at all, and the H can be eliminated by annealing. This mechanism may be partially responsible for the recent successful realization of some UV LEDs based on ZnO.

4:00 PM B8.7
Towards p-type doping of ZnO by ion implantation. Victoria Anne Coleman[1], H. H. Tan[1], C. Jagadish[1], S. O. Kucheyev[2] and J. Zou[3]; [1]Department of Electronic Materials Engineering, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, Australian Capital Territory, Australia; [2]Lawrence Livermore National Laboratory, Livermore, California; [3]Division of Materials, School of Engineering, The University of Queensland, Brisbane, Queensland, Australia.

ZnO is a very attractive material for a range of (opto)electronic

devices including blue light-emitting diodes and laser diodes, due to its large exciton binding energy. Though n-type doping has been successfully achieved, p-type doping of ZnO is still a challenge that must be overcome before p-n junction devices can be realized. Ion implantation is widely used in the microelectronics industry for selective area doping and device isolation. Understanding damage accumulation and recrystallization processes is important for achieving selective area doping. In this study, As (potential p-type dopant) ion implantation and annealing studies were carried out. Samples were implanted with high dose (5 X 10^{16} ions/cm^2) 300 keV As ions at room temperature. Rapid thermal annealing (RTA) of samples in the range of 400^oC to 1000^oC was employed to achieve recrystallization of amorphous layers and electrical activation of the dopant. Rutherford backscattering/channelling and transmission electron microscopy were used to monitor damage accumulation and annihilation behavior in the single crystal ZnO. The results of this study have significant implications for p-type doping of ZnO by ion implantation.

4:15 PM B8.8
Effect of Hydrogen Plasma Treatment on Electron Emission of ZnO Nanoneedles. Jinkyoung Yoo, Won Il Park and Gyu-Chul Yi; Materials Sci. & Eng., POSTECH, Pohang, South Korea.

ZnO 1-D nanostructures, among many semiconductor 1-D nanostructures, have attracted much attention because of their excellent electronic and optical properties, offering great potential as building blocks for nanoscale electronic and photonic device applications. For many device applications, defect and doping controls over a wide range must be accomplished. However, to date, dopings of 1-D nanostructures have rarely been investigated, presumably due to difficulty in preparation of high purity nanomaterials and limited doping methods. Here we introduce a simple hydrogen-plasma post-treatment to change the electron emission and electrical properties of ZnO nanoneedles. High quality and vertically well aligned ZnO nanoneedle arrays were prepared on large-scale Si substrates by metal-organic chemical vapor deposition. After the growth, ZnO nanoneedle arrays were plasma-treated under hydrogen flow using a radio frequency (RF)-plasma generator. After the hydrogen plasma treatment, field emission characteristics were measured using parallel-plane geometry. The field emission measurements showed that hydrogen plasma treatment greatly enhances field emission characteristics such as turn-on field and enhancement factor of ZnO nanoneedles. Through a series of electron emission and analytic characterizations of hydrogen plasma treated ZnO nanoneedles, we demonstrate that hydrogen plasma treatment is a useful post-treatment for enhancing electron emission properties of ZnO nanoneedles without damage of aspect ratio and morphology.

4:30 PM B8.9
Experimental Analysis and Theoretical Model for Anomalously High Ideality Factors in Diamond/ZnO p-n Junction Diode. Cheng-Xin Wang and Guo-Wei Yang; State key laboratory of optoelectronic materials and technologies, School of Physics Science & Engineering, Zhongshan University, Guangzhou 510275, P. R. China, Guangzhou, China.

Due to the ever-increasing commercial desire for short wavelength light emitting devices, wide-band-gap semiconductors such as II-VI group semiconductors and diamond have attracted a great deal of attention and have become interesting and potential candidates for blue and ultraviolet light-emitting diodes and lasers. Among the candidates, ZnO and diamond are special, because they have a substantial advantage over other wide-band-gap semiconductor materials. For instance, ZnO has the larger exciton binding energy (60meV) that is about three times as large as that of GaN, and exciton binding energy of diamond is about 80 meV. In principle, these characteristics allow exciton-government short-wavelength light emitting devices to work at room temperature. However, up to date, ZnO and diamond have suffered from the lack of p-type and n-type semiconductor, respectively. Although much progress has been made in the areas, the fabrication of effective ZnO-based and diamond-based light-emitting homo-junction diodes still wait for the further development of the preparation of good, reproducible, p-type and n-type materials, respectively. Therefore, presently, besides seeking effective method to synthesize reproducible p-type ZnO and n-type diamond, naturally, a combination of p-type diamond and n-type ZnO was proposed to be an alternative and attractive route to overcome the doping bottleneck of both wide-band-gap semiconductors. However, to our best knowledge, the combination of the great potential two wide-band-gap semiconductors to fabricate hetero-junction light emitting diodes has not been reported in the literature. Very recently, the fabrications of the heterojunctions of ZnO/diamond and cubic boron nitride/diamond have been attempted in our group. Notably, we have not only successfully fabricated p-type diamond and n-type ZnO hetero-junction diode, but also the prepared diode has excellent rectifying characteristic. Accordingly, we reasonably expected that the combination of two wide-band-gap semiconductors would be a effective way to fabricate hetero-junction light emitting devices for those semiconductors that their partners have doping problem. It is therefore essential to gain a better understanding to electrical property of the p-n junction diode above. In this letter, we reported that the anomalously high ideality factors in the interim bias voltage range were measured in the ZnO/diamond p-n junction diode. Moreover, the detailed electronic characterizations of the p-n junction were conducted, and a theoretical model based on Shah theory was proposed to clarify the much high ideality factors. Importantly, the model was in excellent agreement with the experimental data.

4:45 PM B8.10
ZnO nanorod sensor for detection of biotin-streptavidin interaction. Jin Suk Kim, Won Il Park and Cyu-Chul Yi; Materials Science and Engineering, Pohang University of Science and Technology (POSTECH), Pohang, Gyeongbuk, South Korea.

Nanosensors based on semiconductor nanostructures such as nanocrystal thin films, single-wall carbon nanotubes, and nanowires have recently received considerable attention. Among the variety of systems, the sensors based upon one-dimensional semiconductor electronic devices have been demonstrated as good candidates for ultra-sensitive biosensor applications. In particular, the high surface-to-volume ratio of the nanostructures increases the nanosensor sensitivity. However, most semiconductor surfaces are unstable in an air environment, which leads to formation of an insulating native oxide layer and degradation of device sensitivity. Herein we present the use of air-stable and single crystal ZnO nanorod nanosenors for highly sensitive biological detection. Single crystal ZnO nanorod platforms were prepared for highly specific electronic biomolecule detectors investigating protein-receptor interactions, for example, biotin-streptavidin interaction. For the fabrication of bimolecule nanosensors, single crystalline ZnO nanorods were prepared using catalyst-free metal-organic vapor phase epitaxy. Using the e-beam lithography technique, metal micropatterns were fabricated on a single ZnO nanorod. Conductance of the biosensors was drastically increased upon exposure to streptavidin, resulting presumably from the charge transfer due to biotin-streptavidin interaction. This result indicates that ZnO nanorod biosensors are a promising candidate for electrical detection of biological species with high sensitivity.

SESSION B9: Poster Session
Chairs: Robert Biefeld, Gail Brown, Claire Gmachl, Omar Manasreh and Karl Unterrainer
Thursday Evening, December 2, 2004
8:00 PM
Exhibition Hall D (Hynes)

B9.1
Alloying and Ostwald Ripening Kinetics of CdSe/ZnSe and CdS/ZnS Core-Shell Nanocrystals. Yun-Mo Sung, Yong-Ji Lee, Kyung-Soo Park, Jung-Jun Na and Kyung-Woo Kim; Materials Sci. & Eng., Daejin University, Pochun-si, Kyunggi-do, South Korea.

Semiconductor nanocrystals (CdSe, CdS, CdTe, ZnS, ZnSe, ZnTe, etc.) have been intensively studied for their unique photo absorption and emission characteristics. They show specific quantum confinement effects and thus show visible range emission depending on each particle size. To improve quantum efficiency a semiconductor nanocrystal core is often covered with another semiconductor shell with a high-energy band gap. Some research results show that alloying of two semiconductors can improve photoemission stability of nanocrystals compared to core/shell structures. However, sometimes alloying of two semiconductors with different atomic size is incomplete and alloying effect is not fully achieved. In this study CdSe/ZnSe and CdS/ZnS core/shell nanocrystals were synthesized and further heated at different temperatures for different time periods. The kinetics of alloying was investigated using X-ray diffraction (XRD). The intensities of XRD peaks from CdSe and ZnSe decreased with alloying temperature and time. The XRD quantitative analyses were performed to obtain the volume fractions of alloying and these values were used for Johnson-Mehl-Avrami (JMA) isothermal kinetic analyses. The JMA plots were produced and Arrhenius plots were also produced using the y-intercepts of JMA plots. The activation energy for alloying was obtained and discussed based upon diffusion of Cd^{2+} ions in CdSe-ZnSe and CdS-ZnS systems. Also, a kinetics equation for Cd^{2+} ions was derived based upon a diffusion couple model. The diffusion rates of Cd^{2+} ions in ZnSe and ZnS, respectively were estimated and activation energy values for diffusion were determined. The activation energy values were compared with those from Arrhenius plots. Ostwald ripening kinetics during heat treatment was also studied for these core/shell nanocrystals using transmission electron microscopy (TEM) and photoluminescence (PL) analyses.

The activation energy for ripening was determined and compared with that of alloying. The alloying and ripening mechanisms were suggested in detail for the core/shell systems.

B9.2
New Routes To Metal Chalcogenide Nanostructures.
Paul Christian and Paul O'Brien; Chemistry, University of Manchester, Manchester, United Kingdom.

There is considerable current interest in the synthesis of metal chalcogenide nanostructred materials particularly for the manufacture of so called 3rd generation solar cells. The facile, large scale, synthesis of such materials is critical to enabling such technology. The synthesis of these materials, especially those of cadmium, has been widely discussed in the literature. However, whilst routes involving pyrophoric materials give high quality particles and structures, their inherent reactivity results in complications in handling, where as less reactive systems generally result in poorer size distributions. Further more there are in general problems in the synthesis of tellurium containing materials. This paper describes a new method providing a general synthesis of metal chalcogenide nanomaterials in a TOP/TOPO reaction system involving easy-to-handle reagents. Results for cadmium will for the basis of the discussion, which will include examples from a wider range of metals. The use of cadmium acetate in TOP and solutions of chalcogenides in TOP in the presence of suitable reducing agents provides an exceptionally reactive system. Using mass flow and seeding techniques all three chalcogenide nanomaterials may be produced. The system is highly flexible and may be applied to a wider range of chalcogenide based nanomaterials.

B9.3
Properties of Gallium Selenide Doped with Sulfur. Valeriy G. Voevodin[1], Svetlana A. Bereznaya[1], Zoya V. Korotchenko[1], Aleksandr N. Morozov[1], Sergey Yu. Sarkisov[1], Nils C. Fernelius[2] and Jonathan T. Goldstein[2]; [1]Semiconductor Materials Science Laboratory, Siberian Physico-Technical Institute, Tomsk, Siberia, Russian Federation; [2]Materials & Manufacturing Directorate, Air Force Research Laboratory, AFRL/MLPSO, WPAFB, Ohio.

This work presents the results of investigations on GaSe:S crystals grown by the Bridgman method from melts with content of sulfur of 0.01-3 mass %. Hall effect, thermally stimulated currents (TSC), optical absorption and microhardness measurements on S doped samples showed the following: a) a decrease in the conductivity and mobility with concentration of carriers: b) the appearance of two TSC peaks corresponding to centers with activation energies 0.36 and 0.41 eV for crystals containing 2 and 3 mass % of sulfur; c) a linear increase of the forbidden band gap with the changing of dopant concentration from 0.1 to 3 mass %; d) the appearance of two peaks of phonon absorption with energy maxima of 78.7 meV & 73.8 meV in addition to the three peaks at 67 meV, 63 meV & 59 meV observed in undoped crystals; e) a considerable residual conductivity after illumination; e) an increase in microhardness. The observed photoconductivity spectra of GaSe:S crystals show a band of intrinsic photoconductivity at 400-600 nm and two bands of impurity photoconductivity at 500-900 nm and 900-1700 nm. The 600-900 nm band, observable in the interval of sulfur concentration 0-1 mass %, consists of two elementary peaks with maxima at wavelengths 650 nm and 800 nm, which, apparently, are connected with intrinsic point defects of GaSe. Activation energies of these defects are 1.85 and 1.5 eV, respectively. The acceptor ionization energy, found from electrical measurements, is 0.12 eV. Photoconductivity in the region 900-1700 nm decreases as the sulfur content increases. The results are explained by assuming the formation of solid solutions GaSxSe1-x with the increase of sulfur concentration and relating it to the decrease of cation vacancies (acceptor levels in the forbidden band) and the increase of anion vacancies (donor levels in the forbidden band). The analysis of the results shows the presence, along with solid solution formation and crystal homogenization, of the competitive processes of point defects and structural disorder formation, which prevail in the 0.01-1 mass % concentration region.

B9.4
Nanometer sized Pb(Se,Te) islands and their crystallographic structures. Peter Moeck[1], Mukes Kapilashrami[1,2], Jeahuck Lee[3], James Morris[3], Nigel D. Browning[4] and Patrick McCann[5]; [1]Department of Physics, Portland State University, Portland, Oregon; [2]Department of Materials Science, The Royal Institute of Technology, Stockholm, Sweden; [3]Department of Electrical & Computer Engineering, Portland State University, Portland, Oregon; [4]Department of Chemical Engineering and Materials Science, University of California at Davis, Davis, California; [5]School of Electrical and Computer Engineering, University of Oklahoma, Norman, Oklahoma.

Tensibly strained nominal PbSe islands were grown on an (111) oriented PbTe/BaF2 pseudo-substrate by molecular beam epitaxy (MBE). The morphology and crystallographic structure of these islands were analyzed by means of atomic force microscopy (AFM) and transmission electron microscopy (TEM). On the basis of the AFM measurements, we distinguish between three different groups of island. The two groups of smaller islands are considered to be fully strained as they show the typical black-white and coffee-bean diffraction contrasts in the TEM. Their combined number density is approximately 2 x 10 to the power 10 cm-2. Larger islands, on the other hand, possess a number density of approximately 2 x 10 to the power 9 cm-2. Transmission electron diffraction pattern at different tilts, i.e. at [111] and [112] zone axes were consistent with Pb(Se,Te) in the halite structure. Regions with very small and essentially unstrained entities of an estimated diameter on order of magnitude 5 nm were also identified in the transmission electron microscope. We speculate that these entities consist of atomically ordered Pb(Se,Te) compounds.

B9.5
Spectroscopic ellipsometry study of CdSe and CdTe nanoparticles embedded in SiO2 films.
Padullaparthi Babu Dayal[1,2], Mehta Bodh Raj[1,2] and P. D. Paulson[2,1]; [1]Physics, IIT Delhi, New Delhi, Delhi, India; [2]Institute of Energy Conversion, University of Delaware, Newark, Delaware.

Semiconductor nanoparticles dispersed in glass matrix (SDGs) have attracted due to the unique properties of optical gain, bi-stability and ultra-fast relaxation time due to quantum confinement of charge carriers. Since the surface of the nanoparticles is made of a large number of atoms that are not fully co-ordinated, it is important to disperse nanoparticles in a protective medium. In case of SDGs, the optically transparent glass matrix provides an effective way of studying the optical properties while maintaining the individual nanoparticle characteristics and preserving the surface structure. SiO2 matrix diminishes the crystallite surface activity and supplies a stable chemical environment. Because of the possibility of achieving higher nanoparticles concentration, controlled nucleation and growth and better film uniformity, RF magnetron sputtering is a superior physical vapor deposition technique for making SDGs. In the present study, CdTe and CdSe semiconductor nanoparticles have been prepared by magnetron sputtering of high quality elemental Cd, Se and Te along with SiO2 targets. Post deposition annealing has been done in different ambinets of vacuum, air and nitrogen. The composition of the nanoparticles has been controlled using elemental targets of pre-decided target areas (in comparison to compound targets reported elsewhere) and the effect of post deposition annealing treatment on the size, structure and optical properties has been studied in detail. The structural and compositional characterization of nanoparticles has been done using glancing angle x-ray diffraction (GAXRD) and transmission electron microscopy (TEM) studies carried out on CdTe:SiO2 and CdSe:SiO2 nanoparticle samples clearly demonstrate the well controlled growth of nanoparticles in SiO2 films. The effect of nanoparticle size on optical properties of CdTe:SiO2 films has been studied using variable angle spectroscopic ellipsometry VASE technique on vacuum annealed samples. Optical constants have been determined using Tan $\Psi$and Cos Δ. Measured and fitted $\epsilon 1$ and $\epsilon 2$ dielectric spectra of CdTe nanoparticles have been estimated using four layer optical modeling using Bruggman Effective Medium Approximation. The dielectric response [second derivative of dielectric constant $\epsilon 2$ spectra ($\epsilon 2$")] of the CdTe nanoparticles show four critical points (E0, E0+Δ0, E1 and E1+Δ1) corresponding to the allowed optical transitions in the electronic band structure of CdTe. E0 is blue shifted by a very small amount and approaches the bulk value with the increase in the size of nanoparticles. Optical absorption studies carried out on CdTe: SiO2 and CdSe:SiO2 samples show formation of defect free and well-crystallized nanoparticles with excitonic features. In both cases the absorption edge has been blue shifted from the corresponding bulk band gap values, which has also been convincingly confirmed by photoluminescence studies.

B9.6
Development & Spectroscopic Characterization of Cr+2 Diffusion Doped ZnSe for Mid-Infrared Laser Applications.
Ivy Krystal Jones, Department of Physics, Hampton University, Hampton, Virginia.

Tunable mid-infrared (MIR) solid-state lasers are of considerable importance for various scientific applications, for instance laser atmospheric remote sensing, medical procedures, analytical spectroscopic techniques, and military related technologies. An attractive technology of MIR solid-state lasers is based on Cr2+ doped II-VI semiconductors (e.g. ZnSe, CdTe, CdMnTe). The main challenge to further optimize current Cr2+ lasers lies in the optimization of the Cr doping process, which ultimately can result in higher quality laser crystals. For the production of Cr2+ laser materials, Cr2+ ions are introduced via post-growth diffusion doping in a polycrystalline ZnSe window material. The objective of this research project is to optimize the Cr diffusion process in ZnSe (and other II-VI hosts) in terms of

furnace temperature, diffusion time, dopant source (Cr, CrSe, CrTe, and CrCl2), dopant purity, and dopant morphology. First experiments using CrSe as a dopant source have been carried out. Cr2+ ions were doped into ZnSe under isothermal conditions at 750 degrees celcius at 4 days. The absorption spectrum of Cr: ZnSe showed a characteristic broad absorption band peaking at 1.77 micrometer. Using a Tm fiber laser operating at 1.9 micrometer as the excitation source resulted in a broad MIR emission from 2000-3000 nm. The Cr2+ lifetime was determined to be around 5 to 7 microseconds at room temperature. The lifetime was nearly temperature independent, which suggests high emission efficiency at room temperature.

B9.7

Gallium Selenide: Large Single Crystal Growth and Characterization for THz Applications. Krishna C. Mandal[1], Caleb C. Noblitt[1], Michael Choi[1], R. David Rauh[1], Kai Liu[2], Caterina Soldano[2], Jingzhou Xu[2] and X. -C. Zhang[2]; [1]Materials Research Division, EIC Laboratories, Inc., Norwood, Massachusetts; [2]Center for Terahertz Research, Rensselaer Polytechnic Institute, Troy, New York.

In recent years there has been considerable interest in tunable monochromatic and ultra-broadband terahertz (THz) sources for biomedical diagnostics, THz spectroscopy and biochemical identification. Gallium selenide (GaSe) is one of the most promising materials for all these applications. However, there are significant problems associated both with growing large single crystals and with their unsatisfactory mechanical and optical qualities. Recently, we have been very successful of growing large single crystals (7.0 cm long and 2.0 cm diameter) by a vertical Bridgman technique using zone refined selenium and high purity gallium feedstocks. The grown GaSe crystals have shown promising characteristics as an efficient tunable THz source with good optical quality (absorption coefficient ⟨0.1 cm^{-1} in the spectral range of 0.62-18 μm). The crystals have been characterized thoroughly by X-ray diffraction (XRD), energy dispersive analysis by x-rays (EDAX), Raman spectroscopy, X-ray photoelectron spectroscopy (XPS) and low temperature photoluminescence (PL) measurements. Various chemo-mechanical surface treatments and different processing steps involved in fabricating GaSe crystals as THz source will be presented.

B9.8

Synthesis and Characterization of Metal Chalcogenide Aerogels by Thiolysis: The Case of Germanium and Zinc Sulfides. Kennedy Kabaso Kalebaila and Stephanie L. Brock; Chemistry, Wayne State University, Detroit, Michigan.

Aerogels are a unique class of solid materials that consist of a highly porous internal structure, a low solid content (1-10%), and nanoscale building blocks. Aerogels are well-suited for applications as catalysts/catalyst supports, sensors and thermal insulators. The chemistry of aerogel formation is well developed for oxide systems, in particular silica. However, despite the wide range of functional properties associated with the aerogel architecture, there has been very little work on non-oxide forms, except for carbon. We are interested in extending the chemistry of aerogels to metal chalcogenide (S, Se, Te) materials, as many of these are technologically relevant semiconductors that might be expected to demonstrate unique photophysical and photocatalytic properties if prepared as porous nanostructures. Recently, we have demonstrated CdS aerogel formation by a process involving nanoparticle synthesis, aggregation to form a gel-network, and supercritical fluid extraction. In this work, we will evaluate the ability to use simple thiolysis reactions to go from a molecular precursor to the gel stage, thus reducing the number of steps to aerogel formation. Here we report the application of thiolysis reactions to formation of GeS_2 and ZnS xerogels (bench-top dried materials) and aerogels (supercritically dried materials), and evaluate the influence of the synthetic methodology on morphology and surface area. The generality of this method will be discussed and compared to the multistep process developed previously in our lab.

B9.9

New Electroluminescence Spectrum from Co-doped ZnS:(Mn, Si) Films Prepared by Chemical Vapor Deposition Combined with Laser Ablation. Makoto Ozawa, Tomomasa Satoh and Takashi Hirate; Faculty of Engineering, Kanagawa University, Yokohama, Japan.

ZnS:Mn has been well known as a phosphor for thin film electroluminescent (TFEL) devices. The ZnS:Mn films prepared by conventional method have an amber EL emission spectrum at wavelength of 580 nm. However, we have demonstrated different EL emissions from ZnS:Mn using a new preparation method which is the combination of the ZnS synthesis by a low-pressure thermal chemical vapor deposition (CVD) with the impurity doping by laser ablation of a Mn target. Although details of the reason why this preparation method provide unusual EL emissions are unknown, a possible mechanism is that some Mn compound species produced in the laser plume lead to some complex luminescent centers related to Mn. Here, we have prepared ZnS:(Mn, Si) thin films using MnSi alloy for Mn as a laser ablation target, expecting other new EL emissions. H_2S gas and metal Zn vapor as precursors, and N_2 gas as their carrier gas was used in the CVD synthesis of ZnS. Mn and Si were doped into the ZnS by laser ablation of MnSi alloy target during the ZnS synthesis. A pulsed Nd:YAG laser (wavelength =1.064 μm, pulse width =8 nsec, frequency of laser =10 shot/sec) was used for the laser ablation. The parameters for the preparation of ZnS:(Mn, Si) were the deposition temperature (450 to 630 °C) and the laser power (0.01, 0.12 J/shot). Other preparation conditions were as follows. The Zn evaporation temperature was 570°C. The H_2S flow rate was 3.0 SCCM. The deposition pressure was 67 Pa. The laser-irradiated area on the target was 0.38 mm^2. The deposition time was 15 min. The EL characteristics were measured by fabricating a double-insulated AC TFEL device. The EL spectrum for the lower laser power of 0.01 J/shot was same as that of the conventional ZnS:Mn at any deposition temperature and at any position in the substrate. However, the higher laser power of 0.12 J/shot provided new spectra, although the appearance of the new spectra depended on the deposition temperature and on the position in the substrate. In the case of the deposition temperature of 450°C for the higher power of 0.12 J/shot, only a peak same as that of the conventional ZnS:Mn was observed. The devices deposited at 580°C and 630°C for the higher laser power showed new EL emission peaks in the wavelength range 380 to 470 nm and in the infrared region in addition to the same peak as that of the conventional ZnS:Mn. Especially, the new peaks at 410 and 460 nm with the higher intensities than that of 580 nm have been obtained. The result was interesting for realizing a blue inorganic TFEL device.

B9.10

Composition Dependence of the Intensity Parameters in TeO2-PbF2 : Tm3+ Glasses. Idris Kabalci[1], Gonul Ozen[1,3], Adnan Kurt[2] and Alphan Sennaroglu[2]; [1]Physics Department, Istanbul Technical University, Istanbul, Turkey; [2]Laser Research Laboratory, Department of Physics and Electrical Electronics Engineering, Koc University, Sariyer, Istanbul, Turkey; [3]Department of Physics, Boston College, Chestnut Hill, Massachusetts.

Recently, glasses based on TeO2 have attracted a considerable amount of interest when doped with Thulium ions. This is because of their possible use in the development of optical amplifiers and fiber lasers. Until now, the optical amplifiers have been made of rare-earth doped fluoride, phosphate, and silica glasses although the phonon cut-off frequency of the latter glass is high. Tellurite glasses, compared with silicate, borate, and fluoride glasses, have more advantages as laser hosts due to their superior physical properties such as low melting temperature, high dielectric constant, high refractive index and low phonon energies. Furthermore, they present large transparency from the near ultraviolet to the mid-infrared region. They are resistant to atmospheric moisture and capable of rare-earth ions into the matrix. One of the most important properties for the evaluation of the host glasses is the spontaneous emission probability for the 4f-4f transitions of the rare-earth ions in them. Spontaneous emission probability is directly related to the stimulated emission cross-section, radiative quantum efficiency, and fluorescence branching ratio. The Judd-Ofelt theory is usually used to determine the electric dipole transition probabilities including the spontaneous decay rate by utilizing the absorption cross-sections of several 4f-4f transitions. This presentation reports the effect of PbF2 content on the 4f-4f spontaneous and stimulated transition probabilities of 1.0 mol.% Tm3+ in (1-x)TeO2-(x)PbF2 glasses. The composition dependence of the intensity parameters were determined by applying Judd-Ofelt theory to the absorption spectra measured at room temperature. Thulium doped glasses have two emission bands that peak around 1470 nm and 1800 nm in the near infrared due to the 3H4 to 3H6 and 3F4 to 3H4 transitions. These emission bands are potentially important in the development of fiber-optic amplifiers and fiber lasers. Judd-Ofelt intensity parameters and radiative lifetimes of the 3H4 to 3H6 and 3F4 to 3H4 transitions for the different host compositions were estimated from the optical absorption spectra. The present study show that one of the Judd-Ofelt intensity parameters, $\Omega 2$, increase while the radiative life times of the 3F4 and 3H4 levels decrease with the increase of PbF2 content.

B9.11

Growth and Characterization of High Purity Single Crystals of α and β Alq3 for Charge Transport Studies. Ali N. Rashid[1,2] and Donald C. Craig[3]; [1]School of Physics, UNSW, Sydney, New South Wales, Australia; [2]Institute of Quantum Electronics, ETH, Zurich, Switzerland; [3]School of Chemistry, UNSW, Sydney, New South Wales, Australia.

Tris-(8-hydroxyquinoline) aluminum III (Alq3) is a stable metal chelate that has received a great deal of attention over the past years due to its use in the fabrication of organic light emitting diodes

(OLED). Despite all the interest in this remarkable material very little information on its' solid-state properties and packing exists. Nearly all of the available information comes from studies that have been carried out on vacuum deposited thin films. This is mainly due to the difficulty in obtaining large high quality/high purity single crystals of this material. While much information can be obtained from the study of powders and thin films, the presence of disorder, traps, grain boundaries and impurities can obscure the intrinsic properties of the materials under investigation. Therefore studies on high-quality single crystals are required in order to gain a clear understanding of the fundamental properties of these materials. In this contribution we present a method for the growth of large high quality single crystals of α and βAlq3, the crystal structure of Alq3 in the unsolvated α phase derived from single crystal data will also be presented, along with SCLC measurments that were performed on these crystals. This structure corrects some errors that were encountered in the x-ray powder structure reported in the literature.

B9.12
Abstract Withdrawn

B9.13
Abstract Withdrawn

B9.14
The Improvement of Efficiency by an Electron Blocking Layer in Multilayered Polymeric Light-Emitting Diodes.
Soo-Hyoung Lee[1], Sang Yeol Kim[2], Jai Kyeong Kim[1] and Yiyeol Lyu[2]; [1]Optoelectronic Materials Research Center, Korea Institute of Science and Technology, Seoul, South Korea; [2]E-Polymer Lab, Samsung Advanced Institute of Technology, Suwon, South Korea.

We report high efficiency blue light-emitting diodes obtained by inserting an electron blocking layer (EBL) into the multilayered polymeric device structure. New materials which have UV or thermally cross-linkable moieties were synthesized and used for electron blocking materials. The devices, with configuration of indium tin oxide (ITO)/ poly(3,4-ethylene dioxythiophene)-poly(styrene sulfonic acid) (PEDOT-PSS) (65 nm)/EBL (10-20 nm)/ poly(octylfluorene) derivative (70 nm)/ BaF_2(2 nm)/Ca(50 nm)/Al(300 nm), were fabricated by spin coating and thermal evaporation. In the devices, the EBL requires a hole transporting property and a relatively higher band gap, especially a lower LUMO level, than the emitting polymer in order to block electrons from cathode effectively and accumulate them in the emitting polymer. Specially, thermally cross-linkable electron blocking molecules show stable film qualities such as small root mean square (RMS) roughness and small thickness variation by an additional emitting layer fabrication. The devices with EBL exhibit a higher luminance efficiency and brightness than those in devices without EBL. The synthesis, characterization, device fabrication, and electroluminescence properties will be presented.

B9.15
Si nanotip arrays with tunable refractive-index as super anti-reflection layer. Hung-Chun Lo[1,5], Chia-Fu Chen[1], Yi-Fan Huang[2], Chih-Hsun Hsu[3], Jih-Shang Hwang[4], Chii-Ruey Lin[2], Li-Chyong Chen[3] and Kuei-Hsien Chen[5]; [1]Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu, Taiwan; [2]Institute of Mechatronic Engineering, National Taipei University of Technology, Taipei, Taiwan; [3]Center for Condensed Matter Sciences, National Taiwan University, Taipei, Taiwan; [4]Institute of Optoelectronic Sciences, National Taiwan Ocean University, Keelung, Taiwan; [5]Institute of Atomic and Molecular Science, Academia Sinica, Taipei, Taiwan.

Silicon (Si) nanotip arrays, with tunable reflectance, were fabricated by using self-masked dry etching (SMDE) technique in an electron cyclotron resonance plasma enhanced chemical vapor deposition (ECR-CVD) reactor. The resultant Si nanotips with ultra-sharp apex (1 nm) and continuous volume gradient in shape were observed by high-resolution scanning electron microscopy (HR-SEM). The rigorous coupled-wave analysis (RCWA) model (Appl. Opt. 31, 4371, 1992) was employed to simulate the refractive index (R.I.) variation of these Si-nanotip arrays as a function of their geometry. Using this simple model, nanotip array could be taken as single homogeneous anti-reflection layer. It was found that the Si nanotip arrays possess a maximum reflectance (6.0%) form VIS to NIR range (400 to 2700 nm) and show a super anti-reflection property approaching 0.001% within the visible region (400 to 800 nm). A tunable R.I. can be achieved by controlling the shape of nanotips experimentally. In the optimum case, the R.I. can be tuned within 1.01 to 3.10, limited by the R.I. of air (1.0) and Si (3.4), respectively, at the two extremes. A thorough discussion between the geometry of Si nanotip and its corresponding anti-reflection property will be presented.

B9.16
Phosphorescent Dendrimers for highly efficient OLEDs.
Kevin Knights[1], Paul L. Burn[1] and Ifor D. W. Samuel[2]; [1]Chemistry, Oxford University, Oxford, United Kingdom; [2]Physics and Astronomy, University of St. Andrews, St. Andrews, United Kingdom.

Organic light-emitting materials are being intensively investigated for use in organic light-emitting diodes (OLEDs). The materials investigated fall into three main classes based on structure and processing, namely molecular, polymeric, and more recently dendrimeric. These materials can also be divided on the basis of emission process, that is, fluorescence or phosphorescence. Much of the early work in the field focussed on fluorescent molecular and polymeric materials. The disadvantage of fluorescent materials is that there are substantial efficiency losses, up to 75%, due to non-emissive triplet formation. As a consequence phosphorescent molecular emitters have led to a breakthrough in efficiency. However, the disadvantage of molecular materials is that they are processed by evaporation and it is currently thought that they will be of less use for large area displays. We have reported that OLEDs incorporating solution-processed dendrimers with phosphorescent chromophores at the core can be very efficient.[1-3] Dendrimers consist of a core, dendrons, and surface groups. In our work we have developed the dendrimers so that the core is the light-emitting species, and utilised the structural scaffold of rigid dendrons to control the intermolecular interactions of the light-emitting cores. The main family of phosphorescent emitters are those based on iridium (III) complexes.[4] Iridium complexes that emit across most of the visible range have been reported.[3-6] However, in the main the phosphorescent iridium emitters have been used in guest host blends with the iridium complex being in low concentration. The host materials have generally contained carbazole units.[1-7] We have recently discovered that the incorporation of carbazole units into iridium (III) complex cored dendrimers have improved properties. In this presentation we will present the synthesis of three generations of a new family of phosphorescent dendrimers with carbazole dendrons. We will discuss the photophysical and device properties of the dendrimers. [1] S-C Lo, N A H Male, J P J Markham, S W Magennis, P L Burn, O V Salata, I D W Samuel, Adv. Mater., 2002, 14, 975. [2] J. P. J. Markham, S.-C. Lo, S. W. Magennis, P. L. Burn, I. D. W. Samuel, Appl. Phys. Lett., 2002, 80, 2645. [3] T. D. Anthopolous, M. J. Frampton, E. B. Namdas, P. L. Burn, I. D. W. Samuel, Adv. Mater., 2004, 16, 557. [4] M A Baldo, S Lamansky, P E Burrows, S R Forrest, M E Thompson, Appl. Phys. Lett., 1999, 75, 4. [5] C. Adachi, M. A. Baldo, S. R. Forrest, S Lamansky, M. E. Thompson, R. C. Kwong,, Appl. Phys. Lett., 2001, 78, 1622. [6] C. Adachi, R. C. Kwong, P. Djurovich, V. Adamovich, M. A. Baldo, M. E. Thompson, S. R. Forrest, Appl. Phys. Lett., 2001, 79, 2082. [7] K Brunner, A van Dijken, H Borner, J J A M Bastiaansen, N M M Kiggen, B M W Lageveld, J. Am. Chem. Soc., 2004, 126, 6035.

B9.17
Preparation of Silicon Carbide Nano-Materials Using Pulsed Laser Ablation and Arc Discharge in Liquid.
Hiroharu Kawasaki[1], Yoshikai Suda[1], Tamiko Ohshima[1], Shouta Nakashima[1], Tetsuya Toma[2] and Shinichi Kawazoe[2]; [1]Electrical Engineering, Sasebo National College of Technology, Sasebo, Nagasaki, Japan; [2]Japan Nanotech. Co. Ltd., Omura, Nagasaki, Japan.

Interest in nanomaterials has been rapidly growing for the past several years. In particular, carbon nanomaterials including fullerene molecules, carbon nanotubes, nanohorns and nanoonions are promising new materials for a variety of potential applications. Recently, silicon and/or silicon carbide nano-particles also attract due to their unique functionality. Silicon nano-materials have been studied enthusiastically as a quantum dot transistor, optical devices and super large-scale integrated circuit, called "bottom up nano-size integrated circuit". These nanomaterials have been produced by various methods such as arc discharge in a buffer gas, chemical vapor deposition (CVD), and etc.. Especially, laser ablation method is a famous technique for the deposition high quality nanomaterials; while the method is not for mass production. Recently, it has been demonstrated that carbon nanomaterials can be synthesized also by arc discharge generated in a liquid medium such as water or liquid nitrogen. The liquid arc method, which does not require expensive vacuum equipment, is more economical than the other methods, and may have some advantages in the mass production of nanomaterials. In this paper, we have developed a new production method for nanoparticles by pulsed arc discharge in liquid, which is triggered by the laser ablation on the graphite electrodes. High-resolution transmission electron microscopy observation revealed that the main products obtained by this method were crystalline carbon nanoparticles. The particle density was $10\hat{1}1cm\bar{-}3$ and size was distributed from 1 nm to 100 nm. Mean diameter of the particles was approximately 30 nm, and. On the other hand, nanotubes shape materials were not formed.

B9.18
Dopant Activation in Bulk Germanium and Germanium-on-

Insulators. Yu-Lin Chao[1], Simon Prussin[1], Roland Scholz[2] and Jason C.-S. Woo[1]; [1]Electrical Engineering, UCLA, Los Angeles, California; [2]Max-Plank Institute of Microstructure Physics, Halle/Salle, Germany.

High levels of electrical activation of both p- and n-type dopants are realized by pre-amorphization implantation (PAI) in bulk germanium wafers and germanium-on-insulator (GOI) substrates. In bulk germanium, p-type dopant yields an electrical activated concentration of 1.5×10^{20} /cm^3 after 400C rapid thermal annealing (RTA), which is one order higher than the samples without PAI. N-type dopant also shows comparable improvement as 1×10^{20} /cm^3 after 600C RTA. Both results are the highest ever being reported and are sufficient for advanced CMOS applications. The tail of dopant profile in PAI samples show back-diffusion characteristics in both p- and n-type groups as annealing time is increased. The dislocation loops resulted from PAI are suspected acting as dopant sinks. PAI approach was also employed in dopant activation in GOI substrates. Carrier concentrations of 6×10^{20} /cm^3 and 5×10^{19} /cm^3 were observed for p- and n-type dopants respectively with identical RTA conditions as bulk germanium counterparts. Incorporated hydrogen in GOI wafers which were prepared by Smart-Cut^{TM} approach shall be responsible for the discrepancy of activated concentrations between bulk germanium and GOI. Nevertheless, PAI shows the promise of dopant activation in germanium and can be readily adopted in current CMOS processes.

B9.19
High-Quality Heterojunction Between P-Type Diamond Single-Crystal Film and N-Type Cubic Boron Nitride Bulk Single Crystal. Cheng-Xin Wang and Guo-Wei Yang; State key laboratory of optoelectronic materials and technologies, School of Physics Science & Engineering, Zhongshan University, Guangzhou 510275, P. R. China, Guangzhou, China.

Due to several unique properties including extreme high hardness, very high thermal conductivity, large band gap, and chemical inertness, etc., diamond films are expected to be an important semiconductor material for high-temperature and high-power microelectronics device, and UV-light emitting optoelectronics. However, the development of diamond films electronics has been hampered by several problems, in which the big issue is that the search for n-type doped diamond fitted for the preparation of homojunction diode. Accordingly, high-quality homojunction of diamond films are hardly fabricated. Although Koizumi and co-workers have recently realized a p-n diode of diamond films, the current density and turn-on voltage of the device are not good due to the poor n-type doping. Besides seeking effective method to prepare n-type doped diamond films with relatively low resistivity, another route to fabricate high-quality heterojunction of diamond films has been attempted, i.e., n-type doped c-BN was employed to substitute n-type diamond of diamond homojunction. It is well known that c-BN strongly resembles diamond in the ways of structures and properties, especially, the lattice mismatch between c-BN (as=0.3615 nm) and diamond (a0=0.3567 nm) is about 1.3%. Therefore, c-BN is regarded as a suitable heteroepitaxial substrate in the preparation of diamond films. Furthermore, many literatures have reported diamond films growth on the c-BN bulk single crystal and polycrystalline films. Additionally, c-BN can be prepared into both p- and n-type semiconductors with HPHT grown single crystals by Be and Si or S doping, respectively. Naturally, a combination of p-type doping diamond and n-type doping c-BN would be a route to overcome the doping bottleneck of both wide-band-gap semiconductors. Based on the comparison of the particular electronic properties between p-type diamond and n-type c-BN, a heteroepitaxial growth of p-type diamond on n-type c-BN can reasonably be expected to lead to a wide-band-gap p-n heterojunction. However, to our knowledge, the high-quality p-type diamond single crystal film/n-type c-BN bulk single-crystal heterojunction has not been reported yet due to the high resistivity of n-type c-BN bulk single crystals synthesized by conventional HPHT method. Here, we developed a simple surface diffusion to prepare the n-type c-BN bulk single crystals with relatively low resistivity. Furthermore, we reported the fabrication and characterization of high-quality heterojunction between p-type diamond single crystalline film and n-type cubic boron nitride (c-BN) bulk single crystal.

B9.20
Electronic and Optical Properties of SiGe Alloys Within First-Principles Schemes. Giancarlo Cappellini[1,2], Guido Satta[1,2], Maurizia Palummo[3] and Giovanni Onida[4]; [1]Physics, University, Cagliari, Italy; [2]SLACS, INFM, Cagliari, Italy; [3]INFM-Physics, University of Rome II "Tor Vergata", Rome, Italy; [4]INFM-Physics, University of Milano, Milano, Italy.

We present first-principles calculated electronic and optical properties of some SiGe alloys. The ground-state, electronic excitations and optical properties have been calculated with Ge and Si atoms arranged in different ways among the sites of a diamond-type lattice[1]. For the ground state a DFT-LDA scheme and for the electronic excitations a DFT-GW approach have been respectively used. For the optical properties the RPA-LDA scheme has been applied for alloys going in composition from Si(100%) to Ge(100%): obtained results have been compared with existing experimental and theoretical data. For the noticeable Si(50%)Ge(50%) alloy also two-particle effects have been evaluated using the Bethe-Salpeter equation.[2] [1]R. Braunstein,A.R. Moore,F. Herman, Phys. Rev. 109, 695(1958) [2]G.Onida,L.Reining,A.Rubio, Rev. Mod. Phys. 74, 601(2002)

B9.21
Ab-Initio Calculations for the Electronic Spectra of Cubic and Hexagonal Boron Nitride. Giancarlo Cappellini[1,2], Guido Satta[1,2], Valerio Olevano[3] and Lucia Reining[3]; [1]Physics, Cagliari University, Cagliari, Italy; [2]SLACS, INFM, Cagliari, Italy; [3]CNRS-CEA, Ecole Polytechnique, Palaiseau, France.

We present state of the art first-principles calculations for the optical spectra and the loss functions of bulk boron nitride in the cubic (c-BN) and in the hexagonal (h-BN) phases. We start from a DFT-LDA density functional Kohn-Sham bandstructure.[1] We investigate the influence of many-body effects beyond the Random Phase Approximation (RPA) on the optical spectra through the inclusion of self-energy and excitonic effects by a GW calculation and the solution of the Bethe-Salpeter equation.[2] For the loss function we only perform RPA calculations. We show to which extent, and in which kind of spectra, the description of many-body effects is important for a meaningful comparison with experiment, and when they can be neglected due to mutual cancellation. We also present results obtained for c-BN within Time-Dependent Density Functional Theory, both in the adiabatic local density approximation (TDLDA) and using a recently proposed long-range approximation for the exchange-correlation kernel.[3] [1] G.Cappellini,G.Satta,M.Palummo,G. Onida, Phys.Rev. B 64, 035104-1(2001) [2] G.Onida,L.Reining,A.Rubio, Rev.Mod.Phys.74,601(2002) [3] L.Reining,V.Olevano,A.Rubio,G.Onida, Phys.Rev. Lett. 88, 66404-1(2002)

B9.22
Transport Properties of Polycrystalline SiGe Thin Films grown on SiO_2. Minoru Mitsui[1], Keisuke Arimoto[1], Junji Yamanaka[1], Kiyokazu Nakagawa[1], Kentarou Sawano[2] and Yasuhiro Shiraki[3]; [1]University of Yamanashi, Kofu, Japan; [2]The University of Tokyo, Bunkyo-ku, Japan; [3]Musashi Institute of Technology, Setagaya-ku, Japan.

Low temperature crystallization of amorphous Si (a-Si) on SiO_2 is key to fabrication of advanced thin film transistors. However the crystallization temperature of a-Si by solid phase crystallization is higher than 600°C. Therefore, low cost glass substrate cannot be used because of its low softening temperature. Polycrystalline SiGe film can be formed at the lower crystallization temperature, since Ge atoms can reduce the total bond energy by forming Si-Ge bonds. The nucleation and growth mechanisms of SiGe have been investigated by many researchers, but there have been only a few reports for the electronic properties. Therefore, we have investigated the influence of Ge concentration on electronic properties of SiGe films by Hall measurements. Amorphous $Si_{1-x}Ge_x$ (x=0.3, 0.5, 0.7) films with thicknesses of 100nm were deposited by molecular beam epitaxy (MBE) technique on quartz substrates at room temperature. Then, the Hall bar geometry was fabricated on the a-SiGe film. The samples were annealed for crystallization in N_2 atmosphere for 1 hour. The annealing temperature was varied from 700 to 800°C. For Hall measurements, Al was deposited on the samples and the samples were annealed at 400°C for 15min to make electrodes. The crystallinity of polycrystalline SiGe films was studied by TEM. All samples show P-type behavior. The room temperature hole densities of $Si_{1-x}Ge_x$ annealed at 700°C are 4x10^{13}, 6x10^{14} and 6x10^{16} cm^{-3} for x=0.3, 0.5 and 0.7, respectively. The acceptor levels, which are determined from the temperature dependence of the hole density, are 0.22, 0.20 and 0.17 eV for x=0.3, 0.5 and 0.7, respectively. The room temperature Hall mobilities of $Si_{1-x}Ge_x$ are 15, 20 and 17 cm^2/Vs for x=0.3, 0.5 and 0.7, respectively. The potential barrier heights, which are determined from temperature dependence of the mobility, are 0.16, 0.10 and 0.028 eV for x=0.3, 0.5 and 0.7, respectively. The barrier height, which is thought to exist at the grain boundary, decreases with Ge concentration. By increasing annealing temperature for crystallization, the acceptor levels become deeper than those samples annealed at 700°C. The mobilities increase and barrier heights decrease with the annealing temperature. We think that the decrease of barrier height with the annealing temperature is due to the improvement of grain boundaries, and as a result the mobility increases. This result agrees with Thermal Emission model, in which the mobility is determined by scattering at grain boundaries. However, in the case of high Ge concentration ($Si_{0.3}Ge_{0.7}$), although the barrier

height is lowest and the carrier density is highest among the other samples, mobility is not high. This result indicates that the mobility of $Si_{0.3}Ge_{0.7}$ is not dominated by grain boundary scattering. We consider that the defects are easily introduced in SiGe grain due to low energy of SiGe bond and as a result the crystal quality is not high.

B9.23

High Power RF Diamond FETs with Low Resistive Source/Drain Carbide Ohmic Layer using Focused Ni Ion Irradiation. Hideo Hata[1,2], Tatsuya Arai[1,2], Souichi Mejima[1], Hitoshi Umezawa[1,2], Domingo Ferrer[1], Takahiro Shinada[1], Iwao Ohdomari[1] and Hiroshi Kawarada[1,2]; [1]Waseda University, Tokyo, Japan; [2]NEDO, Tokyo, Japan.

Semiconducting diamond exhibits superior material properties which are promising for future electronic devices, such as a wide band gap (5.5 eV), high breakdown field (>10 MV/cm), maximum thermal conductivity in materials (22 W/cm·K). We have developed RF diamond field effect transistors on hydrogen-terminated conductivity, the sheet resistance of which is about 10kΩ/ and achieved over 20GHz cutoff frequency in 0.2μm gate MOSFETs[1]. However the hydrogen-terminated surface is sensitive to environmental changes, the conductivity easily decrease by increase of temperature, and there are troubles in operating stably in long-term. Furthermore, another problem in our RF diamond FETs is high parasitic resistance due to the source-gate distance. The parasitic resistances result in low MAG(maximum available gain), fmax/ft ratio of the RF MISFET is low as 1.1-1.5[1]. This surface channel also restricts the maximum drain current because of very shallow carrier profiles of the surface channel. Realization for high performance RF diamond FETs, 1kΩ/ of sheet resistance is required. In order to meet these problems, the technique which fabricates the stable low resistive source-drain regions replaced with hydrogen-terminated surface is necessary. In this study, an FIB(Focused Ion Beam) apparatus with nickel metal ion source with accelerating volatage of 30 kV is used to realize low resistive. Accelerating ions are locally irradiated on oxygen-terminated diamond surface which has 1GΩ/ of sheet resistance. In consequence, the diamond surface is locally modified to nickel carbide. In this results, when 1017 ions/cm2 are irradiated, sheet resistance decreases to 10kΩ/ which is correspondence to hydrogen-terminated conductivity. Furthermore, when 1019 ions/cm2 are irradiated, sheet resistance decreases to 1.3kΩ/.Because Nickel carbide works as a metallic low resistive layer, which can be used to source and drain regions. If this layer is utilized between source and gate or drain and gate of MISFETs, higher drain current of 1A/mm and 60GHz of fmax is expected. [1]H.Matsudaira et al., IEEE Electron Device Lett.25, (2004) in press

B9.24

Fine Determination of the Lattice Longitudinal Shift Between Layers of the Strain-Compensated Si/SiGeC/Si HBT. Siranush E. Bezirganyan[1], Hakob (Akop) P. Bezirganyan[1], Hayk H. Bezirganyan[2] and Petros H. Bezirganyan[3]; [1]Dept of Solid State Physics, Yerevan State University, Yerevan, Armenia; [2]Faculty of Informatics and Applied Mathematics, Yerevan State University, Yerevan, Armenia; [3]Dept of Computer Science, State Engineering University of Armenia, Yerevan, Armenia.

The investigation of dependence of the heterojunction bipolar transistor (HBT) performance characteristics upon the lattice longitudinal space shift between HBT epitaxial layers and the substrate is one of the important problems of non-destructive control in HBT fabrication process technology. Investigation methods based on the Grazing-Angle Incidence X-ray Backdiffraction (GIXB) technique are extremely sensitive for the measurements of the longitudinal space phase shifts stipulated by the misfit dislocations of the interface planes of the HBT epitaxial layers. The GIXB configuration first is considered in our papers [1, 2]. Lattice mismatch between Si and Ge constrains the design of SiGe/Si heterojunction. Substitution incorporation of carbon into SiGe makes it possible to reduce and to control the compressive strain between the epitaxial layer and the substrate in Si/SiGeC/Si HBTs (e.g. see [3-5]). The buffer (base) SiGeC films in HBTs have less strain than a base SiGe films with the same bandgap. On the other hand the introduction of carbon in the base suppresses outdiffusion of boron, by which the parasitic barriers would be created. The performance features of HBTs with SiGeC base layer practically do not change after the high temperature processing. Consequently, Si/SiGeC/Si HBTs are well situated in application in Bipolar CMOS device technology (BiCMOS), i.e. in combination of the ultra-high-speed HBT and the mid-to-low speed signal processing CMOS (Complementary Metal-Oxide Semiconductor). The investigation of one layer SiGeC/Si strain-compensated heterojunction by the GIXB is given e.g. in [6]. In the presented theoretical paper we are investigating the process of the GIXB by strain-compensated Si/SiGeC/Si HBT. Diffracting net planes of the considered model of the HBT have the same lattice constant for the epitaxial layers and the substrate, though there exist a longitudinal space shifts between space periods of the epitaxial layers and the substrate. The reflectivity coefficient of specular reflected vacuum wave in the case of GIXB configuration is considered here depending on the values of the phase shifts between heterostructure space periods and of the Bragg angle. References: [1]. A.P. Bezirganyan, and P.A. Bezirganyan, Phys. Stat. Sol. (a), 105 (1988) 345. [2]. A.P. Bezirganyan, Phys. Stat. Sol. (a), 109 (1988) 101. [3]. B. Dietrich, H.J. Osten, H. Rucker, M. Methfessel, and P. Zaumseil, Phys. Rev. B, 49 (1994) 17185. [4]. D.J. Paul, Adv. Mater., 11(3) (1999) 191. [5]. X. Shao, R. Jonczyk, M. Dashiell, D. Hits, B.A. Orner, A.-S. Khan, K. Roe, J. Kolodzey, P.R. Berger, M. Kaba, M.A. Barteau, and K.M. Unruh, J. Appl. Phys., 85(1) (1999) 578. [6]. H.A. Bezirganyan Jr, S.E. Bezirganyan, A.P. Bezirganyan, and P.A. Bezirganyan Jr, in Proc. Materials Research Society (MRS) 2002 Spring Meeting , eds. J. Veteran, D.L. O'Meara, V. Misra, P. Ho, San Francisco, CA (USA), 716, B4.31.1 (2002).

B9.25

1.55 μm Photoluminescence from β-$FeSi_2$ Microprecipitates-containing Films Prepared via Pulsed Laser Deposition. Aiko Narazaki, Tadatake Sato, Yoshizo Kawaguchi and Hiroyuki Niino; Photonics Research Institute, National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan.

β-$FeSi_2$, the semiconducting low-temperature phase of iron disilicide, is promising as Si-based optoelectronic devices because of 1.55 μm luminescence well-matched to the transmission window of optical silica fibers as well as epitaxial relationship with Si crystalline structure. In a different perspective, β-$FeSi_2$ has received attention as an eco-friendly semiconductor due to the rich abundance of its constituents in natural resources and non-toxicity. These advantages have been intensively accelerating the formation of β-$FeSi_2$ thin films by a variety of methods including ion beam synthesis, reactive deposition epitaxy, and magnetron-sputtering. However, these methods generally required high-temperature multi-processes such as film deposition at $\geq$ 450 °C and following post-annealing at $\geq$ 800 °C from several hours up to a few days to achieve the precipitation of the beta phase. Such high-temperature procedures are not suitable for the device integration and degrade the semiconducting properties of β-$FeSi_2$ due to the appearance of other Fe-Si metallic phases. In this work, we successfully realized the room-temperature fabrication of β-$FeSi_2$ microprecipitates by the active use of micrometer-sized droplets generated by the laser ablation. We performed the KrF excimer laser ablation of an α-$FeSi_2$ metallic target and deposited hemispherical and doughnut-like droplets on a Si substrate kept at room temperature. Micro-Raman spectroscopy confirmed that thus obtained droplets precipitated preferentially as the β-$FeSi_2$ crystalline phase, whereas the rest of the deposited film was amorphous. Further improvement in the crystallinity of β-$FeSi_2$ was observed after pulsed laser annealing. It was also found that films containing a high density of β-$FeSi_2$ microprecipitates exhibited 1.55 μm photoluminescence at low temperatures up to 200 K after annealing at 800 °C for 6 h in an argon atmosphere.

B9.26

Study of Germanium Out-Diffusion in HfO_2 Gate Dielectric of MOS Device on Germanium Substrate. Qingchun Zhang, Nan Wu and Chunxiang Zhu; Electrical and Computer Engineering, National University of Singapore, Singapore, Singapore.

Germanium is an interesting channel material for MOSFET since it offers much higher mobility than silicon. However, the poor quality germanium oxide obstructs the fabrication of germanium MOS devices. With high-κ material replacing the conventional thermal oxide in future VLSI technology, germanium is promising to be the channel material of high performance device. Several works on high-κ HfO_2 deposition on germanium have been reported. The results show that, during HfO_2 deposition or the following post deposition annealing (PDA), large amounts of germanium were found inside HfO_2 film. Thus, it is very interesting to study the mechanism of germanium diffusion into HfO_2 and its impact on the electrical properties of HfO_2 gate stack. In this work, the dependences of Ge diffusion on high-k deposition method, PDA temperature as well as PDA ambient were investigated. In addition, the electrical properties of HfO_2 MOS capacitors after Ge-incorporation were addressed. Thin HfO_2 film (5nm) was deposited on cleaned Ge single crystal wafer by MOCVD using Hf t-butoxide precursor and O_2 at 400°C. A high concentration of germanium (8 atomic %) was found in the as-deposited HfO2 by XPS at a 10° take-off angle. The presence of germanium was also confirmed by SIMS depth profiling. By using a surface nitridation with NH3, the germanium concentration reduced about 50%. This shows surface nitridation can effectively prevent the germanium diffusion. However, Ge is still observed in HfO_2 film. It is suspected that the Ge out-diffusion may relate to the relative high temperature during MOCVD process. To exclude the effect of deposition temperature on Ge out-diffusion, reactive sputtering method, by using a pure Hf target in O_2 ambient at room

temperature, was used to prepare thin (10nm) HfO2 films. Much less germanium was found in as-dep PVD HfO_2 film than MOCVD film. After 700°C PDA, the germanium concentration increased about 10 times. To get a better SIMS profiling of germanium in HfO_2, thick HfO_2 (100nm) films were prepared in the same method with PDA temperature ranging from 400°C to 700°C in N2 for 2 min. No Ge out-diffusion was observed on 400°C annealed sample. The diffusion took place at PDA temperature of 500°C and the higher temperature annealing has more germanium diffusion. Besides, one sample was annealed in O_2. Strong enhancement of germanium diffusion by oxygen was observed. There are reports that germanium oxidation starts around 400°C. Thus, the Ge out-diffusion may be related to the Ge oxidation due to the oxygen ambient or oxygen residue inside the chamber. Finally, several electrical measurements have been performed on MOS capacitors with Ge-incorporated HfO_2 gate dielectric. High hysteresis and interface trap density are found with the presence of germanium.

B9.27

Impact of Hydrogen Bubble Formation in the Early Stages of Electro-chemical Etching on Creating Nanopores in Silicon.
Fung Suong Ou, Laxmikant Saraf and Donald R. Baer; Environmental Molecular Science Laboratory, Pacific Northwest National Laboratory, Richland, Washington.

Nanoporous silicon surfaces have been used in a varity of research studies and are being employed in some applications with many others envisioned in the areas of opto-chemical, gas and bio sensing applications. We are exploring the use of engineered defects to tune the formation of the nanopores with specific patterns and properties. During electro-chemical etching, it is known that hydrogen is released from silicon surface. However, little is known about the impact of hydrogen bubbles on the silicon surface etching process, especially in the early stages of nanopore formation. In this study we investigate the impact of hydrogen bubbles on the nanopore formation on silicon surface and as a control mechanism for creating designed nanostructures. Nanopore formation in the early stages was observed for etching times of 5-20 seconds in heavily n-doped silicon samples at low current densities 5 mA/cm2. The nanopores were also observed to align in the form of circular craters representing possible etching at hydrogen bubble interface. We will discuss the impact of variation in experimental parameters like current density, doping density and etching times. There is some evidence to suggest that pinning in these hydrogen bubbles is possible at some random sites which are believed to be surface defect sites. By using combination of lithography and electro-chemical etching, we will suggest some of the possible ways to gain more control on the pinning process which potentially can lead towards tuning specific optical and chemical properties of nanoporous surface. Finally, we will discuss the details of hydrogen bubbles stability on silicon surface in achieving the favorable etching conditions.

B9.28

Control of Crystal Tilt in MOCVD Films of InAs on (100) GaAs.
Susan Babcock[1,2], Anish Khandekar[3], Thomas Kuech[1,3,2] and Ganesan Suryanarayanan[2]; [1]Materials Science and Engineering, University of Wisconsin-Madison, Madison, Wisconsin; [2]Materials Science Program, University of Wisconsin-Madison, Madison, Wisconsin; [3]Chemical and Biological Engineering, University of Wisconsin-Madison, Madison, Wisconsin.

The electronic structure and properties of InAs are attractive for the development of new high-speed devices and device capabilities, many of which require a semi-insulating substrate for their realization. Unfortunately, lattice-matched semi-insulating substrates for the 6.1 Angstrom semiconductors (InAs, GaSb and AlSb) are not readily available, leaving GaAs, with an almost 7% lattice parameter mismatch, as the substrate of choice for In-As based electronics. This large mismatch can lead to copious defect generation in InAs films grown by MOCVD, among them specifically a one micron-scale grain structure in which the InAs grains each have one of discrete set of preferred tilts with respect to the GaAs substrate. This work has explored optimization of the MOCVD growth conditions and design of mask patterned substrates for lateral overgrowth epitaxy (LEO) to promote singular orientation in the film. X-ray diffraction, backscattered-electron Kikuchi diffraction pattern (BEKP) analysis and BEKP-based orientation imaging microscopy (OIM) were used to study the origin of the observed multiple orientations and its amelioration on both masked-free and mask-patterened GaAs substrates. InAs growns on GaAs by an island growth mechanism. A correlation between the deduced size of the islands at coalescence and the presence of singular or multiple orientations in continuous films was observed in x-ray rocking curves and BEKP/OIM. Conditions that favored higher (lower) nucleation rates and thus coalescence at small (large) island size resulted in singular (multiple preferred) orientation(s) in the film. These effects were observed on both mask-free substrates, for which the nucleation rate was varied via the growth temperature and gas phase composition, and on LEO substrates where the nucleation rate and the spatial distribution of islands are influenced by the mask pattern dimensions. BEKP of InAs isolated islands of lateral sizes of a few micron prior to coalescence clearly revealed within the same set of multiple orientations within each island as was observed in continuous films grown under the same conditions. These results indicate that distribution of orientations is established in the islands before they coalesce and propagates largely unchanged during further growth. Study of LEO films showed enhanced nucleation rates along the window edges. The disappearance of multiple orientations at higher growth temperatures when the window width was reduced to one micron, spatially forcing coalescence at an island size of about one-half to one micron, supports the conclusion that the singular orientation is obtained when the island size is less than one micron at coalescence. These results suggest that substrate design may provide an alternative means to control defect generation and increase flexibility in growth conditions for epitaxial systems with large mismatches.

B9.29

Mechanism on Selective Epitaxial Growth in LPCVD.
Woo-Seok Cheong, Y.G. Yoo, E.K. Kim, H.J. Ryu and M.C. Back; Basic Research Center, Information Storage Device Team, Electronics and Telecommunications Research Institute, Daejeon, South Korea.

Future devices demand an aggressive scale-down of physical dimensions. One of the most important issues is to achieve reliable electrical properties in small-size and high aspect ratio structures. Among the spotlighted technologies, there is selective epitaxial growth(SEG). SEG has showed a possibility for good electrical properties as well as advantages in building microstructures. In spite of such merits, several problems have made the application difficult, which include selectivity loss, local loading effect, and so on. According to the conventional SEG theory, they can not be explained easily because it deals with only heterogeneous reactions on the surface. Recently, predictions from the CVD thermodynamics are found to be in good consistent with experimental data in LPCVD. The thermodynamic analysis originates from a new SEG model, which can be explained by three steps: dynamic equilibrium state by fast homogeneous reactions, formation of charged clusters in the gas phase, and influx of Si sources toward conducting materials by electrical forces. This model implies that sources for silicon growth are mainly supplied from the gas-phase reactions, not from the surface ones. In addition, SEG process diagrams can be developed from CVD thermodynamics. They can not only be helpful with understanding of SEG, but also offer good experimental guidelines for the process. On the other hand, this model uses the effective supersaturation ratio to explain the loading effect, which are related with growth uniformity and selectivity loss in LPCVD system. Moreover, the loading effect should be controlled by proper methods for optimization of SEG process. Three methods are introduced for the requirements; lowering the supersaturation ratio in SEG condition, cleaning the surface of a wafer and inserting dummy active patterns into insulators.

B9.30

Beam Induced Lateral Epitaxy of GaAs on GaAs/Si Template.
Shigeya Naritsuka[1,2], Koji Saitoh[1], Toshiyuki Kondo[1] and Takahiro Maruyama[1,2]; [1]Materials Science and Engineering, Meijo University, Nagoya, Japan; [2]21st century COE program "NANO FACTORY", Meijo University, Nagoya, Japan.

Epitaxial lateral overgrowth is important for the fabrication of superior electronic and optoelectronic devices, because the dislocation density in the overgrown layer can be drastically reduced. We have proposed an utterly new technique, named as beam induced lateral epitaxy (BILE), to achieve lateral overgrowth in molecular beam epitaxy (MBE) [1]. In the technology of BILE, lateral overgrowth is realized by incidence of molecular beam at a low angle to a substrate with a truncated ridge structure. Therefore, selective growth can be achieved under a relatively low growth temperature without SiO_2 mask. In this study, BILE is applied to the heteroepitaxial growth of GaAs on Si substrate. First, a 6.6 μm-thick GaAs layer was grown by molecular beam epitaxy using 2-step growth technique on a (111) Si substrate, named as GaAs/Si template. Then, truncated, parallel ridges were fabricated by photolithography and chemical etching. BILE was performed at 580 °C with the incidence angle of beams at 12 degrees. Consequently, a 5.2 μm-width overgrown region of GaAs was successfully grown laterally from the side of the truncated ridges. Though the surface morphology was not quite smooth, the formation of (111) facet on the top surface brought a wide lateral overgrowth. It was also found that the shape of the underside of the layer was defined by the shadow effect of the neighboring ridge. Seen that the features of the grown shape were similar to those of a GaAs homoepitaxial BILE, the heteroepitaxial BILE was worked in the same growth mechanism as the homoepitaxial one. In addition, the dislocation revealing etching showed that almost no dislocation existed on the lateral grown region while a high density of dislocations

remained on the region above the truncated ridge. Thus, the result confirmed the usefulness of BILE to reduce dislocations in highly mismatched heteroepitaxial system. Reference: [1] T. Suzuki et al. Cryst. Res. Technol. 38, No. 7-8, 614 - 618 (2003).

B9.31
Novel Noncontact Thickness Metrology for Partially transparent and Nontransparent Wafers for Backend Semiconductor Manufacturing. Wojciech J. Walecki, Vitali Souchkov, Kevin Lai, Phuc Van, Manuel Santos, Alexander Pravdivtsev, S. H. Lau and Ann Koo; Frontier Semiconductor, San Jose, California.

Single probe low coherence optical interferometry [1] has been proven to be an effective tool for characterization of thin and ultra-thin semiconductor wafers [2]. Purpose of this paper is to present an extension of this method to characterization of ultra-thin partially transparent and nontransparent wafers mounted on tapes and insulating carriers. The metrology of thin and ultra-thin wafers has been identified very early as one of the technology gaps of the industry. Most commonly employed metrologies include capacitance and air pressure techniques. These two competing technologies have been proven reliable and quite accurate methods of measurement limited to relatively thick materials. Capacitance method however is not suitable for measuring thickness of semi-insulating and insulating materials such as sapphire, or SiC, and very thin wafers (thinner than 100 μm). Air pressure based sensors are able to measure insulating materials, however they cannot be directly applied to wafers mounted on carriers. Single probe low coherence interferometry provides accurate information only about thickness of layers transparent to probing radiation [2]. Very common structures are composed of nontransparent materials (metal patterns, copper layers, etc). We report measurement using dual probe low coherence interferometer synchronously probing top and bottom surfaces of wafer. This dual probe configuration allows measuring nontransparent wafers of arbitrary thickness, while providing additional information on topography (bow and warp) of measured surfaces. The reproducibility of the measurement of this system in so called single shot mode is 0.6 μm for measurement with range of up to 7 mm, and acquisition time of 20 msec. Reproducibility of measurement in averaging mode (over 10 measurements) is of the order of 0.2 μm which meets most of industry requirements. The accuracy of dual probe system does not depend on exact values of refractive indices of measured wafers. The synchronous operation of the delay stages in instrument efficiently reject vibration related noise. We present theoretical predictions and estimate that noise due to vibrations for symmetric synchronously operated system contributes less then 0.01 μm to total thickness measurement. We also present real life examples of applications of this technique in wide range of applications such as: silicon and compound materials, bumped wafers, patterned and non-patterned wafers, wafers mounted on sapphire, glass and tape carriers. [1] D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, J. G. Fujimoto, Science 254, 1178-1181 (1991). [2] W.J. Walecki, R. Lu, J. Lee, M. Watman, S.H. Lau, A. Koo, 3 rd International Workshop on Thin Semiconductor Devices - Manufacturing and Applications November 25, 2002, Munich, Germany

B9.32
First-Principles Simulations of the Reactivity of Barrier Layers of Ti, Ta and W and Their Nitrides Towards Precursors for CVD Copper Deposition. Hansong Cheng[1], Diwakar Garg[1], Eduardo Machado[2], Marcin Kaczmarski[2], Benoit Braida[2], Eduardo Hernandez[2] and Pablo Ordejon[2]; [1]Computational Modeling Center, Air Products and Chemicals, Inc., Allentown, Pennsylvania; [2]Institut de Ciencia de Materials de Barcelona, Barcelona, Spain.

We present first-principles Density Functional Theory calculations of the reactivity of Ti, Ta and W surfaces and their nitrides with Cu-hexafluoracetylacetonato-trimethylvinylsilane [Cu(hfac)(tmvs)], a commonly used chemical precursor for CVD growth of Cu films. We show that the surfaces of the pure metals are highly re-active, and that the ligands in Cu(hfac)(tmvs) decompose spontaneously upon con-tact with the surface. The products of the decomposition attach strongly to the sur-face, forming a fluorine, carbon and hydrogen containing layer on the barrier layer, which may lower the efficiency of the Cu deposition and the adherence of the Cu layer. For the case of the metal nitrides, those surfaces prepared with an orientation such that no transition metal atom is exposed to the surface do not show such reactiv-ity, with the ligands staying intact upon interaction with the surface. Our simulations suggest strategies for improved deposition efficiency and adhesion properties of Cu films deposited by CVD on transition metal barrier layers.

B9.33
Dielectric Properties of Semiconductors by TDDFT in Real-Space and Real-Time Approach. Yasunari Zempo and Nobuhiko Akino; Sumitomo Chemical, Tsukuba, Japan.

Time-dependent density-functional theory (TDDFT) has been widely recognized as a useful method to study the time-dependent phenomena. In this study, we apply this theory to the semiconductors and focus on their dielectric response, which is one of the most important physical properties in the fabrication of electronic devices. The various types of semiconductors such as C, Ge, Si, GaAs, etc. are considered, and their static and dynamic dielectric functions are calculated. Throughout the calculations, we use Troullier-Martins pseudopotentials in the separable form, and carry out within the framework of the local density functional theory by using the real-space[1] and real time technique[2]. We use a uniform grid spacing throughout the space. As the grid spacing is related to the energy resolution, it is needed to be small enough to have desired accuracy. In the real-time method, the time-dependent mean-filed equation is solved directly in real time under instantaneous and small perturbation. The number of the total time steps affects the resolution of the spectrum, especially at the low energy, thus one may need to run with a large number of steps. As the result, the good agreement is obtained with the experiment. In the presentation, we will compared the electronic properties in different semiconductors, together with the result by other calculation techniques, and discuss the calculation details and our future plans. [1] J. Chelikowsky, N. Troullier, K. Wu and Y. Saad, Phys. Rev. B50, 11355(1994) [2] K. Yabana and G. F. Bertsch, Phys. Rev. B54, 4484(1996)

SESSION B10: ZnO II
Chair: David Look
Friday Morning, December 3, 2004
Constitution A (Sheraton)

8:30 AM B10.1
Pt/Au and W/Pt/Au Schottky Contacts to Bulk n-ZnO. Kelly Ip[1], Brent Gila[1], Andrea Onstine[1], Eric Lambers[1], Young-Woo Heo[1], David Norton[1], Stephen Pearton[1], Jeffrey LaRoche[2] and Fan Ren[2]; [1]Materials Science and Engineering, University of Florida, Gainesville, Florida; [2]Chemical Engineering, University of Florida, Gainesville, Florida.

Electron-beam deposited Pt/Au contacts and sputtered W/Pt/Au contacts on bulk, single-crystal n-ZnO are reported. UV-ozone cleaning prior to metal deposition significantly improves the rectifying characteristics on these contacts. The surface carbon concentration determined by Auger Electron Spectroscopy showed significant decrease after the ozone cleaning, from 29.5 at.% to 5.8 at.%. Pt/Au contacts deposited directly on the as-received ZnO surface exhibited ohmic-like behavior. However, with UV-ozone cleaning prior to deposition, the Pt/Au contacts exhibited rectifying behavior with Schottky barrier height of 0.70 $\pm$ 0.04 eV at 25 °C, ideality factor of 1.49, and a saturation current density of 6.17×10^{-6} $A{\cdot}cm^{-2}$. For the W/Pt/Au contacts, the as-deposited contacts are ohmic, independent of the use of ozone cleaning. The contacts became rectifying after post-deposition annealing at 700 °C to remove sputter-induced damages. The annealed W/Pt/Au contacts have Schottky barrier heights of 0.45 eV for control samples and 0.49 eV for those cleaned with ozone exposure. The improvement in rectifying properties of both the Pt/Au and W/Pt/Au contacts is related to removal of surface carbon contamination from the ZnO.

8:45 AM B10.2
Preparation of SrS:Ce/ZnO core-shell nanoparticles using reverse micelle method. Yusuke Kusakari, Shinji Ishizaki and Masakazu Kobayasi; Laboratory for Material Science and Technology, Waseda University, Sinjyuku Tokyo, Japan.

SrS, which is a member of the alkaline earth sulfides, doped with rare-earth ions of Ce is one of the most promising inorganic materials for blue-green color display devices. Researches in nanometer-sized semiconductor particles including core/shell type composite particles have been actively studied in recent years because of their characteristics differing from bulk materials such as fluorescence activation arising from the confinement effect. In this report, SrS:Ce nanoparticles were prepared using a reverse micelle method. The particles were then coated by ZnO, and optical properties were studied. The reverse micelle method is a suitable way for obtaining the uniform and size controllable nanoparticles. The aggregation of formed particles would be relatively easily avoided. The SrS:Ce nanoparticles were prepared in di-2-ethylhexylsulfosuccinate sodium salt and heptanes reverse micelle solution. The preparation of the nanoparticles was achieved by mixing two solutions at the temperature range of 30 to 60 degrees. One solution contained reverse micelle with Sr(NO3)2, Ce(NO3)3−6H2O, and the other contained Na2S−9H2O. A zinc compound and an alcohol were reacted under the

existence of SrS:Ce nanoparticles to form the core/shell structure. The mean particle size was measured using a dynamic light scattering method (HORIBA LB-550), and the mean diameter could be controlled as small as about 3 nm. The photoluminescence (PL) property was measured using a filtered high-pressure mercury rump as an excitation source; the light whose wavelength shorter than 360 nm was eliminated. A broad PL whose peak was at around 440 nm was observed from the SrS:Ce nano-particles. The UV absorption spectrum was also measured, and peaks were observed at around 275 nm and 325 nm. The PL peak intensity of the SrS:Ce/ZnO core-shell nanoparticle was about four times stronger than that of the SrS:Ce nanoparticle. Core/shell nanoparticles were also prepared using a ball milling method and the variation of optical properties related to the variation of the fabrication method was studied. The SrS:Ce/ZnO core/shell nanoparticles could be applied to various types of device structures. This work was supported in part by Waseda University Open Research Center Projects, Waseda University Grant for Special Reserch Projects (Individual Reserch).

9:00 AM *B10.3

ZnO/GaN heteroepitaxy. Takafumi Yao[1,2], K. W. Jang[1], D. C. Oh[1], Tsutomu Minegishi[1], Hideyuki Suzuki[1], Takashi Hanada[2], Hisao Makino[2] and M. W. Cho[2]; [1]Center for Interdisciplinary Research, Tohoku University, Sendai, Japan; [2]Institute for Materials Research, Tohoku University, Sendai, Japan.

The heteroepitaxy system of ZnO-based II-VI oxide/GaN-based III-V nitride has unique features: (1) ZnO/GaN provides a close lattice matching heterostructure; (2) Type-II band alignment with variable band offset with alloy composition; (3) spontaneous polarization field exists regardless of lattice misfit, while piezoelectric field is generated by lattice misfit; (4) ZnO and GaN are eco-friendly materials. Owing to those properties, the ZnO/GaN heterostructure will provide unique applications in various fields. The purpose of this paper is to overview the heteroepitaxial growth of ZnO on GaN and GaN on ZnO and to present prospect of ZnO/GaN heteroepitaxy. The topics to be discussed will include: polarity control of ZnO/GaN heteroepitaxy; evaluation of ZnO substrates for GaN epitaxy; interface electronic properties of ZnO/GaN.

SESSION B11: Dilute Nitrides

Chair: Oana Malis
Friday Morning, December 3, 2004
Constitution A (Sheraton)

10:00 AM B11.1

Improved Optical Quality from Indium-Free GaNAsSb in the Dilute Sb (<3%) Limit. Homan B. Yuen[1], M.J. Seong[2,3], Robert Kudrawiec[4], Seokhyun Yoon[3], Seth R. Bank[1], Mark A. Wistey[1], Jan Misiewicz[4], Angelo Mascarenhas[3] and James S. Harris[1]; [1]Solid State & Photonics Lab, Stanford University, Stanford, California; [2]Department of Physics, Chung-Ang University, Seoul, South Korea; [3]National Renewable Energy Laboratory, Golden, Colorado; [4]Institute of Physics, Wroclaw University of Technology, Wroclaw, Poland.

The addition of N into InGaAs has allowed growth of dilute-nitride materials which have much longer emission wavelengths than previously obtainable on GaAs. Contrary to the behavior of most III-V semiconductors, small amounts of N in GaAs decrease both the overall lattice parameter and the band gap. GaInNAs has enabled the development of lasers at the important fiber communication wavelength of 1.3 μm. However, the incorporation of N into (In)GaAs degrades the optical properties of the material due to non-radiative traps, phase segregation, and/or relaxation. These issues are even more apparent at higher compositions of In and N in GaInNAs to reach the technologically important wavelengths near 1.55 μm. Sb acts as both a surfactant and constituent when introduced during GaInNAs growth, forming high quality GaInNAsSb. Since Sb in GaAs also decreases the band gap, GaInNAsSb lasers have been demonstrated at wavelengths as far as 1.5 μm. Although Sb had been used to improve GaInNAs material quality and surface characteristics, it provided little improvement on indium-free material. The benefits of Sb were somehow only apparent in the presence of In. GaNAs(Sb) layers were grown by molecular beam epitaxy utilizing an rf N plasma source. The GaNAs(Sb) samples contained smaller amounts of N and Sb (0.5-0.8% N and <3% Sb) than used in previous studies and were examined for their optical and electronic properties as well as any interactions between them. Secondary-ion mass spectrometry, high-resolution X-ray diffraction (HRXRD), electroreflectance spectroscopy (ER), and photoluminescence (PL) measurements were used to study those properties. We found that the addition of small amounts of Sb enhanced the incorporation of N into GaAs similar to other studies which used 5-15 times the amount of Sb. The N concentration increased with increasing Sb flux. PL measurements also indicated an improvement in optical quality with increasing N and Sb concentrations (and thus longer wavelengths) - contrary to conventional wisdom that adding more N further degrades material quality. We collected and simulated ER spectra to examine the general band properties of the layers. Valence band splitting results agreed with strain measurements obtained from HRXRD. Isoelectronic co-doping can explain the improved quality when Sb is added to GaNAs. The improvement in GaNAs with small amounts of Sb holds great promise for improving strain compensated GaInNAs(Sb)/GaNAs devices. By improving the optical properties of the barriers, carrier loss into the barriers from the quantum well can be reduced, improving threshold current densities and, in general, laser performance.

10:15 AM B11.2

Compositional Fluctuations and Optical Properties of InGaAsN Quantum Wells Analysed by Transmission Electron Microscopy. Martin Albrecht[1], Thilo Remmele[1], Lutz Geelhaar[2], Henning Riechert[2] and Axel Hoffmann[3]; [1]Department of Charactersiation, Institute for Crystal Growth, Berlin, Germany; [2]Corporate Research Photonics, Infineon, Muenchen, Germany; [3]Institut fuer Festkoerperphysik, TU Berlin, Berlin, Germany.

InGaAsN is a solid solution with a large size mismatch of the constituents on the group-V-sublattice. This size mismatch leads to a number of unusual optical properties, e.g. a strong bandgap bowing, a large Stokes shift between absorption and emission and a blueshift of the emission with increasing excitation power, characteristic for carrierlocalisation. Up to know it is not a known, which localization mechanism dominates the optical properties of the alloy for which range of composition. Experimental work up to now discusses the influence of compositional and well width fluctuations on carrier localization more qualitatively. Formation of quantum dot like structures, N and In-clustering and short range order have been evidenced to induce carrier localization in InGaAsN. However, the reported values of localization energies, Stokes shift and photoluminescence line width will vary over a large range even for comparable In and N concentrations. This clearly shows that a quantitative analysis of structural (evaluation of length scale and amount of compositional fluctuations, quantum well thickness) and optical properties of InGaAsN dependent on N and In concentration is needed. In this paper we will show how transmission electron microscopy can contribute to solve this problem and to correlate directly optical and structural properties of InGaAsN quantum wells: The samples analysed have been grown by molecular beam epitaxy in the temperature range between 400 C and 450 C. We use both, high resolution transmission electron microscopy based methods and energy selective imaging with a post column energy filter to reveal compositional and well width fluctuations. By these m,ethods In and N concentration fluctuations in the quaternary alloy can be analyzed with a spatial resolution as high as 1 nm. Monochromatic cathodoluminescence images are obtained in the scanning transmission electron microscope and are directly correlated to structural properties of the material. Our analysis yields that InGaAsN exhibits two different localization mechanisms: In fluctuations on a mesoscopic length scale leads to strong carrier localization with localization energies between 10-20 meV . Such layers have a PL line width in the range of 30-70 meV. N leads to weak localization and broadens the line width up to 20 meV. Moreover our measurements show, that addition of N influences the growth mode of the layer: under the presence of N the quantum wells tend to grow three dimensional with increasing growth temperature.

10:30 AM B11.3

Near band-edge and excitonic behavior of Ga(In)AsN epilayers grown by Chemical Beam Epitaxy. J.A.H. Coaquira, W. Zhu, M.-A. Pinault, Alex Freundlich and A. Lytvynchuk; TcSAM, University of Houston, Houston, Texas.

In Ga(In)AsN alloys, the substitution of arsenic by nitrogen atoms produces a large band-gap reduction that has sparked an intensive investigation in the field of diluted N-containing III-Vs. For relatively low nitrogen compositions (0.5%⟨x⟨2%) the near band-edge properties of these alloys are well described within the framework of the band anticrossing model. However for higher compositions, data on the position of the fundamental bandgap, as often extracted from low-temperature photoluminescence features, are scattered. Moreover the understanding of the optical properties of these alloys is further puzzled by large annealing induced energy shifts that have been reported by number of investigators. In this work a systematic study of the near band-edge optical properties of $Ga(In)As_{1-x}N_x$ (0.5%⟨x⟨7.1%) alloys was undertaken using 13-300K photoluminescence and absorption spectroscopy. In particular, the presence of sharp excitonic-like feature in the photoluminescence spectra of samples and a systematic study of the near band-edge intrinsic properties by transmission/absorption spectroscopy provide a new light on the understanding of the optical properties of Ga(In)AsN alloys. The samples studied here were grown on (001) GaAs substrates

by chemical beam epitaxy. Relatively thick 0.1-1 μm Ga(In)AsN films were fabricated at temperatures ranging from 420-480 C. The nitrogen content for these samples, as determined from X-ray diffraction data, ranged from 0.5-7.1%. The low-temperature photoluminescence spectra of these samples contained two set of features: (i) a relatively broad peak at low energy in the vicinity of the predicted bandgaps and (ii) a sharp excitonic feature at higher energy (about 100 meV higher than the deep luminescence peak for x 4%). At low temperature the binding energy of this higher energy excitonic peak was found to be consistent with the increased electron effective masses and the bandgap as extracted from absorption/transmission data. In order to further understand the evolution of these photoluminescence features, samples were subjected to a post-growth rapid thermal annealing (RTA) for 10-120s (in increments of 10s) at 850C. The increase in annealing treatment time resulted in a strong enhancement of the luminescence intensity of the higher energy excitonic peak; however, neither noticeable change in the position of this peak, nor an annealing induced shift of the absorption-edge was detected. This behavior contrasted with that of the deeper luminescence peak (probably associated with nitrogen-defects) that revealed reduced luminescence and position shift as a function of annealing treatments. A careful examination of the data obtained in this work suggests that for high nitrogen compositions (x)2%) the fundamental bandgap of Ga(In)AsN is located at significantly higher energies than those commonly accepted for these alloys.

10:45 AM B11.4
Charge Coupled Cyclotron Motion of Electrons and Holes in InGaAsN Epitaxial Layers. Horia-Eugen Porteanu, Oleg Loginenko and Frederick Koch; TU Muenchen, Garching, Germany.

The purpose of this work was to investigate the long range interaction of the nitrogen potential with the host lattice. Previous electroreflectance measurements determined nitrogen energies within the conduction band. Optical measurements show a decrease of the bandgap with increasing the N content and also the existence of a number of defect states within the bandgap. From PLE, photovoltage or electroreflectance measurements it was estimated the effective mass and in this way the long range influence of the N potential. The initial results are contradictory and are based on many assumptions, not directly verified by experiments. The first attempt to measure directly the effective mass with help of cyclotron resonance was done on GaAsN and it was concluded that with increasing of N content the electron effective mass increases and the bandgap decreases. Our study is done on several InGaAsN layers with In content chosen to match the lattice constant of the GaAs substrate. We used a new technique, time resolved cyclotron resonance, which allows to determine with 50 ns resolution the time variation of the real and imaginary part of the conductivity. Although our samples contain In, we confirm the same increase of the electron effective mass with the N concentration and the values are very close to that reported for GaAsN. We observe in addition the hole resonance. The microwave absorption decays within tens of milliseconds, in spite of a nanoseconds decay of the photoluminescence. This suggests a charge separation, having as consequence a time dependent band banding, but also a partial trapping of the charge carriers. Within this decay the absorption peaks for electron and holes shift on the B-field scale, suggesting an increase of the effective mass with the time i.e. with reducing the carrier density, and a broadening of the resonances, correlated with a decrease of the scattering time. Because we measure separately the real and imaginary part of the conductivity, we can understand better the meaning of the relatively distorted hole resonance. The full interpretation suggests the existence of a coupling between the motion of electrons and holes. The partially trapped holes modify dynamically the local potential and in this way the motion of electrons. There are many experimental and theoretical studies about the Coulomb coupled cyclotron motion of electrons in a 2D electron gas especially in the extreme quantum limit and very high mobility limit. Our case is in the opposite limit, therefore a new theoretical approach was necessary. In the frame of our theory we find that holes have a very short scattering time (i.e. broad resonance and partially trapped) and they are strongly coupled with few relatively free electrons. The effective mass of the holes is higher than that of GaAs. This result contradicts the initial expectation that nitrogen levels perturb only the conduction band.

11:00 AM B11.5
Nitrogen Induced Optical Phonon Shift in GaN_yAs_{1-y} Studied by Raman Scattering. Li-Lin Tay, David J. Lockwood and James A. Gupta; Institute for Microstructural Sciences, National Research Council, Ottawa, Ontario, Canada.

Recent advances in the growth of dilute nitride compounds have attracted, in particular, attention to GaN_yAs_{1-y} and $In_xGa_{1-x}N_yAs_{1-y}$ due to their potential application as lasers, photodetectors and solar cells. Introducing dilute amounts of nitrogen into GaAs is complicated by the large difference between the GaAs and cubic GaN lattice constants. GaNAs epilayers grown coherently on GaAs exhibit tensile strain, which will have a significant influence on the properties of the alloy. Here we present results from Raman studies on the pseudomorphically strained epitaxial films of the ternary alloy GaN_yAs_{1-y} grown on GaAs(100) with y ranging from 0 to 0.06. The optical phonon Raman spectrum of the alloy displays a two-mode behavior. The GaAs-like first order modes are represented at y = 0.06 by the strong longitudinal optic (LO_1) mode at 287.4 cm^{-1} and the weaker transverse optic (TO_1) mode at 268.4 cm^{-1}, while the GaN-like LO_2 mode is observed at 476.1 cm^{-1}. Two very broad disorder-induced acoustic bands are evident at 80 and 170 cm^{-1} due to atomic disorder within the crystalline network. Raman studies show that as the nitrogen concentration in the alloy increases, the GaAs-like LO_1 band shifts linearly towards lower wavenumber while the GaN-like LO_2 phonon band displays a surprisingly sub-linear increase in wavenumber that is not evident for nitrogen concentrations less than 0.03. The non-linear shift of LO_2 phonon will also be discussed.

11:15 AM B11.6
MBE-Grown GaNAsBi Matched to GaAs with 1.3-μm Emission Wavelength. Masahiro Yoshimoto, Wei Huang, Junji Saraie and Kunishige Oe; Kyoto Inst. Tech., Kyoto, Japan.

$GaN_yAs_{1-x-y}Bi_x$ alloy lattice-matched to GaAs has been grown by molecular beam epitaxy (MBE). The grown layer emitted photoluminescence (PL) at a wavelength of 1.3 μm at room temperature. Since the temperature coefficient of the PL peak energy was measured to be much smaller than that of GaAs, $GaN_yAs_{1-x-y}Bi_x$ is suitable to realize a new semiconductor laser diode with a temperature-insensitive wavelength for optical fiber communication light sources. The new laser diode will eliminate the use of massive temperature-control equipment in wavelength-division-multiplexing (WDM) fiber communication systems. III-V semiconductor alloys including semimetal components such as GaBi are currently attracting significant attention as they are expected to have temperature insensitive bandgaps. In our previous study, the temperature coefficient of the bandgap for $GaAs_{1-x}Bi_x$ evaluated by photoreflectance spectroscopy decreased with increasing GaBi molar fraction (x). For x=0.026, the temperature coefficient at room temperature was measured to be -0.15 meV/K, that is, 1/3 of the value of GaAs. Recently, we have reported the first successful growth of $GaN_yAs_{1-x-y}Bi_x$ alloy by MBE. Lattice-matching to GaAs and bandgap adjustment to the optical fiber communication waveband can be achieved simultaneously for $GaN_yAs_{1-x-y}Bi_x$. Since the Bi incorporation into the epilayer can be achieved only in a low-temperature growth, MBE with plasma-activated nitrogen source has advantage to realize the incorporation of both Bi and N. $GaN_yAs_{1-x-y}Bi_x$ was grown on (001)-oriented GaAs substrate in MBE with solid sources of Ga, As and Bi. Activated nitrogen generated from N_2 gas in rf plasma was used as the nitrogen source. The sample was grown in the structure of $GaAs/GaN_yAs_{1-x-y}Bi_x/GaAs/GaAs$ substrate. GaAs homoepitaxial and capped layers were grown at substrate temperature of (T_{sub}) of 550°C. $GaN_yAs_{1-x-y}Bi_x$ layer was grown at T_{sub} in the range between 350 and 380°C. The incorporation of Bi and N atoms into the epilayer was confirmed by Rutherford back scattering (RBS) measurements and secondary ion mass spectroscopy (SIMS), respectively. The lattice-matching of $GaN_yAs_{1-x-y}Bi_x$ to GaAs was investigated by X-ray diffraction measurements on a series of $GaN_yAs_{1-x-y}Bi_x$ with various GaBi and GaN molar fractions. In the case of the lattice-matching of $GaN_yAs_{1-x-y}Bi_x$ to GaAs, the diffraction peak of $GaN_yAs_{1-x-y}Bi_x$ overlapped the peak of GaAs. PL emission at the wavelength of 1.3 μm was observed from $GaN_yAs_{1-x-y}Bi_x$ epilayer matched to GaAs at room temperature. The temperature coefficient of the PL peak energy in a temperature range 150-300K for $GaN_yAs_{1-x-y}Bi_x$ was smaller than that of GaAs, as in the case of $GaAs_{1-x}Bi_x$. This is the first report on both lattice-matching to GaAs and bandgap adjustment to 1.3-μm waveband for $GaN_yAs_{1-x-y}Bi_x$. This alloy will lead to the fabrication of laser diodes with an emission of temperature insensitive wavelength.