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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 diagnostic tools. The most common sources within this spectral range are gas lasers with cumbersome designs that consume a great deal of energy and are difficult to access. The quantum efficiency of these lasers is relatively low, and their bandwidths are typically several nanometers.

Turning to quantum dots, there is a lack of compact and coherent solid-state radiation sources. In the Terahertz (THz) region of the electromagnetic spectrum (30-300 μm), these sources would play a key role. Quantum dots are small semiconductor particles that can emit radiation with a frequency in the THz range. They are formed by pairs of coupled quantum dots. We study here the temperature-dependent cathodoluminescence (CL) properties of InAs quantum dots grown on InP substrates by metal organic chemical vapor deposition (MOCVD). Growth conditions were chosen to maximize photoluminescence intensity and to obtain high output powers from the Quantum Dot lasers. One of the main advantages of InAs quantum dots is that they have a red shift from bulk material, 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 to larger 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 features of the QWs in our samples. The QW effects help 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 thermalization of carriers 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.

Atomic force microscopy (AFM), characterization of both capped and uncapped self-assembled InAs quantum dots embedded in InAs/GaAs 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 the Quantum Dot lasers. One of the main advantages of InAs quantum dots is that they have a red shift from bulk material, 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 to larger 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 features of the QWs in our samples. The QW effects help 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 thermalization of carriers 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.

Intersubband Transitions in In0.3Ga0.7As/GaAs Multiple Quantum Dots of Varying Dot-Sizes. Jie Liang, Omar Manasreh, Y. C. Chua, B. C. Passmore, E. A. Decuir, Zhiming Wang and G. J. Salamo; 1Electrical Engineering, University of Arkansas, Fayetteville, Arkansas; 2Physics, 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. A wavelength range of 8.60 - 13.76 μm 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 spectra. 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.

Quantum-Dot Molecules for Potential Applications in Terahertz Devices. Valeria Gabriela Stoleru, Debdas Pal; 1Electronics and Photonics Laboratory, The Aerospace Corporation, El Segundo, California; 2Space Materials Laboratory, The Aerospace Corporation, El Segundo, California; 3Jet Propulsion Laboratory, Pasadena, California.

InAs quantum dot growth has been recently demonstrated on (110) GaAs substrates. Both the growth and characterization of these (110) quantum dots will be discussed. Dots grown on the (110) surface with extremely low densities (3x10^8 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.

Additional characterization of gas lasers allows for the growth of these nanostructures on the cleaved edges of GaAs samples. The cleaved GaAs samples used in this work incorporated intermixed InGaAs quantum wells, which were shown to have a line-shape of 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. D Wasserman and S.A. Lyon; 1Electronics and Photonics Laboratory, The Aerospace Corporation, El Segundo, California; 2physics, University of Arkansas, Fayetteville, Arkansas.

Quantum-Dot Molecules for Potential Applications in Terahertz Devices. Valeria Gabriela Stoleru, Debdas Pal; 1Electronics and Photonics Laboratory, The Aerospace Corporation, El Segundo, California; 2Space Materials Laboratory, The Aerospace Corporation, El Segundo, California; 3Jet Propulsion Laboratory, Pasadena, California.

There is a lack of compact and coherent solid-state radiation sources within 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 diagnostic tools. 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 transition have been demonstrated. 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 quantum dot molecules. The properties of artificial quantum-dot molecules have not been extensively studied experimentally up to now. The sources studied in this work are grown by molecular beam epitaxy. Two InGaAs 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 10-15 meV, as a consequence, the photon energy lies in the THz range. We investigate the intersubband transitions using photoluminescence spectroscopy. The experimentally measured spectra agree with the theoretically calculated ones and prove the presence of an intersubband quantum dot 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 within dot molecules, and in the development of new THz devices.
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. For instance, a way to improve performance. 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 efficiency, and additional optical features over that of QDI-suppressing ones. The latter approach, filled with GaAs and overgrown with AIGaAs. Because of the absence of the intermixing, the photoluminescence (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 intermixing in InGaAs/GaAs QD material and the suitability of the SISA approach for the generation of a plurality 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 region. To demonstrate the SISA process in the QD material, patterns containing lines and squares of various sizes (3-100 microns) are used. In some cases, larger fill factors over 40% were thermally treated 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). In all fill factors above 40%, the shifts appeared to saturate and even decrease slightly. The effect of the feature size and shape was 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 (29 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 substrate has been demonstrated.

4:00 PM B1.7
Optical characterization of hierarchically self-assembled GaAs/AIGaAs quantum dots. Franco Marabelli, Armando Rastelli, Oliver Schmidt, Guillaume Beaurin, Mario Geddo and Giorgio Guizzetti

In various studies to date formation of small atomic clusters and their growth have been modeled numerically at conditions that have not matched any spatial restrictions. As a rule, the structure 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 atom clusters that may or may not be involved in the process of nucleation 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, conditions of 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 parameters and the direct optical energy gaps 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 is the case for the chain organic molecules reported recently. The major parameters defining the effects of the restricted growth cluster 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. K. Bangarajavan, V. Elarde and J. Coleman

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 the 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 InAs 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 InP substrate. The SCH material consists of an InGaAs/GaAs quantum well, which is sandwiched between a lower barrier region, which is a 65 nm GaAs inner barrier layer grown at 625 C. A unique feature is the use of a 725 nm GaAs inner barrier layer grown at 600 C. The temperature is ramped down to 500 C for the deposition of the self-assembled dot layer (1.6 monolayers of InAs/GaAs). The InAs/GaAs quantum dots are capped with a 15 nm GaAs layer grown at 600 C. The control for this experiment is InGaAs quantum dots grown under similar conditions, 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 InP substrate. The SCH material consists of an InGaAs/GaAs quantum well, which is sandwiched between a lower barrier region, which is a 65 nm GaAs inner barrier layer grown at 625 C. A unique feature is the use of a 725 nm GaAs inner barrier layer grown at 600 C. 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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 layers. 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 GaSb and InSb dots, in which only planar growth was preserved in them. 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 intermixing of the material at the interfaces.

InAs/GaSb superlattices grown by molecular beam epitaxy on either GaSb (001) or AlSb (001) substrates with InSb interfacial layers were employed. We believe that the GaAs interfacial bonds, in which the InAs layers remain planar, is a key contributing factor to the reduced average lateral size as well as height, where these decreases can be attributed to the freezing of the growth surface post AlAs growth. In the XRD spectra, the satellite peaks from C-AFM correspond well with threshold voltages and barrier heights obtained with C-AFM technique (in a controlled atmosphere) and electrical properties of InAs/GaAs 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 nanowires. On these devices, fluctuations on I-V curves at certain conditions were observed both parallel and perpendicular to the wires long axis direction. At these low temperatures, the temperature dependence 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 nanowires. 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 hoping through localized states of quantum wires and dots.

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 placed in strained InGaAs (001) substrates 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 structures was done after p-type layers were removed by chemical etching. Cross-sectional micrograph images of samples were obtained by using dark-field TEM, which is sensitive to composition so that the shape of dot superlattices was clearly observed. We found that the average dot volume in the first layer was nearly 36% 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 the Bragg reflections measured with four-crystal X-ray diffractometer, 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. This was taken into account the number of layers by TEM 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 InAs/InGaAs volume fractions 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 growth-rate tailing was assigned 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 Advancing Telecommunications Technology Research Foundation (SCAT).
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 nanotube 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

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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^{-5}-10^{-3} 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 of 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 μ-type with specific resistance r=10 Ohm·cm, at the energy of ions 40 keV with the implantation dose 10^{15} 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 °C. After the annealing the samples possessed the specific resistance of n-type of conductivity with r 10^{5} 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 80 mA, frequency varied from 10^{2} to 10 Hz, and the modulation coefficient approached 200%. A mechanism of the observed auto-oscillations can be explained by transitions of types Mn^{3+}→Mn^{4+} or Mn^{4+}→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, D.-J. Won, A. Sharan, T. Scheidematel, B. Jackson, Neil F. Bantle, A. Robing, V. Gopalan, A. Amemos and P. Szczepanek, Materials Research Institute, Pennsylvania State University, University Park, Pennsylvania; 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 parallel aligned semiconductor wires in a silicon 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 Regenerative 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


The performance of detectors and sensors is degraded by dark current generation, which is due to defects and impurities in the materials. Electric fields from the generation of the 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-4×10^{5} 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 0.5 MV/cm. Many detectors collect a charge packet before they are read, and the preamplifier noise charge change 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. 1. G. Vincent, A. Chantre, and D. Bois, J. Applied Physics 50, 5484 (1979); 2. A. Schenk, Solid-State Electronics 35, 1585 (1992); 3. O. K. B. Lui and P. Migliorato, Solid-State Electronics 41, 575 (1997).

B2.8 Longitudinal Modes in InAlGaAs/InGaAs High-Power Laser Diodes

Omar Mansour, S. C. Chua, Jens W. Tomm and Brandon S. Passmore, 1 Electrical Engineering, University of Arkansas, Fayetteville, Arkansas; 2Max-Born-Institut, Berlin, Germany.

The emission from bias voltage driven In0.65Al0.35Ga0.86As/0.7Al0.33As 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 Application in the 1.8-2.3 μm Spectral Range

Jadwiga Zynek, Agata Jasiel, Jaroslav Gaca, Marek Wojciech, Wlodzimierz Strupinski, Jaroslav Rutkowski and Artur Wnuk, 1Institute of Electronic Materials Technology, Warsaw, Poland; 2Military University of Technology, Warsaw, Poland.

Conventional photodiodes for the wavelengths longer than 1.7 μm exhibit high dark current densities at the room temperature. The solution providing improvement in the photodiode 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 photodiode (RCE). This concept has been used to fabricate a photodiode for 1.8 μm, based on InP and containing a thin, pseudomorphic, strained In0.85Ga0.15As 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 - 2.3 μm spectral range. The absorption region consists of a single or double quantum well fully formed by the layer system InP/In0.53Ga0.47As/In0.53Ga0.47As/In0.53Ga0.47As/InP. The employment of In0.53Ga0.47As 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 analysis of cross-sections, 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 has influenced the composition profiles. After photodiode processing dark current densities below 10⁻⁶ A/cm² 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. The resonant cavity back mirror is made of In0.53Ga0.47As/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 observed 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, Rong-Mu Hong, Yi-Hao Wu, Yu-Hsiao Huang, Li-Hong Laih and Jung-Lung Yu, 1Electronic Engineering, Ching Yuan University, Jung-Li, Taiwan; 2R&D Production, Millennium Communication Co.,
Infrared states in the active region of a multi-quantum well laser diode (MQW) are studied. The good temperature performance is caused by the offset of cavity resonance and optical gain. When the temperature increases, 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 between the cavity resonance and peak gain. An optimum offset of 10nm is used to obtain the good temperature performance.

The device grown by metal-organic chemical vapor deposition (MOCVD) is consisted of a 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 lower DBR and emitting from the surface. By designing and simulation, the main reflected wavelength is designed at 870nm. The DBR is consisted of high and low refractive index materials, which contain a quarter wavelength of refractive index. The high refractive index material is A10.12Ga0.88As and low refractive index material is A10.92Ga0.08As.

In summary, two kinds of 870nm RCLEDs were investigated to obtain the optimum temperature performance. A 870nm RCLED with gain offset of 10mm shows the best temperature performance for IrDA applications.

**B2.11 Electrical Measurement of Non-Radiative Recombination Lifetime in Blue Light Emitting Diodes**

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 or AlGaN/InGaN/GaN heteroepitaxial films grown either on sapphire or Si 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 semiconductor. The measurement of the recombination processes 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 (L-V) and current-voltage (C-V) measurements. In order to determine the reverse recovery characteristic of multiple bias points, 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, \( \tau \), is given by 1.25ts, where ts is the representative value. A representative value of 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 \( \sim 10^{17} \text{cm}^{-3} \) 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 1.7 to 2.5, 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 \( 2 \times 10^{15} \text{cm}^{-3} \) corresponding to states located 530 meV above the valence bandedge. These deep-level states introduce non-radiative recombination centers which are expected to reduce the efficiency of the LEDs by electroluminescence and radiative recombination paths.

**B2.12 Impurity Dominant Layer Disorder of AlGanP/GanP Multi-Quantum Well Laser Diodes**

Impurity dominant layer disordering of AlGanP/GanP MQW laser diodes (LD) has been observed in this study. The LDs were fabricated using a MOCVD growth technique. The active region of the diodes is consisted of 30nm AlGanP layers with high In content on either side of a 100nm GanP well. The laser diodes were evaluated using standard electrical and optical measurements. The LDs were operated at temperatures ranging from 5 to 300 K. The light output power and differential quantum efficiency were measured as a function of current density. The threshold current density was found to decrease with increasing temperature. The observed weak dependence of the recombination lifetime, \( \tau \), on low biases was consistent with 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 \( 2 \times 10^{15} \text{cm}^{-3} \) corresponding to states located 530 meV above the valence bandedge. These deep-level states introduce non-radiative recombination centers which are expected to reduce the efficiency of the LEDs by electroluminescence and radiative recombination paths.

**B2.13 Si integrated BaTiO3-electro-optic modulators**

Yashiv Avrahami, Luciano Soeci, Francesco Lopez-Reyna and Harry L. Tuller; Microphotonics Center, MIT, Cambridge, Massachusetts.

BaTiO3 (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 BaTiO3 plays a major role in determining the quality of the film and its optical properties.

Films of BaTiO3 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 BaTiO3 ridge waveguides was 3.5 dB/cm in TE polarization. Measured electrooptic coefficients were approximately 180 ppm/V, three times larger than the electrooptic coefficient \( \Lambda = 30.8 \text{pm/V} \) of single crystal LiNbO3.

BaTiO3 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 BaTiO3 films. Sputtered and PLD BaTiO3 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 BaTiO3 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**

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 to each other at room temperature. A further higher temperature (220°C) 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 (OADM) and photonic band-gap crystals (PBGs). Our particular interest is in the development of OADM using this low temperature wafer fusion process. A typical OADM structure consists of 4 ports equally spaced from each other, and emitting in an equally spaced grating 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 performance of the InP samples was studied for bonding at 200°C and 250°C. The samples were immersed in HF and applied on the wafer surfaces. The bonding was carried out in a Karl Suss Bonder system with temperature in the range between 220 to 250 °C for 30 minutes.
with the application of pressure (80N). After the bonding, the samples remained sandwiched and without the cleaving process. A more robust treatment was given to the samples by using 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. Cleaved 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 exclusively the optical properties of the Raman spectrum showed signals corresponding to first-order and second-order disorder-active surface phonons, which are signatures corresponding to clean semiconductor surfaces [2]. The results of the detailed investigation will be presented [1]. M. Richter, B. Liu, Y. Okuno and J.E. Bowers., IEEE Photonics Technology Letters, Vol. 13, No.6, 2001 [2] K. Hinrichs, A. Schierhorn, P. Huier, E. Esser, W. Richter and J. Sahm., Physical Review Letters., 79, no.6, 1997

B2.15

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 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) Oxide, to deposit dielectric oxides using TEOS-Ozone chemistry, now enables us to tune locally the strain in the channel region without voids and seams for aggressive geometries of sub-65nm design rules.

B2.16
Imaging the Evolution of GaAsN Film Growth. N. G. Budzinski, 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 epitaxy using a 10%N2/90%Ar or pure N2 radio frequency plasma can enhance the potential of GaAsN for mid-IR applications. Recently, low nitrogen content InGaAsN and GaAsN alloys have attracted much attention for their unusual fundamental features as well as their potential application in optoelectronics operating in the mid-infrared (1.6-2.0 microns) window. One of the most important consequences of GaAsN is a change in the shift of band gap of the novel alloys. The bandgap can be further red shifted by tensely straining a thin layer of GaAsN, provided the thickness 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 GaN0.87As0.13N (binally tensile) and InAs (binally compressive) strained to InP (001) and a preliminary experimental study of 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 GaN0.87As0.13N/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)x(InAs)y superlattice short period (where x,y represent the number of monolayers (ML)) superlattices. The study predicts the evolution of the electron and hole miniband levels and associated miniband widths for various thickness (lML-5ML) and composition combinations. The transmission probability calculation of the material system matched to InP substrate potential obtained 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 nitrided CBE will be presented at the meeting.

B2.19
On the optical properties of Er and Yb-related emission in Yb co-implanted Alx.7Ga0.30As: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 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 high-energy shell of Er ions. So far, Er ions were co-implanted with impurity ions (Si, C, O, N etc.) into Al0.7Ga0.30As substrates; we have realized the increase in intensity of Er-related shell luminescence. These substrates were grown undoped Alx.7Ga0.30As layer on GaAs (100) by Molecular Beam Epitaxy (MBE). In this work, we studied the transfer efficiency and the optical sensitization of Alx.7Ga0.30As:Er substrate with co-implanted Ytterbium (Yb) ions and studied the defect using PAS (Positron Annihilation Spectroscopy). Er implantation was carried out at 1MeV

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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/GaAs single quantum well samples. The doping level is on the order of mid-1016cm-3. The Raman spectra were analyzed by fitting them with the dielectric function constant that contains both the phonons and plasmon contributions. The electrons concentrations (n) and drift mobilities were extracted from the plasmon frequency (wp) and damping rate of the modes, respectively. An empirical correlation of n-drift mobilities concentration determined as [n] {2.38x1016 (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 (7-20) cm2/Vs, while the relaxation time (Γ1) is found to be in the range of (2.0-0.5)x10-15s for all tested samples.

B2.18
Short-Period Strain-balanced Ga1-xAsxN/InAs(N) Superlattices Lattice-matched to InP(001): a new material with 0.45-0.6 eV mid IR applications. Loknath Bhushan, A. Andemat-Aminou, and Alex Freundlich; 1Texas Center for Superconductivity and Advanced Materials, University of Houston, Houston, Texas; 2Physics 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 their potential application in optoelectronics operating in the mid-infrared (1.6-2.0 microns) window. One of the most important consequences of GaAsN is a change in the shift of band gap of the novel alloys. The bandgap can be further red shifted by tensely straining a thin layer of GaAsN, provided the thickness 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 GaN0.87As0.13N (binally tensile) and InAs (binally compressive) strained to InP (001) and a preliminary experimental study of 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 GaN0.87As0.13N/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)x(InAs)y superlattice short period (where x,y represent the number of monolayers (ML)) superlattices. The study predicts the evolution of the electron and hole miniband levels and associated miniband widths for various thickness (lML-5ML) and composition combinations. The transmission probability calculation of the material system matched to InP substrate potential obtained 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 nitrided CBE will be presented at the meeting.
with doses of $1 \times 10^{13}$ cm$^{-2}$ at RT. Yb$^{3+}$ ions were co-implanted at energy of 1 MeV with doses of $3 \times 10^{12}$ cm$^{-2}$. After implantaing the ions, the film was heated in a tube furnace at 500 °C for 10 min by the face-to-face technique in hydrogen atmosphere. The influence of the introduction of Yb$^{3+}$ ions on Er$^{3+}$ luminescence in Al$_{20}$.2Ga$_{40}$As was studied, using photoluminescence (PL), photoluminescence excitation (PLE), and selective photoluminescence (SPL) techniques. Co-implanted Yb$^{3+}$ enhanced PL intensity of Er$^{3+}$ related emission. Er-related main peak (1538 nm), in addition to Yb$^{3+}$ dose, was enhanced approximately two times. The energy transfer from $^{4}S_{3/2}$ (the first excited state) $^{4}I_{11/2}$ (the ground excited state) of the Er$^{3+}$ (the excited state) $^{4}I_{15/2}$ (the ground state) 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 Miyasaka, Takashi Kimpara, Tomonasu Sato and Takashi Hirata; Electrical, Electronics and Information Engineering, Kanagawa University, Yokohama, Japan.

Recently, various microstructures of ZnO such as nanowire, nanorod, nanobelts, 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 were deposited on a p-Si(111) substrate by a chemical vapor deposition method combined with laser ablation to dope an impurity of Mn into ZnO. Metal Zn vapor and O$_2$ are used as precursors to synthesize ZnO nanorods. Then, they were heated up to temperature of 400 °C. The EL emission from the inside of the ITO film was measured using the Delayscherrer equation. The EL intensity of the ZnO nanorods was increased after annealing with an increase in the annealing temperature. The threshold voltage of the EL emission was decreased with the increase of the annealing temperature. The EL emission from the nanorods was enhanced approximately two times. The energy transfer from $^{1}S_{0}$ (the first excited state) $^{3}P_{0}$ (the ground state) and $^{1}S_{0}$ (the first excited state) $^{3}P_{0}$ (the ground state) of the Er$^{3+}$ was observed. We report systematically the experimental results of PL, PLE, SPL and PAS.

B2.21 Zinc Oxide Quantum Dot Formation Using Low Energy Ion Implantation, Julia C. Muntele, Bopha Chhay, Paul Thavench, Chaudhu I. Muntele and Daryush Ila; Physics, Alabama A&M University, Normal, Alabama; Physic, 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 size 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 Ito and Masakazu Kobayashi; Laboratory for Material Science and Technology, Waseda University, Shinjuku Tokyo, Japan.

In recent years, the concern over dopant 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 co-implantation 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 the 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 20 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 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 Mn2+ to establish the core/shell structure. The core/shell structure was confirmed by the 2D-dimensional mapping of the transmission electron microscopy 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. This 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+ to ZnS:Mn2+/ZnS nanocomposites. 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 prepared using a physical milling method. The nanoparticles 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 Ryozen, Ino Sakaguchi, Takashi Ohgaki, Naoki Ohashi and Hajime Haneda; Physics, Alabama A&M University, Normal, Alabama; National Institute for Materials Science, Tsukuba, Japan; *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 and enhance the performance of the sensor. 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 was induced by heating annealed on 18-oxygen atmosphere. After diffusion process, we also used cobalt, aluminum and magnesium as tracer to evaluate cation diffusion. The result of diffusion analysis indicated that oxygen radical irradiation made significant influence on defect structures in ZnO films prepared on both ZnO substrates and YAG substrates. The oxygen radical irradiation cause no significant change in defect structures for the films homoeopitaxially grown on ZnO single crystalline substrate. Regarding cation diffusion, anomalous diffusion behavior was observed in the ZnO films and bulk ZnO single crystals. Diffusion behavior 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.

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Visible emission of ZnO is of great importance for cathodoluminescence applications as well as understanding of the defects present in ZnO. In this study, dual 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 below 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 H3As 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 and Ultrasonication
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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 Si3N4SiO3 using O2 and N2 atmospheres. X-ray analysis of the films deposited on Si3N4SiO3 revealed a c-axis 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 O2 pressure was n-type with resistivity ~ 10^-3 cm, sheet resistance ~ 1700 ohm/square, mobility ~ 5 cm^2/Vs and sheet Carrier Concentration ~ 7.10^12 cm^-2 (all at room temperature). Films deposited under relatively high O2 pressure were highly resistive. However, the resistivity decreased upon irradiation with ultraviolet light. The ZnO film deposited in N2 atmosphere exhibited resistivity ~ 1 ohm, sheet resistance ~ 4.10^11 ohm/square, mobility ~ 10 cm^2/Vs and sheet Carrier Concentration ~ 5.10^12 cm^-2 (all at room temperature). The carrier type of this sample could not be determined unambiguously. The variation of the resistivity with wavelength range of 0.2772K 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 Nanonals, Hoeven Son1, Dake Wang1, Yuhua Zheng1, Sheng-De Lin2, Michael Bozack1, John Williams1 and Minseo Park1; 1Department of Physics, Auburn University, Auburn, Alabama; 2Department 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 nanoals were prepared by the synthesis of ZnO vapor deposition. The morphology of the sample was studied using scanning electron microscopy. The shape of the nanoal 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 nanoal cavity exhibits unique characteristics. It also showed that the optical characteristics of the nanoals are strongly dependent on the shape and size of the nanoal. These results indicate that a novel nanophotonic device can be fabricated by engineering the shape of the nanoal. X-ray diffraction pattern, Raman spectra, and photoluminescence spectra of these materials will be presented. Optical characteristics of the nanoals will be presented and the size of the nanoal will be correlated with Photoluminescence

B2.27
Synthesis and Characterization of ZnO Nanoparticles.
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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 solvothermal reaction. Sonochrochemistry arises from an acoustic cavitation phenomenon, that is, the formation, growth and implosive collapse of bubbles in a liquid medium (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 denonized distilled water in 125 mL round bottom flask. This reaction mixture was irradiated with a high-intensity ultrasonic horn (T-born, 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) 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 over a hotplate at a temperature of 560-600 °C for 1 min. 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 nanoclasters 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. Y, 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, Neha Awasthi1, Pijush Bhattacharya2, B. Sundararaman3 and Rani S. Kattar4; 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 unclear and not well understood. In this work, LVM were observed in chemically doped ZnO ceramics, which were prepared using conventional ceramic processing techniques. The LVM were observed on the Cu-A103 substrate using pulsed laser deposition technique and ceramic targets. The dopant concentration was varied between 1 to 10 mole percent in the target. The substrate temperature was varied in the range of 700-800°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 scattering studies revealed a blue transition doping in ceramic and thin films. Raman scattering in V doped ZnO shows sharp and strong vibrational modes at 377.1 cm^-1 , 395.6 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. The study of these localized vibrational modes will be correlated with Photoluminescence.
(PL) spectroscopy of the transition metal-doped ZnO ceramics and thin films.

**B2.29**

**Intersubband Transition in GaN/AlGaN Multi Quantum Wells.** Omar Manaresi1, Eric A. Depire2, Y. C. Chua3, B. S. Passmore4, Bongsoo Xe5, Hydrock2,6,7, Robert A. Freitas3 and J. Ferguson2.

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 waveguide transitions were identified by detecting 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 Blinov1, Jiaping Zhang2, Xiaohong Hu3, Alex Ianov1, Jianyu Dong4, Remis Gaska5, Michael Shur6 and Asif Khan7.

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 beyond 265 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 output power ascribed to the quality of AlGaN layers up to 70% of Al and emitting in the spectral range. The output power of the lamps decreases from 305 nm to 247 nm and few times reduction in the lifetime at the same current densities. The CW output power of 2x2 LED array arrays at 25 A/cm2 current density decreased from 1.2 mW for 300 nm lamps to 0.120 mW for 290 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' behavior for an up to 350 hours. The most dramatic drop in the output power at 250 nm was detected in 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, Matemática e Física, 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 from MgO, NiO, and WO3 powders. The samples were prepared 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 SrSO4:Ce(SO4)2.H2O by eco-thermally reduction.** P. Thiagarajan1,2, M. Kottasaimy2, K. Sethupathi1 and M.S.R. Rao1,2,3,4.

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

An efficient blue green emitting SrS:Ce has been prepared from SrSO4:Ce(SO4)2.H2O by eco-thermally 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 900°C 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 sulphur 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 up to 50% compared with the SrS:Ce prepared without any external addition of Sulphur 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+ substituting 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**


In general, transparent conducting oxide(TCO) films show 80% of optical transmittance in visible light region and about 2e16-1 cm-3 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. 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 by using both x-ray diffraction and optical measurements. The deposition parameters in a visible region were determined as a function of process parameters such as TMT ratio mole, microwave power, magnetron 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 **

**TB3.1**

T-shaped quantum wire lasers with high uniformity.

Hidetumi Akiyama, ISSP, University of Tokyo, Chiba, Japan.
interface improved by a growth-interrupt high-temperature anneal [1]. We achieved ground state lasing in single-quantum-wire lasers (T < 60 K) [2-3] as well as 20-quantum-wire lasers (T < 120 K) [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-wires has been very good as well [4].

Micro-polutumoluminescence (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 electron microscopy has shown that the free-standing 1-D quantum-wire and 1-D photoluminescence at 1 eV peak is fairly large (90 cm⁻¹ 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 3 eV, which is below the free-standing 1-D quantum-wire and 1-D red-shifted broad PL band. The evolution of this PL band suggests formation of Coulomb-correlated electron-hole plasma [3,4]. Recent features (charged excitons, band-gap renormalization, Fermi edge singularity, and so on) to be related to many-body optical response of 1-D carriers. All experimental results on doped and undoped T-wires seem to indicate importance of Coulomb interactions among carriers.


9:00 AM B3.5

Coulomb Blockade and Andreev Reflections in Superconductor-Coupled Semiconducting Nanowires.

Yong-Joo Do1, D. S. Franceschetti1, L. P. Kouwenhoven1, A. Roest1,2, E. P. A. M. Bakkers2, S. F. Feiner2 and J. A. van Dam1,1Kavli Institute of Nanoscience, Delft University of Technology, Delft, Netherlands.

We have studied the electronic transport properties of InAs and InAs 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 InAs nanowire devices, the normal state resistance below 1 kΩ at T < 2 K. Below superconducting transition temperature Tc = 1.1 K, our every InAs device shows a suppression of zero-bias conductance. Particularly for the highly resistive device, the I(V) characteristics show distinctive negative differential resistance, caused by Andreev reflection. With increasing temperature, the current-voltage curves below Tc show clear characteristics of zero-bias conductance. Our typical specific contact resistance between InAs nanowires and superconducting electrodes is about 10⁴ Ω cm⁻². The normal state resistance ranges from 1 Ω cm⁻² to 80 Ω cm⁻² after deposition of nanowires on p-type Si wafer with 250 nm thick surface oxide. The normal state resistance below 1 kΩ after deposition of nanowires on p-type Si wafer with 250 nm thick surface oxide. The normal state resistance ranges from 1 Ω cm⁻² to 80 Ω cm⁻².

9:15 AM B3.3

Optical and Magnetic-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 spectroscopy of nanotubes of specific chirality, allowing use to study their unique intrinsic optical properties of some 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 SWNTs, I will describe two recent experiments: 1) using magneto-absorption, magneto-photoluminescence, and magneto-photoluminescence-excitation spectroscopy at high magnetic fields, we have detected the optical properties of the Aharonov-Bohm phase [1]; and 2) using pump-probe spectroscopy, we have detected previously-unobserved, long-lived photon-carriers with lasting polarization memory, especially when the nanotubes were excited resonantly carrier out [3,4]. This work was carried out in collaboration with Gordon Ostojic, Sasa Zoric, 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 Research Initiatives 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. Zoric, J. Kono, M. Strano, V. C. Moore, R. H. Hauge, and R. E. Smalley, “Interband resonant emission from a novel optical cavity of a single walled carbon nanotube. Optics Express 10, 2198 (2002). 4. Y. Hashimoto, Srivastava, J. Kono, M. Strano, V. C. Moore, R. H. Hauge, and R. E. Smalley, “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), IPD4.

10:15 AM B3.4

Quantum Dots for Optoelectronic Device Applications.


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 InGaAs QDs grown on GaAs substrates. The emission wavelength of these QDs are still limited to less than 1.3 μm, 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 effect the formation of GaAs/InAs QDs grown on GaAs and InP substrates. Edge wavydige InGaAs/GaAs/InP QD alloy 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 1.55 μm. 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 quantum dot-based optoelectronic integrated circuits.

10:45 AM B3.5

Sub-band Resonance of Ion Beam Synthesized Dense Packaged Embedded CdSe Nanoclusters.

Helmut Karl, Ingo Grossmann, Peter Huber and Bernd Stritscher, 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 presentation 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 600 nm thick thermally grown SiO2 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 sizes we measure an increase of the PL-intensity with increasing laser excitation power.
Colloidal preparations of nanocrystals have attracted much attention because of their size-dependent electronic properties. 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. Thioctic 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 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.

11:45 AM B3.8

While the development of molecular routes to binary II-VI semiconductor nanomaterials continues to be a burgeoning pursuit, entry into ternary 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-VI II-VI nanomaterials. The principle of this developed approach is focused on the synthesis of a series of complexes $[\text{L}_4M(ES_{\text{Me}_3})_2]$ (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 $(\text{tmeda})_2\text{ZnCd}_2\text{E}_2$ (E = S, Te) affords access to nanocluster molecules $(\text{tmeda})_2\text{ZnCd}_2\text{E}_2\text{E}(\text{EPh})_2(\text{PPPr}_3)_4$ where $\text{Zn}$ and $\text{Cd}$ centers are intimately mixed within the cluster core. This assignment of 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-VI II-VI colloids where precise control of the Zn/Cd ratio results in a series of nanorods whose absorption and emission properties can be tuned. Further study 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

1:30 PM B4.1
Ultrashort Pulse Generation with Semiconductor Modelocked Lasers Using Saturable Absorbers Based on Intersubband transitions in GaN/AlGaN Quantum Wells. Farzad Razi Ahmad, Paul George, Jahan Dawlatty and William 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 (>$100 \text{ pJ}$) optical pulses with semiconductor modelocked lasers. Pulse energies 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 experimental and theoretical 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 pJ. We will also show that detailed experimental studies of these 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. We will present experimental and theoretical results that demonstrate that intersubband saturable absorbers consisting of GaN/AlGaN/AIN quantum wells grown on AlGaN buffer layers on Sapphire substrates will be presented that demonstrate low pulse saturation energies.
Semiconductor structures such as quantum-wells are frequently described using the concept of a single quantum-mechanical electron moving in a potential well, which is the basis of the quantum mechanical model of the semiconductor. In this model, the energy of the electron is quantized in a potential well, and the electron's momentum is also quantized. This model is useful for understanding the optical properties of quantum dashes, which are one-dimensional nano-structures with quantum-confined levels. The quantum-confined Stark effect (QCSE) is a phenomenon in which the energy levels of an electron in a quantum well are modified by the application of an electric field. This effect can be used to modulate the optical gain of quantum dashes, which is important for the operation of quantum dash lasers.

In quantum dash lasers, the gain medium is typically a quantum well, and the gain is modulated by the application of an electric field. This electric field can be provided by the application of a voltage across the laser, which creates an external electric field within the laser cavity. The electric field modulates the energy levels of the electron in the quantum well, which in turn modulates the gain of the laser. This effect is used in quantum dash lasers to modulate the output of the laser, and it is also used in quantum dot lasers to modulate the wavelength of the laser output.

In conclusion, quantum dash lasers are a promising technology for optical communication and information processing applications. They offer a high gain per unit length, which is important for applications where the laser needs to be operated at high power levels. They also offer a high modulation bandwidth, which is important for applications where the laser needs to be modulated at high frequencies. These features make quantum dash lasers a promising technology for optical communication and information processing applications.

References:
Vertical-Cavity Surface-Emitting Lasers with cw-Emission at Long Wavelengths: Garden Springs, Thomas Schwartz, Josef Fuest, Michael Boeblert, Harald Pascher and Wolfgang Heinze. 1 Institut fuer Halbleiterphysik, University of 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 nonradiative 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 7.5 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.


Small group velocity is crucial in a variety of applications, ranging from optical delay lines and low-threshold lasers, to studies 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 associated optical pumping 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 0.003c. We will also describe our work on design, fabrication, and experimental setup. 2D CPRCA’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 spherical microcavities formed by removing a single air hole. When cavities are tilted 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 GM 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 band-edge mode [1]. The device employs a two-dimensional spherical microcavity, obtaining room temperature lasing. The emission wavelengths can be tuned by varying the size of the microcavities, 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.

Time Reversal of Light with Linear Optics and Modulators. Mehmet Fatih Yagi and Shuo Her Han. 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 applied 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/ι < 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.


Semiconductor cadmium selenide nanocrystals (NCs) are attractive as lasing media given their photostability, spectrally narrow gain profiles, color-tunableness and ease of chemical processing. However, the short lifetime of these (laser) lifetimes of CdSe NCs creates difficulties in the development of a laser device using this material. We have developed a facile and robust method of incorporating colloidially synthesized CdSe/CdZnS NCs onto the surface of micron-sized silica or polystyrene microspheres by depositing a NC / silica 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 lasing media. No nonlinear multi-photon effects such as four-wave mixing are observed. The narrow gap lead salt semiconductors are well suited 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

9:00 AM B5.2 Processing of Deeply etched GaAs/AIGaAs quantum cascade lasers with DBR mirrors. Sebastian Golka, Christian Pfuegel, 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 in a very convenient model system due to their low electric surface recombination losses. Furthermore the strong diffraction properties of PhCs 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 (up to 1:260K) have a threshold current density of 2.1 kA/cm².

The active region of the laser is based on a double quantum well structure. The DBR is measured on cleaved as etched samples show that sidewall roughness is wanted for lasing 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 (up to 1:260K) have a threshold current density of 2.1 kA/cm².

The active region of the laser is based on a double quantum well structure. The DBR is formed with etching of GaAs on the bottom of the cavity, and a 4-quantum well, two phonons deep etching becomes crucial in preventing leakage of the optical mode into the substrate. Subsequent process challenges caused by high aspect ratios (up to 1:260K) have a threshold current density of 2.1 kA/cm².

9:15 AM B5.3 Optimization of 9 μm Quantum-Cascade Lasers for Room-Temperature Continuous-Wave Operation. Thierry Aellen, Mattias Beck, Marcellin Giovannini 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 design and technology. In the present work, the lasing dependence on both dense-coupling and injection-width 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-Perot (FP) lasers exhibit a decrease of both threshold current and negative differential resistance while lowering the doping concentration. Dependence on both device design and injection current is high. The above results point out the importance of the injection current on the performance of mid-infrared lasers.


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 interband population dynamics and to the waveguide properties. Electron-electron and interface roughness scattering represent the main scattering mechanisms at room 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 a discrete ladder of cyclotron quantum levels, 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 increase from the variation of the emission frequency as a function of the temperature of the active region Tact. We find values of Rₐ = 6.6 K/W, corresponding to G₁ = 9.8 W/K/cm², with a tuning coefficient β = (1/ν) (Δν/ΔT) = -9.50 × 10⁻³ K⁻¹.

The energy of the surface states, electrons and holes, is affected by the confinement and interaction with the crystal lattice. The heavy hole absorption peak shifts from 6.7 THz to 7.5 THz when 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 toward designing a hole quantum cascade emitter will also be discussed.

11:15 AM B5.8
Zener Tunneling of Light in an Optical Superlattice.

Mr. S. V. Baskar, 1 Dr. T. J. Kippenberg, 1 Dr. A. L. Gaeta, 2, 3 Phys. Rev. Lett. 103, 226403 (2009), 1Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, USA, 2Department of Physics, University of California, Santa Barbara, CA, USA, 3Department of Physics and Astronomy, University of Arizona, Tucson, AZ, USA.

The energy density of the THz light fields is increasing with the rapid growth of high-speed electronics. The potential applications of THz source technologies range from remote sensing and imaging, to telecommunications and imaging, to non-contact infrared imaging. The operation of a semiconductor superlattice 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. Ultrathin semiconductor 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 semiconductors.

11:30 AM B5.9
Dispersion Engineering of Three-Dimensional Silicon Photonic Crystals: Fabrication and Applications.

Sriram Venkataraman, Garrett Schneider, Janusz Murakowski, Shouynn Shu and Donna W. Prather; Electrical Engineering, University of Delaware, Newark, Delaware.

The 2008 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 wire scaling issues such as scaling issues that can be 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 microphotonic chips is the challenge of 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 optoelectronic devices, due to the performance enhancement they provide in terms of emission control, guiding, and dispersion engineering, combining dense interconnects 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 fabrication costs, multistep processing, tight alignment tolerances, long turnaround times, and inconsistency with an integrated photonics platform amenable to mass fabrication, leave the scope for novel ideas for their fabrication. In this paper we report on our efforts toward the fabrication of three-dimensional (3D) photonic-crystal structures using conventional planar silicon micromachining. The method utilizes a single planar etch mask coupled to two sidewall passivating, deep nanotextured 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 (S2B) 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/thin-doped 3D photonic crystals to enable sub-micron-routing channels and low-loss optical interconnects.
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 Hoeken1, Jordana Bandaru1, Shoulei Nikzad2 and Steven E. Holland2, 1Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California; 2Lawrence Berkeley National Laboratory, Berkeley, California.

We have developed a process for growing delta-doped epitaxial silicon wafers with δ-layers of N-type delta-doping 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 further into the infrared (i.e., 200μm devices are capable of detecting wavelengths up to 1μm 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 unacceptable 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 shallowly localized radiative recombination 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. Si-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 Si-doped CCDs. High resolution, low leakage current and excellent uniformity have been achieved. We will discuss the effects of surface preparation, temperature, and thickness on the leakage current and quantum efficiency of these detectors.


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 an optimal photoreponse cut-off. The effect of design parameters on the photoreponse cut-off are explained by a nonperturbative, modified envelope function approximation (EFA) calculation that includes the interface coupling of heavy, light, and intermediate valleys. 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 InAs/InGaAs interfaces. Interface effects on the EFA-calculated band structure are important limits on the performance of InAs/InGaAs-based image detectors. Good passivation of InAs/InGaAs interfaces enables 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 further into the infrared (i.e., 200μm devices are capable of detecting wavelengths up to 1μm 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 unacceptable 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 shallowly localized radiative recombination 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. Si-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 Si-doped CCDs. High resolution, low leakage current and excellent uniformity have been achieved. We will discuss the effects of surface preparation, temperature, and thickness on the leakage current and quantum efficiency of these detectors.

2:00 PM B6.2  Correlation Between Photoreflectance Spectra and Electrical Characteristics of InP/GaSb Heterostructure Bipolar Transistors. Hiroki Sugiyma1, Yasuhiro Oda1, Haruki Yokoyama2, Masahiro Uchida2, Noriyuki Watambo2 and Takashi Kobayashi1; 1NTT Photonics Laboratories, Atsugi-shi, Japan; 2NTT Advanced Technology Corporation, Atsugi-shi, Japan.

InP/GaSb 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 and base 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) 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/GaSb HBTs have been reported [2]. In this paper, we present PR spectroscopy of InP/GaSb 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 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/GaSb HBT wafers with low recombination forward current at the E/B heterojunction. In contrast, with recombination current was dominant at the E/B heterojunction, we could not observe FKOs from the emitter. These results indicate that the PR signal amplitude from the emitter reflects the crystal quality of E/B heterojunction. We found that the PR signal amplitude of our InP/GaSb HBTs was usually quite smaller than that of InP/InGaN HBTs, though the PR measurement conditions and crystal quality of the InP emitter and collector were almost the same. We attribute the small PR ampliude in the InP/GaSb HBTs to the significant recombination at the E/B heterojunction. In order to avoid recombination at type-II interfaces, we employed pseudomorphic InAlP as the emitter in the GaSb-base HBTs. PR spectra and current-voltage characteristics of E/B heterojunction confirmed the suppression of the recombination at InP/GaSb heterojunctions. [1] M. Dvorak et al. IEEE Electron Device Letters 22, 361 (2001). [2] C. Bru-Chevallier et al. Thin Solid Films 450, 151 (2004).

2:15 PM B6.3  Roughness Analysis of Ion Beam Processed GaSb and InSb Surfaces. K. Krishnaa,1 D. F. Benner,2 S. R. Vangala,1 C. Sugiyama1, M. Grozicki2, D. Goodrich,2 M. Santeufemio1, M. Grzesik1 and W. D. Goodhue1; 1University of Dayton Research Institute, Dayton, Ohio; 2Materials & Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB 45433-7707, Ohio.

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 ion beam assisted etching (IBAIE) were investigated as to their potential for engineering the substrate surfaces for applications in the areas of molecular beam epitaxy (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 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/GaSb HBT wafers with low recombination forward current at the E/B heterojunction. In contrast, with recombination current was dominant at the E/B heterojunction, we could not observe FKOs from the emitter. These results indicate that the PR signal amplitude from the emitter reflects the crystal quality of E/B heterojunction. We found that the PR signal amplitude of our InP/GaSb HBTs was usually quite smaller than that of InP/InGaN HBTs, though the PR measurement conditions and crystal quality of the InP emitter and collector were almost the same. We attribute the small PR ampliude in the InP/GaSb HBTs to the significant recombination at the E/B heterojunction. In order to avoid recombination at type-II interfaces, we employed pseudomorphic InAlP as the emitter in the GaSb-base HBTs. PR spectra and current-voltage characteristics of E/B heterojunction confirmed the suppression of the recombination at InP/GaSb heterojunctions. [1] M. Dvorak et al. IEEE Electron Device Letters 22, 361 (2001). [2] C. Bru-Chevallier et al. Thin Solid Films 450, 151 (2004).

Bandgap Tuning of InAs/GaSb Type-II Superlattices for Mid-Infrared Detection. Jianhua H. Li, Santoshi L. Ammu and Simon C. Moss; Department of Electrical and Computer Engineering, Sandia National Laboratories, Albuquerque, New Mexico; 2Physics Department, U.C. Santa Barbara, Santa Barbara, California; 3Duke University, Durham, North Carolina.

We have demonstrated that double quantum well field-effect transistors with a lateral gate configuration as THz detectors. Early measurements explored voltage tunable terahertz conductivity exhibiting a relatively narrow linewidth of 15 GHz, and confirmed that the resonant frequency is determined by the 2-dimensional magnetic quantum Hall effect in the two-dimensional system of the composite structure. Baseband-operated, 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) exhibit 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.


During the MOCVD growth of GaP, Ga and In cations on the (001) surface tend to order to the well known CuPt ordering in the bulk. This is indicated by 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 (\(P(Sb/P) < 1\times10^{-6}\)) is known to affect the degree of order in GaP 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.

Absorption Analysis of Lateral Compositionally Modulated InAs/GaSb Superlattices. Julia C. Wickett, Donna W. Stokes, Jianhui 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 absorption and sub-bandgap 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 AISb buffer layer. From the XRD analysis it is 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 AISb 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 AISb (001) buffer are under significantly reduced tensile strain (expected for nominally InAs layers grown on AISb). 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. Similar to 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 \(\mu\)m. In the sample with no modulation, the cutoff wavelength was 8 \(\mu\)m and the transitions involving the highest energy optical transitions in the GaSb and InAs quantum well and the electron subbands of the InAs electron quantum well were easily identified. For the LCM grown samples 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 AISb buffer, optical transitions were clearly identifiable. The Sb cross contamination in the InAs layers leading to 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 AISb buffer, which preserves the optical quality of the sample, may be a key component in employing these LCM samples for optical applications.
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 optical communications, 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 photodiode that grows directly on Si substrates that covers the whole B 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 0.7 nm were selectively grown directly on Si windows opened up on SOI in a two-step growth, where a 45 nm 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 a 1 hour annealing at 900°C to remove 99% of the dislocations. Using the use of 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 0.89 eV at 0.777 eV and extending the effective photodetection range up to 1.6 μm. 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 3.5 GHz, mainly limited by the RC delay. The transit time limited bandwidth was measured to be as large as 20 GHz. At a reverse bias of -2 V the responsivity of the device at 1310 nm, 1550 nm and 1600 nm are 0.72A/W, 0.40A/W and 0.19A/W, respectively, with a bias voltage increased by 45% with an antireflection coating. The responsivity at 1310 nm and 1550 nm are comparable to the InGaAs photodetectors currently used in optical communications. With high quality selectively grown Ge epitaxial layers and adequate device design, the device exhibits a sensitivity of 300 μA/W at 100 μm distance and 15 kV at 300 μm distance is recorded for Schottky contacts, while an unoptimized vertical device with an ohmic contact has demonstrated a forward voltage drop of 70 mV at 100 μm. The device performance characteristics are currently being optimized and efforts are underway to further explore the structure of the results described above to other unipolar as well as bipolar diamond electronic devices.

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 3-5 nm randomly oriented crystallites (1,2) may contribute to the realization of this goal. The semiconducting properties of boron doped UNCD 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 10^12/cm^3 and mobilities in the range 1-3/cm^2V-1s-1 (4).

This value is higher than the reported one in ref(3) and well above that of the recent news of superconductivity in heavily boron-doped diamond synthesized by high pressure sintering was received with considerable surprise [5]. Opening up new possibilities for diamond-based electrical devices, the systematic investigation of these phenomena clearly needs to be achieved. Here we show unambiguous evidence of superconductivity in heavily boron-doped diamond thin films. The heavily boron-doped diamond thin film (polycrystalline diamond) was deposited on a silicon (100) 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 nitrogen. This finding establishes the superconductivity to be a universal property of boron-doped diamond, validating that device applications is indeed a feasible challenge [1]Collins, A T & Williams, W.S. The nature of the acceptor centre in semi-insulating diamond J.Phys. C 1789-1800 (1971) [2]Chenko, R M Baron, The dominant acceptor in semi-insulating diamond Phys Rev B 4596-4607 (1973) [3]Eklund, F.A. et al. Superconductivity in diamond. Nature, 428, 542 - 545(2004).

8:30 AM B7.3
A New All-Diamond Heterostructure Diode, Dieter M. Gruen1, Oliver A. Williams2, Erhard Kohn3, T. Zimmerman3 and M. Kubovic3, 1Materials Science Division, Argonne National Laboratory, Argonne, Illinois; 2Center for Nanostructure Materials, Argonne National Laboratory, Argonne, Illinois; 3Dept of Electronic Devices and Circuits, University of Ulm, Ulm, Germany.

Diamond has always been admired 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 boron doped diamond synthesized by high pressure sintering was received with considerable surprise [5]. 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 films. The heavily boron-doped diamond thin film (polycrystalline diamond) was deposited on a silicon (100) 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 nitrogen. This finding establishes the superconductivity to be a universal property of boron-doped diamond, validating that device applications is indeed a feasible challenge [1]Collins, A T & Williams, W.S. The nature of the acceptor centre in semi-insulating diamond J.Phys. C 1789-1800 (1971) [2]Chenko, R M Baron, The dominant acceptor in semi-insulating diamond Phys Rev B 4596-4607 (1973) [3]Eklund, F.A. et al. Superconductivity in diamond. Nature, 428, 542 - 545(2004).
great interest in reproducibly obtaining n-type diamond in connection to applications requiring massive electron transport, especially those involving photovoltaics and nanocrystalline diamond (n-D:S) thin films forming in the bulk-Si regions. Also, on thin SiC misfits are much films are grown using methane (CH₄), hydrogen (H₂) and hydrogen scattering (LEIS), X-ray photoelectron spectroscopy (XPS) and studied as a function of cycle number on HF last, NH₃ and ozone silicon-on-insulator (SOI) in some cases and others soon will be synthesized by hot-filament chemical vapor deposition (HFCVD). The surface preparations. Hf[N(CH₃)₂C₂H₅]₄ + O₃ films were 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 oxidation during the first O₃ half cycle. LEIS, RBS, and XPS results for Hf[N(CH₃)₂C₂H₅]₄ + O₃ will be compared with those for HfC₄ + H₂O. Additionally, a non-contact technique using deposited thermalized ions is applied to the film growth mode for Hf[N(CH₃)₂C₂H₅]₄ + O₃ and HfC₄ + H₂O.

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, high thermal stability, 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 device. Recently, we have demonstrated a metal-oxygen semiconductor FET (MOSFET) with a substantially unpinned interface which can provide enhanced subthreshold characteristic and electron mobility. Additionally, III-Nitride MOSFETs eliminate the need for field plate gate structures as the electric field geometry in the gate-drain region changes with the tunneling field effects due to charge in depletion mode. Low-rf dispersion InGaN/GaN MOSFETs exhibit excellent microwave performance with f₅ = 8GHz for optically defined gate 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 apply those 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 relative to competing electronic devices in coming years for 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 Si Based Devices, Shiv Gupta1, R. D. Vispute2, K. Johnson1, M. Ervin1, and I. Kazarov1

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Silicon Carbide (SiC) is a wide-bandgap 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 AIC 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 changes 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.


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 work functions are expected to resolve many problems of high-k gate dielectric MOSFETs such as poly-depletion and Fermi-level pinning. In this study, TaN was evaluated as a metal gate for hafnium-silicate (HSISO) 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. 30-100A 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 altered depending on the the thickness of TaN. When 30-A thick TaN gate was used, the film thickness was decreased. HISIO-MOSTET 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 30mV in P-MOSFET with 100A TaN gate. On the other hand, Vth reduction was altered depending on the the thickness of TaN. When 30-A thick TaN gate was used, the film thickness was decreased. HISIO-MOSTET 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 30mV in P-MOSFET with 100A TaN gate. On the other hand, Vth reduction was altered depending on the the thickness of TaN. When 30-A thick TaN gate was used, the film thickness was decreased. HISIO-MOSTET with TaN metal gate exhibited 30% higher drain current compared to poly-Si gate, which can be explained by reduced EOT and improved mobility. 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High performance nanoscale FETs obtained in this study show a strong blue-shifted near-band-edge ultraviolet emission, and the size and size distribution of the particles also be utilized to form ZnO nanoparticles successfully by this method. The particle growth is found to be pH, reaction time and temperature dependent. Deposition 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 E2(2) (TO) mode and other vibration modes are attributed to the acetate group. The CO stretching mode in the 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.
devices including blue light-emitting diodes and laser diodes, due to its large exciton binding energy. Though p-type doping has been successfully accomplished for type doping of ZnO, there is still a large 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 were carried out. Samples were implanted with high dose (5 x 10^{15} ions/cm^2) 100 keV As ions at room temperature. Rapid thermal annealing (RTA) of samples in the range of 400°C to 1000°C was employed to achieve recrystallization of amorphous layers and electrical activation of the donor. Rutherford backscattering/channeling 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.

4:45 PM DB 8

ZnO nanorod sensor for detection of biotin-streptavidin interaction, Jin Suk Kim, Won Il Park and Cyu-Chul Yi; Materials Sci. & Eng., POSTECH, Pohang, 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 on 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 an example of air-stable and single crystal ZnO nanorods as sensors for highly sensitive biological detection. In particular, ZnO nanorods platforms were prepared for highly specific electronic biosensor arrays detecting protein-receptor interactions, for example, biotin-streptavidin interaction. For the fabrication of nanoscale biosensors, 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 a high sensitivity.
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 Christy* and Paul O'Brien, The University of Manchester, Manchester, United Kingdom.

There is considerable current interest in the synthesis of metal chalcogenide nanomaterials, due to their potential applications in electronics and optoelectronics. The synthesis of such materials is critical to enabling such technology. The synthesis of these materials, especially those of cadmium, has been widely studied in the literature. However, whilst the synthesis of metal chalcogenide compounds offers high quality particles and structures, their inherent reactivity results in complications in handling, where less reactive systems generally result in poorer size distributions. Further more there are 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 be 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 containing materials.

**B9.3 Properties of Gallium Selenide Doped with Sulfur.**

Valeriy G. Voevodin1, Svetlana A. Berezanyova1, Zoya V. Korotchenko2, Aleksandr N. Morozova1, Svetlana Yu. Sarkevich1, Nina G. Fomina4, T. Goldstein2, 1Semiconductor Materials Science Laboratory, Siberian Physical-Technical Institute, Tomsk, Siberia, Russian Federation; 2Materials & 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), electrical absorption, infrared absorption, reflectance and luminescent properties of the undoped and doped samples showed the following: a) the increase of the concentration and mobility with concentration of carriers; b) the appearance of two 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 and 73.8 meV in addition to the three peaks at 67 meV, 63 meV and 59 meV observed in undoped crystals; e) a considerable residual conductivity after illumination; f) an increase in microhardness. The observed photoconductivity shows that of GaSe:S crystals is substantially smaller than that of undoped crystals. The structural and compositional characterization of nanoparticles 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 nanoparticles. The system has been used in studies of the optical properties of nanoparticles. 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 the forbidden band gap.

**B9.4 Nanocrystal sized Pb(Se,Te) islands and their crystallographic structures.**

Peter Mook1, Mukes Kapilashrami1,2, Jinhuek Lee1, James Morris3, Nigel D. Browning2 and Patrick McCann3, 1Department of Physics, Portland State University, Portland, Oregon; 2Department of Science, Royal Institute of Technology, Stockholm, Sweden; 3Department of Electrical & Computer Engineering, Portland State University, Portland, Oregon; 4Department of Chemical Engineering and Materials Science, University of California, Davis, Davis, California, 5School of Electrical and Computer Engineering, University of Oklahoma, Norman, Oklahoma.

Tensely strained nominal PbSe islands were grown on an (111) oriented PbTe/InP(111) 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 AFM and TEM measurements, we distinguish between three different groups of islands. 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. The combined number density is approximately 2 x 10^12 to the power 10 cm^-2. Larger islands, on the other hand, possess a number density of approximately 2 x 10^13 to the power 9 cm^-2. Transmission electron diffraction pattern at different tilts, i.e., at [111] and [100], axes were consistent with the expansion of the Se/Te(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 PbSe:Te compounds.

**B9.5 Spectroscopic ellipsometry study of CdSe and CdTe nanoparticles embedded in SiO2 films.**

Padulapathababu Dayal1,2, Mehta Bodi Raj1,2 and P. D. Paulson3,1, 2Physics, IIT Delhi, New Delhi, Delhi, India; 3Institute 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 the stability and improvement of SDGs, the studies of the optical properties of SiO2 nanoparticles have been made by magnetron sputtering of high quality elemental Cd, Se and Te along with SiO2 targets. Post deposition annealing has been done in different ambients of vacuum, air and nitrogen. The optical properties of SiO2 nanoparticles have 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 nanoparticles. The system has been used in studies of the optical properties of nanoparticles.

**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, astronomical spectroscopic techniques, and military related technologies. In 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...
infrared, and pulse width = 8 nsec, a power of 0.1 μJ/shot was used as a laser ablation target, expecting other new EL emissions. H2S gas and metal Zn vapor as precursors, and N2 gas as their carrier gas was used in the CVD synthesis of ZnS. Mn and Si were doped into the ZnSe laser ablation target during the ZnS synthesis. A pulsed Nd:YAG laser (wavelength = 1.06 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 to 0.12 J/shot). Other preparation conditions were as follows. The Zn evaporation temperature was 570°C. The H2S flow rate was 3.0 SCCM. The deposition pressure was 0.62-18 cm-' in the spectral range of 0.62-18 cm-' in the spectral range of 0.62-18 cm-' in the spectral range of 0.62-18 cm-1. The deposition temperature and on the position in the substrate. However, 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 Te0.2-PbF2 : Tm3+ Glasses. Idris Kabalci1, Gonul Ozen,2 Adnan Kurt2 and Alphan Sennaroglu2; 1Physics Department, Istanbul Technical University, Istanbul, Turkey; 2Laser Research Laboratory, Department of Physics and Electrical Electronics Engineering, Koc University, Sariger, Istanbul, Turkey; 3Department of Physics, Boston College, Chestnut Hill, Massachusetts.

Recently, glasses based on TeO2 have attractted a considerable amount of interest when doped with Thulium ions. This is because of their potential use in the development of optical amplifiers and optical switches. 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-Olfelt theory is usually used to determine the spontaneous dipole transition probabilities associated with the appearance of the new spectra depended on the deposition temperature and on the position in the substrate. 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.

**B9.11**

Growth and Characterization of High Purity Single Crystals of α and β Alq3 for Charge Transport Studies. Ali N. Rashid1,2, and Donald C. Craig3; 1School of Physics, UNSW, Sydney, New South Wales, Australia; 2Institute of Quantum Electronics, ETH, Zurich, Switzerland; 3School of Chemistry, UNSW, Sydney, New South Wales, Australia.

Tris-[8-hydroxyquinoline]aluminum III (Alq3) is a stable metal complex 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 and the little information on its solid-state properties and packing exists. Nearly all of the information available is 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 β-Alq3, the crystal structure of Alq3 in the unsolvated α phase derived from single crystal data will also be presented, along with SCLC measurements that were performed on these crystals. This structure corrects some errors in the literature that were encountered in the x-ray powder structure reported in the literature.

B9.13 Abstract Withdrawn

Soo-Hyung Lee1, Sang Yeol Kim2, Jay Kyeong Kim3 and Yiyeol Lyu4; 1Poptoelectronic 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 for use as electron blocking layer that have unique thermal and optical properties were synthesized and used for electron blocking materials. The devices, with configuration of indium tin oxide (ITO)/p(3,4-ethylenedioxythiophene)-polystyrene sulfonic acid) (PEDOT-PSS) (85 nm)/EBL (10-20 nm)/poly(9,9-octylfluorene) derivative (70 nm)/BaF2 (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 high 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 layers 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 lumiance 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.
Chih-Min Chiu-Fu Chen1, Yang-Yi-Fan Huang2, Chih-Hua Hsu3, Jhi-Shang Hwang4, Chi-Ruey Lin2, Li-Chyong Chen5 and Kuei-Hsien Chen5; 1Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu, Taiwan; 2Institute of Mechatronic Engineering, National Taipei University of Technology, Taiwan; 3Department of Condensed Matter Sciences, National Taiwan University, Taipei, Taiwan; 4Institute of Optoelectronic Sciences, National Taiwan Ocean University, Keelung, Taiwan; 5Institute 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, 4271, 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-reflective layer. It was found that Si nanotip arrays possess a Walker maximum reflectance (6.0%) form VIS to NIR range (400 to 2700 nm) and show a super anti-reflectivity property approaching 0.001% within the visible range (400 to 800 nm). A device with R.I can be controlled by controlling the shape of nanotip experimentally. In the optimum case, the R.I. can be tuned within 1.0 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-reflectivity property will be presented.

B9.16 Phosphorescent Dendrimers for highly efficient OLEDs.
Kevin Knights1, Paul L. Burn1 and Ibor D. W. Samuel2; 1Chemistry, Oxford University, Oxford, United Kingdom; 2Physics 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 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 dendrimers has 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 physical and device properties of the dendrimer core and show how these materials have improved properties. It will be shown that OLEDs fabricated from these dendrimers have improved properties.

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Interest in nanomaterials has been rapidly growing for the past several years. In particular, carbon nanotubes, fullerene molecules, carbon nanotubes, nanohorns and nanocones 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 nanomaterials 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 nanocones 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 carbon nanocones. In this paper, we have developed a new production method for nano-particles by pulsed arc discharge in liquid, which is triggered by the laser ablation on the graphite electrodes. High-resolution transmission electron microscopy observations proved that the main nano-particles obtained by this method were crystalline carbon nanocones. The particle density was 16111cm-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, nanocones shape materials were not formed.

B9.18 Dynamic Activation in Bulk Germanium and Germanium-on-
Incorporated films. Furthermore, many literatures have reported diamond films as a semiconductor material for high-temperature and high-power applications due to their very high thermal conductivity, large band gap, and chemical inertness. When boron nitride (BN) is incorporated in diamond films, it can be used as a suitable heteroepitaxial substrate in the preparation of diamond homojunction. It is well known that c-BN has a lattice mismatch of 1.3% with diamond. The high-quality conduction band of c-BN is about 0.3615 nm, while the lattice constant of diamond (a(0)=0.3567 nm) is about 1.3%. Therefore, c-BN is regarded as a suitable substrate for diamond epitaxy. Additionally, c-BN can be prepared into both p- and n-type single crystalline forms. Incorporated hydrogen in c-BN wafers which were prepared by Smart-CutTM approach can be used as a suitable substrate for diamond epitaxy. The diffusion to prepare the n-type c-BN bulk single crystals with relatively low resistivity is an important problem for the growth of high-quality heterojunction diamond films.

We present state of the art first-principles calculations for the optical spectra in the cubic (c-BN) and in the hexagonal (h-BN) phases. We start from a DFT-LDA functional Kohn-Sham bandstructure. 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 GW calculation and the solution of the Bethe-Salpeter equation [1]. We report high-quality conduction and valence band structures of c-BN in the cubic phase. Both results are obtained for c-BN within Time-Dependent Density Functional Theory, and for bulk c-BN for which a recent long-range approximation for the exchange-correlation kernel [3] has been used.

We present high-quality diamond single-crystal films and n-type cubic boron nitride bulk single-crystal diamond films grown on SiO2, SiGe, and Ge substrates. Additionally, c-BN can be prepared into both p- and n-type single crystalline forms. 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 single crystalline forms. Based on the comparison of the particular electronic properties between p-type diamond and n-type c-BN, a heteropitaxial growth of p-type diamond on n-type c-BN can 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 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.

We present first-principles calculations 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 GW approximation have been used. For the optical properties the RPA-LDA scheme has been applied for alloys going in composition from Si(100%) to Ge(100%). The results have been compared with existing experimental and theoretical data. For the noticable Si(0%)Ge(100%) alloy also two-particle effects have been evaluated using the Bethe-Salpeter equation [2]. 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 functional Kohn-Sham bandstructure, 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 GW calculations and the solution of the Bethe-Salpeter equation [1]. We report high-quality conduction and valence band structures of c-BN in the cubic phase. Both results are obtained for c-BN within the Time-Dependent Density Functional Theory, and for bulk c-BN for which a recent long-range approximation for the exchange-correlation kernel [3] has been used.

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 functional Kohn-Sham bandstructure, 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 GW calculations and the solution of the Bethe-Salpeter equation [1]. We report high-quality conduction and valence band structures of c-BN in the cubic phase. Both results are obtained for c-BN within the Time-Dependent Density Functional Theory, and for bulk c-BN for which a recent long-range approximation for the exchange-correlation kernel [3] has been used.
height is lower and the carrier density is highest among the other samples, mobility is not high. This result indicates that the mobility of SiGe, which is a well-known material, is significantly lower than that of silicon. Therefore, we consider that the defects are easily introduced in SiGe 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 IRRADIATION. Hide Hata 1,2; Istuya Aru 1, Souchi Mejima 1, Hiroshi Kawarada 1,2; Waseda University, Tokyo, Japan; 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), and high thermal conductivity in materials (22 W/cmK). We have developed RF diamond field-effect transistors (FETs) with SiGe carbide (SiC) as the channel conductivity, the sheet resistance decreases due to 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 exist in low MAG (maximum available gain), fmax/f0 of the RF MISFET is low as 1-1.3 [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, 1μΩ of sheet resistance is required. In order to meet these problems, the technique which fabricates the stable low resistive source-drain regions replaces with hydrogen-terminated surface is necessary. In this region, if an FID (Focused Ion Beam) apparatus with nickel metal ion sources with low energy of 50 keV are irradiated and 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 NiC phase. In this results, when 1017 ions/cm² are irradiated, sheet resistance decreases to 10μΩ which is correspondence to hydrogen-terminated conductivity. Furthermore, when 1019 ions/cm² are irradiated, sheet resistance decreases to 1kΩ. Because Nickel carbide used for local modifying can be used to source and drain regions. If this layer is utilized between source and drain, gate of MISFETs, higher drain current of 1A/mm and 60GHz of fmax is expected. [2] H. Matsuda 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/ SiGe/Si HBT. Sirinush E. Bezirganyan 1, Hakob (Akop) P. Bezirganyan 1, Hayk H. Bezirganyan 2 and Petros H. Bezirganyan 3; 1Dept of Solid State Physics, Yerevan State University, Yerevan, Armenia; 2Faculty of Informatics and Applied Mathematics, Yerevan State University, Yerevan, Armenia; 3Dept 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 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 shift 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 SiGeSi heterojunction. Substitution incorporation of carbon into SiGe makes it possible to reduce and control the compressive strain between the epitaxial layer and the substrate in SiGeSi/Si HBTs (e.g. see [3-5]). The buffer (base) SiGe films in HBTs have less strain than 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 SiGe base layer practically do not change after the high temperature processing. Consequently, SiGeSi/Si HBTs are well situated in application in Bipolar CMOS (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 SiGeSi strain-compensated structure HBT is possible by using X-ray scattering (GIXB) technique. In the presented theoretical paper we are investigating the process of the GIXB by strain-compensated SiGeSi/Si HBT. Diffraction 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 if given e.g. [6]. In the presented theoretical paper we are investigating the process of the GIXB by strain-compensated SiGeSi/Si HBT. Diffraction net planes of the considered model of the HBT have the same lattice constant for the epitaxial layers and the substrate, though there exist

B9.25  1.55 μm Photoluminescence from β-FeSi2 Microprecipitates-containing Films Prepared via Pulsed Laser Deposition. Aiko Nasuaki, Tadatada Sato, Yoshio Kawaguchi and Hironori Nishio; Photonics Research Institute, National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan

β-FeSi2, 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-FeSi2 has received attention as an eco-friendly semiconductor due to the rich abundance of its constituent elements in natural and non-toxicity. These advantages have been intensively exploring the formation of β-FeSi2 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 ≥ 450 °C and following post-annealing at ≥ 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-FeSi2 due to the formation of other Fe-Si metallic phases. In this work, we successfully realized the room-temperature fabrication of β-FeSi2 microprecipitates by the active use of micrometer-sized droplets generated by the laser ablation. We performed the KrF excimer laser ablation of an α-FeSi2 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-FeSi2 crystalline phase, whereas the rest of the deposited film was amorphous. Further improvement in the crystallinity of β-FeSi2 was observed after pulsed laser annealing. It was also found that films containing a high density of FeSi2 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 HfO2 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 material for MOSFET since it offers much higher mobility than silicon. However, the facility germanium oxide obstructs the fabrication of germanium MOS devices. With high-k 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 using HfO2 deposition on germanium have been reported. The results show that, during HfO2 deposition or the following post deposition annealing (PDA), large amounts of germanium were found inside HfO2 film. Thus, it is very interesting to study the effect of germanium diffusion into HfO2 and its impact on the electrical properties of HfO2 gate stack. In this work, the dependence of Ge diffusion on high-k deposition method, PDA temperature as well as PDA ambient were investigated. In addition, the electrical properties of HfO2 MOS capacitors after Ge-incorporation were addressed. Thin HfO2 film (5nm) was deposited on cleaned Ge single crystal wafer by MOCVD using Hf-t-butoxide precursor and O2 at 400°C. A high concentration of germanium with an atomic concentration of 5% 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 almost five times. This shows surface nitridation can effectively suppress germanium diffusion. However, Ge is still observed in HfO2 film. It is suspected that the Ge out-diffusion may relate to the relative high temperature during MOCVD process. To exclude the effect of temperature on out-diffusion, reactive ion etching method, by using a pure H2 target in O2 ambient at room
temperature, was used to prepare thin (10nm) HfO2 films. Much less germanium was found in as-dep PVD HfO2 film than MOCVD film. After 700°C amorphization, the former exhibited the same amorphization as shown by 500°C for 30 times. To get a better SIMS profiling of germanium in HfO2, thick HfO2 (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 is expected on 400°C annealing. Ge diffusion 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 HfO2 with Ge-incorporated HfO2 gate dielectric. High hysteresis and interface trap density are found with the presence of germanium.


Pung Shuang Ou, Laxmikant Saraf and Donald R. Bayer, Environmental Molecular Science Laboratory, Pacific Northwest National Laboratory, Richland, Washington.

Nanoporous silicon surfaces have been used in a variety 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 bubbles are generated 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. 


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% mismatch, as the substrate of choice for InAs-based electronics. This mismatch can be alleviated using Ge in InAs films grown by MOCVD, among them specifically a one micron-scale grain size film. We have demonstrated that epitaxial lateral overgrowth takes place at PDA temperature of 500°C and the higher temperature annealing has more germanium diffusion. Besides, one sample was annealed in Ge. Strong enhancement of germanium diffusion by oxygen was observed. It is expected that hydrogen bubbles are generated 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.

B9.29 Beam Induced Lateral Epitaxy of GaAs on GaAs/Si Template. 

Shigeoya Nartuwa, Koji Sato, Yoshiki Kondo and Takahiro Maruyama, Materials Science and Engineering, Meijo University, Nagoya, Japan; 21st century COE program "NANO FACTORY", Meijo University, Nagoya, Japan.

Epitaxial lateral overgrowth is important for the fabrication of electronic and optoelectronic devices, because the discontinuity in the overgrown layer can be drastically reduced. We have proposed an utterly new technique, named as beam induced lateral epitaxy (BIE), to achieve lateral overgrowth in molecular beam epitaxy (MBE) [1]. In the technology of BIE, 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 SiO2 mask. In this study, BIE was performed at 680 °C with a low angle of incidence 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. BIE was performed at 680 °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 ridge. Thus, 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 formation of the grown shape is similar to those in homoepitaxial BIE, the heteroepitaxial BIE 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...


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 substrates. Very common topographies of ultra-thin wafers have 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 techniques 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. Very common topographies of ultra-thin wafers 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 non-transparent 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 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 related noise. We present theoretical predictions and estimate that noise due to vibrations for symmetric synchronously operated system contributes less than 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. [J.] 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); R. J. Lee, W. Chang, S. H. Lau, A. Koo, 3rd 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. Hangou Cheng1, Divakar Gang1, Eduardo Machado1, Marcin Kuczmarski2, Benoit Braband2, Eduardo Hernandez2 and Pablo Ordejon2; 1Computational Modeling Center, Air Products and Chemicals, Inc., Allentown, Pennsylvania; 2Institut 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-hfacacetfe(acetonitrile-toluene-vinylsilane) [Cu(hfac)(tmvs)](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 contact with the surface. The products of the decomposition attack strongly to the surface, forming a fluoride, carbon and hydrogen containing layer on the barrier layer, which may lower the efficiency of the Cu deposition and the adhesion 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 reactivity, 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-Time Approach. Yasunari Zempo and Nobuhiko Akiyama; 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 our 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 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. Trouiller, K. Wu and Y. S. Sand, Phys. Rev. B50, 11355 (1994) [2] K. Yabana and G. F. Bertsch, Phys. Rev. B64, 4484(1996).
Although Sb had been spectrum was also measured, and peaks were observed at around 275 nm, which is stronger than that of the SrS core nanoparticle. Core/shell nanoparticles were also prepared using a ball milling and the variation of optical properties related to the variation of the fabrication method was studied. The SrS/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 Research Projects (Individual Research).

9:00 AM *B10.3
ZnO/GaN heteroepitaxy, Talaifumi Yag1, K. W. Kang, D. C. Oh1, Tutomu Minegishi2, Hideyuki Suzuki3, Tsunehisa Hanada4, Hisao Makino5, and M. W. Cho6, 1Center for Interdisciplinary Research, Tohoku University, Sendai, Japan; 2Institute 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 fields are generated by lattice misfit; (4) ZnO and GaN are eco-friendly materials. Owing to these properties, the ZnO/GaN heterostructure will provide unique applications in various fields. The purpose of this paper is to overview the heteroepitaxy and optical properties of ZnO/GaN core/shell nanoparticles 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 (Schorlerton)

10:00 AM B11.1
Improved Optical Quality from Indium-Free GaNAsSb in the Dilute Sb (<3%) Limit, Homan B. Yuen1, M.J. Seong2,3, Robert Kudrawiec4, Seokyoun Yoon1, Seth R. Bunk1, Mark A. Wiest3, Jan Masichek2, Angelo Macenas2, and James S. Harris1,1Solid State & Photonics Lab, University of California, Berkeley, California; 2Department of Physics, Chung-Ang University, Seoul, South Korea; 3National Renewable Energy Laboratory, Golden, Colorado; 4Institute of Physics, Wrocław University of Technology, Wrocław, Poland.

The addition of N into InGaAs has allowed growth of dilute-nitride materials which have much longer emission wavelengths than previously observed in In(Ga)As. 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. GaNAsN has enabled the development of lasers at the important fiber communication wavelength of 1.3 μm. However, the incorporation of N into GaAsN 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 GaInAsN. Contrary to the behavior of most III-V semiconductors, small amounts of N in GaNAsN decrease both the overall lattice parameter and the band gap. GaNAsN has enabled the development of lasers at the important fiber communication wavelength of 1.3 μm. As a result, the addition of N into (In)GaAsN degrades the optical properties of the material, but not as much as non-radiative traps affect the optical properties of GaAs. GaNAsN in GaAsN degrades the optical properties of the material, but not as much as non-radiative traps affect the optical properties of GaAs.

InGaAsN alloys, the substitution of arsenic by nitrogen atoms produces a large band-gap reduction that has sparked interest in this system for applications in the infrared region. GaNAsN degrades the optical properties of the material, but not as much as non-radiative traps affect the optical properties of GaAs. GaNAsN in GaAsN degrades the optical properties of the material, but not as much as non-radiative traps affect the optical properties of GaAs.

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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 concentration, as determined from the photoluminescence data, ranged from 0.5-7.1%. The low-temperature photoluminescence spectra of these samples contained two sets 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 their 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 10-150s (in increments of 10s) at 850°C. 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 contrasts 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 GaInAsN is located at significantly higher energies than those commonly accepted for these alloys.

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. Theoretical calculations show a decrease of the bandgap with increasing 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 GaNAs and it is believed that with increasing N content of the effective mass and 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, the absorption peaks for electron and holes shift on the B-field scale, reducing the carrier density, and a broadening of the resonances, 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.

MBE-Grown GaNAsBi Matched to GaAs with 1.3-µm Emission Wavelength. Masahiro Yoshimoto, Wei Huang, Junji Saraike and Kunishige Oe; Kyoto Inst. Tech., Kyoto, Japan.

GaNAsBi, 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, GaNAsBi 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 seminmetal 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 GaAsBi, 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 GaNAsBi alloy by MBE. Lattice-matching to GaAs and bandgap adjustment to the optical fiber communication wavelength can be achieved simultaneously for GaNAsBi. 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. GaNAsBi was grown on (001)-oriented GaAs substrate in MBE with solid sources of Ga, As and Bi. Activated nitrogen generated from N2 gas in plasma was used as the nitrogen source. The sample was grown in the structure of GaAs/GaNAs1-x-yBi1-x-y/GaNAs/GaAs substrate. GaAs homoepitaxial layer was grown at temperatures of 580-600°C. GaNAsBi, GaAs and N2 source was increased from 100°C to 350°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 GaNAsBi to GaAs was investigated by X-ray diffraction measurements on a series of GaNAsBi with various GaBi and GaN molar fractions. In the case of the lattice-matching of GaNAsBi to GaAs, the diffraction peak of GaNAsBi overlapped the peak of GaAs. PL emission at the wavelength of 1.3 µm was observed from GaNAsBi, as the GaAsBi epilayer matched to GaAs at room temperature. The temperature coefficient of the PL peak energy in a temperature range 150-300K for GaNAsBi was smaller than that of GaAs, as in the case of GaNAsBi. This is the first report on both lattice-matching to GaAs and bandgap adjustment to 1.3-µm wavelength for GaNAsBi. This alloy will lead to the fabrication of laser diodes with an emission temperature insensitive wavelength.

Molecular Beam Epitaxy-Grown GaNAsBi Matched to GaAs with 1.3-µm Emission Wavelength. Masahiro Yoshimoto, Wei Huang, Junji Saraike and Kunishige Oe; Kyoto Inst. Tech., Kyoto, Japan.

Recent advances in the growth of dilute nitride compounds have attracted, in particular, attention to GaNAsBi and InGaAsBi due to their potential application as lasers, photocathodes for 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 bandgap. Early reports from Raman studies on the pseudomorphically strained epitaxial films of the ternary alloy GaNAsBi 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) mode at 287.4 cm⁻¹ and the weaker transverse optic (TO) mode at 285.4 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 LO1 band shifts linearly towards lower wavenumber while the GaAs-like LO2 mode 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 LO2 photon will also be discussed.

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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. Theoretical calculations show a decrease of the bandgap with increasing 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 GaNAs and it is believed that with increasing N content of the effective mass and 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, the absorption peaks for electron and holes shift on the B-field scale, reducing the carrier density, and a broadening of the resonances, 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.

Nioby, Induced Optical Phonon Shift in GaNAsBi

Studied by Raman Scattering. Li-Lin Tsy, 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 GaNAsBi and InGaAsBi due to their potential application as lasers, photocathodes for 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 bandgap. Early reports from Raman studies on the pseudomorphically strained epitaxial films of the ternary alloy GaNAsBi 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) mode at 287.4 cm⁻¹ and the weaker transverse optic (TO) mode at 285.4 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 LO1 band shifts linearly towards lower wavenumber while the GaAs-like LO2 mode 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 LO2 photon will also be discussed.