SYMPOSIUM V

Rare-Earth Doping for Optoelectronic Applications

March 29 - 31, 2005

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Doping (Moscone West)

These data present the first demonstration of a new technique method able to three-dimensional photonic crystal waveguides. Three-dimensional photonic crystals, doped with rare-earth ions that act as sensitizers for Er, can be efficient sensitizers for the Er luminescence. A model based on this technique enables accurate measurements in a thin-film geometry, i.e. without the need to fabricate waveguides, and can be applied to all rare-earth ions. We find, contrary to earlier claims, that the intra-4f transitions of Er are not affected by the presence of Si quantum dots that act as sensitizers for Er. Finally, we present data on controlled spontaneous emission of Er in photonic crystals. Er-doped nanocrystals are made in two-dimensional SiO2 photonic crystal waveguides. Three-dimensional photonic crystals, doped with erbium, were made using colloidal self-assembly followed by infiltration with Si using CVD. The photonic crystals possess a full photonic band gap around 1.5 μm. By varying pump wavelength and temperature, we are able to probe the effect of the local optical density of states on the emission from Er and Nd ions located at different symmetry locations in the photonic crystal.

8:30 AM *V1.1

Erbium in Semiconductors: Where are we Coming From; Where are we Going?  A.B. Pope. The University of Manchester, School of Electrical Engineering & Electronics, Manchester, United Kingdom.

It is one of the curious twists of technology that transitions which are parity forbidden in the free ions of rare earths should have become of immense importance in solids used in fluorescent lighting, cathode ray tubes and optical amplifiers. It is not an unreasonable expectation that this area will make a transition from the realm of research to a mature technology in the next 10 years. We can already see the first signs of this. Since Ennen demonstrated good low temperature electroluminescence in silicon in the early 80's, a formidable amount of work has been done to try to understand the excitation and quenching mechanisms in common semiconductor hosts such as silicon and gallium arsenide. Although some remarkable experimental results have been obtained for erbium in nanostructures, insulators and wide band-gap materials the performance in bulk silicon and silicon germanium is disappointing. More importantly we still have not achieved a comprehensive, detailed understanding of the processes of non-radiative competition to the rare earth emission. In this paper the key steps that have been made over the last 20 years towards our present day knowledge of erbium luminescence in semiconducting hosts are reviewed and an assessment made of what remains to be done.

9:00 AM *V1.2

Microcavity-Controlled Radiation From Rare Earth Ions. Albert Polman, FOM-institute AMOLF, Amsterdam, Netherlands.

Microcavities provide a photonic environment to rare earth ions that dramatically modifies their emission rate and emission spectrum. We first demonstrate this in toroidal optical microcavities that are doped with erbium by ion implantation. Cavity quality factors as high as 10^10 are achieved and as a consequence, the erbium emission splits up in a sharply peaked mode spectrum, with the modes separated by the cavity free spectral range. Using confocal optical microscopy, Er ions in particular sections of the cavity are selectively excited and different degrees of mode coupling can be spatially resolved. When pumped trough a tapered optical fiber at 1480 nm, these Er-doped microcavities show single-mode lasing at 1.5 μm above a threshold pump power as low as 4.2 W. These data present the first erbium-doped microcavity laser on a silicon substrate that is fabricated entirely using CMOS technology. A model that describes the Er population dynamics in the cavity is presented, and very well describes the experimentally found dependence of lasing characteristics on Er concentration, pump power, and coupling conditions. Next, Er-doped toroidal microcavities were co-doped with Si nanoclusters to transform the cavity into a highly efficient sensitizers for Er.

9:30 AM *V1.3

Light Emitting Devices based on rare-earth doped silicon nanoclusters. Francesco Priolo 1, Alessia Irrera 2, Domenico Pacifici 1, Giorgia Franzetta 3, Calogero Presti 1, Fabio Inacona 2, Defo Santillii 1, Gianfranco Di Stefano 1 and Giorgio Ficalbi 1.

1Dopce, Physics & Astronomy, MATES-INFM & Univ. Catania, Catania, Italy. 2 IMM, CNR, Catania, Italy; 3 STMicroelectronics, Catania, Italy; 4Scuola Superiore di Catania, Catania, Italy.

In the last decade, rare-earth doping of silicon nanoclusters has been proposed to be one of the most promising methods to achieve scarce light emission capabilities of silicon. It is nowadays ascertained that silicon nanoclusters are very efficient sensitizers for the Er luminescence at 1.54 μm. Indeed, each nanocluster absorbs the incoming photons with effective absorption cross section which are more than three orders of magnitude higher than for Er, and then rapidly transfers its energy to nearby Er ions, thus producing an emission of light at 1.54 μm which is two orders of magnitude more efficient than for Er in pure silica. Recently, higher quantum efficiencies have been obtained by incorporating in the film high concentrations of very small amorphous silicon clusters, thus demonstrating that amorphous, as well as crystalline, Si nanoclusters can be efficient sensitizers for the Er luminescence. A model based on an energy level scheme taking into account the coupling between each Si nanocluster and the neighboring Er ions will be reported. The role of Si nanoclusters and of strong gain limiting processes, such as non-radiative up-conversion and non-radiative carriers absorption from an excited nanocluster, in determining positive gain at 1.54 μm will be investigated in details, and the implications of the finite transfer time on the overall efficiency of the energy transfer mechanism will be discussed. Efficient room temperature light emission from electroluminescent devices based on Ge and In-doped Si nanoclusters has been demonstrated. It has been shown that the silicon nanoclusters dispersed in the active layer allows for a good current injection in the otherwise insulating matrix and determine an efficient excitation of the rare-earth. In particular, an effective excitation cross section of the order of 10^-14 cm^2, i.e. two orders of magnitude higher if compared to optical pumping, has been measured under electrical excitation. Due to the high excitation cross section and to the efficient current injection, internal quantum efficiencies of the order of 1% have been estimated. For application, we are mostly interested in the power efficiency of these devices. In order to increase the external efficiency, we coupled the emitting system with a 2D photonic crystal structure opportunely fabricated to efficiently couple the emitted radiation to the free space vertical modes, thus reducing the internal reflection of the emitted light and increasing the overall emission yield. These data will be presented and future trends discussed.

10:30 AM *V1.4


1Semiconductor Physics, Institute for Physics of Microstructures RAS, Nizhny Novgorod, Russian Federation; 2Solid State Physics, Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria; 3Solid State Physics, Institute of Physics PAS, Warsaw, Poland; 4Optoelectronics, Van der Waals - Zwanze Institute, University of Amsterdam, Amsterdam, Netherlands.

The research on Er-doped silicon continues to be spurred by the prospects for realization of silicon-based photonic components first of all efficient light-emitting diodes and lasers. In this contribution we describe an original method of sublimation MBE (SMBE) and show its capabilities for the growth of highly efficient light-emitting diodes and lasers structures, in particular for the growth of a novel type of Er-doped structures - the multilayer Si/Si:Er/Si:Er.../Si structures exhibiting superior luminescence properties. Results of high-resolution PL and magneto-optical spectroscopy studies performed for such kind of structures will be presented. It will be shown the ability to achieve these structures the preferential formation of a single type of optically active Er-related centers, of the particular Er-I center. We identify the orthorhombic-I symmetry of the Er-I center. High concentration of this specific center (up to 32% from the total amount of Er impurity) was found in Si:Er multilayer structures. The ultra-narrow linewidth (~10eV) being characteristic for a single Er-I center emission, indicates a possibility of a 100-ps lifetime and high reflective gain coefficient in multilayer Si:Er structures. Therefore, these structures emerge as the plausible candidates for achieving population inversion and stimulated emission in Si based materials. The gain factor accessible in Si:Er SMBE structures is estimated as 3-30 cm^-1. The results of simulations for the parameters of real laser-type structures and the principles for their realization will be discussed. Electroluminescence in SMBE light emitting diodes is observed both in p-n homojunction and reverse bias regimes. LEDs emit a strong red light bright enough to be used as a red light source. The results are presented at the 31st International Conference on Microelectronics. Low temperature behavior of Er ions in Si at low temperatures is also discussed.
11:00 AM V1.5

Following recent reports from Coffa et al. [1] that claim rather high quantum efficiency from Er ions in Si:Er layers, we have grown MOMBE films of Si:Er and studied the crystalline structure, optical properties, and electrical characteristics of these films. We have also studied...
Energy Exchange between Silicon Nanocrystals and Er Ions.

Minaru Fujii, Department of Electrical and Electronics Engineering, Faculty of Engineering, Kobe University, Kobe, Japan.

Si nanocrystals act as an efficient photosensitizer for Er ions. By doping Si-ncs into Er-doped silica glasses, effective energy exchange has been observed. In this work, we discuss the energy transfer process in wide ranges of Er concentration and Si nanocrystals size. The results indicate that energy transfer is effective at the nanosecond time scale.

In-situ Er-doped silicon-rich silicon oxide (SRSO) films grown by electron cyclotron resonance enhanced chemical vapor deposition (ECR-PECVD) have been annealed in the temperature range from 800 to 950 °C in argon and oxygen atmospheres. Using photoluminescence (PL) measurements at room temperature we find that light emission around 1.53 μm is most intense after annealing at 875 °C in an argon ambient. This is a result of the compromise between optimum values of Si nanocrystal concentration and size, which have contradictory effects on the distance between Si nanocrystals and Er ions and thus on the PL intensity. The nucleation rate of Si nanocrystals increases with temperature, however, they appear to stabilize at a critical size which increases with annealing temperature. Thus we observe shorter annealing times are required to achieve the maximum PL intensity at annealing temperature increases.

The PL intensity saturates after long annealing time at all temperatures. From these measurements we are able to determine the formation energy of the Si nanocrystals, which is controlled by Si oxidation. The effect of annealing in an oxygen ambient has also been observed. The oxidation of Si nanocrystals begins as their nucleation process completes. Thus for long annealing times, the dominant process is the consumption of the Si nanocrystals via thermal oxidation. We observe a decrease in PL intensity and hence an increase in the efficiency of the energy transfer from nanocrystals to Er ions during the formation of this nanocrystal-surface oxide.

Calculation of the activation energy governing this decrease in intensity is consistent with the presence of the Er-doped Si nanocrystal diffusion in SRSO. Transmission Electron Microscopy (TEM) is being used to characterize the change of the Si nanocrystal size in the oxidation process.
energy transfer rate can be estimated from the analysis of the rising part. The energy transfer rate showed a strong dependence on the distance between the Er active layer and an Au thin film. The distance dependence can be well explained by the modification of PMD in active layers caused by the presence of an Au thin layer. To our knowledge, this is the first demonstration that the transfer rate from excitons in semiconductors to rare-earth ions can be controlled by PMD.

3:00 PM *V2.6 Optical Gain in Strongly Coupled Erbium-doped Silicon Nanocrystals Annealed at Low Temperatures. Luca Dal Negro1, Michael Stolfi1, Michael Michel1, Xiaoyuan Duan1, John LeBlanc2, Jack Haavisto2 and Lionel Kimerling1; 1Materials Science, MIT, Cambridge, Massachusetts; 2Charles Stark Draper Laboratory, Cambridge, Massachusetts.

Erbium and silicon nanocrystal (Si-nc) co-doped SiO2 slab waveguides were fabricated on silicon (Si) substrates by reactive radio-frequency (RF) magnetron sputtering followed by single thermal annealing step. In the presence of Si-nc the Er emission is maximized at annealing temperatures between 600 °C and 700 °C, where the 1.54 μm emission is enhanced by more than two orders of magnitude relative to reference Er in SiO2 samples. For samples annealed at 600 °C, pump dependent variable stripe length (VSL) measurements indicate optical gain of 4 cm−1 at 1.54 μm. A large coupling coefficient γc = 150 x 10−15 cm2/s between Er ions and Si-nc was found by using a simple coupled rate equation model to describe both the optical emission and the gain data. The fitting of the gain versus pump power data requires a Si-nc density which is almost one order of magnitude higher than the one deduced by TEM analysis on the samples annealed at 1100 °C. According to classical nucleation and growth theory, the lower annealing temperature of 600 °C yields a higher density of smaller Si-nc than the standard 1100 °C annealing. Therefore, the enhanced radiative rate associated with small Si clusters yields a higher coupling factor γc that, together with a larger Si-nc density, explains the stronger sensitization effect that we have experimentally observed at 600 °C for the first time. The effect of the annealing temperature on the coupling factor γc will also be highlighted for the first time through power dependent VSL analysis. These Er:Si-nc films can be used to fabricate compact waveguide optical amplifiers and integrated light sources with full CMOS compatibility.

4:00 PM V2.7 High-Rate Deposition of Rare-Earth Doped Silicate Nanoparticles for Porous and Dense Optical Films. Craig Horne1,2,3, Pierre de Mascarel1, Russell Blume4, Jesse Jur3, Cecile Cohen-Jonathan3, Michael Chapin3, Jonathan Posner3 and William McGovern1; 1Kainos Energy, San Jose, California; 2NanoGram Corporation, San Jose, California; 3Neophotonics Corporation, San Jose, California.

Laser Reactive Deposition (LRDTM) is a novel process for depositing multicomponent nanoparticles covering a wide range of compositions at high rates for production of porous and dense films. The process shows results of using LRDTM processes for fabricating rare-earth containing glass films. The results are presented in terms of compositional complexity and versatility, microstructures, physical and optical properties, and refractive index uniformities of less than 2% (one std. dev.) and refractive index uniformities less than 0.005% (one std. dev.) were routinely achieved. The glass films were synthesized by consolidation of nanoparticle coated onto silicon substrates with thermal SiO2 (TOX) layers using LRDTM. Erbium-doped borophosphosilicate (EBPS), Erbium-doped borophosphosilicate (EBPS), and erbium-doped sodium aluminosilicate (ENAS) glass systems have been demonstrated for active core fiber films. Precursors were delivered using an aerosol delivery route due to the low vapor pressure of erbium and sodium compounds. TOX substrates up to 100 mm diameter were used with final film thicknesses ranging from 1 to 8 microns. As-deposited layers were comprised of single nanoparticles of uniform primary size distribution and average primary size as low as 12 nm. Thickness uniformities of less than 2% (one std. dev.) and refractive index uniformities less than 0.005% (one std. dev.) were routinely achieved. Er lifetime and photoluminescence were performed to assess the active properties of the films. Er excited state lifetimes greater than 8 ns and PL spectra with FWHM greater than 40 nm have been attained in films with Er concentrations on the order of 1019 ions/cc. Optical loss of 0.1 dB/cm, measured at 1550 nm and found to be 0.1 dB/cm. The low optical attenuation is indicative of low impurity content and low level of defects in glass films densified from LRDTM-produced nanoparticle coatings. The high quality of the physical and optical properties along with the cost benefits associated with high-speed deposition demonstrate that films produced using LRDTM technology are suitable for active planar lightwave circuits for telecom applications.

4:15 PM V2.8 Pump-probe Experiments in Er-doped Silicon-rich Oxide Slab Waveguides. Manuel Porras1, Nathaniel Smith and Robert Elliman; Electronic Materials Engineering, Australian National University, Canberra, Australian Capital Territory, Australia.

Erbium (Er) doped photonic materials and structures continue to attract considerable attention due to possible applications in telecommunications at a wavelength of 1.54 μm. Photo-excitation of Er ions in an insulator is generally achieved by passing high power beams of light through a slab of the material to be excited. However, efficient non-resonant excitation has been demonstrated in the presence of silicon nanocrystals (Si-nc), when both are present in the same silicon substrate. The nanocrystals are believed to act as a sensitizer, absorbing incident radiation over a wide spectral range and coupling it efficiently to Er3+ ions. In comparison with Er-doped bulk silicon, this new medium (SiO(Si-nc)+Er) shows a stronger room temperature 1.54 μm emission due to a reduction in non-radiative recombinations. This raises the possibility of making a room-temperature optical amplifier that operates under broad band pumping. To this end, we have examined the optical properties of slab waveguides containing Si nanoclusters and Er ions under optical pumping conditions. Optical pump-probe measurements were performed on Er-doped slab waveguides, with excess silicon in the form of nanoclusters or nanocrystals. A 1.5 μm pump beam was prism coupled into the waveguide and its intensity monitored as it exited the edge of the guide. The temporal response of this signal was then measured as the waveguide was optically pumped from above, using either continuous or pulsed excitation. Induced absorption and optical gain and compare these with our results. The pump-probe experiments will be discussed in detail and the sensitizing effect of silicon nanoclusters will be explored as a means of minimizing induced absorption in amplifier structures.

SESSION VB: RE-Doped GaN and Related Materials

Chairs: Minoru Fuji and Michal Lipson

Wednesday Morning, March 30, 2005

Room 2009 (Moscone West)

8:30 AM *V3.1 GaN:Eu Interrupted Growth Epitaxy: Thin Film Growth and Electroluminescent Devices. Chanaka Munasinghe1, A. J. Steckl1, E. Nyman2, H. Hommerich3, H. Peng4, E. Everitt5, Z. Fleischman5, V. Dullmann6 and J. Zavada6; 1Electrical Engineering, University of Cincinnati, Cincinnati, Ohio; 2Department of Physics, Hampton University, Hampton, Virginia; 3Department of Physics, Duke University, Durham, Virginia; 4Department of Physics, Lehigh University, Bethlehem, Pennsylvania; 5Army Research Office, Research Triangle Park, North Carolina.

Interrupted Growth Epitaxy (IGE) growth technique was developed as an attempt to optimize GaN/RE electroluminescence (EL) devices. In conventional MBE all molecular beams are incident upon the growth surface simultaneously during the entire growth. A variation of MBE is migration enhanced epitaxy (MEE) wherein each individual beam is incident repeatedly onto the substrate for rather short periods (~seconds). IGE is a combination of conventional MBE and MEE. In IGE, rather long growth periods (~minutes) are used where all beams are incident on the substrate followed by periods where only selected beams are incident. In GaN, it is known that N incorporation rate is much less than that of Ga. IGE is designed to eliminate this problem, with the GaN film being periodically exposed to the N beam only while the growth is interrupted. Hence, the IGE film growth occurs in a periodic fashion, with the slätter of group 11 elements (Ga and Eu) being open (ON) for a part of the cycle and closed (OFF) throughout the rest of the time. The group V is ON during the entire IGE cycling time. The ON times are varied from 5 to 60min. For our initial experiments, Ga and Eu were used. The MBE growth occurs only during the ON time. To maintain a constant 60min growth time, the IGE cycles were repeated accordingly (i.e. 12 times for 5min IGE, 4 times for 15min IGE, etc.). The 60min growth sample exhibited continuous growth corresponding to conventional MBE growth. The Eu incorporation in the films was approximately the same at ~0.5 at.%, which is below the onset of luminescence concentration quenching. Above band gap excitation showed a strong...
influence of the ON time on the emission intensities of various Eu transitions. The main emission peaks were at ~621 nm and ~632 nm. For GaN:Eu films grown on Si substrates, 20min IGE doping achieved 200% enhancement in intensity over the MBE (60min IGE). For films grown on glass substrates, 10min IGE showed an enhancement of 30% over the MBE. We also observed a change in the highest intensity emission from the 0.33 to the 0.22 reduction in ON-time. This observation shows the possibility of Eu3+ ions locating at different sites within the GaN lattice at various group III cycling conditions. AC EL devices were fabricated using the IGE-grown GaN:Eu and ZnO thick dielectric layers. These devices produced strong luminescence of ~1000 cd/m² at an efficiency of ~0.15 lm/W. This luminescence is 12x higher than the MBE grown devices. The optimized IGE GaN:Eu device has nearly ideal phosphor characteristics with reduced below-gap absorption and reduced dependence on substrate type. Our overall goals in IGE are to understand in detail the Eu3+ incorporation and optical activation mechanisms and to optimize GaN:RE EL devices. In addition to the growth and device results presented in this paper, in situ investigations of the optical properties of GaN:Eu IGE films using a variety of characterization techniques.

9:00 AM V3.2 Luminescence and Lifetime Properties of Europium Doped Gallium Nitride Compatible with CMOS Technology.
Gan Patil1, Michal Lipson2, Huiqiang Wu1 and Michael G. Spencer; Electrical and Computer Engineering, Cornell University, Ithaca, New York.

The doping of wide band gap materials like GaN with rare earth (RE) elements such as erbium and europium allows for reduced quenching of the emission of the RE ions, resulting in their increased room temperature emission. LEDs using GaN:Eu have already been demonstrated and many colors available from RE ions make them appealing from full color displays telecommunication applications. Here we study europium doped gallium nitride which is in powder form. This powder can easily be spun into thin films on substrates like silicon wafers. The films can withstand high temperatures, up to approximately 1000°C, opening the door to active structures compatible with CMOS technology. The powder is obtained by heating a gallium/europium mixture in an argon ambient to 1000°C, at which point an ammonia ambient is used. The furnace is then kept at the same temperature for a few hours. Bismuth is also used as a wetting agent. We measured the luminescence of the powder using a 18 mW HeCd laser. The powder exhibits a strong luminescence at 621 nm when pumped with the laser above gap at 325 nm, indicating an efficient energy transfer from the crystal to the rare earth ions. The relatively long lifetime of the Eu allows the device to be on-chip active devices based on population inversion including amplifiers and light emitters. In order to analyze the energy transfer process in these films, we present a study of the emission and lifetime dependence of the films as a function of pump power, wavelength and temperature.

9:15 AM V3.3 Infrared Emission from Er-doped III-N Light Emitting Diodes. John Zavada1, 2, 3, Dong-Seon Lee3, Andrew J. Steckl4, Carl Poitras, Michal Lipson, Huaqiang Wu and Michael G. Spencer; Electrical and Computer Engineering, Cornell University, Ithaca, New York; 1Physics, Kansas State University, Manhattan, Kansas; 2SVTA, Eden Prairie, Minnesota.

We report on the infrared emission of Er-doped III-N light-emitting diodes. Films grown with high temperatures up to approximately 1000°C, opening the door to active structures compatible with CMOS technology. The powder is obtained by heating a gallium/europium mixture in an argon ambient to 1000°C, at which point an ammonia ambient is used. The furnace is then kept at the same temperature for a few hours. Bismuth is also used as a wetting agent. We measured the luminescence of the powder using a 18 mW HeCd laser. The powder exhibits a strong luminescence at 621 nm when pumped with the laser above gap at 325 nm, indicating an efficient energy transfer from the crystal to the rare earth ions. The relatively long lifetime of the Eu allows the device to be on-chip active devices based on population inversion including amplifiers and light emitters. In order to analyze the energy transfer process in these films, we present a study of the emission and lifetime dependence of the films as a function of pump power, wavelength and temperature.

9:45 AM V3.5 Excitation-Wavelength-Dependent and Time-Resolved Photo-Luminescence Studies of Europium Doped GaN Grown by Interrupted Growth Epitaxy (IGE). EiEi Nyein1, 2, 3, Uwe Hommerdjic1, Chanaka Munasinghe1, Andrew J. Steckl4, Carl Poitras, Michal Lipson, Huaqiang Wu and Michael G. Spencer; 1Department of Physics, University of Cincinnati, Cincinnati, Ohio; 2SVTA, Eden Prairie, Minnesota; 3Electronics, Army Research Office, Research Triangle Park, North Carolina.

We report on the photo-luminescence properties of Eu-doped GaN samples prepared by interrupted growth epitaxy (IGE). IGE was recently developed at the University of Cincinnati in an effort to optimize the red emission properties of GaN:Eu for display applications. During IGE the group III shutter is closed for a certain time interval, which allows the GaN:Eu film to compensate for any nitrogen deficiency. Improvements in the GaN:Eu electroluminescence device performance by more than an order of magnitude were observed compared to conventional MBE and in situ doping of Er during MBE growth. Subsequently, the multilayer structures were processed into LED devices using a standard process. A variety of LEDs with different sizes and geometric shapes were produced. The produced LED structures were first examined using X-ray diffraction. No change was observed compared to results made at above room temperature. The L-I and V-I characteristics of these devices were measured at above room temperature. From the L-I characteristics the product of effective excitation cross-section and lifetime of GaN:Er LEDs was determined. From the excitation cross-section measurement no changes were observed.
to ~200 μs (1/e lifetimes). Interestingly, the shortest emission lifetime under above-gap excitation was observed from the GaN:Eu sample excited with 365 nm. The Eu3+ PL properties were observed from this set of GaN: Eu samples under resonant excitation at 471 nm (FWO→5D0). Independent of Ga cycling time, all samples exhibited nearly identical PL spectra under intra-4f Eu3+ excitation with a half-width of 622 nm. Moreover, the Eu3+ PL intensities and lifetimes varied significantly less compared to above-gap excitation. The excitation wavelengths dependent PL results indicate the existence of different Eu3+ centers in GaN:Eu, which can be controlled by the Ga shuttle cycling time. More results of temperature and excitation wavelength dependent studies will be presented at the conference.

11:30 AM V3.9 Energy-Back-Transfer Process in Rare-Earth-Doped AlGaN. Akihiro Wakahara1, Tetsuya Fujiwara1, Hiroshi Okada1, Akira Yoshida2, Takeshi Ohshima1 and Yoshiyuki Ishibashi2; 1Electrical Engineering, Toyohashi University, Toyohashi, Japan; 2JAERI, Takasaki, Takasaki, Japan.

More results of temperature and excitation wavelength dependent studies will be presented at the conference.
were there are examples even when the size of PM V4.3/FF4.3 Rev. Lett.,... 700,.....,900nm int.o PM V4.5/FF4.5 Turas For some devices there is very reduced the. The... for a reliable operation of such devices silicon nanoclusters are needed. The splitting of the trapping characteristics, and operation lifetime for dedicated excited 419/2 and 4111/2 free Er ion level in weak crystal field of the... electrical properties at higher current densities without any advanced electrical performance. The silicon dioxide layer was analysed regarding luminescence spectra, decay time, impact excitation cross relaxation, and power efficiency. Top values of the efficiency of GaN corresponding to external quantum efficiencies well above the percent range were reached. The electrical properties of these devices such as carrier injection, charge-to-breakdown, charge trapping characteristics, and operation lifetime for dedicated applications were also evaluated. Although former works showed that for a reliable operation of such devices silicon nanoclusters are needed in the silicon dioxide matrix it will be shown that with the advanced MOS capacitors an increase of the operation lifetimes by a factor of 100-1000 is possible. This allows an analysis of the electro-optical and electrical properties at higher current densities without any degradation problem. The recently demonstrated worldwide first ultraviolet silicon-based light emitter [1] was produced with the here presented device type and will be discussed in more detail. Finally, application prospects in the field of biosensing will be shown. [1] J.M. Sun, W. Skorupa, T. Dekorsy, M. Helm, L. Rebholz, T. Gebel, Appl. Phys. Lett. 85, 3387 (2004)

2:00 PM V4.2/FF4.2 Characterization of Er/O-Doped SI-LEDs with Low Thermal Quenching. Amir Karim, Goran Hanson, Wei-Xin Ni and Anders Elffling; Department of Physics and Measurement Technology, Linkoping University, Linkoping, Sweden.

Electroluminescence studies of MBE-grown Er/O-doped Si-diodes at reverse bias have been done. For some devices there is very reduced thermal quenching of the emission at 1.54 μm, there are examples where the temperature dependence is abnormal in that the intensity for a constant current even increases with temperature up to e.g. 90 C. These devices were studied with cross-sectional transmission electron microscopy to see the microstructure of the Er/O-doped layers as well as the B-doped SiGe-layers that are used as electron emitters during reverse-bias. Although there are defects in the layers there is no evidence for precipitates of SiO2. While reduced thermal quenching often is attributed to having the Er-ions within SiO2 layers or precipitates, this is not the case for our structures as evidenced by our TEM studies. The origin of the abnormal temperature dependence is attributed to the two mechanisms of breakdown in the reverse-biased diodes. At low temperature the breakdown current is mainly due to ionization resulting in low-energy electrons and holes that quench the intensity by Auger de-excitation of the Er-ions. At higher temperatures the breakdown current is mainly phonon-assisted tunneling which results in a more efficient pumping with less de-excitation of the Er-ions. Finally at the highest temperatures the thermal quenching sets in corresponding to activation energy of 125 meV, which is slightly lower and thus more favourable than 160 meV that has been reported in other studies.

2:15 PM V4.3/FF4.3 High Efficiency Visible Electroluminescence from Silicon Nanocrystals Embedded in Silicon Nitride. Gun Yong Sung¹, Nae-Man Park¹, Tae-Youb Kim¹, Kyung-Hyun Kim¹, Seoheen Shin¹, Kwan Sik Choi¹ and Jung H. Shin¹; ¹Future Technology Research Division, ETRI, Daejon, South Korea; ²Dept. of Physics, KAIST, Daejeon, South Korea.

Semiconductor electronics is strongly dominated by silicon technology. However silicon technology does not allow easy integration with optical components since silicon is a poor light emitter. There has been much effort to solve the inability of silicon to act as a light emitting source such as porous silicon, erbium doped silicon, and silicon nanocrystals(nc-Si). Among these, nc-Si dispersed in SiO2 matrix has attracted a great interest because their band gap is enlarged in comparison with bulk silicon due to quantum confinement effects. However, it is reported that due to silicon-oxygen double bonds, nc-Si in SiO2 matrix have localized levels in the band gap and emit light only in the near-infrared range of 700~900nm even when the size of nc-Si was controlled to below 2nm. Previously, we reported that red to blue PL were observed from nc-Si quantum dots as well as amorphous Si quantum dots in silicon nitride matrix. [1] Therefore nc-Si in silicon nitride matrix supplies the possibility of Si-based full-color emission. We have fabricated light-emitting diodes (LEDs) with a transparent doping layer on silicon nanocrystals (nc-Si) embedded in silicon nitride matrix formed by plasma-enhanced chemical vapor deposition. Under forward biased conditions, orange electroluminescence (EL) with its peak wavelength at about 600nm was observed at room-temperature. The peak position of the EL is very similar to that of the photoluminescence (PL) and the emitted EL intensity is proportional to the current density passing through the device. We suggest that the observed EL is originated from electron-hole pair recombination in nc-Si. By using ITO and n-type wide bandgap semiconductor layer combination as a transparent doping layer, we obtained high external quantum efficiency greater than 2.0%, which is the highest value ever reported in a valence band emission LED. [1] Nae-Man Park et al., Phys. Rev. Lett. 86, 1355 (2001). [2] Tae-Youb Kim et al., Appl. Phys. Lett. Nov. 8, 2004 , in press.

2:30 PM V4.4/FF4.4 Study of Optical Gain in Thick GaN Epilayers by Variable Stripe Length Technique. Gintautas Tamulaitis¹, Jarra Micevicius², Michael Shur², Qhalid Fareed² and Remis Gaska²; ¹Semiconductor Physics, Vilnius University, Vilnius, Lithuania, ²Department of EGS and CIE, Rensselaer Polytechnic Institute, Troy, New York; ²Sensor Electronic Technology, Inc. Columbia, South Carolina.

We report on the gain study in high-quality thick GaN layers grown by Metal Organic Chemical Vapor Deposition (MOCVD) at different conditions using the Variable Stripe Length (VSL) technique. The amplification of light propagating along the layer surface (parallel to the c-axis of the crystal) and perpendicular to the layer (along the c-axis) for the layers with thicknesses ranging from 1 to 11 nm was investigated. Peak gain coefficients of up to 7300 cm-1 in the GaN were estimated by fitting the experimental stripe length dependence of the edge luminescence with one-dimensional light amplification in medium with positive gain. Involvement of new gain modes after saturation of the highest-gain modes was observed. GaN samples with different optical gains were also characterized using spontaneous photoluminescence spectroscopy, time-resolved photoluminescence technique, and light-induced transient grating technique that allowed us to determine the nonequilibrium carrier lifetimes. Finally, we discuss the limitations of the VSL technique related to the assumption of one-dimensional light propagation, to the high gain saturation due to the light amplification caused by stimulated transitions at the stripe lengths of several micrometers and consider the influence of heating of the photoexcited electron-hole plasma on the light amplification.


A series of nontraditional twisted intramolecular charge-transfer (TICT) chromophores were designed and synthesized. These chromophores exhibit ultra-high hyperpolarizabilities (βetas) and optical absorption features strongly dependent on the intermolecular dihedral angle. The tunable structural characteristic that promotes these optical/ nonlinear optical features/responses is a stereochemically enforced reduction of the D-A Pi-conjugation that enforces chiroptanical behavior in the ground state and large-oscillator strength intramolecular excitation feature. The
consequence is that molecules with a relatively small number of Pi-electrons exhibit responses far larger than those of corresponding planar Pi-conjugated chromophores. Evaluations of electro-optic devices based on these chromophores are in progress.JSONArray

1.6{LIU/hour.

SESSION V5/FF5: Joint In-Room Poster Session:

Leaking Materials and Luminescence Devices

Chairs: Astrid Almene Dyrshty and Tony Peaker

Wednesday Afternoon, March 30, 2005
3:30 PM - 5:00 PM
Room 3020 (Moisco West)

V5.1/FF5.1

Influence of Rapid Thermal Annealing on Self-Assembled Quantum-Dot Superluminescent Diodes. Ziyang Zhang1, Ying Yin Tsu1, Robert Fedosejevs1 and Zhanhuan Wang2; 1University of Alberta, Department of Electrical & Computer Engineering, Edmonton, Alberta, Canada; 2Key Laboratory of Semiconductor Materials Science, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, China.

Superluminescent diodes (SLD) have great potential for application as light sources including optical gyroscopes and sensors, optical time domain reflectometers (OTDR) and wavelength-division multiplexing (WDM) system testing. High output power and large spectral bandwidth are key features for SLD. In recent years, self-assembled quantum dots (SAQD) instead of quantum well have attracted significant attention for laser diodes (LD) application. QD-LD are expected to attain high power, high temperature, passively mode-locked operation, and a remarkable reduction in threshold current, due to the discrete atom-like states in QD. Much of the interest in QD-LD focuses on the uniform growth of QDs to obtain sufficient gain to lase. However, it is noted that non-uniform characteristics of the size can be beneficial to SLD to realize the desired wide spectral bandwidth. In this work, two kinds of SAQD-SDLs have been fabricated. Both of them were with tilted-stripe active region. The only difference between them was one has been treated with rapid thermal annealing (RTA) while the other has not. Continuous wave (CW) output power of 200mW and a spectral width of 60nm were realized at room temperature by the sample which has not been treated with RTA. In addition, the CW output power of 200mW was obtained at only 1.4A injection current. As a SLD, it was a very high efficiency. However the CW Maximal output power was only 140mW and the spectral width was 40nm of the sample which has been treated with RTA. As we know, the homogeneity of quantum dots can be effectively improved after RTA, and it will generally be beneficial for QD-LD. However, in this case, for QD-SDL, the RTA effect was quite different from that of QD-LD. It indicated that the appropriate inhomogeneity of QD is an important factor to realize high performance Superluminescent diodes. One of the authors (Ziyang Zhang) would like to acknowledge financial support from the Alberta Ingenuity Fund.

V5.2/FF5.2

A Novel Class of Imidazole-Containing Excited-State Intramolecular Electron Transfer Materials: Synthesis and Amplified Spontaneous Emission from a Single Crystal. Sanghyuk Park1, Min-Geun Kim2, Joon Du-Joun Kang2, Sangwoo Park2, Moon-Gung Choi3 and Soo Young Park1; 1Materials Science and Engineering, Seoul National University, Seoul, South Korea; 2School of Chemistry, Seoul National University, Seoul, South Korea; 3Department of Chemistry, Graduate School, Yonsei University, Seoul, South Korea.

The excited-state intramolecular electron transfer (ESIPT) reactions have been extensively investigated because of the fundamental importance of this process and its potential applications in laser dyes, solar energy concentrators, and electrochromic materials. To realize a compact and rugged device with better performance, most of the ESIPT applications demand a highly concentrated solid matrix, it normally happens that the intermolecular interactions in the condensed system raise the problem of significant concentration quenching in the fluorescence intensity, which is an important challenge in the fluorescent ESIPT materials. In this work, we reported highly concentrated but still ESIPT-active solid materials by introducing dendrimer structures, and we have been successful in demonstrating that the fluorescence intensity can be greatly enhanced in the aggregated system when the molecular structure is properly designed. As a continued effort in these works, we have designed and synthesized a novel class of ESIPT materials, hydroxy-substituted tetraphenyl imidazole (HPI) and its derivative HPI-Ac, which assumes aggregation-induced fluorescence emission (AIE) in the solid state. Prepared materials showed transparent and well-formed single crystals with intense blue photoluminescence and amplified spontaneous emission (ASE). The structural characteristics of HPI and HPI-Ac were fully identified by X-ray crystallography. The crystal structures were triclinic and the two phenyl rings at 1- and 5-positions of central imidazole ring are twisted perpendicular to the plane. These two twisted phenyl rings appropriately prevent direct stacking of the active chromophores in a zig-zag manner and maintain proper intermolecular distance, and reduce the concentration quenching of ESIPT fluorescence. The ESIPT kinetics and proton-transfer ASE were studied by an actively/passively mode-locked Nd:YAG laser (Quantel, YG701) and a 10-ps streak camera (Hamamatsu, C2830) attached to a CCD detector (Princeton Instruments, RTE1248). The intrinsic four-level nature of the ASE contributes to easy population inversion, and the low-threshold ASE from HPI-Ac will be discussed in this work.

V5.3/FF5.3

Organic/Inorganic Hybrid Glasses Doped with (Erbium-ions/CdSe nanoparticles) for Laser Amplifiers. Kyung M. Choi, 1Bell Labs, Lucent Technologies, Murray Hill, New Jersey; 2Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois.

A new family of organic/inorganic hybrid silicate materials, bridged polysilsesquioxanes, was designed and synthesized through a molecular-level mixing technique. By modifying the Si-O-Si polymeric network, we produced controllable, porous glass materials for facile and uniform doping of various ions, metals or semiconductor particles. By taking advantage of void volume created in those molecularly modified silicate systems, we developed hexylene-bridged fluoroalkylene-bridged polysilsesquioxane doped with both Er3+ ions and CdSe nanoparticles for the development of new laser amplifier materials. In photoluminescence experiments, a significant enhancement in fluorescent intensity at 1540 nm has been obtained from the fluoroalkylene-bridged glass. Analysis by nuclear magnetic resonance indicates a dramatically enhanced degree of condensation and a low level of hydroxyl environment in the fluoroalkylene-bridged glass matrix. The presence of CdSe nano-particles, by virtue of their low photon energy, also appears to significantly influence the nature of the surrounding environment of Er3+ ions in those modified silicate systems, resulting in the increased fluorescent intensity.

V5.4/FF5.4

PL Excitation Mechanism of Eu and Pr doped GaN Grown by Hydrate Vapor Phase Epitaxy on Sapphire. Wojciech M. Jowasienczak,1 Henryk J. Lozykowski1 and Richard J. McBranch.2 1School of ECECS, Ohio University, Athens, Ohio; 2Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts.

We report measurements of the photoluminescence excitation (PLE) spectra, time resolved spectra and kinetics using tunable Sunlight laser system for Eu and Pr doped GaN. Investigated samples grown by hydrate vapor phase epitaxy were implanted with different rare earth ions doses and thermally treated at 1100 C in N2 and Ar/02 gas flow ratio increased. Especially, a high quality glass thin films that remove ion implantation-induced damages, and make RE impurities optically active. From PLE experiments we have found that the defect level near conduction band of GaN Eu doped samples are increased in an energy transfer of 4f electrons of Er3+ ion. On the basis of experimental results the possible excitation mechanisms for RE3+ ions are briefly discussed.

V5.5/FF5.5

Fabrication of Er3+/Pr3+ Co-Doped Soda Lime Glass Thin Films Using RF Magnetron Sputtering and Optical Property Characterization. Sang Hoon Shin, Ki Young Yoo, Dong-ryul Jung, Jong Ha Moon and Jin Hyeok Kim; Department of Materials Science & Engineering, Chonnam National University, Gwangju, South Korea.

Er3+/Pr3+ co-doped soda lime thin films have been fabricated using RF magnetron sputtering method and their structural and optical properties have been studied. Deposition rate, crystallinity, and composition of glass thin films were investigated by scanning electron microscopy, transmission electron microscopy, and electron probe micro area analysis. Reflective index, birefringence, and binding characteristics between atoms have been investigated using a prism coupler and x-ray photoelectron spectroscopy. Er3+/Pr3+ co-doped soda lime thin films were prepared by changing substrate temperature (room temperature - 550°C), RF power (90W-150W), and Ar/O2 gas flow ratio at processing pressure of 4 mTorr. The deposition rate depends on the processing parameters. It increased as the RF power increased and decreased as the Ar/O2 gas flow ratio increased. Especially, a high quality glass thin films that have similar composition with the compositions of the targets were obtained at 350°C, RF power of 130W, and gas flow ratio of Ar/O2 (40:0) with max deposition rate of 1.65um/hour. Reflective index increased from 1.5614 to 1.5838 and birefringence increased from 0.001514 to 0.000552 as the content of Pr increased. Binding energy of
rare earth ions increased as the content of Pr increased.

**V5.6/FF5.6**

A Novel Approach to Achieve Broadband Luminescence from Tm$^{3+}$ and Er$^{3+}$ Codoped Al$_2$O$_3$ Thin Films. Zhiqiang Xiao$^1$, Rosalia Serna$^1$, Carmen N. Afoano$^1$ and Ian Vickridge$^2$.

Integrated optoelectronic circuits need the development of light sources and optical amplifiers in planar waveguides. Rare earth (RE) doping of dielectrics allows preparing suitable materials for these applications. Moreover, there is a great effort to develop devices for wavelength-division-multiplexing (WDM) in local networks, systems and a demand for optical amplifiers utilized near 1.4 $\mu$m and 1.6 $\mu$m, in addition, to the present silica-based erbium (Er) doped amplifiers (1530-1600 nm). Thus it is interesting to explore the possibility of profiting from emission of one more kind of RE ion in a single integrated device. Tm$^{3+}$ is promising as a complement to Er$^{3+}$ ($\lambda$ at 1.54 $\mu$m) due to the presence of similar electric properties. In particular, we have found in Tm$^{3+}$ doped Al$_2$O$_3$ two efficient emission bands peaked at 1.48 $\mu$m and 1.64 $\mu$m. The aim of this work is to achieve the broadband luminescence by codoping thin films with Er$^{3+}$ and Tm$^{3+}$ and controlling both concentration and dopant distribution in the nanoscale. The amorphous aluminum oxide (Al$_2$O$_3$) thin films codoped with Er$^{3+}$ and Tm$^{3+}$ have successfully been prepared by pulsed laser deposition (PLD). The number of Tm-Tm layers between two Er layers separated 6 nm has been corresponding to 1, 2, and 5, and Tm$^{3+}$ ions with Tm$^{3+}$-Tm$^{3+}$ layer in-depth separation of 3, 2 and 1 nm, and an areal density of Tm$^{3+}$ in the range of 2.15x10$^{17}$ - 1.67x10$^{18}$ $\mathrm{cm}^{-2}$ determined by the RBS analyses. Er$^{3+}$ areal density is 8 - 2.15x10$^{15}$ $\mathrm{cm}^{-2}$ for all Al$_2$O$_3$ films. When pumping with 794 nm light from a Ti:sapphire laser a broad photoluminescence (PL) band with a full-width half maximum (FWHM) up to 250 $\mu$m was observed. This broad PL band is the result of the convolution of simultaneously luminescent Er$^{3+}$ and Tm$^{3+}$ ions. By the addition of Tm$^{3+}$ the typical Er$^{3+}$ spectrum in Al$_2$O$_3$ peaked at 1540 nm (FWHM 80-60 $\mu$m) was modified by an enhancement of the PL intensity in the region of 1500-1600 nm and the appearance of a broad shoulder peak at 1640 nm. The broad band spectrum was studied as a function of the Tm$^{3+}$/Er$^{3+}$ concentration ratio. As the concentration ratio increases both the PL intensity and lifetime of 1540 nm peak increased and in the meantime both the PL intensity and lifetime of 1540 nm peak decrease. It is shown that this is the consequence of energy transfer between the transition of Er$^{3+}$: $^4I_{13/2} - ^4I_{15/2}$ and Tm$^{3+}$: $^4F_4 - ^4H_6$. It will be shown how by adjusting the Tm content and Er-Tm separation between two Er layers can be used to tailor 1.4-1.7 $\mu$m PL response of Er-Tm co-doped Al$_2$O$_3$ films for broadband applications.

**V5.7/FF5.7**

The Impact of Deposition Parameters on Optical and Composition Properties of Er Doped SRSO Thin Films Deposited by ECR-PECVD. Michael Flynn$^1$, Jacek Wojcik$^1$, Edward Irving$^1$, and Peter Mascher$^2$.

Silicon rich oxide silicon (SRSO) thin films have been deposited, with in-situ Er doping via an organometallic precursor, using electron cyclotron resonance plasma enhanced chemical vapor deposition (ECR-PECVD). The films had thicknesses of approximately 1000 $\AA$ and silicon concentrations ranging from 33 to 45%. Using heavy ion elastic recoil detection, it was found that the SRSO composition, specifically the silicon to oxygen ratio, was significantly impacted by the erbium incorporation. It was also determined that varying the microwave power affects the incorporation of erbium during the thin film deposition process. Additionally, ellipsometry has been used to characterize the thin films. The microwave power and the erbium concentration level had a large impact on the optical properties of the films. Results from Fourier transform infra-red absorption measurements of these films will be discussed in relation to the composition and optical measurements and with reference to the broader field of silicon based photonic devices. This work is being supported by Ontario Centre of Excellence (OCE) Inc. and the Ontario Photonics Consortium (OPC).

**V5.8/FF5.8**

Luminescence of Rare Earth Doped Si/ZrO$_2$ Co-Sputtered Films. Carlos Rozo Roso$^1$, Luis Fonseca, Oscar Resto and Zvi Weiss.

Silicon-rich silicon oxide (SRSO) thin films have been deposited with in-situ Er doping via an organometallic precursor, using electron cyclotron resonance plasma enhanced chemical vapor deposition (ECR-PECVD). The films had thicknesses of approximately 1000 $\AA$ and silicon concentrations ranging from 33 to 45%. Using heavy ion elastic recoil detection, it was found that the SRSO composition, specifically the silicon to oxygen ratio, was significantly impacted by the erbium incorporation. It was also determined that varying the microwave power affects the incorporation of erbium during the thin film deposition process. Additionally, ellipsometry has been used to characterize the thin films. The microwave power and the erbium concentration level had a large impact on the optical properties of the films. Results from Fourier transform infra-red absorption measurements of these films will be discussed in relation to the composition and optical measurements and with reference to the broader field of silicon based photonic devices. This work is being supported by Ontario Centre of Excellence (OCE) Inc. and the Ontario Photonics Consortium (OPC).
very promising material for the development of optical waveguide amplifier in the range of 1.4 - 1.7 µm.

9:00 AM V6.2
Gallium Oxide as a Host for Rare Earth Elements. John Muth, Christian Kloen, Anuj Dhawan and Jason Kekas; ECE Dept Box 7911, NC State University, Raleigh, North Carolina.

Using Pulsed Laser Beam and Pulsed Laser Deposition single crystal β-Go2O3 was grown epitaxially on double side polished c-axis oriented doping sapphire substrates. The resulting films were smooth with RMS surface roughness by AFM of about 1 nm. Prism coupling was used to obtain the refractive index of 1.83 at 832 nm resulting in a natural planar waveguide. The wide band gap of 4.9 eV suggests that the films could be a suitable host for rare earth elements. Optical waveguiding, cathodoluminescence and optical transmission measurements of rare earth doped Gallium Oxide films on sapphire will be presented.

9:15 AM V6.3
Rare-Earth Doped Chalcogenide Thin Films for Photonic Application by Excimer Laser Absonion. Prabhakaran Kumar Dass1,2, F. Allen1,2, J. Y. Yau3,1, S. O. Kassap1; 1Electrical and Computer Engineering, University of Alberta, Edmonton, Alberta, Canada; 2Photonics, TRI Labs, Edmonton, Alberta, Canada; 3Electrical Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Chalcogenide glasses have been extensively studied as host media for rare-earth (RE) doped chalcogenide thin films due to their potential application as optical amplifiers for optical telecommunication. However, fabrication of RE doped homogeneous thin films of chalcogenide glass systems is a difficult task. The composition of the films usually deviates from that of the source material and depends on the conditions of the film deposition technique. Doping high amounts of RE atoms (1 to 2 at%) using conventional preparation methods such as glass quenching or physical vapor deposition techniques often results in physical or chemical clustering of the RE atoms in the glass matrix also. The respective evaporation rates of chalcogenide glass and rare-earth atoms are so different that vacuum evaporation of doped bulk glass leads to nearly undoped films. In this paper, we report the deposition and properties of RE doped chalcogenide films fabricated by pulsed laser deposition (PLD), using 15 ns KrF laser pulses at various laser energy densities and substrate temperatures. This method was used in order to take advantage of its ability to create homogeneous films with complex compositions. We have used the PLD technique to fabricate Er3+ and Nd3+ doped chalcogenide glasses of different compositions. The composition of the bulk and respective thin film samples were determined by Wavelength Dependence X-ray analysis (WDX). The optical constants of the deposited films were determined by analyzing transmission spectra obtained using a spectrophotometer. The photoluminescence (PL) of the films was studied using a set of laser diodes operating at different wavelengths. We examined the effects of changing the substrate temperature during deposition on the optical constants and photoluminescence.

9:30 AM V6.4
Infrared Electroluminescence from Zinc Sulfide Doped with Rare Earth Fluorides. Avni A. Argun1, David M. DeVito2, Ajay Kale1, William Glass1, Mark Davidson2 and Paul H. Holloway1; 1Materials Science and Engineering, University of Florida, Gainesville, Florida; 2MICROFABRITECH, University of Florida, Gainesville, Florida.

Thin film electroluminescent (EL) devices serve as an excellent design for high efficiency infrared emitters. A variety of applications exist for infrared emitters including chemical analysis, infrared displays, communications, and therapeutic treatment. Rare earth elements, such as Er3+, Neodymium, and Holmium are ideal choices for photoluminescence because of the many sharp transitions they possess in the visible region from 500-700 nm and in the infrared region from 850-2800 nm. Zinc sulfide (ZnS) is a suitable host material as it provides a stable wide band gap of 3.6 eV at 300K in which the electrons can be excited to adequate energies to produce emission from rare earth dopants. Thin films of rare-earth doped ZnS were RF magnetron sputter deposited at 120 W and 160 °C deposition temperature from dual targets of an undoped ZnS and a rare-earth fluoride doped with varying duty cycles. Suppression of visible wavelengths is desirable and can result in enhanced near infrared emission and emergence of new transitions at longer wavelengths. This is achieved by post-deposition annealing of thin film phosphors at temperatures between 290 and 360 °C. As an example, the maximum EL radiance for ZnS:Er3+ at 1550 nm has increased from ~1 µW/cm² (pre-anneal) to 28 µW/cm² (post-anneal). Achieving optimum brightness and selective wavelength emission require proper concentrations of both rare-earth ion and fluorine which were determined by EDS and SIMS analysis.

9:45 AM V6.5
Erbium-doped Amorphous Si-C-O matrix (a-Si:C,O:Er) - A Novel Silicon-Based Material for Near-Infrared Optoelectronic Applications. Spyros Gallis1, Menghui Huang1, Vasileios Nia3,ü Hurry Efstathiou3, Eric Eisenbraun4, Alan E. Kasper1, Jennifer Freeman2, Et El Nyein4 and Uwe Hommerich2; 1College of Nanoscale Science and Engineering, The University at Albany-SUNY, Albany, New York; 2Department of Physics, Hampton University, Hampton, Virginia.

Due to its low-k dielectric value, and excellent mechanical and chemical properties, amorphous silicon oxy carbide (Si:C,O) has recently received much attention in copper interconnect-related applications. In this work, we demonstrate that Si:C,O matrix can also be an excellent host matrix for erbium (Er)-doped silicon-based optoelectronics. Amorphous-Si:C,O (a-Si:C,O) materials were synthesized via thermal chemical vapor deposition (TCVD) at 900°C using single source oligomers: 2,4,6-trimethyl-2,4-divinyl cyclopentadiene (C(=H)n=3) and Amorphous (C=H)n=2). By carefully modulating the flow rate of oxygen, the Si:C,O thin film composition could be controlled, resulting in Si:C,O films with varying carbon (x) and oxygen (y) compositions in the range of 0 - 1.71. The resulting Si:C,O samples along with a SiO2 sample were implanted with Er ions at 260 keV to a dose of 1 x 1015/cm². Following post-implantation annealing annealing at 900°C, room temperature photoluminescence (PL) measurements were performed under both ultra-violet (wavelength range 336-363 nm) and visible light (wavelength range 496.7 nm) excitations to monitor the intra-4f transition of doped Er ions. The chemical and structural characteristics of Si:C,O films also characterized using various analytical techniques including ion scattering, transmission electron microscopy (TEM), x-ray photoelectron spectroscopy (XPS) and Fourier transform infrared spectroscopy (FTIR). The Er-doped Si:C,O materials exhibited a strong room-temperature PL at ~1532 nm wavelength. Furthermore, the infrared PL intensity was found to be highly dependent on the compositions of carbon and oxygen, while the strongest luminescence emission was obtained from an Er-doped Si:C,O:O thin film. The data suggested that a white light source or light emitting diode could be used as the pump for exciting Er in Si-C-O materials. In comparison with Er-doped SiO2, the PL intensity from Er-doped SiC01.4O:O was enhanced by factors of ~23 and ~14 under visible light and UV excitation respectively. The enhanced performance observed herein is comparable with those reported in previous work that used Si nanocrystals as Er sensitizers in silica oxide. Neither Si nor SiC nanoclusters were seen in the Si:C,O samples grown under the above-mentioned processing conditions. In this context, the efficient infrared Er-related luminescence was correlated to the elemental composition and chemical bonding of the Si:C,O films. The work by the present investigators thus presents a novel approach for achieving efficient infrared luminescence emission from Er ions through engineering the structures of Si-C-O networks.

10:00 AM V6.6
A New Photoluminescence Band in Hafnium-implanted Silicon. Ravinder Sachdeva1, Andrei A. Istratov1, Prakash Deenapanavar2 and Eicke R. Weber1; 1Materials Science and Engineering, U.C. Berkeley, Berkeley, California; 2Center for Sustainable Energy Systems, The Australian National University, Canberra.

A new photoluminescence (PL) band in the energy range of 700 meV to 950 meV associated with hafnium implanted in silicon is reported. Activation of the Hf-optical centers requires a 1000°C anneal step. The intensity of the PL lines appear to depend on the cooling conditions. The spectrum consists of five peaks in the rapidly quenched sample as opposed to twenty one in the slow cool sample. The peak with the highest intensity is found in the rapidly quench sample at 943.8 meV with two phonon replicas. Temperature and excitation power dependent PL are performed on this peak. It is also found that cooling coimplantation has little effect on the PL intensity. A shift in the position of photoluminescence peaks observed on the samples implanted with two different isotopes of Hf confirms the Hf-related origin of the observed photoluminescence band.

10:45 AM V6.7
Lattice Location of Rare Earth Ions in Semiconductors: Interpretation and Limitations of using g Values. David Carey, University of Surrey, Guildford, United Kingdom.

The g values of rare earth ions obtained from either paramagnetic resonance or Zeeman measurements are often used to interpret the local structure surrounding the rare earth ion. For ions with cubic symmetry the g value can be used to distinguish between substitutional and interstitial sites. For centers with less than cubic symmetry the average g value, taken as 1/3 trace of the g tensor, is often used as an indication of the lattice location and/or a measure of
the strength of the local crystal field. This approach has been widely used but is based on the assumption that the non-cubic terms to the crystal field parameters are small compared to the cubic crystal field. In this paper we have explored this assumption by calculating the principal g values for a range of non-cubic crystal fields for the Er3+ ion. We determine the limits over which the average g value approach is valid and other effects, should as the reduction in the g values due covalence effects, are also discussed. Comparison is made with published results from paramagnetic resonance and Zeeman measurements.

11:00 AM V6.8
UV Excitation Mechanism of Rare Earth Ions in AIN. Henryk J. Losykowski1, Wojciech J. Jadowszczyk1, Abdelsalam Bensouila2, Chris Bosey3 and Ottsen Monteure2,1; School of ECECS, Ohio University, Athens, Ohio; 2Petites Matieres Laborer, University of Houston, Houston, Texas; 3Lawrence Berkeley National Laboratory, University of California, Berkeley, California.

We report measurements of the luminescence properties and excitation mechanism of RE ions implanted into AIN films grown by plasma source molecular beam epitaxy. Investigated samples were implanted with Pr, Eu, Tb and Tm ions at room temperature and thermally activated at a temperature of 1050 C in N2 or N2H3 to remove ion implantation-induced damages, and make RE impurities optically active. The PL measurements were performed using a He-Cd laser, Sunlight laser (pulse operating), and tunable light source utilizing a Xenon high pressure lamp with double grating monochromator. The high-resolution photoluminescence (PL) and photoluminescence excitation (PLE) measurements have been carried out in temperature range from 13 K to 300 K. These studies show that under below bandgap excitation all investigated samples show well-defined visible emissions due to intra 4f-shell transitions of the RE3+ ions. The PLE spectra have revealed several excitation bands in the 200 nm - 360 nm spectral range. Finally, on the basis of experimental results the possible excitation mechanisms of RE3+ ions are briefly discussed.

11:15 AM V6.9
A New Method to Produce Rare Earth-Doped Gallium Nitride Phosphor Powders. Gustavo A. Hirata1,2, Jonathan H. Tao1, Po Yu Chen1, Kailash C. Mishra3 and Joanna McKittrick1; 1MAE, UCSD, La Jolla, California; 2CCMC-, UNAM, Ensenada, Baja California, Mexico; 3Central Research, ORSAM Sylvanian, Beverly, Massachusetts.

We report on the fabrication and luminescent properties of rare earth-doped gallium nitride (GaN) phosphor powders. Single phase GaN and GaN:RE3+ powders were prepared by using a novel chemical route. Traditionally, GaN powders are produced by placing Ga or Ga2O3, or one of the Ga halides in an ammonia flow. However, the formation of a GaN layer on the surface reaction, resulting in poor crystallinity and contaminated powders [1]. Precursors such as [H2GaNH2]2 and Ga(GaC2H5)NH3/NH3, can be thermally decomposed to produce GaN nanocrystals but the resulting materials show traces of carbon [2]. Solid state decomposition reactions have been carried out to synthesize polycrystalline GaN using Ga3 and Li3N under high pressure (4.5 GPa), and to synthesize GaN nanocrystals using Ga203 and Li20 in a hot bismuth solution under high pressure [3]. In this work a new method for the synthesis of high purity, single phase doped GaN powders is reported. (GaN-xREx)xN (and Ga-xTMM)xN) powders are obtained by dissolving metal nitrates (GaN(NO3)3, RE(NO3)3, TM2(NO3)2) in deionized water with ammonium hydroxide in order to form a gallium/RE or gallium/TM hydroxide. The hydroxides are then reacted with ammonium fluoride to form ammonium hexafluoroRE-gelate or hexafluoroTM-gelate. The dried hexafluorate powders are placed in a boron crucible and reacted at 1200 C in a high purity N2 flow followed by a NH3 flow. X-ray diffraction analysis showed that single phase GaN powders are formed. Preliminary results show (Ga20,55Eu0,45)N powder to be luminescent, with the main emission occurring at 613 nm from the 5D07F2 transition of the Eu3+.

High-purity GaN powders are obtained according to X-ray photoelectron spectroscopy (XPS) chemical analysis. HRTEM performed on individual crystals with hexagonal (wurtzite) structure showed small cubic domains (zincblende) and a high density of stacking faults, all aligned along the [0001] and [111] directions, respectively. These powders were used to fabricate targets for thin film deposition studies. This method can be used to obtain red-luminescence GaN:Eu3+ and other rare earth (e.g. Er, Tb, Tm) doped GaN powders to produce green and blue luminescence as well. A more detailed discussion of these new RE-doped GaN materials will be presented at the conference.

11:20 AM V6.10
Visible Light Emission from Er:GaN and Eu:GaN Powder. Huagiang Wu1, Janet Huntley2, Carl B. Poitras1, Michel Lipson1, Francis J. DiSalvo2 and Michael G. Spencer1; 1School of Electrical and Computer Engineering, Cornell University, Ithaca, New York; 2Department of Chemistry & Chemical Biology, Cornell University, Ithaca, New York.

We report on the first demonstration of rare earth elements doping in GaN power at high temperature. The recent demonstration of visible (blue, green, red) and infrared (1.5 μm) electro-luminescence from rare earth (RE) doped GaN brings significant interest to this class of materials for possible applications in optical communications and full color displays. In these works, the incorporation of RE atoms into GaN is achieved by either in situ epitaxial growth with the GaN layer or ion-implantation after the layer growth step. Although extensive work has been done on doping GaN in bulk form with RE, few studies have been done on doping GaN in a powder form with RE. In this work RE is successfully incorporated into GaN powder through the reaction between molten (Ga2+RE) and NH3 at 1000°C using Bi as a wetting agent. Photo excitation with an Ar and UV laser results in strong visible light emissions from two narrow lines at 537 and 508 nm (identical to Er transitions in Ga2O3) in our Er:GaN powders. Red emission at 623 nm corresponding to transition 5D0 → 7F2 has also been achieved from Eu doped GaN powder. X-ray diffraction shows that both structures of the GaN powder doped with Er and Eu are the wurtzite structure. Microprobe analysis reveals that Er or Eu is distributed evenly in the powder particles. These rare earth doped GaN powders are used to make thin film on Si, glass and sapphire substrates. Continuous and highly oriented films showed good luminescence properties. Structure, morphology, cathodoluminescence and photoluminescence characterizations have been carried out on these films. Electroluminescence measurements are carrying out and will be reported during the meeting. 1. A. J. Steck and J. M. Zavadka, Mater. Res. Bull. 24, 31 (1999). 2. A. J. Steck, J. C. Heikenfeld, D. S. Lee, M. J. Garter, C. C. Baker, Y. Wang, and R. Jones, IEEE J. Selected Topics in Quantum Electronics, 8, 749 (2002).

11:45 AM V6.11
How to Make Algae Glow in the Dark. Michael Weatherspoon, Shawn Michael Allan, Ye Cai, Jeffrey King, Christopher Summers and Kenneth Sandilands; Materials Science and Engineering, Georgia Institute of Technology, Atlanta, Georgia.

Intense global activity to produce micro-to-nanoscale devices with well-controlled structures for optoelectronic applications has led to appreciable interest in three-dimensional (3-D) self-assembly processes. Elegant examples of self-assembly can be found in nature. Certain biomineralizing micro-organisms are adept at mass-producing 3-D nano-structures with genetically precise morphologies. An exceptional variety of silica-based structures are generated by aquatic micro-algae known as diatoms. Diatoms are single-celled organisms that assemble microshells (frustules) comprised of silica nanoparticles. With the tens of thousands of extant diatom species present on the planet provide a rich variety of frustule shapes for devices, the range of potential applications is severely limited by the natural silica-based chemistry. We demonstrate here how a sol-gel coating technique can be used to convert such biogenic silica-based structures into luminescent (non-silica-based) rare-earth-doped materials while preserving the intricate 3-D shapes and features. Europium-doped BaTiO3-based replicas have been synthesized using a multi-step process consisting of: i) reactive conversion of the Si-O-Si scaffolding to a chemically-compatible substrate and ii) application of an alkoxide-derived coating that is then fired to the desired multiple-component luminescent ceramic phase. Eu-doped BaTiO3-based frustules exhibited a bright red luminescence upon exposure to 537 nm stimulation. This shape-preserving chemical conversion approach may also be applied to a wide variety of other self-assembled 3-D biogenic structures. Potential applications for such luminescent, biologically-assembled micro-structures will be discussed.

11:50 AM V6.12
Stable Luminescence from Er:GaN and Eu:GaN Powder. Zhe Chen1,2, St. J. Hwang3, J. P. Campbell3, J. M. Zavadka2, and J. C. Heikenfeld2. 1Department of Chemistry, Ohio University, Athens, Ohio; 2Nitride Materials Laboratory, University of Houston, Houston, Texas; 3Lawrence Berkeley National Laboratory, University of California, Berkeley, California.

The luminescence properties of rare earth doped GaN powders have been studied with excitation at room temperature and at 4.2K. GaN:Eu3+ and other rare earth (e.g. Tb, Sm, Eu) doped GaN powders to be luminescent, with the main emission occurring at 622 nm corresponding to transition 5D0 → 7F2. We determined the limits over which the average g value approach is valid and other effects, should as the reduction in the g values due covalence effects, are also discussed. Comparison is made with published results from paramagnetic resonance and Zeeman measurements.

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