SYMPOSIUM L
L: New Materials for Microphotonics
April 12 - 15, 2004

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* Invited paper
This tutorial will cover optical phenomena in materials with characteristic length scales ranging from nanometers to micrometers. We will first discuss the concept of micro-photonic integrated circuits, in which light is guided in optical waveguides that are made on a planar substrate. By proper materials design and engineering, passive devices such as optical splitters and multiplexers can be made. By adding optically active impurities such as rare-earth ions, optical amplifiers or lasers have been realized. Various microresonator designs will be introduced in which light can be stored and confined in small volumes at high intensities. We will review the optical properties of rare-earth ions as well as Si quantum dots that serve as active elements in waveguide structures, and novel LED designs. We will then focus on the concept of photonic crystals, materials composed of a regular arrangement of a dielectric material that shows strong interaction with light. The fabrication, optical band structure and optical characteristics of two- and three-dimensional photonic crystals will be discussed, and their effect on optical mode propagation and the control of spontaneous emission will be reviewed. To manipulate optical information on a scale smaller than the wavelength of light, an entirely new technology is emerging in which optical energy is stored in plasmon states of materials. We will discuss the intriguing properties of small metal and dielectric nanostructures from a physical and materials point of view. Focus will be put on photonic and plasmonic applications, ranging from energy guiding and storage to imaging and sensing. The concept of surface plasmons will be introduced for thin films, nanowires, and clusters. Applications such as waveguiding, plasmonic diffraction and Raman spectroscopy, and integration of metal nanostructures with dielectric microcavities in the near-infrared will be discussed. Prominent investigation tools for plasmons in single and ordered arrays of metal nanoparticles will be reviewed, including finite-difference time-domain simulations and near-field optical microscopy.

Instructors:
Stefan Majer, California Institute of Technology
Albert Polman, FOM-Institute AMOLF

SESSION Ll: Erbium - doped Structures
Chair: Chris Buchal
Tuesday Morning, April 13, 2004
Room 2008 (Moscone West)

8:30 AM *L1.1
Rare-earth doped nano-cluster silicon for silicon based photonic application. Se-Young Seo and Jung H. Shin; KAIST, Taegon, South Korea.

The efficient luminescence of silicon based materials has been a long-standing issue, since the combination of well-established silicon process technology with light emission functionality can pave the way for integrated silicon photons. Whereas silicon based photonics had been hindered by the inefficient light emitting process of indirect bandgap nature of bulk silicon, some circumventing ways have been exploited for last decades. One of predominant approaches utilizes sharp and intrinsic luminescence of 4f transition in rare-earth ions. However, rare-earth (RE) ions in bulk silicon suffer from significant de-excitation processes which result in the inefficiency of luminescence and excitation process. After strong RE (Er, Nd, Tm, and Yb) luminescence from RE-doped nc-Si was observed at room-temperature, nc-Si has been recognized efficient material for RE-doping. Even though the dominant excitation process of BE-doped nc-Si is via excitons of nc-Si similar to RE excitation process of bulk-Si, the inhomogeneous structure of nc-Si allows complex couplings and interaction between free/bound carriers and rare earth ions. Thus the identification and control of such interactions need to be clarified for further photonic application of rare-earth doped nc-Si. In this work, we report on investigation on such interactions in rare-earth doped silicon rich oxide (SRSO), which consists of nc-Si embedded in silica matrix. Rare earth doped SRSO films were excited with electron beam exposure by electron beam exposure, enhanced chemical vapor deposition with co-sputtering of rare-earth target, and were rapid-thermal annealed for nc-Si precipitation. The dependence of rare earth luminescence intensity and luminescence lifetimes on pump power and background illumination indicated that all possible de-excitation processes, which can reduce excitation and luminescence efficiency of rare-earth ions, are completely suppressed. Investigation of dynamics of energy transfer of rare-earth doped nc-Si indicate that the excitons are coupled strongly to rare earth ions rather than to nc-Si, suggesting that such efficient rare-earth ions are located in nc-Si/Si interface or silica matrix. However, these exciton/rare-earth couplings are not so strong enough to activate the backtransfer process of excited rare-earth ions. Due to such exciton-mediated excitation process, two or more different species of rare-earth ions can be simultaneously excited using single pump source, acquiring broad infrared luminescence.
The dot size effect of amorphous silicon quantum dot on 1.54-μm Er luminescence. Nae-Man Park', Tae-Yoob Kim', Gun Yong Sung', Baek-Hyun Kim², Seong-Ju Park², Kwan Sik Cho³, Jung H Shin³, Jung-Kun Lee³ and Michael Nastasi¹; ¹Applied Device Research, Basic Research Lab., ETRI, Daegu, South Korea; ²Materials Science and Engineering, KIST, Kwangju, South Korea; ³Physics, KAIST, Daegu, South Korea; ⁴Materials Science & Technology Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

Er-doped silicon nanocrystals, showing efficient light-emission attracts greatest interest because of its promising future in the development of light-emitting diodes and lasers operating at the wavelength 1.54 μm, which falls at the absorption minimum of optical fibers. The amorphous Si quantum dot (a-Si QD) has stimulated interest in the control of dot size in a small dimension compared to nanocrystals and theoretical calculation also showed the efficient radiative property. In a recent report, the density effect of a very small a-Si QD on Er luminescence in Si-rich SiO₂ was investigated, where a high density of a-Si clusters enhanced PL efficiency compared to Si nanocrystals. In this study, we will present the effect of the size of a-Si QDs on Er luminescence. a-Si QDs embedded in silicon nitride film were grown on Si substrate by plasma enhanced chemical vapor deposition with various dot size. The samples were classified into three groups, referred to as large dot, medium dot, and small dot samples in accordance with dot sizes of 2.5, 1.8, and 1.4 nm. Subsequently, Er ions were implanted with a dose of 1x10¹⁴/cm² into nitride films containing a-Si QDs to overlap the profiles of Er ions and a-Si QDs. Finally, the samples were annealed at 500 °C for 0.5 h in order to reduce the residual defects led by the implantation process. Photoluminescence measurements were performed by 488 nm Ar and 325 nm He-Cd lasers. The critical dot size, needed to take advantage of the positive effect on Er luminescence, was considered to be about 2.6 nm, below which a small dot is very effective in the efficient luminescence of Er.

Ultra-low-diameter erbium-implanted toroidal microlaser on silicon. Albert Polman¹,², B.K. Min¹, J. Kalkman², T.J. Kippenberg¹ and K.J. Vahala¹; ¹California Institute of Technology, Pasadena, California; ²FOM-Institute AMOLF, Amsterdam, Netherlands.

We present the first microlaser on silicon operating at 1.5 μm that is completely made using standard CMOS silicon fabrication technology. The 40-μm diameter toroidal microresonator is made using a combination of erbium ion implantation, photolithography, wet and dry etching, and laser annealing, using a thermally grown SiO₂ film on a Si substrate as the starting material. Light is coupled into the laser cavity using a tapered optical fiber that is evanescently coupled to a resonator mode. Carefully tuning the fiber-resonator distance, different modes of operation could be probed. Laser cavity quality factors as high as 4x10⁹ are achieved, corresponding to a modal propagation loss as low as 0.007 dB/cm. Single-mode lasing is observed at a threshold below the lowest reported threshold by a factor of 4 than any other erbium laser fabricated to date. The lowest lasing threshold is observed at low Er concentration (0.1 at.%), while the highest quantum efficiency is observed at high Er doping levels (5 at.%). The experimentally found threshold, optimum Er concentration and quantum efficiency are in good agreement with a model that describes the erbium population dynamics and pump and signal mode propagation in the microresonator. At high doping levels bright green emission is observed, that is attributed to a combination of cooperative upconversion and excited state absorption in Er³⁺.

The enhancement of the Er³⁺ ions photoluminescence (PL) emission at 1.54 μm in a Si and Er co-implanted alumino-silicate glass is investigated in details. Post-implantation annealing has been performed to recover the damage induced by the implantation process and to promote Si aggregation. It is shown that 1h treatment in N₂ atmosphere is not sufficient to induce Si precipitation for the investigated temperatures, up to 500 °C. Nevertheless, the most intense Er³⁺ PL emission at 1.54 μm is achieved at 400 °C. Such emission has been investigated by pumping in and out of resonance. The results suggest that good energy transfer mediators should be Si aggregates and not only crystalline clusters. The effective erbium absorption cross section of Er³⁺ ions has been determined for Si nano-aggregates. A sample with a high Er concentration, yielding a 2x10⁻¹⁸ cm², many orders of magnitude higher than the direct absorption cross section of Er³⁺ ions: about 1x10⁻¹⁸ cm² in this glass. The structural and optical properties of this material are discussed and compared to those found for a standard silica substrate.
that produces optical centers, which emit light in extremely narrow spectral lines. The presence of silicon spacer structures in the structure facilitates a periodic generation of excitons. Differences were observed in the power dependence and absorption cross-section of the 1.5 micron Erbium photoluminescence when excitation of the Erbium either via resonantly generated excitons or via electron-hole generation, in what allows us to identify distinct excitation pathways leading to the excitation of Erbium in these systems. These experiments, together with mid-infrared experiments performed with a free-electron-laser deliver information on the structure of the center involved in producing the sharp spectral lines observed.

SESSION L2: Photonic Bandgap Crystals
Chair: Albert Polman
Tuesday Afternoon, April 13, 2004
Room 2008 (Moscone West)

1:30 PM L2.1

Recent efforts toward the smallest possible lasers in the form of the 2-D triangular lattice monopole mode single-cell photonic crystal laser and the high-Q square lattice single-cell photonic crystal laser are summarized. Both forms of photonic crystal lasers operate in the infrared non-linear optical regime that has a mode that can flow through the central post and its experimental demonstration will also be summarized. These ultra-small high-Q lasers can be a potential candidate for the efficient on-demand single photon source for quantum communication, which can be coupled efficiently into single-mode fiber. Very low-threshold lasing action from such small-area G-point band edge lasers and enhanced light extraction from photonic crystal light emitting devices are also discussed.

2:00 PM L2.2

Photonic crystals are typically highly symmetric structures with submicron minimum feature sizes when active in the near-infrared. By the careful arrangement of regions of high and low index it is possible to create structures with optical properties far different from those of the host material. Three dimensional photonic crystals are difficult to fabricate, especially relative to simpler two dimensional structures. As a result, the bulk of the work in this area has been on two dimensional structures. However, three dimensional photonic crystals, when designed and fabricated correctly, offer the advantage of possessing a photonic bandgap in all directions. This property is critical for certain applications and motivates much of the work in this area. There have been, and continue to be, many approaches to the problem of how to fabricate three dimensional photonic crystals. In our work we have demonstrated that structures active in the infrared can be fabricated using modifications of standard silicon processing techniques. Typically, photonic crystals have been fabricated in either dielectric or semiconductor materials systems. Metals are not usually considered due to their finite and complex absorption coefficients. However, since metals have a finite absorption coefficient they also possess a finite emissivity. We have found that the novel combination of a full three dimensional photonic bandgap and a finite metallic emissivity gives rise to highly modified thermal emission behavior. In particular, we have experimentally demonstrated that tungsten photonic crystals with full 3-D bandgaps can exhibit thermalizers that are currently increasing. In all pass reflection filters such as Gires-Tourois interferometers, proper signal processing is needed in signal extraction. Also, cascading multiple devices to obtain a high capacity delay line remains a challenge in this reflection mode. Here, we introduce a new type of optical all-pass transmission filter based upon guided resonance in photonic crystal slabs, which consists of a periodic lattice of air holes introduced into the dielectric slab. We use two degenerate resonances with opposite symmetry to cancel out the effect of the strong variation in the transmission intensity. This accidental degeneracy of the even and odd mode generates a large resonant group delay while maintaining complete transmission both on and off resonant frequencies. First we demonstrate a coupled photonic crystal slab configuration as a physical realization of this all pass characteristics. Furthermore, we extend this work to obtain all pass transmission in the spectral form by generating two guided resonances in a single layer of photonic crystals. In this configuration, there are significant structural advantages over the existing optical all pass filters, in addition to the operational advantages. We note that this compact device can serve as a building block for high capacity optical delay lines when we consider multiple stage cascading, and therefore expect these novel devices to play important roles in optical communication systems.

1:30 PM L2.3
Tunable infrared emitters and sensors from periodic lattices: theoretical limitations. Bruno Bislang1, Chiangcheng Ding2, Yiping Yu1, Ibha El-Kady4,5, Irisa Paschotta1, Edward Johnson2, Martin Pralle3, James Daly3, Anton Greenwald3, Brian Kinkeade1, Michael McNeal5 and Nicholas Moeller1; 1Dept. of Physics, Microelectronics Res Ctr and Ames Lab, Iowa State University, Ames, Iowa; 2Sandia National Labs, Albuquerque, New Mexico; 3Ion-Optics Inc.; Wallingford, Connecticut.

Tunable infrared emissions have been fabricated from metal-coated silicon wafers etched with a periodic array of holes. Such periodic structures thermally emit in a controllable narrow band at infrared wavelengths [1] and are very promising for sensor applications. We develop the theory of the electromagnetic behavior of such metal photonic lattices. Transfer-matrix calculations describe the sharp reflectivity dip from such lattices. The primary reflectivity feature is modeled well by the surface plasmon modes at the top surface. The effect of different filling ratios and lattice symmetries has been calculated to develop optimal structures. The thermal emission from these lattices is enhanced by the presence of the two-dimensional photonic crystal. We model the emission of these metal-covered photonic crystals by calculations of the surface plasmon bands at both the metal-air and metal-semiconductor interfaces. We calculate the density of states of the plasmon modes and the coupling of the plasmons at the interfaces. Calculations of the classical plasmon-mediated emission from these structures will be presented and compared with measurements. Partially supported by the NSF.[1] M. Pralle et al, Appl. Phys. Lett. 81, 4685 (2002)

2:15 PM L2.4
Band-gap and localized states properties of CMOS-compatible complex photonic structures. Luca Dal Negro2, Michael Stolfi1,2, Yash Yi1, John LeBlanc2, John Haavisto2, Jurgen Michel2 and Lionel Kimerling1; 1MIT, Cambridge, Massachusetts; 2CHARLES STARK DRAPER Laboratory, Cambridge, Massachusetts.

In the recent years, the interest in one dimensional complex photonic structures, i.e. structures with non-periodic refractive index profile, has widely increased after the fabrication of the first photonic bandgap (1D) Fibonacci optical quasicrystals by Merlin et al [1]. Recently, the experimental demonstration of strongly suppressed light transport at the quasi-localized band-edge states of 1D Fibonacci quasicrystals [2] suggests the use of quasi-disorder-induced localized states in quasicrystals as an alternative approach to achieve strong dispersion and gain enhancement effects inside active complex photonic materials. However, no systematic studies of both the band-gap properties and the localized states character of 1D complex photonic structures has been realized so far, and the feasibility of quasicrystal-based devices for CMOS-compatible microphotonic is still under debate. To investigate the potentialities of this stimulating approach, Periodic, Quasiperiodic, Aperiodic and Random Si/SiO2 photonic structures have been fabricated by RF-magnetron sputtering deposition of 32 layers alternating two building-block layers A (SiO2) and B (Si) of constant thickness (satisfying the A/4 Bragg condition at 1.55 μm) according to different well known non-periodic sequences. Thue-Morse quasicrystals, Fibonacci quasicrystals, Randomly Disordered and Periodic Photonic Crystal (PCs) have been grown under the same processing conditions in order to perform the first comparative study of the omnidirectional band-gap properties under different regimes of layers organization. Good quality Thue-Morse (TM) a-periodic structures have been experimentally fabricated and the presence of wide omnidirectional band-gaps have been demonstrated in these systems. The evolution of the band-gap states properties with time through variable-angle FTIR analyses. 1) R. Merlin, K. Bajenaa, R. Clark, F. Y. Jung, P.K. Bhattacharya, Phys. Rev. Lett., 55, 1768, (1985) 2) L. Dal Negro, C.J.Oton, Z. Galurao, L. Pravesi, P. Johnson, A. Lagedijk, M. Bigluni, L. Colocci, D. Wiersma, Phys. Rev. Lett., 96, 5, 223
Preparation of opal-based PBG crystals to develop multiple stop bands. Yen-Tai Chen and Leo Chau-Kuang Liau; Chemical Engineering, Yuan Ze University, Chung-Li, Taiwan.

Preparation of opal-based PBG crystals to develop multiple stop bands Yen-Tai Chen and Leo Chau-Kuang Liau Department of Chemical Engineering, Yuan Ze University, 135 Yuan-Tung Rd., Chung-Li, Taiwan. In our work, we used the low-cost sol-gel method to fabricate PBG crystals. Linearly polarized electromagnetic waves could be guided and be trapped in the nanostructure and would lead to the stop bands. Yen-Tai Chen and Leo Chau-Kuang Liau; Chemical Engineering, Yuan Ze University, 135 Yuan-Tung Rd., Chung-Li, Taiwan.

Photonic crystals offer opportunities for miniaturizing and integrating a variety of optical devices. 3D photonic crystals have the critical advantage over 2D structures in that they eliminate the otherwise inevitable radiation losses. The layers in our 3D photonic crystal are an alternating stack of the two characteristic types of 2D (or slab) photonic crystals: dielectric rods in air and air holes in dielectric. Compared to the "woodpile" structure that had been fabricated previously, our structure has the advantages of a larger band gap (up to 25% of the mid-gap frequency versus 17% for the "woodpile" structure) and a variety of designs and analysis done in 2D structures. A seven-layer structure of such a crystal was fabricated at near-infrared via a layer-by-layer approach. We employed electron-beam lithography to align and define the pattern, reactive-ion etching to transfer the pattern, and spin-on-dielectrics to planarize the surface. Four such cycles were sufficient to complete the fabrication. The existence of a 3D photonic band gap was verified by FTIR microscopy at various incident angles. "Dielectric" point defect structures were introduced with a random distribution, and the associated defect states were observed with an FTIR reflection measurement. This is a critical first step toward the realization of devices based on 3D photonic crystals. Future directions in fabrication will also be discussed.

We have prepared 2D arrays of hexagonally arranged, mono-disperse silver, gold, copper and nickel nanowires embedded in an alumina template. The degree of template filling is nearly 100% using an improved electrochemical deposition technique. The interpore distance is 110 nm and the pore diameter can be adjusted between 35 and 80 nm. Optical transmission measurements in the direction parallel to the long axis of the metal nanowires show a plasmon-enhanced absorption for Ag, Cu and Au nanowires. This is also confirmed by scanning near-field optical measurements of the nanowire arrays embedded in the porous alumina matrix. We have then studied surface-enhanced Raman scattering (SERS) to gain additional insight in the effect of the orientation of the wire towards the electromagnetic field. SERS measurements have been carried out on silver wires in the matrix or free standing wires as well as in-situ by selectively dissolving the alumina matrix while monitoring the SERS signal. It turns out that the SERS signal and therefore the plasmon resonance strongly depends on the orientation of the wires. During these experiments, mainly the active surface area increases, thus the SERS signal augments almost linearly. The orientation of the wires hardly changes. For the free standing wires, the SERS signal is sometimes
significantly reduced since the wires are now oriented with an angle to the propagation axis of the electric field as confirmed by scanning electron microscopy. However, under certain conditions the coupling of the neighboring wires are forming sheaves as observed by SEM. For this configuration, we observe an increased SERS signal as theoretically predicted at the sheave connection points. Interestingly, we observe even for typical reactive metal like Au, a resonance-based SERS signal in the sheave configuration supporting the model of huge field enhancement at the connection points.

9:30 AM L3.3
Advanacement in Fabricating Layer-by-Layer Photonic Band Gap Crystals by Modified Microtransfer Molding Techniques. Henry Kang1,2, Kristen Constant1,2, Hans Biswas1,2, Chang-Hwan Kim1,2, Yinglong Guo1,2, Wai Lam1,2, and Kai-Ming Ho1,2,3. 1Materials Science and Engineering, Iowa State University, Ames, Iowa; 2Physics and Astronomy, Iowa State University, Ames, Iowa; 3Materials Laboratory DOE, Ames, Iowa.

Here we update the recent progress of fabricating three-dimensional layer-by-layer (LBL) photonic band gap (PBG) crystals operating in the infrared range. Multilayers polymeric and titania structures have been built with various modified microtransfer molding techniques based on the use of PMDS stamps. These techniques provide relatively rapid and easy fabrication processes at low costs. As the LBL ceramic structures usually suffer significant shrinkage after drying and sintering due to the nature of the precursor materials used, we also investigate different ways to improve the shrinkage while maintaining reasonably dense sintered structures. It is found that the shrinkage can be reduced by: 1) using hybrid sol-gel precursors or high volatile/low volatile colloid ceramic slurries as starting materials; or 2) varying sol-gel processing parameters such as drying and aging conditions. Optical properties of the PBG crystals are also studied and compared with the theoretical calculations.

9:45 AM L3.4
Modified spontaneous emission and long-range pulse propagation in plasmonic waveguides. J. Kalman1, J.A. Dionne1,2, A. Swardrick3, C. Strohmayer4, H.A. Atwater5 and Albert Polman,6,7; 1FOM-Institute AMOLF, Amsterdam, Netherlands; 2California Institute of Technology, Pasadena, California.

Surface plasmons are electromagnetic modes that propagate at the interface between a metal and a dielectric. Due to momentum mismatch, surface plasmons do not couple to plane-wave photons of the same frequency. We demonstrate two combined methods to overcome this mismatch problem, enabling the integration of optical and plasmon phenomena in microphotonics integrated circuits. First, we consider the coupling between optically excited erbium atoms and a nearby silver film. Experimental, theoretical, and finite-difference time-domain studies indicate that the erbium ions decay by the generation of a surface plasmon, which then propagates along the interface between the silver film and a silica substrate. The near-field radiation damping effect of imperfections (such as side wall and plasmonic modes. To test these calculations, and to study the probe ions placed in the plasmonic mode.

Assuming a Bruggeman model for the composite media we were able to convert a commercially available NSOM into a variable incidence angle PSTM. The PSTM is comprised of three component systems: an excitation microscope, a collection microscope, and a scanning stage connecting the two. The novel use of a Total Internal Reflection Fluorescence (TIRF) objective in the excitation microscope provides for SPP excitation via a variable range of illumination incidence angles. Meanwhile, the collection microscope detects light that is scattered from the evanescent fields of the SPPs by an apertured cantilever probe. Initial results on metal thin films have demonstrated the validity of this method, and this model has been used in calculating the momentum and field coupling for SPPs to verify the attained images. It will be shown how the optical properties of the metal film can be extracted from the PSTM measurement, and these results will be correlated by structural properties obtained via AFM, XRD, and TEM characterization.

10:30 AM L4.1
Low loss silica waveguides containing Si nanocrystals. Cristina Garcia1,2, Paolo Pellegrino1,2, Blas Garrido1,2, Jose Antonio Moreno1,2, Joan Ramon Morante3,1, Mirko Melchiorri4,1, Nicola Daldosso4,1, Lorenzo Pavesi5,1, Gerard Sanchez6,1, John Carney7,1, Caroline Bonafos8,1 and Alain Claverie4,1.

We report a study on the optical and structural properties of rib-loaded waveguides working in the 600-900 nm spectral range. A Si nanocrystal-rich SiO2, with Si contents ranging from 10 to 20%, formed the active region of the waveguide. Starting materials were fused silica wafers and 2 microns-thick SiO2 thermally grown onto Si substrate. Si nanocrystals were precipitated by annealing at 1100 °C degrees after quadruple Si ion implantation high-dose in a flat profile. The complete phase-separation and formation of Si nanocrystals were monitored by means of optical tools, such as Raman, optical absorption and photoluminescence. Grain size distribution was obtained by electron microscopy (HRTEM). The actual Si excess content was obtained by X-ray photoelectron spectroscopy.

The rib-loaded structure of the waveguides was fabricated by photolithographic and reactive-ion-etching processes, with patterned rib widths ranging from 1 to 4 microns. Extremely efficient propagation of light was observed when coupling a probe signal at 780 nm into the waveguide. M-lines spectroscopy measurements provided a direct measurement of the refractive index and thickness of the active layers versus Si ion implantation fluences. Assuming a Bruggeman model for the composite media we were able to obtain the dielectric function of the Si nanocrystals. The attenuation losses inside the waveguides were found to be 4.8 dB/cm at the experiment wavelength. The possible contributions to such losses have been studied and will be discussed in detail.

10:45 AM L4.2
In-situ Control of Nitrogen Content and the Effect on PL Properties of SiNX Films Grown by Ion Beam Sputter Deposition. Kyungjoong Kim1, Dae Won Moon2, Moon-Seung Yang2, JHong Je3 and Jung Hoon Shin2,3; 1Nano Surface Group, Korea Research Institute of Standards and Science, Daejeon, South Korea; 2Physics, Korea Advanced Institute of Science and Technology, Daejeon, South Korea.

The control of size and density of Si nanocrystal(nc-Si) is an...
important factor to determine the energy and intensity of the photoluminescence. PL properties of SiNx films were studied as a function of nitrogen content. SiNx films were grown by ion beam assisted deposition (IBSD) where nitrogen ions were used as sputtering ions. The thin films grown at the deposition chamber could be transferred to a surface analysis chamber without exposing to the air. Therefore, the nitrogen content was determined by secondary ion mass spectroscopy (SIMS) and x-ray photoelectron spectroscopy (XPS). The relative sensitivity factor (RSF) of Si 2p and N 1s peaks were calculated by comparison of the in-situ XPS analysis and RBFs of a preliminarily grown SiNx film. After thermal annealing at temperatures higher than 1100 °C, the existence of Si nanostuctures, which was well correlated with strong visible luminescence and a blue-shift due to quantum confinement effect with increased nitrogen contents. SiNx films showed maximum PL intensity near x=1.1 with the PL wavelength near 570 nm. The visible photoluminescence at the range of 500-660 nm imply the possibility that SiNx thin film is promising material for full-color light-emitting device.

11:00 AM LA4.3
Optical study of amorphous silicon quantum dots embedded in silica microspheres. Tae-Yulle Kim1, Nae-Man Park1, Sung Kim1, Yung-Jai Cho2 and Gun Yong Sung1. 

Although bulk silicon has the indirect transition property, silicon nanostructures that have a quantum confinement effect provide a breakthrough to optoelectronic applications. Since the discovery of visible photoluminescence from porous silicon at room temperature, several research groups have investigated the optical properties of silicon quantum dots. In this work, a silicon nitride film was used as a matrix material to embed a-Si quantum dots (QDs). A silicon nitride film is expected to be better than silicon oxide in optical device applications because carriers can be easily transported to the a-Si QDs in the silicon nitride matrix due to the lower tunneling barriers. The aim of the study is to show that refractive index measurement is a powerful method suitable for investigating the size information of a-Si QDs. Samples were prepared by plasma enhanced chemical vapor deposition, where argon-diluted 10% SiH4 and N2 were used as reactant gas sources. Photoluminescence and optical absorption energy measurement of a-Si QDs with various sizes revealed that the tuning of the photoluminescence emission from 440 to 700 nm was possible by controlling the size of the a-Si QD. Also, when the photoluminescence peak was shifted toward long wavelength, the refractive index value increased from 1.62 to 2.13. The silicon nitride composition was measured by XPS and FTIR bonding spectra. Significant changes of refractive indices and optical band gap provide the size information of a-Si QDs.

11:15 AM LA4.4
Spectroscopic Ellipsometric Study of SiO2/nanocrystalline-Si Superlattices. Hoon Lee1, Kang-Joo Lee2, Seung Hee Hong1, Suk-Ho Choi1, Kyung Jung Kim2 and Dae Won Moon2. 

Using variable-angle spectroscopic ellipsometry, we measured the pseudo-dielectric functions of as-deposited and annealed SiO2/SiOx superlattices (SLs). The SiO2 (20nm)/SiOx (20nm) SLs have been prepared under various deposition temperature by ion beam sputtering. The annealing at temperatures higher than 1100 °C leads to the formation of Si nanocrystals (nc-Si) in the SiO2 layer of SLs. The high-resolution transmission electron microscopy images clearly demonstrate the existence of nc-Si. We assumed a Tauc-Lorentzian lineshape for the dielectric function of nc-Si, and used effective medium approximation for SiO2/nc-Si SLs as a mixture of nc-Si and SiO2. We successfully determined the dielectric function of nc-Si and its volume fraction. The estimated volume fraction of nc-Si were compared with the expected values, which were estimated from the stoichiometry of SiOx in as-deposited SiO2/SiOx SLs. We found that the volume fraction of nc-Si decreased with increasing x. At the same x, the volume fraction of nc-Si decreased with increasing deposition temperature. This phenomenon was attributed to different amount of SiOx ions in as-deposited SiO2/SiOx SLs, affecting to x-ray photoelectron spectroscopy measurements. The fitted band gap threshold energy of nc-Si increased with increasing x. This can be attributed to the increase of quantum confinement effect due to the decreasing average diameter of nc-Si. ** This work was supported in part by KRF-2003-005-C00001.

11:30 AM LA4.5
Optical Studies of Nucleation and Growth of CdTe Nanoparticles in Glass Microspheres with CO2-Laser Excitation. Anuranga Tewary1, April S Montoya Varekla2, Subhash R Risbud3 and Mark L Brongersma4. 

Glass microspheres with embedded semiconductor quantum dots are intriguing experimental systems that present the opportunity to observe a combination of photonic and electronic confinement in three dimensions. We present in-situ studies of nucleation and growth of CdTe nanoparticles in borosilicate glass microspheres using CO2 laser annealing. We found that nucleation and growth in microspheres is studied as a function of laser power and irradiation time and is compared with nanoparticle formation in bulk glass samples. Whereas traditional furnace heat treatments require times on the order of hours for nanoparticles to grow, nanoparticle growth can be induced with a CO2 laser in a few minutes with laser powers as low as 1W/mm2. The differences in the nucleation process between these two cases will be discussed. Results from optical studies, including photoluminescence (PL) measurements, absorption measurements with a tunable laser, and wavelength dependent reflection measurements, in microspheres and in bulk samples are used to obtain information on nanocrystal size distribution. These optical techniques are compared with structural studies on the nanoparticles using transmission electron microscopy (TEM). Preliminary scanning electron microscopy (SEM) and atomic force microscopy (AFM) studies of the nanoparticle morphology indicate that the surface roughness is less than 5 nm. The smooth surface characteristics allow for the possibility of the CdTe-embedded microspheres to have high optical quality factors (Q). The optimization of the size distribution of the nanocrystals, control of the surface roughness, and the knowledge gained from the PL measurements may be of importance to the development of a microcrystal laser.
which the detected intensity of photoluminescence is modulated by the charge stored on the silicon nanocrystal array embedded in the device. The hot electron photoluminescence from nanocrystals in a quenching process that occurs when photoexcited excitons recombine in the presence of a free charge carrier. This same optoelectronic response phenomenon can be used to construct an optical modulator. We will present results for an optoelectronic device in which the photoluminescence of an array of nanocrystals within a capacitor structure is electrically modulated. The emitted signal is inhibited by programming the nanocrystal array with quenching charge carriers and restored to the removal of the stored charge. We have fabricated such devices with nanocrystal arrays made by high temperature annealing of silicon implanted into a 15nm thermally grown oxide in which the charge state of the nanocrystals is controlled electrically via a 50nm semi-transparent polysilicon gate contact. Low frequency operation of these optical modulators shows that photoluminescence can be suppressed by 50 percent with the application of a 3V bias and by 80 percent for 9V applied potentials. These devices exhibit a hysteretic response to cycling at negative biases, but the steady state suppression of photoluminescence is roughly symmetrical under positive and negative applied biases. We believe that both holes and electrons act as quenching free charge carriers and that appropriate bipolar cycling of the devices may allow for high frequency operation. The useful modulation bandwidth of such devices will be limited by the slowest relevant process occurring. Optical transitions in silicon nanocrystals remain quasi-forbidden as in bulk silicon due to the indirect band gap of the material, resulting in microsecond radiative recombination lifetimes. The time scales for storing and removing charge from the nanocrystal array via Fowler-Nordheim tunneling are ideally suited for the range of time scales of the slowest relevant process occurring. We will address the performance of our modulator structures with regard to these fundamental time scales, as well as the simple RC electrical time scales imposed by our device geometries.

2:00 PM L5.2 Electroabsorption Properties of GaInNAs(Sb) Quantum Wells at 1300-1600nm. Vincenzo Lodi, Homan B Yuen, Seth R Bank, Mark A Wistey and James S Harris; Solid State and Photonics Laboratory, Stanford University, Stanford, California.

Electroabsorption modulators operating in the telecommunications wavelength range (1300-1600nm) have enabled optical fiber communications, but also for use in optical interconnects to replace the electrical lines limiting the future speed of microelectronics. The novel dilute nitride III-V alloys, GaInNAs and GaInNASb, are promising materials systems for realizing quantum well (QW) devices on GaAs that operate in this wavelength range. Electroabsorption spectra of GaInNAs and GaInNASb QWs with GaNAs barriers grown in p-n diode structures on GaAs were measured using the photocurrent technique at various temperatures from 25 to 300 K, with applied electric fields up to 200 kV/cm. The spectra demonstrated very nice quantum confined Stark effect (QCSE) behavior, with sharp exciton peaks with FWHM less than 25 meV at 295 K. The GaInNAs/GaN QW showed characteristics suitable for optical modulation operating at 1300 nm, while the GaInNASb/GaN QWs operated around 1550 nm. Electroreflectance and photoluminescence spectroscopies were used to further study the surface states and the apparent band edge that correspond to different N nearest neighbor configurations. Rapid thermal annealing (RTA) shifts the distribution of configurations with larger band gap. The anneal-induced blue shift of the operating wavelength of the material has homogenized. The exciton lineshape at 295 K was found to be Gaussian, rather than Lorentzian, indicating a strong exciton-photon interaction and/or a high density of lattice defects in the material, consistent with theoretical expectations. Samples were grown by molecular beam epitaxy (MBE), with atomic N supplied by a radio-frequency nitrogen plasma and Sb supplied by a cracked solid source. Growth at 480-485 °C was followed by RTA at 720-800 °C for up to 3 min. Each consisted of two p-i-n diodes with a 0.5 µm thick intrinsic region containing the QWs. GaNAs active regions included up to nine QWs (8 nm thick) with 20 nm barriers; GaInNASb active regions included up to 3 QWs. The GaNAs active region was 1.7% N and 20% In, while the GaInNASb was 2.5% N, 2.7% Sb, and 40% In. The barriers contained 2.0% and 2.7% N, respectively.

2:15 PM L5.3 Hybrid Integrated Microphotonics and It's Applications. Taeil Kim and Sungtae Jung; Samsung, Suwon, South Korea.

Hybrid Integration of passive and active optical devices is emerging as a key technology of optical component, because it can increase functionality and reliability of optical device module, lowers the packaging cost and enables the automation in manufacturing. Many applications of hybrid integrated microphotonic devices are low cost optical modules for FTTH system and metro access network. There are various technical issues in hybrid integration modules. It requires coupling of active optical devices to a passive waveguide. The embedded functional block converts a laser diode, coupler, switch and WDM filter are essential elements to improve optical performance of integrated devices. The packaging solution for low cost and small size is also required. We have developed SSC-LD(Spot Size Converted Laser Diode) and RMP PD(Reflection Mirror Facet Photo Diode) for the improved coupling to planar waveguide. Simple and cost-effective silica PLC platform with terraced-silica, PLC grating and coupler have been developed. Using these technologies, we have demonstrated the bi-directional, triplexer and ECL(External Cavity Laser). In this paper, we will present the detailed results of our recent R&D activities for hybrid integrated microphotonic devices.


The growth of the microelectronics industry in the past 40 years has been governed by the ability to scale down device size, to increase performance and functionality, and to reduce cost. The emerging field of microphotonics has the potential of becoming analogous to its electronic counterpart, microelectronics. However, there have been many technical challenges that have been roadblocks in wide adoption of microphotonics, including poor input/output coupling efficiency of microphotonic circuits, high transmission losses, and inaccurate, manual testing/measurements. We report for the first time, revolutionary advances that have been made in the field of microphotonics that make it truly a scalable platform. We report over 80% improvement in coupling efficiency into a modal area change by a factor of 100, with our mode converter technology, thus solving the input/output coupling problem of high index contrast waveguides, typically used in microphotonic. This coupling solution is used in a simple yet efficient coupling of microphotonic circuit to nanophotonic waveguide, as well as to other photonic chips. We report a method of making extremely accurate measurements of high index contrast waveguide devices with our mode converters, thus solving the measurement challenges of photonic chips. We also report a method of using on-wafer probing of planar optical devices, similar to automated wafer probing in electronics industry. We demonstrate the repeatability of our on-wafer probing technique within 0.11 (1B standard deviation for 3600 repeated measurements). This method shall dramatically reduce the cost of test and measurement of microphotonic devices. With these innovations, microphotonic has demonstrated that it is the scalable platform for photonic and opto-electronic applications that will continue to grow for the coming years.

3:45 PM L5.5 Subwavelength Optics with Materials and Material Structures Manufactured in Deep Submicron CMOS Technology. Peter Bert Catryse,1, Mark Brongersma1 and Shanhui Fan1; 1Department of Electrical Engineering, Stanford University, Stanford, California, 2Department of Material Science and Engineering, Stanford University, Stanford, California.

The materials used in CMOS integrated circuit technologies are chosen to optimize electronic performance. Upon closer examination, these materials are also suitable for manipulating and detecting optical signals at short optical wavelengths. Research into the potential for the integration of photonic functionality with CMOS technology at the micrometer scale. Following the trend of increased integration in the field of CMOS image sensors, we integrated color-filtering capabilities inside image sensor pixels. Specifically, we demonstrated wavelength selectivity of subwavelength patterned metal layers in a 180-nm CMOS technology. Here, we show that the materials and material structures available in more advanced deep submicron CMOS technologies can be used for photonic and plasmonic devices and circuits. In addition to scaling, new materials have become available, i.e., copper replaces aluminum in interconnects and low-k dielectrics serve as insulators. Using finite-difference time-domain (FDTD) simulations, we argue that while these trends are motivated by improved electronic performance, they also benefit photonic and plasmonic performance. To experimentally verify predictions and to evaluate the use of deep submicron CMOS technology as a fabrication platform for integrated nano-photonic and nano-plasmonic device-under-test, we fabricated test structures that are capable of performing plasmonic and plasmonic performance. To experimentally verify predictions and to evaluate the use of deep submicron CMOS technology as a fabrication platform for integrated nano-photonic and nano-plasmonic device-under-test, we fabricated test structures that are capable of performing plasmonic and plasmonic performance. To experimentally verify predictions and to evaluate the use of deep submicron CMOS technology as a fabrication platform for integrated nano-photonic and nano-plasmonic device-under-test, we fabricated test structures that are capable of performing plasmonic and plasmonic performance. To experimentally verify predictions and to evaluate the use of deep submicron CMOS technology as a fabrication platform for integrated nano-photonic and nano-plasmonic device-under-test, we fabricated test structures that are capable of performing plasmonic and plasmonic performance.
resonant-enhancement (e.g., C-type) shapes. The optimized design of nano-apertures, measuring 100-200 nm, benefits a wide variety of applications such as near-field scanning optical microscopy, high-density optical data storage, or multi-spectral imaging. In these applications, it is important to achieve high light throughput and localization in a small volume. We believe that our rapid prototyping approach, used in real-time wavefront control with time-domain FDTD simulations, provides a powerful platform for nano-aperture fabrication, characterization and optimization.

4:15 PM L5.6
Optoelectronic Simulation of the Klein Paradox Using Left Handed Materials. Durdu Gune" and David A. Meyer; 1Electrical & Computer Engineering, University of California, San Diego, La Jolla, California; 2Mathematics, University of California, San Diego, La Jolla, California.

We show that the Klein paradox for the Klein-Gordon equation of spin-zero particle manifests exactly the same kind of wave propagation and negative refraction phenomena which also exist in the scattering of transverse-magnetic polarized electromagnetic wave incident on a plasmonic left handed medium (LHM). Based on this peculiar nature of LHMs, it is possible to simulate the Klein paradox, using current microelectronic fabrication and optical integrated circuits technology. The system consists of three integrated blocks. The pre-processor mainly includes microcontrollers, microelectromechanical systems, transmitters, optical filters, and modulators. Having defined the problem in the pre-processor, it is simulated by the LHM processor inspired by the remarkable mathematical analogy with the problem to be computed. The output is displayed after the post-processing in the third processor. The pre-processor was modeled as a standard CMOS-based photodetectors, analog-to-digital converters, and logic circuits. Numerical results for the sample negative refractive indices of -1.3 and -2.1 are shown to be consistent with the pair distribution that would be observed in the Klein paradox with corresponding potential barriers of heights 11.04 μeV and 12.71 μeV, respectively. Real time controlling and processing of some related quantum processes involving controlled pair production rate and distribution, among others, could be achieved by this optoelectronic simulator designed using other, appropriate, transformations and approximations. Comparing the cost for a typical high energy physics experiment to that of optoelectronics, such processor would be priceless provided that the transformations are extended and/or shaped according to the need.

4:30 PM L5.7
Creation of left-handed materials using dielectric photonic crystals. Alexander Pokrovsky and Alexei L. Efros; Physics, University of Utah, Salt Lake City, Utah.

We show that a two-dimensional photonic crystal (PC) made from a non-magnetic dielectric is a left-handed material in the sense defined by Veselago. Namely, it has negative values of both the electric permittivity \( \varepsilon \) and the magnetic permeability \( \mu \) in some frequency range. This follows from a recently proven general theorem. The negative values of \( \varepsilon \) and \( \mu \) are found by a numerical simulation. Using these values we demonstrate the Veselago lens, a unique optical device predicted by Veselago. An approximate analytical theory is proposed to calculate the values of \( \varepsilon \) and \( \mu \) from the PC band structure. It gives the results that are close to those obtained by the numerical simulation. The theory explains how a non-zero magnetization arises in a non-magnetic PC.

4:45 PM L5.8
Optical and Nanomechanical characterization of an omnidirectional reflector encompassing the 850 nm wavelength. Manish Deepra, Christopher A. Schuh and Yoel Fink; Department of Materials Science & Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

A tin sulfide-silica multilayer system has been developed and characterized for optical as well as nano-mechanical properties. This multilayer system acts as a 1-D photonic band-gap omnidirectional reflector and exhibits omnidirectional reflectivity for a range of wavelengths which encompass the 850 nm wavelength. A refractive index contrast of 2.7146 is achieved with omnidirectional range spanning over 150nm. Instrumented nanoindentation procedures have been developed to assess Young's modulus and hardness for these very fine layers in order to confirm suitability for practical applications. The indentation procedure reveals that the mechanical properties are in line with expectations based on a rule-of-mixtures composite model. These reflectors have several applications which include mirrors for laser cavities and as waveguides for guiding high power laser light.


The U.S. Army has an interest in developing a multi-color spectrometer that is fast-adapting to different environments for improved situational awareness. This would improve the Army's capability to identify objects in various obscurants. A multi-color spectrometer would be able to provide an image at multiple wavelengths and thus reduce the effects of camouflage. An infrared focal plane array that is electronically controllable is promising for meeting these application requirements. Other potential defense applications that require spectrums in the infrared range include landmine detection and identification of chemical and biological agents. We report on the fabrication of quantum grid infrared photodetector (QGIP) arrays and demonstrate their feasibility for use as detector elements in a multi-channel long wavelength infrared spectrometer. The quantum well infrared photodetector (QWIP) structure used for the detector was designed to exhibit broadband absorption in the wavelength range of 6 um to 16 um. By fabricating QGIP devices with this innovative broadband QWIP material, scattering of light at an individual wavelength of interest within the range of 6 um to 16 um can be enhanced for narrow band absorption in each device. Arrays of QGIP devices with varying geometry, each tailored to respond to a discrete wavelength were fabricated. Details of the epi-growth, processing steps taken to fabricate required device features for narrowband absorption of the QGIP devices, and characterization methods will be discussed.


Photonic crystals, with their potential ability in controlling the propagation of light, have attracted a lot of research attentations lately. One of the most frequent approaches to fabricate such type of three-dimensional periodic nanostructures is to utilize self-assembly of monodisperse nanoparticles. However, in order to integrate photonic crystals into communication devices, it is desirable to fabricate photonic crystals in a planar fashion, which can work as or interconnect with functional optical components such as switches, mirrors, filters and waveguides. We have developed a fabrication procedure to synthesize photonic crystals in the lithographic defined microchannels, which enables easy integration with other optical components. This technique is based on the directed evaporation induced self-assembly of nanoparticles in the microchannels. Substrates with pre-patterned microchannels (30-100 μm wide) were dipped into solution of nanoparticles for several days. By controlling the evaporation rate, the meniscus contacting the microchannels will undergo evaporation-induced self-assembly. The capillary forces cause nanoparticles to crystallize within the microchannels forming photonic crystals in the microchannels. Two types of colloidal particles, polystyrene and silica, have been employed to fabricate colloidal photonic crystals in the microchannels. Both types of colloidal particles were found to form large-area well-ordered colloidal single crystals in the microchannels. The optical reflection spectra from the (111) surfaces of the colloidal crystals formed by various sizes of nanoparticles have been measured. And the measured reflection peaks agree with the photonic bandgap calculated by the plan wave expansion method.


There is an acute need for the development of high quality, robust, photonic circuitry to serve as an integrating medium for optical networks and to perform basic, on-chip functions such as signal conditioning and signal processing. Photonic crystal (PC) materials
Er-doped Silicon-Rich Silicon Oxide Microdisk Resonators. Joo Yeon Sung, Jung H. Shin, Yong-Seok Choi and Yong-Hee Lee; Dept. of Physics, KAIST, Daejeon, South Korea.

The need for compact integrated microphotonics calls for active optical components that can be integrated into planar optical circuits using standard processing techniques. For this reason, microdisk resonators are of much attention. Here, we report on the use of optical microdisk resonators as a versatile platform for on-chip photonic components. The microdisk resonators were fabricated using electron beam lithography, electron cyclotron resonance plasma enhanced chemical vapor deposition, and reactive ion etching. The microdisk resonators were characterized by optical measurements such as reflection spectra and transmission spectra. The microdisk resonators showed high quality factors and sharp resonance peaks, which are ideal for photonic components such as filters and add/drop multiplexers. In addition, the microdisk resonators were used as active components such as mode-lockers and optical amplifiers.
for C co-doped SRSO, strong green luminescence, visible to the naked eye under ambient conditions, can be obtained. These results indicate the possibility of display devices covering the entire visible range may be fabricated using various co-dopants for SRSO.

### L6.9

**Subnanometer Depth Resolution of Silicon Nanocrystal Precipitation in Implanted Thin (<15 nm) Oxide Films.**

Nick Chiang, Robert J Walters,8 Harry A Atwater,8 Robert Lindstedt8 and George I Bourianoff2; 1Applied Physics, California Institute of Technology, Pasadena, California; 2Intel Corporation, Portland, Oregon.

Silicon nanocrystal floating gate memories are promising candidates for CMOS compatible nonvolatile memory devices and have recently been explored as a CMOS compatible optoelectronic device technology. Of the many ways to grow silicon nanocrystals for integration into CMOS devices, perhaps the most accessible route is ion implantation of silicon followed by thermal annealing to precipitate nanocrystals from a super-saturated solid solution. Most previous fundamental investigations of nanocrystal synthesis by this growth technique have used relatively thick (100 nm) oxides grown on silicon wafers in which the peak of the implantation profile is more than one diffusion length from the substrate during the annealing process. For CMOS compatible device applications, it is necessary to synthesize nanocrystal arrays in much thinner oxide films where the precipitation dynamics are complex, since they are strongly affected by the proximity of the substrate that forms the device channel. We have grown silicon nanocrystals using ion implantation and annealing, within oxide layers as thin as 8 nm and analyzed the resulting depth distribution of nanocrystals using optical and photoluminescence spectroscopy and ellipsometry of samples thinned with a custom built computer-controlled combinatorial wet chemical etching apparatus. This technique enables accurate characterization of the depth distribution of the embedded silicon nanocrystal array at near Angstrom resolution. The results will be interpreted in the context of electrical characterization of program/erase performance of similarly fabricated silicon nanocrystal floating gate MOS capacitors and transistors.

### L6.10

**Visible Electroluminescence from Silicon-rich Silicon Oxide.**

Kwan Won Cho,4 Chul H. Shin4 and Seung Ju Park5; 1Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon, South Korea; 2Electronics and Telecommunications Research Institute, Daejeon, South Korea; 3Material Science and Engineering, Kwangju Institute of Science and Technology, Kwangju, South Korea.

Semiconductor electronics is strongly dominated by Si technology. However Si technology does not allow easy integration with optical component since Si is indirect bandgap material. It is reported that am-sized Si can emit visible light at room temperature due to quantum confinement effect. Recently the electrical and optical properties of C-doped oxide films have been reported. In this paper, we present the results of using silicon-rich silicon oxide, which consist of nanocrystal Si embedded inside an SiO2 matrix, and C-doped SRSO to obtain light emitting diodes in the visible range. Typical SRSO photoluminescence spectrum peaked at 800 nm from quantum confined excitons in the nc-Si was obtained after an annealing at 1100°C for 30 min. Many combinations of p-type, p+ type, n-type, and n-type Si substrates and top contact materials of Poly-Si, TiO, and NiO were investigated in fabricating SRSO LEDs. The best result was obtained using p-type substrate and NiO top contact. We find that the electroluminescence spectrum is blueshifted by about 150 nm compared to the photoluminescence spectrum. Interestingly, the electroluminescence was obtained in both forward and reverse biased cases, indicating that impact excitation is the main excitation mechanism of nc-Si. We also obtained blue-green photoluminescence form C-doped SRSO films after an anneal at 900°C. The result of using C-doped SRSO to obtain blue-green LED will also be discussed.

### L6.11

**RP-CVD grown Ge/Si (001) islands stacking for 1.3-1.6 μm photodetectors.**

Benjamin Van Dellef, Jean Francois Damiencourt1, Benoît Cluzeau2, Vincent Calvo2, Jean Marc Fedeli1 and Thierry Billon1; 1Cea-Leti, Grenoble, France; 2cea-DrFmc, Grenoble, France.

To face the future bottlenecks of metallic interconnects in integrated circuits, the optical way is of great interest but require that near-infrared optical components, i.e. light sources, modulators and photodetectors, can be manufactured using a technology compatible with the silicon industry. This study focuses on modulation and photodetection in the 1.3-1.6 μm range with the use of devices based on Ge islands. Ge is used as selective material due to its lower threshold voltage which is lower than silicon and because it is already used in IC technology. Ge/Si layers were deposited in a 200 mm industrial cluster tool equipped with reduced pressure chemical vapour deposition chambers. In a first time, we report the influence of main deposition process parameters on single Ge islands layers morphology (islands size, shape and surface density). At 650 and 700°C, kinetics study shows the Stranski-Kranatov growth steps, i.e. 2D growth followed by 3D growth; pyramids are first initiated and evolve into spheres which further plastically relax to form big multifaceted domes. Secondly, photoluminescence analyses are correlated with layers morphology (dependence of photoluminescence spectra on islands size and surface density). Optical properties of layers deposited at 650°C are better than the ones of layers grown at 700°C. The low energy emission line is centred at 1.58 μm for layers deposited at 650°C. Consequently, further development have been achieved by adjusting the ion channel etch parameters (germane partial pressure and total pressure) highly act on surface density and domes size: domes surface densities up to 1.8x10^10 per square centimetre were obtained, with diameter and height of 70 and 10nm respectively. Next, an array of islands stacking is described, because such structures may be integrated in photodetection and modulation devices. Vertical ordering of islands in successive layers is analysed, mainly as a function of silicon spacer thickness and island size. Islands growth on buried island layers is precisely studied, in order to optimise the germanium amount and hence the islands density for each layer. Islands growth is modified either by strain field induced by buried islands and by silicon layer surface morphology. Different regimes of growth are shown, including a self-organization of islands are evidenced as a function of silicon spacer thickness. Photoluminescence analyses of islands stacking are used to point out best deposition conditions and layers sizes for optoelectronic applications. We analyse the optical properties of vertical and lateral islands correlations schemes. Finally, we present results concerning photodetector- and modulator-like devices that show that germanium islands-based structures are good candidates for optical interconnects, or more generally optoelectronic devices. The ability of industrial deposition systems to grow such structures is also evidenced.

### L6.12

**Structural properties of Si nanoclusters produced by thermal annealing of SiOx films and Si/SiO2 superlattices.**

Simone Boninelli1, Fabio Inacon,1 Corrado Biongorno1, Corrado Spinella1 and Francesco Priolo2; 1CnR-Imm, Catania, Italy; 2Department of Physics, Enfm & University of Catania, Catania, Italy.

Si nanoclusters embedded in SiOx have been produced by isothermal and isochronal thermal annealing processes of SiOx films prepared by plasma enhanced chemical vapor deposition (PECVD). The structural properties of the system have been investigated by energy filtered transmission electron microscopy (EFTEM) and density functional theory (DFT) electron transmission microscopy (DFFTEM). The comparison of the EFTEM and DFFTEM data has demonstrated that as deposited SiOx films are homogeneous and fully amorphous materials, without any evidence of phase separation; the first steps of the phase separation in the system is described, because such structures may be integrated in photodetection and modulation devices. Vertical ordering of islands in successive layers is analysed, mainly as a function of silicon spacer thickness and island size. Islands growth on buried island layers is precisely studied, in order to optimise the germanium amount and hence the islands density for each layer. Islands growth is modified either by strain field induced by buried islands and by silicon layer surface morphology. Different regimes of growth are shown, including a self-organization of islands are evidenced as a function of silicon spacer thickness. Photoluminescence analyses of islands stacking are used to point out best deposition conditions and layers sizes for optoelectronic applications. We analyse the optical properties of vertical and lateral islands correlations schemes. Finally, we present results concerning photodetector- and modulator-like devices that show that germanium islands-based structures are good candidates for optical interconnects, or more generally optoelectronic devices. The ability of industrial deposition systems to grow such structures is also evidenced.
L6.14 Solvothermal Synthesis and Characterization of Zn(NH\textsubscript{2})\textsubscript{2}CO\textsubscript{3}·Single Crystal, Fushan Wen\textsuperscript{1,2,3}, Jiesheng Chen\textsuperscript{2}, Taeun Kim\textsuperscript{1}, Jin Hyeok Kim\textsuperscript{1} and Wenlian Li\textsuperscript{1}; \textsuperscript{1}Center for Photonic Materials and Devices, Materials Science and Engineering, Chonnam National University, Kwangju, South Korea; \textsuperscript{2}State Key Laboratory of Inorganic Synthesis & Preparative Chemistry, College of Chemistry, Jilin University, Changchun, China; \textsuperscript{3}Key Laboratory of the Excited Mechanics and Physics, Chinese Academy of Sciences, Changchun, China.

A new 3-dimensional zinc carbonate Zn(NH\textsubscript{2})\textsubscript{2}CO\textsubscript{3} has been synthesized from a glycol system with urea and zinc acetate as raw materials. The crystal structure, photoluminescent and photovoltaic properties have been investigated using X-ray diffraction, smart CCD IR, ICP, DTA-TGA and FL. The compound crystallizes in an orthorhombic system with space group of Pna2\textsubscript{1} with M = 142.41, a = 9.1449(18) \text{Å}, b = 7.5923(15) \text{Å}, c = 5.4989(11) \text{Å}, V = 381.35(13) \text{Å}\textsuperscript{3}, Z = 4, R = 0.0286 and RW = 0.0745. The NH\textsubscript{3} and CO\textsubscript{3}\textsuperscript{2-} are connected through the Zn-N bond and Zn-O bond in the symmetric unit. The zinc atom is coordinated by three oxygen atoms at distances of 1.929(4) - 1.989(4) \text{Å} and one nitrogen atom at distance of 2.014(6) \text{Å}. Screw chains along the a axis and C-Zn 10-membered rings parallel to the c axis were observed in the structure. Photoluminescent property was observed in the compound at room temperature and the excited and emission peaks are located at around 350 and 490 nm, respectively. The powder of the compound also shows photoluminescence in the range from 300 nm to 390 nm with the peak at about 325 nm.

L6.15 Hydrothermal Synthesis of Ce\textsuperscript{3+} and Tb\textsuperscript{3+} co-doped Ca\textsubscript{3}Al\textsubscript{2}(OH)\textsubscript{12}: Luminous Material, Fushan Wen\textsuperscript{1,2,3}, Jiesheng Chen\textsuperscript{2}, Jin Hyeok Kim\textsuperscript{1}, Taeun Kim\textsuperscript{1} and Wenlian Li\textsuperscript{1}; \textsuperscript{1}Dept. of Mater. Sci. & Eng., Photonic and Electronic Thin Films Lab, Kwangju, South Korea; \textsuperscript{2}College of Chemistry, State Key Lab of Inorganic Synthesis & Preparative Chemistry, Changchun, China; \textsuperscript{3}Key Lab of the Existed States Process, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun, China.

Ce\textsuperscript{3+} and Tb\textsuperscript{3+} co-doped calcium aluminate luminous material (Ca\textsubscript{3}Al\textsubscript{2}(OH)\textsubscript{12}: Ce\textsuperscript{3+}, Tb\textsuperscript{3+}) was synthesized at about 453 K in hydrothermal system without any protective atmospheres. All the reactants used in the system were simple inorganic salts. The typical molar composition of the reaction mixture was CaO: Al\textsubscript{2}O\textsubscript{3}: Tb\textsubscript{2}O\textsubscript{3}: Ce\textsubscript{2}O\textsubscript{3}: H\textsubscript{2}O = 1: 2 : 0.02 : 0.01 : 170. The crystallinity and luminescent property of as-synthesized compound were investigated using X-ray diffraction, ICP and luminescence spectrometer. The compound formula was confirmed to be Ca\textsubscript{3}Al\textsubscript{2}(OH)\textsubscript{12}. The emission spectrum showed that only typical Tb\textsuperscript{3+} emission was observed and the emission from Ce\textsuperscript{3+} was almost not observed, which should be attributed to the energy transfer from Ce\textsuperscript{3+} to Tb\textsuperscript{3+} in the compound. The emission peaks at about 486 nm and 498 nm, 550 nm, 582 nm and 623 nm should be assigned to D\textsubscript{4-F\textsubscript{2}}, D\textsubscript{4-F\textsubscript{3}}, D\textsubscript{4-F\textsubscript{4}}, and D\textsubscript{4-F\textsubscript{5}} transitions of Tb\textsuperscript{3+} ions. The weak emission peak at about 380 nm should be assigned to the transition of Ce\textsuperscript{3+} ions in the compound.

L6.16 Characterization of strontium-titanate-oxide (SrTiO\textsubscript{3} or STO) thin films for optical devices application, Mourad Gaid\textsuperscript{1}, Mohamed Chaker\textsuperscript{1}, Joelle Margot\textsuperscript{2} and Mykola Kulish\textsuperscript{3}; \textsuperscript{1}Departement de physique, Universite de Montreal, Montreal, Quebec, Canada; \textsuperscript{2}INRS-EMT, Varennes, Quebec, Canada; \textsuperscript{3}Adtek Photomask, Montreal, Quebec, Canada.

Strontium-titanate-oxide (SrTiO\textsubscript{3} or STO) thin films are of great interest for several applications, including the fabrication of tunable optical filters for telecommunication systems. The integration of STO layers into such devices requires optimizing simultaneously the deposition method and the patterning process. In this context, STO thin films have been deposited on silicon substrates by means of a pulsed magnetron deposition technique using a combination of sputtering gases (Ar, N\textsubscript{2}, O\textsubscript{2} and H\textsubscript{2}). In this work, the influence of the oxygen deposition pressure on the STO film microstructural properties and on the film optical quality is investigated. X-ray diffraction, photoluminescence and IR, ICP, DTA-TGA and FL. The compound crystallizes in an orthorhombic system with space group of Pna2\textsubscript{1} with M = 142.41, a = 9.1449(18) \text{Å}, b = 7.5923(15) \text{Å}, c = 5.4989(11) \text{Å}, V = 381.35(13) \text{Å}\textsuperscript{3}, Z = 4, R = 0.0286 and RW = 0.0745. The NH\textsubscript{3} and CO\textsubscript{3}\textsuperscript{2-} are connected through the Zn-N bond and Zn-O bond in the symmetric unit. The zinc atom is coordinated by three oxygen atoms at distances of 1.929(4) - 1.989(4) \text{Å} and one nitrogen atom at distance of 2.014(6) \text{Å}. Screw chains along the a axis and C-Zn 10-membered rings parallel to the c axis were observed in the structure. Photoluminescent property was observed in the compound at room temperature and the excited and emission peaks are located at around 350 and 490 nm, respectively. The powder of the compound also shows photoluminescence in the range from 300 nm to 390 nm with the peak at about 325 nm.

L6.17 Electro-Optical Properties of Na\textsubscript{0.5}K\textsubscript{0.5}Nb\textsubscript{0.33}O\textsubscript{3} Films on Si by Free-Space Coupling Technique. Alexander M Grishin and Sergey I Karivsch; Condensed Matter Physics, Royal Institute of Technology, Stockholm-Kista, Sweden.

Highly polar axis oriented 3\textmu m thick Na\textsubscript{0.5}K\textsubscript{0.5}Nb\textsubscript{0.33}O\textsubscript{3} (NKN) films have been grown on Pt(100nm)/Ti(10nm)/SiO\textsubscript{2}/Si(001) substrates by rf-magnetron sputtering. Semitransparent gold electrodes (diameter of 2 mm) were deposited onto the NKN films by a thermal evaporation through the contact mask. Processing parameters have been specially optimized to obtain "electrooptic" NKN film with: a non-linear fatigue-free P-E characteristics: low remnant polarization 3.6 \textmu C/cm\textsuperscript{2}, induced polarization as high as 28 \textmu C/cm\textsuperscript{2} @ 522 kV/cm, and the coercive field as low as 39 kV/cm. Electro-optical characterization of NKN/Pb/Si films has been performed using waveguide reflectometry: a free-space coupling of a light beam into the thin-film waveguide modes. Intensity of TM- and TE-polarized light of 670 nm laser diode reflected from the free surface of NKN film and Au-cladding NKN/Pb/Si waveguide was recorded at zero and 30 V (100 kV/cm) bias electric field. Extraordinary and ordinary refractive indices as well as electro-optic coefficient have been determined by fitting these experimental data to the Fresnel formulas. Applying 160 V (530 kV/cm) across the parallel plate NKN capacitor (diameter of 2 mm, thickness 3 \textmu m), modulation of the reflected light as high as 40% was achieved.

Integrating optical isolators with various optoelectronic devices allows sources to be integrated at lower costs and alignment with longer lifetimes. Magneto-optical gargets are used in most bulk isolator components that utilize Faraday rotation. However, the deposition techniques of these gargets on some important substrates still need to be developed. We are investigating magneto-optical glass which do not have high temperature or lattice match issues for easier integration. Glasses rich in rare-earth ions have large Verdet constants, so large Faraday rotations. Among the rare-earth ions used in magneto-optical gargets, Tb ions have large Faraday rotation per ion and the glasses are transparent down to 1.6 μm. We have explored the metastable phases present in the Tb-Al-Si-O system in order to fabricate paramagnetic films with the highest possible Faraday rotations, lowest optical losses and that are easily integrated with semiconductors. We found that Tb-Al-O glasses films were composed of quasi-crystalline structures. By quasi-crystalline we mean that a broad peak was observed in the microdiffraction pattern around θ = 28°. This peak corresponds with the close-packed Tb-O plane spacing, (111) for FCC Tb4O7 or (002) for HCP Tb2O3. Only films with very little Tb concentrations yielded amorphous structures. Similarly, quasi-crystalline Tb:SiO4 films were obtained if Tb:Si ratio was larger than 1:1, but films were amorphous when the ratio is reduced to 1:2. A new discovery was found in the case of the ternary Tb-Al-Si-O system. Here, amorphous films were obtained even when the Tb concentration was very high, e.g. Tb:Al:Si=14:1:4. Since high concentrations of Tb are known to devitrify glasses, and this was verified by our two binary systems, the discovery of a Tb-concentrated glass is exciting.

**L6.19 Observation of color transition behaviors between ZnBi1-xGa1-xO4 and Mn2+ doped ZnBi1-xGa1-xO4**

Wonyon Kim1, H. L. Park1, G. C. Kim2 and J. S. Kim1; 1Institute of Physics and Applied Physics, Yonsei University, Seoul, South Korea; 2School of Natural Arts, Korea University of Technology and Education, Cheonan, South Korea.

Optical properties for color transition behaviors between ZnBi1-xGa1-xO4 with θ = 450 nm and Zn(1-x)Bi(0.9)Ga0.1O4: Mn2+ phosphors have been studied. Two synthetic processes (reduction, and non-reduction) were performed. Photoluminescence (PL) spectra with λex = 270 nm and photoluminescence excitation (PLE) spectra with λem = 450 nm and λem = 563 nm showed the different behaviors for the reduction and non-reduction processes. The Mn2+ ion doped ZnBi1-xGa1-xO4 phosphor exhibited the green main peak wavelength of 503 nm under the non-reduction process, while the PL intensities of the Zn(1-x)Ga1-xO4: Mn2+ materials have been decreased as the doping concentrations of Mn2+ ion were increasing under the non-reduction process. The peak wavelength of ZnBi0.9Ga0.1O4 (270 nm) has been shifted to the low energy of Zn(1-x)Ga1-xO4: Mn2+ (300 nm) for PLE spectra with λem = 503 nm under the reduction process. It indicates that the transition due to Bi3+ ion (blue) in ZnBi0.9Ga0.1O4 has been transferred to Mn2+ ion (green) in Zn(1-x)Ga1-xO4: Mn2+. No great variations of peak wavelengths in Zn(1-x)Ga1-xO4: Mn2+ were appeared from PLE spectra in the range of 450 nm for both reduction and non-reduction processes. We also found that the decay time of Zn(1-x)Ga1-xO4: Mn2+ material was shortened as the doping concentration of Mn2+ ion was increasing.

**L6.20 Optical Properties and Microstructure in RF Sputtered ZnO Thin Films**

Istem Ozen and Mehmet A Gulgun; Sabanci University, Istanbul, Turkey.

ZnO films were coated on various substrates by RF magnetron sputtering. The films were sputtered at different temperatures, 50 and 200 °C. Glass, polyethylene, mica, silicon, and sodium chloride were used as same substrates and crystalline substrates. The films were characterized by scanning electron microscopy (SEM) and atomic force microscopy (AFM) for microstructure and surface roughness, by transmission electron microscopy (TEM) and x-ray diffractometry (XRD) for crystal structure and by variable angle spectroscopic ellipsometry (VASE) for film thickness and refractive index. TEM and XRD measurements revealed a self-induced, [002] oriented texture on all substrates. VASE measurements showed that the films grown on different substrates were different reflective substrates were sputtered under identical conditions. Effects of substrate temperature and structure on residual thermal stresses and growth stresses on different substrates are discussed in light of the observed XRD peak shifts.

**L6.21 Eu-doped yttria and lutetia thin films grown on sapphire by PLD**

Sebastian Bac1, Guenner Hube1, Jose Gonzal2, Angel Perea2, Aurelio Climent-Font1, Ferrn Pasqui and Munz Martin1; 1Institute of Laser-Physics, University of Hamburg, Hamburg, Germany; 2International Laboratorio de Fisica Aplica da y CMM, Universidad Autonoma de Madrid, Madrid, Spain; 4Federal Institute for Materials Research and Testing, Berlin, Germany.

The development of integrated optic devices demands the fabrication of high quality optically active thin films. This work focuses in particular on thin sesquioxide films, which are promising materials because they are well known hosts for rare earth doped luminescent materials and solid state lasers. Good crystalline thin films of rare earth doped yttria and lutetia have been grown by pulsed laser deposition on single crystal (0001) sapphire substrates. Sapphire substrates offer a lattice constant that nearly matches that of cubic Y2O3 in the [111] direction. The lattice constant of Lu2O3 is 10.3 Å and thus, this value matches better the lattice constant of sapphire than Y2O3 leading to the incorporation of mismatch-induced dislocations. The crystal structure of the films (thicknesses between 1nm and 500nm) was determined by X-ray diffraction (XRD) and surface X-ray diffraction (SXRD) analysis. These measurements show that the films were textured along the [111] direction, but with a small polycrystalline component, which is negligible in thick films. Using Rutherford backscattering analysis (RBS) the correct stoichiometric composition of the films could be proved. At the optimum growth conditions the epitaxial growth of the Y2O3 film along the [0001] direction on the [0001] sapphire was evidenced by the observation of channelling in the RBS experiments. The surface morphology of the thin films has been studied using atomic force microscopy (AFM). While the amorphous film shows a defined surface structure the crystalline films show a triangular surface morphology, which is attributed to the [111] growth direction. The same structure is observed at the cleavage of a yttria bulk crystal. Thin films with a thickness of 5nm have completely covered surface but show island growth, where the shape of the single crystallites is triangular or quadrangular with at least one angle of 60° or 120°, which is an indication for the [111] growth direction in the early stage of film growth. Spectroscopic measurements, such as absorption in the UV and emission, of the rare earth doped films will be presented. The emission and excitation spectra of the Eu-doped films down to a thickness of 100nm look similar to those of the corresponding crystalline material, whereas films with a thickness ≤ 20nm show a completely different emission behaviour. To avoid surface effects, which might cause this change due to quenching processes, all films were covered with an undoped yttria layer. Finally, post-deposition annealing of the films was performed to improve the crystalline quality.

**L6.22 Fabrication of Tunsten-Tellurite Glass Thin Films using Radio Frequency Magnetron Sputtering Method and Optical Property Characterization**

Ki-Young Yoo, Youngman Kim, Jong-Ha Moon and Jin Hyeok Kim; Materials Science and Engineering, Chonnam National University, Kwangju, South Korea.

Tungsten-tellurite glass thin films were fabricated by radio-frequency (rf) magnetron sputtering method at various processing parameters such as substrate temperature, Ar/O2 processing gas flow ratio, Ar pressure, gas flow rate, and rf power from a 80Te2O2-20W2O5 target fabricated by solid-state sintering method. The effects of processing parameters on the growth rate, the surface morphologies, the crystallinity, and refractive indices of thin films were investigated using atomic force microscopy, X-ray diffractometer, scanning electron microscopy, and prism coupler. Amorphous glass thin films with a surface roughness of 2 nm were obtained only at room temperature and crystalline phase were observed in all as-deposited thin films prepared at above the room temperature. The deposition rate strongly depends on the processing parameters. It increases as the rf power increases and the processing pressure decreases. Especially, it changes remarkably as varying the Ar flow rate from 10 sccm to 80 sccm. When the films were formed in pure Ar atmosphere it shows a deposition rate of 0.15 μm/h, whereas 1 μm/h when the films were formed in pure O2 atmosphere. Details about structural and optical properties will be further discussed.

**L6.23 Carbon layer as a new material for optics**

Richard Clergeaux1, David Escach2, Steve Martin2, Patrice Baynard1 and Frederic Gaillard2; 1Laboratoire de Genie Electrique de Toulouse, Toulouse, France; 2DTEN, Commissariat a I Energie Atomique, Grenoble, France.

Amorphous carbon layer are frequently deposited by plasma enhanced chemical vapour deposition (PE-CVD). This technology is very promising because of its high control of film quality, its easy integration in current micro-electronics technologies, its low cost, high efficiency and reproducibility. Here, we report a study of carbon layers
deposited by weak heat balance PE-CVD process which can be used as optical materials. We focus on the effect of external process parameters (substrate temperature type (high or low density), plasma power and monomer structure, on their optical properties. From the film characterization by Raman spectroscopy and ellipsometry, we can understand the effect of these different parameters on the layer structure (ap2 rate, density), its optical properties (transparency, refractive index) and finally enable us to link the structure and properties. Depending on monomer structure and/or plasma power, the carbon layer structure runs from polymer-like to graphitic-like in the IR range (the optical band-gap runs from 0.1 to 2.6 eV depending on the process). Furthermore, refractive index from 1.3 to 2.2 can be reached by scanning the plasma power. In addition, the ratio main phase to amorphous phase (which is about 5 times higher in LF than in RF, for example, with C2H2, 120nm-min-1 in LF against 25 in RF). Then, it is able to control the intrinsic film properties such as transparency, refractive index and band gap energy of the relaxed samples was determined to be about 11 meV higher than that of the highly strained samples. This work is supported by the Research Grants Council of Hong Kong SAR (Ref. No. CURE14/15/03E).

**L6.24 TEM and PL Study of Stress Effects on Band Gap Properties of FeSi2 Precipitates.** Yun Guo*,1 Sai Peng Wang*,1 Wenyi Cheung1, Ning Ke1,2,3 Quan Li1,2,3 Guo Sheng Shao1,2,3 Manon Lourenco4,5 and Kevin Homewood5; 1Dept. of Electronic Engineering, Chinese University of Hong Kong, Hong Kong, China; 2Materials Science and Technology Research Centre, Chinese University of Hong Kong, Hong Kong, China; 3Dept. of Physics, Chinese University of Hong Kong, Hong Kong, China; 4School of Engineering, University of Surrey, Guildford, United Kingdom; 5School of Electronic Engineering, University of Surrey, Guildford, United Kingdom.

In this work, FeSi precipitates were formed in Si by iron implantation into silicon using a metal vapor vacuum arc ion source. The FeSi2 precipitates were found to be either highly strained or relaxed depending on the implantation and annealing conditions. Transmission electron microscopy (TEM) and photoluminescence (PL) were used to determine the FeSi2 precipitate structure and the strain states. Photoluminescence (PL) spectra were measured as a function of temperature from 80K to 300K. It was found that the relaxed FeSi2 precipitates showed a narrower PL line width than the highly strained FeSi2 precipitates, which was mainly attributed to an increase in the defect density in the FeSi2 precipitate amorphous phase. The experimental results suggest that the visible photoluminescence emission, at room temperature, could be related to the intrinsic film properties such as transparency, refractive index and band gap energy of the relaxed samples.
from 2 to 10 electrons. The charged state of these nanostructures can
be explained by the interaction of the charged state of the long axis of the nanoparticle with the charged states of the nearby charged states of chromophoric groups. Since the electrostatic interaction between these charged states is important for the stability of NLO activity, it is connected, in particular, with photonic-based technologies. The ability to accurately detect and quantify charges on a nanoscale is becoming increasingly important as interest in nanoscale photonics and molecular electronics grows. A combination of near-field probe-microscopy and electric force microscopy (EFM) was used to study the charged states of common conjugated polymer (poly phenylene vinylene) nanoparticles. These nanoparticles, prepared by ink jet printing techniques and collected on glass cover slips, exhibit uniform orientation perpendicular to the substrate plane, suggesting an extraordinary level of ordering in their chain configuration. EFM measurements showed that the nanoparticles carried a net negative charge, which is produced during droplet ejection from the narrow orifice. The excess charge on these nanoparticles was found to range from 2 to 10 electrons. The charged state of these nanostructures can explain their unique orientation. Since the electrostatic interaction between the negatively charged rod-shaped nanoparticles and the charged states on the glass substrate would result in the preferential orientation of the long axis of the nanoparticle perpendicular to the substrate, these results suggest that similar oriented nanostructures from a variety of charged polymers could be created on ordered substrates, which would open up novel nanoscale photonic and electronic applications.

L6.32
New Functionalized Copolyimides for Optoelectronic Applications. Arlen Valozhyn', P. Berczynski' and E. Schab-Balcerzak 2; ITechnical University of Szczecin, Poland, Szczecin, Poland; 2Polish Academy of Science, Zabrze, Poland.

The development of new technologies has generated a need for the preparation of new polymeric materials with specific properties. This is connected, in particular, with photonic-based technologies. In recent years, a considerable amount of research has been directed toward the development of materials with nonlinear optical (NLO) properties [1]. These materials have significant potential for such photonic devices as electro-optic modulation, high-speed photonic switching, sensors, and electro-optic characterization is presented. The ability to accurately detect and quantify charges on a nanoscale is becoming increasingly important as interest in nanoscale photonics and molecular electronics grows. A combination of near-field probe-microscopy and electric force microscopy (EFM) was used to study the charged states of common conjugated polymer (poly phenylene vinylene) nanoparticles. These nanoparticles, prepared by ink jet printing techniques and collected on glass cover slips, exhibit uniform orientation perpendicular to the substrate plane, suggesting an extraordinary level of ordering in their chain configuration. EFM measurements showed that the nanoparticles carried a net negative charge, which is produced during droplet ejection from the narrow orifice. The excess charge on these nanoparticles was found to range from 2 to 10 electrons. The charged state of these nanostructures can explain their unique orientation. Since the electrostatic interaction between the negatively charged rod-shaped nanoparticles and the charged states on the glass substrate would result in the preferential orientation of the long axis of the nanoparticle perpendicular to the substrate, these results suggest that similar oriented nanostructures from a variety of charged polymers could be created on ordered substrates, which would open up novel nanoscale photonic and electronic applications.

L6.33
Electroluminescence properties of new light-emitting polyp(phenylene vinylene) derivatives with netw

Introduction of NLO-active moieties into a polymer chain requires the presence of a reactive functional group in the polymer chain. The synthesis of polymers containing reactive groups can be the first step toward preparing materials with NLO properties [3]. Copolyimides (CPI) with chromophore groups in side chain are one of the most promising type of polymeric materials for application in second harmonic generation (SHG) and electro-optical modulation due to their excellent thermal stability, high mechanical, dielectrical properties and high glass transition temperature (Tg > 250°C). We have synthesized two series of new CPI with functional groups (OH, COOH) in main chain for further NLO modification with chromophore compounds. First group of polymers was prepared from benzenophenone dicarboxylic dihydrid and diaminobenzoic acid or oxidainoline. The second kind of CPI or copolymides was obtained from same dianines and biphenyldicarboxylic dihydrid. The using different ratio of dianines and dihydrides let to obtain a series of copolymides. Polymers have been synthesized by using different ratio using thermal polycrystallization, and post-subsequent thermal cycling. These polymers give flexible foils, which have properties such as: mech., elec., optical & thermal stability were investigated. New side-chain CPI films bearing chromophore groups were synthesized and investigated in solution state as well as in film state to compare them with that of PPV derivatives without network structure. The electroluminescence of the new PPV derivatives is also characterized to evaluate the effect of crosslinking between PPV polymer backbones. ** This work was supported by the Korea Research Foundation Grant (KRF-2000-003-C0001).

L6.34
Novel photopolymer composed of the photoactive binders for holographic application: Effect of functionality of the monomer. Dong Hoon Choi, Hyuk Yoon, Min Ju Cho, Jae Hong Kim and Seung Il Han; Department of Material Science, Kyung Hee University, Suwon 449-701, South Korea; 2Department of Chemistry, Kyung Hee University, Suwon 449-701, South Korea.

New photopolymers were designed and prepared using the thermoplastic and the photoactive binders. Poly(vinylcysteate-co-vinylalcohol) and poly (2-hydroxyethylmethacrylate) were used as a thermoplastic polymer binder and 3-isopropenyl-a,a-dimethylbenzyl isocyanate (m-TMI) was tethered to the side chain of the above polymers. The monomer, di-, and tri-acrylate monomers were selected to investigate their effect on the diffraction behavior. The holographic gratings were successfully fabricated in these photopolymer film samples by conventional optical interference method. The dynamic behavior of the gratings formed was studied with the change of exposure intensity in terms of the diffraction efficiency. We also investigated the effect of photoaction between the polymer binder and newly formed polymer in the constructive region on the diffraction behavior and its stability. The stabilities of the diffraction efficiency were compared to study the effect of the chemical bond formation between the acrylate group in the monomer and a-methylene group in the polymer binder. a)Corresponding author: dchoi@khu.ac.kr

L6.35
Photoinduced anisotropy and micro-patterning of a novel photoresponsive azo material with a nematic liquid crystalline phase. Chaemin Chun, Mi-Jeong Kim, Dojin Park, Yong-Young Noh and Dong Yu Kim; Materials science & engineering, KJIST, Gwangju, Gwangju, South Korea.

azo benzenes-based polymers have been extensively investigated due to
various photoinduced properties which are applicable to information storage, optical elements, and sensors through reversible photo-isomerization of spiro-bifluorenone dye-polymer systems. Recently, it was reported that amorphous molecular materials with azo chromophores could exhibit more efficient photodynamic behaviors and resulting surface relief gratings (SRGs) formation. Therefore, we used amorphous molecular material, spiro-ADA was designed and synthesized via a palladium catalyzed anination reaction. The introduction of bulky spiro linked bifluorenone with the non-planar structure of spiro-ADA prevented polymerization of the molecules and led to the good amorphous film formation and thermal stability with a high glass transition temperature. Photoinduced behaviors such as optically induced birefringence and formation of SRGs were investigated. Because of the high concentration of azobenzene groups and a low molecular mass, the films showed a very rapid response to linearly polarized light, a high diffraction efficiency, and a large measurable range in 3D printing. In addition, we also investigated charge transport of spiro-ADA containing four triphenylamine groups in the side of spiro-bifluorenone.

L6.36
The characteristics of joints with Indium-silver alloy using diffusion soldering method, Jeoyon Kim, min soo Youn, hwa young Kim and man young Sung; electrical engineering, KOREA university, seoul, South Korea.

Bonding process using indium-silver alloy which can withstand high temperature was investigated at relatively low temperature. We used a thermal evaporator and vacuum coater for making indium-silver contact. From the result of experiment, we estimated that indium and silver films which have good quality are formed. The composition of indium-silver contact which is made by diffusion is AgIn2, Ag2In, Ag3In, etc. From phase diagram of In-Ag alloy, we can get melting point of these silver compounds. Therefore, we have developed Ag/In/Ag multi-layer composite which has melting point that is near normal melting point. The melting point of Ag/In/Ag multi-layer is about 700°C. Bonding was executed by annealing and within vacuum atmosphere at a time. The joints are examined using a SAM(scanning acoustic microscope) to confirm the bonding quality. The joint cross-sections are studied using SEM(scanning electron microscope) into EDX(Energy Dispersive X-rays). From these data, we observed that the composition and microstructure of Ag/In/Ag multi-layer were reliable and this bonding procedure might be a good technique for high temperature electronic devices in the future and from the conventional structure of quantum light LED, GaN/LED structure was made by using substrate for substrate. And from the InGaN/Inselfusion/Sl structure which has Pd-In adhesion layer, we replaced the In-Ag layer for Pd-In adhesion layer. Consequently, the new structure which has In-Ag adhesion layer is going change the trend of LED market. Because anode and cathode electrodes are placed vertically in the experimental LED, the new LED structure is going to be dominant for cost saving and improvement in fabrication.

L6.37
Phase Stability of Wurtzite Alx-yInyN (0.1<x<0.9) During Growth by Magnetron Sputter Epitaxy, T Sempenn, G Z Radnoczy, B Pecz, L Hultman and J Birch, 1Thin Film Physics Division, Linkoping University, Linkoping, Sweden; 2Research Institute for Technical Physics and Materials Science (MTA) of the Hungarian Academy of Sciences, Budapest, Hungary.

AlInN is a very attractive and useful III-V nitride alloy: e.g. Al0.35In0.65N is predicted to be a good lattice-matched insulation layer for GaN based electronic devices [1]. Also, the wide band-gap range, from 0.9 eV for pure InN to 6.2 eV for AlN, opens possibilities to engineer electronic devices operating from near infra-red to deep ultra-violet. However, it has been proposed that the ternary III-V nitride alloys are prone to spinodal phase decomposition due to largely mismatched binaries [1,2,3] in the composition range 0.1<x<0.9. Theoretical calculations suggest that the nitrogen gap gives rise to unpredictable values of the band-gap for AlN [3]. In this work, ternary wurtzite Alx-yInyN thin films with 0.05<x<0.89 were grown onto (111)-oriented single crystal seed layers of TiN and ZrN by magnetron sputter deposition. The as-deposited films were then cooled to room temperature. Film compositions and lattice parameters were determined using X-rays diffraction, respectively. XRD also showed that the Alx-yInyN films were epitaxially grown onto TiN and ZrN with the relations: Al1-x-InyN[0001]//TiN(ZrN)[111] and Al1-x-InyN<10-105>//TiN(ZrN)<110>. In the composition range 0.2<x<0.6 the measured c/a ratio deviates systematically from 1.62 to a minimum of 1.59, thus indicating lattice frustration. Outside this region c/a followed the typical wurtzite ratio of 1.60 to 1.61 for AlN and InN, respectively. A growth temperature phase-diagram for photoinduced phase of Alx-yInyN between 300 and 3000 °C was established. Single-phase alloy films could be obtained with x(1) at 300 °C on both ZrN and TiN. Moreover, at 600 °C, the solubility of In in the films was reduced to a minimum of 0.15x and 0.3x for ZnN and TiN, respectively. At 900 °C almost pure AlN was formed. Cross-sectional High-Resolution Electron Microscopy (HREM) verified that the solubility of In was limited in the wurtzite Al1-x-InyN lattice was reduced at higher temperatures. An amorphous layer of pure InN was formed on top of the Al1-x-InyN lattice at deposition temperatures >600 °C. The Al1-x-InyN layers grew in a columnar mode with grain sizes ranging from 10 to 100 nm. HREM and XRD also revealed a generic columnar growth mode of Al1-x-InyN where the structure is tilted continuously with respect to the c-axis, toward the Al sputter source due to limited adatom mobility and self-shadowing effects. HREM showed that the columnar tilt is due to a lattice parameter gradient within each column. These results show that the possibility of forming single-phase Al1-x-InyN with 0.05<x<0.89 by MBE, without experiencing spinodal phase separation, at temperatures up to 600 °C. [1] S. Yamanouchi et al. J. of Crystal Growth 195, (1998) 309-313. [2] T. Tsukazawa et al. Jpn. J. Appl. Phys. 30, (2000) 5057-5062 [3] E. V. Klahnshnikov, V. I. Nikolskov, M.IJ-NSR. http://nsr.mij.org/j3/3_complete.html

L6.38
Bonding a thin In0.5Ga0.5P layer to GaP substrate for the heteroepitaxy growth of (AlxGa1-x)0.5In0.5P', Po Chun Liu and Pe Chuan Luh and Yung Jung SuWu, Materials Science and Engineering, NUI, Chao Tong University, Hunchau, Taiwan.

The heteroepitaxy integration of III-V semiconductor compound, which was limited by the lattice mismatch, now can be accomplished by using relative close angle wafer bonded compliant substrate. In this study, a novel method was used for the heteroepitaxy of (AlxGa1-x)0.5In0.5P (layer on lattice-mismatched (3.3%) GaP substrates for fabricating high brightness light emitting diodes (LEDs). A thin In0.5Ga0.5P (50nm) layer which is lattice matched with (AlxGa1-x)0.5In0.5P epitaxial alloy was bonded with GaP substrate. By using this buffer layer, (AlxGa1-x)0.5In0.5P heteroepitaxy layers can be grown on the GaP substrate over critical thickness without high density threading dislocation.

L6.39
New InfraRed (2.04mm) Material: GaInAs(NSB)InP, Junji Hu1,2, Seth Bank3, Mark Wiesty3, Homan Yuen4 and James Harris2, 1Department of Applied Physics, Stanford University, Stanford, California; 2Solid State and Photonics Lab., Stanford University, Stanford, California.

GanNAS on GaAs has been extensively studied in the optical communication field. The main mechanism of getting small bandgap materials working at 1.3μm and 1.55μm is that the small size of added nitrogen atoms, the bandgap bowing effect of GaNASAs, and the strain in the active region layer grown on GaAs substrate significantly reduce the bandgap. On the other hand, the wavelength range of 2-2.5μm is of specific interest for gas sensing, chemical detection, and especially near-infrared Fourier transform spectrometer. Lattice-matched Gan0.47As0.53In0.53N0.53As1-x, x=0.05-0.2μm grown on InP substrate has the strain in the active region layer grown on GaAs substrate significantly reduce the bandgap. In this paper, the GaNAS(NSB) sample was grown in two SSMME systems. One system has a sublimation cell with GaP source which was used to provide P2 atmosphere to blowoff the oxide and grow a InP buffer layer. The other system has a nitrogen plasma source and an antimony cracker source. Arsenic-capping technique was utilized to protect the substrate from being exposed to the air when transferring wafers between the two MBE systems. The samples should grow two quantum well structures, GaInNASg/InAs and GaInNASg/InNASg/InAs. The sample growths were monitored by in-situ RHEED before and after the GaInNAS(NSB) layer was grown. The samples were characterized by ex-situ XRD and room temperature photoluminescence. The effects of InP buffer layer and InGaNAs buffer layer on the samples growth were investigated. The nitrogen incorporation under different growth condition was studied by varying substrate temperature, growth rate and nitrogen flux. Room temperature photoluminescence shows peak wavelength at 2.04μm.

L6.40
Structural Characterization of Molecular Beam Epitaxy Grown GaInNAS and GaInNASb Quantum Wells by Transmission Electron Microscopy, Tihomir L Gugov, Mark Wiesty, Homan Yuen, Seth Bank and James S Harris, Solid State and Photonics Laboratory, Stanford University, Stanford, California.
The quaternary GaInNAs alloy is a very promising material system for optical sources in the 1.2-1.6 micron range with application in telecommunications and photonic networks. It is not a thermodynamically stable alloy and considerable growth challenges need to be overcome to improve the optical emission efficiency of the material. Considerable progress in dealing with these difficulties has been made by alloys containing around 30% In and 2% N which emit light around 1.3 microns. The effort to push emission out to 1.5 microns, the wavelength for long haul networks, by adding more In (up to 40%) has proven considerably more difficult. Recently, the addition of small amounts of Sb has proven to play back on track for the 1.5 micron challenge by dramatically improving the luminescence efficiency of the material. In this work, several different TEM techniques are used for the first time as powerful tools in the structural characterization of GaInNAs(Sb) quantum well structures at the atomic level. High resolution TEM (HRTEM) is used to map out the local strain and compositional fluctuations in the quantum wells and barriers and correlate these effects with the optical properties of the EFTEM imaging as well as dark field (DF) imaging with the chemically sensitive (002) reflection. Both GaInNAs and GaInNAsSb samples were characterized with these techniques. We found that In tends to segregate for the GaInNAs samples while Sb is responsible for a much more uniform distribution of In in the GaInNAsSb samples. The results of this work bring further understanding of the performance of real devices. GaInNAs lasers are known to have broad emission spectra and high threshold currents. Researchers have speculated that this could be due to local compositional fluctuations. Our results confirm that this indeed occurs and give considerable insight into the role of Sb in improving the material quality leading to high luminescence efficiency.

L6.41 TRANSFERRED TO L4.2

SESSION L7: Polymers
Chair: Bruce Wessels
Thursday Morning, April 15, 2004
Room 2008 (Moscone West)

8:30 AM #L7.1
Polymer Light-Emitting Diodes - Status and Outlook with a View to Photonic Applications. Eric A Meedenkamp, Philips Research, Royal Philips Electronics, Eindhoven, Netherlands

Polymer light-emitting diodes were discovered about 13 years ago. Since then, the field has seen enormous progress in understanding and rational design of materials and devices. This has led to orders of magnitude improvements in operational lifetime, and major improvements in efficiency, luminance and driving voltage. In parallel, the necessary technology for large-scale manufacture has been developed. This included scale-up of materials synthesis, deposition technology, testing protocols, reliable packaging and driving schemes. The combined effort by universities, chemical industry and electronics industry has led to successful introduction of polymer LEDs in commercial display and lighting products. The performance of polymer LEDs is now such that other applications are coming within reach. One example that receives a lot of attention in the field of organic LEDs is lighting. Another area of interest is photonics. In this presentation the status of polymer LEDs, ongoing developments to improve display performance, and related work will be discussed with a view to applications in (micro-)photonic devices. One aspect concerns device characteristics such as power consumption, peak luminance and response time. Tailoring the spatial or wavelength distribution of light emission through use of cavity effects, pursued for display applications, is also relevant to photonics. A second aspect relates to deposition technology. The major route towards industrialisation of full-colour polymer photonic devices is vacuum deposition, which may also be eminently suited to fabricate small light-emitting structures as single light sources, comparable to a single sub-pixel in a display. Finally, the electro-optical characteristics of light-emitting polymers in polymer LEDs can be used not only for generating light, but also for sense light. Indeed, devices optimised for light emission in forward bias do still show interesting photo-voltaic effects in reverse bias.

9:00 AM #L7.2

Quantum and statistical mechanical calculations have been used to guide the development of a new generation of electro-optic materials exhibiting electro-optic coefficients of approximately 200 pm/V (six times greater than lithium niobate) and second response times of the order of nanoseconds (leading to device 3 dB bandwidths in excess of 200 GHz). These advances have been based on (1) improvement in molecular first hyperpolarizability by design of novel chromophores and (2) control of intermolecular electrostatic interactions by nanoscopic engineering to realize improved noncentrosymmetric (ferroelectric) order. Theoretical calculations have also demonstrated that various limits of electro-optic activity that can be achieved with a variety of material development approaches including exploiting of dendritic and dendronized polymer structures and self-assembly, sequential synthesis fabrication. A clear paradigm for the short-term improvement of electro-optic activity is the factor of ten greater than lithium niobate will be given as will a longer term development program for improvement to values thirty (or more) times greater than lithium niobate. New nanoscopic-engineered electro-optic materials also exhibit dramatically improved optical loss, thermal stability, and photochemical stability as well as improved control of solubility and processability. Structure/function studies have clarified the variation of photostability with chromophore structure, macromolecular structure, length of the electro-optic component, and the presence of chemical and physical quenchers of singlet oxygen. It is clear that materials surpassing Telcordia standards can be prepared. Insights into the photostability of electro-optic materials to space radiation will also be presented. Finally, organic electro-optic materials have been used to fabricate a variety of novel stripe, cascaded prism (and superprism), and ring modulator (and photonic crystal) devices indicating that these devices are conformal and flexibility. An overview of the unique performance properties of such devices will be presented for applications such as active chipscale wavelength division multiplexing and space-based antenna applications.

10:00 AM L7.3

In the last decade, photonic devices based on a variety of polymers have been demonstrated or commercialized. Polymeric materials are finding particular success, with regard to both performance and cost, in short-haul communications applications such as metro and local area networks, where specifications such as loss, polarization and thermal sensitivities and long-term reliability can be less stringent compared to those for dense wavelength division multiplexing (DWDM) or long-haul systems. However, even with higher tolerances, key material properties such as birefringence must be carefully controlled to allow polarization insensitive devices such as AWGs and tunable filters to be designed and fabricated. For coarse (C)WDM, where channel spacings are typically 20 nm, a material birefringence of 10^-4 is still required in order to allow polarization independent operation of the device. In this work we address some key issues in the control of birefringence in the fabrication of polymer photonic devices. The materials used in this work are pentfluoroarylenes modified fluorinated poly(arylene ether ketone). The presence of the pentfluoroarylene crosslinker allows thermal processing at lower temperatures (~200°C) and fluorination decreases the propagation loss around 1550 nm associated with the C-H vibration overtones. Bulk material loss in these materials has been measured to be < 0.5 dB/cm. Optical waveguides have been fabricated in these materials using standard photolithographic processing, metal lift-off and reactive ion etching. Amorphous process variables such as spin coating parameters, baking temperatures and solvents effects can be adjusted to slightly improve layer birefringence, the dominant factor in the birefringence in polymer waveguides is the difference in coefficients of thermal expansion (CTE) between the layers and the substrate. By employing plastic substrates, stress in the waveguide structures can be drastically reduced compared to those on semiconductor substrates, and lower birefringence can be achieved. The photolithographic patterning process has been optimized to fabricate simple photonic devices on plastic substrates. The use of plastic substrates offers additional advantages of cost and weight savings; but often produces some degree of anisotropic etching of end-face preparation such as dicing and polishing. A method for preparing endfaces of polymer waveguides on plastic substrates using excimer laser radiation is presented. Using a focussed excimer laser beam at 193 nm, clean vertical cuts have been achieved through plastic substrate, polymer waveguide core, and upper cladding material. This technique allows efficient coupling of light from an optical fiber into all-polymer photonic devices. Characterization of these polymer waveguides will be presented, and their potential applications in CWDM systems discussed.

10:15 AM L7.4

Polymeric photonic crystal structures and large group velocity dispersion features and large group velocity dispersion...
characteristics in photonic crystals (PCs) are expected to find use in nonlinear optical devices such as high-efficiency optical switching, frequency conversion devices, and others, in combination with NLO host materials. These applications are possible with PCs because an extremely low group velocity, originating from anomalous band structure, produces a strong enhancement in the electromagnetic field of the excitation wave. Furthermore, photonic band structure features made it possible to obtain phase matching through appropriate band design. Despite their importance, few technology potential, experimental realization and subsequent analysis of two-dimensional (2D) PC waveguides formed out of highly nonlinear host material has not yet been achieved. This is due to the limitations of the employed microlithographical techniques in the fabrication processes for the best-known NLO materials such as LiNbO3. Recently, to overcome these problems, we have proposed an NLO polymer with metallic cladding as one of the best candidate materials for 2D PC waveguides with large optical nonlinearity. In this work, first, we propose and fabricate the new 2D PC waveguide structure suitable for nonlinear optical processes. This structure, exhibiting high precision feature at a subwavelength scale, is the periodic patterned semi-core and the nonlinear optical core layers are separated by very thin oxide layer. We call this structure the PC-NLO hetero-waveguide-structure. Since the nonlinear optical layer separates from the periodic patterned layer, the process damage by plasma etching can be prevented perfectly in this structure. And, this structure can reduce scattering losses at the boundaries of the PC structure. Therefore, this new PC-NLO hetero-waveguide-structure has high potential for NLO applications. As one example investigated, first harmonic generation (FHG) and second harmonic generation (SHG) processes in the PC-NLO hetero-waveguide-structure, and we demonstrate for the first time SHG and FHG spectra in the ultraviolet region and these strong enhancements are derived from photonic band nonlinearity of this waveguide. Third, the dynamic shift of the photonic band resonance with the laser intensity is investigated. The dip position changes based on the optical Kerr effect in reflectance spectra were clearly observed in angle-dependent reflectivity measurements. And finally, we consider the nature of the enhancement of NLO processes originating from photonic bands in this PC waveguide by comparing observed photonic band structure with the theoretical band structure calculated by 3D finite-difference time-domain (FDTD) method. These works may lead to the development of new and high-efficiency nonlinear optical devices.


Tunable laser action, in the visible spectrum, has been established using dye-doped, silica nanoparticle gain media for the first time. The silica nanoparticles ranging from 8 to 13 nm in diameter, appear to be uniformly dispersed in the poly-methylmethacrylate (PMMA) matrix, since the optical homogeneity of the gain medium is maintained. The gain maximum is observed at 530 nm. polymer (w/w) silica nanoparticles, laser action was established in the 577-630 nm range. At the peak wavelength (λ 580 nm) laser conversion efficiency is 63% at a beam divergence of 1.9 mrad. The new solid-state gain medium also exhibits a reduction in dn/dT. Optics Letters, in press, November 2003.


Ferroelectric thin film structures are being developed for microphotonics. Of particular interest are high band width electro-optic modulators. Both the single-crystal phase modulators and Mach-Zehnder waveguide modulators have been reported for BaTiO3 ferroelectrics. BaTiO3 shows considerable promise for high band width applications owing to its large electro-optic coefficient. Phase velocity matching can be potentially obtained by using a thin film structure, whereby the substrate has a low microwave index. Recently we have been developing strip-loaded waveguides using BaTiO3 for high bandwidth, thin film electro-optic modulators. Progress towards achieving a low V-ripple thin film ferroelectric modulator will be reviewed.


The magneto-optical Faraday rotation (FR) in garnets is strongly enhanced by doping with special elements, such as bismuth or cerium in iron garnets. We present properties and problems of completely bismuth-substituted iron garnet (BIG) films prepared by pulsed laser deposition. As one example investigated FR, (1.0 deg/micrometer at 540 nm) and the high specific Faraday rotation of 22 deg/micrometer at 540 nm is not maintained in thick BIG films. In addition to increasing FR in the material, special multilayer structures can be designed to enhance FR at certain design wavelengths. We demonstrate for example yttrium-iron-garnet/BIG multilayer structure in simulation and experiment, where FR is more than doubled at the design wavelength while the loss in transmission is below 20%. The multilayer structure also helps to accommodate stress and thus avoid film cracking, which occurs for BIG films above 1 micrometer thickness.

11:45 AM L8.3 Rapid Thermal Annealing for Integrated Yttrium Iron Garnet. Sang- Yeob Sung, Xiaoyuan Qi, Samir K Mondal and Bethanie J. H. Stadler; ECE, University of Minnesota, Minneapolis, Minnesota.

The critical active element in optical isolators is a magneto-optical garnet. These isolators are required for integrated light sources as they allow extended lifetimes by blocking back-reflected light. However, garnet is difficult to integrate with semiconductors due to the high thermal budget usually required to obtain the garnet crystal structure. For example, current isolator garnets cannot be integrated monolithically into a photonic integrated circuit due to the growth process, liquid phase epitaxy. In this work, magneto-optical garnets were grown monolithically by low-temperature reactive RF sputtering, followed by an ultra-short (<15 sec) anneal. It was found that in addition to low thermal budgets due to timing, the temperature required (~750°C) for garnet crystallization was also reduced compared to standard tube furnace annealing (>1000°C). MgO and fused quartz were used as substrates because they will be useful for future buffer layers and optical claddings. Y-Fe-O films were made with systematically varied composition and the chemical, structural, and optical properties of the resulting films were analyzed. After RF sputtering processing, the films were amorphous Y-Fe-O. Several rapid thermal anneal (RTA) processes were used to determine the optimal conditions for the lowest total thermal budget as well as the highest crystalline quality. The resulting YIG quality was confirmed by vibrating sample magnetometry (VSM), X-ray diffraction (XRD), and measurements of Faraday rotation (FR). Although the XRD results showed that the films had isotropic crystallinity, the VSM indicated that slope anisotropy dominated the magnetic properties. Out of plane FR measurements yielded up to 0.27/μm at 632nm rotations. This rotation will be higher in plane and dopants (Ce and Bi) are incorporated. All of these tests demonstrated that the YIG was comparable to YIG grown by standard annealing and also helps to accommodate stress and thus avoid film cracking, which occurs for BIG films above 1 micrometer thickness.

SESSION L9: Compound Semiconductors
Chair: Robert J. Hamers
Thursday Afternoon, April 15, 2004
Room 2008 (Moscone West)

13:00 PM L9.1 Reliable InGaAsP/GaAs 40W lasers grown in solid source
808 nm lasers have become attractive [1-3] as they have found great application in pumping solid-state lasers and in material processing. Lasers with InGaAsP active layer have been shown to possess advantages over conventional AlGaAs lasers due to their resistance to dark-line defects [4], and high threshold of catastrophic optical damage (COD) [5]. In this paper we report on 808nm lasers with AlGaAs active layer grown in solid-source MBE with phosphorus-cracker. Laser structures with InGaAsP quantum well were grown on GaAs substrates. Threshold current density Jth as low as 2900A/cm² and slope efficiency as high as 1.35W/A were obtained at 35°C with uncoated chip with a high 
emitter length of 100μm. Coated laser bars show very good reliability. After 857

1:45 PM L0.2
High-Performance InGaAsN Quantum-Well-Broad-Area and Single-Mode Ridge Lasers for Telecommunication. Nelson Tomson1, Masahiro Yoshimoto1, Wei Huang1, Luke Jade2. 1Center for Optical Technologies, and Department of Electrical and Computer Engineering, Lehigh University, Bethlehem, Pennsylvania; 2Reed Center for Photonics, and Department of Electrical and Computer Engineering, University of Wisconsin-Madison, Madison, Wisconsin.
High-performance InGaAsN quantum-well (QW) lasers, grown using metalorganic chemical vapor deposition (MOCVD), have been realized with room-temperature emission wavelengths in the range 1300-1382 nm. Extensive studies were conducted on both low and high In-content InGaAs and InGaAsN QW lasers. From these studies, we find that the utilization of higher In-content InGaAsN results in the best device performance. Advantages from the utilization of the high In-content InGaAsN QW lasers include the significant suppression of carrier leakage from the QW, and improved photoluminescence intensity. The optimum design of the active region is based on an InGaAsN QW utilizing very high In-content (approximately 40%), with tensile-strained GaAsP barriers for strain compensation purpose. All laser structures are grown by low-temperature, low-pressure MOCVD with Arsine (AsH₃) and U-Dimethylhydrazine as group V sources. Continuous-wave operation of In₀·₄GaₓAs₁₋ₓ₀·₀₉₅N₀·₀₀₅ QW broad-area lasers (with width of 100-micron) has been realized, at a room-temperature near-threshold emission wavelength of 1295 nm, with a threshold current density of 75 A/cm² (Lcav=2000-micron) and a transparency current density of 75 A/cm². Single-mode 1300-nm ridge lasers (width of 4-micron) with In₀·₄GaₓAs₁₋ₓ₀·₀₉₅N₀·₀₀₅ QW also exhibit low-threshold-currents of only 15 mA for 1000-micron long cavity devices at room temperature, corresponding to a threshold current density of 375 A/cm². Temperature characteristics of the threshold current density of the single-mode ridge lasers correspond to T₀ values of 93 K, for the temperature range of 25°C to 80°C. Utilizing GaAs, asP₀·₁, barriers directly adjacent to the QW to suppress the thermionic hole leakage, threshold current densities of only 390 A/cm² and 440 A/cm² were realized for In₀·₄GaₓAs₁₋ₓ₀·₀₉₅N₀·₀₀₅ QW lasers (Lcav=2000-micron) at temperatures of 80°C and 90°C, respectively. By increasing the N-content in the InGaAsN QW (with 40% In-content), 1360-nm and 1382-nm diode lasers were realized with room-temperature threshold current densities of 450 A/cm² and 1010 A/cm², respectively.

2:00 PM L0.3

The selective area growth (SAG) of InGaAsP/InP or AlGaInAs/InP by MOCVD is a very potential method for realizing spot-size converter integrated laser diodes (SSC-LD)[1], because the active and waveguide layer can be grown at the same time and it is possible to reduce the size of far field pattern without a lens between laser diode and fiber. AlGaInAs is recently a promising material for uncooled optical device operation. The conduction band offset of AlGaInAs/InP systems is larger than that of InGaAsP/InP systems, which results in better electron confinement and higher current density. We have developed 1.3μm AlGaInAs/InP SAG by MOCVD in order to fabricate SSC-LD for hybrid integration with passive devices. SiO₂ patterning was varied from 0.8μm to 2.0μm and SAG optical was fixed to 1.5μm and 2.0μm. The active layer consists of 6 AlGaInAs wells enclosed in AlGaInAs separated confinement heterostructure layers. In order to suppress undesirable electron overflow and etching of active region in the ridge waveguide (RWG) structure, we adopted a new design having a p-InP cladding layer. The optical characteristics of grown materials were measured with 1μm diameter spot micro-photoluminescence (PL) method. In the viewpoint of optical quality of selective grown AlGaInAs MQW structures, it quite different from that of InGaAsP. Unlike InGaAsP, PL intensity and FWHM of selective grown AlGaInAs MQW were very poor compared to those of conventional epitaxial growth. The reason of bad optical quality of AlGaInAs is not clearly understood. It is worth considering that the surface migration of SAG mechanism is highly suspected for its poor optical quality. In order to restrict the surface migration, thick InP buffer and migration blocking and MBA were used at the both side of active layer.

2:15 PM L0.4
White Light Emitting Diode through Ultraviolet GaN-pumped Sr₂Si₁₋ₓGeₓO₄: Eu³⁺ phosphor. Jungae Kim1, P.E. Jeon2, W.N. Kim3, J.C. Choi2, H.L. Park1 and G.C. Kim2; 1Institute of Physics and Applied Physics, Yonsei Univ., Seoul, South Korea; 2Department of Electrical Engineering, Yonsei Univ., Seoul, South Korea; 3School of Liberal Arts, Korea University of Technology and Education, Cheonan, South Korea.

The Sr₂Si₁₋ₓGeₓO₄: Eu³⁺ phosphor is formed by means of a new synthesis method. The Sr₂Si₁₋ₓGeₓO₄: Eu³⁺ has the mean particle size of 100 nm and the spherical shape. The Sr₂Si₁₋ₓGeₓO₄: Eu³⁺ shows two emission colors: the blue color of 470 nm and the yellow color of 560 nm. The 470 nm peak is attributed to the 4f-5d transition of Eu³⁺ ion doped in Sr₂SiO₄ (8) sites with weak crystal field, while 560 nm peak is originated from Eu³⁺ ions on Sr₂SiO₄ (28) sites with strong crystal field. As the increase of Ge³⁺ ions, the 470 nm emission intensity of Sr₂Si₁₋ₓGeₓO₄: Eu³⁺ are more dominant. This behavior can be understood in terms of the effect of Ge³⁺ ions on electron transfer from 5d6 4f1 to 5d10 4f10. For 100 nm-sized crystal, continuous wave operation was realized. The fabricated white light emitting diode using ultraviolet InGaN chip or SiC chip with blue and yellow emitting Sr₂Si₁₋ₓGeₓO₄: Eu³⁺ phosphor shows higher color rendering index and higher color stability against input power variation in comparison with a commercial ultraviolet-pumped YAG:Ce³⁺. This white light emitting diode can generate the white color with various color temperature by controlling Ge³⁺ ion concentrations.

2:30 PM L0.5
New semiconductor GaNASBi alloy grown by molecular beam epitaxy. Masahiro Yoshimoto1, Wei Huang2, Yoji Takeda2, 1Center for Optical Technologies, and Department of Electrical and Computer Engineering, University of Wisconsin-Madison, Madison, Wisconsin; 2Kansai, Ilked, Japan.

New semiconductor GaNASBi alloy has been grown by molecular beam epitaxy (MBE). This alloy is suitable to realize both a temperature-insensitive bandgap in the wavelength region of optical fiber communication and the lattice temperature-insensitive bandgap (WDM) fiber communication systems. III-V semiconductor alloys consisting of semiconductor and semimetal components have been proposed to obtain materials with temperature-insensitive bandgaps. In our previous study, the bandgap of GaNASBi has been found to be insensitive to temperature. In this study, we have grown GaNASBi alloy using molecular beam epitaxy (MBE) and showed weak temperature dependence. The Bi incorporation into the
Conversion system utilizing a sample-and-hold scheme with low-temperature-grown GaAs (LT-GaAs) metal-semiconductor-metal (MSM) photoconductive switches. Due to the low growth temperature, LT-GaAs is highly non-stoichiometric, with a large density of excess arsenic incorporated into the GaAs matrix, forming a high concentration of A-related deep level defects. These defects result in ultra-short carrier lifetime. Post-growth anneal is utilized to increase the carrier mobility, but not substantially increase the lifetime. LT-GaAs has demonstrated a good combination of short carrier lifetime and reasonably high mobility, as well as high sheet resistance, making it ideal for ultrafast photodiode applications. But there is almost a trade-off between obtaining a fast speed and high responsivity. A relatively simple but effective orthogonal design of experiments method, Taguchi method, is used to optimize the quality of LT-GaAs materials. The optimization process will be reported in this presentation. We have previously used a flip-chip bonding technique for integration of LT-GaAs, demonstrated and demonstrated a two-channel prototype ADC with 3.5 effective bits of resolution for an input bandwidth up to 40GHz and an estimated total timing jitter less than 80fs. To minimize the input capacitance, monolithic integration was investigated. In this presentation, growth of LT-GaAs on both GaAs and Si are compared. The material issues associated with heteroepitaxial growth are addressed. A time-resolved electro-optic sampling technique was used to determine the responsivity and speed of the switches and to study the transient response. Typically the full-width at half-maximum (FWHM) switching time is ~2 picoseconds. The responsivity and dark current of switches from LT-GaAs on Si material was comparable to their homoeopitaxial counterparts.

3:30 PM L9.7
Optimization of Low-Temperature GaAs and its Integration with Silicon Circuits Used in a Hybrid Photonic/CMOS Assembling to Digital conversion system. Kuo-Ma and James S Harris, Solid State and Photonics Laboratory, Stanford University, Stanford, California.

Modern communications and high-speed instrumentation require much higher speed analog-to-digital converters (ADC) with bandwidths up to several tens of GHz. Conventional electronic ADCs are powerful in signal processing. However, their performance at high speeds is limited by low input bandwidth and fundamental timing jitter problem. On the other hand, photonic devices have high bandwidth and superior timing accuracy advantages, although their signal processing capability is inferior to electronic devices. Therefore a hybrid system would potentially combine the advantages of both technologies. Based on this idea, we studied a CMOS/photon A/D
the 4T1 (4G)-6A1 (6S) transition in the Mn2+ ion. Ba2Zn3S3: Mn2+
phosphors synthesized by double-crucible method have broad emission
spectra (550nm 750nm) with FWHM (full width at half maximum
broadband) about 66nm. In our research, the Ba2Zn3S3 doped with 0.7
at% Mn2+ has the highest luminescent intensity as thermal treatment
at 975 °C for 10 hours and the CIE coordinate is x=0.66, y=0.33.