SYMPOSIUM L

L: New Materials for Microphotonics

April 12 - 15, 2004

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* Invited paper

TUTORIAL

Photonic Micro- and Nanostructures
Monday April 12, 2004
1:30 PM - 5:00 PM
Room 2008 (Moscone West)

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 microresonater 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, with a focus 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 below the diffraction limit, sensing and Raman spectroscopy, and integration of metal nanostructures with dielectric microoptics 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 Maier, California Institute of Technology
Albert Polman, FOM-Institute AMOLF

SESSION L1: 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, Taejon, South Korea.

The efficient luminescence of silicon based materials has been a long-standing issue, since the combination of well-established silicon process technology and light emission functionality can pave the way for integrated silicon photonics. 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 for optical dopant of silicon. 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 RE-doped nc-Si is mediated via excitons of nc-Si similarly 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 silicon oxide (SRSO), which consists of nc-Si embedded in silica matrix. Rare earth doped SRSO films were fabricated with electron cyclotron resonance-plasma 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 temperature, 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/silica 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.

9:00 AM *L1.2
Rare Earth Doped Si Nanostructures For Microphotonics. Domenico Pacifici[1], Giorgia Franzo'[1], Simona Boninelli[1], Maria Miritello[1], Alessia Irrera[2], Fabio Iacona[2] and Francesco Priolo[1]; [1]Physics and Astronomy, INFM & University of Catania, CATANIA, Italy; [2]CNR-IMM, Sezione di Catania, CATANIA, Italy.

Silicon has an indirect band gap electronic structure and for a long time it has been considered a quite poor light emitter. In the last decade, a strong effort has been devoted towards the achievement of efficient light emission from silicon. Among the others, rare earth-doping of Si nanostructures is one of the most promising methods. Indeed, light emission two orders of magnitude more efficient than in pure insulating hosts has been obtained from different rare earths, due to the strong sensitizing action of Si nanocrystals. In this work we will show that upon introduction of the rare earth through ion implantation, the Si nanocrystals are completely amorphized and the subsequent annealing at 900°C is not able to recrystallize them. This demonstrates that amorphous as well as crystalline Si clusters are able to act as efficient sensitizers for the rare earths. Aim of this work is to understand the details of the interaction mechanisms occurring between Si nanoclusters and the rare earth ions, with a particular attention to the Er-doped Si nanoclusters system. A model based on an energy level scheme taking into account the coupling between each Si nanocluster and the neighboring Er ions will be reported. Through a comparison with photoluminescence data, a value of $3x10^{-15}$ cm^3s^{-1} for the coupling coefficient has been determined. Moreover, an energy transfer time of $\sim$1 μs has been estimated, confirming that Si nanoclusters can actually play a crucial role as efficient sensitizers for Er. However, a strong cooperative up-conversion mechanism, active between two excited Er ions and characterized by a coefficient of $7x10^{-17}$ cm^3s^{-1}, is shown to limit the Er excitation rate at high pump powers. The role of Si nanoclusters and of strong gain limiting processes, such as cooperative up-conversion and confined carriers absorption from an excited nanocluster, in determining positive gain at 1.54 μm will be investigated in details, and the implications of the finite transfer time on the overall efficiency of the energy transfer mechanism will be discussed. In view of the realization of an all-Silicon based optoelectronics, high efficiency, tunability, spectral purity and directionality of the light emission are important issues to be first addressed. Indeed, a highly directional and pure light emission from both Si nanocrystals and rare earth-doped Si nanoclusters can be obtained by embedding the emitting centers in an all Si based optical microcavity. Moreover, the feasibility of efficient electrical pumping of both Si nanocrystals and rare earths doped Si nanoclusters embedded in light emitting diodes will be demonstrated. The impact of these findings on the future development of an all Si based microphotonics will be discussed.

9:30 AM L1.3
Optical properties of Si:Er nanolayers grown by sublimation MBE method. Nguyen Vinh[1], Boris Andreev[2] and Tom Gregorkiewicz[1]; [1]Van der Waals-Zeeman Institute, University of Amsterdam, Amsterdam, Netherlands; [2]Institute for Physics of Microstructures, Nizhny Novgorod, Russian Federation.
Si/Si:Er multi-nanolayer structures grown by sublimation MBE technique exhibit unusual optical properties which make them very interesting for photonic applications. In particular, recent investigations show that preferential formation of a single type of optically active Er-related center can be successfully realized in these structures. In that way one of the basic requirements for development of optical amplifier based on Si:Er is finally fulfilled. Using magneto-optical spectroscopy we show that the Er-related center optically active in the nanolayers is characterized by the orthorhombic-I symmetry, as predicted by some theoretical models in the past. We show that practically all the major spectral features appearing in luminescence from the nanolayers originate from the dominant center. Low-temperature high-resolution time-resolved spectroscopy shows that the Er-1 spectrum is characterized by an ultra-narrow linewidth of ?E = 10 microeV, which represents most probably the smallest value ever measured for emission band in a semiconductor host. The extremely small linewidth indicates large absorption cross-section and opens new hopes for the possibility of optical amplification in Si:Er. [1] N.Q. Vinh et al. Phys. Rev. Lett. 90, 066401(2003).

9:45 AM L1.4
The dot size effect of amorphous silicon quantum dot on 1.54-μm Er luminescence. Nae-Man Park[1], Tae-Youb Kim[1], Gun Yong Sung[1], Baek-Hyun Kim[2], Seong-Ju Park[2], Kwan Sik Cho[3], Jung H. Shin[3], Jung-Kun Lee[4] and Michael Nastasi[4]; [1]Applied Devices Research, Basic Research Lab., ETRI, Daejeon, South Korea; [2]Materials Science and Engineering, KJIST, Kwangju, South Korea; [3]Physics, KAIST, Daejeon, South Korea; [4]Materials 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 cluster on Er PL in Si-rich SiO_2 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 $1x10^{21}/cm^3$ into nitride films containing a-Si QDs to overlap the profiles of Er ions and a-Si QDs. Finally the samples were annealed at 950 ^oC for 0.5 h in order to reduce the residual defects left 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 2.0 nm, below which a small dot is very effective in the efficient luminescence of Er.

10:30 AM *L1.5
Ultra-low-threshold erbium-implanted toroidal microlaser on silicon. Albert Polman[1,2], B.K. Min[1], J. Kalkman[2], T.J. Kippenberg[1] and K.J. Vahala[1]; [1]California Institute of Technology, Pasadena, California; [2]FOM-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 SiO_2 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. By carefully tuning the fiber-resonator distance, different modes of operation could be probed. Laser cavity quality factors as high as $4x10^7$ are achieved, corresponding to a modal propagation loss as low as 0.007 dB/cm. Single-mode lasing is observed at a launched power threshold as low as 5 μW, much lower 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 (over 10 %) is observed at Er doping levels around 1 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 Er^{3+}. The green emission provides a high-resolution probe of the resonator mode fields. We think this work will open up a whole new field of microresonator science and technology. For example, Si-based microresonators can now be implanted with other rare earth ions to fabricate lasers that operate in the visible, with noble metals to form nanocrystals with well-defined surface plasmon resonances and associated non-linear properties, and with Si quantum dots that can serve as sensitizers for Er or may show lasing in the near-infrared. Several of these new applications will be discussed.

11:00 AM L1.6
Rare-earth doped microlasers by sol-gel surface functionalization of ultra-high-Q microcavities. Lan Yang and Kerry J Vahala; Applied Physics, Caltech, Pasadena, California.

Sol gels provide a highly flexible technique for preparation of both planar and non-planar oxide thin films. They also enable the incorporation of various dopants into the films. In this work we describe the application of erbium-doped sol gel films to surface functionalize optical microresonators. The resulting microlaser devices are especially interesting because their emission band falls in the important 1.5 μm window used for optical communications. Both microsphere and ultra-high-Q microtoroid resonators-on-a-chip (see Armani, Spillane, Kippenberg, Vahala, Feb 27, 2003 Nature) were functionalized into lasers and then characterized. The erbium-doped sol-gel films were applied to the resonator surface and subsequently a CO2 laser was used to induce flow and densification of the sol-gel film on the surface. Optical quality thin films were obtained after the CO2 laser induced anneal. By varying the doping concentration and thickness of the applied sol-gel layers in microsphere resonators, we can vary the laser dynamics so that both continuous-wave and pulsation operation are possible. Single mode performance with high differential quantum efficiency was also obtained using the ultra-high-Q microtoroid resonator. These chip-based microlasers enable integration with other optical or electronic functions (see Yang, Armani, Vahala, Aug 04 2003 App. Phys. Lett.).

11:15 AM L1.7
High Index Contrast Silicon Oxynitride Materials Platform for Er-Doped Microphotonic Amplifiers. Sajan Saini, Jessica Sandland, Anat Eshed, Daniel Knight Sparacin, Jurgen Michel and Lionel C. Kimerling; Dept. of Materials Science & Engineering, MIT, Cambridge, Massachusetts.

Er-based optical amplification continues to be the ideal low noise, WDM crosstalk free, broadband candidate for waveguide amplifiers. Design analysis of the applicability of Er-Doped Waveguide Amplifiers (EDWAs) for micron-scale integrated photonics in a planar lightwave circuit concludes: (i) an >80x increase in gain efficiency, and (ii) a >40x increase in device shrink can be realized, for a high index contrast EDWA (with a core-cladding index difference of 0.1<->0.7), compared to a conventional Er-doped fiber amplifier. The materials challenge now is to establish a robust materials system which meets this high index difference design requirement while simultaneously leveraging the capability of silicon (Si) processing: a host platform for EDWAs must be found which can integrate with Si Microphotonics. Silicon nitride (Si3N4), silicon oxide (SiO2) and a miscible silicon oxynitride mixture (SiON) of the two meets this materials challenge. We present the results of reactive and conventional magnetron sputtering based materials characterization for this high index host system. Room temperature and 4 K photo-luminescence studies for annealed samples show the reduction of non-radiative de-excitation centers while maintaining an amorphous host structure. Atomic force microscopy shows less than 1 nm peak-to-peak roughness in deposited films. Prism coupler measurements show a robust reproducibility of host index of refraction with waveguide scattering loss <2 dB/cm. We conclude that the SiON host system forms an optimal waveguide core for an SiO2-clad EDWA. Preliminary optical amplification measurements will be presented.

11:30 AM L1.8
Optical and structural investigation on the energy transfer in a multicomponent glass co-doped with Si nanoaggregates and Er3+ ions. Francesco Enrichi[1], Giovanni Mattei[1], Cinzia Sada[1], Enrico Trave[1], Elisabetta Borsella[4], Mauro Falconieri[5], Domenico Pacifici[2], Giorgia Franzo[2], Francesco Priolo[2], Fabio Iacona[3] and Michel Prassas[6]; [1]Physics Department, INFM - University of Padova, Padova, Italy; [2]INFM - University of Catania, Catania, Italy; [3]CNR - IMM Catania, Catania, Italy; [4]ENEA - Frascati, Frascati (Roma), Italy; [5]ENEA - Casaccia, Roma, Italy; [6]Corning SA, Avon, France.

The enhancement of the Er^{3+} ions photoluminescence (PL) emission at 1.54 μm in a Si and Er co-implanted aluminosilicate 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 N_2 atmosphere is not sufficient to induce Si precipitation for the investigated temperatures, up to 500°C. Nevertheless, the most intense Er^{3+} 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 could be small Si aggregates and not only crystalline clusters. The effective excitation cross section of Er^{3+} ions has been measured in the best performing sample yielding a value of 2×10^{-16} cm^2, many orders of magnitude higher than the direct absorption cross section of Er^{3+} ions: about 10^{-21} cm^2 in this glass. The structural and optical properties of this material are discussed and compared to those found for a standard silica substrate.

11:45 AM L1.9
Selective excitation in multi- nanolayers of Si:Er with resonant exciton generation. Mark Klik[1], Boris Andreev[2] and Tom Gregorkiewicz[1]; [1]Physics, Van der Waals-Zeeman Institute, Amsterdam, Netherlands; [2]Institute for Physics of Microstructures, Nizhny Novgorod, Russian Federation.

By using infrared and mid-infrared radiation we were able to get a unique insight in the processes of energy transfer between ions of the rare earth Erbium and its Si host. The multi-layered samples that were studied are grown with a special sublimation MBE technique

that produces optical centers, which emit light in extremely narrow spectral lines. The presence of silicon spacers in the structure facilitates an efficient generation of excitons. Differences were observed in the power dependence and absorption cross-section of the 1.5 micron Erbium photoluminescence when exciting the Erbium either via resonantly generated excitons or via electron-hole generation, which enables us to identify two 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
Ultra-Small 2-D Photonic Crystal Lasers. Y. H. Lee, H. Y. Ryu and H. G. Park; Physics, KAIST, Taejon, South Korea.

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 inherent nondegenerate mode that has a node at the center through which electrical current could flow. It turns out that the introduction of a small post in the middle of the resonator does not introduce noticeable optical losses and, therefore, does not degrade the quality factor of the resonator appreciably. A feasible current injection scheme through this 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 communications. Very low-threshold lasing action from 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
Active Metallic Photonic Crystals in the Infrared. Jim Fleming and Shawn-Yu Lin; Sandia National Labs, Albuquerque, New Mexico.

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 thermal emission well in excess of that of a blackbody, cavity emitter over a range of wavelengths near the band edge. In this presentation we will further discuss our results in this area. We will also examine the deviation in total energy emitted from these structures from the value predicted by Stefan-Boltzmanns law. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL 85000.

2:15 PM L2.3
Compact All Pass Transmission Filter using Photonic Crystal Slabs. wonjoo suh and shanhui fan; Electrical Engineering, Stanford University, Stanford, California.

Optical all pass filters have been useful for applications such as optical delay or dispersion compensation and the demand for making compact optical filters is currently increasing. In all pass reflection filters such as Gires-Tournois 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 consist 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 a more compact 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.

2:30 PM L2.4
Tunable infrared emitters and sensors from periodic lattices: theory and experiment. Rana Biswas[1], Changgeng Ding[1], Yiying Ye[1], Ihab El-Kady[2,1], Irina Puscascu[3], Edward Johnson[3], Martin Pralle[3], James Daly[3], Anton Greenwald[3], Brian Kinkade[3], Michael McNeal[3] and Nicholas Moelders[3]; [1]Dept. of Physics, Microelectronics Res Ctr and Ames Lab, Iowa State University, Ames, Iowa; [2]Sandia National Labs, Albuquerque, New Mexico; [3]Ion-Optics Inc., Waltham, Massachusetts.

Tunable infrared emitters 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 coated lattices. Transfer-matrix simulations describe well 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 optimum structures. The 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)

3:15 PM *L2.5
Band-gap and localized states properties of CMOS-compatible complex photonic structures. Luca Dal Negro[1], Michael Stolfi[1,2], Yasha Yi[1], John LeBlanc[2], John Haavisto[2], Jurgen Michel[1] and Lionel Kimerling[1]; [1]MIT, Cambridge, Massachusetts; [2]CHARLES 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 largely increased after the fabrication of the first one dimensional (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 microphotonics is still under debate. To investigate the potentialities of this stimulating approach, Periodic, Quasiperiodic, A-periodic 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 $\lambda/4$ Bragg condition at 1.55 μm) according to different well known non-periodic sequences. Thue-Morse quasicrystals, Fibonacci quasicrystals, Randomly Disordered and Periodic Photonic Crystals (PBGs) have been grown under the same processing conditions in order to perform the first comparative study of the omnidirectional band-gaps and localized states properties under different regimes of layers organization. Good quality Thue-Morse (TM) a-periodic structures have been experimentally fabricated and the presence of wide omni-directional band-gaps have been demonstrated in these systems for the first time through variable-angle FTIR analysis. 1) R.Merlin, K.Bajema, R.Clark, F.Y.Juang, P.K.Bhattacharya, Phys.Rev.Lett., 55, 1768, (1985) 2) L.Dal Negro, C.J.Oton, Z.Gaburro, L.Pavesi, P.Johnson, A.Lagendijk, M.Righini, L.Colocci, D.Wiersma, Phys.Rev.Lett., 90, 5,

art.num.055501-1 (2003)

3:45 PM L2.6
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 320 email: lckliau@saturn.yzu.edu.tw Photonic band gap (PBG) crystals are functional structures in which certain frequency ranges can be forbidden during the propagation of electromagnetic waves. One of the practical methods to fabricate PBG crystal in 3-D structure starts from colloidal crystals following with self-assembly methods. For opal-based PBG crystals, the fabricating procedure includes the steps of colloidal crystal synthesis, dispersion, sedimentation and thermal treatments; each one of the steps can affect the PBG properties, such as stop band range and location. Therefore, the difficulties of developing multiple stop bands within a crystal are increased due to the complex fabricating procedures. In the developed process, the preparation of colloidal particle size by a sol-gel process and the operation of the self-assembly step are found the most essential factors to influence the PBG properties. In this work, different colloidal sizes of samples are mixed and prepared using sol-gel methods. The prepared samples can affect the stack layers and structural regularity for forming PBG crystals. Furthermore, the PBG properties of the prepared samples can be varied by the self-assembly methods to improve the stop band intensity and determine the stop band range and location shift with different temperature treatments. The effects of compositions of different colloidal sizes and thermal treatment conditions on the opal-based PBG properties were evaluated using a design of experiment (DOE) method. In addition, the interactions of the different colloidal sizes to form a crystal were also discussed in the material structure viewpoints by analytical instruments. The results can be applied to fabricate the multiple stop bands of a PBG crystal.

4:00 PM L2.7
3D Photonic Crystals with Point Defects at Near-Infrared. Minghao Qi, Elefterios Lidorikis, John D Joannopoulos and Henry I Smith; Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

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 an easy upgrade to 3D for 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 defects 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.

4:15 PM L2.8
optical spectroscopy of silicon-on-insulator waveguide photonic crystals. Matteo Galli[1], Michele Belotti[1], Daniele Bajoni[1], Maddalena Patrini[1], Mario Agio[1], Lucio Andreani[1], Giorgio Guizzetti[1], David Peyrade[2] and Yong Chen[2]; [1]Dept. of Physics, University of Pavia, Pavia, Italy; [2], LPN-CNRS, Marcoussis, France.

We report on a complete optical investigation on two-dimensional silicon-on-insulator (SOI) waveguide photonic crystals obtained by electron beam lithography and reactive ion etching. Optical characterization of the photonic band structure and transmission properties are obtained by means of variable-angle reflectance (VAR) and edge-coupling techniques. The investigated samples consisted in a) large-area (300μm x 300 μm) 2-D graphite lattices of pillars and triangular lattices of holes and b) small-area triangular lattices of holes with different number of periods and/or line defects integrated in a 6 μm wide by 2mm long ridge-type waveguide structure. In the case of large area samples, variable-angle reflectance is measured from the sample surface in a wide spectral range from 0.2 to 2 eV. Measurements are performed from near-normal incidence up to 70 degrees by means of micro-reflectometer coupled to a Fourier-Transform spectrometer, in both TE and TM polarizations and along the high symmetry directions of the brillouin zone. The sharp resonances observed in the polarized reflectance spectra give evidence of the quasi-guided modes and allows mapping of the photonic band structure above the light-line by determining the energy and angular dependence of the resonant structures. Photonic bands are determined and compared to those calculated by means of an expansion on the basis of the waveguide modes. In the case of ridge-type waveguide integrated photonic crystals, transmission measurements are performed in the 0.9-1.7 eV spectral range by means of an home-made spectroscopic microscope, where the white-light from a Hg arc-lamp is coupled to one cleaved edge of the waveguide and then collected at the other cleved edge. Measured transmission spectra give clear evidence of TE-like and TM-like photonic gaps along the Γ-M and Γ-K directions respectively, even when a small number of hole periods is integrated in the ridge waveguide. Good agreement is obtained by comparing the measured transmission spectra with the calculated photonic bands and simulated transmission, indicating good guiding properties and relatively low losses through the SOI photonic crystal waveguides.

SESSION L3: Plasmonics
Chair: Francesco Priolo
Wednesday Morning, April 14, 2004
Room 2008 (Moscone West)

8:30 AM *L3.1
Coupling in Plasmonics: From Plasmon Polariton Modes in Films to Nanostructures and from Active to Passive Structures. Harry A. Atwater, Luke A. Sweatlock, Jennifer A Dionne, Robb Walters, Julie S Biteen and Albert Polman; Thomas J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, California.

Localized surface plasmon excitation on metal surfaces, in thin films and in metal nanoparticles can form the basis for optical waveguides operating either 1) below the diffraction limit, at nanoscale dimensions, with quite large attendant loss/length or 2) in smooth planar films with very low(db/cm) loss. A challenge for plasmonics is to define the engineering of waveguide circuit architectures that allow in-coupling of light into surface plasmon modes from optical sources with low coupling and propagation loss, but which also enable light localization in volumes of a few cubic nanometers, where the high (eV/nm) local electric fields may enable nonlinear phenomena to be exploited for modified spontaneous emission from dipole emitter sources, for optical switching and for molecular detection. We describe recent work defining the thickness-dependent plasmon polariton dispersion relations for thin films that enable estimation of wavelength- and wavevector-dependent propagation loss and critical coupling angles from radiative free space modes. Experimental observation of eV/nm fields in nanoparticle chain arrays and an assessment of the coupling from dipole emitter sources to plasmon-supporting nanoparticles will be discussed.

9:00 AM *L3.2
Plasmon-enhanced absorption and SERS of ordered metal nanowire arrays. Ralf B. Wehrspohn[1,2], Yun Luo[2], Kornelius Nielsch[2], Ulrich Goesele[2], Guido Sauer[3], Sigfried Schneider[3], Heinrich Graener[4] and G. Seifert[4]; [1]Department of Physics, University of Paderborn, Paderborn, Germany; [2]Max-Planck-Institute of Microstructure Physics, Halle, Germany; [3]Department of Physical Chemistry, University Erlangen-Nuremberg, Erlangen, Germany; [4]Department of Physics, University Halle, Halle, Germany.

We have prepared 2D arrays of hexagonally arranged, monodisperse 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 nanowire arrays. This is also confirmed by scanning-nearfield 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 ex-situ for 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 the in-situ 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 etching conditions, neighboring wires are forming sheaves as observed by SEM. For this cofiguration, we observe an increased SERS signal as theoretically predicted at the sheave connection points. Interestingly, we observe even for typically SERS-inactive metals like nickel a clear SERS signal in the sheave configuration supporting the model of huge field enhancement at the connection points.

9:30 AM L3.3
Advancement in Fabricating Layer-by-Layer Photonic Band Gap Crystals by Modified Microtransfer Molding Techniques. Henry Kang[1,3], Kristen Constant[1,3], Rana Biswas[3,2], Chang-Hwan Kim[2,3], Yong-Sung Kim[2,3], Jae-Hwang Lee[2,3], Wai Leung[3] and Kai-Ming Ho[2,3]; [1]Materials Science and Engineering, Iowa State University, Ames, Iowa; [2]Physics and Astronomy, Iowa State University, Ames, Iowa; [3]Ames 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 PDMS 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 volume% nano-scale colloidal ceramic slurry 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. Kalkman[1], J.A. Dionne[2], L.A. Sweatlock[2], C. Strohhofer[1], H.A. Atwater[2] and Albert Polman[1,2]; [1]FOM-Institute AMOLF, Amsterdam, Netherlands; [2]California 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 microphotonic 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 coupling between erbium and the metal involves a broad distribution of momentum components, thereby resolving the mismatch problem. We then utilize a grating structure at the Ag-silica interface to couple the plasmon mode to a far-field photonic mode. By selecting the grating vector to match the momentum difference between photon and plasmon, plasmon energy can be coupled out at a well-defined, frequency-dependent, angle. As a result of the high-frequency selectivity of the coupling, we detect large variations in the emission spectrum from Er in the metallo-dielectric grating, depending on output angle. The enhancements are in agreement with calculations based on the plasmon dispersion relation. In this way, the Er emission bandwidth was enhanced by up to a factor 2, and distinct behavior is detected for s and p polarizations. Surface plasmons at near-infrared wavelengths have propagation lengths of the order of hundreds of microns. By using thin metal films or stripes -rather than a semi-infinite metal- the propagation length can be further enhanced. Our calculations show that for a 20 nm thick Ag film, plasmon propagation lengths at 1.5 μm can exceed 1 cm. This enables the design and fabrication of a new class of photonic integrated circuits in which optical information is propagating in highly concentrated plasmonic modes. To test these calculations, and to study the radiation damping effect of imperfections (such as side wall and surface roughness) we present experimental data on the propagation of 1.5 μm surface plasmons along Ag films, imaged by rare earth probe ions placed in the plasmonic mode.

10:00 AM L3.5
Photon Scanning Tunneling Microscopy for Surface Plasmon Excitation and Characterization. Rashid Zia[1,2] and Mark Brongersma[1]; [1]Materials Science and Engineering, Stanford University, Stanford, California; [2]Electrical Engineering, Stanford University, Stanford, California.

In recent years, the optical properties of metals have been the subject of renewed interest. Researchers have proposed the use of metal optics in regimes where conventional dielectric optics are inoperable. In particular, much attention is now focused on the potential of guiding "light" below the diffraction limit in the form of surface plasmon polaritons (SPPs) along metallic nanostructures. The propagation of SPPs is critically dependent upon the structural and optical properties of the metal. It is therefore important to develop techniques that can study these properties at short (sub-wavelength) length scales. To date, researchers have mainly relied upon Near-Field Scanning Optical Microscopes (NSOMs) or prism-based Photon Scanning Tunneling Microscopes (PSTMs). Here, we describe an alternative dual-objective PSTM which has been used to excite and characterize SPP propagation. We have converted 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 wide, 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 well-established frequency, polarization, and incidence angle dependencies of SPPs excitation. Specifically, we have mapped the near-field intensity of the excited SPPs at visible frequencies (488 and 514 nm) for smooth Au films with thicknesses from 30-40nm. Due to the use of the TIRF objective, the nature of the excitation beam differs significantly from prism-based PSTMs. We propose a model to describe both the momentum and spatial distributions of the excitation beam, and this model has been used in combination with the momentum and field coupling conditions 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.

SESSION L4: Nanocrystals
Chair: Harry Atwater
Wednesday Morning, April 14, 2004
Room 2008 (Moscone West)

10:30 AM L4.1
Low loss silica waveguides containing Si nanocrystals. Cristina Garcia[1], paolo pellegrino[1], Blas Garrido[1], Jose Antonio Moreno[1], Joan Ramon Morante[1], Mirko Melchiorri[2], Nicola Daldosso[2], Lorenzo Pavesi[2], Gerard Sarrabayrouse[3], Marzia Carrada[4], Caroline Bonafos[4] and Alain Claverie[4]; [1]Electronics, University of Barcelona, barcelona, Spain; [2]Physics, University of Trento, Trento, Italy; [3]LAAS - CNRS, Toulouse, France; [4]Ion Implantation Group, CEMES - CNRS, Toulouse, France.

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 excess nominally 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 to high doses 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 (HREM). The actual Si excess content was obtained by X-ray photoelectron spectroscopy. The rib-loaded structure of the waveguides was fabricated by photolitographic and reactive-ion-etching processes, with patterned rib widths ranging from 1 to 8 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 excess, in perfect agreement with HREM. 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 Kim[1], Dae Won Moon[1], Moon-Seung Yang[2], Ji-Hong Jhe[2] and Jung-Hoon Shin[2]; [1]Nano Surface Group, Korea Research Institute of Standards and Science, Daejeon, South Korea; [2]Physics, Korea Advanced Institute of Science and Technology, Daejeon, South Korea.

The control of size and density of Si nanocrystal(nc-Si)s is an

important factor to determine the energy and intensity of the photoluminescence. PL properties of SiNx films were studied as a function nitrogen content. SiNx films were grown by ion beam sputter 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(x) of the SiNx was directly analysed by in-situ x-ray photoelectron spectroscopy (XPS). The relative sensitivity factor (RSF)s of Si 2p and N 1s peaks were calculated by comparison of the in-situ XPS analysis and RBS results of a preliminarily grown SiNx film. After thermal annealing process, HR-TEM image showed the existence of Si nanostructures, 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 500-650 nm imply the possibility that SiNx thin film is promising material for full-color light-emitting device.

11:00 AM L4.3
Optical study of amorphous silicon quantum dots embedded in silicon nitride thin films. Tae-Youb Kim[1], Nae-Man Park[1], Yong-Jai Cho[2] and Gun Yong Sung[1]; [1]Basic Research Laboratory, ETRI, Daejeon, South Korea; [2]Division of Optical Metrology, KRISS, Daejeon.

Although bulk silicon has the indirect transition property, silicon nanostructures having a quantum confinement effect have provided a breakthrough to optoelectronic applications. Since the discovery of visible photoluminescence from porous silicon at room temperature, several researches were consecrated for applications of this silicon to optoelectronic devices. This exciting discovery has stimulated growing experimental and theoretical interest in understanding the optical properties of semiconductor structures with reduced dimensions like silicon. Amorphous silicon (a-Si) has important advantages compared with bulk crystalline Si : The luminescence efficiency is higher than the bulk crystalline Si and the band gap energy of bulk a-Si (1.6 eV) is larger than that of bulk crystalline Si (1.1 eV), so a-Si is a good candidate for short-wavelength luminescence. 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 investing the size information of a-Si QDs. Samples were prepared by plasma enhanced chemical vapor deposition, where argon-diluted 10% SiH_4 and N_2 were used as reactant gas sources. Photoluminescence and optical absorption energy measurement of a-Si QDs with various sizes revealed that 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 matrix 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 L4.4
Spectroscopic Ellipsometric Study of SiO_2/nanocrystalline-Si Superlattices. Hosun Lee[1], Kang-Joo Lee[1], Tae-Dong Kang[1], Seung Hee Hong[1], Suk-Ho Choi[1], Kyung Jung Kim[2] and Dae Won Moon[2]; [1]Dept. of Physics, Kyung Hee University, Suwon, Kyonggi, South Korea; [2]Nano Surface Group, KRISS, Taejeon, South Korea.

Using variable-angle spectroscopic ellipsometry, we measured the pseudo-dielectric functions of as-deposited and annealed SiO_2/SiO_x superlattices (SLs). The SiO_2(2nm)/SiO_x(2nm) 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 SiO_x 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 SiO_2/nc-Si SLs as a mixture of nc-Si and SiO_2. 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 stoichiometery of SiO_x in as-deposited SiO_2/SiO_x 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 Si_2^+ ions in SiO_x layers of as-deposited SLs, according to in-situ 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 L4.5
Optical Studies of Nucleation and Growth of CdTe Nanoparticles in Glass Microspheres with CO_2-Laser Excitation. Anuranjita Tewary[1], April S Montoya Vaverka[3], Subhash H Risbud[3] and Mark L Brongersma[2]; [1]Department of Applied Physics, Stanford University, Stanford, California; [2]Department of Materials Science and Engineering, Stanford University, Stanford, California; [3]Department of Chemical Engineering and Materials Science, University of California, Davis, Davis, California.

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 bulk glasses and microspheres during CO_2 ($\lambda = 10.6$ um) laser annealing. Microspheres are fabricated by heating the sharp tip of a fiber pulled from a bulk sample of CdTe-doped borosilicate glass. Spheres of diameters ranging from 50 um to 300 um have been made. Nanoparticle 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 CO_2 laser in a few minutes with laser powers as low as 1W/mm^2. 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 dependant reflection measurements, in microspheres and in bulk samples are used to obtain information on the 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 microspheres 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 nanoparticles, control of the surface roughness, and the knowledge gained from the PL measurements may be of importance to the development of a microsphere laser.

11:45 AM L4.6
Defect- versus nanocrystal- related luminescence from Si^--implanted sapphire. Suk-Ho Choi[1], Sung Kim[1], C. J. Park[2], H. Y. Cho[2] and R. G. Elliman[3]; [1]College of Electronics and Information and Institute of Natural Sciences, Kyung Hee University, Suwon 449-701, South Korea; [2]Quantum-functional Semiconductor Research Center and Dept. of Physics, Dongguk University, Seoul 100-715, South Korea; [3]Electronic Materials Engineering Department, Research School of Physical Sciences and Engineering, Australian National University, Canberra, Australian Capital Territory, Australia.

The light-emitting and structural properties of Si nanocrystals in (1102) sapphires have been studied by cathodoluminescence (CL), photoluminescence, and transmission electron microscopy. Implantation with 30 keV Si ions and subsequent annealing at 1100^{o}C create Si crystallites of about 4 5 nm diameter together with extended defects parallel to the (0001) planes of (1102) Al_2O_3. The luminescence properties of these samples strongly depend on annealing temperature and implant dose. The CL bands found in Si^--implanted sapphires before and/or after annealing are compared with those from O^-- and Al^-- implanted ones. Among 3 major CL bands, a yellow CL band at 2.16 eV is shown to be nanocrystal-related and the other ones at 3.92 and 4.11 eV defect-related. These properties are very different from those of similar samples using SiO_2 films and fused silica as host materials.

SESSION L5: New Concepts and Devices
Chair: Jung Shin
Wednesday Afternoon, April 14, 2004
Room 2008 (Moscone West)

1:30 PM *L5.1
Silicon Nanocrystal Optical Modulator. Robert J Walters[1], Harry A Atwater[1], Robert Lindstedt[2] and George I Bourianoff[2]; [1]Applied Physics, California Institute of Technology, Pasadena, California; [2]Intel Corporation, Portland, Oregon.

Silicon nanocrystals are a promising candidate material system for future CMOS compatible microphotonic devices. Nanocrystal based optical memory structures have previously been demonstrated in

which the detected intensity of photoluminescence is modulated by the charge stored on the silicon nanocrystal array embedded in the device. The change in photoluminescence is attributed to an Auger 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 optical modulator 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 by 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 semitransparent 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 with the application of 8V. Our 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 in the nanosecond range although leakage conduction paths also play a role. 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 Lordi, 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 of 1300-1600 nm are important not only for 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 GaInNAsSb, are promising material systems for realizing quantum well (QW) devices on GaAs that operate in this wavelength range. Electroabsorption spectra of GaInNAs and GaInNAsSb QWs with GaNAs barriers grown in p-i-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/GaNAs QWs showed characteristics suitable for optical modulation operating at 1300 nm, while the GaInNAsSb/GaNAs QWs operated around 1550 nm. Electroreflectance and photoluminescence spectroscopies were used to further study a series of transitions near the apparent band edge that correspond to different N nearest neighbor configurations. Rapid thermal annealing (RTA) shifts the distribution of configurations toward those with larger band gaps. The anneal-induced blue shift of the operating wavelength saturates after the material has homogenized. The exciton lineshape at 295 K was found to be Gaussian, rather than Lorentzian, indicating a strong exciton-phonon 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 400-425 °C was followed by RTA at 720-800 °C for up to 3 min. The test device consisted of a GaAs p-i-n diode with a 0.5 μm thick intrinsic region containing the QWs. GaInNAs active regions included up to nine QWs (8 nm thick) with 20 nm barriers; GaInNAsSb active regions contained up to 3 QWs. The GaInNAs composition was 1.6% N and 30% In, while the GaInNAsSb 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 KIim and Suntae 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 automated manufacturing. Major 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 devices such as mode converter, grating, 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 RMF 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 diplexer, triplexer and ECL(External Cavity Laser). In this paper, we will present the detailed results of our recent R&D activities for hybrid integrated microphotonics.

3:15 PM *L5.4
Revolutionary Innovations In Microphotonics.
Kevin Kidoo Lee, LNL Technologies, Cambridge, Massachusetts.

The growth of the microelectronics industry in the past 40 years has been governed by the ability to scale down devise 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 a truly scalable platform. We report over 8000 % improvement in mode conversion efficiency for 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 microphotonics. This coupling solution is used for efficient coupling of microphotonic circuits to external fibers, 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 microphotonics. We also report a method of automated 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 dB standard deviation for 3600 repeated measurements. This method shall dramatically reduce the cost of test and measurement of microphotonic devices. With these innovations, microphotonics 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 Catrysse[1], Mark Brongersma[2] and Shanhui Fan[1]; [1]Department of Electrical Engineering, Stanford University, Stanford, California; [2]Department 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-length scales. Recently, we explored 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 photonics and plasmonics at the nanometer scale. In these technologies, metal interconnect feature sizes reach down below 100 nm, enabling the design of nano-slits and nano-apertures that allow control of optical signals at subwavelength dimensions. 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 plasmonic devices, we are developing a laboratory-on-chip environment. This environment consists of a CMOS image sensor chip with more than 100,000 pixels, each of which is designed as an independent, integrated laboratory containing its own nano-photonic or plasmonic device-under-test, photodetector and signal processing circuitry. Such an approach enables us to perform rapid prototyping and to do exhaustive design space exploration. We are evaluating the approach using metal layers with one-dimensional arrays of nano-slits and two-dimensional arrays of nano-apertures, including square, triangular, coaxial, and

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 conjunction with three-dimensional 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 Guney[1,2] and David A. Meyer[2]; [1]Electrical & Computer Engineering, University of California, San Diego, La Jolla, California; [2]Mathematics, 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 part. The post-processor is mainly composed of 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 ϵ and the magnetic permeability μ in some frequency range. This follows from a recently proven general theorem. The negative values of ϵ and μ 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 ϵ and μ 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 Deopura, 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 2.7/1.46 is achieved with an omnidirectional range spanning over 150nm. Instrumented nanoindentation procedures have been developed to assess Youngs modulus and hardness for these very fine laminates 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.

SESSION L6: Poster Session: New Materials and Devices for Microphotonics
Chairs: Mark Brongersma, Chris Buchal, Francesco Priolo and Jung Shin
Wednesday Evening, April 14, 2004
8:00 PM
Salons 8-9 (Marriott)

L6.1
Fabrication of Quantum Grid Infrared Photodetectors. Gerard Dang, K. K. Choi and John Little; US Army Research Lab, Adelphi, Maryland.

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 configurable 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) epi-structure used for the detectors 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 broadband absorption range of the material 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.

L6.2
Fabrication of Photonic Crystals in Microchannels. Chun-Wen Kuo[2,1], Hui-Mei Hsieh[2,1], Jung-Chuan Ting[3,1], Yi-Hong Cho[1], Kung Hwa Wei[2] and Peilin Chen[1]; [1]Inst. Appl. Sci. & Res. Eng., Academia Sinica, Taipei, Taiwan; [2]Material Science and Engineering, National Chiao Yung University, HsinChu, Taiwan; [3]Department of Chemistry, National Chung Cheng University, ChaiYi, Taiwan.

Photonic crystals, with their potential ability in controlling the propagation of light, have attracted a lot of research attentions lately. One of the most frequent approaches to fabricate such type of three-dimensional periodic nanostructures is to utilize self-assembly of monodisperse nanospheres. 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 nanospheres 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.

L6.3
Active photonic crystal devices in self-assembled electro-optic polymeric materials. J. Li[1], P. J. Neyman[2], M. Vercellino[3], J. R. Heflin[2], R. Duncan[3] and S. Evoy[1]; [1]Electrical Engineering, Univ. of Pennsylvania, Philadelphia, Pennsylvania; [2]Department of Physics, Virginia Tech, Blacksburg, Virginia; [3]Luna Innovations, Blacksburg, Virginia.

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

offer a completely new, yet much powerful mechanism for the control of light compared to the traditional way relied in general on the total internal reflection mechanism. However, most work to date in these areas involve the fabrication of passive structures such was waveguides. The development of a photonic crystal technology in electro-optic (EO) materials would now provide a novel approach for the development and integration of important active devices such as switch, interferometers, etc. We report such development of a novel active photonic crystal technology that uses ionically self-assembled multilayer (ISAM) as materials platform. Specifically, we concentrate on ISAM film grown from the alternate deposition of individual monolayers of Procion Red MX-5B (PR) and poly(allylamine hydrochloride) (PAH). Films grown with this method show a second harmonic generation (SHG) factor $\chi(2)$ as high as 11 x 10-9 esu, and a r33 coefficient of 3 pm/V. Active photonic crystal are designed and demonstrated in this material using the FEMLAB software. In a first design, a simple switch is implemented by simple shift of the photonic crystal bandgap of a waveguiding structure. A Mach-Zehnder photonic crystal interferometer structure is also demonstrated, in which a 1800 phase shift is readily obtained between the two arms. The realization of 2D photonic crystals operating at $\lambda = 1.55$ μm is also reported in these materials. Using a combination of electron beam lithography and reactive ion etching (RIE), photonic crystals composed of 250 nm-diameter hole with center to center spacings of 420 nm have been achieved. We will report on the preliminary realization of active photonic crystal devices using this novel material self-assembly and nanofabrication platform.

L6.4
Abstract Withdrawn

L6.5
The Investigation of Erbium Complexes and Erbium Doped Silica Matrices. Seunghoon Lee, Ung Kim, Juntae Kim and Sangman Koo; Chemical Engineering, Hanyang University, Seoul, South Korea.

Erbium ion (Er^{3+}) doped materials are of great interest for their optical amplification, lasing and frequency up-conversion properties. A major problem that often arises when preparing such materials is the formation of Er-rich oxide clusters that induce optical quenching, even at low Er^{3+}-ion concentrations, which severely reduced the optical yield. Such clustering might be avoided by preparing suitable precursors. If an encapsulation of the Er with optically silent alkoxy derivatives, e.g. Al, Ti, Zr, Ta, and Nb, clustering can be avoided and higher doping levels can be achieved. The optically silent alkoxy deriviatives surrounding the Er^{3+} are more easily dispersed in the matrix material. In this study, erbium phenoxide complex was obtained by metathesis reaction of erbium chloride ($ErCl_3$) with potassium phenoxide (KOPh). And Heterometallic complexes were also synthesized by encapsulation of the Er with Al, Ti derivatives. In addition, the Er-doped silica matrices using the erbium complexes were investigated about their optical properties. The complexes were characterized by elemental analysis, infrared spectroscopic analysis, near infrared emission, nuclear magnetic resonance spectroscopy, and UV-vis spectroscopy. Their crystal structures were determined by X-ray single crystal diffraction analysis. Moreover, the Er-doped silica matrices were characterized by scanning electron microscopy, transmission electron microscopy, and photoluminescence spectroscopy.

L6.6
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 have attracted much attention since they can be used to achieve many critical functions such as filters and add/drop multiplexers in a microphotonic circuit. Furthermore, if the microdisk is optically active, it can act as a compact, high efficiency light source due to its low-threshold lasing operation. Recently, we have shown that optical gain at 1.54 μm is possible in Er-doped silicon-rich silicon oxide, which consist of nanocrystal Si embedded inside an SiO_2 matrix. In this work, we report on fabrication and characterization of Er-doped SRSO microdisk. Er-doped SRSO film was deposited on a Si (100) substrates by electron cyclotron resonance plasma enhanced chemical vapor deposition of SiH_4 and O_2 with co-sputtering of Er. The film was subsequently annealed at 900 °C for 30 min to form Si nanocrystals in silica matrix. Standard photolithography techniques were used to define circular photoresist masks with diameters in the range of 10-30μm on Er-doped SRSO film. Buffered oxide etcher was then used to transfer patterns into Er doped SRSO film. After removing the photoresist masks using acetone, the Si substrate was etched anisotropically using KOH solution, leaving a disk of Er-doped SRSO supported by a Si pedestal in the center. The microdisks show strong room temperature Er^{3+} luminescence at 1.54 μm, with luminescence lifetimes in the range of 3-8 msec. We find that the Er^{3+} PL intensity and lifetimes are unaffected by the entire fabrication process, demonstrating the advantage of using Er-doped SRSO. Furthermore, the Er^{3+} luminescence is obtained in a top-pumped configuration, which greatly simplifies the photonic circuit design. FDTD calculations show that the microdisks support whispering gallery modes that are confined near the disk perimeter. The experimental results of mode characterizations will be presented, and the possibility of realizing Si-based lasers using Er-doped SRSO microresonators will be discussed.

L6.7
Electroluminescent devices based on Si nanoclusters and rare earth doped Si nanoclusters. Alessia Irrera[1], Domenico Pacifici[2], Maria Miritello[2], Fabio Iacona[1], Giorgia Franzo'[2], Delfo Sanfilippo[3], Gianfranco Di Stefano[3], PierGiorgio Fallica[3] and Francesco Priolo[2]; [1]CNR-IMM, Catania, Italy; [2]Department of Physics, INFM & University of Catania, Catania, Italy; [3]STMicroelectronics, Catania, Italy.

We have studied the structural, electrical and optical properties of MOS devices, where the dielectric layer consists of a substoichiometric SiO_x (x ⟨ 2) thin film deposited by plasma enhanced chemical vapor deposition. After deposition the SiO_x films were annealed at high temperature to induce the separation of the Si and SiO_2 phases with the formation of Si nanocrystals (nc) embedded in the insulating matrix. When the devices are polarized, a strong light emission at room temperature has been observed at a wavelength of about 900 nm. Devices emitting at different wavelengths have been fabricated by implanting the SiO_x films with rare earth ions; in particular, devices based on Er-doped Si nanoclusters exhibit an intense 1.54 μm room temperature EL, while devices based on Tm-doped Si nanoclusters exhibit two EL peaks at 0.78 μm and 1.7 μm. The effects of the Si concentration in the SiO_x layer and of the annealing temperature on the electrical and optical properties of these devices are reported and discussed. We have also studied in details the electroluminescence (EL) properties of such devices as a function of the time, of the current density and of the temperature to elucidate the radiative and non-radiative de-excitation properties of the system. We have evaluated the excitation cross section of Si nc under electrical pumping at room temperature, by finding a value of $4x10^{-14}$ cm^2; this value is about two orders of magnitude higher than that relative to the optical pumping (at 488 nm) of the same system. We have also calculated the excitation cross section for Er ions in presence of Si nanoclusters under electrical pumping and we have found a value of about $1x10^{-14}$ cm^2, very similar to that one found for the electrical excitation of undoped Si nanocrystals, confirming the active role played by Si nanoclusters in the excitation of Er ions also under electrical pumping.

L6.8
Blue-green luminescence from Carbon doped Silicon-Rich Silicon Oxide. Se-Young Seo and Jung H. Shin; KAIST, Taejon, South Korea.

The report of efficient luminescence from silicon-rich silicon oxide, which consist of Si nanocrystal embedded inside SiO2 matrix, has led to many investigation of SRSO as a possible material that can realize active Si-based microphotonics. However, the luminescence from SRSO has been limited to the infra-red range despite controlling the nc-Si size down to the nm range. In fact, recent results suggest that the luminescence observed from SRSO is due to oxygen-related surface states, and that obtaining visible luminescence from SRSO is difficult even though the bandgap of nc-Si itself is sufficient for such visible luminescence. On the other hand, such result indicate that by carefully engineering the nc-Si surface to introduce competing luminescent states, visible luminescence from nc-Si may be obtained. In the presentation, we report on the result using carbon co-doping of SRSO. Carbon co-doped SRSO films were fabricated with electron cyclotron resonance-plasma enhanced chemical vapor deposition using SiH_4, CH_4, and O_2, followed by a high temperature anneal. FTIR measurements indicate presence of Si-C bonds, but no C=O or C=C bonds. We obtain intense blue-green luminescence, naked to the visible eye under ambient conditions, from C co-doped SRSO after an anneal at 900 °C. The luminescence peak blue-shifts with increasing C concentration, but redshifts with increasing anneal temperature. Interestingly, strong redshift is also observed with increasing excess Si and C content, even though the excess Si / C ratio was kept constant. Based on the results, we argue that the luminescence is unlikely to be due to formation of oxycarbide phases. Rather, we argue that the results can be explained consistently by assuming that the luminescence is due to formation of carbon-related luminescence centers in the nc-Si. Furthermore, achievement of blue luminescence opens the door to obtaining luminescence in the the entire visible range. In fact, we demonstrate that by using Tb as an optical dopant

for C co-doped SRSO, strong green luminescence, visble to the naked eye under ambient conditions, can be obtained. These results indicate the possibility that all-Si 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 (< 15nm) Oxide Films.
Nick Chiang[1], Robert J Walters[1], Harry A Atwater[2], Robert Lindstedt[2] and George I Bourianoff[2]; [1]Applied Physics, California Institute of Technology, Pasadena, California; [2]Intel Corporation, Portland, Oregon.

Silicon nanocrystal floating gate memories are promising candidates for future 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 and high temperature 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 (100nm) 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 8nm and analyzed the resulting depth distribution of optically active nanocrystals via photoluminescence 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 Sik Cho[1], Nae-man Park[2], Jung H. Shin[1] and Seong-Ju Park[3]; [1]Department of Physics, Korea Advanced Institute of Science and Technology, Daejon, South Korea; [2]Electronics and Telecommunications Research Institute, Daejon, South Korea; [3]Materal 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 easily integration with optical component since Si is indirect bandgap material. It is reported that nm-sized Si can emit visible light at room temperature due to quantum confinement effect. Recently the electrical and optical properties of nc-Si light emitting devices 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. SRSO films are prepared by electron-cyclotron resonance plasma enhanced chemical vapor deposition of SiH4 and O2 with varying SiH4 gas flow rate. C-doped SRSO films were prepared by co-flowing CH4 during deposition of SRSO. Typical SRSO photoluminescence spectrum peaked at 800 900nm from quantum confined excitons in the nc-Si was obtained after an annealing at 1100oC for 30min. Many combinations of p-type, p+ type, n-type, and n-type Si subtrates and top contact materials of Poly-Si, ITO, 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 150nm 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 oC. 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 photodetection.
Benoit Van Delle[1], Jean Francois Damlencourt[1], Benoit Cluzel[2], Vincent Calvo[2], Jean Marc Fedeli[1] and Thierry Billon[1]; [1]CEA-LETI, GRENOBLE, France; [2]CEA-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/Si islands. Ge is an attractive material due to its band gap 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-Krastanov growth steps, i.e. 2D growth followed by 3D growth : pyramids are first initiated and evolve to domes 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 developments have been achieved at 650°C. Gas-phase parameters (germane partial pressure and total pressure) highly act on surface density and domes size : domes surface densities up to 1.8E10 per square centimetre were obtained, with diameter and height of 70 and 10 nm respectively. Next, growth 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 layers. Islands growth is modified either by strain field induced by buried islands and by silicon layer surface morphology. Different regimes of vertical and in-plane 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 optical applications. We analyse optical properties of miscellaneous 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 SiO_x films and Si/SiO_2 superlattices.
Simona Boninelli[2], Fabio Iacona[1], Corrado Bongiorno[1], Corrado Spinella[1] and Francesco Priolo[2]; [1]CNR-IMM, Catania, Italy; [2]Department of Physics, INFM & University of Catania, Catania, Italy.

Si nanoclusters embedded in SiO_2 have been produced by isothermal and isochronal thermal annealing processes of SiO_x 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 dark field transmission electron microscopy (DFTEM). The comparison of the EFTEM and DFTEM data has demonstrated that as deposited SiO_x films are homogeneous and fully amorphous materials, without any evidence of phase separation; the first steps of the phase separation between Si and SiO_2 become visible at 900 °C, but well defined amorphous Si clusters are formed only at 1000 °C. At 1100 °C the amorphous clusters start to become crystalline, and the crystalline fraction increases by further increasing the annealing temperature. Furthermore, the capability of the EFTEM technique to detect all the Si clusters, independently of their crystalline state, has allowed us to make a very reliable determination of some parameters, such as the Si nanocluster mean radius and density as a function of the annealing temperature. These parameters are not available, or can be derived with a quite high degree of uncertainty, by using conventional dark field or high resolution TEM analyses. Finally, the availability of a much more complete quantitative picture allowed the demonstration that amorphous Si clusters constitute a relevant fraction of the overall population in samples annealed at intermediate temperatures and play also a fundamental role in determining the photoluminescence properties of the system. Si nanoclusters have been also produced by thermal annealing of Si/SiO_2 superlattices deposited by PECVD. Different annealing temperatures have been adopted to induce the formation and the crystallization of Si nc. The structural analysis performed by EFTEM and DFTEM on the annealed samples shows the formation of grains, whose size depends on the experimental conditions. From the comparison of the above techniques it has been also possible to demonstrate that the early stages of the formation of crystalline grains involve the formation of an amorphous Si network, in which the Si nc are embedded. The above new evidences constitute a relevant step for a full comprehension of the structural and optical properties of Si nanoclusters and for their application for the development of a Si-based optoelectronics.

L6.13

Effects of Annealing Atmosphere on the Bonding Characteristics and Optical Properties of SiON Films Prepared Plasma Enhanced Chemical Vapor Deposition. KiJun Yun, Dong-Ryeol Jung, SungKil Hong, JongHa Moon and JinHyeok Kim; Department of Materials Science and Engineering, Chonnam National University, KwangJu, South Korea.

SiON thin films were deposited by plasma-enhanced chemical vapor deposition (PECVD) method at 350 ^oC using N_2O/SiH_4 gas mixtures as precursors. As-deposited SiON films were annealed in different gas atmospheres (air, N_2, and O_2) and at different annealing temperatures (800^oC 1100^oC). Effects of annealing atmosphere on the Si-O,Si-N, Si-H and N-H bonding characteristics in SiON films and their structural and optical properties have been investigated. Cross-sectional and planar microstructures were characterized by scanning electron microscopy and atomic force microscopy, crystallinity was investigated by X-ray diffraction. Chemical bonding characteristics and optical properties SiON films were studied using fourier transform infrared spectroscopy, x-ray photoelectron spectroscopy, and prism coupler. X-ray diffractions showed no evidence of any crystals in all SiON films. The deposition rate strongly depended on the processing parameters such as RF power, N_2O/SiH_4 flow ratio, and SiH_4 flow rate. Deposition rate increased as N_2O/SiH_4 flow ratio increased and SiH_4 flow rate increased. It was possible to obtain SiON films with a surface roughness of 1 nm and a high deposition rate of 4_μm/h when the processing parameters were optimized as RF power of 200W, N_2O/SiH_4 flow ratio of 3, SiH_4 flow rate of 100sccm. It was observed that the intensity and the shift of the Si-O stretch and Si-N peaks depended on the annealing atmosphere as well as the annealing temperature. The intensity of Si-O peaks increased in the samples annealed in oxygen atmosphere, but it decreased in the sample annealed in nitrogen atmosphere. The intensity of Si-N peaks decreased in the samples annealed in oxygen atmosphere, but it increased in the sample annealed in nitrogen atmosphere. The position of Si-O peaks shifted from 1030 nm to 1140 nm in the sample annealed in oxygen and nitrogen atmosphere. It was also observed that the intensities of Si-H(2250 cm^{-1}) and N-H(3550 cm^{-1}) peaks decreased apparently as the annealing temperature increased in the samples annealed in air and in nitrogen atmosphere. However, the intensity of Si-H peak increased as the annealing temperature increased in the sample annealed in O_2 atmosphere. Details about the opitcal properties of SiON films will be further discussed.

L6.14

Sovolthermal Synthesis and Characterization of $Zn(NH_3)CO_3$ Single Crystal. Fushan Wen[1,2,3], Jiesheng Chen[2], Taeun Kim[1], Jin Hyeok Kim[1] and Wenlian Li[3]; [1]Center for Photonic Materials and Devices, Materials Science and Engineering, Chonnam National University, Kwangju, South Korea; [2]State Key Laboratory of Inorganic Synthesis & Preparative Chemistry, College of Chemistry, Jilin University, Changchun, China; [3]Key Laboratory of the Excited States Process, Changchun Institute of Optics, Changchun, China.

A new 3-dimensional zinc carbonate $Zn(NH_3)CO_3$ 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 $Pna2_1$ with M = 142.41, a = 9.1449(18) $\AA$, b = 7.5963(15) $\AA$, c = 5.4982(11) $\AA$, V = 381.95(13) $\AA^3$, Z = 4, R = 0.0285 and RW = 0.0745. The NH_3 and CO_3^{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) $\AA$ and one nitrogen atom at distance of 2.014(6) $\AA$. 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 exited and emission peaks are located at about 350 nm and 426 nm, respectively. The powder of the compound also shows photovoltaic effect in the range from 300 nm to 390 nm with the peak at about 325 nm.

L6.15

Hydrothermal Synthesis of Ce^{3+} and Tb^{3+} co-doped $Ca_3Al_2(OH)_{12}$ Luminescent Material. Fushan Wen[1,2,3], Jiesheng Chen[2], Jinhyeok Kim[1], Taeun Kim[1] and Wenlian Li[3]; [1]Dept.of Mater.Sci.& Eng., Photonic and Electronic Thin Films Lab, Kwangju, South Korea; [2]College of Chemistry, State Key Lab of Inorganic Synthesis & Preparative Chemistry, Changchun, China; [3]Key Lab of the Exited States Process, Changchun Institute of Optics, Fine Mechannics and Physics, Chinese Academy of Scineces, Changchun, China.

Ce^{3+} and Tb^{3+} co-doped calcium aluminates luminescent material ($Ca_3Al_2(OH)_{12}$: Ce^{3+}, Tb^{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 initial mixture were CaO: Al_2O_3: Na_2O: Tb_4O_7: CeO_2: H_2O = 1 : 2 : 2 : 0.02 : 0.01 : 175. 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 $Ca_3Al_2(OH)_{12}$. The emission spectrum showed that only typical Tb3+ emission was observed and the emission from Ce^{3+} was almost not observed, which should be attributed to the energy transfer from Ce^{3+} to Tb^{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 $^5D_4$-$^7F_6$, $^5D_4$-$^7F_5$, $^5D_4$-$^7F_4$, and $^5D_4$-$^7F_3$ transitions of Tb^{3+} ions. The weak emission peak at about 380 nm should be assigned to the transition of Ce^{3+} ions in the compound.

L6.16

Characterization of strontium-titanate-oxide thin films for optical devices applications. Mounir Gaidi[2], Luc Stafford[1,2], Mohamed Chaker[2], Joelle Margot[1] and Mykola Kulishov[3]; [1]Departement de physique, Universite de Montreal, Montreal, Quebec, Canada; [2]INRS-EMT, Varennes, Quebec, Canada; [3]Adtek Photomask, Montreal, Quebec, Canada.

Strontium-titanate-oxide (SrTiO3 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-laser-deposition technique. In this work, the influence of the oxygen deposition pressure on the film microstructural properties and on the film optical quality is investigated. From x-ray diffraction spectrometry, it is found that the crystallization quality of the film strongly decreases with increasing O2 pressure. This degradation is accompanied by an increase of the film porosity, as observed using both scanning electron microscopy and Rutherford backscattering spectroscopy (RBS). RBS depth profiles also show that the film composition remains quite homogeneous, even though a non-uniform amorphous phase is observed near the silicon substrate surface for all deposition pressures. A closer analysis of the RBS spectra also indicates that the Sr:Ti ratio remains close to one for any O2 pressure, while an important excess of oxygen atoms is observed. The penetration of exceeding oxygen atoms into the STO film is found to take place in the space separating the grains. As a consequence, oxygen atoms are trapped at the grain boundaries, and not within the grains. On the other hand, as the O2 pressure increases, the optical quality of the film deteriorates, thereby indicating a direct relation between the microstructural properties of the film and its optical quality. Based on these observations, the relationship between microstructure, density, film composition, and optical properties is established. Finally, the influence of the growth conditions on the STO patterning characteristics is discussed.

L6.17

Electro-Optical Properties of Na0.5K0.5NbO3 Films on Si by Free-Space Coupling Technique. Alexander M Grishin and Sergey I Khartsev; Condensed Matter Physics, Royal Institute of Technology, Stockholm-Kista, Sweden.

Highly polar axis oriented 3μm thick Na0.5K0.5NbO3 (NKN) films have been grown on Pt(100nm)/Ti(10nm)/SiO2/Si(001) substrates by rf-magnetron sputtering. Semitransparent gold electrodes (diameter of 2 mm) were deposited ontop the NKN films by a thermal evaporation through the contact mask. Processing parameters have been specially optimized to obtain "electrosoft" NKN film: with a non-linear fatigue-free P-E characteristics: low remnant polarization 3.6 μC/cm$\hat{2}$, induced polarization as high as 26 μC/cm$\hat{2}$ @ 522 kV/cm, and the coercive field as low as 39 kV/cm. Electro-optical characterization of NKN/Pt/Si films has been performed using waveguide refractometry: 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/Pt/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 μm), modulation of the reflected light as high as 40% was achieved.

L6.18

Structure analysis of terbium aluminosilicate glass films for easily integrated magneto-optical components. Xiaoyuan Qi, Sang-Yeob Sung, Samir K. Mondal and Bethanie J. H Stadler; Electrical and Computer Engineering, U. of Minnesota, Minneapolis, Minnesota.

Integrating optical isolators with various optoelectronic devices allows sources to be integrated at lower costs and alignment and with longer lifetimes. Magneto-optical garnets are used in most bulk isolator components that utilize Faraday rotation. However, the deposition techniques of these garnets on some important substrates still need to be developed. We are investigating magneto-optical glasses 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 paramagnetic glasses, Tb3 ions have large Faraday rotation per ion and the glasses are transparent down to 1.6um. 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 glass films were composed of quasi-crystalline structures. By quasi-crystalline we mean that a broad peak was observed in the microdiffraction pattern around 2θ=30deg. 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-Si-O 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 $ZnBi_{0.001}Ga_2O_4$ and Mn^{2+} doped $ZnBi_{0.001}Ga_2O_4$.
Wonnyon Kim[1], H. L. Park[1], G. C. Kim[2] and J. S. Kim[1]; [1]Institute of Physics and Applied Physics, Yonsei University, Seoul, South Korea; [2]School of Liberal Arts, Korea University of Technology and Education, Cheonan, South Korea.

Optical properties for color transition behaviors between $ZnBi_{0.001}Ga_2O_4$ with λem = 450 nm and $Zn_{(1-x)}Bi_{0.001}Ga_2O_4$:x$Mn^{2+}$ 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 = 503 nm showed the different behaviors for the reduction and non reduction processes. The Mn^{2+} ion doped $ZnBi_{0.001}Ga_2O_4$phosphor exhibited the optimum peak wavelength of 503 nm under the reduction process, while the PL intensities of $Zn_{(1-x)}Bi_{0.001}Ga_2O_4$:x$Mn^{2+}$ materials have been decreased as the doping concentrations of Mn^{2+} ion were increasing under the non reduction process. The peak wavelength of $ZnBi_{0.001}Ga_2O_4$ (270 nm) has been shifted to the low energy of $Zn_{(1-x)}Bi_{0.001}Ga_2O_4$:x$Mn^{2+}$ (300 nm) for PLE spectra with λem = 503 nm under the reduction process. It indicates that the transition due to Bi^{3+} ion (blue) in $ZnBi_{0.001}Ga_2O_4$ has been transferred to Mn^{2+} ion (green) in $Zn_{(1-x)}Bi_{0.001}Ga_2O_4$:x$Mn^{2+}$. No great variations of peak wavelengths in $Zn_{(1-x)}Bi_{0.001}Ga_2O_4$:x$Mn^{2+}$ were appeared from PLE spectra with λem = 450 nm for reduction and non reduction processes. We also found that the decay time of $Zn_{(1-x)}Bi_{0.001}Ga_2O_4$:x$Mn^{2+}$ material was shortened as the doping concentration of Mn^{2+} 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 two different temperatures, 50 and 200 C. Glass, polyethylene, mica, silicon, and sodium chloride were used as amorphous 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 had different refractive indices although they 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 Baer[1], Guenter Huber[1], Jose Gonzalo[2], Angel Perea[2], Aurelio Climent-Font[3], Ferenc Paszti[3] and Munz Martin[4]; [1]Institute of Laser-Physics, University of Hamburg, Hamburg, Germany; [2]Instituto de Optica, CSIC, Madrid, Spain; [3]Departamento de Fisica Aplicada y ICMAM, Universidad Autonoma de Madrid, Madrid, Spain; [4]Federal 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 quality 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 10.39$\AA$ and thus, this value matches better the lattice constant of sapphire than Y2O3 leading to the production of films with less 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 [111] 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 films have no 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 no 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, including excitation in the VUV 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 bulk material, whereas films with a thickness$\leq$ 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 Tungsten-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 temperatures, Ar/O_2 processing gas flow ratio, processing pressure, and rf power from a $80TeO_2$-$20WO_3$ 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/O_2 gas flow ratio from 40sccm/0sccm to 0sccm/40sccm. 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 O_2 atmosphere. Details about structural and optical properties will be further discussed.

L6.23
Carbon layer as a new material for optics.
Richard Clergereaux[1], David Escaich[1], Steve Martin[2], Patrice Raynaud[1] and Frederic Gaillard[2]; [1]Laboratoire de Genie Electrique de Toulouse, Toulouse, France; [2]DTEN, Commissariat a l 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, such as plasma type (high/13.56MHz or low/100kHz frequency), 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 (sp2 rate, density), its optical properties (transparency, refractive index) and finally enable us to link structure and properties. Depending on monomer structure and/or plasma power, the carbon layer structure runs from polymer-like to graphite-like layers. For example, the sp2 rate can reach 30 to 80% when the monomer chain length increases (CH4 -> C4H10) and/or when the plasma power increase. Then, these films are transparent in different optical range: polymer-like generally cut in the visible optical range and graphite-like in the IR range (the optical band-gap runs from 0.1 to 2.6eV depending on the process). Furthermore, refractive index from 1.3 to 2.2 can be reached by scanning the plasma power. In addition, the plasma type mainly affects the deposition rate 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 from the external process parameters. As such layers can be easily etched by oxygen-fluorine mixture plasma, they can be used for a great number of optical components (light source, detector, amplifier, waveguide, optical sensor, etc.).

L6.24

TEM and PL Study of Stress Effects on Band Gap Properties of FeSi2 Precipitates. Yun Gao[1,2], Sai Peng Wong[1,2], Wing Yiu Cheung[1,2], Ning Ke[1,2], Quan Li[3,2], Guo Sheng Shao[4], Manon Lourenco[5] and Kevin Homewood[5]; [1]Dept. of Electronic Engineering, Chinese University of Hong Kong, Hong Kong, China; [2]Materials Science and Technology Research Centre, Chinese University of Hong Kong, Hong Kong, China; [3]Dept. of Physics, Chinese University of Hong Kong, Hong Kong, China; [4]School of Engineering, University of Surrey, Guildford, United Kingdom; [5]School 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. Tansmission electron microscopy (TEM) was used to determine the crystal 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 shape and a higher thermal quenching temperature. I addition, the 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. CUHK4231/03E)

L6.25

Kinetic analysis of the photoluminescent decay profiles of the excited state in amorphous tungsten and nickel doped PZT. Rubens Soeiro Goncalves, [1]DMM, CEFET-MA, Sao Luis, Maranhao, Brazil; [2]Tecnologia, UNESP, Araraquara, Sao Paulo, Brazil; [3]Quimica, UFSCAR, Sao Carlos, Sao Paulo, Brazil.

Photoluminescence studies of PZT powders at room temperature are presented. The polymeric precursor method was used to synthesize the pure and doped PZT powders. The polyester precursor was decomposed at 280 and 300 celsius degraus for 60 hours to obtain the amorphous phase. The experimental results suggest that the visible photoluminescence emission, at room temperature, could be related to the disorder structural, which is in the interface between amorphous and crystalline state. The photoluminescence properties were investigated and correlated with doping. Analysis of the photoluminescent decay profiles of excited state suggests two lifetimes. This analyze is developed for us at the first time in this research. The optical gap were calculated using the Wood and Tauc method whereas the absorption coefficient,a, was obtained from Kubelka-Mulk model using the UV_vis data. The powders were characterized also by DRX.

L6.26

Optical Second Harmonic Generation of Hemicyanine Dyes Incorporated in Zeolite Films. Hyun Sung Kim[1], Seung-mook Lee[2], Kwang Ha[1], Yun-Jo Lee[1], Doseok Kim[2], Bum Ku Rhee[2] and Kyung Byung Yoon[1]; [1]Chemistry, Sogang UNIV., Seoul, South Korea; [2]Physics, Sogang Univ., Seoul, South Korea.

Silicalite-1 films (thickness = 400 nm) supported on both sides of glass plates were prepared and hemicyanine dyes (HC-n) with different alkyl chain lengths (n, n = 3, 6, 9, 12, 15, 18, 22, and 24) were included into the silicalite-1 films by dipping SL/Gs into each methanol solution of HC-n (1 mM) for 1 d. The included number of HC-n per channel (NC) generally decreased with increasing n, i.e., they were 6.4, 23.1, 15.4, 8.2, 5.7, 3.5, 0.9 and 1.2 molecules per channel for n = 3, 6, 9, 12, 15, 18, 22, and 24, respectively. The d33 value gradually increased with increasing n but decreased when n > 18, i.e., they were 1.12, 0.50, 2.25, 3.59, 4.99, 5.30, 1.71, and 2.57 pmV-1 for n = 3, 6, 9, 12, 15, 18, 22, and 24, respectively. However, d33/NC progressively increased with increasing n. The d31 values were about 100 times smaller than the corresponding d33 values, and the average d33/d31 ratio was 109, which is 5 times higher than those of nonlinear optical (NLO) dyes in Langmuir-Blodgett (LB) films, and 30-50 times higher than those NLO dyes in poled polymers. The estimated average tilted angle of the dyes with respect to the channel direction was 7.7, and the calculated average order parameter was 0.97, which is about 480 times higher than the values observed from poled polymers. The degree of uniform alignment (DUA) generally increased with increasing n. The progressive increase in both DUA and d33/NC with increasing n is attributed to the increase in the tendency of HC-n to enter hydrophobic silicalite-1 channels with the hydrophobic alkyl chain first. More than 134-fold increase in DUA was observed upon increasing n from 6 to 24. The DUA of HC-24 in the silicalie-1 film was concluded to be close to 1. The HC-n-SL/Gs films retained their initial d33 values even after keeping them in the atmosphere for 1 year or at 395 K for 24 h. Although the observed d33 values were lower than the LB films of NLO dyes as a result of very small densities of the dyes in silicalite-1 channels, the methodology bears a great potential to be developed into the methods for preparing practically viable NLO films.

L6.27

Ordered Microparticle Structures in a Liquid Crystal −Formation and Physical Properties. Ke Zhang, Anatoliy Glushchenko and John L. West; Liquid crystal institute, Kent State University, Kent, Ohio.

Ordered colloids are of great scientific and practical interests. Liquid crystals offer enhanced ways of producing structurally ordered colloids. Single particles embedded in the visco-elastic liquid crystal medium create a number of new and fascinating effects. The collective behavior of colloidal particles associated with the nematic to isotropic phase transition has only begun to be investigated but demonstrated complex and novel physical phenomena such as drag effects and particles pumping effects. These new effects can be used to control the movement of the particles and to create a variety of particle structures in a liquid crystal matrix. The liquid crystal phase stabilizes these complex structures. We therefore studied the rheological and electro-rheological properties of the structured colloids as a means of probing this stabilization. We found that the mechanical properties of the colloids and stability of their 3D structures can be controlled by the particles size and distribution. In addition, when an electric field is applied, we observed an increase in the apparent viscosity with saturation at high electric fields. This effect depends on the shear rate and temperature. The results are also compared with the published data for the viscosity measurements of pure liquid crystals and isotropic colloids. While we are only beginning to understand the details of these complex colloids we expect they will find a wide variety of applications.

L6.28

Transparent Organic-Inorganic Nanocomposites for Optical Applications. Wenbin Hong, Marco Bersani, John H. Harreld and Galen D. Stucky; MC-CAM, UCSB, Santa Barbara, California.

Optically transparent nanocomposites were synthesized from trimethoxysilylpropylmethacrylate (TMSPM), methylmethacrylate (MMA) and titania nanoparticles using a modified sol-gel approach, which contained three steps. The organic network constituents (TMSPM and MMA) were firstly UV polymerized as precursors for inorganic network formation. After that, rutile-phase titanium nanoparticles were obtained by controlled hydrolysis of titanium tetrachloride in acidic solution. Finally, the nanoparticles were added to the precursors and the mixture was thermally cured to generate optically clear coatings as thick as 1.0mm with extremely low lateral shrinkage (<3%). NMR and FTIR results demonstrated the bonding between the titanium nanoparticles and the organic network. UV-VIS spectra suggested the good transparency of the nanocomposite in the visible region. The refractive index of the nanocomposite was found to increase with increasing titanium content. The thermal stability and hardness of the nanocomposite was considerably improved relative to pure PMMA and PMMA-TMSPM hybrid material. The results suggest that the nanocomposite has potential applications for optical devices.

L6.29

Comparison of Experimental and Theoretical Optical Properties of Perfluorocyclobutyl (PFCB) Polymers. John Ballato[1], Dennis W. Smith[2] and Stephen H. Foulger[1]; [1]Materials Science and Engineering, Clemson University, Pendleton, South Carolina; [2]Chemistry, Clemson University, Clemson, South

Carolina.

This paper computes the theoretical optical absorption spectrum for PFCB polymers and makes comparison to measured values over the spectral range covering the visible and near-infrared telecommunications bands. Structure-optical property relationships are provided. The results suggest that PFCB polymers provide for intrinsic attenuations below 10 dB/km in the visible and from 1.3 to 1.6 microns. The results are used to predict directions for the application of PFCB in optical fibers, planar lightwave circuits, and optical amplifiers.

L6.30
Microfabrication and Electro-optic Characterization of Perfluorocyclobutyl Polymers. S. Suresh[1], Shengrong Chen[1], Chris Topping[1], John Ballato[2], Stephen Foulger[2], Greg Nordin[3], Nazli Rahmanian[3] and Dennis W. Smith[1]; [1]Dept of Chemistry, Clemson University, Clemson, South Carolina; [2]School of Materials Science & Engineering, Clemson University, Clemson, South Carolina; [3]Center for Applied Optics and Department of Electrical Engineering, University of Alabama, Huntsville, Alabama.

Perfluorocyclobutyl (PFCB) polymers are developed for integrated microphotonics due to their unique combination of properties such as high temperature stability, controlled refractive index, excellent processability, variable thermo-optic coefficient, and low transmission loss. Novel chromophore monomers with high hyperpolarizability have been prepared and copolymerized. Synthesis, micro-fabrication using micro-molding as well as traditional RIE lithography, and electro-optic characterization is presented.

L6.31
Quantitation of Charged States of Conjugated Polymer Nanoparticles Using Electric Force Microscopy. Adosh Mehta[1], Pradeep Kumar[2], Thomas G. Thundat[1] and Michael D. Barnes[3]; [1]Life Sciences Division, Oak Ridge National Lab, Oak Ridge, Tennessee; [2]Department of Chemistry, University of Tennessee, Knoxville, Tennessee; [3]Chemical Sciences Division, Oak Ridge National Lab, Oak Ridge, Tennessee.

The ability to accurately detect and quantify charges on a nanoscale is becoming increasingly important as interest in nanoscale photonics and molecular scale electronics grows. A combination of Kelvin 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 stray charges 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 conjugated polymers could be created on other substrates, which would open up novel nanoscale photonic and electronic applications

L6.32
New Functionalized Copolyimides for Optoelectronic Applications. Arlen Valozhyn[1], P. Berczynski[1] and E. Schab-Balcerzak[2]; [1]Technical University of Szczecin, Poland, Szczecin, Poland; [2]Polish 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 optic (NLO) properties [1]. These materials have significant potential for such photonic devices as electro-optic modulation, high-speed photonic switching, sensors, sources of ultraviolet radiation & second harmonic generation. Apart from NLO properties, polymers for such applications should exhibit a high glass transition temperature, high thermal stability & good mechanical & thermomechanical properties. Polyimides can meet these requirements; they are one of the most promising group of polymeric materials for such special applications. The high thermal stability and the high glass transition temperature serves to minimize reorientation of chromophores , which is important for the stability of NLO activity at operating temperatures. Aromatic polyimides functionalized with chromophoric groups have shown promising potential for NLO device applications. NLO chromophores can be introduced into a polyimide as a side chain or guest-host NLO chromophore-polyimide system [2]. 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 chromopore groups in side chain are one of the most promising type of polymeric materials for application in second harmonic generation (SNG) 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 futher NLO modification with chromophore compounds. First group of polymers was prepared from benzophenonedicarboxylic dianhydride and diaminobenzoic acid or oxydianiline . The second kind of CPI or copolyimides was obtained from same diamines and biphenyldicarboxylic or cycloaliphatic dianhydride. The using different ratio of diamines and dianhydrides let to obtain a series of copolyimides. Polymers have been synthesized by low temperature polycondensation & with subsequent thermal cyclization. These polymers give flexible foils, which properties such as: mech., elec., optical & thermal stability were investigated. New side-chain CPI films bearing chromophore groups were syntesized and investigated References [1] Samyn C, Verbiest T and Persoons A 2000 *Macromol.RapidCommun.* **21** 1 [2] Sakai Y, Ueda M, Fukuda T and Matsuda H 1999 *J.Polm.Sci.Polym.Chem.* **37** 1321 [3] Schab-Balcerzak E, Sec D, Grabiec E, Volozhyn A and Khamenko T 2001 *HighPerform.Poym.* **13** 35

L6.33
Electroluminescence properties of new light-emitting poly(p-phenylene vinylene) derivatives with network structure in polymer chain. Jong Seok Song[1], In-Hee Chang[1], Kyu Il Han[1], Suk-Ho Choi[1], Min Ju Cho[2], Jae-Hong Kim[2] and Dong Hoon Choi[2]; [1]College of Electronics and Information and Institute of Natural Sciences, Kyung Hee University, Suwon 449-701, South Korea; [2]College of Environment and Applied Chemistry and Institute of Natural Sciences, Kyung Hee University, Suwon 449-701, South Korea.

A number of investigations have been carried out on the synthesis of poly(p-phenylene vinylene) (PPV) derivatives, which could be utilized as emitter in optoelectronic device applications. Recently, we have synthesized new PPV derivatives with network structure in the polymer chain formed by using cross-linker as a monomer. This design is based on the premise that the aromatic polymer chain could be connected by covalent bonding with no change of chromophore. Their absorption and photoluminescence spectral characteristics have been investigated in solution state as well as in film state to compare them with those 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-2003-005-C00001)

L6.34
Novel photopolymer composed of the photoreactive binders for holographic application: Effect of functionality of the monomer. Dong Hoon Choi, Hyuk Yoon, Min Ju Cho, Jae Hong Kim and Seung Hwan Lee; College of Environment and Applied Chemistry,, Institute of Natural Science, Kyung Hee University, Youngin, Kyungki, South Korea.

New photopolymers were designed and prepared using the thermoplastic and the photoreactive binders. Poly (vinylacetate-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 mono-, 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 behaviors of the grating formation were studied with the change of exposure intensity in terms of the diffraction efficiency. We also investigated the effect of photoreaction 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-methylstrene moiety in the polymer binder. a)Corresponding author: dhchoi@khu.ac.kr

L6.35
Photoinduced anisotropy and micro-patterning of a novel photochromic azo molecular material with spiro-bifluorene. Chaemin Chun, Mi-Jeong Kim, Doojin Park, Yong-Young Noh and Dong Yu Kim; Materials science & engineering, KJIST, Gwangju, Gwangju, South Korea.

Azobenzene-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 azobenzene groups and photoinduced dynamics of polymer chains. Recently, it was reported that amorphous molecular materials with azo chromophores could exhibit more efficient photodynamic behaviors and resulting surface relief gratings (SRGs) formation faster. Therefore, a novel azobenzene-based amorphous molecular material, spiro-ADA was designed and synthesized via a palladium catalyzed amination reaction. The introduction of bulky spiro linked bifluorene with the non-planar structure of triphenylamine of spiro-ADA prevented packing 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 modulation depth in SRGs. In addition, we also investigated charge transport of spiro-ADA containing four triphenylamine groups in the side of spiro-bifluorene.

L6.36
The characteristics of joints with Indium-silver alloy using diffusion soldering method. jeyoon kim, min soo Youm, 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 observed 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 compounds increases with the silver content, i.e. eutectic (144°C)< AgIn2 (166°C)< γ (300°C)< ζ(670°C)< β(695°C). And these compounds are determined by the composition of source metal ratio. Now we confirmed the thermal characteristics of Indium-Silver alloy is controlled by silver. Consequently we have developed Ag/In/Ag multi-layer composite which has higher melting point than that of normal contact. 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 microscopy) and 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 well LED, GaN/Si LED structure was made by using sapphire for substrate. And from the InGaN/adhesion/Si structure which has Pd-In adhesion layer, we substituted In-Ag layer for Pd-In adhesion layer. Consequently, the new structure which has In-Ag adhesion layer is going to 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 $Al_{1-x}In_xN$ (0.1⟨x⟨0.9) During Growth by Magnetron Sputter Epitaxy. T Seppanen[1], G Z Radnoczi[2], B Pecz[2], L Hultman[1] and J Birch[1]; [1]Thin Film Physics Division, Linkoping University, Linkoping, Sweden; [2]Research Institute for Technical Physics and Materials Science (MFA) of the Hungarian Academy of Sciences, Budapest, Hungary.

AlInN is a very attractive and useful III-V nitride alloy: e.g. $Al_{0.83}In_{0.17}N$ is predicted to be a good lattice-matched insulating 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 opto-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 miscibility gap give rise to unpredictable values of the band-gap for AlInN [3]. In this work, ternary wurtzite $Al_{1-x}In_xN$ thin films with 0.09⟨x⟨0.89 were grown onto (111)-oriented single crystal seed layers of TiN and ZrN by magnetron sputter epitaxy (MSE) using dual reactive direct current magnetron sputter deposition under ultra-high-vacuum conditions. Film compositions and lattice parameters were determined using Vegard/s law and high resolution X-ray diffraction (XRD), respectively. XRD also showed that the $Al_{1-x}In_xN$ films were epitaxially grown onto TiN and ZrN with the relations: $Al_{1-x}In_xN$[0001]//TiN(ZrN)[111] and $Al_{1-x}In_xN$<10-10>//TiN(ZrN)<110>. In the composition range 0.3⟨x⟨0.6 the measured c/a ratio deviates systematically from 1.62 to a minimum of 1.50, 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 phase-diagram for MSE of $Al_{1-x}In_xN$ between 300 and 900 °C was established. Single-phase alloy films could be obtained with 0⟨x⟨1 at 300 °C on both ZrN and TiN. However, at 600 °C, the solubility of In in the films was reduced to a maximum of x=0.6 and x=0.5 for ZrN and TiN, respectively. At 900 °C almost pure AlN was formed. Cross-sectional High-Resolution Electron Microscopy (HREM) verified that the solubility of In in the wurtzite $Al_{1-x}In_xN$ lattice was reduced at higher temperatures. An amorphous layer of pure In was formed on top of the $Al_{1-x}In_xN$ lattice at deposition temperatures $\geq$600 °C. The $Al_{1-x}In_xN$ 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 $Al_{1-x}In_xN$ where the structure tilted continuously, up to 30° with respect to the c-axis, toward the Al sputter source due to limited ad-atom mobility and self-shadowing effects. HREM showed that the columnar tilting is due to a lateral lattice parameter gradient within each column. These results show upon the possibility to grow single-phase $Al_{1-x}In_xN$ with 0.09⟨x⟨0.89 by MSE, without experiencing spinodal phase separation, at temperatures up to 600 °C. [1] S. Yamaguchi et.al. J. of. Crystal Growth 195, (1998) 309-313 [2] T. Takayama et.al. Jpn. J. Appl. Phys. 39, (2000) 5057-5062 [3] E. V. Kalashnikov, V. I. Nikolaev, MIJ-NSR: http://nsr.mij.mrs.org/2/3/complete.html

L6.38
Bonding a thin $In_{0.5}Ga_{0.5}P$ layer to GaP substrate for the heteroepitaxy growth of $(Al_xGa_{1-x})_{0.5}In_{0.5}P$. Po Chun Liu and YewChung Sermon Wu; Material Science and Engineering, Nation Chaio Tung University, Hsinchu, Taiwan.

The hetroepitaxy integration of III-V semiconductor compound, which was limited by the lattice mismatch, now can be accomplished by using relative twist angle wafer bonded compliant substrate. In this study, a novel method was used for the heteroepitaxy of $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ layer on lattice-mismatched (3.5%) GaP substrate for fabricating high brightness light emitting diodes (LEDs). A thin $In_{0.5}Ga_{0.5}P$ (50nm) layer which is lattice matched with $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ epitaxial alloy was bonded with GaP substrate. By using this buffer layer, $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ heteroepitaxy layers can be grown on the GaP substrate over critical thickness without high density threading dislocation.

L6.39
Near InfraRed (2.04mm) Material: GaInAs(NSb)/InP. Junxian Fu[1,2], Seth Bank[2], Mark Wistey[2], Homan Yuen[2] and James Harris[2]; [1]Department of Applied Physics, Stanford University, Stanford, California; [2]Solid State and Photonics Lab., Stanford University, Stanford, California.

GaInNAs on GaAs has been extensively studied in the optical communication field. The main mechanism of getting small bandgap materials working at 1.3um and 1.55um is that the small size of added nitrogen atoms, the bandgap bowling effect of GaNxAs1-x, and the strain in the active region layer grown on GaAs substrate significantly reduce the bandgap. On the other hand, the wavelength range of 2-2.5um is of specific interest to gas sensing, chemical detection, and especially near-infrared Fourier transform spectrometer. Latticed-matched Ga0.47-2.72xIn0.53+2.72xNxAs1-x, Ga0.47In0.53As1-x-yNxSby=2.56x grown on InP substrate has the potential to reach that wavelength with only a little bit of nitrogen introduced. In this paper, the GaInAs(NSb) sample was grown in two SSMBE 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 rf-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 studied include two quantum well structures, GaInAs/GaInAs(N)/GaInAs and GaInAs/GaInAs(NSb)/GaInAs. The sample growths were monitored by in-situ RHEED before and after the GaInAs(NSb) layer was grown. The samples were characterized by ex-situ XRD and room temperature photoluminescence. The effects of InP buffer layer and InGaAs buffer layer on the samples growth were investigated. The nitrogen incorporation under different growth condition was studied by varying substrate temperature, growth rate and antimony flux. Room temperature photoluminescence shows peak wavelength at 2.04um.

L6.40
Structural Characterization of Molecular Beam Epitaxy Grown GaInNAs and GaInNAsSb Quantum Wells by Transmission Electron Microscopy. Tihomir L Gugov, Mark Wistey, 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 telecommunication fiber-optic networks. Unfortunately, this 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 for 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 put this alloy 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. This is correlated with Energy Filtered TEM (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 Meulenkamp, 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 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 LED displays uses ink-jet printing, 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 to generate light, but also to 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
Integrated Optics/Electronics Using Electro-Optic Polymers. Larry R. Dalton, Dept of Chemistry and Electrical Engineering, University of Washington, Seattle, Washington.

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 femtosecond response times (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 defined the limits of electro-optic activity that can be achieved with a variety of material development approaches including exploitation of dendritic and dendronized polymer structures and self-assmebly, sequential synthesis fabrication. A clear paradigm for the short term improvement of electro-optic activity to values a 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 nanoscopically-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 including lattice hardness, and the presence of chemical and physical quenchers of singlet oxygen. It is clear that materials surpassing Telacordia standards can be prepared. Insights into the exceptional stability of organic electro-optic materials to space radiation will also be presented. Finally, organic electro-optic materials have been used to fabricate a variety of novel stripline, cascaded prism (and superprism), and ring microresonator (and photonic crystal) devices including devices that 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 antennae applications.

10:00 AM L7.3
Design and Fabrication of All-Polymer Photonic Devices. Claire L Callender[1], Jia Jiang[1], Chantal Blanchetiere[1], Julian P Noad[1], Robert B Walker[1], Stephen J Mihailov[1], Jianfu Ding[2] and Michael Day[2]; [1]Communications Research Centre, Ottawa, Ontario, Canada; [2]Institute of Chemical Process and Environmental Technology, National Research Council of Canada, Ottawa, Ontario, Canada.

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 relaxed compared to those for dense wavelength division multiplexing (DWDM) in 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 pentafluorostyrene modified fluorinated poly(arylene ether ketone)s. The presence of the pentafluorostyrene crosslinker allows thermal processing at lower temperatures ($<$200øC)and fluorination decreases the propagation loss around 1550 nm associated with the C-H vibration overtone. 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 patterning, metal lift-off and reactive ion etching. Although process variables such as spin coating parameters, baking temperatures and solvent 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 reduction, but often precludes the use of conventional methods 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 all-polymer waveguides will be presented, and their potential applications in CWDM systems discussed.

10:15 AM L7.4
Nonlinear Optical Properties of Two-Dimensional NLO Polymer Photonic Crystal Waveguides. Shin-ichiro Inoue and Yoshinobu Aoyagi; Interdisciplinary Graduate School of Science & Engineering, Tokyo Institute of Technology, Yokohama, Japan.

Photonic band structure features and large group velocity dispersion

characteristics in photonic crystals (PCs) are expected to find use in new active and novel high-efficiency nonlinear optical (NLO) applications 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 dispersions at the band edge and/or a very flat band, 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 and high-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 suboptical wavelength scale, is that 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. Second, we investigate the sum-frequency mixing (SFM) and second harmonic generation (SHG) processes in the PC-NLO hetero-waveguide-structure, and we demonstrate for the first time SHG and SFM spectra in the ultraviolet region and these strong enhancements originate from photonic band resonance in 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.

10:30 AM L7.5
Tunable Solid-State Lasers Incorporating Dye-Doped, Polymer-Nanoparticle Gain Media. F J Duarte[1] and R O James[2,1]; [1]Imaging Materials and Media, Eastman Kodak Company, Rochester, 14650, New York; [2]Private, 792 Oakridge Drive, Rochester, 14617, New York.

Tunable laser action, in the visible spectrum, has been established using dye-doped, polymer-silica nanoparticle gain media for the first time. The silica nanoparticles ranging from 9 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. Using rhodamine 6G dye and 30% weight-by-weight (w/w) silica nanoparticles, laser action was established in the 567-603 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 media also exhibits a reduction in dn/dT. Optics Letters, in press, November 2003.

10:45 AM L7.6
The Optical Properties of Perfluorocyclobutyl (PFCB) Polymers. John Ballato[1], Dennis W. Smith[2] and Stephen H. Foulger[1]; [1]Materials Science and Engineering, Clemson University, Pendleton, South Carolina; [2]Chemistry, Clemson University, Clemson, South Carolina.

As the interest in utilizing fluoropolymers in a greater number of value-added photonic applications continues to grow, so does the necessity for accurate and broad band characterization of their optical properties. This work provides the canonical optical properties of refractive index and extinction coefficient for two perfluorocyclobutyl-based polymers over the spectral range from approximately 0.13 ?m to 33 ?m, notes the structure-property relationships, and discusses the prospective applications of this family of fluoropolymers. The data also is used to compare conventionally used fits to dispersion data in order to elucidate the potential pitfalls in computing system-level design criterion, such as bandwidth.

SESSION L8: Electro-optics and Magneto-optics
Chair: Chris Buchal
Thursday Morning, April 15, 2004
Room 2008 (Moscone West)

11:00 AM *L8.1
Ferroelectric thin films for microphotonics. Bruce W Wessels, Northwestern U, Evanston, Illinois.

Ferroelectric thin film structures are being developed for microphotonics. Of particular interest are high band width electro-optic modulators. Both straight channel waveguide phase modulators and Mach-Zehnder waveguide modulators have been reported for $BaTiO_3$ ferroelectrics. $BaTiO_3$ 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 fim structure, whereby the substrate has a low microwave index. Recently we have been developing strip-loaded waveguides using $BaTiO_3$ for high bandwidth, thin film electro-optic modulators.Progress towards achieving a low V-πthin film ferroelectric modulator will be reviewed.

11:30 AM L8.2
Enhanced Faraday rotation in garnet films and multilayers. Soren Kahl and Alexander M Grishin; Condensed Matter Physics, Royal Institute of Technology, Stockholm, Sweden.

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, the high specific FR of approximately 23 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 the example of an 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 grown 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 compositions 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 0.2°/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 by in-situ crystallization. In addition, in the latter cases, the quartz substrate is often warped due to softening, but it was undamaged by the ultrashort anneal performed here.

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

1:30 PM L9.1
Reliable InGaAsP/GaAs 40W lasers grown in solid source

MBE with phosphorus-cracker. Guokui Kuang, Ivan Hernandez, Mark McElhinney, Linfei Zeng, Brian Caliva and Robert Walker; Lasertel Inc., Tucson, Arizona.

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 Al-free active region have shown strong 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 Al-free active region 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 290A/cm2 and slope efficiency as high as 1.36W/A were obtained at 25oC for uncoated laser chips with 1.0mm cavity length and 100um emitter size. Coated laser bars show very good reliability. After 857 hours burn-in at 47A (corresponding to around 47W) at room temperature, power degradation rate was measured to be less than 3x10-6/h. [1] M. Razeghi, et al, 14th IEEE International Semiconductor Laser Conference, 1994, 19-23 Sept. 1994, page: 159 -160 [2] R. F. Nabiev, et al, 16th IEEE International Semiconductor Laser Conference, 1998. ISLC 1998 NARA. 4-8 Oct. 1998, page: 43-44 [3] J. Sebastian, et al, IEEE J. Selected Topics in Quantum Electronics, Vol.7, 334 (2001) [4] S. L. Yellen, et al, IEEEE Photon. Technol. Lett., Vol.4, 1328 (1992) [5] J. K. Wade, et al, Appl. Phys. Lett., Vol.71, 172 (1997)

1:45 PM L9.2
High-Performance InGaAsN Quantum-Well Broad-Area and Single-Mode Ridge Lasers for Telecommunication.
Nelson Tansu[1], Jeng-Ya Yeh[2] and Luke J Mawst[2]; [1]Center for Optical Technologies, and Department of Electrical and Computer Engineering, Lehigh University, Bethlehem, Pennsylvania; [2]Reed 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 $In_{0.4}Ga_{0.6}As_{0.995}N_{0.005}$ 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 220 A/cm^2 (Lcav=2000-micron) and a transparency current density of 75 A/cm^2. Single-mode 1300-nm ridge lasers (width of 4-micron) with an $In_{0.4}Ga_{0.6}As_{0.995}N_{0.005}$ QW also exhibit low threshold-currents of only 15 mA for 1000-micron long-cavity devices at room temperature under continuous wave operation, corresponding to a threshold current density of 375 A/cm^2. Temperature characteristics of the threshold current of these single-mode ridge lasers correspond to T_0 values of 93 K, for the temperature range of 20 ^{0}C to 80 ^{0}C. Utilizing $GaAs_{0.85}P_{0.15}$ barriers directly adjacent to the QW to suppress the thermionic hole leakage, threshold current densities of only 390 A/cm^2 and 440 A/cm^2 were realized for $In_{0.4}Ga_{0.6}As_{0.995}N_{0.005}$ QW lasers (Lcav=2000-micron) at temperatures of 80 ^{0}C and 90 ^{0}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/cm^2 and 1010 A/cm^2, respectively.

2:00 PM L9.3
Selective Area Growth of AlGaInAs for Spot-size Converter Integrated Laser Diode. YoungChurl Bang, Hyun-Su Kim, Jun-Youn Kim, Eun-Hwa Lee, Jung-Kee Lee and Tae-il Kim; Telecommunication R&D center, Samsung electronics Co., Suwon, South Korea.

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 devices(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 in the conduction band and a high temperature stability. We have developed 1.3um AlGaInAs/InP SAG by MOCVD in order to fabricate SSC-LD for hybrid integration with passive devices. SiO2 patterning was varied from 50um to 200um and SAG open area was fixed to 15um and 20um. 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 an electron stop layer before 2 um thick p-InP cladding layer. The optical characteristics of grown materials were measured with 1um diameter spot micro-photoluminescence(PL) method. In the viewpoint of optical quality of selective grown AlGaInAs MQW structure, it is 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 area(MBA) were applied to the both side of mask open area. Compared to PL full width of half maximum(102meV) of selective grown 1.3um AlGaInAs MQW, that of MBA-used SAG was remarkably improved, which is 51meV at 5mW Argon laser power. PL intensity of MBA-used SAG is three times as strong as that of conventional SAG. This MBA-used selective AlGaInAs MQW was then applied to fabricate a RWG SSC-LD. The light output power-injected current(L-I) characteristics at various temperatures under CW operation show that the threshold current was 25mA and 62mA at 25°C and 85°C, respectively. Characteristic temperature between 25 and 85°C was determined to be 77K. The slope efficiency was 0.2W/A at 25°C and 0.11W/A at 85°C. The horizontal and vertical far field pattern(FFPH/V) were reduced from 25° and 42° to 22° and 30°, respectively. We have successfully demonstrated 1.3um AlGaInAs SSC-LD with MBA-SAG. Unlike SAG of InGaAsP, it is very difficult to optimize that of AlGaInAs for its high crystal quality. By suppressing the migration effect of SAG with MBA, the high crystal quality of AlGaInAs SAG was achieved. Reference [1]T. Sasaki et al., Proc. IPRM'98, pp.353-356, May. 1997.

2:15 PM L9.4
White Light Emitting Diode through Ultraviolet GaN-pumped $Sr_2Si_{1-x}Ge_xO_4 : Eu^{2+}$ phosphor. Jongsu Kim[1], P.E. Jeon[2], W.N. Kim[1], J.C. Choi[2], H.L. Park[1] and G.C. Kim[3]; [1]Institute of Physics and Applied Physics, Yonsei univ., Seoul, South Korea; [2]Department of physics, Yonsei univ., WonJu, Kangwondo, South Korea; [3]School of Liberal Arts, Korea University of Technology and Education, Cheonan, South Korea.

The $Sr_2Si_{1-x}Ge_xO_4 : Eu^{2+}$ phosphor is formed by means of a new synthesis method. The $Sr_2Si_{1-x}Ge_xO_4 : Eu^{2+}$ has the mean particle size of 100 nm and the spherical shape. The $Sr_2Si_{1-x}Ge_xO_4 : Eu^{2+}$ 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 Eu^{2+} ion doped in Sr^{2+} (1) sites with weak crystal field, while 560 nm peak is originated from Eu^{2+} ions on Sr^{2+} (2) sites with strong crystal field. As the increase of Ge^{4+} ions, the 470 nm emission intensity of the $Sr_2Si_{1-x}Ge_xO_4 : Eu^{2+}$ are more dominant. This behavior can be understood in terms of the effect of Ge^{4+} ions on the energy transfer from 470 nm band to 560 nm band through a mulipolar interaction. The fabricated white light emitting diode using ultraviolet InGaN chip or SiC chip with blue and yellow emitting $Sr_2Si_{1-x}Ge_xO_4 : Eu^{2+}$ phosphor shows higher color rendering index and higher color stability against input power in comparison with a commercial ultraviolet-pumped YAG:Ce^{3+}. This white light emitting diode can generate the white color with a various color temperature by controlling Ge^{4+} ion concentrations.

2:30 PM L9.5
New semiconductor GaNAsBi alloy grown by molecular beam epitaxy. Masahiro Yoshimoto[1], Wei Huang[1], Yuji Takehara[1], Akiyoshi Chayahara[2], Junji Saraie[1] and Kunishige Oe[1]; [1]Electronics and Information Sci., Kyoto Institute of Technology, Kyoto, Japan; [2]AIST Kansai, Ikeda, Japan.

New semiconductor $GaN_yAs_{1-x-y}Bi_x$ alloy with the GaBi molar fraction (x) up to 3.4% and the GaN molar fraction (y) up to 0.6% has been grown by molecular beam epitaxy (MBE). The alloy is suitable to realize both a temperature-insensitive bandgap in the wavelength region of optical fiber communication and the lattice constant matched to that of GaAs. This alloy will lead up to laser diodes with an emission of temperature-insensitive wavelength, which eliminates the use of massive temperature-control equipment in wavelength-division-multiplexing (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 $GaAs_{1-x}Bi_x$ grown by metalorganic vapor phase epitaxy (MOVPE) showed weak temperature dependence. The Bi incorporation into the

epilayer was achieved at a low substrate temperature (T_{sub}). Since activated nitrogen can be supplied without a decomposition process of a nitrogen source on the growing surface in MBE, MBE has advantage to realize $GaN_yAs_{1-x-y}Bi_x$. $GaN_yAs_{1-x-y}Bi_x$ was grown on (001)-oriented GaAs substrate in MBE with solid sources of Ga, As and Bi. Activated nitrogen generated from N_2 gas in rf plasma was used as the nitrogen source. The sample was grown in the structure of $GaN_yAs_{1-x-y}Bi_x/GaAs_{1-x}Bi_x/GaAs/GaAs$ substrate. GaAs homoepitaxial layer was grown at T_{sub} of 500°C. $GaN_yAs_{1-x-y}Bi_x$ and $GaAs_{1-x}Bi_x$ layers were grown at T_{sub} in the range between 340 and 410°C. Ga, As, and Bi fluxes and T_{sub} were kept constant during growth of $GaN_yAs_{1-x-y}Bi_x$ and $GaAs_{1-x}Bi_x$. Based on Rutherford back scattering (RBS) measurements, x of $GaN_yAs_{1-x-y}Bi_x$ was confirmed to be same as x of $GaAs_{1-x}Bi_x$ underneath $GaN_yAs_{1-x-y}Bi_x$. In θ-2θ scan of X-ray diffraction (XRD) measurements, two diffraction peaks ascribed to $GaAs_{1-x}Bi_x$ and $GaN_yAs_{1-x-y}Bi_x$ were clearly distinguished at lower values of 2θ than that of (004)-diffraction of GaAs. One of the diffraction peaks was located at 2θ corresponding to the lattice constant of $GaAs_{1-x}Bi_x$ with x evaluated by RBS. The other peak was observed at a larger value of 2θ than that of $GaAs_{1-x}Bi_x$, indicating the smaller lattice constant than that of $GaAs_{1-x}Bi_x$. By taking into account that the lattice constant decreases with increasing GaN molar fraction in GaNAs alloy, the latter diffraction peak proves the growth of $GaN_yAs_{1-x-y}Bi_x$. By increasing input power of the nitrogen source to increase the supply of activated nitrogen, the diffraction peak ascribed to $GaN_yAs_{1-x-y}Bi_x$ shifted to a large value of 2θ, indicating an increase in y of $GaN_yAs_{1-x-y}Bi_x$. At this time, $GaN_yAs_{1-x-y}Bi_x$ alloy with x up to 3.4% and y up to 0.6% was obtained. Here, the value of y was estimated on the assumption that Vegard's law holds for the alloy of $GaAs_{1-x}Bi_x$ and GaN_yAs_{1-y}. This is the first successful growth of the $GaN_yAs_{1-x-y}Bi_x$ alloy.

3:15 PM L9.6
Growth studies of single phase GaP on Si by solid-source MBE. Xiaojun Yu[1], Paulina S Kuo[2], Martin M Fejer[2] and James S Harris[1]; [1]Solid-State and Photonics Laboratory, Stanford University, Stanford, California; [2]E. L. Ginzton Laboratory, Stanford University, Stanford, California.

Some zincblende semiconductors such as GaP and GaAs have many advantageous characteristics for nonlinear optical frequency mixing, including the high transparent range, large nonlinear susceptibility, high thermal conductivity; however, its isotropic nature precludes its birefringent phasematching. Various techniques have been developed to achieve qusci-phase matching (QPM) in these materials. Among them, the orientation patterned GaAs film that grown on an all epitaxially fabricated template is highly promising for the device quality material, which has been demonstrated in frequency mixing. Compared with GaAs, GaP have even better properties, such as wider transparent range 0.6 11um, twice as large thermal conductivity, etc. The nonlinear optics application of GaP has become an interesting research field. In order to get orientation patterned GaP film, the GaP/Si/GaP heteroepitaxy is used to create an inverted or antiphase GaP layers on GaP substrates, where Si, which is lattice matched to GaP, is used to break the symmetry of GaP. To utilize the availability of Si substrate, two phases of GaP, which differ by a 90 degree in-plane rotation on the (001) Si substrate, need to be grown on Si substrate. Here, we report a growth study of GaP films grown by solid-source molecular beam epitaxy on (001) Si substrates orientated 4 degree off towards [110]. Growth studies were carried out in terms of the growth temperature, V/III ratio, and prelayers. The growth results were characterized by reflective high-energy electron diffraction (RHEED), atomic force microscopy (AFM) and x-ray diffraction (XRD). The nucleation temperature has been identified as the controlling factor for phase selection. The results showed that high quality, single phase GaP was grown on Si at a high growth temperature, about 500 degree C, with a low P/Ga flux ratio of 2.5X, while at a lower temperature, a second phase with a 90 degree in-plane rotation was grown.

3:30 PM L9.7
Optimization of Low-Temperature GaAs and its Integration with Silicon Circuits Used in a Hybrid Photonic/CMOS Analog to Digital conversion system. Kai 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/photonic A/D conversion system utilizing a sample-and-hold scheme with low-temperature-grown GaAs (LT-GaAs) metal-semiconductor-metal (MSM) photoconductive switches. LT-GaAs is our choice of material for the 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 As-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 carrier mobility, as well as high dark resistivity, making it ideal for ultrafast photoconductor applications. But there is always 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 switches and CMOS circuits 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 made from LT-GaAs on Si material was comparable to their homoepitaxy counterpart.

3:45 PM L9.8
Growth of GaNAsSb and Effects of Adding Sb to GaNAs. Homan B Yuen, Seth Bank, Mark Wistey and James S Harris; Electrical Engineering, Stanford University, Stanford, California.

The dilute-nitride GaInNAs has been found to optically emit at wavelengths longer than previously thought possible for materials grown coherently on GaAs. Kondow discovered the addition of nitrogen to GaAs decreases both the overall lattice parameter and the bandgap [1]. This has allowed for the development of lasers at the important telecom wavelength of 1.3 μm. However, attempts to push out to 1.55 μm have not been entirely successful with GaInNAs. Addition of further indium or nitrogen results in severely degraded material quality due to phase segregation or relaxation. In an effort to improve material quality, Wang discovered that antimony could be used as a surfactant in GaInNAs growth [2]. However, it was discovered that antimony acted as both a surfactant and constituent when used in GaInNAs, forming GaInNAsSb. Until now, devices utilizing GaInNAsSb as the quantum well (QW) material used GaNAsSb as the barrier material [3]. Antimony was used for the barriers because it was also thought it could improve the quality of GaNAs and the QW/barrier interfaces. Although GaInNAsSb has been extensively studied as the quantum well material, there has been little study of GaNAsSb and the effects of adding Sb to dilute-nitrides. In this talk, an analysis of GaNAsSb will be presented along with a study of the effects of adding dilute amounts of Sb to GaNAs. The samples analyzed in these experiments were grown by molecular beam epitaxy with nitrogen supplied by a rf plasma source. Incorporation of nitrogen is linearly dependent upon the inverse of the group-III growth rate, so the barrier compositions are determined by the choice of QW composition. A study of different growth parameters will be presented. High-resolution x-ray diffraction, secondary ion mass spectrometry, photoluminescence, and electroreflectance results are presented to analyze the quality, composition, and strain. After analysis, results indicate GaNAs is a better QW barrier material than GaNAsSb although the addition of dilute amounts of Sb to GaNAs improves the material. [1] Kondow, et al. Jpn. J. Appl. Phys. 35 (1996) 1273 [2] Wang, et al. Appl. Phys. Lett. 75 (2) (1999) 178 [3] Harris, et al. Semicond. Sci. Tech. 17 (2002) 880

4:00 PM L9.9
The Influence of Processing Parameters on Photoluminescent Properties of Ba2ZnS3:Mn Phosphors by Double-Crucible Method. Yu-Feng Lin, Department of Materials Science and Engineering, National Cheng Kung University, Tainan, Taiwan.

Abstract Red light emitting of Mn2+ doped Ba2ZnS3 phosphor powders have been synthesized by double-crucible method at different thermal treatments. XRD results indicate that the raw materials are completely sulfurized above 950°C and the Ba2ZnS3: Mn2+ powders don't change its orthorhombic crystal structure with increasing doping concentration from 0 to 1 at%. The photoluminescence of Ba2ZnS3: Mn2+ powders fulfilled the most efficient emission at the excitation wavelength λex=360 nm and showed the red emission light with peak wavelength λem=627 nm at the doping concentration of Mn2+ ion between 0.1 and 1 at%. The high-luminance red emission results from

the 4T1 (4G)-6A1 (6S) transition in the Mn2+ ion. Ba2ZnS3: 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 Ba2ZnS3 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.