SYMPOSIUM Z

Thin Films for Optical Waveguide Devices

December 1 – 2, 1999

Chairs

Alex K.-Y. Jen
Chemistry Dept
Northeastern Univ
Egan 351
Boston, MA 02115
617-373-5151

Keiichi Nashimoto
Corp Research Lab
Fuji Xerox Co., Ltd
430 Sakai
Kanagawa, 259-0157 JAPAN
81-465-802107

Joseph Shmulovich
Bell Labs, Lucent Technologies
Murray Hill, NJ 07974-0636
908-582-4635

Bruce W. Wessels
Materials Science & Engineering
Northwestern Univ
MLSB
Evanston, IL 60208
847-491-3219

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* Invited paper

SESSION Z1: LUMINESCENT WAVEGUIDE MATERIALS AND DEVICES
Chair: Joseph Shmulovich
Wednesday Morning, December 1, 1999
Room 313 (H)

8:30 AM *Z1.1
EXCITING RARE-EARTH DOPED OPTICAL WAVEGUIDE MATERIALS. A. Polman, FOM-Institute for Atomic and Molecular Physics, Amsterdam, THE NETHERLANDS.

Rare-earth doped planar optical waveguides can serve as miniature optical amplifiers that can be used to compensate for the optical losses in photonic integrated circuits. Three important materials engineering challenges in these devices will be addressed:
1) to find the optimum host for the rare earth to show maximum gain,
2) to minimize the pump power to reach net gain,
3) to minimize the dimension of the amplifier structure.
First, recent measurements will be shown of the optical properties of Er and Nd-doped waveguides based on Al_2O_3, SiO_2, Si, or fluorinated polymer thin films. Sputter deposition, ion implantation, spin coating and sol-gel processing techniques are addressed, as well as the integration with wavelength division multiplexers for pump and signal. The advantages and disadvantages of the various waveguide hosts will be discussed. It is found that higher-order excitations by cooperative upconversion and excited state absorption are the main gain-limiting factors in these materials. A novel nano-composit material, consisting of rare-earth doped colloidal silica particles embedded in a polymer host will also be presented.
Next, three novel sensitized excitation schemes will be presented that reduce the pump power to excite the rare earths. A lissamine sensitizer group is attached to an organic rare-earth doped cage complex embedded in a polymer thin film, and the intra-molecular energy transfer process is studied. Al_2O_3:Er channel waveguides are co-doped with Yb, and a fundamental limit imposed by the Yb↔Er energy transfer rate is discussed. Er-doped SiO_2 thin films are co-doped with Si nanocrystals that can efficiently transfer energy from the quantum-confined bound exciton state to the Er intra-4f states. Finally, a novel Si photonic bandgap structure will be presented, consisting of a cubic arrangement of 5 μm tall Si pillars of 250 nm diameter, that can serve as a waveguide bend with zero bending radius.

9:00 AM Z1.2
Er AND Al CO-DOPED SOL-GEL SILICA FOR OPTICAL WAVEGUIDES. R.A. Hudgins, A.J. Steckl, Nanoelectronics Laboratory, University of Cincinnati, Cincinnati, OH.

The advancement of integrated optics depends on the ability to fabricate low loss on-chip optical waveguides. An inexpensive way to fabricate waveguides is by UV exposure of a photoactive sol-gel. Another method is Focused Ion Beam (FIB) direct milling of the structures. We have fabricated sol-gel silica doped with various rare earths and other metals. We report on the doping of the sols with erbium and aluminum. TEOS (tetraethoxysilane), ethanol, and water with a few drops of nitric acid to control the pH are used to form the base material, SiO_2. The rare earths, in the form of nitrates ($Er(NO_3)_3$, $Al(NO_3)_3$), are mixed separately with ethanol and water and then added to the TEOS solution. Processing is done after the sol-gels set for between 2 to 4 days. All sol-gels are filtered with a 0.2 μm filter before spin coating. High temperature annealing is required to activate the erbium for optical emission and to drive off the water and ethanol. The erbium ions in the sol-gel silica exhibit visible upconversion (524 nm, 548 nm, 707 nm) under 840 nm and 1 μm wavelength excitation. The addition of aluminum to the erbium-doped sol-gel results in an increase in signal strength by a factor of up to 5X. The sol-gel's index of refraction can be modified by adjusting the amount of the heavy molecular weight materials during the mixing of the sol-gel without changing the emission strength. Multi-layer planar waveguides can be achieved by spin-on or dip coating techniques. We report on Er and Er/Al-doped planar and channel waveguides. The bottom isolation layer is undoped (SiO_2) and the top cladding is just air for the waveguides. In addition to upconversion luminescence, absorption transmission spectrometry, XRD, SEM, and AFM are used to determine the optical and physical properties of the sol-gel films.

9:15 AM Z1.3
LUMINESCENCE EFFICIENCY OF ERBIUM DOPED BARIUM TITANATE THIN FILMS. A.R.Teren, B.W.Wessels, Northwestern Univ, Dept of Materials Science and Engineering, Evanston, IL.

Barium titanate($BaTiO_3$) is a promising thin film integrated optic host material because of its large electro-optic coefficient. Epitaxially grown $BaTiO_3$ doped with rare-earth ions, such as erbium, also has potential as an active optical gain medium. Previously, stimulated emission at ~ 1.54 μm was demonstrated in low-loss channel waveguides fabricated from Er-doped $BaTiO_3$ thin films deposited by MOCVD[1]. In order to obtain net optical gain, recent work has focused on improving the luminescence efficiency. $BaTiO_3$ films doped with an Er concentration of ~ 1 x $10^{20}/cm^3$ were deposited at temperatures between 700°C and 850°C on (100) MgO. The emission intensity at 1.54 μm was maximum for films deposited at a temperature of 800°C, a factor of ten larger than for 700°C. The efficiency also depended upon oxygen stoichiometry. Evidence for the importance of the oxygen content in the films was obtained from post-growth annealing treatments. For samples oxidized at 800°C, the fluorescence intensity at 1.54 microns increased between 3 and 20 times. In contrast, reduction in vacuum caused quenching of the emission of up to 50 times. A model for the observed luminescence quenching will be presented. [1] D.M. Gill, G.M. Ford, B.A. Block, B.W. Wessels, and S.T. Ho. 1998 MRS Symposium Proc. Vol. 486(1998).

10:00 AM *Z1.4
SYNTHESIS AND CHARACTERIZATION OF Er^{3+}-DOPED SILICA GLASS BY SOL-GEL PROCESSING WITH ORGANIC COMPLEXATION. Xiuhong Han, Guozhong Cao, Dept of Materials Science and Engineering, Tom Pratum, Dept of Chemistry, Daniel T. Schwartz, Dept of Chemical Engineering, Univ. of Washington, Seattle, WA.

Er^{3+}-doped silica glass (up to 10 wt%) was synthesized by sol-gel processing with the addition of 3-aminopropyl trimethoxysilane (APS) as a complexing agent. Er^{3+} ions reacted with amino groups and, thus, linked to the silica network during the sol preparation. As a result, the motion of Er^{3+} ions was restricted and the formation of Er^{3+} clusters was inhibited. Both fluorescence spectra and magic-angle spinning (MAS) nuclear magnetic resonance (NMR) indicated that the addition of the complexing agent resulted in a homogeneous dispersion of high-level Er^{3+} doping in the resultant gels. After the removal of organic components, however, Er^{3+} clustering occurs when firing at a high temperature for a long period of time, e.g. at 1000 °C for 10hrs, due to enhanced Er^{3+} diffusion.

10:30 AM Z1.5
DEPENDENCE OF THE 1.54 μm PHOTOLUMINESCENCE OF Er-DOPED Al_2O_3 FILMS ON THE Er DISTRIBUTION. R. Serna, M. Jimenez de Castro, J.A. Chaos and C.N. Afonso, Instituto de Optica, CSIC, Madrid, SPAIN.

Pulsed laser deposition is a thin film growth technique which has shown very good results on the production of high quality optical materials, and thus there is a significant research effort towards the production of waveguide materials. Artificial structures can be also easily obtained using the alternate deposition method that allows independent control of the deposition parameters of two separate targets. In this way, Er-doped amorphous Al_2O_3 films have been achieved in which the concentration and nanoscopic distribution of Er can be varied. In this paper we show that the photoluminescence response, intensity and lifetime, can be effectively optimized when the Er-Er ion separation is increased in the nanometer range in one dimension. The thin films are deposited in vacuum using an ArF excimer laser. The targets (Al_2O_3 and Er) are placed in a computer-controlled holder that allows to alternately ablate each of them. The alternate Al_2O_3/Er deposition cycle is performed a number of times, from 33 to 100, and the number of pulses in the Al_2O_3 target is varied accordingly in order to keep a constant film thickness (≈300 nm). The resulting films have a configuration in which dopant layers with an in-plane average areal density as large as 4 x 10^{13} Er/cm^2 are separated by Al_2O_3 spacing layers (Er-Er in depth separation) of a thickness ranging from 3 nm to 9 nm. The films have *average* concentrations of Er of the order of 10^{20} Er/cm^3 and show the characteristic photoluminescence spectra peaked at ~ 1.54 μm. The lifetimes can be as high as 6-7 ms, depending on the Er distribution. The results will be discussed in terms of Er-Er ion interaction.

10:45 AM Z1.6
WAVEGUIDING AND 1.54 μm Er^{3+} PHOTOLUMINESCENT PROPERTIES OF ERBIUM DOPED SILICON-RICH SILICON OXIDE. Se-Young Seo, Hak-Seung Han, and Jung H. Shin, Department of Physics, Korea Advanced Institute of Science and Technology (KAIST), Yusung-gu, Taejon, KOREA.

The waveguiding and 1.54 μm Er^{3+} photoluminescent properties of Er doped silicon-rich silicon oxide (SRSO) are investigated. SRSO films, which consist of nanocrystalline Si clusters embedded inside SiO_2 matrix, with excess Si content ranging from 1 to 10 at.% and Er content ranging from 0.04 to 0.4 at.% were deposited by electron cyclotron resonance plasma enhanced chemical vapor deposition of SiH_4 and O_2 with concurrent sputtering of erbium. After deposition, films were rapid thermal annealed at 950°C to precipitate the silicon nanoclusters. The precipitation of the Si nanoclusters is very rapid, and is essentially complete after 30 seconds. All films show strong room temperature 1.54 μm Er3+ photoluminescence with luminescence lifetimes that can be as long as 7 msec. The refractive indices of the SRSO films, as measured by ellipsometry, range from 2.104 to 2.469, increasing with increasing excess Si content. Thus, slab waveguides can be formed easily by depositing erbium doped SRSO films on 1 μm thick SiO_2 films. Such waveguides guide both internal 1.54 μm Er^{3+} emission and externally coupled 1.3 μm light well, with bulk loss estimated to be as low as 0.35 dB/cm. The dependence of the Er^{3+} luminesent intensities and lifetimes on the pump wavelength, pump power, and background illumination shows that carrier-induced de-excitation mechanisms of excited erbium atoms in SRSO are nearly completely suppressed such that population inversion of Er^{3+} ions by carrier-mediated excitation is possible. Based on such results, a novel erbium-doped planar amplifier that does not require a pump laser is proposed.

11:00 AM Z1.7
CONTROL OF LOCATION AND CARRIER-INTERACTION OF ERBIUM USING ERBIUM DOPED Si/SiO_2 SUPERLATTICE.
Hak-Seung Han, Won-Hee Lee and Jung H. Shin, Department of Physics, Korea Advanced Institute of Science and Technology (KAIST), Kusung-dong, Yusung-gu, Taejon, KOREA.

Erbium doping of silicon is one of the most promising method for developing silicon-based optoelectronics. However, the small bandgap of Si and strong interaction between Er 4f electrons and carriers in Si matrix militate against obtaining efficient Er^{3+} luminescence from Er doped Si. Such efficiency can be greatly increased by using Si quantum structures such as porous silicon or nanocrystalline silicon. However, in such a case, exact control over the location and carrier-interaction of Er is difficult. A much better control over the location of Er atoms and the degree of quantization of Si electronic structures is expected if erbium is doped into Si/SiO_2 superlattices. In this paper, the effects of such control on the luminescent properties of erbium doped Si/SiO_2 superlattices are investigated. Erbium was doped into either the Si layers or the SiO_2 layers only. The Si layer thickeness was varied from ~4 to ~15 nm, and the SiO_2 layer thickness was varied from ~5 to ~50nm. All films show room temperature 1.54 μm Er^{3+} luminescence. The data indicate that the excitation is always dominated by Auger-type excitation by carriers even if Er atoms are confined to SiO_2 layers and thus separated from the carriers. Moreover, the luminescence efficiency is much greater in such a case, and increases as the separation distance is increased, indicating that the carrier-mediated excitation remains efficient over several interatomic distances. The luminescence efficiency can be further increased by several orders of magnitude if Er atoms are further insulated from the Si layers and thus the carriers by inserting a buffer layer of pure SiO_2 between the Er doped SiO_2 layers and Si layers. We also demonstrate that efficient waveguides can be fabricated using such erbium doped Si/SiO_2 superlattices. The current transport properties of such superlattices as well as the possibility of electrical excitation of Er atoms will be discussed.

11:15 AM *Z1.8
ZINC OXIDE ULTRAVIOLET LASER.
M. Kawasaki, Dept of Innovative and Engineered Materials, Tokyo Institute of Technology, Yokohama, JAPAN.

We report on the current status of ZnO thin film work directed towards ultraviolet laser diodes. The growth mode of ZnO thin film is regulated so that nanocrystals are assembled as a honeycomb structure in a self- organized manner. Excitons in the nanocrystals can survive well above room temperature under dense excitation, resulting in a stimulated emission with a low threshold caused by a collision process of excitons. The laser cavity is naturally formed by making use of grain boundaries between nanocrystals as mirrors. TE mode laser emission is observed from the edge of the films with showing six-fold symmetry in the azimuthal angle in the film plane. The band gap of ZnO can be tuned by alloying with MgO or CdO in a range of 3-4eV. Superlattices are readily made to show clear quantum size effect. The valence control into p-type conduction is the most critical materials challenge to realize ZnO ultraviolet laser diodes. In this context, we have been focusing our recent efforts on the preparation of SINGLE CRYSTALLINE thin films grown on lattice matched substrates to reduce residual electron density. Now, our current status has reached to a residual electron density of 1015cm-3 and an electron mobility of 100cm2V-1s-1, which are comparable to those of bulk single crystals. This work was conducted in collaboration with A. Ohtomo, Z.K. Tang, Y. Segawa, and H. Koinuma. This work was supported by JSPS research for the Future Program in the Area of Atomic Scale Surface and Interface Dynamics (JSPS-RF

11:45 AM Z1.9
EXCELLENT CHARACTERISTIC TEMPERATURE (T_0) THROUGH THERMAL ANNEALING OF A 1.3-μm GaInNAs/GaAs SINGLE-QUANTUM-WELL LASER DIODE.
Takeshi Kitatani, Masahiko Kondow, RWCP Optical Interconnection Hitachi Lab., Kokubunji, Tokyo, JAPAN; Kouji Nakahara, Kazuhisa Uomi[1], Toshiaki Tanaka, Central Research Laboratory, Hitachi, Ltd., Kokubunji, Tokyo, JAPAN; [1]Currently with Telecom. System Gr., Hitachi, Ltd., Yokohama, Kanagawa, JAPAN.

To improve the high-temperature performance of long-wavelength semiconductor lasers, we have studied the use of GaInNAs in the active region [1]. However, GaInNAs has poor crystallinity possibly due to phase separation. Recently, though, thermal annealing was found to enhance the optical properties of GaInNAs [2]. In this paper, we report a high characteristic temperature (T_0) in a 1.3-μm GaInNAs/GaAs single-quantum-well (SQW) laser diode by applying optimal annealing conditions.
An index-guided GaInNAs/GaAs SQW laser diode (GaInNAs-LD) was grown by gas-source molecular beam epitaxy, in which nitrogen atoms were produced by RF discharge [1]. The SQW active region, which consisted of a 7-nm-thick $Ga_{0.7}In_{0.3}N_{0.01}As_{0.99}$ strained well layer and 150-nm-thick GaAs barrier layers, was sandwiched between $Al_{0.3}Ga_{0.7}As$ cladding layers. Thermal annealing at 550°C was done simultaneously during the crystal growth of the $Al_{0.3}Ga_{0.7}As$ upper cladding layer. This was the optimal temperature to increase the PL intensity of the GaInNAs/GaAs SQW region. Highly reflective coating (reflectivity: 70% /95%) was deposited on each facet of the GaInNAs-LD.
The lasing wavelength was obtained in the 1.3-μm band. The threshold current (I_{th}) was 83 mA at 20°C under both pulsed and CW conditions. As the operating temperature rose up to 80°C, I_{th} increased to 110 mA under pulsed operation. We calculated T_0 to be 215 K, which is the highest value, to the best of our knowledge, yet reported for long wavelength lasers in the 1.3-μm band. Owing to the improved GaInNAs crystallinity brought about by thermal annealing, high T_0 could be attained. On the other hand, when I_{th} rose to 125 mA at 80°C under CW operation, T_0 was 147 K. This value was still high, but was lower than that under pulsed operation, because of the temperature rise in the active region. Further optimization of the GaInNAs growth condition should enable T_0 of over 200 K even under CW operation.
[1] M. Kondow et al.: Jpn. J. of Appl. Phys., 35 (1996) 1273.
[2] A. Ougazzaden et al.; 10th Indium Phosphide and Related Materials. Tsukuba, Japan, May, WB-1-2 1998.

SESSION Z2: PLANAR OPTICS ON Si AND PHOTONIC CRYSTALS

Chair: Keiichi Nashimoto
Wednesday Afternoon, December 1, 1999
Room 313 (H)

1:30 PM *Z2.1
SILICA-BASED PLANAR LIGHTWAVE CIRCUITS.
Akira Himeno, NTT Photonics Laboratories, Ibaraki, JAPAN.

The rapid and global spread of Internet and multimedia communications has accelerated the growth in optical wavelength-division multiplexing (WDM) communication networks. Silica-based planar lightwave circuits (PLC), integrated with optical fiber-matched silica-based waveguides, can provide various key devices for such networks. Silica-based waveguides are fabricated on silicon substrates by a combination of flame hydrolysis deposition and reactive ion etching. The typical waveguide propagation loss ranges from 0.02 to 0.1 dB/cm. PLCs are suitable for large-scale integration, offer long-term stability, and can be easily mass produced. Passive PLC applications include 1 x N optical power splitters, 1 x N or N x N multi/demultiplexers, and add/drop or crossconnect thermo-optic switches for WDM systems. We have already fabricated a 1 x 128 arrayed-waveguide grating multi/demultiplexer with a 50-GHz spacing, a 16x16 matrix switch integrated with 512 integrated interferometer switching units and a 16 channel add/drop switch. We require high-speed and highly functional devices for the access network or future network node systems. PLC platform technology, which can integrate semiconductor optoelectronic devices efficiently, is a promising way to realize these devices. Recently developed hybrid integrated PLC devices include a low-cost transceiver module for optical access networks, a high-speed wavelength channel selector, and a high-speed receiver module for future photonic packet or IP switching systems.

2:00 PM Z2.2
SURFACE SMOOTHING OF POLYCRYSTALLINE Si WAVE-GUIDES WITH GAS CLUSTER ION BEAMS.
Noriaki Toyoda, Anuradha M. Agarwal, Desmond R. Lim, Lionel C. Kimerling, Massachusetts Institute of Technology, Dept. of Material Science and Engineering, Cambridge, MA; Lisa P. Allen, David B. Fenner, Allen R. Kirkpatrick, Epion Corporation, Billerica, MA.

Silicon microphotonic circuits have been proposed as interconnects in future microprocessors. Polycrystalline Si (polySi) is a candidate material for silicon optical waveguides because of their high refractive index compared to SiO_2 and air which makes possible submicron waveguide dimensions, and its ease of deposition. However, optical transmission loss of as-deposited polySi is much higher than that of crystalline Si. From the previous studies, the significant reason for the loss in single-mode waveguide is scattering on the top surface and side-walls. In this study, a novel gas-cluster-ion-beam is used for the smoothing of polySi. The Ar cluster is an aggregate with several thousands of Ar atoms. Since thousands of atoms impact a target simultaneously, multiple collisions between cluster and target atoms occur, which cause several beneficial irradiation effects, such as high-yield sputtering and surface smoothing. In addition, as the kinetic energy of each atom in the cluster equals the total acceleration energy divided by the cluster size, very low-energy ion beams can be easily realized, which reduces the damage to the target. Ar gas cluster ions with acceleration energy of 20keV are used for the surface smoothing of polySi. After planarization with cluster ion beams, the surface roughness is measured with AFM. Optical loss is obtained for the transmission of $\lambda = 1.54\mu$m light through the polySi waveguide. The dependence of the optical losses on the surface roughness is discussed by comparing with as-deposited polySi and those polished with CMP or gas cluster ions. Preliminary results are reported. Supported at Epion by NIST-ATP (70NAB8H4011).

2:15 PM Z2.3
IMPROVED REFRACTIVE INDICES FROM PRISM WAVE GUIDE COUPLER MEASUREMENT. Tao Liu and Robert Samuels, Georgia Institute of Technology, Dept of Chemical Engineering, Atlanta, GA.

An examination of a three-layer leaky wave-guide model as compared with thin film theory yields a discrepancy between the Nm values (effective refractive index of the m-th order mode) predicted by each theory for the same model parameters. It is found that the difference on Nm between these two theories is systematic and can be fitted to a master curve. Also, since prism wave guide couplers have been used to determine the refractive indices and thickness of freestanding polymer films, the thin film theory is applied to investigate the influence of the air gap on the Nm values of a five-layer prism wave-guide coupler model which includes two air gaps and represents measurement of free standing film.

3:00 PM *Z2.4
MATERIALS AND PROCESS FOR PLANAR LIGHTWAVE CIRCUITS. John T. Kenney, Lightwave Microsystems Corp., San Jose, CA.

Planar lightwave circuits (PLC) are being used in telecommunication systems for wave division multiplexing, as well as switches and other components. In wave division mutltiplexing (WDM) multiple wavelengths of light, each carrying data, are sent through the same optical fiber. As many as 80 separate wavelengths are combined (mulitplexed), transmitted over the fiber and then separated (demultiplexed) into individual data channels. Separations of 50 GHz (0.4 nm) or 100 GHz (0.8 nm) between individual wavelengths are standard in the wavelength band around 1530 nm. These integrated WDM devices provide wavelength separations recently achieved only in high resolution spectrometers. To achieve the low loss, high channel isolation and wavelength specificity for the telecommunication systems requires rigorous control of the materials and processes used for fabrication.
These integrated circuits are made with planar buried channel waveguides. The waveguide consists of a higher refractive index core surrounded by a lower index cladding. The index difference is in the range of 0.6% to 0.9%. The tolerances for the index is tighter than 0.0001. The width/depth of the core is in the range of 6 microns to 8 microns, depending on the index difference. The required dimension control is greater than 0.2 microns. The material and process tolerances and control will be described.

3:30 PM Z2.5
DESIGN AND SYNTHESIS OF A 33-LAYER NARROW BANDPASS FILTER WITH GRADED REFRACTIVE INDEX PROFILES. Xinrong Wang, Hiroshi Masumoto, Lidong Chen and Toshio Hirai, Tohoku University, Institute for Materials Research, Sendai, JAPAN; Yoshihiro Someno, ALPS Electric Co. Ltd., Mechatronic Devices Division 1, Kakuda, Miyagi, JAPAN.

With the development of high speed and great capacity fiber communication, high-quality optical filter has attracted considerable interest in fabrication and design, because it is a key device in the wavelength division multiplexing (WDM) technique. Previously, using the concept of functionally graded materials (FGMs), we have successfully designed and fabricated new reflection filters with graded refractive index profiles, which effectively eliminate the sidelobe outside the stopband. In this paper, we report the design and synthesis of a novel narrow bandpass filter with graded refractive index profiles. Designed 33-layer narrow bandpass filter has a three-cavity structure with graded refractive index profiles. The transmittance spectrum of this filter exhibits a high pass band of 1524 nm to 1576 nm with the transmission of more than 99% in a high reflection region from 1316 nm to 1886 nm. Moreover, there are high transmittances beside the reflection region that is contributed to sidelobe suppression by graded refractive index profiles. On the base of above design, the 33-layer titania-silica system bandpass filter was fabricated by helicon plasma sputtering. Prepared multilayer filter exhibited an almost consistent transmittance spectrum with the designed one. However, the transmittances around the central wavelength of 1550 nm are about 84% that are lower than designed values. The structural characteristics revealed that the absorption of titania layers and the deviation of layer thickness caused the decrease of the transmittance. Inducing the above effects, the fitting spectrum showed well correspondent with experimental spectrum.

3:45 PM *Z2.6
TWO-DIMENSIONAL PHOTONIC CRYSTAL BASED LASERS AND COUPLERS. A. Mekis, A. Dodabalapur, R.E. Slusher, M. Meier, J.A. Rogers, A. Timko and O. Nalamasu, Bell Laboratories, Lucent Technologies, Murray Hill, NJ; and J. Joannopoulos, MIT, Physics Department, Cambridge, MA.

Organic gain media have been employed in pioneering studies of the physics of many classes of laser resonators, including distributed feedback, distributed Bragg reflector, planar microcavity, and whispering-gallery mode lasers. In this presentation we show how organic gain media can be used to study the characteristics of two-dimensional photonic crystal lasers. We also examine, in detail, the properties of output and input couplers based on photonic crystals and show that such couplers can possess more ideal characteristics when compared to one-dimensional grating based couplers. Soft-lithographic techniques have been successfully used to realize photonic crystal based lasers and couplers with both one- and two-dimensional periodicity. Detailed theoretical analysis of the lasing and coupling mechanisms in two-dimensional photonic crystal resonators and couplers will also be presented.

4:15 PM Z2.7
TWO- AND THREE-DIMENSIONAL REFRACTIVE INDEX LATTICES FORMED BY LATERALLY PATTERNED POROUS SILICON LAYERS. Shingo Uehara, Hiroyuki Sasabu and Tadashi Matsubara, Seikei Univ, Dept of Electrical Engineering and Electronics, Tokyo, JAPAN.

Porous silicon layers combined with micro patterning in the lateral direction have been applied to form two- and three-dimensional refractive index lattices for photonic crystal waveguides and devices. Available refractive index by the present technique ranges from over 3 of silicon to around 1.4 of porous layer anodized at 25 mA/cmÅ O2. This wide index controllability range meets the requirement for high index contrast needed to realize photonic bandgap. Periodic index variation along depth necessary to fabricate three-dimensional lattice was formed by the successive change in the anodization current. To introduce lateral periodicity, we studied two schemes. The first one is to use p-type substrate with periodical n-type areas formed by diffusion. During anodization, the n-diffused regions remained unchanged while the p-regions were anodized forming two- and three-dimensional index lattices for constant and periodic current driving, respectively. The second one is to use p-type substrate with periodic step islands formed by etching. The steps induce shift in index period along depth, and thus by setting the step height equal to the depth of the high or low half of the index variation period, a variety of three-dimensional lattices, depending on the step lattice patterns at the surface, can be formed. Fabrication and characterization details of these lattices will be reported.

4:30 PM Z2.8
AN SiO_2/TiO_2 OMNIDIRECTIONAL REFLECTOR AND MICROCAVITY RESONATOR VIA THE SOL-GEL METHOD. K.M. Chen, A.W. Sparks, H.-C. Luan, K. Wada, and L.C. Kimerling, Dept of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA.

Thin films of sol-gel SiO_2 and TiO_2 were used to fabricate a dielectric mirror and microcavity resonator. The dielectric mirror consisted of six layer pairs of alternating high and low refractive index films, designed with stopband centered around λ=1550 nm. Our spectral characterization of the mirror provides the first report of omnidirectional reflectivity in a sol-gel based device. Reflectivity measurements over an incident angle range of 0-80° showed a 1D photonic bandgap of 110 nm (the reflectivity band is 410 nm wide for TE- and 110 nm wide for TM-polarized light), which agrees well with theoretical predictions of omnidirectional reflectivity for this materials system. The microcavity resonator consisted of a TiO_2 Fabry-Perot cavity sandwiched between two SiO_2/TiO_2 dielectric mirrors of three layer pairs each. We have fabricated a microcavity with resonance at λ=1500 nm and have achieved a quality factor of Q=11.7. We measure a modulation in the cavity resonance frequency with a change of defect layer thickness and incident angle of light. This work represents the first report of angle-dependent reflectivity measurements on sol-gel based optical devices.

4:45 PM Z2.9
DEPOSITION AND CHARACTERIZATION OF INORGANIC FILMS FOR OPTICAL WAVEGUIDE COMPONENTS. S. Ponoth, J. Plawsky, Department of Chemical Engineering, N. Agarwal, Department of Electrical, Computer and Systems Engineering; X.G. Huang, P.D. Persans, X.C. Zhang, Department of Physics; Rensselaer Polytechnic Institute, Troy, NY.

Optical communications are becoming technologically important on progressively shorter length scales. As computer chip speeds increase longer metal wire interconnects become problematic and may limit device performance. Wide bandwidth optical interconnects may be used to address this problem. In such applications, it will be necessary to fabricate beam guiding, turning, and splitting structures that are compatible in scale and processing with opto-electronic devices integrated onto a CMOS substrate. We report on the deposition, processing, stability, and optical properties of PECVD silicon nitride and silicon oxide as well as titanium oxide and tantalum oxide thin films for incorporation in on-chip optical interconnects. Of special interest are multilayer mirrors that are deposited onto micron-scale polymer waveguides.
This work is part of the Interconnect Focus Center: Interconnections for Gigascale Integration which is funded by MARCO, DARPA, and New York State.

SESSION Z3: POLYMERS – MATERIAL PROPERTY AND PHOTONIC DEVICES
Chair: Alex K.-Y. Jen
Thursday Morning, December 2, 1999
Room 313 (H)

8:30 AM *Z3.1
MOLECULE AND CHARGE CARRIER DIFFUSION IN OPTICAL AND ELECTRO-OPTICAL DEVICES. H.E. Katz, L. Dhar, A. Hale, M.G. Schnoes, M.L. Schilling, Z. Bao, and A. Dodabalapur, Bell Labs-Lucent Tech, Murray Hill, NJ.

The response of many optics-related materials requires changing their state by inducing migration of electrons, holes, or molecular species. This was evident in early work on nonlinear optical and photorefractive materials. More recent manifestations of this principle are seen in smart LED pixels and photopolymers for holographic data storage. The former depend heavily on charge mobility through organic solids contained in both the LED and its controlling transistor(s), while the latter require maximum molecular diffusion in a polymeric matrix. The potential for integrating such materials and devices with waveguides will be considered.

9:00 AM Z3.2
POLYMERIC STRIP WAVEGUIDES AND THEIR CONNECTION TO VERY THIN ULTRAFAST MSM DETECTORS. Ch. Buchal, A. Roelofs, M. Siegert and M. Loeken, Institut for Thin Film Technology (ISI - IT), Research Center Juelich, Juelich, GERMANY.

We present data on the fabrication process of optical waveguides from four different polymers, which have been patterned to strip waveguides: either by standard lithographical masking and reactive ion beam etching (RIE) or by direct lithographical exposure of primarily photosensitive waveguide material. Three of the resists were directly photosensitive, they could be exposed and developed. Thereafter they can be cured and remain stable. Waveguide losses of 3.5 dB/cm had to be accepted for the photosensitive materials, while the non-sensitive polymers formed very good guides (0.3 dB/cm), but were more difficult to process. We demonstrate the coupling of the strip waveguides to optical fibers on one side and to very thin metal-semiconductor-metal (MSM) photodetectors at the other side. A beam propagation method computer code has been used to evaluate the best coupling efficiencies between the guides and the detectors, which are ultrafast (3.5 ps FWHM) due to their very thin silicon slab design (Si thickness 400 nm, sandwiched between two Schottky contacts).

9:15 AM Z3.3
ORGANIC LIGHT EMITTING DIODE DIRECTLY FABRICATED ON A POLYMER WAVEGUIDE DEVICE. Yutaka Ohmori, Hiroshi Ueta, Department of Electronic Engineering, Osaka University, Suita, Osaka, JAPAN; Makoto Hikita, NTT Photonics Laboratories, Tokai-mura, Naka-gun, Ibaraki, JAPAN; and Katsumi Yoshino, Department of Electronic Engineering, Osaka University, Suita, Osaka, JAPAN.

Organic light emitting devices (OLED) which consists of 8-hydroxyquinoline aluminum (Alq_3) and diamine derivative (TPD) were directly fabricated on a polymer waveguide device. Polymer waveguide device consists of deuterated methacrylate polymer core and UV cured epoxy resin cladding. The waveguide has a square shaped core with 40 μm in width. The substrate of the polymer waveguide was removed, and the waveguide device is a free-standing type. One of the edges of the polymer waveguide was cut in 45 degree, which was served as a mirror, in order to introduce the output light from OLED to the waveguide. The OLED was directly fabricated by evaporation technique at the edge of a waveguide, whose edge served as a mirror. The transmitted light spectra from OLED with Alq_3 are discussed as a function of wavelength. Since the output light from the OLED has a broad band emission centered at 520 nm , the output light intensity after the transmission of polymer waveguide decreases as decreasing the wavelength of the emission light. As increasing the emission wavelength, the transmission loss of the polymer waveguide decreases. Emission and transmission characteristics of the light from red-light-emitting OLED are also discussed as a light source for the polymer based waveguide with low transmission loss.

10:00 AM *Z3.4
RECENT DEVELOPMENTS IN PHOTOCONDUCTING AND PHOTOREFRACTIVE POLYMER FILMS. B. Kippelen, E. Hendrickx, K.B. Ferrio, J.A. Herlocker, Y. Zhang, V. Alain, S. Thayumanavan, S.R. Marder, J.W. Perry, N. Peyghambarian, Univ. of Arizona, Tucson, AZ.

We will review some recent advances in the development of photorefractive polymers for real-time optical recording and processing applications. In particular we will report on the photorefractive properties of a series of substituted styrene chromophores in a PVK matrix and discuss the influence of the ionization potential of the chromophore on the photoconducting properties of the polymer composite, and on the response times for hologram formation. We will also report on two-photon induced photoconductivity in PVK sensitized with nonlinear absorbers and discuss potential applications. Finally, we will present new photoconductors based on triphenyldiamine derivatives and fullerenes that exhibit 100 percent photogeneration efficiency at 633 nm and moderate applied electric field.

10:30 AM Z3.5
ENHANCEMENT OF THE ELECTROOPTIC ACTIVITY OF NLO POLYMERS VIA THE USE OF CONDUCTIVE POLYMERS. James P. Drummond, James G. Grote, Frank K. Hopkins, John S. Zetts, US Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright-Patterson Air Force Base, OH; Robert L. Nelson, U.S. Air Force Research Laboratory, Wright-Patterson Air Force Base, OH; Cheng Zhang, University of Southern California, Department of Electrical Engineering, Los Angeles, CA.

We have demonstrated a 20% increase in the electro-optic (EO) coefficient of PMMA/DR1 using a conductive polymer material, polyethylene dioxythiophene (PEDOT) blended with poly styrene sulphonate (PSS) and poly vinyl alcohol (PVA), spin cast between the metal electrode and the NLO material. We have also demonstrated the lowest poling voltage to date, 300 V, for a 2 micron thick NLO polymer and 2 micron thick PEDOT/PSS/PVA test structure. A conductivity of 0.00005 S/cm has been measured for the PEDOT/PSS/PVA mixture at poling temperature, which ensures that all of the applied voltage is dropped across the NLO polymer during poling. These results show promise for shorter, lower operating voltage devices. The EO enhancement experiments are currently being expanded to new NLO materials with higher EO coefficients and results using these new materials will be presented at the conference.

10:45 AM *Z3.6
LASER BASED FLAT PANEL DISPLAY. Hilary Lackritz, Gemfire Corporation, Palo Alto, CA.

Gemfire Corporation has developed a new concept for a flat panel display technology that promises to offer significant advantages in several areas including ruggedness, thinner, lighter packaging, mechanical flexibility, and transparency. Fabricated in the form of thin polymer films with driver circuitry attached, it features scalability to large formats, high brightness, high efficiency (i.e., low power consumption), and large viewing angle, without sacrificing resolution or cost. Our technology is called Polymer Switch Matrix (PSM). With PSM technology, infrared laser radiation is guided to the pixel locations of the display in a thin polymer film on the surface of a plastic substrate, using an array of waveguide switches. The IR radiation is converted to visible light at each location using up-conversion phosphors. Full color displays can be designed with a color gamut equivalent to or better than current CRTs. Importantly, the integrated structures which make this possible can be fabricated using microlithographic techniques that have been well developed in the semiconductor and LCD industries. Moreover, the use of polymer-based materials allows the display to be rugged and shock resistant, mechanically flexible (i.e., it can be used in curved display architectures), paper-thin and very light weight, and transparent enough for see through display applications. Materials and processing information will be discussed.

11:15 AM Z3.7
MIXED SOL-GEL THIN FILMS OF NITRO-CALIX-4-ARENE and TITANIUM DIOXIDE AS PLANAR WAVEGUIDES.
Anthony W. Coleman, Francis Vocanson, Maurad Regayag, Roger Lamartine and Jacques Mugnier, CNRS and Universitè Claude Bernard Lyon 1, Lyon, FRANCE.

The nitro-calix-arenes are known to be active in Non-Linear Optics, however thin films derived from such compounds are mechanically remlatively unstable. The incorporation of such active molecules into sol-gel thin films represents one method of mechanically reinforcing such structures. In addition to this useful gain in utilisablity we have shown that such films are also active as planar wave guides. Using titanium oxide sol-gels as a matrix it has been possible to dope into the sol-gel, without perturbing the system, varying concentrations of para-nitro-calix-4-arene tetra propoxide. AFM studies have shown that high overall planarity is obtained with RMS roughness values around 5nm, however small structures are observed as round islets of about 1 micron in height. These structures do not substantially interfere with the planar wave guiding properties of these hybrid materials. Wave guided Raman Spectroscopy has been carried out on these systems and the results will be discussed in terms of the local oredering within the materials.

11:30 AM Z3.8
PROPERTIES AND STABILITY OF POLYMER WAVEGUIDE MATERIALS FOR CMOS-COMPATIBLE OPTICAL INTERCONNECTS. N. Agarwal, Department of Electrical, Computer and Systems Engineering; X.G. Huang, P.D. Persans, X.C. Zhang, Department of Physics; S. Murarka, Department of Materials Science and Engineering; S. Ponoth, Department of Chemical Engineering, Rensselaer Polytechnic Institute, Troy, NY.

Optical waveguides are potential candidates to replace metal wires for centimeter-scale on-chip interconnections. The desirable properties for optical waveguide materials are low optical losses and high refractive index. They must also be able to withstand thermal and chemical processing conditions of a CMOS process. We report here on an experimental study of deposition, optical properties and stability of polymer waveguide candidate materials.
This work is part of the Interconnect Focus Center: Interconnections for Gigascale Integration which is funded by MARCO, DARPA, and New York State.

11:45 AM Z3.9
NOVEL ELECTRO-OPTIC POLYMER FILM. Fang Changshui, Shi Wei, Guo Shiyi, Ren Quan, Xu Dong, Institute of Crystal Materials, Shandong University Jinan, PR China.

In recent years, several classes of electro-optic polymers have been extensively investigated due to their large electro-optic coefficient, low dielectric constant, ultra fast response speed and easy of processing. These polymers have potential use in integrated optical devices, such as fast waveguide electro-optic switch. However, some polymers exist lower glass transition temperature (Tg) and thermal stability, larger optical loss at the operating wavelength. In order to improve the properties of polymer, we have synthesized novel polymer host/guest system PEK-C/DCNP and PEK-C/DMACB by molecule designing. The host polymer (PEK-C) is polyetherketone and guest is chromophormes(DCNP-3-(1,1-dicyanothenyl)-1-phenyl-4,5-dihydro-1H-pyrazole, DMACB- Dimethyl-amino-cyano-biphenyl). They were dissolved into trichloride and polymer films were prepared by Spin Coating method. In order to get large electro-optic coefficient, these films must be poled by using COPET (corona onset poling at elevated temperature) method. The Tg of the films were determined by DSC (differential scanning calorimeter) and TGA(thermogravimetric analyzer),Tg is over 200°C. The refractive indices of the films and electro-optic coefficient were measured by the quasi-waveguide m-line method, The electro-optic $\gamma 33$ of the films were the same as that of $LiNbO_3$ crystals. The optic loss of the film was less than 1 db/cm. These results show that novel polymer systems were much better than ordinary PMMA/Azo system. Not only do they have high Tg, but also offer impressive thermal stability and optical transparency. They were promise materials for fabrication waveguide switch devices.

SESSION Z4: INORGANIC FILMS AND DEVICES

Chair: Bruce W. Wessels
Thursday Afternoon, December 2, 1999
Room 313 (H)

1:30 PM *Z4.1
FROM FERROELECTRICS TO POLYMERS - PERSPECTIVES FOR THIN FILM OPTICAL WAVEGUIDES AND DEVICES.
Chris Buchal.

There are many different materials, which have been deposited and patterned in order to fabricate thin film optical waveguides: $BaTiO_3$, $LiNbO_3$, Al_2O_3,MgO, Si, Ge, SiO_2,... and many polymers. Many of these materials have been doped with different ions for various functions as lasers or amplifiers. I want to give a short overview about status and perspectives. Although at present no thin film optical waveguide device has demonstrated a superior optical performance, if compared to the the bulk materials or the optical fibers, there is progress and new potential applications emerge for thin films.

2:00 PM Z4.2
EPITAXIAL $BaTiO_3$ THIN FILMS ON DIFFERENT SUBSTRATES FOR OPTICAL WAVEGUIDE APPLICATIONS. Markus Siegert, Arne Eckau, Judit Lisoni, Juergen Schubert, Chris Buchal, Institut fuer Schicht- und Ionentechnik, Forschungszentrum Juelich GmbH, Juelich, GERMANY; Changhui Lei, Institut für Festkorperforschung, Forschungszentrum Juelich GmbH, Juelich, GERMANY.

In an effort to fabricate electrooptical thin film modulators we investigated the influence of different substrates on the optical and structural properties of $BaTiO_3$ thin films. The films are grown by on-axis pulsed laser deposition (PLD) on MgO(100), $MgAl_2O_4$(100), $SrTiO_3$(100) and MgO buffered $Al_2O_3(1\bar{1}02)$ substrates. The optical waveguide losses and birefringence were measured with a prism coupling setup. The optical data are correlated to the results of Rutherford backscattering spectrometry/ion channeling (RBS/C), X-ray diffraction (XRD), atomic force microscopy (AFM) and transmission electron microscopy (TEM). With $BaTiO_3$ films on MgO(100) substrates, planar waveguide losses of 3 dB/cm and ridge waveguide losses of 5 dB/cm at a wavelength of 633 nm have been achieved.

2:15 PM Z4.3
GROWTH AND CHARACTERIZATION OF $LiNbO_3$ THIN FILMS PREPARED BY LPE TECHNIQUE ON ER PPLN SUBSTRATES.
David Callejo, Veronica Bermudez, Maria Dolores Serrano, Ernesto Dieguez, Laboratorio de Crecimiento de Cristales, Dept Fisica de Materiales, Universidad Autonoma de Madrid, SPAIN.

During the last decade $LiNbO_3$ (LN) thin films have attracted a great attention due to the important role in optical communications. In particular LN channelled waveguides will be one of the most interesting devices used in integrated optic, which can be theoretically achieved with a thin film grown over a Periodically Poled Lithium Niobate (PPLN) substrate. The PPLN substrates has been cut along the z axis from a bulk crystal grown by the Off-centered Czochralski technique from a congruent LN 0.5mol % Er doped melt. PPLN substrates are either optically polished or chemically etched in a HNO_3:HF (2:1) mixture at the boiling temperature. The domain size is 3 μm. The flux used in the LPE technique is 80 mol % $LiVO_3$-10mol% LN Li rich. The time and growth temperature are in the range of 40-5 min and 770-840 °C respectively. When the growth process is finished, the sample is suddenly withdrawn from the melt and slowly cooled to RT. For a polished PPLN substrate, the film reproduces one to one the periodic ferroelectric domain structure of the substrates. This fact is probably due to the different growth rate between the positive and negative domain ends along the z-axis. When a etched PPLN substrate is used, the periodic structure is the same as the previous case, nevertheles the film surface is worse than the preceeding one. High Resolution X-Ray Diffraction (HRXRD) measurements have been carried out in these samples in order to measure the quality of the film crystallinity and the lattice mismatch between film and substrate. In other way a compositional analysis has been made by he Wave-Dispersive X-Ray technique, in order to study the compositional differences between positive and negative domains in the films. The domain structure and the ferroelectric domain modifications after the LPE process have been observed after the etching procedure by optical microscopy, either at the surface or at the edge of the films.

3:00 PM *Z4.4
MBE-GROWN EPITAXIAL PEROVSKITES FOR ELECTRO-OPTIC WAVEGUIDE APPLICATIONS. F.J. Walker and R.A. McKee, Oak Ridge National Laboratory, Oak Ridge, TN.

The growth of epitaxial perovskites on various substrates presents unique challenges for molecular beam epitaxial (MBE) growth. The requirement of optical clarity in waveguide structures for electro-optic applications means that the film must be free of defects over large areas of the film. Such defects include twinning seeded at the substrate and in the film itself. In this paper we describe how epitaxial $BaTiO_3$ thin film waveguide structures have been integrated on silicon using an epitaxial, single crystal MgO isolation layer. An electro-optic phase modulator has been fabricated on this planar, four-layer-waveguide structure in order to measure the linear electro-optic coefficient. At 632 nm, a 1 mm-long $\times$ 20 mm-wide device shows a π phase shift at an applied voltage of 63 Volts. Because the waveguide and electrode structure are deposited on silicon, the conductivity of the silicon reduces the electric field in the guided material. Research sponsored jointly by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, and by the Division of Materials Sciences, U.S. Department of Energy under contract DE-AC05-96OR22464 with Lockh

3:30 PM Z4.5
INTEGRATED (Pb,La)(Zr,Ti)O_3 HETEROSTRUCTURE WAVEGUIDE DEVICES FABRICATED BY SOLID-PHASE EPITAXY. Keiichi Nashimoto, Shigetoshi Nakamura, Hiroaki Moriyama, Koichi Haga, Masao Watanabe, Takashi Morikawa, Eisuke Osakabe, and Tomo Takeda, Corporate Research Laboratories, Fuji Xerox Co., Ltd., Nakai, Ashigarakami, Kanagawa, JAPAN.

It is very attractive to fabricate an electrode/ferroelectric waveguide/ semiconductor structure since low-voltage drive devices will be realized by reducing the electrode gap. For the structure, it is of great interest to use (Pb,La)(Zr,Ti)O_3 (PLZT) ferroelectric materials which have excellent electro-optic properties and Nb-doped $SrTiO_3$ (Nb:ST) semiconductor substrates. However, it has been difficult to prepare a low-loss PLZT waveguide on a Nb:ST substrate. We fabricated a heterostructure of PZT waveguide/PLZT buffer layer on a Nb:ST substrate by solid-phase epitaxy to avoid absorption loss created by the substrate. The solid-phase epitaxy is a simple and useful technique as regards stoichiometric composition control, uniform large-area fabrication, low-loss capability, and waveguide patterning. The substrates were spin-coated with methoxyethoxide precursor solutions and preannealed to form amorphous thin films followed by the solid-phase epitaxial crystallization of the thin films. The propagation loss in the grown epitaxial PLZT heterostructure waveguides was the order of 1 dB/cm. An electro-optic beam deflection device with an ITO prism electrode on the surface of the PLZT heterostructure waveguide presented efficient deflection of the coupled laser beam by applying voltage between the electrode and the substrate. Beam deflection larger than 10 mrad at 5 V and frequency response as fast as 13 MHz were observed. An effective electro-optic coefficient larger than 70 pm/V was estimated from the deflection characteristics. For integrating the electro-optic PLZT waveguide devices with passive waveguide components, channel waveguides and waveguide lenses were also fabricated in the PLZT waveguides using a simple wet-etching process. Based on low-voltage drive structure, low-loss waveguide process, and fine patterning process, digital matrix switch was fabricated and tested.

3:45 PM Z4.6
DYNAMIC RESPONSE OF THE ELECTRO-OPTIC EFFECT IN EPITAXIAL FERROELECTRIC THIN FILMS. Brent H. Hoerman, Barbara M. Nichols, Andrew R. Teren, Bruce W. Wessels, Northwestern Univ, Dept of Materials Science and Engineering, Evanston, IL.

Ferroelectric thin films are being developed for use in active, thin-film waveguide devices such as high bandwidth electro-optic modulators because of their high electro-optic coefficients. For these applications both the static and dynamic response of the electro-optic effect are needed. In this investigation, low frequency electro-optic coefficients were measured on $KNbO_3$ and $BaTiO_3$ epitaxial thin films. For $KNbO_3$ thin films, effective electro-optic coefficients range from 4 to 30 pm/V. By poling, the effective electro-optic coefficient increased by as much as an order of magnitude. The dynamic response of the electro-optic effect after biasing was also measured. The relaxation of the electro-optic response followed a power law upon removal of the bias over the measured range of 6 nanoseconds to 10 microseconds. The measured dynamic electro-optic response in consistent with the frequency response of the dielectric constant for the thin films.

4:00 PM *Z4.7
MAGNETOOPTIC WAVEGUIDE MATERIALS AND DEVICES. Chen S. Tsai, Institute of Applied Sciences and Engineering Research, Academia Sinica, TAIWAN and Department of Electrical and Computer Engineering, University of California, Irvine, CA; Jun Su, Department of Electrical and Computer Engineering, University of California, Irvine, CA.

Ferromagnetic yttrium iron garnet-gadolinium gallium garnet (YIG-GGG) layer structure has long been the sole substrate material for realization of magnetooptic (MO) waveguide devices. In addition to the conventional techniques of LPE and RF sputtering, pulse laser deposition (PLD) technique has been developed recently to prepare pure and doped-YIG guiding layers of high quality. Both YIG and YIG-GGG layers have also been combined with other substrate materials to form hybrid integrated material structures. The YIG/GGG layers prepared using the aforementioned techniques as well as the hybrid material structures have continuously been used as the basic material substrate for construction of optical devices such as isolators and sensors, and magnetostatic waves (MSW)-based microwave and MO devices. In this paper, recent advances in the PLD technique for preparation of Ce doped YIG films on GGG substrate, hybrid integrated material structures such as YIG/GGG- and YIG-GaAs combinations and the resulting integrated microwave and MO devices, and their potential applications are presented. For example, high-efficiency MO Bragg cell modulators have been realized using a non-uniform bias magnetic field as well as an electronic feedback. Such MO devices are being used to form a variety of integrated optic devices such as optical scanners, switches, and frequency shifters. Also, a wideband microwave bandstop filter with a carrier frequency tuning range as high as 2.5 to 23.0 GHz using the hybrid YIG/GGG-GaAs material structure is being employed to conduct MO Bragg diffraction experiment at such high microwave frequencies

4:30 PM Z4.8
CHARACTERISTICS OF ZnO FILMS GROWN BY ULTRAVIOLET-ASSISTED PULSED LASER DEPOSITION. V. Craciun, J. Howard, and R.K. Singh, Department of Materials Science & Engineering, University of Florida, Gainesville, FL; J. Perriere, Groupe de Physique des Solides, Universites Paris VII et VI, Paris, FRANCE; D. Craciun, Laser Department, National Institute for Laser, Plasma, and Radiation Physics, Bucharest, ROMANIA.

ZnO is an interesting semiconductor material that has been used for transparent and conductive films, varistors and chemical sensors. It also exhibits nonlinear optical and piezoelectric properties and has been used as a light modulator, a planar optical waveguide, or for surface acoustic wave devices. Some of these applications require the growth of epitaxial, high quality ZnO layers on sapphire, the substrate of choice. Pulsed laser deposition (PLD) of ZnO has been one of the most used methods to grow high quality ZnO films at relatively moderate temperatures. However, the PLD growth of high quality epitaxial ZnO films requires substrate temperatures around 1023 K, which may be too high for many interesting applications. Recently, we have developed a new type of PLD technique where an ultraviolet source was added to the deposition chamber. This addition provides in-situ irradiation with high energy photons which increase the surface mobility of the adatoms and photodissociate the molecular oxygen employed during reactive deposition. By using this new ultrviolet-assited PLD (UVPLD), we were able to obtain, as assessed by Rutherford backscattering investigations, high quality epitaxial ZnO films on sapphire substrates at a substrate temperature of only 775 K, 250 K lower than that used during conventional PLD. The optical, electrical, and microstructural characteristics of these UVPLD grown ZnO films will be presented. These results clearly illustrate the advantages of the UVPLD technique for the growth of high quality thin films at moderate temperatures.

4:45 PM Z4.9
ROTATING DISK REACTOR-LOW PRESSURE METAL ORGANIC CHEMICAL VAPOR DEPOSITION (MOCVD) OF THIN AND THICK OPTICAL FILMS. Gary S. Tompa, L.G. Provost, Structured Materials Indistries, Piscataway, NJ; J. Doyle, Aerospace Display Systems, Hatfield, PA.

Complex oxide films, such as ZnO, ZnSiO, and BST, among others, are being developed for rapidly maturing applications, including waveguides, transparent and conductive, electro-optic, memory, pyroelectric, superconducting, MEMS, giant-magnetoresistive devices, and so on. High quality, thin or thick films are needed for these applications. These desired attributes are generally best achievable by MOCVD. We have developed a large scale MOCVD system for producing high optical quality films. We use a rotating disk reactor, operating at low pressures, with conventional gas or bubbler sources, as well as liquid delivery flash evaporation methodology, as appropriate. The high rate of rotation of the susceptor creates a viscous drag that counters thermal buoyancy effect to produce a non-recirculating laminar flow of gases through the system, thus allowing us to functionally separate vapors (oxidizers, precursors and so on) until they mix at the deposition plane in the reactor. This and the lack of recirculation greatly reduce pre reactions. Further, since the substrate is hotter than the surrounding reactor, thermophoresis drives particles and any potential mist droplets away from the wafer and into the exhausting gas stream. The use of radially symmetric reactant distributing injectors improves thickness and composition uniformity, while minimizing gas phase prereactions. Plasma enhanced processing has been shown to improve certain properties. We have used the system to deposit a variety of oxide films including transparent and conducting or luminescent films, insulating films and so on. We will review our transparent oxide film deposition results for transparent films on Si, quartz, and glass substrates. Properties measured include conductivity, absorption, compositions, and thickness, among others. The results reported herein have been enabled through NSF and BMDO-sponsored, Air Force and Office of Naval Research-administered development contracts, and collaborations with ARL.

SESSION Z5: POSTER SESSION: THIN FILMS FOR OPTICAL DEVICES

Thursday Evening, December 2, 1999
8:00 P.M.
Exhibition Hall D (H)

Z5.1
AUTOSTOICHIOMETRIC MOCVD OF MULTICOMPONENT THIN FILMS $LiTaO_3$, $LiNbO_3$ AND $Sr_xBa_{1-x}Nb_2O_6$.
Ruichao Zhang, Ren Xu, Univ of Utah, Dept of Materials Science and Engineering, Salt Lake City, UT.

Multicomponent thin films $LiTaO_3$, $LiNbO_3$ and $Sr_xBa_{1-x}Nb_2O_6$(SBN) are important materials for optoelectronic applications. The conventional fabrication methods for these multicomponent oxide films have limitation in composition and stoichiometric control. A novel stoichiometric vapor deposition process, Autostoichiometric MOCVD, was developed in this study to prepare stoichiometric thin films. Heterometallic alkoxides were used as single precursor for two different metal components in Autostoichiometric MOCVD. The molecular ratios of the metals were conserved through the precursor evaporation and the deposition reactions based on the chemical nature of heterometallic alkoxide precursors and the deposition reaction mechanisms. The evaporation processes for different heterometallic alkoxide precursors were systematically investigated. A non-stoichiometric factor K was defined to study the evaporation process of alkoxide precursors. A precursor evaluation method using the K factor and the thermal decomposition analysis was introduced to quantitatively analyze the stoichiometric evaporation characteristic of a heterometallic alkoxide precursor. The results of the precursor study were used in the deposition control for multicomponent oxide films. Single phase $LiTaO_3$, $LiNbO_3$, $SrNb_2O_6$ and $BaNb_2O_6$ were successfully obtained using precursor $LiTa(n\text{-}OBut)_6$ or $LiTa(i\text{-}OBut)_6$, $LiNb(n\text{-}OBut)_6$, $SrNb_2(n\text{-}OBut)_{12}$ and $BaNb_2(n\text{-}OBut)_{12}$, respectively. Solid solution $Sr_xBa_{1-x}Nb_2O_6$(SBN) films were also successfully obtained by a two-step Autostoichiometric MOCVD. The unique capability of precise stoichiometry control, which is inherent to the Autostoichiometric MOCVD, allows convenient composition control for the deposition of multicomponent oxide films and can be significant in applications where the stoichiometry is crucial.
Supported by National Science Foundation DMR-9526165

Z5.2
$BaTiO_3$ WAVEGUIDES ON MgO BUFFERED-SAPPHIRE SINGLE CRYSTALS.
Judit G. Lisoni, M. Siegert, J. Schubert, W. Zander and Ch. Buchal.

Within our program to develop ferroelectric thin film optical waveguides, we have studied the growth of epitaxial waveguides of a-oriented $BaTiO_3$ on R-plane sapphire substrates with a MgO buffer layer. The films were prepared by pulsed laser deposition (PLD). Their structural properties were studied by X-ray diffraction (XRD), Rutherford backscattering (RBS) in random and channeling configuration and atomic force microscopy (AFM). They displayed good crystalline quality, characterized by an RBS/C minimum yield of about 4-6%, a full with at half maximum (FWHM) of the XRD rocking curve measurement of the $BaTiO_3(200)$ reflex of 0.32° and a rms roughness of 1.2 nm in a film of ~1.0 μm in thickness. The epitaxial relationship was found to be $BaTiO_3(100) \parallel MgO(100) \parallel Al_2O_3(1\bar{1}02)$. The refractive index, the birefringence and the optical losses have been measured.

Z5.3
OPTICAL AND ELECTRO-OPTIC PROPERTIES OF HIGHLY ORIENTED $(Sr,Ba)Nb_2O_6$ THIN FILMS PREPARED BY SOL-GEL PROCESS.
Junmo Koo, Jae Hyeok Jang, and Byeong-Soo Bae, Lab of Optical Materials and Coating, Dept of Materials Science and Engineering, Korea Advanced Institute of Science and Technology, Taejon, KOREA.

Ferroelectric strontium barium niobate ($Sr_xBa_{1-x}Nb_2O_6$, where $0.25 \leq x \leq 0.75$) are currently being investigated as potential materials for pyroelectric infrared detector, electro-optic modulator, and holographic storage, and beam steering because of its large pyroelectric coefficient, excellent electro-optic properties, and photorefractive sensitivity. In this work, highly c-axis oriented SBN thin films with various compositions were obtained on MgO(100) and Pt(100)/MgO(100) substrates using sol-gel process. Also, (201) preferred oriented films were fabricated on $Pt(111)/SiO_2/Si$ substrates. Their optical properties such as optical transmittance, refractive index, and optical propagation loss, and electro-optic effect are characterized as a function of the film composition for optical applications. The absorption edge of the films shift to shorter wavelength and the refractive index decreases as Sr content grows. The anisotropy of refractive indices (n_o and n_e) of c-axis preferred oriented films on MgO(100) substrates decrease fairly as Sr content in the film composition increases. And, the optical propagation loss of the film decreases with an increase of Sr content though the film surface roughness is constant due to the optical scattering by the anisotropy of refractive indices. These oriented films show the linear electro-optic effect, and have large electro-optic coefficients. The coefficient of the film increases as Sr content in the film composition increases. And, the coefficients of the c-axis oriented films is higher than those of (201) preferred oriented films.

Z5.4
PREPARATION OF $K_3Li_2Nb_5O_{15}$ (KLN) THIN FILMS BY RF-MAGNETRON SPUTTER PROCESS.
Gwang-Tae Kim, Joon-Hyung Lee, Kyungpook National Univ., Dept. of Inorganic Materials Engneering, Taegu, Korea; Myung-Sik Park, HAN Technology Co.,Taegu, Korea ; Sang-Hee Cho, Univ. of Massachusetts, Center for Advanced Materials, Lowell, MA.

$K_3Li_2Nb_5O_{15}$ (KLN) has been attracted a great deal of attention for their potential usefulness in electrooptic, nonlinear optic, pyroelectric, and SAW device applications. Especially, the KLN single crystal has studied in the field of optics and electronics, but it is hard to get good quality single crystals due to the crack occurrence during crystal growing. One of the solutions of this problem is preparation of thin films. But the intensive study on the preparation and characterization of KLN thin film has not been conducted so far. In this study, the KLN thin films were prepared by RF-magnetron Sputtering method onto Coring 1737 and ITO coated glasses. The effect of working pressure, substrate temperature, RF-power, sputter gas ratio (Ar/O_2) during deposition was investigated. For an optimum deposition condition, the post-annealing, RTA(rapid thermal annealing) and IPA(in-situ post annealing)methods were employed. Both RTA and IPA methods, which were carried out at different deposition and annealing temperature, influenced on surface morphology, ferroelectric and optical properties of the films.

Z5.5
OPTICAL PROPERTIES OF ORIENTED $SrBi_2Ta_2O_9$ THIN FILMS.
S.E. Moon, S.B. Back, S.-I. Kwun, Seoul National Univ, Dept of Physics, Seoul, KOREA; T.K. Song, Chungnam National Univ, Dept of Physics, Taejon, KOREA; J.-G. Yoon, Univ of Suwon, Dept of Physics, Suwon, KOREA.

Ferroelectric $SrBi_2Ta_2O_9$ thin films have been grown on the MgO(100) and MgO(110) substrates by the rf magnetron sputtering deposition method. The structures of the films were characterized by the x-ray θ-2θ scan and the transmission electron microscope. C-axis and a-/b-axis oriented films were grown on MgO(100) and MgO(110) substrates, respectively. Transverse optical phonons which are consistent with the layered perovskite structure of the films, were observed by the infrared reflectance spectroscopy. The composition ratios of the films were analyzed by the electron probe microanalysis. Thin film on the MgO(110) substrate shows quadratic and hysteretic electro-optic characteristics with an effective coefficient of about 2.5×10^{-15} m^2/V^2. * This work was supported in part by KOSEF through RCDAMP at Pusan National University and in part by the academic research fund of the Ministry of Education, Korea.

Z5.6
OPTICAL CHARACTERISTICS OF Er DOPED Al_2O_3 WAVEGUIDE SYNTHESIZED BY ION BEAM ASSISTED DEPOSITION.
Q.Y. Zhang, P.S. Wang, L. Xu, State Key Laboratory for Materials Modification by Laser, Ion and Electron Beams, Dalian University of Technology, Dalian, CHINA.

Er doped A_2O_3 optical waveguides were synthesized on silicon substrates by ion beam assisted method. The optical waveguides synthesized were annealed at different temperature. The optical properties and microstructures of waveguides, and their relationship with anneal condition were investigated. Further optimization of ion beam parameters are also discussed in the paper.

Z5.7
CHEMICAL SOLUTION DEPOSITION OF QUANTUM DOTS DOPED - PZT AND PLZT THIN FILMS FOR PLANAR WAVEGUIDE APPLICATIONS.
Agustin Frattini, Raul A. Trbojevich, Nora Pellegri, Oscar de Sanctis, Ceramic Materials Laboratory, National University of Rosario, ARGENTINA; Carlos.J.R. Gonzalez Oliver, Centro Atomico Bariloche, CNEA, ARGENTINA; Kohei Kadono, Osaka National Research Institute, JAPAN.

Active optical waveguides have been received growing interest over the last decade due to their multiple applications, such as in integrated lasers or amplifiers for communications. Quantum dots dispersed transparent matrices present high third-order optical non-linearity. The matrix dielectric constant has an important role on the nonlinear optical response of the quantum dots doped - films. In this work, semiconductor and metal quantum dots were embedded into amorphous and crystalline ferroelectric thin films using chemical solution techniques. The quantum dots, which were synthesized in reverse micelles, dispersed into PZT and PLZT precursor solutions, subsequently, thin films were grown on silica substrates by means spinning process. Rapid thermal annealing and conventional thermal treatments were performed for film densification. By means glazing ray XRD and Scanning Electron Microcopies carried out the structural characterization. UV-Visible-NIR absorption spectra, refractive indices, thickness film and optical losses were measured. Degenerate Four-Wave Mixing analyzed non-linear optical properties (third-order) of the films. The treatment type, the final temperature, the sequence and the atmospheres, which were used during the film densification, influence strongly the structure and the optical properties of the films. The linear and non-linear optical properties were compared with those quantum dots doped - glass films.