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E-MRS Spring Meeting 2004  
May 24-28, 2004

## SYMPOSIUM A1

Si-based photonics:  
towards true monolithic integration

Symposium Organizers:

Richard Rizk, SIFCOM, ENSICAEN, Caen, France

Philippe M. Fauchet, University of Rochester, USA

Donald S. Gardner, INTEL Corporation, USA

Francesco Priolo, University of Catania, Italy

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# E-MRS 2004 SPRING MEETING

## SYMPOSIUM A1

Tuesday, May 25, 2004

Morning

Session I : Active Si-based devices

Session Chair: R. Rizk and N. Dalbosso

8:50 Opening address

**A1-I.1** 9:00 -Invited-

MANIPULATING LIGHT ON A Si CHIP

**Michal Lipson**, School of Electrical and Computer Engineering, Cornell University, Ithaca NY, USA

Microphotonics – optics on silicon chips – provides a new platform for monolithic integration of optics and microelectronics. There are a number of fundamental challenges that need to be addressed before this technology can successfully be used to resolve current microelectronics bottlenecks. For example, the difficulty of extracting the information in and out of a chip – the equivalent to the electronic soldering, and controlling light and diverting its path; the equivalent to the electronic switching.

Here I will present an overview of the state of Optics on a Silicon Chip. I will present our recent results demonstrating a compact “optical solder” for coupling between micron-size fibers and nano-size waveguides with more than 90% efficiency. I will also present our recent results on all-optical ultra-fast active device on a conventional microelectronics’ Silicon chip, where a beam of light can redirect the flow of another beam of light. All-optical switching on chip, is achieved using highly confining structures to enhance the sensitivity of light to small index changes. The transmission of the structure can be modulated by more than 97% in less than 500 ps using light pulses with energies as low as 40 pJ. This work will enable all-optical circuits compatible with today’s microelectronics technology.

**A1-I.2** 9:30

ROOM TEMPERATURE LASER OPERATION OF STRAINED InGaAs/GaAs QW STRUCTURE MONOLITHICALLY GROWN BY MOCVD ON LE-PECVD Ge/Si VIRTUAL SUBSTRATE

L. Sagnes(a), Y. Chiqui(a), G. Saint-Girons(a), G. Isella(b), H. von Kaenel(b), S. Bouchoule(a), (a)Laboratoire de Photonique et de Nanostructures L.P.N., CNRS UPR20, Route de Nozay, 91460 Marcoussis, France, (b)INFM and L-NESS, Dipartimento di Fisica del Politecnico di Milano Via Anzani 52, 22100 Como, Italy

A large variety III-V GaAs-based laser structures are produced at a commercial scale, and are used in a wide range of optoelectronic applications. Their monolithic integration with silicon-based microelectronic systems could allow to overcome the bottleneck of electrical interconnections, and represents a reliable low cost alternative to wafer bonding techniques. But the direct growth of GaAs on Silicon still remains a challenge. Indeed, the differences in lattice parameters and thermal expansion coefficients between GaAs and Si, and the presence of antiphase boundaries (APBs) – resulting from the epitaxy of polar on non-polar materials – strongly affect the structural and optical properties of the GaAs layers grown on silicon. However, the use of offcut substrates composed of strained relaxed Ge/Si<sub>1-x</sub>Ge<sub>x</sub> buffer layers grown on silicon provides for excellent conditions for the subsequent GaAs growth, due to the absence of APBs and the lattice matched parameters of Ge and GaAs.

In this contribution, we report on first room temperature (RT) laser operation at 1.04μm from strained InGaAs/(Al)GaAs quantum well structures grown by metalorganic vapour phase epitaxy (MOVPE) and monolithically integrated on Si using 6° offcut Ge/GeSi/Si -Virtual Substrate (VS) realized by Low Energy-Plasma Enhanced Chemical Vapor Deposition (LE-PECVD). Similar threshold current density from identical control laser diodes grown on bulk germanium substrates demonstrates the potential of Ge/GeSi/Si-VS for the monolithic integration of long wavelength GaAs-based lasers on Si.

- A1-I.3** 9:50 **DEVICE DESIGN AND FABRICATION FOR A Si/SiGe TERAHERTZ QUANTUM CASCADE LASER**  
R.W. Kelsall(a), Z. Ikonic(a), P. Harrison(a), S.A. Lynch(b), P. Townsend(b), D.J. Paul(b), D.J. Norris(c), S.L. Liew(c), A.G. Cullis(c), J. Zhang(d) and H.S. Gamble(e), (a)Institute of Microwaves and Photonics, The University of Leeds, (b)Cavendish Laboratory, The University of Cambridge, (c)Dept. of Electronic & Electrical Eng., The University of Sheffield, (d)Dept. of Physics, Imperial College, (e)School of Electrical and Electronic Eng., Queens University, Belfast, U.K.  
 Si/SiGe quantum cascade (QC) heterostructures offer a promising route to a silicon based laser. Since QC lasers operate via intersubband transitions, the indirect nature of the silicon bandgap has no adverse effect on the radiative efficiency. The energy gaps between subbands can be controlled by adjusting strain and layer thicknesses, giving access to a wide range of wavelengths across the mid-infrared and terahertz (THz) bands. We have demonstrated THz intersubband electroluminescence from p-Si/SiGe QC heterostructures, using transitions between light and heavy hole subbands of both intra-well ('vertical') and inter-well ('diagonal') types. Laser operation in the THz range requires cavities which are very large, compared to typical epitaxial layer widths. By growing strain-symmetrised Si/SiGe heterostructures on a relaxed SiGe buffer, we have produced devices of up to 600 periods, with no evidence of strain relaxation. Such heterostructures have been processed into ridge-waveguide devices which support long wavelength surface plasmon modes. Mode leakage into the substrate is avoided by use of a buried silicide reflector, prepared using bond and etch-back. The additional loss presented by the silicide layer is outweighed by the greatly improved mode confinement, and optical gains predicted from carrier dynamics simulations for optimised devices comfortably exceed the total cavity loss.
- A1-I.4** 10:10 **STATUS OF OPTICAL GAIN WITH SILICON NANOCRYSTALS**  
P.M. Fauchet, J. Ruan and H. Chen, University of Rochester, USA, L. Pavesi, M. Cazzanelli and L. Dal Negro, University of Trento, Italy, R.G. Elliman, N. Smith, M. Samoc and B. Luther-Davies, Australian National University, Canberra, Australia  
 An extensive experimental study of optical gain in silicon nanocrystals is under way. Different types of samples have been tested (e.g., nanocrystalline silicon superlattices prepared in Rochester, ion implanted silicon dioxide prepared in Canberra) using different measurement techniques (e.g., variable stripe length method in Trento and in Rochester, prism coupling in Canberra) and different pump laser sources (from femtosecond to cw). All the results presented here have been reproduced in at least two different laboratories, making it unlikely that experimental artifacts play a role. So far, we have observed nsec-duration gain in the visible/near infrared range in nanocrystalline silicon superlattices under high photoinjection conditions with short laser pulses. For other conditions (e.g., lower photoinjection, ion implanted samples with a lower concentration of quantum dots), we have not observed gain. We will discuss these and other results. We will also report on the possibility of manufacturing cavities that might allow lasing.
- A1-I.5** 10:30 **OPTICAL GAIN IN NANOCRYSTALLINE SILICON: COMPARISON OF PLANAR WAVEGUIDE GEOMETRY WITH A NON-WAVEGUIDING ENSEMBLE OF NANOCRYSTALS**  
K. Luterova, I. Pelant, and K. Dohnalova, Institute of Physics, Cukrovarnicka 10, 162 53 Praha 6, Czech Republic, J. Valenta, Charles University, Ke Karlovu 3, 121 16 Praha 2, Czech Republic, M. Cazzanelli and L. Pavesi, Universita di Trento, Via Sommarive 14, 38050 Povo, Italy, J.-P. Likforman, P. Gilliot, B. Hönerlage and T. Ostatnický, IPCMS, B.P. 43, 23 rue du Loess, 67034 Strasbourg Cedex 2, France, S. Cheylan, Australian National University, Canberra ACT 0200, Australia  
 Stimulated emission from nanocrystalline silicon in the visible has become a hot topic during these years. Various forms of silicon nanostructures are being exploited, among them planar optical waveguides made of silicon nanocrystals, silicon superlattices and tiny silicon nanoparticles. We report on optical gain measurements using the variable-stripe-length and the shifting-excitation-spot methods in two different types of nanocrystalline samples: A planar nanocrystalline waveguide prepared by silicon-ion implantation (400 keV,  $4 \times 10^{17} \text{ cm}^{-2}$ ) into a silica substrate and a layer of porous silicon grains embedded in a sol-gel derived SiO<sub>2</sub> matrix. The latter does not exhibit any waveguiding. While at a first sight one would expect much more favourable conditions for the stimulated emission occurrence in the former type of samples, in fact we observed small optical gain in both types (modal gain of 12 cm<sup>-1</sup> at ~670 nm in ion implanted sample and 25 cm<sup>-1</sup> at ~650 nm in sol-gel embedded sample, respectively), however, under different pumping conditions. We discuss advantages and disadvantages of both nanostructures, referring in particular to leaky-mode emission that may occur in planar waveguides on transparent substrates.
- 10:50 **BREAK**

## Session II : Light modulation and infrared photodetection

Session Chair: D. Gardner, P. Boucaud

- A1-II.1** 11:10 -Invited- **MATERIALS CHALLENGES IN DESIGN OF A GIGAHERTZ SILICON OPTICAL MODULATOR BASED ON A METAL–OXIDE–SEMICONDUCTOR CAPACITOR**  
**Dean Samara-Rubio**, Ling Liao, Ansheng Liu, Richard Jones, Mike Morse, Intel Corporation, 2200 Mission College Blvd, CHP3-109, Santa Clara CA 95054, USA, and Doron Rubin, Oded Cohen, Intel Corporation, S.B.I. Park Har Hotzvim, Jerusalem 91031, Israel  
It is well-known that low-loss silicon waveguides can be fabricated on SOI substrates. SOI waveguide devices such as arrayed waveguide gratings (AWG), Bragg filters, variable optical attenuators (VOA), photodiodes, and others have been developed for telecom applications. The relative ease of manufacturing and low cost of Si-based devices has fuelled the drive to increase the variety and quality of optical functions which can be monolithically integrated with SOI waveguides. However, two key functions are still lacking: high-speed data encoding (optical modulation), and efficient lasing (light generation/amplification). Here we describe an SOI waveguide optical modulator which operates at speeds in excess of 1GHz. This is a significant milestone since the fastest SOI-based optical modulator measurement found in literature is ~20 MHz.  
The device reported here is based on free-carrier plasma dispersion in an accumulation-mode metal–oxide–semiconductor (MOS) capacitor. Incorporating the MOS stack into the waveguide is a departure from the previous works which relied on carrier injection across forward-biased diode junction(s). The primary advantage of the MOS capacitor operating in accumulation bias is the elimination of the minority carrier lifetime from the optical response of the modulator.  
The conversion to an MOS structure, however, poses some materials and design challenges that will be discussed, including the need for highly-doped silicon and poly-silicon in the optical path, changes in optical characteristics due to the presence of a low-index gate layer, and a constraint on the available free-carrier density due to gate reliability limits.
- A1-II.2** 11:40 **MID/FAR-INFRARED DETECTION USING A MESFET WITH MODULATION DOPED Ge-DOT/SiGe-WELL MULTIPLE STACKS IN THE CHANNEL REGION**  
B. Adnane, E. Dawi, M. Zhao, A. Elfving, B. Magnusson, G. Hansson and W.-X. Ni, Dept. of Physics, Linköping University, 581 83 Linköping, Sweden  
It has recently been demonstrated that the efficiency of p-Ge/Si quantum dot (QD) mid-infrared photo detectors is improved by adding strained SiGe quantum wells (QWs) close to the dot layers, acting as high mobility channels for the intraband-excited holes. By using a similar idea, we have fabricated and studied a field effect transistor for mid- and far-infrared detection. In these devices, 10 modulation-doped Ge dot layers with desired subband structures are used for the infrared absorption, while there is 2D SiGe QW adjacent to the each dot layer for the enhanced carrier inplane transport. Furthermore, we have also processed a top gate, in order to control the carrier transfer from dots to QWs through in a desired case the tunneling process. The investigated structures were grown by solid source molecular beam epitaxy on n-type Si (001) substrates through the self-assembled process at a substrate temperature around 510 °C, and the modulation–doping was provided by a high-temperature boron effusion cell. From a non-optimized device, a broad photocurrent signal has been observed in the mid-infrared range of 3-20 μm. A peak responsivity was estimated to be as high as 100 mA/W at T = 4 K. This work indicates that SiGe QD/QW structures using lateral photoconduction can be potential candidates for photodetectors operating in the technologically challenging far-infrared range. Further work on optimizations of both the devices design and manufacturing is underway.
- A1-II.3** 12:00 **MODULATION OF SENSITIZED ERBIUM EMISSION IN SI OPTICAL NANOCRYSTAL MEMORIES**  
Robert J. Walters(a), Harry A. Atwater(a), Albert Polman(a,b), George I. Bourianoff(c), (a)Caltech, Pasadena CA, USA, (b)FOM-AMOLF, Amsterdam, The Netherlands, (c)Intel Corporation, Portland OR, USA  
We have fabricated silicon optical nanocrystal memory devices on 300mm wafers with silicon nanocrystals (Si-NCs) formed by high-T annealing of silicon implanted into thermally grown gate oxides. A semitransparent gate contact allows simultaneous optical and electronic probing of the nanocrystals that form the floating gate in a transistor structure.  
These devices have been shown to exhibit a modulation of photoluminescence (PL) intensity proportional to their programmed memory state. The observed attenuation of nanocrystal PL in the charged device state is attributed to a non-radiative Auger recombination process in the presence of the additional charge carrier, which is programmed by either electrical or optical injection. When erbium is introduced into such devices by co-implantation, Si-NC PL is suppressed and emission is observed at 1.55 microns. Comparison to implanted 'control' devices containing Er but not Si-NCs confirms that the 1.55 micron Er PL is sensitized by the presence of Si-NCs by over one order of magnitude. We can conclude that the dominant excitation pathway for Er ions in these devices is via energy transfer from photoexcited Si-NCs. Under electrical programming conditions, erbium PL is suppressed by 40% under the application of a programming gate bias of +8 Volts. This decrease in erbium PL under gate bias is attributed to the onset of nnp Auger recombination in the Si-NCs due to the injection of electrons. The suppression of erbium PL is less efficient under negative biases, perhaps because the excitation pathway competes more effectively with the slower npp Auger recombination process. We will discuss these results in the context of Erbium sensitization by Si-NCs and comment on the device prospects for such Er-Si optical nanocrystal memories.

**A1-II.4** 12:20

**Ge-QUANTUM DOT/SiGe-QUANTUM WELL SUPERLATTICE FOR NEAR INFRARED PHOTO-DETECTION**

A. Elfving, G.V. Hansson and W.-X. Ni, Dept. of Physics, Linköping University, -581 83 Linköping, Sweden

Although we have demonstrated that one can obtain a very high photoresponse (0.5 A/W at 1.31  $\mu\text{m}$ ) with the implementation of Ge dot layers in the base-collector junction of a transistor, the bipolar nature of the devices may rise the junction capacitance, which limits the speed performance of the devices. Here we report a study on another type of detectors with Ge quantum dot (QD) layers as the active region for near infrared absorption of normal and edge incident light, while the photo-current is measured via carrier lateral transport through a coupled SiGe 2-D layer (QW) adjacent to the dot layer. The structure contains 10 i-SiGe-QW/Ge-QD pairs separated by 10 nm Si. Each device was built up by mesas with finger patterns as metal contacts. For edge incidence measurements, a proper light coupling was achieved by a polished facet with an angle of 30° to the in-plane and the absorption volume was increased by fabricating detectors with total lengths of 1.5 mm. Photoconductivity measurements show about 7 times larger photoresponse for these detectors compared to reference detector structures grown without SiGe QWs. For normal incidence devices, responsivity values of 65 and 20 mA/W have been measured at 1.31 and 1.55  $\mu\text{m}$ , respectively, from non-optimised devices without any coupling rescaling. Edge incidence measurements preliminary show that the photoresponse was increased by more than a factor of two. We have also processed the devices with a third metal contact on top of the mesas, i.e. a gate-controlled three-terminal MESFET photo-detector, such that the hole transfer into the QWs could be more efficient. Furthermore, the switching properties of this type of detectors will be studied.

12:40

**LUNCH**

Tuesday, May 25, 2004

Afternoon

Session III : Er-Si coupling

Session Chair: T. Gregorkiewicz and F. Priolo

- A1-III.1** 14:00 -Invited- PHOTOLUMINESCENCE PROPERTIES OF RARE-EARTH IONS AND/OR SHALLOW IMPURITIES DOPED SILICON NANOCRYSTALS  
**Minoru Fujii**, Yuji Takase, Kenji Imakita, Yasuhiro Yamaguchi, and Shinji Hayashi, Department of Electrical & Electronics Engineering, Faculty of Engineering, Kobe University, Rokkodai, Nada, Kobe 657-8501, Japan  
The electronic structure of Si nanocrystals (nc-Si) is strongly modified from that of a bulk silicon crystal due to the spatial confinement of electrons and holes. The quantum confinement results in the efficient visible photoluminescence (PL) at room temperature. The confinement also modifies the behavior of impurity atoms doped into (or on the surface of) nc-Si, and adds new functions on nc-Si. One example is that Er ions existing nearby nc-Si can efficiently be excited by the energy transfer from nc-Si and show temperature-independent PL at 1.54 micrometer, which is a standard fiber telecommunication wavelength. Similar below-bandgap PL can be realized by controlling shallow impurities in nc-Si without doping optically active materials. Simultaneous doping of n- and p-type impurities into nc-Si results in the recombination of electrons and holes via band tails; for relatively large nc-Si, strong PL was observed at around 0.9 eV at room temperature. The simultaneous doping improves PL intensity of nc-Si due to the relaxation of momentum conservation rule during the optical transition and due to the smaller probability of the impurity-related Auger recombination compared to either n- or p-type impurity doped nc-Si.
- A1-III.2** 14:30 -Invited- FABRICATION AND OPTICAL PROPERTIES OF UNDOPED AND Er-DOPED MULTILAYERS Si-rich SiO<sub>2</sub>/SiO<sub>2</sub>: SIZE CONTROL, OPTIMUM Er-Si COUPLING AND INTERACTION DISTANCE MONITORING  
**F. Gourbilleau**, C. Dufour, R. Rizk. SIFCOM, UMR CNRS 6176, ENSICAEN, 6 Bd MI-Juin, 14050 Caen Cedex, France  
The multilayer (ML) fabrication approach aiming at controlling the size of Si growing within a silica matrix for photonic applications is examined for both undoped and Er-doped Si-rich SiO<sub>2</sub> (SRSO)/SiO<sub>2</sub> MLs obtained by reactive magnetron sputtering. For Er-free MLs, the visible emission was studied through the behavior of the two visible peaks versus the SRSO thickness. This behavior was well described by a theoretical model that considers the existence of a 8-Å width interface including a radiative centre responsible of one peak, while the quantum confinement effect explains the evolution of the second peak. Hence, the change of SRSO thickness was found to govern the emission color, from yellow to deep red. The counterpart system doped with Er was also studied and more particularly the impact the Si nanocluster (Si-nc) size on the energy transfer efficiency inducing more than 100 times increase of the emission at 1.54 μm. The sensitizing action of Si-nc towards the neighboring Er ions is still effective for both amorphous and crystalline Si-nc, provided that their size remains lower than about 3.5 nm. In accordance with the ML approach, a maximum distance separating the Er ion from the Si-nc was also determined for an efficient Er-Si coupling. Both limiting values of Si-nc size and Er – Si-nc spacing allow optimization of the material composition and hence the fraction of optically active ions that pave the way to performing Si-based photonic devices for optical communications.
- A1-III.3** 15:00 ERBIUM-SILICON-OXIDE CRYSTALLINE FILMS PREPARED BY MOMBE  
**H. Isshiki**, K. Masaki, and T. Kimura, Department of Electronic Engineering, Univ. of Electro-Communications, Tokyo 182-8585, Japan  
Recently optically active and electrically excitable Er-Si-O nano-crystallite on silicon has been demonstrated. The single crystalline nature gives fine structures (line width of 4meV) in photoluminescence and its excitation spectra of the Er<sup>3+</sup> ions even at room temperature. The Er-Si-O nano-crystallites are formed by spin-coating a Si (100) substrate with an ErCl<sub>3</sub> solution, followed by a rapid thermal oxidation and annealing sequence. This process leads to the formation of a self-organized Er-Si-O superlattice, epitaxially aligned with facets on the (100) surface. However, there is a practical difficulty of applying the Er-Si-O nano-complexes since the thin film or bulk has not yet been obtained. In this paper, metal organic molecular beam epitaxial growth (MOMBE) of erbium-silicon-oxide crystalline films is proposed. From the Stark splitting, the local environment of Er ion has been determined to be sixfold-coordination of Er-O<sub>6</sub>. We expect that the Er-O bond is formed preferentially during rapid thermal oxidation, and there occurs the self-organization due to the high temperature annealing. MOMBE growths are performed by using TEOS and Er (TMOD)<sub>3</sub> as the precursors of Si-O and Er-O respectively. Er-Si-O films are grown on Si (100) substrates at 800oC, and then high temperature annealing (1200oC) is performed. XRD results show crystalline nature but unpublished diffraction pattern for any erbium-silicates in JCPDS file. The 1.53 μm PL emission peak with line width of 6meV is observed from MOMBE grown Er-Si-O thin films at room temperature.

**A1-III.4** 15:20

**TIME DEPENDENCE AND EXCITATION SPECTRA OF THE PHOTOLUMINESCENCE EMISSION AT 1.5 MICRON IN Si-NC AND Er CO-DOPED GLASSES**

M. Falconieri, ENEA, C.R. Casaccia, via Anguillarese 301, 00060 Roma, Italy, E. Borsella, ENEA, C.R. Frascati via E. Fermi 45, 00044 Frascati (Roma), Italy, F. Enrichi, INFN, Dip. Fisica Univ. Padova, via Marzolo 8, 35131 Padova, Italy, G. Franzò, F. Priolo, INFN, Dip. Fisica e Astronomia Univ. Catania, via S. Sofia 64, 95123 Catania, Italy, F. Gourbilleau, R. Rizk, ENSICAEN, SIFCOM UMR-CNRS 6176, 6 Bd Marechal Juin, 14050 Caen, France, F. Iacona, CNR-IMM, Stradale Primosole 50, 95121 Catania, Italy

Sensitization of the Er<sup>3+</sup> photo-luminescence emission at 1.54 micron by means of energy transfer from Si quantum dots (Si-nc) has attracted much interest because of potential application in the fabrication of broadly pumpable Er-doped waveguide amplifiers. However, several aspects of the energy transfer mechanism still need to be clarified, especially concerning the excitation dynamics, since most of the previous experiments have been performed using a c.w. Ar<sup>+</sup> laser or a pulsed laser emitting at fixed wavelengths.

We report on the spectroscopic investigation of the energy transfer mechanism in Si-nc/Er co-doped glasses using both the fundamental (700-900 nm) and the frequency-doubled emission of a tunable nanosecond Ti:sapphire laser. The co-doped samples were prepared by two different techniques: PECVD followed by Er implantation or by magnetron co-sputtering. We measured the spectral and temporal dependence of the Er<sup>3+</sup> emission at 1.54 micron after pumping the material in resonance with the Er<sup>3+</sup> ion manifolds at 378 nm and 800 nm, or off-resonance in the 360-430 nm wavelength range, aiming to evidence differences caused by pumping either through Si-nc or through intra-center relaxation. The time resolution of the detection setup was about 1 microsecond. Our results show strong sensitization of the Er<sup>3+</sup> emission in the 360-430 nm range and also a weak sensitization effect in the 700-900 nm range. Moreover, comparison of the rise time of the 1.54 micron emission when pumped through Si-nc or by intra-center relaxation allows us to estimate an energy transfer time  $\approx 2$  microseconds at our dopant concentrations and to shed light on the energy transfer mechanism. These results can have impact on the exploitation of the Si-nc/Er co-doped glasses in photonics.

**A1-III.5** 15:40

**ULTRA-LOW-THRESHOLD ERBIUM-IMPLANTED TOROIDAL MICROLASER ON SILICON**

T.J. Kippenberg(a), B. Min(a), J. Kalkman(b), and K.J. Vahala(a) and A. Polman(a,b), (a)Caltech, Pasadena, USA, (b)AMOLF, Amsterdam, The Netherlands

We present the first microlaser on silicon operating at 1.5 micron wavelength that is completely made using standard CMOS silicon fabrication technology. The laser is based on a 40-micron diameter erbium-doped SiO<sub>2</sub> toroidal microcavity on a Si wafer, fabricated by a combination of erbium ion implantation, photolithography, wet and dry etching, and laser annealing. Highly efficient coupling both into and out of the chip-based microcavity is achieved by using a tapered optical fiber.

Laser cavity quality factors as high as  $4 \times 10^7$  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  $\mu$ W, the lowest threshold for an erbium laser fabricated to date. Minimum 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 theoretical modeling. At high doping levels bright green emission is observed, that is attributed to a combination of cooperative upconversion and excited state absorption in Er<sup>3+</sup>. We think this work will open up a whole new field of microresonator science and technology. For example, the wafer-scale nature of these Si-based microresonators enables implantation with other rare earth ions to fabricate lasers that operate in the visible, or with noble metals to form nanocrystals with well-defined surface plasmon resonances and associated non-linear properties, or with Si quantum dots that can serve as sensitizers for Er or may show lasing in the near-infrared. Several of these new on-chip applications will be discussed.

16:00

**BREAK**

Session IV : Monolithic integration

Session Chair: U. Gösele and M. Lipson

**A1-IV.1** 16:20 -Invited-

**Ge ISLANDS AND PHOTONIC CRYSTALS FOR SI-BASED PHOTONICS**

**P. Boucaud**, M. El Kurdi, S. David, C. Kammerer, X. Li, S. Sauvage, V. Le Thanh, D. Bouchier, J.-M. Lourtioz, Institut d'Electronique Fondamentale, Université Paris XI, 91405 Orsay, France, O. Kermarrec, Y. Campidelli, D. Bensahel STMicroelectronics, 850 Rue Jean Monnet, 38926 Crolles Cedex, France

The development of Si-based photonics and the integration of photonic and electronic circuits require optical devices operating in the 1.3 – 1.55  $\mu$ m spectral range that are compatible with CMOS technology. The combination of Ge/Si self-assembled islands with two-dimensional photonic crystals offer new opportunities to develop small scale devices fully integrated with Si-based signal processing. Carrier localization combined with optical microcavities characterized by small mode volumes can provide enhanced performances for active devices (nanosources) and passive devices. In this presentation, we will review recent advances in the field. It includes the fabrication of two-dimensional photonic crystals and defect-microcavities containing Ge islands on silicon-on-insulator substrates, the microphotoluminescence analysis of their properties and the realization of two-dimensional photonic crystal waveguides with Ge islands as an internal probe. Prospects for the development of high efficiency microsources will be discussed.

- A1-IV.2** 16:50 **ELEMENTARY DEVICES, CIRCUITS AND PROCESSES FOR A MONOLITHIC Si/ III-V-N OEIC**  
H. Yonezu, Y. Furukawa, H. Abe, Y. Yoshikawa, S.-Y. Moon, A. Utsumi, Y. Yoshizumi, Toyohashi University of Technology, 1-1 Hibarigaoka, Tempaku-cho, Toyohashi, Aichi 441-8580, Japan and M. Ohtani, Nara National College of Technology, 22 Yada-cho, Yamatokohriyama, Nara 639-1080, Japan  
 We have successfully grown dislocation-free GaPN, GaAsPN and InGaPN(III-V-N) layers on a Si substrate following a topmost Si layer. The epilayers showed high crystalline quality. Thus, a monolithic OEIC could be constructed in which electronic ICs are formed in the Si epilayer and optoelectronic devices in the III-V-N epilayers. We have been studying elementary devices, circuits and fabrication processes. Relatively bright emission was obtained at 650 nm wavelength in a DH LED with a GaPN active layer. A parallel network for edge detection was designed based on vertebrate retinas. A LSI fabricated in a conventional Si substrate detected the edge of a target with a wide optical dynamic range. A gate oxide of MOS transistors was formed on the Si epilayer at 900 C, which is an optimum annealing temperature of GaPN for increasing light emission efficiency. These results show a high possibility that ultra-fast parallel information and image processings with parallel optical outputs are realized in a single chip, which is completely different from present sequential information and image processing systems in a chip.
- A1-IV.3** 17:10 **MICRORING AND MICRODISK RESONATORS USING SILICON AND ERBIUM PREPARED USING SILICON TECHNOLOGY**  
Donald S. Gardner, Circuits Research, Microprocessor Technology Labs, Intel Corp., Santa Clara CA 95052, and Mark L. Brongersma, Materials Science, Stanford University, Stanford CA 94305, USA  
 There is considerable interest in using light for communications in integrated circuit technology. It would be desirable to have narrow-linewidth light sources that are monolithically fabricated on silicon substrates and compatible with CMOS technology. Currently chip-to-chip communications is severely limited because of the time delays, the power consumed, the number of pads that can be fabricated onto a chip, the silicon area used, and the cost.  
 In this work, micro-resonator based narrow linewidth light sources have been simulated, modeled, fabricated, and characterized. The structures consist of microdisk and microring cavities doped with silicon and/or erbium. The microcavity confines light to a small modal volume by resonant recirculation in a structure with low roundtrip optical loss. Confinement is obtained by creating a microcavity fabricated by first depositing SiO<sub>2</sub> and then introducing excess silicon either during the deposition process or ion implantation. The samples were then patterned with round disks and rings, and then erbium was implanted. Finally, higher quality factors for the resonators can be obtained by reducing the surface roughness that causes light scattering using a CO<sub>2</sub> laser that momentarily melts the surface.  
 The resonators are formed in close proximity to waveguides used for coupling light out of the microcavity. The circumference of the microdisk is chosen to be an integer multiple of the light's wavelength so as to setup a whispering gallery mode. In the rings, resonance is established if the length of the waveguide ring is an integer multiple of wavelengths. Pumping of the microcavity is accomplished by optically pumping with an argon laser from the top, but pumping with a narrow linewidth tunable laser via a second waveguide.
- A1-IV.4** 17:30 **INTEGRATED MICROLENS REFLECTOR AND LIGHT COUPLER**  
M. Nathan, School of Electrical Engineering, Department of Physical Electronics, Tel Aviv University, Tel Aviv 69978, Israel  
 The coupling of light between two micro-optical elements remains one of the main challenges of true monolithic integration in Si-based photonics. The coupled elements may be for example a light source/waveguide (WG) or a waveguide/ buried photodetector (PD). Coupling from an external light source into an on-chip waveguide (particularly a single mode one) requires either a diffraction grating, a prism, or complicated butt-coupling. Coupling from a waveguide into a buried detector is normally leaky mode, which is quite inefficient unless similar gratings and/or anti-reflection coatings are used. This talk presents a novel, simple and efficient coupling component that significantly enhances the WG/PD coupling efficiency. The component is a photoresist microlens formed by reflow techniques over an overlapping WG/PD structure. The microlens acts as a reflector of light propagating along the WG, directing the light into the buried PD. Various such microlens reflectors and light couplers were fabricated and used to couple SU8 waveguides into buried Si PDs. The effects of the microlens shape and size, its positioning over the coupled elements, and the use of additional reflective coatings to further enhance coupling will be presented and discussed.
- A1-IV.5** 17:50 **MICROARRAYS OF SILICON-BASED LIGHT EMITTERS FOR NOVEL BIOSENSOR AND LAB-ON-A-CHIP APPLICATIONS**  
L. Rebohle, T. Gebel, R.A. Yankov, W. Skorupa, Nanoparc GmbH, Bautzner Landstr. 45, 01454 Dresden-Rossendorf, Germany and Institute of Ion Beam Physics and Materials Research, FZ Rossendorf, POB 510119, 01314 Dresden, Germany  
 We have demonstrated intense violet electroluminescence (EL) from thermally-grown SiO<sub>2</sub> films containing Ge nanocrystals produced by ion beam synthesis. An outline is given of the electrical and optical characteristics of ITO/SiO<sub>2</sub>/Al light-emitting devices incorporating Ge nanocluster-rich oxide films. Optimization schemes based on the use of local oxidation of Si (LOCOS) and plasma engineered interface between the oxide layer and the top transparent electrode have been developed and tested successfully. Arrays of 4x6 light-emitting devices with a diameter of 300 &#956;m and spacing of 500 &#956;m between the adjacent devices have been formed using standard lithography patterning. Bioanalyses have been carried out following fluorescent-based detection procedures. As distinct from the standard case of diagnostics in which the light source is typically a laser and the necessary spatial resolution is provided by a CCD camera, our light sources are small enough to immediately ensure high resolution while permitting their light emission to be detected by single inexpensive Si diodes. Finally, the relevance of the all-Si light sources to microarray and miniaturized sensor and Lab-on-a-Chip systems for point-of-care diagnostics is discussed.

- A1-PL1** ENHANCEMENT OF PHOTORESPONSE PROPERTIES OF BETA-FeSi<sub>2</sub>/Si HETEROJUNCTIONS BY Al DOPING  
Yoshihito Maeda(a)and Yosikazu Terai(b), (a)Department of Energy Science and Technology, Kyoto University, (b)Department of Materials Sciences, Osaka Prefecture University, Japan  
 Photoresponse properties of ion-beam synthesized (IBS) poly-crystalline beta-FeSi<sub>2</sub>/Si heterojunctions were examined for the application to monolithic integration of IR-detectors which can response a longer wavelength light than Si detectors. The p-n heterojunction showed a clear atomic scale interfacial structure and a good rectifying I-V property. At room temperature, an evident photoresponse with the threshold energy of 0.62 eV was observed. The pronounced increase of a photoresponse which corresponds mostly to interband transitions in beta-FeSi<sub>2</sub> was observed at 0.87 and 1.1 eV. The maximum open voltage of 0.4 V was obtained. We found that Al doping into beta-FeSi<sub>2</sub> enhanced the photoresponse in the 0.8-1.0 um wavelength region. This suggests that electron-hole recombination centers at deep levels coming from Si vacancies or Fe dangling bonds were reduced effectively by the doping of Al atoms. This finding is crucial to improve the quantum efficiency of a beta-FeSi<sub>2</sub> photodiode.
- A1-PL2** TWO- AND MULTI-TERMINAL CMOS/BICMOS Si LED'S  
M. du Plessis, H. Aharoni\* and L.W. Snyman\*\*, Carl and Emily Fuchs Institute for Microelectronics,CEFIM, University of Pretoria, Pretoria, South Africa, \*Visiting professor from the Ben Gurion University of the Negev, Beer Sheba, Israel, \*\*Currently at the Dept. of Electronic Engineering, Tshwane University of Technology, Pretoria, South Africa  
 Although silicon is an indirect bandgap material, light emission from pn junctions, biased into avalanche or field emission breakdown, has been observed. The quantum efficiency is low, but the integration of these light emitting devices onto silicon chips using the standard IC technology was investigated since it will be very advantageous to utilise these devices in all-silicon opto-electronic integrated circuits (OIC's). In this paper the research results achieved will be discussed in some detail. Two-terminal area, line and point source Si LED's will be presented, as well as multi-terminal Si LED's. The differences between avalanche and field emission light output vs. device current characteristics, as well as differences in the emitted spectrum, will also be discussed. Both gate controlled diode MOS-like and carrier injection BJT-like Si LED multi-terminal devices will be presented. Spatial modulation of the light emitting pattern can be achieved with multi-terminal devices. It will also be shown that intensity modulation via control terminals can be achieved in these devices, and the linearity or non-linearity of the intensity modulation can be selected. The spectral characteristics of all devices will be presented, and a technique to modulate the spectral content of the light emission signal will be proposed.
- A1-PL3** OSIP: OPTICAL SIGNAL AND IMAGE PROCESSING DEVICE OPTIMIZED FOR OPTICAL READOUT  
M. Vieira, M. Fernandes, P. Louro, C. Mendes, A. Fantoni, R. Schwarz, Electronics Telecommunications and Computer Dept, ISEL, Lisbon, Portugal, Yuriy Vygranenko, Univ. Waterloo, Canada  
 Optical signal and image processing (OSIP) devices optimized for optical readout are presented. The configuration is glass/ITO/Cr contact/a-Si:H n-i-p/Cr contact/a-siH(n-i)-a-SiC:H-p/ITO. The interconnection between the top and bottom junction is performed by the 50x50 um Cr floating contact via an a-SiN insulator layer.  
 The device operates under short circuit or slightly reverse bias. The imaging is performed in a write-read simultaneous process: the write exposure, which converts the optical image into a localized packet of charges and the optical read which performs the charge to current conversion by detecting the photocurrent generated by a light beam scanner. During the image acquisition process no charge transfer to move the packets of charge within the sensor is needed. This allows a real-time optically addressed readout. In this work the main emphasis will be put on the optical characteristics. The various design parameters tradeoffs are discussed. If write beam is on, the front photodetector, acting as a load, converts the optical image into a spatially varying electric field across the bottom diode by charging positively the floating node. This leads to the self reverse bias of the bottom diode that switches to its OFF state becoming locally sensitive to the incoming read beam. In the absence of the write beam (erase operation) the sensor becomes almost insensitive to the read beam since the floating node do not self bias and ideally the voltage drops across the bottom one is not enough to switch it to its OFF state. Results show that a trade-off between the read and the write beams wavelength are needed to minimize the cross talk and to improve the contrast ratio. An electrical model is presented and supported by a two dimensional simulation.
- A1-PL4** FLEXIBLE IMAGING DEVICES  
P. Louro, A. Fantoni, M. Fernandes, C. Mendes, R. Schwarz, M. Vieira, Electronics Telecommunications and Computer Dept, ISEL, Lisbon, Portugal, M. Schubert, Institut für Physikalische Elektronik, Universität Stuttgart, Pfaffenwaldring 47, 70569, Stuttgart, Germany  
 Large area a-SiC:H imagers fabricated on plastic substrates at low temperatures are strong candidates for flexible electronic. They can be manufactured, at low cost, taking profit from the amorphous silicon technology.  
 Large area p-i-n image sensors deposited on flexible substrates (PET) were produced at low temperatures (110 °C) by PE-CVD and compared with similar sensors deposited on glass substrates. The same sensing element structure ITO/p(SiC:H)/i(Si:H)/n(SiC:H)/Al or ITO was used for both devices. In this work the efforts are focused mainly on the optimization output characteristics of the sensor when fabricated on plastic substrates. The role of the sensor configuration and readout parameters on the image acquisition process is analyzed. The optical-to-electrical transfer characteristics show a high quantum efficiency, broad spectral response, and reciprocity between light and image signal. A numerical simulation supports the imaging process. First results show that when high image intensities are analyzed the sensors deposited on flexible substrates present a high image-blur effect due to an increased lateral transport near the ITO/p interface. At the illuminated regions the photogenerated holes drift to the ITO and lateral leakage occurs by conduction from the ITO along the interface between the p-layer and the ITO. To avoid this effect a higher resistive p-layer has to be used and also the scanner and the optical image should be kept on opposite sides.

**A1-PL.5****PHOTOLUMINESCENCE ENHANCEMENT IN IMPURITY DOPED BETA-FeSi<sub>2</sub>**

Yoshikazu Teraï(a), Yoshihito Maeda(b), (a)Department of Materials Sciences, Osaka prefecture University, Japan, (b)Department of Energy Science and Technology, Kyoto University, Japan

Beta-FeSi<sub>2</sub> is a candidate for the application to monolithic integration of IR emitting devices because the epitaxial growth of beta-FeSi<sub>2</sub> on Si is possible. In order to improve the photoluminescence (PL) efficiency of beta-FeSi<sub>2</sub>, we investigated the effect of the impurity doping on PL properties in beta-FeSi<sub>2</sub> samples fabricated by ion beam synthesis (IBS). In nondoped beta-FeSi<sub>2</sub> samples, four PL lines of A (0.803 eV), B (0.83 eV), C (0.77 eV), D (0.95 eV) were observed at 10 K. The excitation power dependence of these peaks showed that A and C lines originated from beta-FeSi<sub>2</sub>. And then, B and D lines were the dislocation-related PL from Si matrix. In doped beta-FeSi<sub>2</sub> samples, Al-doped samples showed the enhancement of PL intensity. The result suggests that Si vacancies or dangling bonds of Fe in beta-FeSi<sub>2</sub> are non-radiative centers. This finding is to improve the PL efficiency of beta-FeSi<sub>2</sub>.

**A1-PL.6****NANOSTRUCTURING SI MATERIALS THROUGH COMPUTATION**

R.Q. Zhang, Center Of Super-Diamond and Advanced Films (COSDAF) & Department of Physics and Materials Science, City University of Hong Kong, Hong Kong S.A.R., China

The shrinkage of dimensions of nanomaterials is expected to reveal new fascinating properties related to size effects leading to the next generation exciting applications (e.g. optoelectronic, chemical and biological sensing). Different aspects of nanoscience and technology (nanomaterials structure, growth mechanisms and properties) can be studied by modern computational methods, providing insight that experimental methods cannot and predicting properties thus guiding the experimentalist. Here, we present examples of computations performed in CityU that address different aspects of science and technology and demonstrate the power of computational tools in nanoscience and nanotechnology. These examples include: the mechanism of oxide assisted formation of silicon nanowires, structural transition in nanosized silicon clusters, the thin stable short silicon nanowires, and size-dependent oxidation of silicon nanostructures.

**A1-PL.7****ROOM TEMPERATURE PHOTO- AND ELECTRO-LUMINESCENCE FROM SI/GE MULTILAYER STRUCTURE DOPED BY SB.**

N. Zakharov, V. Talalaev, P. Werner, Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle(Saale), Germany and G.E. Cirlin, A. Tonkikh, A.F.Ioffe Physico-Technical Institute RAS, Polytechnicheskaya 26, 194021 St.Petersburg, Russia  
In the present work we would like to report on the fabrication of defect-free multilayer structures containing Ge QDs layers in a Si matrix exhibiting strong room temperature Photo- (PL) and Electro-luminescence (EL) at 1.55 μm. The structures were grown by molecular beam epitaxy (MBE) and consist of 20 Ge layers (0.7 nm Ge) separated by 5.5 nm Si spacers. The first 2 nm of each Si spacer were intentionally doped with Sb. The lateral size of the Ge islands was about 80 nm, their heights lay in a range of 3-5 nm. Surprisingly abrupt interfaces were formed and no significant intermixing was observed even at the relatively high substrate temperature (600°C). The average density of Ge QDs is about 10<sup>10</sup> cm<sup>-2</sup>. The stacked Ge islands form a superlattice from an electrical point of view. Due to recombination of confined holes and quasi-free electrons (in growth direction), strong PL occurs up to RT. First results show intensive electroluminescence from SL at RT in the region of 1.55 μm. The described Si/Ge-SL is a promising candidate for a light-emitting device in the 1.5μm region.

**A1-PL.8****MATERIAL AND OPTICAL PROPERTIES OF GaAs GROWN ON (001) Ge/Si PSEUDO-SUBSTRATE FOR THE MONOLITHIC INTEGRATION OF LIGHT EMITTING DEVICES ON SILICON.**

Y. Chriqui(a), L. Largeau(a), G. Patriarche(a), G. Saint-Girons(a), S. Bouchoule(a), D. Bensahel(b), Y. Campidelli(b), O. Kermarrec(b), I. Sagnes(a), (a) Laboratoire de Photonique et Nanostructures, LPN-CNRS / UPR 20, Route de Nozay, 91460 Marcoussis France, (b) STMicroelectronics, 850 Rue Jean Monnet, 38926 Crolles Cedex, France

One of the major challenges during recent years was to achieve the compatibility of III-V semiconductor epitaxy on silicon substrates to combine optoelectronics with high speed circuit technology. However, the growth of high quality epitaxial GaAs on Si is hindered by the lattice mismatch and difference in thermal expansion coefficients of the two materials. Moreover, the presence of antiphase boundaries (APBs) is deleterious for light emitting device performance. Recently the successful fabrication of high quality germanium layers on (001) Si (forming Ge/Si pseudo-substrates (PS)) by chemical vapour deposition enabled to match the GaAs lattice parameter, providing for excellent conditions for the subsequent GaAs growth. We studied the morphology of GaAs grown on Ge/Si PS using atomic layer epitaxy (ALE) at the interface between Ge and GaAs.

We present results on the reduction of APBs and dislocation density on (001) Ge/Si PS when ALE is applied. We will show the ALE allows a drastic decrease in the APB density, and a reduction of the residual dislocation density in the GaAs layers to 10<sup>5</sup> cm<sup>-2</sup>. The enhancement of the optical properties of the grown material will also be discussed. Using an optimised ALE sequence, light emitting diodes based on strained InGaAs/GaAs quantum well as well as In(Ga)As quantum dots on an exactly oriented (001) Ge/Si pseudo-substrate were processed and characterized.

**A1-PL.9****THE PUZZLING QUESTION OF THE EXCITATION TRANSFER MECHANISM IN ERBIUM-DOPED SILICON NANOCRYSTALS**

A.J. Kenyon and F. Lucarz, Department of Electronic & Electrical Engineering, University College London, Torrington Place, London WC1E 7JE, U.K.

That there exists an efficient excitation exchange mechanism between silicon nanoclusters and rare-earth ions in dielectric matrices is now well established. However, the nature of the exchange is still unclear; it has been assumed that dipole-dipole interactions between absorbing nanoclusters and emitting rare earth ions allow excitation migration: however, alternative schemes involving Auger transfer have also been proposed. In this paper we study the implications of assuming dipole-dipole interaction, and evaluate the critical radius, R<sub>0</sub>. We show that current data cannot conclusively rule out the dipole-dipole mechanism, but there are significant problems with this interpretation.

- A1-PL10** LUMINESCENCE AND CHARGE STORAGE CHARACTERISTICS OF Ge NANOCRYSTALS EMBEDDED IN SiO<sub>2</sub> MATRIX  
S.K. Ray, K. Das and A. Dhar, Department of Physics & Meteorology IIT Kharagpur 721 302, India  
 Nanocrystals of group-IV semiconductors are being widely studied as they open up new possibilities for applications in optoelectronics, with the main advantage of being compatible with silicon based device technology. In this paper, we report the optical and charge storage characteristics of Ge nanocrystals embedded in SiO<sub>2</sub> matrix formed by rf magnetron co-sputtering followed by rapid thermal annealing. High-resolution transmission electron microscopy showed the formation of nearly spherical Ge nanocrystals of diameter 10 - 30 nm. Raman spectra of the grown films showed a pronounced Ge optical phonon mode peaked at about 301 to 303 cm<sup>-1</sup> with full-width-half-maximum comparable to that of bulk Ge at room temperature, indicating the presence of Ge clusters with good crystallinity. The annealed nanostructures exhibited strong and broad photoluminescence (PL) in the visible range (570 to 800 nm) at room temperature due to the quantum confinement of carriers in Ge nanocrystals. The broad PL spectrum is composed of multiple peaks overlapping each other attributed to the size distribution of Ge nanocrystals. The charge storage characteristics of Ge nanocrystals were studied through the capacitance-voltage measurements of the metal-insulator-semiconductor trilayer structure fabricated using the tunneling and cap silicon oxides. Under optimized annealing conditions, an enhancement of the charge storage capability of nanocrystals was observed in agreement with the optical emission characteristics.
- A1-PL11** OPTICAL AND ACOUSTIC PHONON MODES IN SiGe QD's SUPERLATTICES: EXPERIMENTAL AND THEORETICAL STUDY  
M.Ya. Valakh, V.M. Dzhanan, V.P. Kladko, A.M. Yaremko, V.O. Yukhymchuk, Lashkaryov Institute of Semiconductor Physics, NAS of Ukraine, Prospekt Nauki 45, 03028 Kyiv, Ukraine, A.G. Milekhin, Institute of Semiconductor Physics, RAS, 630090 Novosibirsk, Russia, N. Mestres, Institut de Ciència de Materials de Barcelona, CSIC, 08193 Bellaterra, Spain, J. Pascual, Departament de Física, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain  
 A series of SL's with SiGe QD's obtained by deposition of 8 ML Ge at temperatures 300 to 600°C have been studied by Raman, HRXRD and AFM techniques. The values of composition and strain in the islands have been derived from the Raman spectra. Si-Ge intermixing in the island has been found to occur even at growth temperature as low as 300°C. Grown at this temperature pyramidal islands are highly strained and uniform. As the growth temperature rises to 400°C, the situation changes dramatically due to increase of the number of dome-shaped islands. Two types of differently strained and shaped islands give rise to doublet of Ge-Ge Raman peaks corresponding to phonons in each type of islands. Further growth temperature increase results in lowering of strain in the islands due to both increase of the portion of domes and Si content in all islands. Correlation between the results of Raman and HRXRD experiments was obtained. Raman spectra on folded-acoustical phonons have also been observed and described theoretically.
- A1-PL12** EFFECT OF BUFFER LAYERS ON THE OPTICAL PROPERTIES OF SILICON NANOCRYSTAL SUPERLATTICES  
 M. Glover and A. Meldrum, Department of Physics, University of Alberta, Edmonton, AB, T6G 2J1 Canada  
 Silicon nanocrystal superlattices consisting of alternating layers of silicon-rich oxide (SRO) and silica (SiO<sub>2</sub>) were grown by electron beam evaporation, followed by thermal annealing. All of the SRO depositions and the thermal processing steps were done under conditions that were as similar as possible so as not to vary the average nanocrystal size. Two sets of samples were synthesized. In the first set, the SRO layers were grown with a different thickness in the different samples, while the buffer layers were always 20 nm thick. In the second set, we used 20-nm-thick SRO layers while the silica buffer layers varied in thickness. There were pronounced differences in the photoluminescence spectrum and decay dynamics due to the differences in the thickness of the various layers. The results are interpreted in terms of the migration of charge carriers between nanocrystals, and illustrate that the peak of the PL spectrum can vary between 750 and 900 nm without changing the average particle size. Finally, we also grew a set of samples in which the buffer layers were erbium oxide instead of silica and interpret the results in terms of efficient carrier migration through the nanocrystal-containing layers.
- A1-PL13** OPTICAL PROPERTIES OF ER/YB-DOPED GEO<sub>2</sub>  
Hideyuki Yamaguchi, Nobuhiro Onouchi, Atsushi Shinbori, Takamichi Sumitomo, Satoru Matsumoto, Keio University, Yokohama, Japan  
 For integrating optical amplifiers on Si substrate, the rare-earth doped oxide materials having a large gain per unit length are required. The optical properties of Er-doped SiO<sub>2</sub> and Er/Yb-doped GeO<sub>2</sub> have been investigated with cathode luminescence (CL) at room temperature by varying the content of the rare-earth elements. The rare earth doped SiO<sub>2</sub> or GeO<sub>2</sub> were prepared with simultaneous sputtering of rare earth (Er/Yb) and Si or Ge in oxygen ambient. After sputtering, samples were annealed at 600 C for 1 h in N<sub>2</sub> ambient. The mol% of respective elements was determined with electron probe mass analysis (EPMA). Er concentrations of the highest CL intensity in SiO<sub>2</sub> and GeO<sub>2</sub> were 0.45 mol% and 0.24 mol%, respectively. The important result is that CL intensity at 1537 nm of Er-doped GeO<sub>2</sub> is much larger than that of Er-doped SiO<sub>2</sub>. It is also found that the improvement in CL intensity is obtained by co-doping of Er and Yb into GeO<sub>2</sub> due to the energy transition between Er and Yb.
- A1-PL14** STUDY OF THE PHOTOLUMINESCENCE OF AMORPHOUS AND CRYSTALLINE Si CLUSTERS IN SiO<sub>x</sub> AND SiN<sub>x</sub> THIN FILMS  
M. Molinari, Laboratoire de Microscopies pour l'Etude des Nanostructures (E.A. CNRS 2061), Université de Reims Champagne Ardennes, BP 138, 51685 Reims Cedex 2, H. Rinnert, O. Jambois, M. Vergnat, Laboratoire de Physique des Matériaux, (U.M.R. CNRS 7556), Université Henri Poincaré Nancy 1, B.P. 239, 54506 Vandœuvre-lès-Nancy Cedex, France  
 Si-rich silicon oxide and Si-rich silicon nitride thin films were prepared by silicon evaporation under a controlled molecular oxygen atmosphere and under a flow of nitrogen and hydrogen ions provided by an electron cyclotron resonance plasma source. We focus on the photoluminescence properties for annealing temperatures close to the crystallization temperatures. The amorphous or crystalline character of the films and the crystallized silicon clusters size have been determined by grazing incidence x-ray diffraction and by transmission electron microscopy. In both amorphous and crystalline structure, an intense luminescence is observed in the visible range at room temperature. For the amorphous and the crystalline states, the correlation between the structural and photoluminescence results shows that the quantum confinement effect in both amorphous and crystallized clusters can explain the PL evolution. The effects of the crystallization are an improvement of the PL efficiency and a blueshift of the PL wavelength which is consistent with theoretical calculations.

- A1-PL15** PHOTOLUMINESCENCE AND ELECTROLUMINESCENCE OF AMORPHOUS SiO<sub>x</sub> FILMS PREPARED BY REACTIVE EVAPORATION OF SILICON WITH OXYGEN.  
O. Jambois, M. Molinari\*, H. Rinnert, M. Vergnat, Laboratoire de Physique des Matériaux, (U.M.R. CNRS 7556), Université Henri Poincaré Nancy 1, BP 239, 54506 Vandœuvre-lès-Nancy Cedex, France, \*Laboratoire de Microscopies pour l'Etude des Nanostructures (E.A. CNRS 2061), Université de Reims Champagne Ardennes, BP 138, 51685 Reims Cedex 2, France  
 By reactive evaporation of pure silicon in a controlled molecular oxygen atmosphere, thin films of amorphous SiO<sub>x</sub> can be obtained with 0.7 <math>x</math> <math>1.85</math>. The thickness was 200 nm. The composition and the structure of the films were investigated by energy dispersive x-ray, infrared absorption and x-ray photoelectron spectroscopies. By conveniently choosing the oxygen pressure, the as-deposited films exhibit visible room-temperature photoluminescence. The photoluminescence peak is centered at about 650 nm. The study of the transport properties shows that the current-voltage characteristics can be fitted with a Poole-Frenkel mechanism for bias values lower than around 5 V. For greater bias values, the transport properties become different. The conductivity is much higher. In this range, the samples present electroluminescence at 77 K. The electroluminescence band is centered at 700 nm with a width equal to 350 nm.
- A1-PL16** SOLAR CELL TECHNOLOGY FOR FABRICATION OF SILICON LIGHT-EMITTING DIODES  
 M.S. Bresler, O.B. Gusev, and E.I. Terukov, A.F. Ioffe Physico-Technical Institute, Politekhicheskaya 26, 194021 St. Petersburg, Russia  
 Application of solar cell technology is considered for fabrication of silicon-based light-emitting diodes, which are especially interesting as optoelectronic devices compatible with the conventional silicon technology. First experimental results obtained with non-optimized amorphous silicon-crystalline silicon heterostructure demonstrate an external quantum efficiency of 0.013 % (the internal quantum efficiency being 0.3 %). The measures directed to a further development of such light-emitting diodes are discussed. They indicate a possibility to increase the quantum efficiency up to several percent.
- A1-PL17** I-V CHARACTERISTICS OF STRUCTURES WITH POROUS SILICON IN ELECTROLYTE  
 Z.H. Mkhitarian, A.A. Shatveryan, A.Z. Adamyan, V.M. Aroutiounian, Dept. Physics of semiconductors and microelectronics, YSU, 1 Manoikian Str., 375025 Yerevan, Armenia  
 In order to evaluate possibilities of the use of porous silicon structures in large temperature range, the DC current-voltage characteristics (CVC) of p- and n-type single crystalline silicon (Si) samples with porous Si (PS) layer were measured in air. CVC were investigated also for porous silicon /electrolyte/ counter-electrode structures (liquid contact) at room temperature and temperature of liquid/solid phase transfer of electrolyte. A noble metal or semiconductor was selected as counter-electrode. The rectifying behavior of CVC detected for samples with solid contact indicates that applied voltage drops mainly on the isotype single crystalline Si/PS heterojunction because of the PS layer is sufficiently thin. The measurements have shown the part of metal/PS contact is negligible. The hysteresis phenomena have been found on the CVC of the samples with liquid contacts. The shape of the CVC determined by a counter-electrode material depends on whether the interphase barrier between counter-electrode and electrolyte is formed. The temperature measurements have shown that a monotone increase in the conductance with rise of temperature in the range of the ice-water phase transfer changes to sharp increase. The temperature features are connected with ice two-dimensional hexagonal structure in the nanopores.
- A1-PL18** LUMINESCENCE OF POLYMORPHOUS SILICON CARBON ALLOYS  
 V. Suendo and P. Roca i Cabarrocas, Laboratoire de Physique des Interfaces et des Couches Minces UMR 7647 CNRS, Ecole Polytechnique, 91128 Palaiseau Cedex, France  
 Silicon rich polymorphous silicon carbon alloys (pm-SiC:H) have been prepared at 200 °C using standard capacitively coupled RF glow discharge technique from the decomposition of SiH<sub>4</sub>-CH<sub>4</sub>-H<sub>2</sub> mixtures at high pressure, under conditions where the formation of clusters, agglomerates and powders occurs in the plasma and contribute to deposition. Visible photoluminescence (PL) was observed at room temperature in these materials with narrow peaks in the spectral region from red to orange. The PL intensity and peak position show a strong dependence on the deposition pressure. Moreover, electroluminescence (EL) diodes with p-i-n structure were realized using the optimized materials as the i layer with a thickness of ~0.1 μm. EL spectra, comparable to the PL ones, were obtained by applying a DC voltage above 8 V. Moreover EL is stable for several hours which makes of these devices interesting for applications.
- A1-PL19** MONOLITHIC AND HYBRID NEAR INFRARED DETECTION AND IMAGING BASED ON POLY-GE PHOTODIODE ARRAYS  
G. Masini, L. Colace, G. Assanto, NOOEL, INFN and University Roma Tre, Via Vasca Navale, 84, 00146 Roma, Italy, V. Cencelli, F. De Notaristefani, INFN Sez RM3, Via della Vasca Navale 84, 00146 Roma, Italy  
 Photodetection and imaging in the near infrared (NIR: 0.8-2 μm) has been a fast growing area owing to the large number and importance of related applications: communications, remote sensing, biology, etc. While the mainstream technology in this field is based on III-V InGaAs photodetectors, the lack of compatibility with the standard Si CMOS process of the latter has pushed toward the exploitation of alternative Si-based approaches. In recent years, a number of Ge-on-Si technologies for fabrication of NIR photodetectors integrated on Si substrates has been proposed. In particular, using a low temperature (300°C) technique, poly-Ge on Si photodetectors have been demonstrated with high speed and reasonable responsivity in the NIR. The low temperature of the process allowed a seamless, monolithic, integration of the detectors as a final step in the fabrication of a Si CMOS integrated circuit.  
 In this paper we describe a novel integrated circuit (NIRCAM-G) designed as a readout/control circuit for arrays of poly-Ge on Si photodetectors both monolithically integrated on the IC as well as wire-bond connected using a hybrid approach. Up to 64 (32) detectors can be connected using the monolithic (hybrid) approach. Photocurrent generated by the detectors is converted to digital by the integrated ADC's after subtraction of the dark component thus allowing a convenient digital readout of the array. Extensive optoelectronic characterization of the IC will be presented in the paper.

- A1-PL.20** STUDIES OF Ga DIFFUSION AND THE ELIMINATION OF PINHOLES IN Ga-DOPED b-FeSi<sub>2</sub> FILMS PREPARED BY MBE  
R. Kuroda, Y. Hoshino, Nippon Institute of Technology, Saitama 345-8501, Japan, Z.X. Liu, Y. Suzuki, M. Osamura, T. Ootsuka, T. Mise, System Eng. Co., Ltd., Kanagawa 242-0001, Japan, Y. Fukuzawa, S.N. Wang, N. Otagawa, Y. Nakayama, Kankyo Semiconductors. Co., Ltd., AIST Tsukuba West, Ibaraki 305-8569, Japan, H. Tanoue, Y. Makita, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba Central 2, Ibaraki 305-8568, Japan  
 In our previous studies we proved that for molecular beam epitaxy (MBE) growth of b-FeSi<sub>2</sub> films, Ga is an effective p-type dopant. We successfully achieved the doping level of net hole concentration range from  $2 \times 10^{17}$  to  $2 \times 10^{18}$  cm<sup>-3</sup>, with mobilities from 200 to 10 cm<sup>2</sup>/Vs. It was however revealed that when the concentration of Ga exceeds a critical value high density pinholes were generated in the doped layers. We evaluated Ga-doped b-FeSi<sub>2</sub> layers by Auger electron spectroscopy (AES) and scanning electron microscopy (SEM) and found out that the formation of pinholes is closely related with Ga diffusion in b-FeSi<sub>2</sub> layers. Ga diffuses much faster in b-FeSi<sub>2</sub> layer than in Si and it tends to segregate toward the surface of b-FeSi<sub>2</sub> during the high temperature thermal anneal. The segregated Ga was further identified to evaporate significantly by anneal above 800°C. In order to suppress the evaporation of Ga, we deposited Si or SiO<sub>2</sub> capping layer (~500 nm in thickness) on Ga-doped Fe/Si multilayers in the MBE chamber prior to anneal. The results indicate that Ga segregation can be greatly restrained by this capping layer, which leads to the considerable reduction of pinhole density in b-FeSi<sub>2</sub> film. Using this method, one can fabricate desired p/n heterojunctions between b-FeSi<sub>2</sub> and Si layers to make various electronic and optoelectronic devices.
- A1-PL.21** GALLIUM DOPING FOR BETA IRON-DISILICIDE FILMS PREPARED BY MBE  
Y. Fukuzawa, S.N. Wang, N. Otagawa, Y. Nakayama, Kankyo semiconductors Co. Ltd., W1-1306, AIST Tsukuba West, Onogawa 16-1, Tsukuba, Ibaraki 305-8569, Japan, Y. Suzuki, Z.X. Liu, M. Osamura, T. Ootsuka, T. Mise, SYSTEM ENGINEERS' Co., Ltd., Yamato, Kanagawa 242-0001, Japan, R. Kuroda, H. Tanoue, Y. Makita, National Institute of Advanced Industrial Science and Technology (AIST), AIST Tsukuba Central 2, Umezono 1-1-1, Tsukuba, Ibaraki 305-8568, Japan  
 b-FeSi<sub>2</sub> is expected as a new material for light emitting diode and optical sensor operating at 1.5 μm. However, doping techniques suited for various fabrication methods of b-FeSi<sub>2</sub> films have not been established. In this report, we present the results of Ga doping as a p-type impurity during MBE growth of b-FeSi<sub>2</sub> films.  
 b-FeSi<sub>2</sub> films were prepared by alternating Fe/Si multilayers deposition on Si substrate at room temperature in MBE chamber, and by post annealing. Ga was added into the films only during Si layer deposition. Ga concentration was adjusted by changing both Knudsen effusion cell (K-cell) temperature and opening time of shutter equipped in front of K-cell. Our un-doped b-FeSi<sub>2</sub> films were n-type, having residual net electron concentration  $\sim 3 \times 10^{16}$  cm<sup>-3</sup> and mobility  $\sim 400$  cm<sup>2</sup>/Vs. When b-FeSi<sub>2</sub> films were doped with Ga above a critical concentration, they changed to p-type. By varying Ga concentration, net hole concentration ranging from  $7 \times 10^{16}$  to  $2 \times 10^{18}$  cm<sup>-3</sup> with mobilities from 200 to 10 cm<sup>2</sup>/Vs were obtained. XRD and optical absorption measurements showed that Ga-doped b-FeSi<sub>2</sub> films have high epitaxial crystallinity as un-doped ones with systematic change of optical absorption edges for increasing net hole concentration. These results demonstrate that Ga is an effective p-type dopant for b-FeSi<sub>2</sub> films to fabricate various electronic and optoelectronic devices.
- A1-PL.22** ON THE RELATIONSHIP BETWEEN ELECTROLUMINESCENCE AND PHOTOLUMINESCENCE IN Er DOPED SILICON DIOXIDE CONTAINING SILICON NANOCLUSTERS  
J.M. Sun and W. Skorupa, Institute of Ion Beam Physics and Materials Research Forschungszentrum Rossendorf, Dresden, Germany, A.N. Nazarov, Institute of Semiconductor Physics, NASU, Kyiv, Ukraine  
 Erbium and silicon rich silicon dioxide layers were demonstrated to be efficient light emitters at the telecommunication wavelength (~1.5 μm). In this work the correlation between electroluminescence (EL) and photoluminescence (PL) was studied in ITO/SiO<sub>2</sub>: Er, Si /Si-MOS structures, where the SiO<sub>2</sub> layer was implanted with silicon in the concentration range 1-10 % and erbium with a concentration of 0.24%. After annealing at 1100°C for the formation of Si clusters, the PL line at 1530 nm of Er<sup>3+</sup> ions shows a strong increase with increasing Si nanocluster density. On the contrary, the EL from both the green and infrared lines of Er<sup>3+</sup> shows a dramatic quenching with increasing the density of Si clusters. This reveals that the excitation process of the EL from Er<sup>3+</sup> in SiO<sub>2</sub> is contrary to an exciton transfer from excited Si nanoclusters to Er<sup>3+</sup> ions near the Si/SiO<sub>2</sub> interface which is normally observed in PL excitation of Er-doped SiO<sub>2</sub> containing Si clusters. An electric field-induced quenching of the photoluminescence of the 1535 nm line of Er<sup>3+</sup> was observed, which shows that the energy transfer from Si nanoclusters to Er<sup>3+</sup> ions is blocked under high electric field in the EL process. These results indicated that the EL excitation process of Er<sup>3+</sup> ions is governed by the direct impact excitation by hot electrons. An increase of the Si nanocluster density causes direct tunneling of electrons between Si clusters, thus reducing the population of energetic hot electrons for impact excitation of Er<sup>3+</sup> ions and leading to a strong quenching of the EL.
- A1-PL.23** GROWTH AND PROPERTIES OF SiGe/Si(001) SELF-ASSEMBLED ISLANDS GROWN ON SiGe SEED LAYER  
D.N. Lobanov, A.V. Novikov, N.V. Vostokov, Z.F. Krasilnik, A.N. Yablonskiy, Institute for Physics of Microstructures RAS, 603950, Nizhny Novgorod, GSP-105, Russia  
 In this work the growth and properties of SiGe/Si(001) structures with self-assembled islands grown on a Si<sub>1-x</sub>Ge<sub>x</sub> seed layer (x = 0.20) has been investigated. The decrease of critical thickness of 2D Ge film growth with an increase of Ge content in the Si<sub>1-x</sub>Ge<sub>x</sub> seed layer has been observed. The decrease of critical thickness of 2D Ge film growth is associated with an increase of the elastic strain stored in the Si<sub>1-x</sub>Ge<sub>x</sub> layer. The increase of the island surface density and the island sizes with an increase of Ge content in the Si<sub>1-x</sub>Ge<sub>x</sub> seed layer has been found out. The increase of the island surface density is caused by the enhancement of the surface roughness after the Si<sub>1-x</sub>Ge<sub>x</sub> layer deposition. The increase of island sizes is associated with a decrease of Ge content in them. The increase of the island surface density and the island sizes results in that the island sizes become smaller than the distance between them. As a result, one could see the local ordering in the disposition of islands on the surface. More regular disposition of islands the surface is confirmed by the analysis of the sample surface with a autocorrelation function. The increase of Si content in the islands grown on the Si<sub>1-x</sub>Ge<sub>x</sub> layer shifts the photoluminescence signal from the islands towards the high energies. The sufficient enhancement of the photoluminescence signal has been observed at room temperature from the islands grown on the Si<sub>1-x</sub>Ge<sub>x</sub> layer in comparison with island growth on a Si buffer layer. The increase of intensity of PL signal is caused by the increase of the part of surface covered by islands and, therefore, by more effective capture of the charge carriers in the densely packed islands.

**A1-PI.24****DOPING OF b-FeSi2 FILMS WITH BORON AND ARSENIC BY SPUTTERING AND ITS APPLICATION FOR PHOTOELECTRONIC DEVICES**

Z.X. Liu, M. Osamura, T. Ootsuka, Y. Suzuki, T. Mise, System Engineers' Co., Ltd., Yamato 242-0001, Japan, Y. Makita, R. Kuroda and H. Tanoue, National Institute of Advanced Industrial Science and Technology (AIST), AIST Tsukuba Central 2, Tsukuba 305-8568, Japan, S.N. Wang, Y. Fukuzawa, N. Otagawa, Y. Nakayama, Kankyo Semiconductors Co., Ltd., AIST Tsukuba West, Tsukuba 305-8569, Japan

Semiconducting b-FeSi<sub>2</sub> is a promising material for Si-based optoelectronic devices due to its direct band gap of 0.85 eV (~1.5 nm) and high optical absorption coefficient (>10<sup>5</sup> cm<sup>-1</sup>). Therefore, a suitable doping technique for b-FeSi<sub>2</sub> film is urgently necessitated. In this work, we fabricated impurity-doped b-FeSi<sub>2</sub> films on Si (111) substrate with boron for p-type films and with arsenic for n-type ones by co-sputtering method. Doping source materials were elemental boron chips and arsenic heavily doped Si wafers, respectively.

For boron-doped p-type b-FeSi<sub>2</sub> films, doping level of net hole concentration from 3 × 10<sup>17</sup> to 1 × 10<sup>19</sup> cm<sup>-3</sup> and mobilities from 100 to 20 cm<sup>2</sup>/Vs were successfully achieved. The crystallinity and electrical properties of p-type b-FeSi<sub>2</sub> films were found to be critically dependent on the temperature-decreasing rate of anneal process. For arsenic-doped n-type b-FeSi<sub>2</sub> films, net electron concentration from 1 × 10<sup>17</sup> to 1 × 10<sup>19</sup> cm<sup>-3</sup> and mobilities from 400 to 1 cm<sup>2</sup>/Vs were obtained. Activation of arsenic dopant needed longer anneal time than that of boron and the features of n-type b-FeSi<sub>2</sub> films were independent on the temperature-decreasing rate. p/n homojunctions of b-FeSi<sub>2</sub> were formed by successively depositing p- and n-type b-FeSi<sub>2</sub> films on Si substrates in the same sputtering chamber. They showed good rectifying I-V characteristics and strong photo response for 1.3-1.5 μm infrared light.

**A1-PI.25****SILICON BASED NEAR INFRARED TUNABLE FILTERS BASED ON LIQUID CRYSTALS**

G. Pucker, M. Crivellari, C. Kompocholis, P. Bellutti, A. Lui, Istituto Trentino di Cultura, Centro per la Ricerca Scientifica e Tecnologica, Microsystem Division, Via Sommarive 18, 38050 Povo (Trento), Italy, N. Daldosso, F. Riboli, M. Saiani, Z. Gaburro, L. Pavesi, INFN and Department of Physics, Università di Trento, Via Sommarive 14, 38050 Povo (Trento), Italy

We describe here the first results on the realization of optical switches and routers working at 1.55 μm integrated on 4" Si-wafers.

Complementary metal-oxide-semiconductor-compatible tunable Fabry-Perot microcavities filled with liquid crystals (LCs) were realized and studied in the near-infrared region. The microcavities were produced by chip bonding technique, which allows one to infill LC between two [SiO<sub>2</sub>/Si]<sub>n</sub> λ/4 (λ = 1.55 μm) Dielectric Bragg Reflectors (DBRs) grown by a series of LPCVD deposition and thermal oxidation steps, and separated by 950 nm thick SiO<sub>2</sub> posts. Liquid crystals with positive and negative dielectric anisotropy were used, i.e. MerckE7 and Merck-6608 LC. Mirror-integrated electrodes allow an external bias to induce an electrical field and to tune the LC refractive index and, hence, the microcavity resonance. Electric-field-induced shifts of the second-order cavity modes of ~120 nm and ~50 nm were obtained for Merck-E7 and Merck-6608 LC, with driving potentials of 5 V and 10 V, and a threshold voltage about 2 V and 3 V, respectively. The transmittance at the cavity resonance is typically in the order of 10%. Simulation of the microcavities allows identifying surface roughness of the DBRs as the major origin of the transmission losses. Both switch-on ton and switch-off toff times were measured as function of applied fields and were found to be lower than 5 ms. Our approach opens the route to the integration of a large number of integrated Si-based near-infrared tunable filters on a single wafer.

**A1-PI.26****EFFECT OF Si NANOCLUSTERS ON CHARGE TRAPPING AND LIGHT EMISSION IN Er DOPED SiO<sub>2</sub>**

A.N. Nazarov\*, J. Sun, and W. Skorupa, Institute of Ion Beam Physics and Materials Research Forschungszentrum Rossendorf, Dresden, Germany, I.N. Osiyuk, I.P. Tjagulskii and V.S. Lysenko, Institute of Semiconductor Physics, NASU, Kyiv, Ukraine, L. Rebohle, R.A. Yankov and T. Gebel nanoparc GmbH, Dresden, Germany

\*currently with the Kyiv group

Erbium and silicon rich silicon dioxide layers were demonstrated to be efficient light emitters for the telecommunication wavelength (~1.5 μm). This work is devoted to the study of charge trapping in ITO/SiO<sub>2</sub>:Er,Si/Si-MOS structures, where the SiO<sub>2</sub> layer was implanted with silicon in the concentration range 1-10% and Erbium with a concentration of 0.24 %. Charge trapping was investigated evaluating the shift of the capacitance-voltage (C-V) characteristics as well as the change of the voltage applied to MOS structure during high-field electron injection into the oxide in the constant current regime. The charge transfer was controlled by the current-voltage (I-V) characteristics. It will be demonstrated that Er doped SiO<sub>2</sub> layers contain hole traps with a large capture cross-section (~10-13 cm<sup>2</sup>) and a large concentration of electron traps with capture cross-sections in range from 10-14 to 10-15 cm<sup>2</sup>. The embedding of Si nanoclusters in the Er doped SiO<sub>2</sub> results in the generation of additional electron traps with (~10-13 cm<sup>2</sup>), which compensates for the total positive charge in the oxide. If the Si excess content in the SiO<sub>2</sub> layer reaches a concentration of about 10% the charge capture in Er-related traps (electron traps with ~10-14 cm<sup>2</sup>, electron and hole traps with ~10-18 cm<sup>2</sup>) considerably reduces, and the mechanism of charge transfer through the oxide changes. The mechanism of electroluminescence suppression at 1534 nm wavelength at high concentration of Si in Er doped SiO<sub>2</sub> will be discussed.

**A1-PI.27****RECENT PROGRESS IN INTEGRATED WAVEGUIDES BASED ON OXIDIZED POROUS SILICON**

M. Balucani, A. Ferrari, INFN unit E6 Università di Roma "La Sapienza", Via Eudossiana 18, 00184 Roma, Italy and V.P. Bondarenko, A.A. Klusko, Belarussian State University of Informatics and Radioelectronics, P.Brovka Street 6, 220013 Minsk, Belarus

In this work, we report the latest improvements in integrated optical waveguides (WG) based on oxidized porous silicon (OPS). Remarkably low propagation loss (0.2 dB/cm in the visible) are demonstrated and planar bending loss are estimated for the first time in OPS WGs. Straight OPS WGs 1-10 cm long and bent OPS WGs with different curvature radii ranging from 125 to 2500 μm were fabricated in N<sup>+</sup>-type silicon substrates. Optical loss in the visible and IR were measured by original method utilizing the 90 degree vertical bending at the waveguides endings which is an unique property of our OPS WGs. Significant improvement of OPS WG characteristics has been made by optimizing the WG technology: (a) elimination of negative effect of Swirl defects on uniformity of PS layers; (b) development of the anodization regimes allowing the careful control of the porosity through the PS thickness; (c) use of silica mask instead of silicon nitride mask. Hybrid integration of laser diodes with OPS WGs is demonstrated to show the potential of OPS WGs for optical chip-to-chip interconnects.

**A1-PI.28****PHOTOLUMINESCENCE FROM ERBIUM INCORPORATED IN OXIDIZED POROUS SILICON**

V.P. Bondarenko, N.M. Kazuchits, Belarussian State University of Informatics and Radioelectronics, P.Brovka Street 6, 220013 Minsk, Belarus and M. Balucani, A. Ferrari, INFN unit E6 Università di Roma "La Sapienza", Via Eudossiana 18, 00184 Rome, Italy

In the present work, photoluminescence (PL) and photoluminescence excitation (PLE) spectroscopy was used to study oxidized porous silicon (OPS) doped with Er by electrochemical migration. Three types of OPS were investigated: (a) partially oxidized PS (POPS); (b) fully oxidized PS (FOPS); (c) oxidized PS co-doped with Fe (OPS:Fe).

The OPS consists of oxide, Si nanoclusters and voids, and their composing fraction is dependent on the PS porosity and oxidation regime. The main result of this work is the observation that the location of Er ions in composing fractions of OPS has a profound effect on the PL and PLE spectra. We show that for POPS and FOPS, Er exhibits a broad 1530 nm PL spectrum similar to that observed in the Er-doped oxide glasses. For POPS, the PLE spectrum of the 1530 nm Er PL band comprises a superposition of sharp peaks which are attributed to the absorption transitions of Er ions incorporated into the oxide fraction and a broad band which is related to the absorption band of Si nanoclusters. For FOPS, the PLE spectrum consists just of sharp peaks. In striking contrast to POPS and FOPS, for OPS:Fe, Er PL spectrum consists of 21 highly resolved peaks. PLE spectrum of the strongest 1535 nm PL peak represents a wide band which is attributed to the absorption band of Fe containing nanoclusters formed inside OPS:Fe. Mechanism of excitation and luminescence of Er ions in OPS is presented. Possible application fields for the OPS:Er are discussed.

**A1-PI.29****UHV-CVD GROWTH AND ANNEALING OF THIN FULLY RELAXED GE FILMS ON SI(001)**

M. Halbwax, M. Rouviere, D. Debarre, Lam H. Nguyen, V. Yam, E. Cassan, S. Laval, D. Bouchier, Institut d'Electronique Fondamentale, Bât 220, Université Paris-Sud, CNRS UMR 8622, 91405 Orsay Cedex, France, Y.Zeng, Laboratoire de Minéralogie-Cristallographie, Universités Paris VI et Paris VII, CNRS UMR 7590, 4 place Jussieu, 75252 Paris Cedex 05, France, C.Clerc, Centre de Spectrométrie Nucléaire et Spectrométrie de masse, Bât 108, Université Paris-Sud, 91405 Orsay Cedex, France

In order to build integrated photodetectors at 1.3-1.55  $\mu\text{m}$  in micro-waveguides, pure germanium appears as an attractive material because of its high absorption coefficient. For that, a fully relaxed Ge film must be grown on Si with a total thickness of 400 nm. A known process by UHV-CVD consists in beginning the growth up to 30 nm at low temperature and completing it at 600°C. The relevance of that process is related to a rapid relaxation observed at the very beginning of the growth at 330°C and to a continuous 2D growth [1]. In situ RHEED measurements and channeling RBS analyses indicated a crystalline improvement during the growth at 600°C, as shown by a  $\Delta\theta$  value as low as 4% in the film bulk.

In an attempt to reduce the density of threading extended defects which are nevertheless observed by TEM, post-deposition annealings at 720°C and thermal cycles between 750°C and 870°C, as proposed in ref [2], were compared. Thermal cycles were found to be efficient, but, in return for it, interdiffusion at the Ge/Si interface, deterioration of the buffer crystalline quality and increase of the surface roughness were observed. Moreover, the measured absorption coefficient decreased drastically with respect to as-deposited films. On the contrary, single annealings were found to be less detrimental.

[1] Halbwax et al, Phys. Stat. Sol. (a), (2004) in press

[2] H-C Luan et al, Phys. Lett. 75, 2909 (1999)

**A1-PI.30****COMPARATIVE STUDIES OF SILICON NANOCRYSTALS PROCESSED BY LASER ABLATION AND SPARK DISCHARGE**

J. Aguilar-Hernández, A. Medina-Torres, M. Cárdenas-García, G. Contreras-Puente, Escuela Superior de Física y Matemáticas, Instituto Politécnico Nacional, Edificio No. 9. U.P.A.L.M. Lindavista, C.P.07738 México D.F., México

Since the first observation of luminescent emission in porous silicon at room temperature, the processing of silicon nanocrystals arose as a technological possibility for device manufacturing based on silicon. This work delivers some results concerning the processing of silicon nanocrystal by using techniques such as laser ablation and spark discharge. It has been studied the luminescent response at room temperature for the processed samples. We also studied the photoluminescence as a function of the growth parameter and temperature.

**A1-PI.31****LUMINESCENCE PROPERTIES OF Si NANOCRYSTALLINE THIN FILMS ON VARIOUS SUBSTRATES**

Kyung Ah Jeon, Jong Hoon Kim, Gun Hee Kim and Sang Yeol Lee, Department of Electrical and Electronic Engineering, Yonsei University, 134, Shinchon-dong, Seodaemun-ku, 120-749, Seoul, Korea

Nanocrystalline silicon (nc-Si) thin films have been fabricated by pulsed laser deposition technique on p-type Si, p++-type Si, n++-type Si, and Al<sub>2</sub>O<sub>3</sub>. After deposition, samples were annealed in nitrogen gases at 800°C. Strong violet-indigo photoluminescence has been observed at room temperature from all Si nanocrystalline thin films. Dependence of the electroluminescence (EL), electrical, and structural properties on various substrates is investigated using metal/nc-Si/substrate/metal structure. The physical reason for the EL is discussed.

**A1-PI.32****FORMATION MECHANISM OF SILICON NANOCRYSTALS FABRICATED BY PULSED LASER DEPOSITION**

Jong Hoon Kim, Kyung Ah Jeon, Gun Hee Kim and Sang Yeol Lee, Department of Electrical and Electronic Engineering, Yonsei University, 134 Shinchondong, Seodaemunku, Seoul, 120-749, Korea

Nanocrystalline silicon (nc-Si) thin films on silicon substrate have been prepared by pulsed laser deposition (PLD). The optical and structural properties of films have been investigated depending on deposition temperature, annealing, and oxidation process. When the deposition temperature increased, photoluminescence (PL) intensity abruptly decreased and peaks showed red shift. Annealing process can reduce the number of defect centers. Oxidation has considerable effect upon the formation and isolation of the nanocrystals. These results indicate that the formation mechanism of Si nanocrystals grown by PLD can be explained by three steps of growth, passivating defect centers, and isolation, sequentially.

- A1-PL.33** PHOTOSENSITIZATION OF ORGANIC MOLECULES BY SILICON NANOCRYSTALS  
Minoru Fujii, Motofumi Usui and Shinji Hayashi, Department of Electrical & Electronics Engineering, Faculty of Engineering, Kobe University, Rokkodai, Nada, Kobe 657-8501, Japan, and Egon Gross, Dmitri Kovalev, Nicoletti Kuenzner and Joachim Diener, Technische Universität München, Physik-Department E16, 85747 Garching, Germany  
 Photosensitized degradation of an organic molecule, 1,3-diphenylisobenzofuran (DPBF), has been studied by using porous Si as a photosensitizer in organic solution, in air or in vacuum. It is demonstrated that DPBF introduced in the pore of a porous Si layer is degraded by shining red light, which is not directly absorbed by DPBF. The effect was strongly suppressed if a monolayer of oxide was formed below the hydrogen-terminated surface of Si nanocrystals (nc-Si) comprising porous Si. The results indicate that the overlap of wavefunctions of excitons in nc-Si and that of DPBF, and resultant strong interaction causes the degradation of DPBF. The interaction may be made by the charge transfer from the excited state of nc-Si to DPBF (Type I pathway). In addition, indirect interaction termed Type II pathway is considered to occur simultaneously, if oxygen is available; nc-Si transfer energy to oxygen molecules and generate singlet oxygen. The generated singlet oxygen undergoes a 1,4-cycloaddition reaction with DPBF forming endoperoxides, which in turn decompose to yield irreversible products.
- A1-PL.34** WITHDRAW
- A1-PL.35** INFLUENCE OF EXCESS SILICON ON CLUSTERING OF ER AND YB ATOMS AND EXCITATION OF ER<sup>3+</sup> IONS IN SILICON OXIDE  
D. Kuritsyn, and A. Kozanecki, Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland  
 In this work we perform studies of the influence of defects due to excess Si on excitation and relaxation of Er PL at 1.54  $\mu\text{m}$ . We also perform studies of precipitation of Er and Yb ions in silicon oxide layers implanted with high doses of silicon to check if luminescence (PL) efficiency is limited by Er clustering. The formation of precipitates was observed using Transmission Electron Microscopy and Rutherford backscattering of He ions was applied to control impurity profiles. We show that the presence of excess Si prevents clustering of Er atoms and enhances migration of Yb atoms. Dependence of the decay time of the Er PL, excited using optical parametric oscillator, on excitation wavelength was measured. The PLE data show that excess silicon suppresses the resonant channel of excitation of Er<sup>3+</sup> ions – the resonant absorption peaks disappear with the increasing annealing temperature after implantation as well as with the Si dose. Increasing size of Si clusters with the increasing silicon dose results in stronger temperature quenching and shortens the Er PL lifetime. It is shown that the Er PL lifetime reaches its maximum (~6 msec) for resonant excitation, as it comes predominantly from isolated Er. With the increasing Si contents the distance between nc-Si and Er ions decreases and it manifests itself in shorter decay time, as for the distance less than 1 nm isolated Er do not exist.
- A1-PL.36** ELECTRON HOLE LIQUID IN SINGLE SILICON QUANTUM WELLS  
N. Pauc, V. Calvo, J. Eymery, N. Magnea, CEA Grenoble, DRFMC/SP2M, 17 avenue des martyrs, 38054 Grenoble Cedex 9, France, F. Fournel CEA Grenoble, LETI/DTS, 17 avenue des martyrs, 38054 Grenoble Cedex 9, France  
 Low temperature photoluminescence (PL) studies have been carried out on crystalline single Si quantum wells with SiO<sub>2</sub> dielectric barriers obtained from Silicon On Insulator (SOI) wafers. It is shown excitons condense into a metallic liquid state called electron-hole liquid whose properties and thermodynamic equilibrium conditions are strongly modified compared with 3D infinite media. Two confinement regimes are clearly identified: a spatial confinement is observed for well thickness  $l_z$  between 15nm and 200nm, and a quantum confinement for  $l_z < 15\text{nm}$ . In the latter case, we observed a blueshift of the e-h recombination line with decreasing  $l_z$ . A model including on the one hand the dielectric mismatch between the well and the barriers, and on the other hand quantum confinement effects on the band edge positions is used to account for the modifications of the many body properties of the 2D electron-hole liquid. These data constitute the first unambiguous observation of quantum confinement effect in Si/SiO<sub>2</sub> heterostructures.
- A1-PL.37** PHOTOLUMINESCENCE OF NANOMETRIC SINGLE SILICON QUANTUM WELLS  
N. Pauc, V. Calvo, J. Eymery, N. Magnea, CEA Grenoble, DRFMC/SP2M, 17 avenue des martyrs, 38054 Grenoble Cedex 9, France, F. Fournel, CEA Grenoble, LETI/DTS, 17 avenue des martyrs, 38054 Grenoble Cedex 9, France  
 We present photoluminescence (PL) studies of ultra thin (thickness  $l_z < 4\text{nm}$ ) crystalline single silicon quantum wells obtained from Silicon On Insulator (SOI) wafers. We have shown previously that the electron-hole recombination line monotonically blueshifts with decreasing  $l_z$  for  $l_z > 4\text{nm}$ . For  $l_z < 4\text{nm}$ , we observe a discretisation of the recombination spectrum. Data are compared with ab-initio calculations giving the variation of the band edge positions and with a model taking into account the dielectric mismatch between the well and the barriers. The observed series of lines gives a set of values of  $l_z$  we attribute to monolayer fluctuation of the quantum well thickness. These spectroscopic observations are corroborated by AFM images of the sample surface after deoxidation which show a planar distribution of Si nanoplates. Below 10nm, a fixed red PL line arises [1] and is still visible at room temperature. This line is attributed to the activation of interfacial traps.  
 [1] M. V. Wolkin et al, Phys. Rev. Lett. 82 (1), p197, 1999.
- A1-PL.38** WITHDRAW
- A1-PL.39** PREPARATION AND OPTICAL PROPERTIES OF RARE EARTH DOPED MIXOXIDES FROM (1-X) GeO<sub>2</sub> - XSiO<sub>2</sub>  
 Tran Thu Huong, Tran Kim Anh, Charles Barthou\* and Le Quoc Minh, Lab. Photochem and Optonics, Ins. Materials Science, NCST of Vietnam, 18 Hoang Quoc Viet Hanoi, Vietnam, \*Laboratoire d'optique des solides, UMR 7601, Uni. Pierre & Marie Curie, Paris, France  
 The solgel technique is a highly flexible technique for fabrication of oxide multicomponent glasses and various researchers have reported fluorescence studies of rare earth -doped solgel films and monoliths. Here we report the fabrication of Er-doped (1-X) Germania - X silica host with X from 10 to 25 at %. The films were coated on silicon substrate by dip-technique. The optical properties and surface morphology of the film were characterized by AFM, profilometry, and prism coupling technique for optical loss. The fluorescence and decay time of Er-activator in films were measured and discussed toward to active wave guide materials applied for telecommunication.

**A1-PL.40****IRON DISILICIDE FORMED IN a-Si: Fe THIN FILMS BY MAGNETRON CO-SPUTTERING**

V.Kh. Kudoyarova, E.I. Terukov, O.I. Konkov, O.B. Gusev, V.Yu. Davidov, G.N. Mosina, Ioffe Physicotechnical Institute, Russian Academy of Sciences, 194021 St.Petersburg, Russia

Formation of Si-based structures emitting in the 1.5  $\mu\text{m}$  region (transparency window of silicon and silica optical fibers) has attracted much interest over the last 10 years. One of the main approaches for the formation of buried layers of low-defect, emitting b-FeSi<sub>2</sub> is an iron-beam synthesis (IBS) i.e. high-dose Fe<sup>+</sup> implantation in Si with subsequent high-temperature and long-duration annealing.

In this work the formation iron disilicide (b-FeSi<sub>2</sub>) nano-precipitates in amorphous silicon has been observed at low temperature without implantation Fe. Amorphous silicon films doped with Fe (a-Si: Fe) have been prepared by magnetron co-sputtering. Subsequent short-time annealing results in the transformation of amorphous silicon doped with Fe into microcrystalline one and the production of b-FeSi<sub>2</sub> nano-precipitates. The phase composition of the films was studied by Rutherford backscattering spectrometry (RBS). The microstructure of the layers was studied using Raman spectroscopy and transmission electron microscopy (TEM). TEM data show the precipitate sizes to be in the range 20-25 nm. It is shown that the synthesized layers are able to emit at 1.5  $\mu\text{m}$  at 100K.

**A1-PL.41****POROUS SILICON OPTICAL DEVICES FOR DNA SENSING APPLICATIONS**

V. Torres-Costa(a), F. Agulló-Rueda(b), R.J. Martín-Palma(a), J.M. Martínez-Duart(a), (a)Departamento de Física Aplicada, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain, (b)Instituto de Ciencia de Materiales de Madrid - CSIC, Cantoblanco, 28049 Madrid, Spain

Porous silicon (PS) has a great potential in a wide range of fields due to its tuneable effective refractive index, which resides on the precise control of the formation parameters. In particular, high/low porosity layer stacks result in optical multilayer interference filters, such as Bragg reflectors and microcavities. In addition, due to its large internal surface, the optical properties of porous silicon are highly sensitive to the environmental conditions. Hence, a change in these conditions results in a shift of the reflectance spectrum of the PS multilayer structures. Thus, monitoring the wavelength position of the reflectance spectrum features (the reflectance peak of the Bragg mirror or the resonant peak of the microcavity) a PS optical biosensor can be developed.

DNA sensors can be achieved through the immobilization of DNA strands onto the porous silicon surface. If the complementary DNA strand is present in the ambient, it attaches to the immobilized strand, thus modifying the sensor's optical properties and redshifting its reflectance spectrum. In a first approximation, these sensors can be considered of 'on/off' type, since the DNA strand is either detected or not detected, which means that the reflectance spectrum is shifted in a given amount, regardless of the DNA concentration. Even in the case of very low concentrations, where the biosensor is not completely covered by the strand to be detected, a superposition of the 'on' and the 'off' characteristic spectra is expected. Summarizing, high sensitivity, low cost DNA biosensors can be fabricated with porous silicon optical devices.

**A1-PL.42****OPTICAL AND MICRO STRUCTURAL CHARACTERISATION OF LEPECVD GROWN GERMANIUM VIRTUAL SUBSTRATES FOR CMOS AND OPTICAL DEVICE INTEGRATION**

R. Ginige, M. Modreanu and B. O'Looney, NMRC, University College Cork, Lee Maltings Prospect Row, Cork, Ireland

In recent years there has been a rapid advance in SiGe technologies. A number of companies have successfully integrated SiGe technologies in BiCMOS HBT processes. The full potential of SiGe will only be realised when CMOS IC's (complementary metal-oxide semiconductor integrated circuits) and optical devices can be fully integrated on the same platform. Such a roadmap requires device fabrication on the Silicon host substrate, SiGe intermediate graded layers and the Germanium overlayer (Virtual Substrate) of the Si/SiGe/Ge LEPECVD grown substrates. We have studied and determined the optical characteristics of the virtual Germanium overlayer and the SiGe graded layer. The optical characteristics of the Germanium overlayer are in good agreement with that of crystalline Germanium wafers. The Raman spectra for the SiGe were used to determine the composition. The composition determined from Raman was cross-checked by XRD and was found to give excellent correlation. We have also used Modulated Photoreflectance techniques to determine the strain, the tensile strain is known to significantly increase carrier mobility and thus accurate determination of the strain and composition is important in device fabrication.

**A1-PL.43****PHOTOLUMINESCENCE AT 1.5  $\mu\text{m}$  FROM SINGLE-CRYSTAL SILICON LAYERS SUBJECTED TO MECHANICAL TREATMENT**

R.I. Batalov, R.M. Bayazitov, Zavoiiski Physicotechnical Institute, Kazan Scientific Center, Sibirski trakt 10/7, Kazan 29, 420029 Tatarstan, Russia, B.A. Andreev, D.I. Kryzhkov, Institute for Physics of Microstructures, Nizhni Novgorod, 603950 Russia, E.I. Terukov, and V. Kh. Kudoyarova, Ioffe Physicotechnical Institute, Politekhnicheskaya ul. 26, St. Petersburg, 194021 Russia

In the last 10-15 years, active efforts have been made to develop new Si-based light-emitting structures. The basic approaches to the development of such emitters are Si doping with erbium ions (Si:Er), the synthesis of direct-gap iron disilicide b-FeSi<sub>2</sub>, and the formation of Si dislocation structures causing a number of emission lines D1-D4, where line D1 (~0.81 eV) is of particular interest for optoelectronics. The basic ways of introducing extended-defect structures into Si that emit at 1.5  $\mu\text{m}$  (D1 line) are plastic deformation of the Si crystal, SiGe layer growth on a Si substrate, heavy-ion implantation into Si followed by annealing and Si surface melting by a laser beam.

In this paper, we report the results of studying the PL of single-crystal silicon layers (100) whose rear surface was subjected to conventional mechanical processing (grinding and polishing). An intense PL signal at 77 K with a peak at 0.83 eV (1.5  $\mu\text{m}$ ) and FWHM = 50 meV was observed after annealing at 800C. This peak differed in spectral position and shape from the well-known D1 line caused by dislocations. We have investigated the structure and composition of the silicon layers subjected to mechanical treatment. The possible origin of this signal is discussed and is tentatively related to dislocations decorated by impurity atoms.

**A1-PL44**

**SILICON NANOCRYSTALS PREPARED EX-SITU OF THE HOST SiO<sub>2</sub> MATRIX**

V. Švrcek(a), J.L. Rehspringer(b), E. Gaffet(c), A. Slaoui(a), J.C. Muller(a), (a)CNRS-PHASE, 23 rue du Loess, 67037 Strasbourg, France, (b)IPCMS, 23 rue du Loess, 67037 Strasbourg, France, NanoMaterials Research Group, (c)NRG/UMR CNRS 5060, Site de Sévenans, 90010 Belfort, France

We have investigated the fabrication of silicon nanocrystals (Si-nc) ex-situ of the silicon dioxide (SiO<sub>2</sub>) host matrix. Two different methods were used: pulverisation of porous silicon and ball milling. We show that both ways allow preparing Si-nc with quantum confinement size (< 10 nm). The ex-situ preparation of the Si-nc can permit to investigate additional properties when dispersed in different liquids (ethanol, doped or undoped SiO<sub>2</sub> spin-on-glasses SOG). The identification of the Si-nc in the colloid was performed by Malvern Autosizer experiments. We have shown the clustering effect and also the way to declusterize the Si-nc in the SOG solutions. This could be of interest for filling very narrow gaps and/or nanotubes with Si-nc embedded in SOG. We have also prepared silica thin films (130 nm thick) on silicon substrates that contain different concentration of Si-nc. We have studied and compared the structural (Micro-Raman, HR-TEM) and optical properties (luminescence) of Si-nc versus the preparation method. A strong room temperature photoluminescence in the visible was detected.

**A1-PL45**

**PHOTOLUMINESCENCE FROM AN ACTIVE PLANAR OPTICAL WAVEGUIDE MADE OF SILICON NANOCRYSTALS: DOMINANCE OF LEAKY SUBSTRATE MODES IN DISSIPATIVE STRUCTURES**

T. Ostatnický(a,b), J. Valenta(a), I. Pelant(c), K. Luterová(c), R.G. Elliman(d), S. Cheylan(e), and B. Hönerlage(b), (a)Department of Chemical Physics & Optics, Faculty of Mathematics & Physics, Charles University, Prague, Czech Republic, (b)IPCMS, Groupe d'Optique Nonlinéaire et d'Optoélectronique, UMR 7504 CNRS-ULP, Strasbourg, France, (c)Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic, (d)Electronic Materials Engineering Department, Research School of Physical Sciences and Engineering, Australian National University, Canberra, Australia, (e)Institut de Ciències Fotoniques, Barcelona, Spain

Asymmetric optical waveguides made of Si nanocrystals are fabricated by implanting synthetic silica slabs with 400 keV Si<sup>+</sup> ions to doses varying in the range from 1 to 6x10<sup>17</sup> cm<sup>-2</sup>. The propagation of light originating from silicon nanocrystal luminescence inside such planar waveguide is studied both experimentally and theoretically. Photoluminescence (PL) spectra detected from the sample facet mainly contains narrow (full-width-at-half-maximum of 10 – 20 nm), polarisation-resolved transverse electric and transverse magnetic modes instead of the usual broad nanocrystal emission band peaked at 700 – 800 nm. Spatial distribution of emitted light is detected using a micro-PL and a goniometer-based set-ups. A theoretical model identifies this microcavity-like PL behaviour as due to leaky-mode spontaneous emission propagating along the waveguide/substrate boundary. The narrow modes are observable only in that case when their intensity is greater than the intensity of the usual guided modes (inside the nanocrystal plane). This condition results in a competition between the two types of spectra and the peculiar observation of the PL from the facet of our samples is a direct consequence of the dominance of the substrate modes. We discuss conditions under which the substrate modes prevail as well as the implication of the phenomenon to occurrence and detection of optical gain.

**A1-PL46**

**WAVELENGTH TUNABLE FILTER WITH POLY-SI/SiO<sub>2</sub> MULTI-LAYER BY THERMO-OPTIC EFFECT**

Hun-Yong Park(a), Chong-Hun Park(a), Byung-Chul(a) Hwang, Seung-Gol Lee(a), Beom-Hoan O(a), El-Hang Lee(a), Doo-Sun Choi(b) and Se-Geun(a), (a)Park m-PARC, School of Information & Communication Engineering, Inha University, Incheon 402-751, Korea, (b)Nano Process Laboratory, Intelligence & Precision Machine Department, Korea Institute of Machinery and Materials 171 Jang-Dong, Yusong-Gu, Daejeon, Korea

Wavelength tunable filter is the key component of Wavelength Division Multiplexing (WDM) systems. In this paper, we utilize thermo-optic effect of multi-layers whose refractive indexes are changed by temperature variation effect, to tune transmitted wavelength. Tunable filter is designed using Fabry-Perot interference effect. Distributed Bragg Reflector (DBR) mirror structure is composed of 4-pairs of high index poly-Si layer (n=3.48) and low index SiO<sub>2</sub> layer (n=1.44). The filter has the structure of DBR layer/tunable cavity layer/DBR layer. The cavity material is poly-Si. Thickness of DBR mirror material is  $\lambda/4$  and that of cavity layer is  $\lambda/2$ , where  $\lambda$  is the center wavelength of 1550nm. Poly-Si has very high thermo-optic coefficient of  $dn/dT=2.25 \times 10^{-4}/K$ . Thus it is efficient material for thermo-optic tunable filter. Poly-Si is deposited by LPCVD at 625°C; using SiH<sub>4</sub>, and SiO<sub>2</sub> by PECVD at 300°C; using SiH<sub>4</sub>/N<sub>2</sub>O.

**A1-PL47**

**BLUE EMISSION IN MESOPOROUS SILICA EXCITED BY SYNCHROTRON RADIATION**

A. Anedda, C.M. Carbonaro, F. Clemente, R. Corpino and P.C. Ricci, Dipartimento di Fisica, Università di Cagliari, and INFN, UdR-Ca, s.p. n°8, Km 0.7, 09042 Monserrato, Cagliari, Italy

The scaling improvement of silicon technology requires the investigation of Si and SiO<sub>2</sub> nanometric layers. Indeed intermetal insulation can be realized by porous silica films [1] and the circuit integration miniaturization process leads to gates whose nanometric thickness is comparable to the skeleton walls of porous silica [2]. In addition it has been shown that the photoluminescence of porous silica closely resembles the one observed in oxidized porous silicon [3]. Thus, sol-gel synthesized mesoporous silica is a suitable candidate to study the optical properties of thin SiO<sub>2</sub> layers and its relation with the chemical and physical properties of the surface.

The aim of this work is the analysis of the blue photoluminescence of mesoporous silica in samples with different specific surface values (i.e. different pore diameters). By exciting with synchrotron radiation we investigate the optical properties of the emitting center to assess its possible correlation with the surface conditions of the samples. The recorded data allow to picture the optical levels of the centers and to estimate the decay time of the observed emission.

[1] J.K. Hong, H.S. Yang, M.H. Jo, H.H. Park, S.Y. Choi, Thin Solid Films 308&309 (1997) 495.

[2] M.A. García-Sánchez, A. Campero, J. Non-Cryst. Solids 296 (2001) 50.

[3] G.G. Qin, J. Lin, J.Q. Duan, G.Q. Yao, Appl. Phys. Lett. 69 (1996) 1689.

**A1-PI.48**

**SUPER LINEAR POSITION SENSITIVE DETECTORS USING MIS STRUCTURES**

H. Águas, L. Pereira, F. Soares, D. Costa, E. Fortunato, R. Martins, Departamento de Ciência dos Materiais/CENIMAT, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, and CEMOP / UNINOVA, Campus da Caparica, 2829-516 Caparica, Portugal

This work reports the fabrication process and performances presented by Metal Insulator Semiconductor (MIS) linear Position Sensitive Detectors (PSD) with an active length of 7 cm. The use of long sensitive areas allows the PSD to achieve higher resolution without the need of a highly accurate light spot integration mechanism. The PSD is built in a multi-layered structure consisting of Cr / a-Si:H (n+ doped) / a-Si:H (intrinsic) / SiO<sub>2</sub> (passivation layer) / Au, where the active a-Si:H layers were deposited by a Modified Triode Plasma Enhanced Chemical Vapour Deposition (MTPECVD) which allows the deposition of highly electronic grade material with a low ( $1 \times 10^{15} \text{ cm}^{-3}$ ) defect density inferred by CPM.

The sensor linearity and signal to noise ratio shows a dependence on the sensor width and Au layer thickness. The maximum signal ( $\pm 100 \text{ mV}$ ) was achieved with an optimised structure with an active length of 7 cm and a linearity better than 98%. Besides that, this type of MIS structure allows an improved spectral response near the UV region than the standard p-i-n structure, since the a-Si:H p doped layer limits the sensor response in the UV region. The SiO<sub>2</sub> passivation layer plays an important role in the device performance, since it allows the increase of the sensor signal besides allowing the use of large active areas free of pinholes (shortcuts) that damage the device.

**A1-PI.49**

**SIMULTANEOUS OBSERVATION OF “SELF TRAPPED EXCITON” AND Q-CONFINED EXCITON LUMINESCENCE EMISSION IN SILICON NANOCRYSTALS**

J. De La Torre, A. Souifi, G. Bremond, G. Guillot, Laboratoire de Physique de la Matière, UMR-CNRS 5511, INSA de Lyon, France, N. Buffet, P. Mur, CEA-LETI, 38054 Grenoble, France

Improvements in photoluminescence (PL) properties of silicon nanocrystals (nc-Si) obtained by Low Pressure Chemical Vapor Deposition (LPCVD) technique has been studied. In this work, 200nm thick SiO<sub>x</sub> layers were deposited and annealed under different conditions to analyze the modifications of their luminescent properties and Fourier transform infrared (FTIR) measurements were used to complement the PL studies. The PL spectra of these samples show two main PL bands clearly related to nc-Si and their energy position shows a clear dependence on annealing conditions (atmosphere and time), sample temperature and excitation power. Following the position of each PL band we have calculated the average nanocrystal's size by using different Q-confinement models proposed in the literature and these results were confronted to average nanocrystal's size obtained by Transmission electron microscopy (TEM) measurements. Finally, these results are explained in the frame of a competitive radiative recombination process between “free” excitons confined inside nc-Si and “self trapped” excitons (STE) located at the nc-Si/SiO<sub>2</sub> interface. To our knowledge, this is the first time that both luminescence processes are simultaneously observed.

**A1-PI.50**

**THEORETICAL MODELLING OF FUNCTIONALITY OF SiO<sub>2</sub>:Er WITH SILICON NANOCLUSTERS**

I.N. Yassievich, A.C. Moskalenko, M.S. Bresler and O.B. Gusev, Ioffe Physico-Technical Institute, St.Peterburg, Russia

Electron-hole pairs confined in silicon spherical quantum dots are theoretically investigated. The energy spectrum and wave functions are calculated with an account of Coulomb interaction and ellipsoidal shape of electron energy spectrum. The exciton energy levels obtained are in the agreement with experimental data. The probabilities of optical, Auger and multi-phonon nonradiative processes are found as a function of QD size, intensity of pumping and temperature.

Based on these results and available experimental data, the functionality of the optoelectronic material SiO<sub>2</sub>:Er with Si nanoclusters is analysed.

Wednesday, May 26, 2004

Afternoon

Session V : Light emitting devices

Session Chair : W. Skorupa and E. Borsella

- A1-V.1** 13:30 -Invited- STRUCTURAL CHARACTERIZATION OF Si NANOCCLUSERS AND THEIR APPLICATIONS IN LIGHT EMITTING DEVICES  
**F. Iacona**, A. Irrera, C. Bongiorno and C. Spinella, CNR-IMM, Sezione di Catania, Stradale Primosole 50, 95121 Catania, Italy, G. Franzò, D. Pacifici, S. Boninelli, M. Miritello and F. Priolo, INFN-MATIS and Dipartimento di Fisica e Astronomia, Università di Catania, Via S. Sofia 64, 95123 Catania, Italy, D. Sanfilippo, G. Di Stefano and P.G. Fallica, STMicroelectronics, Stradale Primosole 50, 95121 Catania, Italy  
In the last decade a strong effort has been devoted towards the achievement of efficient light emission from Si and rare earth (RE) doping and quantum confinement in Si nanostructures have shown great potentialities. In this work the synthesis, the properties and some relevant applications of low dimensional Si structures will be presented.  
Si nanoclusters (nc) embedded in SiO<sub>2</sub> are obtained by thermal annealing of SiO<sub>x</sub> films. They exhibit a strong room temperature photoluminescence (PL), characterized by a weak temperature dependence and by a clear blue shift with decreasing the nc size. When Si nc are doped with Er they act as very efficient sensitizers for the RE and a strong emission at 1540 nm is obtained. The energy filtered transmission electron microscopy technique has been employed in order to investigate the structural properties of Si nc. It has been possible to quantify the Si nc mean radius and density by taking also into account the amorphous fraction. The correlation between structural and optical data has demonstrated that amorphous Si clusters constitute a relevant fraction of the overall population and play also a key role in determining the PL properties of the system and the energy transfer effect in Er-doped systems. Si nc can be also used for the fabrication of light emitting devices exhibiting a strong room temperature emission at about 900 nm. Devices emitting at different wavelengths have been fabricated by implanting the SiO<sub>x</sub> films with RE ions. The electrical and optical properties of the devices have been optimized by changing the Si nc size and density and the annealing temperature, and operating voltages as low as 4 V have been obtained. The relevance of the above data for the development of a Si-based optoelectronics will be discussed.
- A1-V.2** 14:00 EFFICIENT SILICON LIGHT EMITTING DIODES BY BORON IMPLANTATION: THE MECHANISM  
**J.M. Sun**, T. Dekorsy, W. Skorupa, A. Mücklich, B. Schmidt and M. Helm, Institute of Ion Beam Physics and Materials Research, Forschungszentrum Rossendorf, Dresden, Germany  
This report will give a review of our research activities on the mechanism of light emission in silicon pn-diodes prepared by boron implantation (Si-LED) [1]. A broad range of experimental parameters such as implantation dose, energy, co-implantation of Si as well as annealing temperature and time were investigated. Experiments and theoretical modeling were concentrated on the understanding of the mechanism of the efficient electroluminescence (EL) from these boron implanted Si-LEDs. Based on transmission electron microscopy and energy dispersive X-ray analysis, it will be explained that preformation of boron-rich nanoclusters leads to locally enhanced boron doping (spikes) in the most efficient LEDs with an external power efficiency above 0.12%. The correlation of these results to those of an extensive evaluation of the temperature dependent EL peaks from the related bound excitons and free electron-hole pairs leads to a concise clarification of the mechanism for the enhancement of band edge EL based on excitons bound to strained and unstrained boron doping spikes. [2,3]  
[1] Wal Lek Ng, et al. Nature 410, 192 (2001).  
[2] T. Dekorsy, et al. Appl. Phys. A (in press).  
[3] J. M. Sun, et al. Appl. Phys. Lett. 82, 2823 (2003).
- A1-V.3** 14:20 SILICON-BASED LIGHT EMISSION AFTER ION IMPLANTATION  
**M. Kittler(a)**, T. Arguirov(b), W. Seifert(a), (a)IHP microelectronics, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany, (b)BTU Cottbus, Experimentalphysik II, Universitätsplatz 3-4, 03044 Cottbus, Germany, IHP/BTU Joint Lab, Universitätsplatz 3-4, 03044 Cottbus, Germany  
In a recent report by W.L. Ng et al. [1] it was demonstrated that light-emitting diodes (LED) operating efficiently at room temperature can be formed by implantation of boron into silicon. In this paper, we report observations on light emission from silicon after both boron and phosphorus implantation. An increase of the band-to-band luminescence intensity by one order of magnitude is observed upon rising the temperature from 80 K to 300 K. Defect luminescence arising from the implanted layer is found only at low temperatures. Contrary to Ref. 1 the remarkable band-to-band luminescence can be explained on the basis of the known properties of silicon. It is attributed to a high Shockley-Read-Hall lifetime caused by the gettering action of implantation defects.  
Our observations show that ion implanted Si is a promising candidate for producing light emitters with standard Si technology. However, the lifetime of the material has to be very high to get a sufficient efficiency for the light emission. Consequently, a LED based on this principle does not have a fast switching behavior. However, it can be combined with an electro-optic modulator such as proposed by C.A. Barrios et al. [2]. This modulator is based on both absorption and refraction by free carrier and allows to switch sub-bandgap light. The needed shift of the band-to-band line to longer wavelengths may be realized by using SiGe layers instead of Si.  
[1] W.L. Ng, M.A. Lourenco, R.M. Gwilliam, S. Ledain, G. Shao, K.P. Homewood, An efficient room temperature silicon-based light emitting diode, Nature 410, 192 (2001)  
[2] C.A. Barrios, V.R. Almeida, R. Panepucci, M. Lipson, Electrooptic modulation of silicon-on-insulator submicrometer size waveguide devices, J. of Lightwave Technology 21, 2332 (2003)

- A1-V.4** 14:40 **WAVELENGTH TUNABLE SIGE-BASED LIGHT EMITTING DEVICE**  
 N. Yasuhara(a) and S. Fukatsu(a,b), (a)Graduate School of Arts and Sciences, The University of Tokyo, Komaba, Meguro, Tokyo 153-8902, Japan, (b)PRESTO, Japan Science and Technology Corporation, Japan  
 Type-II band line-up unique to pseudomorphic Si1-XGeX/Si allows electrons to be responsive to electric fields. As such, new possibilities arise that we could control the technologically useful properties of a SiGe light emitter by simply applying appropriate voltage waveforms. In this work, we demonstrate a wavelength selective SiGe light emitter.  
 Sample was a pseudomorphic Si1-XGeX/Si double quantum well (DQW). A buried well (34Å, x=0.15) and a near-surface well (126Å, x=0.30) are separated by a 0.8-µm-thick Si. Al electrodes were made on both wafer faces. Changing emission wavelengths in an incoherent light source is a challenge as compared to wavelength tuning based on feedback in a gain medium. However, SiGe-DQW can do it with an alternating electric field. The operation principle is that in a hole rich system the number of electrons controls the recombination: collecting more electrons to one of the two QWs results in an enhanced emission of that QW while letting the other one's diminished. This works fine for dc and an extinction ratio >100 was a routine. Dynamics of such SiGe-LED is of interest in view of application such as optical interconnects. With a positive bias voltage is on the surface, electrons are swept away from the buried QW towards the near-surface QW working as an electron reservoir. Upon voltage pulse of reversed bias, electrons rush toward the buried QW sending off a short light pulse by recombining with holes there. Pulses can be addressed at arbitrary time and the width can be much shorter than the luminescence decay. All this is associated with temporal hole burning in the decay of the other and hence a NOT operation on the two complementary wavelengths. More than GHz is expected for operation bandwidth.
- A1-V.5** 15:00 **SILICON NANOCRYSTALS IN COLLOIDAL SOLUTIONS: FROM SINGLE NANOCRYSTALS TO PHOTONIC STRUCTURES**  
J. Valenta and P. Janda, Department of Chemical Physics and Optics, Charles University, Prague, Czechia, K. Dohnalová, Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czechia, D. Nižcanský, Department of Inorganic Chemistry, Charles University, Prague, Czechia, F. Vácha, Institute of Physical Biology, University of South Bohemia, Budweis, Czechia, J. Linnros, Department of Microelectronics and Information Technology, Royal Institute of Technology, Kista, Sweden  
 Colloidal solutions of Si nanocrystals (NCs) are prepared from light-emitting porous Si grains obtained by mechanical pulverization of electrochemically etched layers. Solutions of Si NCs in various solvents are characterized by absorption, photoluminescence (PL), PL excitation and Raman spectroscopy - attention is paid to the effect of coagulation and ageing. These colloidal solutions have multiple advantages for both fundamental investigation and nanotechnology. In one extreme, single molecule spectroscopy techniques can be applied to investigate photoluminescence of single grains of Si NCs dispersed on substrates from highly diluted solutions. On the other hand, highly concentrated colloids are applied to fabricate bulk solids and layers of SiO2 with embedded Si NCs or to prepare self-organised nanostructures on surfaces. We discuss technological aspects, optical properties and potential application of such silicon nanostructures.
- A1-V.6** 15:20 **STUDY ON BLUE-GREEN LIGHT EMISSION FROM A-SiC:H-BASED FABRY-PEROT MICROCAVITIES**  
 Yongzhao Yao, Yan Wang, Ruifeng Yue, Litian Liu, Institute of Microelectronics, Tsinghua University, Beijing 100084, P.R. China  
 This paper proposes a Si-based novel Fabry-Perot microcavity structure which can emit blue-green light at room temperature. One of its Bragg reflector consists of transparent ITO electrode and periodically stacked PECVD a-SiO2/a-Si:H layers deposited on the glass through which the emitting light is sent out. The other reflector is sputtering Al film. The active region between these two reflectors is constituted of p-type a-SiC:H/a-SiC:H junction from where the electroluminescence is originated. By designing film thickness and refractive index of the PECVD films, the Bragg reflector can meet the demand of high reflectivity (>95%) for the expected wavelength, which has been demonstrated by reflection spectra and transmission spectra. The I-V characteristic of the device is the same as that of a PN junction whose threshold voltage is 8V. The electroluminescence spectra of this device are recorded by RENISHAW RM200 and a sharp, strong electroluminescence peak with the FWHM of 20nm is observed at the wavelength of 483nm (the expected luminescence wavelength is 500nm) when the device is driven by DC voltage of 8V, 12V and 18V at the room temperature. The intensity of electroluminescence increases with the applied voltage while the peak wavelength keeps constant. Compared with the electroluminescence spectra of the same structure without the Bragg reflector, the luminescence intensity is about 20 times enhanced and the peak is narrowed greatly. This property is very important for color flat display and Si-based optic-electro integration. The mechanism of luminescence is analyzed in details.

**A1-V.7** 15:40 **BANDSTRUCTURE ANALYSIS OF STRAIN COMPENSATED Si/SiGe QUANTUM CASCADE STRUCTURES**

H. Sigg, A. Borak, S. Tsujino, C. Falub, M. Scheinert, E. Müller, D. Grützmacher, Laboratory for Micro- and Nanotstructures, Paul Scherrer Institute, 5232 Villigen-PSI, Switzerland, M. Meduna, T. Fromherz, G. Bauer, Institute for Semiconductor and Solid State Physics, University of Linz, Altenbergerstr. 69, 4040 Linz, Austria, O. Kermarrec, STMicroelectronics, 38926 Crolles-Cedex, France

Understanding of the bandstructure in strain compensated Si/SiGe quantum wells (QW) is crucial for the development of Si based quantum cascade lasers. To improve existing parameters sets for modelling of the energy spectrum in these structures, such as band offsets and Luttinger parameters, a detailed analysis of interband and intersubband transitions is performed. Samples with various barrier and well widths as well as Ge concentrations ( $0.7 < x < 0.85$ ) have been prepared by low temperature MBE on relaxed Si<sub>0.5</sub>Ge<sub>0.5</sub> buffer layers. Data of a very careful structural analysis using TEM, X-ray diffraction and X-ray reflectivity of strain compensated modulation doped Si<sub>0.5</sub>Ge<sub>0.5</sub>/Si<sub>1-x</sub>Ge<sub>x</sub> QW's permit a determination of the composition and the thickness within  $\pm 0.5\%$  of Ge and  $\pm 0.2$  nm, respectively. Reflectivity measurements using synchrotron radiation revealed an interface roughness of  $< 0.4$  nm. The unique set of structural parameters determined with high accuracy in combination with polarization resolved intersubband absorption spectra deduced from the same set of samples allows for a detailed comparison with 6 band k.p calculations and refinement of the most relevant input parameters.

16:00

**BREAK**

Session VI: Spectroscopy and devices

Session Chair : M. Brongersma and H. Sigg

**A1-VI.1** 16:20 **SINGLE DOT OPTICAL SPECTROSCOPY OF SILICON NANOCRYSTALS: HOMOGENEOUS LINEWIDTH AND THE K-CONSERVATION RULE BREAKDOWN.**

I. Sychugov, R. Juhasz, J. Valenta and J. Linnros, Dept. of Microelectronics and Information Technology, Royal Institute of Technology, Electrum 229, 164 40 Kista-Stockholm, Sweden

Single dot spectroscopy allows studying the properties of a single quantum dot avoiding inhomogeneous broadening of the emission band. Due to the extremely low emission rate of indirect band-gap quantum dots, however, it has been difficult to employ this technique for studies of e.g. single silicon nanocrystals. Here, we present data obtained by this technique for Si nanocrystals fabricated by electron beam lithography, plasma etching and subsequent size-reduction by oxidation.

First of all, blinking (on-off intermittence) of the luminescence was observed for most individual nanocrystals, although some of them showed perfectly stable luminescence. This phenomenon is known to be a hallmark of single fluorescent nano-objects, but seems to be system dependent. For different sizes of nanocrystals two emission peaks were resolved at 80 K with separation of about 55 meV. We attribute them to a quasi-direct recombination (zero phonon line) and to a TO-phonon assisted process. The dependence of the peak ratio on confinement energy is in line with data obtained by energy-selective optical spectroscopy for Si nanocrystals in a SiO<sub>2</sub> shell, suggesting the k-conservation rule breakdown at high confinement energies. While at room temperature the full width at half-maximum of the emission peaks of nanocrystals of different sizes was measured to be 120-150 meV, at 80 K the linewidth of the zero phonon line appeared to be about 30 meV only. The observed temperature dependence of the homogeneous linewidth may lead to an understanding of the exciton-phonon interaction in indirect band-gap quantum dots.

**A1-VI.2** 16:40 **TWO-Dimensionally-Patterned Silicon Nanocrystal Arrays**

A. Meldrum, K.S. Buchanan, C.A. Ryan, and A. Hryciw, Department of Physics, University of Alberta, Edmonton, AB, T6G 2J1, Canada

Numerous exciting developments have been made to enhance and control the optical properties of silicon nanocrystal composites, such as the development of planar optical cavities and optical waveguide structures. Here, we report on a method that uses ion implantation to control the location of the silicon nanocrystals within the two-dimensional implanted plane. First, we used conventional deep-UV lithographic techniques to develop masks sufficiently thick and durable to withstand extremely high-dose ion implantation protocols without losing structural integrity or delaminating from the specimen surface. We were able to use this method to create single and two-color micropixelated arrays of nanoparticles with feature sizes below one micron. We also find that implantation of silica microspheres is a good method to create in-plane spatial control over the location of the nanocrystals, although in this case there was significant material deformation. Both methods, however, offer effective means of patterning silicon nanocrystal composites on a micron- to sub-micron scale, and suggest the possibility for the development of new types of patterned luminescent materials based on silicon nanocrystal composites.

A1-VI.3 16:50

#### COMPARISON OF STRIP AND RIB SOI MICROWAVEGUIDES FOR INTRA-CHIP LIGHT DISTRIBUTION

L. Vivien, F. Grillot, E. Cassan, D. Pascal, S. Lardenois, A. Lupu, S. Laval, IEF, CNRS UMR 8622, Université Paris Sud, 91405 Orsay Cedex, France, and M. Heitzmann, J.-M. Fédéli, CEA-LETI, Avenue des Martyrs 38054 Grenoble Cedex 9, France

Among the possible applications, the marriage between microelectronic circuits and silicon microphotonics is a promising solution to remove the bottleneck of global electrical interconnects within CMOS chips by the introduction intra-chip optical interconnects using Silicon-On-Insulator (SOI) microwaveguides [1,2].

A comparison has been made between light distributions using either strip SOI or rib microwaveguides. On one hand, submicron single mode SOI rib waveguides benefit from a lower confinement of light, which allows easier light coupling and waveguide crossings at right angle with negligible crosstalk. On the other hand, single-mode strip waveguides must have a cross-section smaller than  $0.1 \mu\text{m}^2$  and then lead to more compact devices. Their use yet requires advanced coupling scheme such as 3D tapering [3]. Propagation losses of both kind of waveguides have been measured at  $\lambda = 1.31 \mu\text{m}$  and are respectively of 0.4 dB/cm and 6 dB/cm for the rib and strip geometries. Higher losses of strip waveguides, which are mainly due to sidewall roughness, have been theoretically studied, and a range of strip geometry leading to reduced losses has been found. Experimental and theoretical (3D FDTD) studies have proved that the best photonic devices needed for light distribution at the chip scale (bends, mirrors, splitters, ...) are not the same for the strip and rib families. The performances of a 1 input to 16 outputs light distribution using rib waveguides are presented.

A1-VI.4 17:10

#### EXCITATION SPECTROSCOPY OF ERBIUM PL IN EPITAXIALLY GROWN Si:Er AND SiGe:Er STRUCTURES

B.A. Andreev, Z.F. Krasilnik, V.P. Kuznetsov, A.N. Yablonskiy, Institute for Physics of Microstructures RAS, Nizhny Novgorod, Russia, T. Gregorkiewicz, M.A.J. Klik, Van der Waals-Zeeman Institute, University of Amsterdam, The Netherlands

Er-doped silicon attracts considerable interest as a promising material for effective light emitting at the wavelength  $1.54 \mu\text{m}$ . Application of the original method of sublimation molecular-beam epitaxy (SMBE) allows producing uniformly and selectively erbium-doped Si and SiGe layers with high crystalline quality demonstrating intense erbium photoluminescence at  $1.54 \mu\text{m}$ .

In the present paper we report on the excitation spectroscopy of Er photoluminescence for the Si:Er/Si and SiGe:Er/Si structures produced by SMBE. The excitation spectra have been measured using Nd:YAG-pumped optical parametric oscillator in the wide range of the excitation wavelength ( $\lambda = 450\text{--}1500 \text{nm}$ ). It has been shown that both for Si:Er and SiGe:Er structures considerable signal of erbium PL can be observed at excitation photon energies much lower than the band gap of Si ( $\lambda = 1060 \text{nm}$ ). Moreover at high pumping power rapid increase of the Er luminescence intensity has been observed in the range  $1000\text{--}1050 \text{nm}$  of the excitation wavelength. At the same time for the band-to-band luminescence strong decrease of intensity in the same wavelength range has been revealed and no noticeable signal of the band-to-band PL was observed at excitation photon energies below the Si band-gap ( $\lambda > 1060 \text{nm}$ ). The possible mechanisms of the Er excitation at the photon energies below the band-gap of Si will be discussed.

The work was supported by NWO-047-009-013, INTAS-01-0194, INTAS-01-0468, RFBR 02-02-16773.

A1-VI.5 17:30

#### FREE-ELECTRON LASER SPECTROSCOPY OF EXCITATION AND RECOMBINATION PROCESSES IN Si:Er

M. Forcales, M.A.J. Klik and T. Gregorkiewicz, Van der Waals—Zeeman Institute, University of Amsterdam, The Netherlands

Er-doped crystalline silicon (c-Si:Er) features an attractive combination of sharp atomic like emissions with a relatively large cross-section of band-to-band absorption which makes it interesting for photonic applications. Despite numerous studies, current knowledge of excitation and deactivation paths in c-Si:Er remains mostly phenomenological. While the key role of the weakly bound states is generally accepted, details of their particular involvement remain unclear. Here we discuss spectroscopic investigations of energy transfer processes by two-color (2C) experiments with a free-electron laser (FEL). Photoluminescence (PL) of  $\text{Er}^{3+}$  ions is achieved by primary band-to-band excitation (Nd:YAG). Subsequently, the sample is illuminated with intense mid-infrared (MIR) radiation from the FEL in order to directly probe individual steps of the energy transfer process. Specific shallow levels of the material are selectively addressed by appropriate tuning of the FEL energy. In that way, unique microscopic information on energy flow between the Si matrix and  $\text{Er}^{3+}$  ions is obtained. In the presentation we will review a variety of effects recently revealed in c-Si:Er by the 2C spectroscopy. These include energy storage (PL “afterglow” and an optical memory effect), and an optically-induced Auger process involving energy transfer to free carriers. Special attention will be given to the energy “back transfer” effect of excitation reversal, selectively activated with the MIR beam. Consequences of these new findings for the potential of c-Si:Er for silicon photonics will be discussed.

M. Forcales et al., Phys. Rev. B65 (2002) M.A.J. Klik et al., Phys. Rev. Lett. 89 (2002)

M. Forcales et al., Phys. Rev. B67 (2003) M. Forcales et al., Phys. Rev. B68(2003)

A1-VL6 17:50

STRUCTURAL RELAXATION AND OXIDATION: INFLUENCE ON THE OPTICAL AND ELECTRONIC PROPERTIES OF SILICON NANOCRYSTALS

Hans-Christian Weissker, Luis Ramos, Jürgen Furthmüller, Friedhelm Bechstedt, Institut für Festkörperteorie und Theoretische Optik, Friedrich-Schiller-Universität, Max-Wien-Platz 1, 07743 Jena, Germany

Ab initio calculations of nanocrystals are still a demanding task. The ionic degrees of freedom have only recently become amenable to first-principle methods for larger crystallites because of the large computational requirements.[1] We use the projector augmented-wave (PAW) method in order to alleviate this problem. Excitation energies are calculated by means of a DSCF method.

The ionic relaxation is a twofold problem. First, there is the technical problem of finding reasonable model structures for the crystallites. Relaxation patterns of quasi-spherical Si crystallites are discussed. The second problem is the structural relaxation after electronic excitation, which results in a contribution to the Stokes shift. Model calculations of the Stokes shift are presented and discussed in the light of other results.[3,4] The inclusion of oxygen is computationally more demanding than H-terminated crystallites, requiring higher energy cut-offs. By means of our results we can explain redshift and blueshift found in measurements.[5,6] Oxidation causes a blueshift when the effective size of the crystallite is reduced.[7] On the other hand, -OH passivation causes a drastic closing of the gap.[7] We discuss the relaxed structure as well as the effects of the oxygen on the excitation energies and spectra.

[1] H.-Ch. Weissker, J. Furthmüller, and F. Bechstedt, Phys. Rev. B 67, 245304 (2003).

[3] H.-Ch. Weissker, J. Furthmüller, and F. Bechstedt, Phys. Rev. B (in press).

[4] A. Puzder et al., J. Am. Chem. Soc. 125 (9): 2786 (2003).

[5] A.A. Seraphin, E. Werwa, and K.D. Kohlenbrander, J. Mater. Res. 12, 3386 (1997).

[6] M.V. Wolkin et al., Phys. Rev. Lett. 82, 197 (1999).

[7] L.E. Ramos, J. Furthmüller, and F. Bechstedt, Phys. Rev. Lett. (submitted).

A1-VL7 18:10

OPTICAL BIREFRINGENCE IN MONO-DISPERSED SILICON NANOCRYSTALS PLANAR WAVEGUIDES

D. Navarro-Urrios, F. Riboli, N. Daldosso, L. Pavesi, INFN-Dipartimento di Fisica, Università di Trento, via Sommarive 14, 38050 Povo (Trento), Italy, C. Oton, Departamento de Física Basica, University of La Laguna, Avda. Astrofísica Fco. Sanchez s/n, 38204 La Laguna, Spain, L.X. Yi, R. Scholz, and M. Zacharias, Institute of Microstructure Physics, Max Planck Institute, Weinberg 2, 06120 Halle, Germany

In this work, we present a characterization of the waveguiding properties of a set of mono-dispersed silicon nanocrystal (NC) superlattices. The measured modal refractive indexes (obtained by the m-line technique) of different samples can only be explained by assuming a “form birefringence” of about 1% originated by the particular structure of the active core, i.e. a periodical set of parallel planes of two different material refractive indexes. By means of a simple model for the ordinary and extraordinary refractive indexes in this kind of structures, by making use of TEM images and of the nominal growth parameters and considering as free parameters both the upper limit of the diameter of silicon NC and the refractive index of the NC layers, we are able to fit the m-line measurements in a unique way. As a result we have obtained also a different procedure to estimate the NC size, which is consistent with the behaviour of the photoluminescence peak for the different samples. In comparison, a characterization of samples grown by ion implantation technique, i.e. samples not in a superlattice configuration, has also been made, and, as expected, they show a non-birefringent behaviour.

Gain measurements on mono-dispersed silicon nanocrystal superlattices waveguides will be reported, too.

A1-VL8 18:30

TUNABLE PHOTONIC BANDGAP STRUCTURES FOR OPTICAL INTERCONNECTS

S.M. Weiss, M. Haurylau, M. Molinari and P.M. Fauchet, Department of Electrical and Computer Engineering and The Institute of Optics, University of Rochester, Rochester NY, USA

Optical interconnects have begun replacing electrical wires in long distance, backplane applications. As their switching speed and efficiency improves, optical interconnects will penetrate deeper into the device architecture for inter- and intra-chip communications where direct integration with silicon microelectronics is a necessity. Tunable 1-D and 2-D silicon-based photonic bandgap structures are viable building blocks for optical interconnects because they have the capability to redirect light both in- and out-of-plane. In this work, we report on external modulation of the optical properties of 1-D and 2-D photonic bandgap structures made of porous silicon infiltrated with liquid crystals. Modulation can be accomplished in several ways and in this talk we will demonstrate tunability using various perturbations, including external electric field and temperature. This class of modulators offers an inexpensive and versatile way of integrating optical interconnects with standard microelectronic circuits. Some systems considerations will be discussed as well.

Thursday, May 27, 2004

Morning

Joint Session Symposium A1, A2: Silicon-based nanophotonics

Session Chair : P. Fauchet and A. Polman

- A1-A2/01** 08:30 -Invited- NANOENERGETICS, NANOMATERIALS, NANODEVICES, NANOCOMPUTING - PUTTING THE PIECES TOGETHER  
**G. Bourianoff**, Intel Corporation, USA  
The enormous growth of the communication industry has increased the demand for new photonic functionality at a low cost. For this purpose, it would be highly desirable to have light sources, waveguides, amplifiers, and detectors that are monolithically fabricated on Si with CMOS technology. The materials used in current CMOS integrated circuit technologies are chosen to optimize electronic performance. However, upon closer examination these materials are also suitable for producing, manipulating, and detecting optical signals. The unique properties of Si nanostructures such as nanoparticles and nanowires can be exploited to fabricate Si-based light sources and detectors. SiO<sub>2</sub> can be used to fabricate highly transparent optical waveguides and high Q micro-disk resonators. Metallic interconnects can serve as plasmonic waveguides that guide electromagnetic waves at optical frequency ("light") below the diffraction limit.  
To evaluate the use of deep submicron CMOS technology as a fabrication platform for integrated nanophotonic and plasmonic devices, our group is developing a laboratory-on-a-chip environment. On this platform we are fabricating and testing light emitting Si nanostructures, CMOS image sensors utilizing subwavelength metallic nanostructures, and plasmonic devices. Optical techniques, including scanning near-field optical microscopy are used to investigate the unique properties of these devices and study the fundamentals of light-matter interactions at the nanoscale.
- A1-A2/02** 09:00 -Invited- TOWARDS CMOS COMPATIBLE NANOPHOTONICS  
**M.L. Brongersma**, Stanford University, Geballe Laboratory for Advanced Materials, 476 Lomita Mall, Stanford CA 94305, USA
- A1-A2/03** 09:30 -Invited- PHOTONIC CRYSTALS BASED ON MACROPOROUS SILICON  
**U. Gösele**, S. Matthias and F. Müller, Max-Planck-Institut für Mikrostrukturphysik, Experimentelle Abteilung II, Weinberg 2, 06120 Halle/Saale, Germany  
An overview on 2-dim and 3-dim photonic crystals will be given based on electrochemical etching of silicon. It will be shown how new breakthroughs in electrochemical etching may also allow fabrication of large-scale 3-dim photonic crystals with a complete photonic band gap. A comparison with other techniques to fabricate photonic crystals will be given and various potential applications will be discussed.
- A1-A2/04** 10:00 -Invited- Si-BASED NANOPHOTONICS  
**S. Coffa**, ST Microelectronics, Catania, Italy

**A1-PII.1****SI BASED PHOTOLUMINESCENT MATERIALS FOR HIGH QUALITY FACTOR EMITTERS**

F. Mazen, J. Verbert, P. Noe, V. Calvo, E. Picard, E. Hadji, CEA/DSM/DRFMC/SP2M/SiNaPS, 17 avenue des martyrs, 38054 Grenoble cedex 9, France

In the framework of the active research on the fabrication of photonic devices with Silicon based technology, one of the main problems which still remains is the realization of an effective and reliable light emitter. In this work, we study different ways to produce Si based photoluminescent materials by evaporation. First, SiO<sub>x</sub> films, with x varying between 1.5 and 2 determined by RBS and FTIR, are obtained by electron beam gun evaporation of silicon under reactive oxygen atmosphere. The influence of process conditions on the photoluminescence properties of these layers are investigated: silicon evaporation rate, oxygen flow and post deposition annealing atmosphere and temperature. These SiO<sub>x</sub> layers are co-deposited with metallic erbium thermally evaporated. The characteristic band of erbium at 1.54 micrometer is observed at ambient temperature. We study the influence of x in SiO<sub>x</sub>, erbium concentration, measured by RBS, annealing temperature and annealing atmosphere on the photoluminescence intensity. The photoluminescence properties of SixNy layers, obtained by silicon evaporation under reactive nitrogen atmosphere, are compared to the SiO<sub>x</sub> ones. Finally, these materials are integrated in resonant devices providing optical confinement: photonic band gap material and microdisk resonator to achieve a high efficiency light source for optical devices and interconnects.

**A1-PII.2****THE FEATURES OF ER ELECTROLUMINESCENCE KINETICS IN SILICON STRUCTURES WITH ACTIVE LAYER POSITIONED RELATIVE TO SPACE-CHARGE REGION**

B. Andreev, Z. Krasil'nik, D. Kryzhkov, V. Kuznetsov, Institute for Physics of Microstructures RAS, N. Novgorod 603950, Russia, W. Jantsch, Institut für Halbleiter- und Festkörperphysik, Johannes Kepler Universität, Linz, Austria

Since more than ten years the investigation of Er in silicon is of great interest. Unfortunately, the intensity of PL and EL from RE-doped silicon reduces strongly due to nonradiative recombination upon temperature increase. For the overcome of the problem the more clear understanding of Er ions and electron subsystem interaction is necessary.

To clarify the role of electrically-active impurities and free carriers in the processes of Er-ions deexcitation we have produced and investigated for the first time n-Si/n-Si:Er/n-Si/p-Si structures with the Er-doped layer (70 nm) spatially separated (0,1 ? 1 ?m) from the p-n junction. Varying distance (D) between Er-doped layer and p-n junction we could change position of this layer with respect to the space-charge region. For the structure n-Si/n-Si:Er/n-Si/p-Si with the active layer located in the space-charge region kinetics of EL in the regime of forward and reverse bias has been investigated. For this structure dominating role of the Auger-process with participation of nonequilibrium free carriers in erbium ion deexcitation during the current excitation has been shown. During the experiments with the "positioned" layer at low temperatures (T~70K) we observed for the first time "delayed" Er<sup>3+</sup> ion EL when applying short (~10 ?s) reverse bias pulse long term (>100 ms) after the end of the exciting forward bias pulse.

The work was supported by RFBR 02-02-16773, FWF 13497 ? INTAS 01-0194.

**A1-PII.3****STRIPES OF 2D PHOTONIC CRYSTAL OBTAINED FROM MACROPOROUS SILICON**

E.V. Astrova, T. Borovinskaya, V.A. Tolmachev, Ioffe Physico-Technical Institute, St.Petersburg 194021, Russia, T.S. Perova, R.A. Moore, University of Dublin, Trinity College, Dublin 2, Ireland

New technological process has been developed to form pattern from macroporous silicon. Contrary to the previous technique [1], based on Si<sub>3</sub>N<sub>4</sub> protection, filling of the pores with polycrystalline silicon or Al, and photolithography from the face side of the wafer, the proposed technique does not require pore filling and planarisation of the surface, thanks photolithography from the backside of the wafer. Free standing stripes with vertical walls were prepared from macroporous silicon of 4 nm lattice period. The stripe width was about 90 nm (22-26 rows), its thickness 200nm (180nm porous layer + 20nm substrate). The method was applied to form the bars of 2D photonic crystals oriented in G-M and G-K directions in the inverse space of triangular lattice. These structures were characterized by FTIR microscopy. An interesting by-product of the developed process are oxide microtubes, which possess a strong photoluminescence at ~ 570 nm with excitation by green line (514 nm) of Ar+ ion laser. One of the possible applications of these tubes can possibly be a combinatorial chemistry, since a million transparent tubes arranged in a periodic array may be formed in a chip.

[1] S.Ottow, V.Lehmann, H.Foll. J.Electrochem. Soc. 143, 385 (1996).

**A1-PII.4****SI COMPATIBLE WAVEGUIDES FOR OPTICAL INTERCONNECTS**

Sebania Libertino(a), Antonella Sciuto(a), Roberto Oliveri(b), Gaetano Di Marco(c), Concetto Puglisi(d), Daniele Vitalini(d), (a)CNR – IMM sez. Catania, Stradale Primosole 50, 95121 Catania, Italy, (b)Dept. of Physics, Univ. of Palermo, Via Archirafi 36, 90123 Palermo, Italy, (c)CNR – IPCF sez. Messina, Via La Farina 237, 98123 Messina, Italy, (d)CNR – ITCP sez. Catania, Piazza Roma 2, 95125 Catania, Italy

The continuous shrinking of electronic devices and the requirements for higher speed and lower power consumption devices has forced the microelectronic community to ideate and develop new and faster intra-chip interconnects. Optical interconnects are considered a promising alternative to electrical ones and monolithic integration in Si is the only choice when high volumes, low fabrication costs and reduced spaces are needed. Aim of this paper is to present optical waveguides fully compatible with Si VLSI technology operating at both 1.55 um, the standard in optical fiber communication, and in the visible range, useful for inter-chip connections. To this purpose, we fabricated and tested waveguides using different materials: Si was used as core for waveguides operating in the near infrared (NIR), while various kinds of polymers, some of which were opportunely synthesized, were used to fabricate waveguides operating in both the IR and visible range. The waveguides were fabricated using epitaxial Si wafers as substrate and standard clean room processing. Opportunely calibrated reactive ion etching (RIE) processes were developed to pattern the polymers. The polymer films, deposited by spinning, were also characterized as a function of both the deposition parameters (i.e. polymer concentration in solution, spinning velocity) and the temperature processes, needed to remove the solvent and to study the effect of front-end processing on the waveguide. The glassing temperature was also defined and the optical properties variations determined. The waveguides were structurally characterized using both SEM and TEM measurements. Both the coupling and transmission optical losses were measured using the cut-back method. Examples of active device integration will also be provided.

**A1-PII.5****ELECTRICAL CONDUCTION MECHANISM IN ER-DOPED SRO FILMS FOR LED APPLICATIONS**

Monaco Mariantonietta, Salvatore Coffa, Maria Eloisa Castagna, STMicroelectronics, Si optoelectronics and post-Si technology, Corporate R&D, Stradale Primosole 50, 95121, Catania, Ital

In this work we report on the performances of efficient Si-based light sources consisting in a MOS structure with Er-doped SRO (Silicon Rich Oxide) as gate dielectric. These devices result the best candidate as Si-based light sources for integration of electrical-optical devices on Silicon. These sources show emission at 1540nm and an external quantum efficiency of 0.2% and the emitted power decreases when the Si excess in the film increases. The high stability and the reliability of the device are confirmed by measures of charge to breakdown.

We propose a model to describe the electrical conduction mechanism in a Silicon Rich Oxide film. The electrical characteristics can be fitted by a Schottky emission mechanism at low electrical fields and by a Space Charge Limited Conduction (SCLC) model for high electrical fields calculating the power coefficient, the interfacial barrier energy and the permittivity depending on the Si excess in the film. Data obtained from C-V measurements confirm the proposed model.

**A1-PII.6****THE ELECTRONIC AND OPTICAL PROPERTIES OF SILICON NANOCLUSTERS: ABSORPTION AND EMISSION**

Eleonora Luppi(a), Elena Degoli(b), G. Cantele(c), Stefano Ossicini(b), Rita Magri(a), D. Ninno(c), O. Bisi(b), O. Pulci(d), G. Onida(e), M. Gatti(e), A. Incze(e), R. Del Sole(d), (a)INFM-Research Center for nanoStructures and bioSystems at Surfaces(S3), Dipartimento di Fisica, Universita' di Modena e Reggio Emilia, via Campi 213/A, 41100 Modena, Italy, (b)INFM- Research Center for nanoStructures and bioSystems at Surfaces(S 3), Dipartimento di Scienze e Metodi dell'Ingegneria, Università di Modena e Reggio Emilia, via Allegrì 13, 42100 Reggio Emilia, Italy, (c)INFM and Dipartimento di Scienze Fisiche, Università di Napoli "Federico II", Compl. Univ. M. S. Angelo, Via Cintia, 80126 Napoli, Italy, (d)INFM, Dipartimento di Fisica dell'Università di Roma Tor Vergata, Via della Ricerca Scientifica, 00133 Roma, Italy, (e)INFM, Dipartimento di Fisica dell'Università di Milano, via Celoria 16, 20133 Milano, Italy

The optoelectronic properties of Si nanoclusters have been investigated through different ab-initio techniques (Pseudopotentials in ground and excited state, TDDFT,GW) as a function of size and symmetry.

The hydrogenated cluster has Td symmetry, nevertheless for excited-state configurations such symmetry is generally lost due to the occupation of excited energy levels. Therefore, for both the ground and excited state configurations, we have done the structural optimisation both by keeping and relaxing the constraint of Td symmetry; we have found that keeping the symmetry leads to wrong geometry and charge density. The presence of an electron-hole pair in the clusters causes a strong deformation of the structures with respect to the ground-state. The nature of the deformation changes: for small clusters it is strongly localized, while as the size increases the distortion is spread out over the entire structure. The structural modifications are reflected into the electronic structure. For the excited clusters the HOMO and LUMO become strongly localised in correspondence of the distortion, giving rise to defect-like states which reduce the gap; these effects are stronger in smaller clusters. We have calculated the Stokes Shift showing a dependence from the cluster size. The changes induced by the presence of oxygen atom at the surface of the cluster have been calculated. Three fundamental aspects come out: first, there is a strong interplay between structural and electronic properties. Second, a consistent explanation of emission processes can be carried out only if such excited configurations are accounted for. Third, optical gaps cannot be calculated simply as the HOMO-LUMO energy separation without introducing errors.

**A1-PII.7****COMPARISON OF GE NANOCRYSTALS IN SiO2 PRODUCED BY CVD AND MAGNETRON SPUTTERING**

Tom Leervad Pedersen, Jesper Skov Jensen, Pia Bomholt, Jacques Chevalier, John Lundsgaard Hansen, Arne Nylandsted Larsen, Brian Bech Nielsen, Rui Pereira, Institute of Physics and Astronomy, University of Aarhus, 8000 Aarhus C, Denmark and Ole Hansen, MIC- Department of Micro and Nanotechnology, DTU, 2800 Kgs. Lyngby Denmark

Nanocrystals have attracted considerable attention in recent years because of their potential applications as a light source in Si technology. Theoretically, Ge nanocrystals formed in SiO2 are expected to be more efficient than Si nanocrystals. In this study we have compared Ge nanocrystals produced both in PE-CVD deposited and magnetron sputtered SiO2 of thicknesses of about 500 nm, doped with Ge during deposition to concentrations between 4-20 at.%, followed by high temperature treatment at temperatures between 500 and 1200 C. The nanocrystals were structurally characterized by RBS and TEM, and the effects of annealing temperature and Ge contents on nanocrystal formation were investigated. Ge nanocrystals of 2-3 nm in diameter could be formed in both types of deposited SiO2 layers. Whereas a temperature of 700 C was sufficient in the case of a magnetron sputtered SiO2, a temperature of 1100 C was needed in the case of a PE-CVD deposited SiO2 layer. Furthermore, the optical activity of the Ge nanocrystals was studied by photoluminescence measurements.

**A1-PII.8****SITE OF ER IONS IN ER-IMPLANTED SILICA CONTAINING SI NANOCRYSTALS.**

C. Maurizio(a), F. D'Acapito(a), F. Priolo(b), G. Franzò(b), F. Iacona(c), E. Borsella(d), S. Padovani(e), P. Mazzoldi(e), (a)INFM-OGG European Synchrotron Radiation Facility, BP 220, 38043 Grenoble-Cedex, France, (b)INFM-Dipartimento di Fisica e Astronomia, Università di Catania, via S. Sofia 64, 95123 Catania, Italy, (c)CNR-IMM Catania, Italy, (d)UTS FIS-ENEA, Via E. Fermi 45, 00044 Frascati (Roma), Italy, (e)INFM and Dipartimento di Fisica, Università di Padova, via Marzolo 8, 35131 Padova, Italy

Erbium doping of Si nanocrystals (nc) has been recently recognized as a quite efficient method of obtaining 1.54 nm luminescence. Indeed, the excited nc preferentially transfer their energy to the Er ions which subsequently de-excite radiatively. Several points of this process are of extreme interest. In particular, the transfer of energy from the nanostructure to Er is much more efficient than direct photon absorption and luminescence intensities 2 orders of magnitude higher than for Er in SiO2 are observed. Therefore the introduction of Er ions in this system results in a strong coupling with the nc. Furthermore, the non-radiative de-excitation processes typically limiting Er luminescence in Si, namely Auger with free carriers and energy back-transfer, are strongly reduced in this case further improving the luminescence yield. All of these observation make this system extremely promising towards application in waveguide amplifiers. In this work the site of Er in silica containing Si nanocrystals is investigated. The Er ions are introduced into a sub-stoichiometric SiOx (x<2) matrix by ion implantation. The effect of different thermal annealings before and after the Er implantation is investigated, as well as the role of the implantation dose. The x-ray absorption spectroscopy (EXAFS), performed at Er LIII-edge shows that the Er site in the matrix strongly depends on the preparation conditions. Possible correlation between the local structure around Er and the luminescence of the investigated system is addressed.

- A1-P11.9** PHOTOLUMINESCENCE SPECTRA OF Si NANOSTRUCTURE FORMED ON THE (111) ORIENTED SILICON WAFER BY THE ION IMPLANTATION AND CHEMICAL ETCHING  
Z. Swiatek, E. Beltowska-Lehman, W. Baliga, Institute of Metallurgy and Materials Science, Polish Academy of Sciences, 30-059 Krakow, 25 Reymonta Str., Poland, I.M. Fodchuk, V.P. Makhniy, Chernivtsi State Univeristy, 274012 Chernivtsi, 2 Kotsyubynsky Str., Ukraine, A. Bonchuk, Institute of Applied Problems of Mechanics and Mathematics, 3B Naukova Str., 79060 Lviv, Ukraine  
 Photoluminescence spectroscopy and transmission electron microscopy were used to study of photoluminescence mechanism in Si nanostructure formed by chemical etching on the n+-type, (111)- oriented Si wafer with buried heavily damaged (BHD) thin layer. The BHG layer was produced by the ion implantation process of phosphorous at energy 180keV and at dose  $10^{15} \text{cm}^{-2}$  followed by thermal treatment in nitrogen atmosphere. The final nanostructure was formed by electroless chemical etching in solution containing concentrated HF, HNO<sub>3</sub> and same surface-active additives. We show that such nanocrystalline silicon thin film exhibits a room temperature photoluminescence at 1.8 - 3.4eV. On the basic of the results obtained, the model of structural changes in the near-surface layers of the Si wafer after applied technological processes as well as the mechanisms of the elementary bands in photoluminescence spectra are discussed.
- A1-P11.10** QUASI-MONOSIZED Si NANOCRYSTAL ARRAYS: QUANTUM CONFINEMENT AND DOPING  
 J. Heitmann, V. Talalaev, T. Lu, R. Scholz, and M. Zacharias, Max Planck Institute of Microstructure Physics, Halle, Germany  
 Dense packed, size controlled Si nanocrystals are prepared by phase separation of SiO/SiO<sub>2</sub> superlattices. The crystal size can be controlled in the range from 2 to 5 nm. The resulting Gaussian shaped nanocrystal size distributions show a deviation from the average size of only  $\pm 0.2\text{-}0.4$  nm. The Si nanocrystal based luminescence is clearly related to quantum confinement as can be shown by a blueshift of the luminescence signal from 950 to 750 nm, the appearance of Si phonon related structures in the resonant excited luminescence signal and the breakdown of the k-conservation rule with decreasing crystal size. The crystal size dependence of the different optical properties differ quantitatively from similar systems and theory. The combination of quantum confinement and exciton migration in the dense arranged nanocrystal array can explain the size and temperature dependence of the different optical properties.  
 Additionally, the energy transfer from the Si nanocrystals to co-doped erbium ions is demonstrated and the role of the exciton migration for this transfer process is discussed. First results on phosphor doping will be presented.
- A1-P11.11** TOWARDS CONTROLLABLE OPTICAL PROPERTIES OF SILICON BASED NANOPARTICLES FOR APPLICATIONS IN OPTO-ELECTRONICS  
E. Trave, V. Bello, F. Enrichi, G. Mattei, INFN, Dipartimento di Fisica, Università di Padova, Via Marzolo 8, 35131 Padova, Italy, E. Borsella, M. Carpanese, C.R. ENEA di Frascati, Via E. Fermi 45, 00044 Frascati (Roma), Italy, M. Falconieri, C.R. ENEA di Casaccia, Via Anguillarese 301,00060 Roma, Italy, C. Abate, Dipartimento di Scienze e Tecnologie Chimiche, Università di Roma "Tor Vergata", Via O. Raimondo 18, 00173 Roma, Italy, N. Herlin-Boime, K. Jursiokova, Laboratoire Francis Perrin (CEA-CNRS URA 2453), Services des Photons, Atome et Molécules, DSM, CEA Saclay, 91191 Gif sur Yvette Cedex, France, F. Costa, L. Costa, L. Gini, Novara Technology S.r.l., Via G. Fauser 4, 28100 Novara, Italy  
 The realization of Si-based nanostructures has received a great attention from the material research community due to their unique, size-dependent optical properties. In particular, the appearance of a strong visible photoluminescence (PL) even at room temperature makes this kind of material very interesting for applications towards optoelectronic devices. Here we present results on the possibility to control the optical properties of Si-based nano-powders by fine tuning of both preparation and processing parameters in order to realize size controlled nanostructures. Si-based nanopowders were prepared by CO<sub>2</sub> laser pyrolysis of gas-phase precursors followed by thermal annealing in controlled atmosphere. After the optical and structural characterization, the nano-powders were dispersed by several methodologies and incorporated in a silica sol-gel matrix. Potential applications in opto-electronics of Si-based nanostructures embedded in film or bulk glasses sol-gel are strictly related to the preservation of their optical and structural properties after the fabrication of the nanocomposite material. To this purpose we have focused our attention on the study of the dependence of the optical properties of Si-nanopowders from the synthesis and processing parameters as well as on the effect of inserting the powders in a sol-gel matrix. Moreover, a study of 1.54 micron Er emission sensitizing effect from Si-based nanostructures in sol-gel glasses is presented.
- A1-P11.12** ON-CHIP POROUS SILICON HOLLOW OMNIGUIDE STRUCTURES  
J. Volk, N. Nagy, É. Vázsonyi, A. Hámori and I. Bársony, Research Institute for Technical Physics and Materials Science MFA, Hungarian Academy of Sciences, Konkoly-Thege 29-33, 1121 Budapest, Hungary  
 The hollow waveguides have two main advantages over the conventional index-step waveguides: the guided mode-spectrum is continuous (omniguide) and the loss can be significantly lowered. In this work novel integrated hollow omniguide structures are proposed by the use of porous silicon multilayer stacks as cladding. The air-core rectangular shape silicon waveguides were fabricated by preparing omnidirectional porous silicon multilayer (PSM) mirrors. The fabrication sequence includes the following main steps: Grooves of square cross section were formed first in the p-type Si substrate by using polishing etch. They constitute later the core of the hollow waveguide. Porous silicon multilayer formation was then carried out on this structure forming the Bragg mirrors on the bottom and the sidewalls of the groove, while the top surface outside the groove area was masked by silicon nitride. The processed wafer was subsequently bonded to another wafer covered by the nominally same PS multilayer stack formed previously on the whole surface. In this way we obtained embedded air-cores flanked by omnidirectional PSM mirrors all around. The cleaved hollow waveguides were investigated by a NIR laser ( $\lambda = 1.24 - 1.54 \mu\text{m}$ ) source in a goniometric arrangement. Mode-spectra were recorded at TE and TM polarisation and the losses of omniguide structures having different core-widths ( $2 - 50 \mu\text{m}$ ) were compared.

**A1-PII.13**

DETERMINATION OF EFFECTIVE ABSORPTION CROSS SECTION OF ERBIUM IN SiO<sub>2</sub> FILMS CONTAINING nc-Si  
C.-C. Kao, L. Bigot, A.-M. Jurdyc, B. Jacquier, B. Gallas, S. Fisson, G. Vuye, J. Rivory, Laboratoire d'optique des solides, Université Paris 6, CNRS-UMR 7601, 4 Place Jussieu, 75252 Paris Cedex 05, France

Erbium doped silica glass is widely used in telecommunication as an optical amplifier medium around 1.53  $\mu\text{m}$ . However, the Er<sup>3+</sup> optical cross sections of intra-4f transitions are quite small, restricting applications of this material to heavily-doped materials. The presence of silicon nanocrystals (nc-Si) in SiO<sub>2</sub> provides high absorption efficiency of the pumping source at energies above the fundamental gap of the nc-Si and an enhancement of the Er emission at 1.53  $\mu\text{m}$  which is attributed to an energy transfer from nc-Si to Er<sup>3+</sup> ions. Here we present an evidence of this energy transfer and an evaluation of the effective absorption cross section of Er.

SiO<sub>x</sub>(Er) films were co-evaporated under reactive O<sub>2</sub> atmosphere from SiO and metal Er sources by two electron guns on Si substrates and then thermally annealed under vacuum and N<sub>2</sub> to obtain nc-Si and active Er<sup>3+</sup> ions in SiO<sub>2</sub>. Photoluminescence (PL) measurements were performed using an Ar Laser with an excitation of 457 nm. Two PL bands peaking at around 0.8 and 1.53  $\mu\text{m}$ , corresponding to nc-Si and Er<sup>3+</sup>, were observed. On some samples the nc-Si were oxidized by thermal annealing under O<sub>2</sub> atmosphere. By comparing the intensities of the Er PL band before and after oxidation, we could infer that the Er<sup>3+</sup> ions were mainly excited by the energy transferred from the nc-Si. The effective absorption cross section was determined both by measuring the variation of the PL intensity and dynamics with the photon flux. An effective cross section of around 10-19 cm<sup>2</sup> was found (i.e., two orders of magnitude larger than without nc-Si). The results of these two methods will be compared. The influence of the growth conditions and annealing sequence on the effective absorption cross section of Er will be presented.

**A1-PII.14**

A SILICON BURIED WAVEGUIDE FOR PLANAR OPTOELECTRONIC DEVICES

Giuseppe Coppola, Mario Iodice, Cristian Rocco Zaccuri, Ivo Rendina, Istituto per la Microelettronica e Microsistemi Consiglio Nazionale delle Ricerche, Via P.Castellino 111, 80131 Napoli, Italy

Interest in silicon as a material for optoelectronics has increased year after year. Modern micromachining technologies are paving the way for the use of silicon motherboards as submounts for the assembly of lasers, photodetectors, and switches, which have to be cost effectively aligned to monomode fibers for hybrid photonic integrated circuits. The newest generation of photonic integrated circuits also provides on-chip optical waveguides for interconnection among active devices and improvement of optical coupling to monomode fibers, for instance, by means of tapered terminations.

In this paper, we present a new silicon planar buried waveguide suitable for the realization of planar optoelectronic devices. The optical confinement is obtained by means of an ion implantation and controlling the depth of the implant. In particular, the implant depth is greater in the central region rather than in the later region of the waveguide. The implant implies a reduction of the refractive index of the silicon layer and as consequence a confinement of the optical wave is obtained in the central region. In full paper a detailed description of the technological steps required for the waveguide realization will be discussed. Moreover, both simulations on the optical behaviour of the waveguide and propagation loss estimation as function of implantation parameters will be report.

**A1-PII.15**

1D PHOTONIC CRYSTAL FABRICATED BY WET ETCHING OF SILICON

V.A. Tolmachev, E.V. Astrova, J.A Pilyugina, Ioffe Physico-Technical Institute, St.-Petersburg, Russia, T.S. Perova, R.A. Moore and J.K. Vij, University of Dublin, Trinity College, Dublin 2, Ireland

Usually, 1D Photonic Crystals (PCs) are formed by multilayered structures with modulation of the refractive index in the vertical direction. Periodic arrays of vertical Si walls and deep grooves prepared by wet anisotropic etching of (110) Si act as 1D PC for the light propagating perpendicular to the Si walls or, in the other words, to the light flow in the plane of Si substrate. Using this technique a number of periodically grooved Si structures with small lattice constants ( $\sim 110:2$  nm), has been fabricated. Digilab 6000 FTIR spectrometer in conjunction with a UMA 500 IR microscope have been used to reveal the photonic band gaps (PBG) in the middle IR range of spectrum. The wide regions of high reflection and consequent low transmission from experimental spectra are in a good agreement with the results of simulation. Grooved Si is an attractive material for monolithic integration since a number of different photonic elements (micro-cavities, coplanar wave-guides, optical filters and modulators, etc.) can be fabricated on its base. A considerable advantage of these PBG devices is the high contrast of the refractive index. This gives possibility to obtain wide PBGs with sharp edges for structures with the low number of periods. The presence of the air space in combination with the high refractive index contrast makes grooved Si a suitable matrix for fabrication of composite 1D PCs by filling the grooves with a variety of substances.

**A1-PII.16**

OPTICAL GAIN AND STIMULATED EMISSION IN SI-BASED QUANTUM DOTS

M. Jo(a), N.Yasuhara(a), and K. Kawamoto(a) and S. Fukatsu(a,b), (a)Graduate School of Arts and Sciences, The University of Tokyo, Komaba, Meguro, Tokyo 153-8902, Japan, (b)PRESTO, Japan Science and Technology Corporation (JST), Kawaguchi, Saitama 332-0012, Japan

Optical gain of interband radiative recombination and the associated stimulated emission have been observed in a new class of Si-based quantum dots (QDs) created by embedding III-V compounds in Si.

Self-assembled GaSb-QDs of a few tens of nm were grown by molecular beam epitaxy on Si(001). Inhomogeneously broadened luminescence band of GaSb-QDs covers the near-infrared of technological importance, 1.1 – 1.7  $\mu\text{m}$ . Although theoretically indirect in both k-space and real-space, strong localization of electrons at the GaSb/Si interface due to the built-in electric dipole allows an enhanced immunity against dissipation as well as admixed electron wave function. In fact, record quantum efficiency of electroluminescence more than 0.3% was obtained. Single path gain was measured in such a way that spontaneous emission from a signal section was coupled to a second section under intense, Q-switched laser pulses and edge-emitting light coupled out of the second section was monitored. Net gain was observed only at low temperature: With increasing temperature, the gain quickly rolled off and only loss was observed above 20K. No net gain could be observed for either allied III-V QDs, such as InAs, GaAs, and InSb or SiGe. The gain spectra extending over 1.1-1.3  $\mu\text{m}$  varied with increasing temperature so that the lower energy wing is significantly diminished. Stimulated emission was found to always accompany optical gain, confirmed as a quick initial decay with a wavelength dispersion unique to interface-localized carriers. Where net optical gain was totally absent, the decay was only very slow in the sub-ms range. A possible population inversion model taking account of such interface-localized electron-hole pairs will be demonstrated.

- A1-P11.17** ERBIUM-SILICON-OXIDE NANO-CRYSTALLITE WAVEGUIDE FORMATION BASED ON NANO-POROUS SILICON  
T. Kimura, K. Ueda, R. Saito, K. Masaki and H. Isshiki, Department of Electronic Engineering, Univ. of Electro-Communications, Tokyo 182-8585, Japan  
 Optical active waveguide devices based on silicon are important for opto-electronic integration and the optical communication system. Recently electrically excitable Er-Si-O nano-crystallite on silicon and the good optical performance has been demonstrated by wet chemical synthesis using ErCl<sub>3</sub>. However, there is a practical difficulty for the device applications of the Er-Si-O nano-crystallite since the thin film or bulk has not yet been obtained. Optical doping of rare earth ions into porous silicon (PS) has been successfully realized and the good optical properties have been reported. In this paper, fabrication of active optical waveguide devices by using incorporation of the Er-Si-O nano-crystallite into nano-PS is demonstrated. PS samples were prepared by anodic etching process on n-type Si (100) wafers with a resistivity of 0.03 Ω·cm in a solution of 48% HF: Ethanol=1:1. The refractive index can be controlled from 3.4 to 2.6 by changing pore diameter between 9 and 24 nm. ErCl<sub>3</sub>/ethanol solution was poured into the double-layered PS by immersion liquid method. Two step annealing process to obtain the Er-Si-O nano-crystallite was carried out for the sample at 900°C for 4 min in O<sub>2</sub> and at 1200°C for 3 min in Ar respectively. An intense PL emission peak at 1.532 μm with a full width at half maximum (FWHM) of 15nm, which is related to Er<sup>3+</sup> ions, is observed. The PL intensity decreases with increasing temperature and the room temperature intensity is about one third of the low temperature intensity.
- A1-P11.18** NEAR BAND GAP ABSORPTION OF Si NANOCRYSTALS IN SiO<sub>2</sub> INVESTIGATED BY SPECTROSCOPIC ELLIPSOMETRY AND PHOTOTHERMAL DEFLECTION SPECTROSCOPY  
L. Siozade, I. Stenger, B. Gallas, C.C. Kao, S. Fisson, G. Vuye, J.Rivory, Laboratoire d'optique des solides, Université Paris 6, CNRS-UMR 7601, 4 Place Jussieu, 75252 Paris Cedex 05, France  
 Si nanocrystals (Si-nc) embedded in a SiO<sub>2</sub> matrix have been extensively studied because of their applications in Si-based optoelectronic devices. The effect of the quantum confinement on the critical points positions has been numerically calculated, generally without taking excitonic, matrix and interfaces effects into account. Photoluminescence (PL) measurements have revealed a blue shift of the luminescence peak of Si-nc diluted in SiO<sub>2</sub> when decreasing the size of the nc-Si. The near band gap absorption and the critical points positions have been measured previously by Spectroscopic Ellipsometry (SE) in the case of porous Si [1]. Indeed, this technique is very efficient to investigate the critical points for strong absorption values (extinction coefficient  $k > 10^{-2}$ ). However, for low absorption values, in particular for materials diluted in a matrix in thin films, an additional technique is required. SiO<sub>x</sub> films (1 < x < 2), approximately 0.4 μm thick, have been elaborated by electron-gun evaporation. A thermal annealing of these films induced a phase separation leading to the formation of Si-nc embedded in a SiO<sub>2</sub> matrix. These films have been studied by PL, SE and Photothermal Deflection Spectroscopy (PDS) measurements. The effective dielectric function of the thin films has been extracted from SE data in the 1.6 eV to 6.5 eV range. PDS measurements allowed us to reach lower absorption values in the spectral range from 0.8 eV to 3 eV. The shift of the absorption edge will be presented as a function of the composition x. In particular, the position of the band edge will be compared with the position of the PL band.  
 [1] U. Rossow, U. Froscher, C. Pietryga, D.E. Aspnes, W. Richter, Appl. Surf. Sci. 104-105, 552 (1996)
- A1-P11.19** CHARACTERISATION OF ROOM TEMPERATURE BLUE EMISSION Si/SiO<sub>2</sub> MULTILAYERS  
M. Modreanu, NMRC, Lee Maltings, Prospect Row, Cork, Ireland, E.Aperathitis, M. Androulidaki, IESL-FORTH, Heraklion, Crete, Greece, M. Audier, O. Chaix, LMPG-INPG, Grenoble, France  
 In this study we report results on a series of Si/SiO<sub>2</sub> multilayers periods deposited by standard CMOS processes on thermally oxidised Si substrates. Each period was formed by an ultrathin silicon thin film (around 15nm in thickness) obtained by low-pressure CVD at T=625°C and a SiO<sub>2</sub> thin film (around 70nm in thickness) obtained by atmospheric pressure chemical vapour deposition at T=400°C. High-resolution TEM (HRTEM), FTIR and Raman spectroscopy have been used for the physical characterisation of the Si/SiO<sub>2</sub> multilayers. The HRTEM analysis revealed a columnar structure, with an average grain size of 15nm for the silicon layers. The Si - SiO<sub>2</sub> interfaces were smooth with a surface roughness for silicon layers less than 1 nm, as estimated from HRTEM analysis. IR spectroscopy shows the presence of SiO<sub>x</sub> structural entities in each Si/SiO<sub>2</sub> interface. Raman measurements demonstrate that the nanocrystalline silicon (nc-Si) layers are free-of-stress. Room temperature photoluminescence (PL) spectra, obtained by using a 325nm laser excitation, showed a broad blue peak centred on 430nm. The intensity of the blue PL band increased with the number of periods in the nc-Si/SiO<sub>2</sub> multilayers. The origin of these intense room temperature blue PL band is discussed. It has been proposed that its origin is related to PL centers within the core of the Si grains or from the Si-SiO<sub>2</sub> interface.
- A1-P11.20** AGING PROCESSES OF Si-RICH/SiO<sub>x</sub> SYSTEMS  
 M. Baran(a), N. Korsunsk(a), L. Khomenkova(a), Y. Goldstein(b), E. Savir(b), J. Jedrzejewski(b), (a)Institute of Semiconductor Physics, National Academy of Sciences of Ukraine, 45 Prospect Nauky, Kyiv 03028, Ukraine, (b)Racah Institute of Physics at Hebrew University Givat Ram, 91904 Jerusalem, Israel  
 The properties of magnetron sputtered and annealed at 1100 C Si-rich/SiO<sub>x</sub> systems are studied by photoluminescence (PL), EPR, infrared absorption (IRA) and Raman scattering methods after preparation and during aging in ambient air. PL spectra of as-prepared samples contain one broad infrared band. Raman scattering spectra show the presence of quantum confinement Si crystallites. EPR spectra contain the signal from Si dangling bonds. IRA spectra show that the oxide matrix is SiO<sub>x</sub> with x~1.8. During aging infrared band intensity increases and its maximum shifts to high energy sides as well as some additional PL bands at 1.7 eV, 2.06 eV and 2.32 eV appear. At the same time Raman scattering spectra show the decrease of Si crystallite sizes. In EPR spectra the signals from Pb-centers and EX ones appear. The latter are oxygen excess defects that were observed earlier in high-temperature oxidized silicon wafers. The decrease of Si crystallite sizes and appearance of EX-centers during aging allow to conclude that oxidation of Si crystallites occurs. This is confirmed by IRA spectra that show the increase of low-energy components of Si-O vibration band (940-1040 cm<sup>-1</sup>) that is explained by increase of silicon suboxide contribution. At the same time the absence of the increase of intensity of high-energy components of Si-O vibration band gives the evidence that essential additional oxidation of silicon oxide matrix does not occur during aging.

**A1-PII.21****OPTICAL GAIN IN a-SiNx:H<Nd>**

Leandro R. Tessler and Daniel Biggemann, IFGW, Unicamp, Campinas, Brazil

We report optical gain measurements in neodymium-doped amorphous hydrogenated silicon sub-nitride (a SiNx:H<Nd>) planar waveguides. Samples (~2 micron thick) were prepared by reactive rf-sputtering from a silicon target partially covered by metallic neodymium platelets using an Ar + N2 + H2 atmosphere. The substrates are oxidized <100> silicon wafers that are cleaved to define highly parallel flat waveguide faces.

At low temperatures, the photoluminescence spectrum measured at the waveguide edge shows an increased and narrowed peak at 1127 nm when compared with the spectrum taken in the direction of the guide top surface. The guided signal presents supralinear intensity dependence and an optical gain in excess of 100 cm<sup>-1</sup> was determined using the variable slit method exciting with the 488 nm line of an Ar+ laser at ~0.2 MW/cm<sup>2</sup>. The photon energy of this line is not resonant with any of the Nd<sup>3+</sup> transitions, indicating that the excitation is efficiently transferred from the host to the rare earth ions. This result indicates that a SiNx:H<Nd> can be used as an active optical medium.

**A1-PII.22****TIME-RESOLVED PHOTOLUMINESCENCE IN a-SiNx:H<Nd> PLANAR WAVEGUIDES: EVIDENCE FOR STIMULATED EMISSION**

Daniel Biggemann and Leandro R. Tessler, IFGW, Unicamp, Campinas, Brazil

We performed lifetime measurements on the 1127 nm Nd<sup>3+</sup> emission of a neodymium-doped amorphous hydrogenated silicon sub-nitride (a SiNx:H<Nd>) planar waveguide. The 2 μm thick sample was prepared by reactive rf-sputtering.

Lifetime measurements were done exciting with the modulated 488 nm line of an Ar+ laser, with a risetime of less than 5 microseconds, and detecting using a monochromator and an InGaAs receiver (response time of 1 microsecond) connected to a digital oscilloscope. The sample temperature was varied between 25 and 300K, and the excitation power between 200 and 4000 mW. In all measurement conditions the luminescence decay can be expressed by two exponentials. The fast decay has a lifetime between 40 and 60 microseconds, and the slow decay has a lifetime between 1 and 3 milliseconds. The excitation photon energy is not resonant with any of the Nd<sup>3+</sup> transitions, as a result the excitation energy must be transferred from the host nitride to the Nd<sup>3+</sup> ions. The fast lifetime is shorter for high temperatures and high excitation powers, indicating that it is related to the excitation transfer process. As the temperature increases the probability of carrier recombination through processes that do not excite Nd<sup>3+</sup> ions increases. The slow lifetime is associated with the intrinsic Nd<sup>3+</sup> lifetime. It is shorter at low temperatures. At 25K, it decreases by a factor 2 when the excitation power goes from 500 to 4000 mW. The lifetime decrease with the excitation power is associated with the onset of stimulated emission.

**A1-PII.23****GROWTH AND STRUCTURAL CHARACTERISATION OF Si/SiGe HETEROSTRUCTURES FOR OPTOELECTRONIC APPLICATIONS**

X.B. Li(a), J.H. Neave(a), D.J. Norris(b), D.J. Paul(c), R.W. Kelsall(d) and J. Zhang(a), (a)Department of Physics, Imperial College London, U.K., (b)Dept. of Electronic & Electrical Eng., University of Sheffield, U.K., (c)Cavendish Lab., University of Cambridge, U.K., (d)Institute of Microwaves and Photonics, University of Leeds, U.K.

The use of SiGe in optoelectronic device structures often places strict requirements on the epitaxial growth process such as precise control of thickness, composition, repeatability as well as strain through the structure. SiGe virtual substrates are often used as templates for strain-balanced structures in order to achieve large active volume (thickness), while keeping the heavily strained individual layers pseudomorphic to the virtual substrate template.

In this contribution, the optimisation of the growth conditions for strain balanced structures is described. The grown structures are characterised by X-ray diffraction reciprocal space mapping, atomic force microscopy and transmission electron microscopy. The experimental findings demonstrate that correct design of the structure of the compositionally graded buffer in the virtual substrate is one of the essential requirements for achieving a totally strain-relaxed virtual substrate providing a template. Other growth conditions also have a strong influence on the surface morphology, lattice tilt and range of lattice tilts in the virtual substrate. Precise strain balance and control of the growth conditions is also a necessity for maintaining the pseudomorphic structure above the virtual substrate. When optimal conditions are met, strain-balanced superlattice large Ge concentration differences and total thickness in excess of 4microns can be fabricated using combination of LPCVD and GSMBE.

**A1-PII.24****PHOTOLUMINESCENCE YIELD OF Si-rich-SiO2/SiO2 MULTILAYERS FABRICATED BY REACTIVE MAGNETRON SPUTTERING**

F. Gourbilleau, C. Ternon, C. Dufour, R. Rizk. SIFCOM, UMR CNRS 6176, Ensicaen, 6 Bd Maréchal Juin, 14050 Caen Cedex, France, O. Guillois, C. Reynaud, Service des Photons et Molécules, CEA- Saclay, 91191 Gif/Yvette Cedex, France

Si-rich-SiO2(SRSO)/SiO2 multilayers have been fabricated by reactive magnetron sputtering of a pure SiO2 target, using alternatively a plasma of pure argon and a mixture of argon and hydrogen. The presence of hydrogen favours the incorporation of excess silicon in the sublayer through reduction of the oxygen originated from the sputtered silica target. After annealing, the microstructure of the films was examined by infrared spectroscopy, Xray reflectometry, electron microscopy and the surface has been analyzed by atomic force microscopy. A perfect alternation of the SRSO and the SiO2 sublayers was evidenced. Photoluminescence measurements were carried out by means of a 266-nm excitation line from a pulsed YAG laser on multilayers with two different SRSO thicknesses and three different periods. By means of a refined experimental approach, the luminescence yield of a SRSO layer was determined. The time resolved PL spectra obtained at different emission energies follow a stretched exponential law. The emission lifetime increases from 100 ms to 300 ms for energies ranging between 2.0 eV and 1.5 eV, for a coefficient  $b \gg 0.65$ .

- A1-PII.25** INFLUENCE OF TEMPERATURE AND HYDROGEN RATE ON SILICON INCORPORATION IN SILICA FILMS OBTAINED BY REACTIVE MAGNETRON CO-SPUTTERING  
S. Chausserie, N. Khalfaoui, C. Dufour, R. Rizk and F. Gourbilleau, SIFCOM-ENSICAEN 6 Bd maréchal JUIN, 14050 Caen, France  
 Silicon-rich silicon oxide layers were deposited by reactive magnetron sputtering of a pure silica target. The main purpose was to understand how the different deposition parameters affect the Silicon incorporation. The excess silicon integrated in the films was on the one hand monitored by the hydrogen rate ( $RH=pH/(pH+pAr)$ ) introduced in the plasma, owing to the ability of hydrogen to reduce the oxygen released from the sputtering of the silica target and on the other hand by the substrate temperature. The silicon incorporation determined via the refractive index using ellipsometry and optical transmission was seen to increase as the temperature rose from 400°C to 700 °C and with the hydrogen rate. At low temperature and low hydrogen rate, the refractive index stands at 2.1 while for the highest RH and temperature the index approaches 3.1. Infrared spectroscopy confirmed the incorporation of excess silicon and microstructural studies determined whether the latter was crystalline or amorphous. Studies using Atomic Force Microscope on tapping mode revealed firstly that the unevenness of the film surfaces depended on the various deposition conditions, and secondly brought out the surface composition of those films thanks to phase contrast imaging. Those results led to the development of multilayers which exhibit luminescence in the visible range.
- A1-PII.26** OPTICAL PROPERTIES OF POLY(VINYL-ALCOHOL) BASED THIN FILMS FOR MICROPHOTONICS  
Paula Obreja(a), Alexandru Obreja(b), Dana Cristea(a), Elena Budianu(a), (a)National Institute for Research and Development in Microtechnologies, Bucharest, Romania, (b)Policolor, Bucharest, Romania  
 Poly (vinyl-alcohol) (PVA) is a photocrosslinkable polymer (UV i-line) used as dichromated resist, biomedical hydro gels or holographic material. The paper presents experimental results concerning the influence of the additives from a solution of the PVA on optical properties of the polymer. The refractive index of the poly(vinyl-alcohol) was modified through the addition inorganic/organic materials and showed values between 1.4-1.65 (depending on the compositions and the curing conditions of the polymer) and the transmittance showed values above 80%. The additives we used were metal oxides/inorganic salts or other vinyl-polymers.  
 The composition and the deposition processes were optimized to allow a better control of the optical parameters (refractive index, transmission), to reduce the processing temperatures and to improve photosensitivity. These new light-sensitive compositions can be easily spin coated onto variety of semiconductor substrates, and directly patterned. The process for channel waveguides fabrication was developed and experimented.
- A1-PII.27** LOW LOSS SILICA WAVEGUIDES CONTAINING SI NANOCRYSTALS  
C. García, B. Garrido, P. Pellegrino, J.A. Moreno, M. López, J.R. Morante, EME, Departament d'Electrònica, Universitat de Barcelona, Martí i Franquès 1, 08028 Barcelona, Spain, N. Daldosso, M. Melchiorri, L. Pavesi, INFN and Department of Physics, Università di Trento, Via Sommarive 14, 38050 Povo (Trento), Italy, E. Scheid, G. Sarrabayrouse, Laboratory for Analysis and Architecture of Systems of CNRS, 7 Avenue du Colonel Roche, 31077 Toulouse, France, N. Cherkashin\*, C. Bonafos, CEMES/CNRS, 29 rue J. Marvig, 31055 Toulouse Cedex 04, France, P. Marie, F. Gourbilleau, R. Rizk, LERMAT-ISMRA, 6 Boulevard Maréchal Juin, 14050 Caen, France  
 \*on leave from Ioffe Physico-Technical Institute, St.Petersburg, Russia  
 We present a thorough study on the optical and structural properties of rib-loaded silica waveguides containing Si nanocrystals, including optical losses and pump & probe measurements. A quadruple implantation of Si ions was performed into a 2 (m-thick thermally-grown SiO<sub>2</sub> layer. The thickness of the resulting flat-profile active region was about 300 nm, with Si excess ranging from 7% to 13% (determined by X-ray photoelectron spectroscopy). Complete phase separation and nanocrystal formation was assured by annealing at 1100°C, and studied by means of optical tools such as Raman, optical absorption and luminescence. Grain size distribution was determined by transmission electron microscopy (TEM) and m-lines spectroscopy (at 632 nm) was used to determine the thickness and refractive index the active region. Spectroscopic ellipsometry measurements (from 1.5 to 5.0 eV) were also performed and the application of a Bruggeman effective medium approximation allowed us to obtain the complex refractive index of the nanocrystals, showing an important quantitative reduction in comparison to that of the bulk and amorphous Si. The rib-loaded structure of the waveguides was fabricated by photolithographic and reactive ion etching processes, with patterned rib widths ranging from 1 to 8 (m. Efficient light propagation was observed when end-fire coupling a probe signal both at 633 nm and 780 nm into the waveguides, with attenuation losses as low as 11 dB/cm in the red. An increase of losses has been observed and explained as a function of the rib width and the mechanisms involved in these losses (scattering and absorption) have been evaluated and discussed. Pump & probe experiments at 780 nm are under-way and will be also presented and discussed.
- A1-PII.28** STUDY OF THE ENERGY TRANSFER MECHANISM IN AN ALUMINOSILICATE GLASS CO-DOPED WITH SI NANOAGGREGATES AND ER<sup>3+</sup> IONS  
F. Enrichi , G. Mattei, C. Sada, E. Trave, INFN, Dipartimento di Fisica, Università di Padova, via Marzolo 8, 35131 Padova, Italy, D. Pacifici, G. Franzò, F. Priolo, INFN-MATIS, Dipartimento di Fisica e Astronomia, Università di Catania, via S. Sofia 64, 95123 Catania, Italy, F. Iacona, CNR-IMM, Stradale Primosole 50, 95121 Catania, Italy, M. Prassas, Advanced Materials for Photonics, Corning SA, 7 bis Avenue de Vilvins, Avon, France, M. Falconieri, ENEA, via Anguillarese 301, 00060 Casaccia (ROMA), Italy, E. Borsella, ENEA, via E. Fermi 45, 00044 Frascati (ROMA), Italy  
 Incorporation of Si-nc in Er doped silica is known to strongly enhance the infrared luminescence of Er<sup>3+</sup> at 1.54µm as a consequence of an energy transfer process. In this work we investigate the formation of Si nano-aggregates and their role in the energy transfer process to Er<sup>3+</sup> ions for a multi-component aluminosilicate glass host. This material can offer better performances than silica in terms of Er solubility and band broadness for integrated Er-doped optical amplifiers. Si and Er were co-implanted in the glass and post implantation thermal treatments were performed to promote Si aggregation. Our results based on Energy Filtered TEM suggest that good energy transfer mediators could be small Si aggregates and not only crystalline clusters. The most intense Er<sup>3+</sup> PL emission at 1.54 µm was achieved after a thermal treatment at 400°C. Such emission was investigated by continuous and pulsed laser pumping in and out of resonance, showing a very efficient energy transfer process in the whole excitation wavelength range 360 &#61624; 515 nm. The effective Er excitation cross section was measured to be higher than 10-17 cm<sup>2</sup> at 379 and 390 nm and about 2 &#61655; 10-16 cm<sup>2</sup> at 476 nm. The coefficient of cooperative upconversion was evaluated to be 2.7 &#8729; 10-18 cm<sup>3</sup> s-1. The structural and optical properties of this material were deeply investigated and compared to those found for Si and Er co-doped silica.

- A1-PII.29** WAVE FUNCTION ENGINEERING IN W DESIGNED STRAINED-COMPENSATED Si/Si<sub>1-x</sub>Ge<sub>x</sub>/Si TYPE II QUANTUM WELLS FOR 1.55  $\mu$ m OPTICAL PROPERTIES  
 N. Sfina(a), J.-L. Lazzari(b), F. Ben Zid(a) and M. Said (a), (a) Unité de Physique des Solides 99/UR/13-19, Département de Physique, Faculté des Sciences de Monastir, Boulevard de l'Environnement, 5019 Monastir, Tunisia, (b)Centre de Recherche en Matière Condensée et Nanosciences, CRMC-N, UPR-CNRS 7251, Campus de Luminy, Case 913, 13288 Marseille cedex 9, France  
 During the past decade, Ge/Si Quantum Dots (huts and domes) and ultra-short period SinGem zone-folded superlattices have been obviously investigated as building blocks for potential light emitting devices compatible with the on-chip CMOS technology. Meanwhile, modulation-doped and metal-oxide field-effect transistors, based on silicon channel strained on relaxed Si<sub>1-y</sub>Ge<sub>y</sub> virtual substrates, have been developed for high frequency analogic and logic applications. For emission and photodetection, few attentions have been strangely paid to the conventional and less sophisticated quantum well (QW) approach. To limit the problems inherent to the type II character of the interface in this system of material and the indirect nature of the bandgap, we propose a Si/Si<sub>1-x</sub>Ge<sub>x</sub>/Si strained double QW embedded in relaxed Si<sub>1-y</sub>Ge<sub>y</sub> barriers. The conduction and the valence band present a W-like potential profile, resulting in a quasi-type I heterostructure. The thickness and compositions ( $x>y$ ) of this single W-QW are computed in order to get (i) the optimum quantum confinement of single electrons and heavy-holes levels, (ii) the optimum out of plane oscillator strength and wave functions overlap and (iii) to satisfy a fundamental emission at a key 1.55  $\mu$ m wavelength below the absorption gap of each constituent materials. Furthermore, the structure is designed in a realistic way for epitaxial growth assuming strain compensation on relaxed Si<sub>1-y</sub>Ge<sub>y</sub> and thickness of each layer being smaller than the known critical thickness.
- A1-PII.30** ROSE'S LAW IN IRRADIATED AMORPHOUS SILICON FILM DETECTORS  
 T. Braz, P. Sanguino, M. Niehus, R. Schwarz, IST, Departamento de Física, Av. Rovisco Pais 1, 049-001, Lisboa, Portugal, F. Maçarico, M. Vieira, ISEL, Electronics and Communications Department, 1949-014 Lisboa, Portugal, C.P. Marques, E. Alves, ITN, Instituto Tecnológico e Nuclear, 2686-953 Sacavém, Portugal  
 Optical detectors, when used as discrete devices or when integrated in on-chip applications, are expected to present a linear response over several orders of magnitude of light intensity. Amorphous silicon-based thin film detectors may show nonlinearities due to the light-dependent change in carrier lifetime. Rose proposed a power-law dependence between photocurrent  $I_{ph}$  and the incident light flux  $F$ ,  $I_{ph} \sim F^a$ , and derived a relation between the shape of the density of defect or trap state distribution in the forbidden gap and the exponent  $a$ . We have looked at the variation of the Rose coefficient  $a$  in undoped a-Si:H before and after irradiation with a 1.5 MeV He<sup>4</sup> beam and 1 MeV proton beam with an upper limit of accumulated fluence of 1015 cm<sup>-2</sup>.  
 As expected, for unirradiated films, we measure an exponent near unity for low light intensity where monomolecular recombination should be relevant. At high intensity, the value of  $a$  decreases towards 0.5 due to dynamic passivation of deep defect states. However, after particle irradiation, even under strong light,  $a$  remains near 1. We can explain this phenomenon by the transition to monomolecular recombination due to the increase of the density of recombination centers in the gap. As a by-product we have used the spatial distribution of the photocurrent response to reconstruct the particle beam profile while taking a correction due to the Rose coefficient into account.
- A1-PII.31** LUMINESCENT PROPERTIES OF Er AND Si CO-IMPLANTED SILICATES  
 P. Pellegrino, B. Garrido, C. Garcia, M. Perálvarez, Y. Lebour and J.R. Morante, Dep. d'Electrònica, Universitat de Barcelona, Martí i Franquès 1, 08028 Barcelona, Spain, P. Bettotti, L. Pavesi, Physics Department, University of Trento, Via Sommarive 14, 38050 Povo (Trento), Italy, M. Prassas, Corning S.A., Fontainebleau Research Centre, 7bis avenue de Vilvins B.P. No.3, Avon, France  
 An extensive research for optical active materials at 1540nm is currently being carried out, on the steam of the strong need for optoelectronic devices which can be integrated in the mainstream Si technology. The formation of Er and Si clusters doped silica films has been shown as one of the promising approaches.  
 In this contribution we explore the emission properties of different silicate glasses co-implanted with silicon and Er ions to various doses. As a starting materials we used soda-lime and aluminum silicates, which show a larger optical bandwidth than silica at 1540nm. A Si multi-implantation scheme has been adopted, in order to provide an uniform Si excess background to the subsequently implanted Er atoms. By isochronal annealing experiments the best conditions have been investigated in order to precipitate the excess implanted Si and activate the Er atoms. Different optimal annealing temperatures have been found in the range of 500-600°C, depending on the particular composition of the original glass substrate. The structural analysis of the resulting structures ensures that the best emission properties are the ones for which a phase separation between the implanted Si and the matrix occurs, even without the formation of crystalline aggregates. A comprehensive study of the emission properties around the 1540nm window from the processed layers has been performed as a function of the matrix characteristics, the Si and Er content in the implanted layers and the excitation wavelength and power density. By means of PL-rise and decay measurements both for resonant and non resonant Er-excitation, we have estimated lifetimes, around 3ms, and effective capture-cross section. [...]
- A1-PII.32** INFLUENCE OF Er CONCENTRATION ON THE EMISSION PROPERTIES OF Er-DOPED SRSO FILMS OBTAINED BY REACTIVE MAGNETRON CO-SPUTTERING  
 M. Carrada, F. Gourbilleau, C. Dufour, M. Levalois, R. Rizk, SIFCOM, UMR CNRS 6176, Ensicaen, 6 Bd Maréchal Juin, 14050 Caen Cedex, France  
 Er-doped silicon-rich silicon oxide (SRSO) thin films have been fabricated by reactive magnetron sputtering of a pure silica target topped by chips of Er<sub>2</sub>O<sub>3</sub>. The incorporation of silicon excess in the films is controlled by the partial hydrogen pressure rate, RH, in the plasma which reduces accordingly the oxygen released by silica target. The incorporated Er content [Er] in the films was controlled by the sputtered surface ratio SR of Er<sub>2</sub>O<sub>3</sub> chips with respect to that of silica target. The 1.54- $\mu$ m photoluminescence (PL) intensities from samples obtained with different SR values and various annealing conditions were compared and interpreted in terms of sensitizing action of Si nanoclusters (Si-nc) towards the neighboring Er ions. Depending on the fabrication parameters, the optimum PL was for [Er] either near 5 $\times$ 10<sup>19</sup>/cm<sup>3</sup> or close to 4 $\times$ 10<sup>20</sup>/cm<sup>3</sup>, coexisting in both cases with quasi similar Si excess. Assuming an equivalent Si-nc density for both [Er] values, the observed optimum emission appears governed by two main aspects: (i) the coupling rate between Er and Si-nc including the fraction of Er dimerization inducing the up-conversion phenomenon, and (ii) the excitation of several Er ions by each Si-nc, estimated to tens in our case.

**A1-PII.33****THE COMPETITION OF DIFFERENT RADIATIVE CHANNELS IN Si NANOSTRUCTURES**

L. Khomenkova, N. Korsunskaya, M. Sheinkman, T. Stara, ISP NASU, 45 Pr. Nauky, Kiev 03028, Ukraine, [T. Torchynska](#), F.G. Becerril-Espinoza, ESFM - National Polytechnic Institute, Mexico D.F. 07738, Mexico

The characteristics of as-prepared and aged porous Si (PSi) are studied by photoluminescence (PL), PL excitation and Raman scattering methods. Using of different electrolyte composition and preparation regimes allows to vary PSi properties. The comparison of PL spectra measured at different temperatures of as-prepared and aged samples prepared in water free electrolyte shows: the presence of two bands at 1.4-1.48 eV (infrared band) and at 1.65-1.72 eV (red one) in PL spectra of aged samples; strong quenching of infrared band with temperature increase and enhancement of red one; high energy shift of infrared band maximum during aging; main contribution of red band to PL spectra at 300 K; main increase of red band during aging; increase of overlapping of both band during aging, one broad band observing at different temperatures; low energy shift of PL peak position with temperature decrease after prolonged aging. The infrared band is ascribed to exciton recombination in Si nanocrystals because of its high energy shift during aging. The latter is connected with the decrease of Si nanocrystal sizes due to oxidation process that is confirmed by Raman scattering data. The study of PL excitation spectra of both PL bands shows that these spectra are similar. So red band is excited due to light absorption by Si nanocrystals that is the reason of competition of radiative recombination in Si nanocrystals and in oxide-related defects. It should be noted that red band is observed in PSi samples anodized in water electrolyte just after preparation. So we can assume that oxidation process takes place during anodization.

**A1-PII.34****PHOTOLUMINESCENCE STUDIES OF Sn QUANTUM DOTS IN Si**

[A. Karim](#)(a), M. Larsson(a), G.V. Hansson(a), P.-O. Holtz(a), W.-X. Ni(a) and H.A. Atwater(b), (a)Department of Physics, Linköping University, Sweden, (b)Thomas J Watson Lab of Applied Physics, California Institute of Technology, Pasadena CA, USA

The development of efficient optical components based on silicon may require heterostructures with a direct band gap semiconductor compatible with existing Si technology. The incorporation of tin (Sn) in Si in terms of small a-Sn precipitates is one option for this. a-Sn is a direct band gap semiconductor with 20% lattice mismatch compared to Si. Because of this large lattice mismatch and the low incorporation and strong surface segregation of Sn in Si, growth-rate and temperature modulated MBE growth is needed to produce nanometer-thick high quality  $\text{Sn}_x\text{Si}_{1-x}$  alloy layers with low Sn concentrations.

It has been reported [1] that a few nanometer thick  $\text{Sn}_x\text{Si}_{1-x}$  alloy layers with  $x < 0.1$  grown on Si (100) can be used to form a-Sn quantum dots as a result of heat treatment of such structures up to 800°C. In ref. 1 it was reported that absorption measurements showed the onset of absorption at 0.25 eV indicating that the a-Sn quantum dots could be used e.g. in IR-detectors or emitters. We have performed low-temperature photoluminescence studies of some of these structures but cannot find any emission near 0.27 eV. The emission is characterized by a broadband emission in the range 0.7-1.0 eV. Furthermore there are narrow features that have previously described as the 789 meV C-O band and the 1018 meV W or II band. More structures with Sn quantum dots are presently produced and will be characterized in terms of their luminescence characteristics.

**A1-PII.35****EXCESS CARRIER DYNAMICS IN SILICON NANOCRYSTAL RICH P-DOPED  $\text{SiO}_2$  MATRICES**

[R. Tomasiunas](#), E. Gaubas, Vilnius University, Sauletekio 10, 10223 Vilnius, Lithuania, V. Švrcek, CNRS-PHASE, 23 rue du Loess, 67037 Strasbourg, France, I. Pelant, Institute of Physics, Cukrovarnicka 10, 162 53 Praha 6, Czech Republic, B. Hönerlage, IPCMS, CNRS-ULP, 23 rue du Loess, 67037 Strasbourg, France

We report on investigation of phosphorus doped sol-gel  $\text{SiO}_2$  films containing high density of Si nanocrystals made by pulverization of porous silicon. The obtained blue shifted red photoluminescence has been attributed either to nanocrystal doping with phosphorus or to improving surface termination by phosphorus atom passivation. Investigation of carrier fast dynamics by means of short pulse light induced techniques (four wave mixing, pump-probe and microwave absorption) reveals the sequence of domination of excess carrier fast processes in nanocrystals. Analysis of the dynamics in differently doped  $\text{SiO}_2$  films shows the influence of doped atoms on carrier recombination velocity, a probable impact to nanocrystal surface passivation. A complex insight by spectral and kinetic investigations helps solving the persisting problem of the competition between radiative and non-radiative recombination channels.

**A1-PII.36****SURFACE PLASMON RESONANCE SENSING IN SILICON-BASED SCHEMES**

S. Patskovsky, [A.V. Kabashin](#), M. Meunier, École Polytechnique de Montréal, Département de génie physique, Case Postale 6079, succ. Centre-Ville, Montréal (Québec), Canada, H3C 3A7, J.H.T. Luong, NRC Biotechnology Research Institute, National Research Council, Montreal, Canada

Surface Plasmon Resonance (SPR) sensing effect with silicon as a coupling material is considered. In contrast to conventional glass-based SPR technology, this approach makes potentially possible an easy miniaturization and integration of the sensor device on a single chip using Si-based microfabrication methods. Calculations on the basis of a theoretical framework and experiments show that silicon-based SPR schemes display quite different regularities of plasmon excitation and polarity of sensing response in comparison with glass-based schemes, which is attributed to substantially different behaviour of dispersion characteristics of silicon in comparison with glasses. Working in the near-IR light, silicon-based schemes also demonstrate relatively high sensitivity and much better ability for sensing of relatively large biological objects. We examine regularities of SPR production and sensitivities of different angular and spectral interrogation configurations and discuss possible sensor embodiments. In particular, we consider different Si-based multi-layer structures, which make possible a simultaneous generation of two angularly separated plasmon polariton modes over the silicon/gold (internal mode) and gold/sample medium (external mode) interfaces due to a relatively high refractive index of Si. We show that the internal plasmon is almost insensitive to the change of the refractive index of the adjacent dielectric medium and can be used as a reference channel for sensing. On the other hand, we show that the internal mode appears to be at least 5-7 times more sensitive to the nanoparticle-enhanced sensing.

**A1-PII.37****GE DOT MID-INFRARED PHOTODETECTORS**

Song Tong, Joo-Young Lee, Hyung-Jun Kim, Fei Liu and Kang L. Wang, Device Research Laboratory, Department of Electrical Engineering, University of California at Los Angeles, Los Angeles CA 90095-1594, USA

For monolithic integration purpose, Si based mid-infrared photodetectors using Ge dots were investigated. p-i-p structures were grown using solid source MBE with boron-doped Ge dots embedded in the intrinsic region. Mesa devices passivated by using LTO were fabricated using conventional method. The sample grown at 540 oC has photoresponse peaked at 2.7 um. FTIR measurements on identical structure showed an absorption band peaked at 3.0 um, consistent with the photocurrent spectra. The devices had a dark current density of 6.4 mA/cm<sup>2</sup> at 77K with 1V bias. Temperature dependent I-V measurements gave an activation energy of 180 meV. Our temperature dependent photoresponse study showed that the devices had good response up to 140K. At lower temperatures, the response intensity tended to decrease due to freeze-out of the holes. The response increased with increasing bias. At 50K, the devices showed photocurrent amplification due to impact ionization effect. The response range can be modified by controlling the substrate temperature during growth. By increasing the growth temperature to 700 oC, the response peak moved to 3.6 um.

**A1-PII.38****PHOTOCONDUCTIVE GAIN OF SiGe/Si QUANTUM WELL PHOTODETECTOR**

Fei Liu, Song Tong, Hyung-jun Kim and Kang L. Wang, Device Research Laboratory, Department of Electrical Engineering, University of California at Los Angeles, Los Angeles CA 90095-1594, USA

In this study, we will describe an alternative photodetector device using a two-terminal Si<sub>1-x</sub>Ge<sub>x</sub>/Si multiple quantum well (MQW) structure. A large photoconductive gain is obtained because of the unique band structure of the proposed SiGe/Si structure, i.e. having a large band offset of the valence band, but a small band offset of the conduction band. Such a structure allows photogenerated holes to be trapped inside the quantum well on one hand, and on the other hand, photogenerated electrons appear in shallow quantum well and electrons have relatively high mobility resulting in a large photoconductive gain, which is only limited by carrier recombination lifetime. Theoretically, the photoconductive gain was calculated using a trap model for MQW structures. Experiments have been carried out with Type-II SiGe/Si MQW photodetector to illustrate the gain mechanism. Room temperature photocurrent spectra of the sample as well as the spectral power of the light source were measured. Using the Si and Si<sub>0.8</sub>Ge<sub>0.2</sub> absorption coefficients and the photocurrent and photon power relation, the photoconductive gain was obtained. The room temperature photoconductive gain up to several hundreds was observed. From 0.1 V to 1 V, the photoconductive gain increased as the bias voltage increased. The photoconductive gain increased for the wavelength longer than 1000 nm. In summary, a two terminal SiGe/Si MQW structure has been demonstrated for high gain photon detection. A trap model was used to analyze photoconductor gain for the MQW. Experimental results illustrated the photoconductive gain mechanism. This work suggests that SiGe/Si MQW structure may be used for high sensitivity detection, in particular, the applications such as single photon detection in quantum communications.

**A1-PII.39****ELECTROLUMINESCENCE FROM THIN n-Si:Er LAYER AT THE BREAKDOWN MODE OF p+/n(Si:Er)/n+ LIGHT EMITTING DIODE**

V. Shmagin, D. Remizov, M. Sharonov, M. Stepikhova, Z. Krasil'nik, Institute for Physics of Microstructures RAS, GSP-105 Nizhny Novgorod, Russia, V. Kuznetsov, V. Shabanov, S. Obolensky, Nizhny Novgorod State University, Gagarin ave., 23/3, Nizhny Novgorod, Russia

Si:Er-based light-emitting diodes p+/n(Si:Er)/n+, in which a thin n-Si:Er layer ( $n \sim 10^{16}$  cm<sup>-3</sup>,  $d \sim 10$ -500 nm) is positioned between high-doped p+ and n+ layers are grown with sublimation MBE. The mechanism of p-n junction breakdown in these diodes is determined by the thickness W of a low-doped layer n-Si:Er. At  $W < 30$ -40 nm a breakdown has a strongly pronounced tunnel character. An increase of n-Si:Er layer thickness leads to the replacement of a tunnel breakdown by avalanche. The maximum of EL intensity is achieved in diodes with mixed breakdown or an insignificant prevalence of a tunnel breakdown. A transference into regions with strongly pronounced tunnel or avalanche breakdown character leads to decrease in EL intensity. A width of the so-called "dead" zone where electrons, warmed up by an electric field of reversally biased p-n junction, accumulate the energy necessary for excitation of Er<sup>3+</sup> is evaluated as 15 - 20 nm. This value appreciably differs from a similar estimation (~ 45 nm), taken in (M.Markmann et al., Appl. Phys. Lett., 78, 210 (2001)) for p+/n tunnel diodes.

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**A1-PII.40****GAIN ANALYSIS AND LUMINESCENT STUDIES OF Si/Si<sub>1-x</sub>Ge<sub>x</sub>:Er HETEROSTRUCTURES PRODUCED BY THE METHOD OF SUBLIMATION MBE IN GAS ATMOSPHERE**

L. Krasil'nikova, M. Stepikhova, Yu. Drozdov, V. Shmagin, Z. Krasil'nik, Institute for Physics of Microstructures, Russian Academy of Sciences GSP-105, Nizhny Novgorod 603950, Russia, V. Shengurov, S. Svetlov, V. Chalkov, Physico-Technical Research Institute at Nizhny Novgorod State University, Gagarin Ave. 23, Nizhny Novgorod 603600, Russia

The silicon doped with erbium is interesting in that the basic optical transitions in 4f Er-shell take place at the wavelength of 1.54 &#956;m. The transitions at this wavelength belong to the spectral area of minimum loss and low dispersion in quartz fibers that makes the material very attractive for device applications particularly for modern telecommunication systems.

In this work we present the results of the gain coefficient analysis performed for epitaxial Si:Er structures grown by an original method of sublimation MBE (SMBE) and discuss possible performance of the laser structures on their basis. An extremely narrow photoluminescence line width (<10 &#956;eV) determines a high gain factor for such materials. The estimated value of gain coefficient is about 30 cm<sup>-1</sup>. As a variant, the waveguiding for a laser can be realized on the basis of Si<sub>1-x</sub>Ge<sub>x</sub>/Si heteropair. In this communication we discuss the results of photo- and electroluminescence studies of Si/Si<sub>1-x</sub>Ge<sub>x</sub>:Er/Si SMBE structures grown with the parameters close to that for a laser&#8217;s. An intense Er-related luminescence has been obtained in such kind of structures, where the low-temperature analysis reveals the dominance in PL spectra of the optically active Er-O centers characterized by their specific fine line pattern. Peculiarities of SMBE growth in gas atmosphere as well as the role of strain relaxation in Si<sub>1-x</sub>Ge<sub>x</sub>:Er layers on their luminescent properties will be discussed. This work was partially supported by the RFBR (grant 02-02-16773) and INTAS (grant NANO&#8211;01-0444).

**A1-P11.41****LIGHT EMISSION IN COUPLED AND CORRELATED GE ISLANDS**

L. Vescan, T. Stoica, D. Dentel, A. Mück, B. Holländer, Forschungszentrum Juelich GmbH, Institut für Schichten und Grenzflächen, 52425 Juelich, Germany and E. Sutter, Department of Physics, Colorado School of Mines, Golden CO 80401, USA

LED structures with two correlated layers of Ge islands embedded in the intrinsic region of a p-i-n diode were studied by electroluminescence (EL) and photoluminescence (PL). The layer sequence of p+SiGe(2%)-Si-Ge-Si-Ge-Si-n+Si on n+Si-substrate has been obtained by LPCVD using selective epitaxy. The thickness of the Si spacer between the two Ge layers was varied in the range 4 – 35 nm. In this range the islands are vertically correlated. For nm-thin spacers, electronic coupling of the islands is expected leading to an increased localization of electrons in the strained region between the islands. The tensile Si between islands may have electrons in energetic minima of the band structure with the k vector perpendicular to the layer, i.e. on the same direction of the electron confinement. Therefore, an increase of the radiative recombination is expected. The experimental results show indeed an enhanced emission for a spacer of ~ 3nm between the correlated islands. The values of the spacer are obtained from TEM images. By comparison of the EL and PL results, different properties of the first and the second deposited Ge layers could be put into evidence.

**A1-P11.42****REALISATION OF SILICON-BASED MODULATORS FOR OPTICAL INTERCONNECTS**

S. David, B. Cluzel, T. Charvolin, E. Picard, E. Hadji, CEA Grenoble, DRFMC/ SP2M/ SiNaPS, 17 rue des Martyrs, 38054 Grenoble, France

The development of photonic circuits implies to generate optical information. The temporal response of laser doesn't allow to modulate directly the light in high frequencies. Silicon is known to be the basic material for the microelectronics industry. In this work, we present two realisations of silicon-based modulators intended for optical interconnects.

A first solution consists in modifying the absorption of Ge/Si self-assembled islands by saturating the energy states of Ge/Si islands with carriers generated by optical or electrical excitations. We will present first measurements of optical modulation. Moreover, the photonic domain offers possibilities to strengthen this modulation. We will show simulations on photonic crystal structures which allows to benefit of slowly guided optical modes. The slow propagation of light should increase its interaction time with Ge/Si nano-structures and thus increases the modulation effect.

A second solution consists in inserting controllable material into the patterns of a photonic crystal devices. Liquid crystal possesses an anisotropic refractive index which depends on the orientation of molecules. Its refractive index can be control by applying a polarisation and could allow to move resonance spectrally. This work is a first step toward the realisation of fast modulators.

**A1-P11.43****1D AND 2D PHOTONIC BANDGAP STRUCTURES REALIZED ON SILICON ON INSULATOR: EFFECT OF LIGHT EXTRACTION.**

M. Zelsmann(a), D. Sotta(a), B. Cluzel(a), A. Salomon(a), V. Calvo(a), T. Charvolin(a), E. Picard(a), E. Hadji(a), M. Heitzmann(b), H. Moriceau(b), (a)DRFMC/SiNaPS, CEA Grenoble, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France, (b)LETI/DTS CEA Grenoble, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France

Due to the difference of optical index between Si and SiO<sub>2</sub>, silicon on insulator (SOI) wafers are efficient to realize optical waveguides in the Si layer. The simultaneous realization of 1D and 2D photonic crystals with these substrates may be a path to control the emission and the propagation of light in the 3D directions of space. The coupling of photonic structures with efficient Si active zone may open the route towards CMOS compatible silicon-based light emitters.

In a first part of the presentation, we will show Photoluminescence (PL) measurements of 1D vertical Fabry-Perrot SOI cavity, and in a second part PL measurements of 2D hexagonal photonic crystals. The samples are fabricated using standard microelectronic process and e-beam lithography. In both cases, optical results show a strong extraction of light compared to the SOI wafer (respectively x30 and x70). Finally, we will present angular emission diagram of a low group velocity photonic crystal sample. Experimental results are well explained by electromagnetic simulation (transfer matrix and FDTD).