SYMPOSIUM I

Optoelectronics of Group-IV-Based Materials

April 21 – 24, 2003

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TUTORIAL

ST I: OPTICAL MATERIAL CRYSTALLINE SILICON
Monday, April 21, 2003
1:30 p.m. - 5:00 p.m.
Salon 14/15 (Marriott)

Silicon is by far the most widely used material in electronics. Because of its indirect gap, however, it is not suitable for light emitters. Such Si-based devices would be very useful in implementing optical functions in integrated circuits, e.g., for fiber optics communication systems, smart power devices or complex ULSI systems, where electronic cross talk is already a problem. Visible emission for displays would also be very attractive for various monolithic solutions.

The tutorial will give an introduction to the optical properties of silicon, with particular emphasis on the luminescence transitions that occur between different electronic states in silicon. In particular, the following issues will be addressed:

- What electronic states are available?
  - The electronic states of pure Si
  - The electronic structure of impurities in Si: generic aspects of the useful "bound exciton" model
- What properties of the electronic states can we measure?
  - Overview of the basic techniques, concentrating on the strengths and weaknesses of the different techniques, but without technical detail
  - Chemical identification of the impurities
- What are the problems with obtaining luminescence from Si?
  - Time scales of processes
  - Some examples

Several directions–including the use of nanostructures like porous Si, and the formation of nanocrystals of Si, and optical doping of Si, in particular by rare earth elements–have been followed in recent years to overcome the inherent physical limitations of Si light emitters. In the second part of the tutorial, the principles, limitations, and possible improvements of optical properties of silicon will be considered. In particular, taking Si:Er as an example, we will discuss:

- The problems of excitation
  - The possible mechanisms for energy transfer from the Si host to the optical dopant
- Non-radiative processes
- Concepts and problems in the technical realization of room temperature emitters

Finally, the chances of realizing a Si-based laser will be addressed.

The tutorial session will be complemented by a brief presentation of recent developments in the field of integration of III-V-based emitting structures with the Si platform. Dr. John Zavada of ARO, who will also chair the tutorial and lead the discussion period, will give this (shorter) review.

Instructors:
Gordon Davies, King's College London
Wolfgang Jantsch, Johannes Kepler University

Chair: John Zavada, ARO

SESSION I1: QUANTUM DOTS
Chairs: Philippe M. Fauchet and Minoru Fujii
Tuesday Morning, April 22, 2003
Golden Gate A1 (Marriott)

8:30 AM OPENING REMARKS - Tom Gregorkiewicz

8:45 AM *I1.1
LUMINESCENCE SPECTROSCOPY OF SINGLE SILICON QUANTUM DOTS. Jan Linnros, Royal Institute of Technology, Dept of Microelectronics and Information Technology, Kista, SWEDEN; Jan Valenta, Charles University, Department of Chemical Physics and Optics, Prague, CZECH REPUBLIC; and Robert Juhasz, Royal Institute of Technology, Dept of Microelectronics and Information Technology, Kista, SWEDEN.

Semiconductor quantum dots have aroused much interest due to their electronic and optical properties where quantum size effects are readily observed. In particular spectroscopic studies of single quantum dots have revealed unexpected new physics such as blinking, spectral diffusion etc, not observed in ensemble studies. In this work we have studied individual silicon quantum dots (nanocrystals, NC's) and spectrally resolved them both in PL and in EL. Arrays of silicon quantum dots were fabricated using e-beam lithography and plasma etching to form nanopillars. By a two-stage oxidation process the size of the remaining Si core was reduced. Under UV excitation using imaging by a CCD-camera, single-dot photoluminescence in the range 700 - 850 nm could be detected. For the brightest dots we calculated a PL quantum efficiency as high as 35%. As expected, the linewidth of individual NC's is reduced compared to the broad ensemble spectrum. Still, the observed linewidth is much broader ($\sim$130 meV) than those reported in the literature for direct bandgap NC's. One may speculate that various phonon-assisted transitions contribute to this homogeneous line broadening. The single-dot PL emission was further supported by detection of characteristic on-off blinking as well as strong polarization effects suggesting geometrical differences in the shape of NC's. Samples used for EL studies were fabricated using Si implantation into a thin oxide to form Si nanocrystals. Imaging of these samples showed that EL originated from individual dots where the single quantum dot behavior was established by observation of on-off blinking and by the quantized type intensity distribution among the dots. Finally, the similar count rates from the EL and PL measurements suggest that, for an individual nanocrystal, the EL efficiency may be very high.

9:15 AM I1.2
TOWARDS SINGLE-PARTICLE SPECTROSCOPY OF Si NANOCRYSTALS. A.L. Tchebotareva[a], J.S. Biteen[b], M.J.A. de Dood[a], H. Atwater[b], A. Polman[a]; [a]FOM-Institute AMOLF, Amsterdam, THE NETHERLANDS; [b]California Institute of Technology, Pasadena, CA.

The effect of doping of Si nanocrystals on their photoluminescence (PL) is studied. Si nanocrystals were prepared by implantation of Si^+ ions into SiO_2 films followed by thermal annealing. Afterwards samples were implanted with Au or P at various concentrations. For increasing Au concentration, a progressive decrease in the PL intensity and lifetime is observed at all emission wavelengths. In contrast to that, doping with P leads to an initial increase in room-temperature PL for low concentrations followed by a decrease at higher concentrations. Yet the PL lifetime shows a steady decrease with increasing P concentration. These changes in the emission properties of P-doped nanocrystals may be attributable to a partial ionisation of P atoms at room temperature. In all cases, the photoluminescence decay traces are described by a stretched exponential model, $I(t) = I_0 \exp[-(t/\tau)^\beta]$, with τ being the lifetime, and β being a measure of the degree of interaction between neighbouring nanocrystals. Our results indicate the presence of such an interaction in the samples.
In order to create samples of Si nanocrystals with reduced interaction, SiO_2 films containing Si nanocrystals were either oxidised or HF-etched. Oxidation leads to a decrease in the average size of nanocrystals; the average distance between them thereby increases. Etching results in a deposition of nanocrystals on the substrate. Indeed, AFM images of etched samples showed $\sim$ 5 nm high particles on the substrate's surface. Clear PL is observed from these nanocrystals, with a spectrum and a lifetime characteristic of the recombination of quantum-confined excitons. However, β was found to be $\simeq$ 0.7, indicating that interaction between nanocrystals is still present.

9:30 AM I1.3
SILICON NANOCRYSTALS NUCLEATION AS A FUNCTION OF THE ANNEALING TEMPERATURE IN SiO_x FILMS. N. Daldosso, G. Dalba, R. Grisenti, L. Pavesi, G. Das, G. Mariotto, INFM-Trento Univ, Dept of Physics, Trento, ITALY; F. Rocca, CNR-IFN, Trento, ITALY; F. Priolo, G. Franzo, M. Miritello, D. Pacifici, INFM-Catania Univ, Dept of Physics, Catania, ITALY; F. Iacona, CNR-IMM, Catania, ITALY.

Si nanocrystals (Si-nc) embedded in amorphous matrix have been obtained by thermal annealing of substoichiometric SiO_x films,

deposited by PECVD (plasma-enhanced chemical-vapour deposition) technique with different amount of Si concentrations (39-46 at.%). Both nucleation and evolution of Si nanocrystals, together with the changes of the amorphous matrix, have been studied as a function of the annealing temperature (500-1250°C) by x-ray absorption measurements in Total Electron Yield (TEY) mode at the Si absorption K-edge. The analysis of x-ray absorption and RBS (Rutherford Backscattering Spectrometry) data allowed to assess the amount of Si atoms clustered in Si-nc and to gain the composition of the embedding matrix and its evolution with thermal annealing for different Si concentrations. Moreover, the comparison with photoluminescence (PL) and Raman spectra and TEM measurements allowed clarifying the processes of Si-nc formation and of Si-nc structural modification as a function of the annealing temperature. The whole range of annealing temperatures from as deposited to highly luminescent materials was investigated. The knowledge of the chemical composition and structure of both amorphous matrix and Si-nc is a fundamental task in order to investigate the mechanism of Si nanocrystals formation, including the very early stages of the process.

9:45 AM I1.4
PHOTOSENSITIZATION OF OXYGEN MOLECULES BY EXCITONS CONFINED IN SILICON NANOCRYSTALS.
Egon Gross, Dmitri Kovalev, Nicolai Künzner, Joachim Diener, Frederick Koch, Technische Universität München, Dept of Physics, Garching, GERMANY; Victor Yu. Timoshenko, Moscow State M.V. Lomonosov University, Dept of Physics, Moscow, RUSSIA; Minoru Fujii, Dept of Electrical and Electronics Engineering, Faculty of Engineering, Kobe University, Kobe, JAPAN.

Photosensitization is an important process employed for the excitation of molecules exhibiting optically forbidden electronic transitions. Of particular interest is molecular oxygen (MO), since it is the most common oxidant and involved in a variety of biochemical reactions. The ground triplet state of MO is chemically inert and the high reactivity of MO results from its energy rich excited singlet states. However, spin selection rules prevent the direct excitation of MO by light. We report on efficient resonant energy transfer from excitons confined in silicon nanocrystals to MO. The remarkable photosensitizing properties of silicon nanocrystal assemblies result from a broad energy spectrum of photoexcited excitons, a long triplet exciton lifetime and a highly developed surface area. Quenching of photoluminescence (PL) of silicon nanocrystals by MO physisorbed on their surface is found to be most efficient when the energy of excitons coincides with triplet-singlet splitting energy of oxygen molecules. We present experimental proof for the efficient generation of singlet MO. Spectroscopic analysis of the quenched PL spectrum evidences that for nonresonant energy transfer the energy is conserved via multi-phonon emission process. From time-resolved measurements the characteristic time of energy transfer is found to be in the range of microseconds. The dependence of PL quenching efficiency on the surface termination of nanocrystals is consistent with short-range resonant electron exchange mechanism of energy transfer. The direct chemical action of photosensitized MO is demonstrated by room temperature photooxidation of silicon nanoparticles.

10:30 AM *I1.5
ELECTRONIC AND DIELECTRIC PROPERTIES OF SILICON NANOCRYSTAL ASSEMBLIES. Dmitri Kovalev.

Porous silicon and other systems containing silicon nanocrystals have been extensively studied using different spectroscopic techniques. We will review the basic optical properties of silicon nanocrystals which can be assigned to the quantum confinement regime. We would like to demonstrate that all general expectations for the behaviour of electronic states confined inside silicon nanocrystals are well fulfilled and emphasise the specifics of indirect band gap nanocrystal assemblies. The following subjects will be discussed in detail: absorbing states in silicon nanocrystals, luminescing states in silicon nanocrystals and nonlinear optical properties of silicon nanocrystals. Over recent years, nanostructuring of semiconductors has been considered as an alternative way to the search for new materials. A key idea is an introduction of optical anisotropy due to reduction of the symmetry of the bulk crystals via ordered nanostructuring. We will report on properties of optical devices based on macroscopically nanostructured single and multiple porous silicon layers: optical in-plane anisotropy of porous silicon layers (retarders) and polarisation-sensitive porous silicon multilayer structures (dichroic Bragg reflectors and microcavities).

11:00 AM I1.6
CALCULATED SIZE DEPENDENCE OF THE OPTICAL GAP OF GROUP IV NANOCRYSTALS. Aaron Puzder, Jean-Yves Raty, Andrew J. Williamson, Jeffrey C. Grossman, Randolph Q. Hood, and Giulia Galli, Quantum Simulation Group, Physics and Advanced Technologies, Lawrence Livermore National Laboratory.

In the nanometer size range, quantum confinement effects significantly alter the optoelectronic properties of semiconductors: as their size decreases, their optical gap increases with respect to bulk values. This effect has been observed experimentally in all group IV insulators and semiconductors (C, Si, and Ge). In spite of apparent similarities in quantum confinement effects, striking differences have recently emerged. In the case of diamond, quantum confinement effects have been found to be negligible for diameters larger than $\sim$1 nm [1], while for Si and Ge they persist up to $\sim$5 and $\sim$10 nm respectively. Despite Ge having the smallest bulk bandgap of group IV elements, a recent experiment [2] indicated that Ge nanocrystals have larger optical gaps than Si nanocrystals of the same size, for diameters smaller than 2-3 nm. Using highly accurate quantum Monte Carlo (QMC) calculations, we show that indeed Ge has a larger gap than Si in this size range, and this is due to smaller excitonic binding energy in Ge than in Si nanocrystals. These results could be obtained only when including many body effects through QMC calculations, while we found that Ge and Si behave in a very similar fashion if a mean field approach such as density functional theory is adopted [3]. [1] J.-Y. Raty et al. [2] "Strong Confinement Effects in the Conduction Band of Ge nanocluster Films", C. Bostedt et al. (submitted) [3] "Accurate Many-Body Calculations of OpticalProperties in Ge Nanoclusters", A. Puzder et al. (in preperation).

11:15 AM I1.7
Sn QUANTUM DOTS IN Si MATRIX. Peter Moeck, Peter Moeck and Armando Acha, Portland State University, Department of Physics; Yuanyuan Lei, Teya Topuria, Nigel D. Browning, University of Illinois at Chicago, Department of Physics; R. Ragan, K.S. Min, H.A. Atwater, Thomas J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA.

Analytical transmission electron microcopy in both the parallel illumination and scanning probe mode revealed the formation of Sn quantum dots in Si matrix by two different mechanisms as well as their subsequent morphological and structural transformations. The so called void-mediated formation mechanism of α-Sn quantum dots [1] may be generally applicable and could possibly be adapted to grow all kinds of semiconductor quantum dots in Si matrix. Morphological transformations with the quantum dot size are driven by an increasing contribution of the elastic mismatch strain energy to the Gibbs free energy and shape transitions form tetrakaidecahedrons to octahedrons have been observed. Structural transformations are probably also driven by thermodynamics, providing an explanation for our earlier experimental observations [2]. A simple estimate shows that an excess Gibbs free energy of about 1.5 eV per atom can be released by structural transformations from α-Sn to β-Sn if the resultant precipitates possess lattice mismatch strain minimizing orientation relationships. [1] Y. Lei, P. Moeck, T. Topuria, N.D. Browning, R. Ragan, K.S. Min, and H.A. Atwater, submitted to Phys. Rev. B. [2] P. Moeck, Y. Lei, T. Topuria, N.D. Browning, R. Ragan, K.S. Min, and H.A. Atwater, Proc. of 47th Annual SPIE Meeting, July 2002, Seattle.

11:30 AM I1.8
EFFECT OF MICROCAVITY STRUCTURES ON THE PHOTOLUMINESCENCE OF SILICON NANOCRYSTALS.
M.G. Spooner, T.M. Walsh, R.G. Elliman, Electronic Materials Engineering Department, Research School of Physical Sciences and Engineering, Australian National University, Canberra, AUSTRALIA.

Silicon nanocrystals show strong room-temperature luminescence but the emission spectrum from an ensemble of such nanocrystals is generally quite broad (150-200 nm) due to homogeneous and inhomogeneous broadening effects. The spectral emission can, however, be narrowed and tuned by incorporating the nanocrystals within a suitable optical microcavity. In this paper, we investigate the effect of different microcavity structures on the nanocrystal luminescence. Structures were grown by plasma-enhanced chemical vapour deposition (PECVD) and consisted of Bragg mirrors, with and without embedded spacer layers. Two types of Bragg mirror structure were also examined, one consisting of alternating layers of SiO_2 and Si_3N_4, and a second consisting of a distributed active layer in which the Bragg mirror was composed of alternate layers of SiO_2 and nanocrystal-containing SiO_2. In all cases, the intensity of the photoluminescence was enhanced for wavelengths corresponding to the resonant mode of the microcavity. These results are discussed and compared with measured and calculated reflectivity data.

11:45 AM I1.9
OPTICAL AND STRUCTURAL PROPERTIES OF SILICON NANOCRYSTALS: INTERFACE VERSUS CONFINEMENT EFFECTS. E. Degoli, S. Ossicini, INFM-Research Center for NanoStructures and BioSystems at Surfaces(S^3), Dipartimento di Scienze e Metodi dell'Ingegneria, Universita di Modena e Reggio Emilia, Reggio Emilia, ITALY; M. Luppi, E. Luppi, R. Magri, INFM-Research Center for NanoStructures and BioSystems at Surfaces(S^3) Dipartimento di Fisica, Universita di Modena e Reggio

Emilia, Modena, ITALY.

Silicon-based light emitting materials, such as porous silicon and Si nanocrystals, have claimed a lot of interest in the last years because of the promising applications in advanced electronic devices based on nanoscale technology. Understanding and improving the properties of these novel semiconductor materials requires to learn more about the atomistic aspects of their structure and fabrication. Passivated-surface silicon clusters are the ideal theoretical model to achieve this aim. In literature the most part of first principle calculations and empirical simulations have used hydrogen as passivating agent for the Si surface, focusing the efforts mainly on the role of quantum confinement effects. Yet it has been recently pointed out that also the surface chemistry produces substantial impact on the Si nanocrystals properties. Here we investigate the structural, electronic and optical properties of Si nanoclusters using different ab initio approaches within the Density Functional Theory. Structural relaxations have been fully taken into account in all cases through total energy pseudopotential calculations. We have considered nanodots covered by hydrogen and the substitution of H-Si bonds with different O-Si bonds (both single and double ones). Moreover we have performed calculations for the optoelectronic properties of Si nanodots embedded in a SiO_2 matrix. The substitution of H with O as passivating agent results in a different cluster geometry and in a reduction of the energy band gap depending on the type of O-Si bond. Moreover also the optical properties strongly depend on the different O-Si bond type. The analysis of the projected density of states reveals that this is due to the different O weight on the band edges states. The results provide a consistent interpretation of the photoluminescence redshift observed in oxidized samples and of recent outcomes on Si single quantum dot photoluminescence bandwidth. For Si dots embedded in the SiO_2 matrix, the final structure shows a deformation of the SiO_2 cage only in the neighborhood of the dots, this interface region participates to the light emission processes. Finally preliminary results about excited states and gain calculations will be presented. A Slater transition state approach and direct excitation approaches are compared for the ab-initio treatment of the excited state and a calculation of the absorption-gain spectra for the different configurations of the Si nanodots is performed.

SESSION I2: DEVICES
Chairs: Robert G. Elliman and Dmitri Kovalev
Tuesday Afternoon, April 22, 2003
Golden Gate A1 (Marriott)

1:30 PM *I2.1
HIGH EFFICIENCY LIGHT EMISSION DEVICES IN SILICON.
Maria Eloisa Castagna, Salvo Coffa, Liliana Caristia, Simona Lorenti, Alberto Messina, STMicroelectronics, Catania, ITALY; Corrado Bongiorno, CNR-IMM, Catania, ITALY.

We report on the fabrication and performances of the most efficient Si-based light sources. The devices consist of MOS structures with erbium (Er) implanted in the thin gate oxide. The devices exhibit strong 1540 nm electroluminescence at 300K with a 10% external quantum efficiency, comparable to that of standard light emitting diodes using III-V semiconductors. Emission at different wavelenghts has been achieved incorporating different rare earths (Ce, Tb, Yb, Pr) in the gate dielectric. The external quantum efficiency depends on the rare earth ions incorporated and ranges from 10% (for an Tb doped MOS) to 0.1% (for an Yb doped MOS). RE excitation is caused by hot electrons impact and oxide wearout limits the reliability of the devices. Much more stable light emitting MOS devices have been fabricated using Er-doped SRO (Silicon Rich Oxide) films as gate dielectric. These devices show a high stability, with an external quantum efficiency reduced to 0.1%. In these devices Er pumping occurs by energy transfer from the Si nanostructures to the rare earth ions. Si/SiO_2 Fabry-Perot microcavities have been fabricated to enhance the external quantum emission along the cavity axis and the spectral purity of emission from the films that are used as active media to realize a Si based RCLED. These structures are realized by chemical vapour deposition on a silicon substrate. The microcavities are tuned at different wavelengths: 540nm, 980nm and 1540nm (characteristic emission wavelength respectively for Tb, Yb and Er). The reflectivity of the microcavities is of 97% and the factor quality ranges from 50 (for the cavity tuned at 540nm) to 95 (for the cavities tuned at 980nm and 1540nm).

2:00 PM *I2.2
EFFICIENT NEAR INFRARED Si/Ge QUANTUM DOT PHOTO-DETECTOR BASED ON A HETEROJUNCTION BIPOLAR TRANSISTOR.
A. Elfving, G.V. Hansson, and W.-X. Ni, Dept. of Physics and Measurement Technology, Linköping University, Linköping, SWEDEN.

Ge dots embedded in Si offer the possibility of Si-based light detection at 1.3-1.55 μm. In this communication, we report a very efficient photo-detector, based on the Si/SiGe heterojunction bipolar transistor structure with 10 Ge dot layers (8 ML Ge each) incorporated in the base-collector junction. The devices were fabricated for both normal and edge incidence with no electrical contact to the base. The processed detectors revealed a rather low dark current (<1 mA/cm^2 at -4 V). Photoconductivity measurements were performed at room temperature, using a commercial InGaAsP/InP quantum well laser module with the beam output coupled into a single mode optical fiber as the light source, which enables accurate determination of the photo-responsivity because of a well-defined size and optical power of the laser spot. At 1.31 μm, responsivity values of 50 mA/W at normal incidence (device area 500 $\times$ 500 μm^2) have been directly measured at V_{ce}= 4 V, without involving any rescaling factor due to light coupling. This value is a 100-fold increase, compared to a reference p-i-n diode with the same dot layer structure, due to the current amplification function of the transistor. An even higher responsivity value of ~0.53 A/W (V_{ce}= 4 V) has been obtained when coupling the fiber through the edge of a device processed with a rib waveguide geometry for having a longer optical interaction length. This high responsivity value has made this detector to be practically useful. Moreover, time-resolved photoconductivity measurements have been carried out. The results have indicated that the device frequency performance is primary limited by the junction capacitance. In order to obtain a high optical-electro-conversion frequency, detectors need to be processed with a smaller junction area, which is presently under way in our lab.

2:30 PM I2.3
EFFICIENT NEAR-INFRARED PHOTODECTORS ON SELECTIVELY GROWN Ge MESAS INTEGRATED ON Si SUBSTRATES.
D.D. Cannon, J. Liu, D.T. Danielson, S. Jongthammanurak, H.C. Luan, J. Michel, K. Wada, and L.C. Kimerling, Dept of Materials Science and Engineering, Massachusetts Institute of Technology.

We have fabricated high-responsivity Ge p-i-n diodes on Ge mesas selectively grown on Si substrates. We have chosen Ge for our detector material because it is compatible with Si processing and has high optical absorption at 1.55um. CMOS compatible integrated photodetectors will allow for substantial cost reduction and high levels of integration with other devices. Due to the 4% lattice mismatch between Ge and Si, the threading dislocation density in as-grown Ge films on Si is on the order of 109/cm2. These threading dislocations act as recombination centers for carriers and greatly degrade device performance. We grow Ge mesas on selectively on patterned SiO2/Si substrates, which yields higher quality Ge films than for blanket growth. By cyclic annealing after growth we reduce the threading dislocation density in the mesas to below 1x106/cm2 and achieve a diode responsivity of 300mA/W at 1.3um. The growth process also has the effect of increasing the spectral response of the Ge photodetectors to longer wavelengths by 60nm, as compared to detectors fabricated from bulk Ge. Because the absorption coefficient of Ge falls rapidly near 1.55um, this shift is very advantageous for telecommunications applications.

2:45 PM I2.4
SILICON NANOCRYSTAL OPTICAL MEMORY DEVICES.
Robert J. Walters, Julie D. Casperson, Pieter G. Kik, and Harry A. Atwater, California Institute of Technology, Thomas J. Watson Laboratory of Applied Physics, Pasadena, CA; Albert Polman, FOM Institute for Atomic and Molecula Physics, Amsterdam, THE NETHERLANDS; Maria Giorgi, Robert Lindstedt, and George I. Bourianoff, Intel Corporation, Portland, OR.

Silicon nanocrystal floating gate devices are promising candidates for CMOS integration of all-optical non-volatile memory elements. Such devices have been previously shown to exhibit photoluminescence under excitation in proportion to their programmed charge state. This photoluminescence is attributed to exitonic recombination of electron-hole pairs at the quantum confined bandgap, commonly observed in the near IR. We have fabricated such optical memory devices on 300mm wafers with silicon nanocrystals formed by high temperature annealing of silicon implanted into thermally grown gate oxides. A semitransparent polysilicon gate contact allows simultaneous optical and electronic access to the nanocrystals that form the floating gate of the transistor. Important questions surrounding the function of these devices include the relative importance of (i) Stark shifting of exciton states due to fields resulting from applied gate biases and (ii) free carrier absorption in the quenching of photoluminescence. We will present the results of measurements addressing this issue and the charge state dependence of exitonic photoluminescent emission in general.

3:30 PM *I2.5
DISLOCATION ENGINEERED LIGHT EMITTING DIODES FOR

SILICON OPTOELECTRONICS. K.P. Homewood, M.A. Lourenco, R.M. Gwilliam, S. Galata, S.A. Siddiqui, M. Milosavljevic, and Guosheng Shao[a], School of Electronics and Physical Sciences, [a]School of Engineering, University of Surrey, Guildford, Surrey, UK.

The field of silicon based optical emitters has progressed rapidly in the last few years with several key reports of silicon based devices that operate at room temperature with practical efficiencies. Here we describe developments of one of the most promising technologies - Dislocation Engineering. A key aspect of this approach, which cannot be over emphasized, given the massive "tool-up" costs in the microelectronics industry, is that all the process steps are completely compatible with ULSI technology. Conventional implantation technology, using the standard dopant species are used to make light emitting diodes (LEDs) in crystalline silicon that operate efficiently at room temperature under forward bias. In the dislocation engineering approach a dislocation loop array, formed by ion implantation, is used to produce a strain field that can be made to modify the band gap of the silicon in such a way that the silicon itself can be used to provide spatial confinement of carriers. This enables the non-radiative recombination in the bulk and at the surface to be decoupled allowing efficient radiative recombination to occur in the active region of the device. Boron implantation has been used to form both the dislocation loop array and the p-type dopant to form a p-n junction in n-type silicon. The device operates conventionally under forward bias. Unpackaged LEDs are achieving external power efficiencies, at room temperature, of up to 0.1%, comparable, to that achievable in conventional III-V infra-red LEDs. The usual thermal quenching of electroluminescence has been eliminated. Indeed, the integrated EL intensity actually increases with temperature showing that we have fully decoupled the radiative carrier population from the non-radiative routes. In this paper we will also discuss methods of tuning the emission wavelength of the device over the important 1.1 to 1.7 micrometer range.

4:00 PM I2.6
ON THE LUMINESCENCE EFFICIENCY OF SILICON DIODES. Donald S. Gardner, Circuits Research, Intel Labs, Santa Clara, California; Seth R. Bank, Lynford Goddard, Peter Griffin, and James S. Harris, Center for Integrated Systems, Stanford University, Stanford California; Richard Swanson, SunPower Corp., Sunnyvale, California; J.R. Patel, SSRL/SLAC, Stanford University, Stanford, California, ALS/LBL, Berkeley CA.

Recently, there has been increasing interest in light emission from silicon for optoelectronic circuits and interconnections. In this work, we have fabricated diodes using both implantation and gas-source diffusion. Devices were prepared using BBr3 gas together with oxygen to create a junction, then annealed. Similar devices were implanted with boron and BF2, then annealed at 1000°C for 20 min. Photoluminescence and electroluminescence was measured from both types of devices. Photoluminescence from implanted junctions is almost an order of magnitude lower than unprocessed Czochralski or float-zone silicon. The efficiency of silicon diodes can be improved by reducing the surface/contact recombination, and bulk recombination (Auger and Shockley-Read-Hall). Efficiencies up to 0.25% were obtained in thin Si devices. The challenge is that because silicon is an indirect bandgap material, the radiative recombination lifetime is long, so large volumes of silicon with long non-radiative lifetimes are needed. This also means that the carriers are removed by slow recombination and diffusion rather than drift resulting in slow switching speeds. Potential solutions for this will be discussed.

4:15 PM *I2.7
EXCEPTIONALLY HIGH RADIATIVE EFFICIENCIES IN SILICON. Martin A. Green, Thorsten Trupke, Jianhua Zhao, Aihwa Wang, Centre for Third Generation Photovoltaics, University of New South Wales, Sydney, AUSTRALIA.

Following on from our group's demonstration of very high silicon light emitting diode efficiency (Nature, Vol. 412, p. 805, 2001), about 10-100 times higher than previous reports, we have begun exploring the limits on radiative efficiency in silicon. By paying particular attention to non-radiative surface recombination rates, parasitic free carrier absorption and carrier injection level, substantially increased radiative efficiency has been demonstrated. Internal quantum efficiencies above 20% have been observed in optimised samples with further improvements expected by the Meeting.

SESSION I3: OPTICAL GAIN / LOW-DIMENSIONAL STRUCTURES
Chairs: Albert Polman and Jan T. Linnros
Wednesday Morning, April 23, 2003
Golden Gate A1 (Marriott)

8:30 AM *I3.1
STIMULATED EMISSION IN NANOCRYSTALLINE SILICON SUPERLATTICE. Jinhao Ruan, University of Rochester, Department of Physics and Astronomy, Rochester, NY; Philippe M. Fauchet, University of Rochester, Department of Electrical and Computer Engineering, Rochester, NY; L. Dal Negro, M. Cazzanelli, L. Pavesi, Universita di Trento, INFM & Dipartimento di Fisica, Trento, ITALY.

Optical gain is usually thought to be impossible in silicon because of the severe limitations arising from its indirect bandgap nature together with the high probability for free carrier absorption and Auger recombinations. A recent report [Pavesi et al., Nature 408, 440(2000)] suggested that gain can be achieved in a waveguide containing highly packed Si nanocrystals. In this abstract, we report results on optical gain in nanocrystalline silicon superlattices prepared by sputtering. The structures were made of alternating layers of a-Si and SiO_2 on Si wafer and annealed at high temperatures to get arrays of silicon quantum dots with narrow size distribution. Waveguides have been obtained to perform gain studies by using the Variable Stripe Length (VSL) method under intense pulsed laser pumping at 355 nm. By performing time resolved VSL experiments, a strong fast component in the nanosecond range was revealed on top of the usual slow (some microseconds) decay. The fast component disappears completely as the pumping length is reduced below a critical interaction length where amplified spontaneous emission can no longer build up. A clear threshold behavior is measured for the fast emission component as a function of the pumping rate. Maximum gain values in the order of 40 cm^{-1} have been measured and a tuning from positive gain to optical losses in the order of 20 cm^{-1} has been obtained by simply reducing the pumping intensity on the sample.

9:00 AM I3.2
PUMP-PROBE MEASUREMENTS USING SILICON NANOCRYSTAL WAVEGUIDES. N. Smith, R.G. Elliman, Electronic Materials Engineering Department, Research School of Physical Sciences and Engineering, Australian National University, Canberra, AUSTRALIA; M.J. Lederer, B. Luther-Davies, Laser Physics Centre, Research School of Physical Sciences and Engineering, Australian National University, Canberra, AUSTRALIA.

In an attempt to measure optical gain from photo-excited silicon nanocrystals, pump-probe measurements were performed on planar slab waveguides containing silicon nanocrystals. The waveguides were fabricated by ion-implanting thermally grown SiO_2 layers with 600 keV Si ions to fluences in the range from 1.3 x 10^{17} to 3 x 10^{17} /cm^2) and annealing at 1100°C for 1 hour in N_2. The refractive index change resulting from the presence of the nanocrystals (up to ≈0.2) was sufficient to form low-loss (∼3-5 dB/cm) waveguides. Pump-probe measurements were then performed by prism-coupling an 800 nm probe beam into the waveguide and monitoring its intensity as a section of the waveguide was irradiated with a 355 nm pump beam (25ns pulse length). In one set of experiments the pump-beam area was kept constant and the fluence varied from 3.5 to 3500 $\mu J/cm^2$, whilst in the second, the average power was kept constant and the excitation length varied. In neither case was gain observed. Instead, the probe intensity decreased with both increasing pump power and increasing strip length. The reduction in probe intensity and its time-response are shown to be consistent with an induced absorption process. The implications for optical gain are discussed.

9:15 AM I3.3
NANOCRYSTAL SENSITIZED, Er DOPED SILICA AS THE MATERIAL BASIS FOR GAIN-PROVIDING, ACTIVE Si-BASED MICROPHOTONICS. Hak-Seung Han, Se-Young Seo, Yong-Seok Choi, Y.H. Lee, and Jung H. Shin.

Erbium, with its intra-4f transition luminescence near 1.54 μm, has been a critical factor enabling the recent information revolution. However, the very same factors that led to success of EDFA require long interaction distances, making it unsuitable as the basis material for Si-based, active microphotonics. In this paper, we demonstrate that by sensitizing Er in silica with nanocystal Si (nc-Si), it is possible to alter the luminescence properties of Er^{3+} sufficiently to enable it to become the material basis for compact, active Si microphotonics. Er-doped silicon-rich silicon oxide (SRSO), which consist of nc-Si embedded inside Er-doped SiO_2, was prepared by electron-cyclotron resonance plasma enhanced chemical vapor deposition of SiH_4 and O_2 with concurrent sputtering of Er and subsequent rapid thermal annealing. Single-mode, ridge-type waveguide was fabricated by wet chemical etching. The waveguide shows signal enhancement of up to 14 dB/cm, corresponding to a possible optical gain of up to 7 dB/cm, of a coupled 1.54 μm external signal when pumped vertically from the top with 477 nm light. From the dependence of signal enhancement on the pump power, we determine that nc-Si sensitization increases the effective excitation and emission cross section of Er^{3+} by factors of 10,000 and 100, respectively. Analysis of data indicate that elimination of free carrier absorption, upconversion, and non-excitable

Er fraction by a careful control of Er and nc-Si concentration to be crucial to obtain a film that can become the material basis for compact, Si-based active microphotonics. Finally, we demonstrate fabrication of microdisk using such nc-Si sensitized, Er-doped silica. The factors necessary for such structures to form the basis for integrated, active Si microphotonics will be discussed.

9:30 AM I3.4
TIME-RESOLVED GaIn DYNAMICS IN SILICON NANOCRYSTALS. L. Dal Negro, M. Cazzanelli, N. Daldosso, L. Pavesi, INFM-Dipartimento di Fisica, Universitá di Trento, ITALY; F. Priolo, G. Franzo, D. Pacifici, INFM-Dipartimento di Fisica, Universitá di Catania, ITALY; F. Iacona, CNR-IMM, Catania, ITALY.

High-power time-resolved photoluminescence (TR-PL) measurements on a set of silicon nanocrystal waveguides obtained by plasma enhanced chemical vapour deposition (PE-CVD) show the appearance of a very fast recombination dynamic (20ns) on top of a much longer one (10μs). Time-resolved variable stripe length (VSL) experiments on the same set of samples have revealed a fast recombination dynamics (20ns) related to population inversion under 6ns optical pumping at 430nm. Modal gain values of about 10 cm^{-1} have been measured at 760nm by VSL technique for the fast recombination component, while optical losses of about -15 cm^{-1} have been measured for the integrated signal in the slow ($\approx$10ms) recombination tail. Threshold behaviour in the emission intensity has been unambiguously observed together with a pumping length and pumping power dependence of both the intensity and the time duration of the fast recombination component. These results are explained within an effective four level rate equations model to describe the strong competition among different Auger processes and stimulated emission. The nature of the four levels is also addressed.

9:45 AM I3.5
PROSPECTS OF LASER OPERATION IN ERBIUM DOPED SILICON. M.Q. Huda, S.I. Ali, Dept. of EEE, Bangladesh University of Engineering and Technology, Dhaka, BANGLADESH.

Prospects of laser operation using the $^4I_{13/2}$- $^4I_{15/2}$ transition of erbium in silicon has been analyzed. Shockley-Read-Hall (SRH) recombination kinetics was used to study the mechanism of spontaneous and stimulated emission of erbium. Erbium atoms have been considered to be introducing strong recombination sites in the silicon lattice. Capture and emission of carriers through the erbium related level have been equated for the effective rate of excitation. Only a fraction of electron-hole recombination at erbium sites was found to have contribution in exciting erbium atoms in the higher energy state. Equating the spontaneous emission rate with the stimulated generation and absorption of photons, an expression for erbium atoms in the excited state has been developed. Our expression shows that, achievement of 100% population inversion of erbium atoms is not possible due to the presence of non-radiative decay processes. Impurity Auger processes involving bound and free carriers were found to have limiting effects in higher doping and stronger excitation levels. A two level system was considered for calculation of optical gain and the laser threshold. For a laser cavity of 300 μm with mirror reflectivities of 90%, and an optimistic absorption coefficient of 5 cm^{-1}, a population inversion of $10^{18}/cm^3$ was estimated as the threshold value. Achievement of the laser threshold condition was found to be possible only in cases of low temperature operation with minimized effects from Auger process involving free carriers. For a typical Auger coefficient of the order of 10^{-14} cm^3s^{-1}, and erbium concentrations over $10^{18}/cm^3$, linear increase of the laser output with threshold value of the order of tens of A/cm^2 has been shown.

10:30 AM *I3.6
ELECTRICALLY EXCITABLE ERBIUM-SILICON-OXIDE NANO-COMPLEXES BY WET CHEMICAL SYNTHESIS. H. Isshiki[a,b], M.J.A. de Dood[a], T. Kimura[b], and A. Polman[a]. [a]FOM-Institute AMOLF, Amsterdam, THE NETHERLANDS; [b]Department of Electronic Engineering, Univ. of Electro-Communications, Tokyo, JAPAN.

An entirely new method to fabricate optically active and electrically excitable erbium complexes on silicon is presented. The Er-Si-O compounds are formed by spin-coating a Si(100) substrate with an $ErCl_3$ solution, followed by a rapid thermal oxidation and annealing sequence. This process leads to the formation of a self-organized Er-Si-O crystalline superlattice, epitaxially aligned with facets on the (100) surface. The superlattice period is 0.9 nm, as determined by high-resolution TEM imaging and diffraction, and the Er content is very high: 10-20 at. %. Intense room-temperature luminescence is observed from the Er-Si-O superlattice, with a line width as narrow as 4 meV at room temperature. From the Stark splitting, it is estimated that Er is encapsulated in six-fold-coordinated Er-O_6 octahedra, with a size of 0.45 nm, corresponding to one half-period of the superlattice. The Er emission at 1.53 μm can be excited both directly and through photocarriers. The excitation spectrum has a cutoff at 1.22 eV, well above the bandgap of bulk Si, suggesting that quantum confinement effects play a role in the excitation process. The results suggest that this new material is composed of a superlattice of alternating layers of Si and Er-doped octahedra. Strong coupling is then achieved between the extended electronic states in the superlattice and the Er intra-4f states. This novel material solves many of the problems encountered with other Er-doped Si-based materials such as Er-doped bulk Si, Er-doped silicon-rich SiO_2, and Si/SiO_2:Er multilayers because: 1) a high active fraction may be achieved due to the large O content, 2) high concentrations can be incorporated without concentration quenching, and 3) the superlattice can be directly electrically addressed from the Si wafer. We think that this new material may inspire novel ideas for the fabrication of electrically injected lasers and optical amplifiers based on silicon.

11:00 AM I3.7
Si(111)-Yb TWO-DIMENSIONAL STRUCTURES: FORMATION AND ELECTRICAL PROPERTIES. Nickolay Galkin, IACP FEB RAS, Vladivostok, RUSSIA; Dmitrii Goroshko, Vladivostok State University of Economic and Service, Vladivostok, RUSSIA; S.A. Dotsenko, A.S. Gouralnik, Andrei Boulatov, IACP FEB RAS, Vladivostok, RUSSIA.

In the present work the room temperature film growth mode and electric properties of Yb/Si{111} system have been studied by methods of AES, EELS and by 6-probe Hall measurements. Morphological properties of the films, its correlation with electrical properties and the chemical phenomena taking place on the Yb/Si{111} interface upon Yb deposition have been discussed in the article. It was established that interface formation process may be divided into five stages: 1} two-dimensional growth of Yb {up to two monolayers}, 2} intermixing and formation of two-dimensional Yb silicide, 3} formation of 3D silicide islands, 4} growth of Yb on 3D silicide islands, 5} coalescence of 3D Yb - Yb silicide islands and formation of continuos Yb film. Hall and conductivity measurements have shown the dependence of the layer conductivity in Yb/Si{111} system on the stage of the film growth. We attribute this character of the conductivity behaviour to the evolution of morphological and electrical properties of the growing Yb film {2D Yb, silicide, near bulk metal} rather than to the changes within the space charge layer under the surface. Two-layer calculations have shown that holes are majority carriers in the deposited Yb layer within all the coverage range studied. It was established that the sheet conductivity through the Yb layer is observed just for the small Yb coverage {0.2 ML}. Some amplitude oscillations have been observed in sheet conductivity within the coverage range below 6 ML where formation of a continuos Yb silicide film completes. Conductivity oscillations are explained by transition from semiconductor-type conductivity at the first growth stages (two-dimensional Yb growth) to metal-like conductivity of 2D and 3D Yb silicide films. It was shown that thin continuos Yb film {13 Ml} has the resistivity close to the bulk refractory metals.

11:15 AM I3.8
OPTICALLY ACTIVATED FUNCTIONALIZATION REACTIONS IN Si QUANTUM DOTS. Fernando A. Reboredo, Eric Schwegler, Giulia Galli, Lawrence Livermore National Laboratory, Livermore, CA.

The energy barrier for the replacement of silicon-hydrogen bonds for silicon-carbon bonds at the surface of silicon quantum dots can be reduced by an amount comparable to the exciton energy if the dots are exposed to light and to unsaturated hydrocarbons. Ab-initio calculations show that after absorbing a photon and decaying to the excited triplet state, silicon quantum dots can form a metaestable intermediate state binding and alkene, which could be measured with spin resonance. The final state can be reached with the excitation energy provided by the absorbed photon. In contrast, if the dot is in the ground unpolarized state, a similar reaction would require an activation energy of (2.12$\pm$0.01) eV. This explains recent experimental results on light activated hydrosilation of porous silicon. The size dependence of the light activated reaction could be used to functionalize and "gap select" silicon quantum dots at the same time.

11:30 AM I3.9
PHOTOLUMINESCENCE OF SILICON NANOSTRUCTURED FILMS FORMED BY PULSED-LASER DEPOSITION. Xiaoyu Chen, Yongfeng Lu, Yihong Wu, Byung-Jin Cho, Laser Microprocessing Laboratory and Silicon Nano Device Laboratory, Department of Electrical and Computer Engineering, National University of Singapore, SINGAPORE.

We report silicon (Si) nanostructured films formed by pulsed-laser deposition (PLD) in both inert gas argon (Ar) and reactive gas oxygen (O2). The as-deposited nanostructured films with visible photoluminescence (PL) show a transition from film structure to nanocrystal ($\sim$7 nm), as the ambient gas pressure is increased from 1

mTorr to 1 Torr. The peak position and intensity of the 2.0 eV PL vary with ambient gas pressure, which reveals its dependence on size distribution and surface morphology of nanostructured films. Intensity changes and blue shifts of the 2.0 eV PL are observed after oxidation and annealing. However, no peak shift is found for the 2.55 eV PL before and after oxidation and annealing. The nanocrystal size distribution in the nanostructured films is studied by transmission electron microscopy (TEM), which is in agreement with the size measured from Raman shifts. X-ray diffraction (XRD) shows that the as-deposited nanostructured films have a polysilicon structure. Subsequent anneal is necessary for a more stable structure and better crystallinity. Nanocrystals were also collected by dispersing the chemical-etched porous Si. The size of the nanocrystals is in a range from serveral nm to tens of nm. The 2.0 eV PL of the nanocrystals shifts to blue with reduced particle size while the 2.55 eV PL remains unchanged. All these results clearly demonstrate that the 2.0 eV PL is due to the quantum confinement while the 2.55 eV PL is related to SiOx.

11:45 AM I3.10
Eu-ACTIVATED MULTICOMPONENT OXIDE PHOSPHORS FOR THIN-FILM ELECTROLUMINESCENT DEVICES.
Tadatsugu Minami, Youhei Kobayashi, Yasuyuki Suzuki and Toshihiro Miyata, Optoelectronic Device System R&D Center, Kanazawa Institute of Technology, Nonoichi, Ishikawa, JAPAN.

High-luminance electroluminescence (EL) was found to be obtainable using newly developed Eu-activated multicomponent oxide phosphors composed of combinations of various binary compounds: Ga2O3, Gd2O3, Y2O3, SnO2, GeO2 or SiO2. The EL characteristics were investigated using a thick ceramic sheet-insulating-layer-type TFEL device. The Eu-activated multicomponent oxide phosphor thin films were deposited by r.f. magnetron sputtering and postannealed. The postannealed films were found to be polycrystalline or amorphous, depending on the postannealing temperature and the composition, as evidenced by x-ray diffraction analyses. In addition, the obtainable photoluminescence (PL) and EL characteristics of red emissions from postannealed phosphor thin films were strongly dependent on the composition as well as the depositing and the postannealing conditions. For example, the luminescent characteristics of ((Ga2O3)1-X-(SnO2)X):Eu thin films were considerably affected by the composition (SnO2 content) as well as the postannealing conditions. It is known that a ternary compound, Ga4SnO8, exists in the ((Ga2O3)1-X-(SnO2)X) system, i.e., composed of Ga2O3 and SnO2. However, the highest luminance was obtained in a TFEL device fabricated using a ((Ga2O3)0.5-(SnO2)0.5):Eu multicomponent oxide thin film prepared with a SnO2 content of about 50 mol.% and a Eu content of 1 at.% and postannealed at 950. Emission peaks due to the transition in Eu3+ ions observed from ((Ga2O3)1-X-(SnO2)X):Eu TFEL devices red-shifted slightly as the SnO2 content was increased; CIE chromaticity color coordinates of the emissions changed slightly. As another example, in ((Y2O3)1-X-(Ga2O3)X):Eu multicomponent oxide thin films, the PL characteristics of the postannealed thin films were considerably affected by the composition (Ga2O3 content) and the postannealing conditions. However, the maximum luminance obtained in ((Y2O3)1-X-(Ga2O3)X):Eu TFEL devices was relatively independent of composition and postannealing temperatures in the range from 700 to 1020. In addition, the color of EL emissions from the ((Y2O3)1-X-(Ga2O3)X):Eu TFEL devices was also relatively independent of composition.

SESSION I4:
Chairs: James A. Hutchby and John M. Zavada
Wednesday Afternoon, April 23, 2003
Golden Gate A1 (Marriott)

1:30 PM *I4.1
INTEGRATED SILICON INFRARED MICROSPECTROMETERS.
S.-H. Kong, G. de Graaf, and R.F. Wolffenbuttel, Delft University of Technology, Faculty for ITS, Dept. for Microelectronics, Delft, THE NETHERLANDS.

Design, fabrication and performance of a microspectrometer fabricated in silicon using micromachining techniques are presented. The optical system is composed of two bonded silicon wafers, which have been subjected to microelectronic process compatible micromachining to enable co-integration of the optical components (an aluminum based grating, an optical path in crystalline silicon and an array of aluminum/polysilicon thermocouples) with readout circuits in silicon [1,2].
The main impediment for such a fully integrated silicon optical micro-spectrometer is the definition of a sufficiently long optical path in combination with the implementation of lenses. Path length is limited by practical IC dimensions to 10 mm and, usually, a simple lensless configuration is pursued. Such a micro-spectrometer offers an inferior spectral resolution (about 15 channels over a defined spectral operating range), as compared to bulky macroscopic device. A collimating lens at the entrance slit can be incorporated in the package, however, placement of the focusing lens require in between the grating and the detector array imposes major technological challenges. This limitation is, however, more than compensated in moderately demanding applications by the advantages of small size and low cost in many applications. These include amongst others: quality inspection in industry and agriculture. The low-cost and small size should apply at the system level, which calls for on-chip integration of the optical and electronic components [3].
Silicon is highly transparent for wavelengths, exceeding 1 μm, beyond which free-carrier absorption can be disregarded. Therefore, the bulk silicon can be used to define the optical path rather than air, which would require etching. The aluminum, that is conventionally exclusively used for interconnect, is also applied here for fabrication of the grating and for shielding the array of detectors to prevent frontside illumination by the incident light.
Measurements confirm a 1-9 μm operating range, with a half-power spectral resolution of 0.5 μm. In a practical device, multiple gratings and associated detectors can be merged in a single silicon analyzer for an improved spectral resolution.
[1] R.F. Wolffenbuttel, Silicon photodetectors with a selective spectral response, in: Sensors Update Vol. 9 Editors: H. Baltes, J. Hesse and J. Korvink, Wiley-VCH 2001, pp. 69-101.
[2] S.H. Kong, D.D.L. Wijngaards and R.F. Wolffenbuttel, Infrared micro-spectrometer based on a diffraction grating, Sensors and Actuators A92 (2001) pp. 88-95.
[3] R.F. Wolffenbuttel (editor), Silicon Sensors And Circuits: On-Chip Compatibility, Chapman & Hall, London, 1996.

2:00 PM I4.2
TWO-COLOR MID-INFRARED SPECTROSCOPY OF ISOELECTRONIC CENTERS IN SILICON.
N.Q. Vinh and T. Gregorkiewicz, Van der Waals - Zeeman Institute, University of Amsterdam, THE NETHERLANDS.

One of the open questions in semiconductor physics is the origin of the small splittings of the excited states of bound excitons in silicon. A free electron laser as a tunable source of the mid-infrared radiation (MIR) can be used to investigate such splittings of the excited states of optical centers created by transition metal dopants in silicon. In the current study, the photoluminescence from silver and copper doped silicon is investigated by two color spectroscopy in the visible and the MIR. It is shown the PL due recombination of exciton bound to Ag and Cu is quenched upon application of the MIR beam. The time-resolved photoluminescence measurements and the quenching effects of these bands are presented. By scanning the wavelength of the free-electron laser ionization spectra of relevant traps involved in photoluminescence are obtained. The formation and dissociation of the bound excitons, and the small splittings of the effective-mass excited states are discussed. The applied experimental method allows correlation of DLTS data on trapping centers to specific channels of radiative recombination. It can be applied for spectroscopic analysis in materials science of semiconductors.

2:15 PM I4.3
SPECTROSCOPIC PROPERTIES OF EUROPIUM-DOPED BOROSILICATE GLASSES.
Jack Y. Ding, C.K. Yin, S.W. Yung, P.Y. Shih, National Lien-Ho Institute of Technology, Department of Ceramic and Materials Engineering, Miao-Li, TAIWAN.

Europium oxide has been doped into sodium borosilicate glasses (59SiO2-33B2O3-8Na2O) at various concentration levels. The glass raw materials were calcinated at 800°C and melted around 1350°C and transparent glasses with red color were obtained by quenching the melt in air. Spectroscopic properties of the glasses were measured. The glasses show strong absorption and fluorescence phenamena. Thermal analysis were also performed for the glasses and experimental results show excellent glass forming capability when the concentration of europium oxide is kept under 3 mol%. The glass transition temperature is around 560-590°C at various doping concentration. A typical softening temperature is around 650-670°C and crystallization temperature about 850°C. The europium-doped sodium borosilicate glasses were further heat-treat in temperatures of 570-600°C for phase-separation. Scanning electronic microscope (SEM), energy dispersive spectroscopy (EDS), FTIR, and differential thermal analysis were used to characterize the structure change in phase-separated glass samples.

2:30 PM I4.4
CW AND TIME-RESOLVED PHOTOLUMINESCENCE ANALYSIS OF SILICON IMPLANTED GLASS LOW-TEMPERATURE ANNEALED AT DIFFERENT TIMES.
Chun-Jung Lin and Gong-Ru Lin, National Chiao Tung Univ, Institute of Electro-Optical Engineering, Hsinchu, TAIWAN, R.O.C.

The effects of annealing time on continuous-wave (CW) and nanosecond time-resolved photoluminescence (PL) spectroscopy of silicon-ion-implanted Borosilicate glass (BSO:Si^+) annealed at 500°C are reported. The BSO:Si^+ samples were prepared by multi-energy implanting the BSO glass with silicon ions of 10^{16} ions/cm^2 dose. The CW PL intensity of the as-implanted BSO:Si^+ sample is first increased after 30-min annealing and subsequently decreased to be comparable with that of unprocessed BSO substrate after annealing for longer durations. The increase in annealing time also caused a redshift effect of the PL spectrum. The peak PL intensity of the as-implanted BSO: Si^+ sample is located at 420nm, however, it is slightly redshifted to 520 nm after annealing for 90 min. The increase of PL intensity in the 30 min annealed BSO: Si^+ reveals that the density of non-bridging oxygen hole center (NBOHC) related defects in the as-implanted sample is highly activated. However, these radiative defects are greatly eliminated after the long-term (>60-min) annealing process with its density reducing by factor of 6. This interprets that either out-diffusion or oxidation of the implanted Si atoms is occurred during long-term atmosphere annealing. The corresponding intensities and lifetimes of the multiple-exponential decayed PL traces were obtained by use of nonlinear least-square-fitting program. The carrier lifetimes of BSO:Si^+ is found to lengthen from 1.7ns to 3.3ns after annealing at 500 degree Celsius for 60 min or longer. In addition, other different fluorescence decay with lifetime of 8~10 ns is also observed for as-implanted and annealed samples. The decrease of radiative defect density of BSO:Si^+ by factor of 2 has also been confirmed by Schokley-Read-Hall model. The relative weighting factor of PL intensities for these two decay components are vicissitudinous each other, in which the gradually reduced intensity of shorter decay corroborates again the elimination of radiative defects after annealing.

3:15 PM I4.5
PREPARATION AND MICROSTRUCTURE OF Au (Ru)-SiO_2 MICRO/NANO PARTICLES. Xicheng Ma, School of Chemistry and Chemical Engineering, Shandong Univ., Jinan, PR CHINA; Yuanhua Cai, Qing Ao, Ning Lun, Shitong Li, Shengli Li, Fengzhao Li, Shulin Wen, School of Material Science and Engineering, Shandong Univ., Jinan, PR CHINA; Fan Dou and Hongwei Zhu, Center of Nano-Coating Technology and Engineering, Yantai, PR CHINA.

Metal and semi-conducting nanocrystallines have attracted much attention recently due to the fact that many interesting applications exist for these nanoparticles, such as for high performance optoelectronic devices. In order to acquire good performance of these nanoparticles, a good dispersion is desirable. In this presentation, we described a study on preparation and microstructure of Au (Ru) nanoparticles embedded in SiO_2 matrix microparticles, which were produced as advanced display materials by using Sol-gel method. Both microstructure and composition of these micro/nano-particles were characterized by HRTEM (high resolution transmission electron microscope), EMP (electron microprobe) and nanoprobe EDS (energy dispersive X-ray spectroscopy). Experimental results showed that the products have three levels in structure. The first level is at micro-scale revealed by EMP, indicating that SiO_2 microparticles with diameters in the range from 0.9um to 2.1um are dispersed very well, no aggregation is observed. The second level is at nano-scale revealed by HRTEM, showing that Au (Ru) nanoparticles with ~80% of them having diameters in the range from 3.5nm to 6.5nm are evenly embedded in SiO_2 microparticles, only slight aggregations are observed, indicating that aggregation of nanoparticles can be extremely diminished by using SiO_2 microparticles as matrices. It is expected to further diminish aggregation by reducing SiO_2 matrices to sub-micrometer scale in diameter. The third level gives the lattices of Au and Ru nanocrystallines, showing that lattice distortions often exist in the surface of these nanoparticles, which are presumed to be responsible for some novel properties. Moreover, EDS measurements at this level revealed that Au nad Ru nanoparticles are always separately embedded in SiO_2 matrices, no alloy of them are observed. Further studies to optimize the preparation parameters and systematically investigate the effect of the size of SiO_2 matrix particles on the dispersion of Au (Ru) nanoparticles are still in pursuing.

3:30 PM I4.6
HYDROGEN PASSIVATION KINETICS OF SILICON NANOCRYSTALS IN SiO_2. A.R. Wilkinson, R.G. Elliman, Australian National University, Research School of Physical Sciences and Engineering, Electronic Materials Engineering Department, Canberra, AUSTRALIA.

Hydrogen passivation of non-radiative defects increases the luminescence intensity from silicon nanocrystals. In this study, photoluminescence and time-resolved photoluminescence were used to investigate the chemical kinetics of the hydrogen passivation process. The Si nanocrystals were synthesised by ion-implanting thermally grown SiO_2 layers with 400 keV Si ions to a fluence of $2x10^{17}cm^{-2}$ and precipitating the excess Si by thermal annealing at 1100°C for 1 hour in a high-purity Ar ambient. Subsequent isochronal and isothermal annealing sequences were used to determine the reaction kinetics for the absorption and desorption of hydrogen, using the generalised simple thermal (GST) model proposed by Stesmans [1, 2] for planar Si/SiO_2 interfaces. This included determination of the activation energies and rate constants for the forward and reverse reactions as well as the associated spread in activation energies. Hydrogen passivation was performed by annealing in high-purity forming gas (5% H_2 + 95% N_2), and hydrogen dissociation performed in high-purity N_2. The reaction kinetics determined from such measurements are discussed in comparison to those for passivation of P_b defects [3] at planar Si/SiO_2 interfaces. [1] A. Stesmans, Phys. Rev. B 61, 8393 (2000) [2] A. Stesmans, J. Appl. Phys. 92, 1317 (2002) [3] Y. Nishi, J. Appl. Phys. 10, 52 (1971).

3:45 PM I4.7
EPITAXIAL $Si_{1-x}Ge_x$ FILMS AND SUPERLATTICE STRUCTURES GROWN BY CVD FOR INFRARED PHOTODETECTORS. Lidia Maddiona, Salvatore Coffa, Simona Lorenti, STMicroelectronics, Catania, ITALY; Corrado Bongiorno, CNR-IMM, Catania, ITALY.

Integration of photodetectors with high sensitivity in the near infrared (1.3-1.55 um) using standard Si technology is important for a variety of applications in the field of on-chip, local area and long haul optical communications. In this work we report a detailed structural and optical characterization of epitaxial $Si_{1-x}Ge_x$ films and $Si_{1-x}Ge_x$ /Si multilayers grown by chemical vapor deposition on Si (100). Cross-sectional transmission electron microscopy analyses show that metastable strained $Si_{1-x}Ge_x$ films of few nanometer with x>40% can be deposited at low growth temperature and pressure. Absorption measurements on these films demonstrate the extension of the photo-response to 1.55 um. Using these films as active layers p-i-n and Schottky integrated photodetectors have been fabricated. Data on responsitivity and dark current will be presented and correlated with the structural data.

SESSION I5: IN-ROOM POSTER SESSION
Chairs: James A. Hutchby and John M. Zavada
Wednesday Afternoon, April 23, 2003
4:00 PM
Golden Gate A1 (Marriott)

I5.1
THE ORIGIN OF THE 0.78 EV LUMINESCENCE BAND IN STRAINED LAYER SiGe/Si SAMPLES. A.J. Kenyon, E.A. Steinman[a], C.W. Pitt and D.E. Hole[b], Department of Electronic & Electrical Engineering, University College London, UNITED KINGDOM. [a] Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow District, RUSSIA; [b] Ion Implantation Laboratory, School of Engineering and I.T., University of Sussex, Falmer, Brighton, UNITED KINGDOM.

The photoluminescence band around 0.78 eV that is sometimes seen in strained layer SiGe samples or deformed silicon containing a high density of dislocations has been attributed to the presence of oxygen complexes. In this study we have prepared a set of Si0.9Ge0.1 samples by MBE which have then been implanted with iron, erbium, or oxygen in order to study the effect of implanted impurities on photoluminescence in the technologically important region around 1.5 microns. Following implantation with oxygen, two luminescence bands appear around 0.85 eV and 0.78 eV, respectively. However, these bands are not present in either the unimplanted sample or those subject to Er or Fe implantation. The correlation between oxygen doping and the appearance of these bands supports the conjecture that they are associated with oxygen complexes.

I5.2
TUNNELING CONDUCTIVITY IN THERMALLY OXIDIZED POROUS SILICON. D.G. Yarkin, L.A. Balagurov, A.F. Orlov, State Institute of Rare Metals, Moscow, RUSSIA; S.C. Bayliss, De Montfort University, Leicester, UNITED KINGDOM; I.P. Zvyagin, Faculty of Physics, Moscow State University, Moscow, RUSSIA.

Metal/PS/c-Si structures with porous silicon (PS) layers of 55-75% porosity were fabricated on moderately doped p- and n-type c-Si substrates and were thermally oxidized at 400-960°C. We studied the effect of oxidation on the photoluminescence and charge carrier transport in these structures. We demonstrate that trap-filled space charge limited current (SCLC) is the dominant transport mechanism at large forward bias. The analysis of the current - voltage characteristics in the SCLC region allowed us to determine the oxidation dependence of the effective thickness d of the trap-rich tissue isthmuses, in which space charge is mostly accumulated. The

exponential d-dependence of the conductance in the ohmic region observed at low bias is explained by carrier tunneling through potential barriers formed by SiOx-isthmuses between silicon crystallites.

I5.3
Abstract Withdrawn.

I5.4
SPECTROSCOPIC CHARACTERIZATION OF Er-1 CENTER IN SELECTIVELY DOPED SILICON. N.Q. Vinh, M.A.J. Klik, T. Gregorkiewicz Van der Waals-Zeeman Institute, University of Amsterdam, THE NETHERLANDS; B.A. Andreev, Institute for Physics of Microstructures, Nizhny Novgorod, RUSSIA.

Emission from the Er-1 center dominates photoluminescence (PL) spectrum of selectively Er doped Si/Si:Er multilayer structures grown by the MBE sublimation method [1]. Recently, the symmetry of this optically active Er related center has been investigated in a magneto-optical experiment [2] and established to be orthorhombic I. This first-ever successful observation of the Zeeman effect in Si:Er conclusively proved that preferential formation of a single type of an Er-related optically active center in crystalline Si has been achieved. This represents a major step forward when compared to materials prepared by ion implantation, where multiple Er3+ centers are simultaneously generated. The possibility of preferential formation makes the Er-1 center a possible candidate for application in future photonic devices based on Si:Er, and provides motivation for further investigation of its properties. In the current study we apply high-resolution time-resolved PL spectroscopy at low temperature. We find that the linewidth of the Er-1 spectrum at LHe temperature is below 10 meV, i.e., a factor 103 smaller than commonly observed in Si:Er, Such an extremely small value has important consequences for theoretical estimates on the possibility of optical amplification in Si:Er. The decay time of PL signal from the Er-1 is measured to be considerably shorter than the $\sim$1 ms value usual for Si:Er, and is characterized by two components of $\sim$1 and $\sim$100 ms (of comparable amplitudes). In the study we investigate excitation power and temperature dependence of the decay time in order to decide on the origin of its shortening. [1] M. Stepikhova et al, Mater. Sci. Eng. B 81, 67. [2] N.Q. Vinh et al, Physica B 308-310, 340.

I5.5
THERMO-ELECTRIC PERFORMANCE OF POLYSiGe. D.D.L. Wijngaards, R.F. Wolffenbuttel, Delft University of Technology, Fac. of ITS, Dept. for Microelectronics, Delft, THE NETHERLANDS

PolySiGe as an IC-compatible material has been investigated for application as superior thermo-electric material in IR optical detectors and for integrated Peltier elements.
The polySiGe under investigation is a 0.6 μm thin-film poly$Si_{0.7}Ge_{0.3}$ layer, grown by epitaxy (700°C at 1 atm.) on an LPCVD-deposited 10 nm polySi seed layer. A gas mixture of hydrogen (40 slm), with 5% germanium (51 sccm) and dichlorosilane (20 sccm) was used to establish a growth rate of 35nm/min. After the 600 nm layer was grown, n- and p-type regions were created by ion implantation, both with an energy/dose of 40 keV / 50x10^{15} ions/cm^2 [1].
To verify the theoretical model of integrated Peltier elements, all relevant thermo-physical properties of the materials have to be determined. This includes determination of the figure-of-merit of the thermoelectric material, polySiGe, as well as other material properties (including their temperature coefficients), i.e., the thermal conductivities of Al, SiO_2 and Si_3N_4, the electrical resistivity of Al, and the electrical contact resistance R_c. For the p- polySiGe the resistivity and TCR are 28.9$\pm$0.2 $\mu\Omega$m and (10.6$\pm\cdot$0.7)$\cdot 10^{-4}$/°C respectively, while these are 29.3$\pm$0.3 $\mu\Omega$m and (5.6$\pm$0.4)$\cdot 10^{-4}$/°C for n-type polySiGe. The Seebeck coefficients α_n and α_p are -174 and 129 μV/K respectively. This data yields a figure of merit Z= $0.4.10^{-3}$ K-1, which is an improvement by a factor 5 as compared to polySi and in agreement with literature [2].
Measurements on single integrated Peltier elements have been performed, proving the cooling ability of polySiGe: The current fabrication process chosen (which is not yet optimized) enables cooling to 2.1 K below ambient temperature, at a pressure of $1.7\cdot 10^{-2}$ mbar. At atmospheric pressure, due to the convective losses through the air, a cooling of 0.4 K was obtained.
[1] D.D.L. Wijngaards, S.H. Kong, P.M. Sarro and R.F. Wolffenbuttel, Thermo-physical characterization of PolySi0.7Ge0.3 for use in thermoelectricdevices, Proc. Transducers 01, Munich, Germany, pp.1010-1013.
[2] F. Völklein, G. Min and D.M. Rowe, Modeling of a micromechanical thermo-electric cooler, Sensors and Actuators A75 (1999) pp. 95-101.

I5.6
ACTIVE, Si-BASED PHOTONIC BANDGAP AND MICROPHOTONIC STRUCTURES BASED ON RARE EARTH DOPED HYDROGENATED AMORPHOUS Si ALLOYED WITH CARBON. Yong-Seok Choi, G.K. Mebratu, Y.H. Lee, and Jung H. Shin.

Great interest lies in Si-based photonic crystals as a way of realizing compact, integrated optical circuits compatible with Si processing technology. However, due to the lack of optical activity in Si, Si-based photonic crystals can only play a passive role. Rare earth doping of silicon-based thin films is a very attractive way of obtaining such an optically active, Si-based photonic material. Of the many possible Si-based materials, hydrogenated amorphous silicon (a-Si:H) has the advantages of being a mature, well-characterized semiconductor with the possibility of low-cost, low-temperature, large-area deposition. Furthermore, its refractive index is sufficiently high to allow formation full photonic bandgap, and the carrier-mediated excitation of RE ions in a-Si:H allows efficient vertical coupling of the pump beam to excite RE ions. In this paper, we demonstrate fabrication of active, Si-based photonic crystal structures operating at room temperature using rare-earth doped a-Si:H alloyed with carbon (a-Si:H:C). a-Si:H:C thin films with 15 at. % C doped with Er or Nd were deposited by electron-cyclotron resonance plasma enhanced chemical vapor deposition of SiH_4 and CH_4 with concurrent sputtering of RE target. The films display clear and strong RE luminescence with strongly suppressed temperature quenching of RE luminescence, and increased electronic conduction due to RE doping. Calculations using measured refractive index show that a photonic crystal with full bandgap is possible with this film. Both microdisks and triangular photonic crystal with an air bridge is fabricated. We observe a strong enhancement of the Er photoluminescence extraction efficiency from the photonic crystal, demonstrating room temperature operation of Si-based, active phtonic crystal structure.

I5.7
ENHANCEMENT OF LUMINESCENCE PROPERTIES OF PULSED LASER DEPOSITED EUROPIUM ACTIVATED YTTRIUM OXIDE THIN FILMS ON LASER ROUGHENED SILICON SURFACES. Jaeyoung Choi and Rajiv K. Singh, Dept. of Materials Science and Engineering, University of Florida, Gainesville, FL.

Europium activated yttrium oxide thin films were grown on bare and laser roughened silicon surfaces at various roughness conditions by pulsed laser deposition. The deposited films were characterized using x-ray diffraction, scanning electron microscopy, optical profilometry, atomic force microscopy, photoluminescence and cathodoluminescence. Measurements of photoluminescence and cathodoluminescence properties of europium activated yttrium oxide thin films showed that the films grown on laser roughened silicon surfaces were brighter than the films grown on bare silicon surfaces under identical deposition conditions. Furthermore, this brightness increased with increasing substrate roughness. Since brightness losses are attributed to internal reflection from smooth interfaces, the increased substrate roughness allows increased brightness from the phosphor films by reducing internal reflections.

SESSION I6: SILICON NANOCRYSTALS / EXCITATION SENSITIZATION
Chairs: Wolfgang Jantsch and Francesco Priolo
Thursday Morning, April 24, 2003
Golden Gate A1 (Marriott)

8:30 AM I6.1
EXPERIMENTAL AND THEORETICAL JOINT STUDY ON THE ELECTRONIC AND STRUCTURAL PROPERTIES OF SILICON NANOCRYSTALS EMBEDDED IN SiO_2: ACTIVE ROLE OF THE INTERFACE REGION. N. Daldosso, G. Dalba, L. Pavesi, INFM-Trento Univ, Dept of Physics, Trento, ITALY; F. Rocca, CNR-IFN, Trento, ITALY; F. Priolo and G. Franzo, INFM- Catania Univ, Catania, ITALY; F. Iacona, CNR-IMM, Catania, ITALY; M. Luppi, E. Degoli, R. Magri, S. Ossicini, INFM- Modena e Reggio Emilia Univ, Modena, ITALY.

The local environment of light emitting silicon nanocrystals (Si-nc) embedded in amorphous SiO_2 has been studied by x-ray absorption spectroscopy (XAS) and by ab-initio total energy calculations. Si-nc have been formed by PECVD deposition of SiO_x with different Si content (from 35 to 44 at.%) and thermal annealing at high temperature (1250°C). In XAS, two detection modes, total electron yield (TEY) and photoluminescence yield (PLY), have been used. The comparison between TEY (which is sensitive to all Si absorbing sites) and PLY spectra (whose information are related only to the light emitting Si sites) has allowed the identification of a modified region of SiO_2 (about 1 nm thick) surrounding the Si-nc, which participates to the light emission of Si-nc. Total energy calculations, within the

Density Functional Theory, have been performed for Si-nc embedded in a SiO_2 matrix. All atomic positions and cell parameter are free to relax. The structural optimisation show that Si-nc are surrounded by a cap-shell of stressed SiO_2 with a thickness of about 1 nm. The electronic properties show the appearance of localized states due to the presence of Si-nc. Direct dipole transitions with energies of 1-2 eV are associated to these states, which are localized not only in the Si-nc core region but also in the stressed SiO_2 region. These experimental and theoretical analyses clearly point out the important role played by a deformed SiO_2 host region in determining the optoelectronic properties of Si-nc embedded in SiO_2.

8:45 AM I6.2
NONOXIDE PASSIVATION OF SILICON NANOCRYSTALS.
Julie S. Biteen, Nathan S. Lewis and Harry A. Atwater, California Institute of Technology, Pasadena, CA; Anna L. Tchebotareva and Albert Polman, FOM Institute for Atomic and Molecular Physics, Amsterdam, THE NETHERLANDS.

We have performed a comparative study of oxide- and nonoxide-passivated silicon nanocrystals to probe the role of the silicon/oxygen interface in low coverage, non-interacting silicon nanocrystal systems. Though the surface conditions of Si nanocrystals are intimately related to their optical properties, most studies of Si nanocrystals for device applications have focused on dense arrays of oxygen-terminated silicon nanocrystals. Recent reports of optical gain and lasing in Si nanocrystal systems[1] have invoked three- or four-level models that include, along with the Si band edges, deep-lying radiative Si=O double bond interface states, underscoring the importance of comparing the optoelectronic response of oxide- and nonoxide-passivated interfaces.
Ensembles of Si nanocrystals characterized by a narrow distribution and diameters of 2-5 nm are first synthesized by ion implantation into SiO_2 films followed by a high-temperature anneal in Ar(g). Nanocrystal sizes have been characterized by TEM and exciton dynamics characterized by photoluminescence spectra and decay traces, indicating microsecond photoluminescence decay lifetimes with a stretched-exponential form that is attributed to nanocrystal-nanocrystal energy transfer in the ion-implanted arrays. A second set of nonoxide-passivated nanocrystals are then synthesized by removal from the SiO_2 film matrix and deposited on Si or quartz substrates using a chemical etch in buffered HF. Initially, these nanocrystals are hydrogen-terminated, but unless further processed, they are subject to ambient oxidation over time, and we discuss the time-evolution of their photoluminescence and oxidation state measured by X-ray photoelectron spectroscopy. In a third set of samples, methyl group passivation of completely unoxidized hydrogen-terminated nanocrystals is achieved by a two-step halogenation/alkylation procedure. AFM data indicates that nanocrystals remain on the substrate following the methylation reaction. X-ray photoelectron spectra taken after ambient exposure indicate that methylated nanocrystals show enhanced resistance to oxidation with respect to the hydrogen-terminated nanocrystals. We will present microwave photoconductive decay lifetime measurements of methyl-passivated Si nanocrystals and compare them to their hydrogen-terminated and oxygen-terminated precursors. Finally, these techniques will be extended to studies of ultrasmall (1 nm range) nanocrystals.
[1] L. Pavesi *et al.*, Nature **408**, 440 (2000); M.H. Nayfeh *et al.*, Appl. Phys. Lett. **80**, 121 (2002).

9:00 AM I6.3
EFFICIENT PHOTOLUMINESCENCE OF SILICON-BASED NANOSTRUCTURES: FROM ELABORATION TO MODELLING.
Celine Ternon, Fabrice Gourbilleau, Christian Dufour and Richard Rizk, LERMAT-ISMRA, CAEN, FRANCE.

Due to the possible emission of silicon in the visible range, many researchers focus their interest on the possible light amplification using silicon quantum dots embedded in an insulating matrix. The gain of such devices is highly under debate. We need to understand the mechanisms involved in the desexcitation of the silicon nanograins as well as to find the appropriate material to evidence such mechanisms. In this connection, we have developed an original method based on reactive magnetron sputtering which allows the control of some parameters, such as the silicon grain size or the existence of interface states, both recognized by the scientific community as responsible of the luminescence of silicon based structure. This method consists in sputtering a pure silica target with a plasma containing a reactive gas, H_2. The nature of the deposited layer is closely linked to the deposition conditions (substrate temperature and hydrogen partial pressure), so that the opportunity is offered to fabricate various multilayered structures constituted of silicon and silica and displaying an intense luminescence. Our study supported by X-ray diffraction, reflectivity experiments, high resolution electron microscopy observations as well as photoluminescence measurements evidences the effect of the Si sublayer thickness on the microstructure and on the emission properties. When the thickness is lower than 3 nm, the silicon layer is amorphous and an amorphous-to-crystalline phase occurs for thicker Si sublayers. Concerning the PL results, two bands are present: the one has a maximum varying in the 550-920 nm range which depends on the Si grain size whereas the other has a maximum localized at 800 nm whatever the Si sublayer thickness. The position of these maxima have been theoretically reproduced using a modelisation which accounts for the exciton radiative recombination in amorphous silicon, quantum confinement in nanosized Si layers and interface states.

9:15 AM I6.4
EFFECT OF PARTICLE-PARTICLE INTERACTIONS ON THE ELECTRONIC STRUCTURE IN Si AND Ge QUANTUM DOTS.
T. van Buuren, C. Bostedt, T.M. Willey, L.J. Terminello.

Until recently the effect of the surface layer on the electronic and structural properties of quantum dots has been neglected due to the inherent difficulty in both modeling and measuring this region. Traditional analysis techniques of nanostructures, such as optical spectroscopy of the band gap transitions in semiconductors, provide useful, but lack surface and element specific information about the electronic structure. Synchrotron radiation has been used to study nanostructures to separately measure occupied states by photoemission spectroscopy (PES) and unoccupied states by core level X-ray absorption spectroscopy. Photoelectron spectroscopy has been shown to be a powerful tool to investigate bulk-crystal semiconductor surfaces due to the inherent surface sensitivity of ejected photoelectrons. We have developed a gas-aggregation based production method for semiconductor nanoclusters, which produces nanocrystals from 1 to 10 nm with narrow size distributions. The semiconductor clusters are condensed out of supersaturated vapor which is cooled down in a He-atmosphere and are subsequently deposited on a variety of substrates. Cluster surfaces can be subsequently passivated with different materials evaporated into the vacuum chamber. This approach allows us to probe in a controlled and dynamic fashion the effect of surface passivation and the degree of particle-particle interaction on electronic properties. PES experiments on unpassivated Ge nanocrystal films have shown a disordered surface shell around a crystalline core. For passivated nanocluster films we find that the passivating agent strongly alters the electronic structure of the clusters. In general the absorption edge shifts to significantly higher energies compared to cluster films without surface passivation. These results will be discussed in terms of a reduction of the particle-particle interactions. The work is supported by the US-DOE, BES Material Sciences under contract W-7405-ENG-48, LLNL.

9:30 AM I6.5
CRN MODELING OF Si NANOCRSTAL FORMATION IN A SILICA MATRIX.
Decai Yu and Gyeong S. Hwang, The University of Texas, Dept of Chemical Engineering, Austin, TX.

Nanocrystalline Si embedded in a silica matrix can produce photoluminescence (PL) efficiently via quantum confinement in the Si nanocrystals or radiative recombination between holes confined in the Si nanocrystals and electrons localized in the structural defects in the nanocrystal-oxide interfaces. The optical properties are strongly influenced not only by the shape, size, and spatial distribution of Si nanocrystals but also by the Si-SiO_2 interface state such as structure, composition, strain, and chemical bonding. Although experiments offer many clues to the nanocrystal formation and interface properties, their interpretations remain often controversial. In this talk, we will present our Continuous Random Network (CRN) modeling of i) initial stage of Si nanocrystal growth in a Si suboxide matrix, ii) Si-SiO_2 interface structures and defect states, and iii) strain distribution across a Si-SiO_2 interface. Our simulations have shown that the Si:O ratio in SiO_x plays an important role in determining the growth pattern of Si, i.e., wires to dots. In addition, the Si-SiO_2 interface structures and strain distributions have been found to be quite different from those of planar (layer-by-layer) Si/SiO_2 systems.

9:45 AM I6.6
RADIATION AND DOPING EFFECTS IN LIGHT-EMITTING Si NANOCRYSTALS.
Gregory Kachurin, Svetlana Yanovskaya, Vladimir Volodin, Anton Gutakovsky, Konstantin Zhuravlev, Institute of Semiconductor Physics SO RAN, Novosibirsk, RUSSIA.

The ability of Si nanocrystals (Si-ncs) to emit strong visible light stimulates the search of a means for their formation and modification. We studied the influence of radiation defects and the dopants on optical and structural properties of luminescent Si-ncs formed in SiO_2 by ion-beam synthesis. The Si-ncs were implanted with He, B, N or P ions or irradiated with 400 keV electrons. The subsequent anneals at 600-1100°C were carried out in the inert ambient. The following new facts have been established. The introduction of even single defect in Si-nc quenched the luminescence originated from quantum confined crystals. On the other hand, the radiation induced single atomic

displacements may cause an instant crystallization of Si nanoinclusions at 20°C. Accumulation of point defects up to the level of ~20 at.% amorphizes Si-ncs. To re-crystallize them very high temperature annealing (>1000°C) has to be performed. Raman spectroscopy revealed in the Si-ncs the presence of 2-3 nm crystalline core and of ~1 nm-thick outer shell. The shell is believed to play a crucial role in amorphization and thermal or instant shock crystallization of Si nanoinclusions, mainly due to the surface tension. Doping effects of the implanted Group V elements depend on their solubility in Si. Nitrogen implantation increases the luminescence intensity by providing the new nucleation sites for Si-ncs and therefore by increase in Si-ncs number. High soluble P atoms enhance the Si-ncs crystallization rate, as it is the case for the bulk Si. The theoretically predicted quenching of photoluminescence by the Auger recombination was not observed and the reasons for that are discussed.

10:30 AM *I6.7
OPTICAL PROPERTIES OF SILICON NANOCRYSTAL ASSEMBLY - EFFECTS OF IMPURITY ATOMS AND IMPURITY MOLECULES. Minoru Fujii, Dept of Electrical & Electronics Engineering, Faculty of Engineering, Kobe University, Kobe, JAPAN.

Impurities in Si nanocrystal (nc-Si) assemblies can be classified into two categories. The first one is those doped into nc-Si. We will discuss how the photoluminescence (PL) properties of nc-Si are modified by doping donor and/or acceptor impurities. If either P or B atoms are doped, exciton PL is quenched significantly due probably to the Auger process. On the other hand, if P and B are doped simultaneously, a broad PL peak appears below bulk-Si band gap at room temperature. This low-energy PL is apparently different from that related to surface dangling bond previously observed and may arise from donor-accepter pairs in nc-Si. The second category of impurities is those on the peripheral region of nanocrystals. We adopt Er ions and oxygen molecules as this type of impurities. Since the intra-4f shell transition of Er ions is dipole forbidden and the transition between the triplet-ground-state and singlet-excited-states of molecular oxygen is spin forbidden, photosensitizer is required to excite these materials efficiently. It will be demonstrated that nc-Si act as very efficient photosensitizer for these optically inactive materials. This new function of nc-Si is strongly related to their molecular-like electronic structure. The energy transfer from excitons in nc-Si to Er ions (molecular oxygen) results in the quenching of exciton PL because it is a preferential non-radiative recombination channel for excitons. However, since the electronic states of Er ions (oxygen molecules) are discrete, the inhomogeneously broadened PL band of nc-Si should not be quenched equally; the strength of the interaction varies depending on the bandgap of nc-Si, resulting in an appearance of structures on the PL band. In fact, very clear periodic features with the period of about 61meV were observed on the PL band of nc-Si. The mechanism of the energy transfer will be discussed based on the PL features.

11:00 AM I6.8
MODELING AND PERSPECTIVES OF THE Si NANO-CRYSTALS-Er INTERACTION FOR OPTICAL AMPLIFICATION. D. Pacifici, G. Franzò, A. Irrera, M. Miritello, F. Priolo, INFM and Dipartimento di Fisica e Astronomia, Catania, ITALY; F. Iacona, CNR-IMM, Sezione di Catania, Catania, ITALY; D. Sanfilippo, G. Di Stefano, and P.G. Fallica, STMicroelectronics, Catania, ITALY.

In the last decade a strong effort has been devoted towards the achievement of efficient light emission from silicon. Among the different approaches, rare earth doping of Si nanostructures has shown great potentialities. In the present work, a quantitative understanding of the Er-Si nanocrystals interaction is reported. We present a model based on an energy level scheme taking into account the strong coupling between each Si nanocrystal and the neighboring Er ions. By fitting the steady state and time resolved luminescence signals at both the 1.54 and 0.98 μm Er lines and at the Si nanocrystals emission (~0.8 μm), we were able to determine a value of $3x10^{-15}$ cm^3 s^{-1} for the coupling coefficient. Moreover, an energy transfer time of ~1 μs has been estimated, confirming that Si nanocrystals can actually play a crucial role as efficient sensitizers for Er. However, a strong cooperative up-conversion mechanism, active between two excited Er ions and characterized by a coefficient of $7x10^{-17}$ cm^3 s^{-1}, is shown to limit the Er excitation rate at high pump powers. The role of Si nanocrystals and of strong gain limiting processes, such as cooperative up-conversion and carriers absorption from an excited nanocrystal, in determining positive gain at 1.54 μm will be investigated in details. We will also show that very narrow, intense and highly directional luminescence peaks can be obtained from both Si nc and Er-doped Si nc embedded within Si/SiO_2 Fabry-Pérot microcavities. Moreover, the electroluminescence properties of Si nc and Er-doped Si nc in MOS devices are investigated. It is shown that an efficient carrier injection at low voltages and quite intense room temperature EL signals with efficiencies up to 1% can be achieved. The impact of these results on the fabrication of electrically driven optical amplifiers will be finally addressed.

11:15 AM I6.9
TIME-RESOLVED EXCITATION SPECTROSCOPY OF Er^{3+} CENTERS IN SiO_2 DOPED WITH Si-NANOCRYSTALS. M. Forcales, M. Wojdak, and T. Gregorkiewicz Van der Waals-Zeeman Institute, University of Amsterdam, THE NETHERLANDS; D. Pacifici, D. Franzò, F. Priolo INFM University of Catania, ITALY; F. Iacona, CNR-IMM, Catania, ITALY.

Doping with silicon nanocrystals (Si-nc) dramatically (factor 10^5) increases excitation cross-section of Er^{3+} centers in SiO_2 and allows the excitation process to proceed in a non-resonant way, via the nanocrystallites [1,2]. Consequently, intense photoluminescence (PL) at $\lambda \approx 1.54$ μm from SiO_2:Er,Si-nc can be obtained under optical pumping in a broad range. However, Er-related PL intensity under (cw low-power) resonant excitation (with an Ar^+ ion laser set to the $^4I_{15/2} \longrightarrow {}^4F_{7/2}$ transition at λ = 488 nm), was measured to increase by approximately two orders of magnitude in the presence of Si-nc [2,3]. This is considerably less that one could expect in view of the much larger excitation cross-section, and indicates that the role of Si-nc is not limited to absorption enhancement. In the present contribution we report results of a systematic study of the role of Si-nc in the excitation and de-excitation of Er^{3+} ions in SiO_2. For that purpose a set of two SiO_2 layers (with and without Si-nc) and with an identical concentration of Er^{3+} ions is prepared by PECVD method. For comparison a reference sample with Si-nc (identical concentration) but not containing Er is used. In the experiment we measure intensity and dynamics of the 1.54 μm emission as function of wavelength and power of excitation with a pulsed OPO laser system (450-2500 nm). Using resonant (λ_{OPO} = 520 or 980 nm) and nonresonant pumping we investigate how excitation cross-section of Er^{3+} ions, lifetime of the $^4I_{13/2}$ excited state, and the concentration of optically active Er-related centers is influenced by introduction of Si-nc into the SiO_2 matrix. In addition, the excitation cross-section is measured from PL intensity power dependence, and compared with literature values obtained under cw pumping. Based on the new experimental findings, role of Si-nc as synthesizers of Er PL is discussed. [1] P.G. Kik, A. Polman, J. Appl. Phys. **88**, 1992 (2000) [2] M. Fujii et al., Appl. Phys. Lett. **71**, 1198 (1997) [3] G. Franzò et al., Appl. Phys. A. **69**, 3 (1999).

11:30 AM I6.10
THE EFFECT OF Nd-NANOCRYSTAL INTERACTION ON DE-EXCITATION OF Nd-DOPED SILICON-RICH SILICON OXIDE. Se-Young Seo and Jung H. Shin, Dept of Physics, Korea Advanced Institute of Science and Technology (KAIST), Yusung-gu, Taejon, KOREA.

Rare earth (RE) doped nanocrystal Si (nc-Si) represent an interesting and successful approach to obtain an active, Si-based photonic materials that combines the best properties of efficient RE luminescence in silica and efficient RE excitation via excitons in silicon. However, despite the amount of research, a detailed picture of the interaction mechanism between nc-Si and RE ions is still lacking. In this paper, we report on the luminescence properties of Nd^{3+} doped into silicon-rich silicon oxide (SRSO) that consists of nc-Si embedded inside a silica matrix. Nd was chosen because its intra-4f luminescence coincides with the nc-Si luminescence, allowing a more direct investigation of RE/nc-Si interaction, and also because its luminescence at 0.9 μm that can be detected with Si diodes. Nd-doped SRSO thin films, were prepared by electron-cyclotron-resonance plasma enhanced chemical vapor deposition of SiH_2 and O_2 with co-sputtering of Nd and subsequent anneal at 950°C. Dependence of Nd^{3+} photoluminescence on the excess Si content and the excitation beam wavelength indicates that Nd is excited through photogenerated, quantum confined excitons in the nc-Si. However, in spite of relative small energy mismatch between exciton and absorption band of Nd, temperature quenching of luminescence intensity and lifetime of Nd^{3+} is much smaller than those of Nd-doped bulk semiconductor material, contrary to the widely accepted model of back-transfer. Based on a model of temperature-induced quenching of RE luminescence, we attribute this small temperature quenching of the luminescence lifetime not to the wide-band gap of host, but to the relative weakness of the coupling between nanocrystals and Nd compared to that between bulk semiconductors and Nd. Based on the result, we propose that for efficient RE luminescence from RE-doped SRSO, it is critical to control the nc-Si/RE interaction such that the coupling is weak enough to result in a small temperature quenching of excited RE ions while still stronger than the intrinsic nc-Si luminescence to allow efficient excitation through excitons in nc-Si.

11:45 AM I6.11
A SILICON-BASED INFRA-RED PHOTODETECTOR EXPLOITING ERBIUM-DOPED SILICON NANOCRYSTALS. A.J. Kenyon, S.S. Bhamber, and C.W. Pitt, Department of Electronic & Electrical Engineering, University College London, London, UNITED KINGDOM.

We have exploited the interaction between erbium ions and silicon nanoclusters to produce a photodetector for use in the spectral region around 1.5 μm. The device consists of an MOS structure in which the oxide layer has been implanted with both erbium and silicon and annealed to produce silicon nanocrystals around 3 nm in diameter. Upon illumination with a 1480 nm laser diode, the well-known interaction between the nanocrystals and the rare-earth ions results in a transfer of excitation from the erbium ion to nearby silicon nanocrystals. The resultant modification of the conductivity of the oxide layer enables a current to flow when a voltage is applied across the oxide layer.

SESSION I7: FUNDAMENTALS / NON-SILICON MATERIALS
Chairs: Gordon Davies and Tom Gregorkiewicz
Thursday Afternoon, April 24, 2003
Golden Gate A1 (Marriott)

1:30 PM *I7.1
MICROSCOPIC STRUCTURE OF OPTICALLY-ACTIVE Er-RELATED CENTERS IN Si. H. Przybylinska, Institute of Physics, Polish Academy of Sciences, Warsaw, POLAND; N.Q. Vinh and T. Gregorkiewicz, Van der Waals-Zeeman Institute, University of Amsterdam, THE NETHERLANDS; B.A. Andreev and Z.F. Krasil'nik, Institute for Physics of Microstructures, Nizhny Novgorod, RUSSIA.

The Si:Er system has been extensively investigated because of potential applications in Si based optoelectronics. Despite this, very little is known on the microscopic structure of optically active erbium centers in silicon, in contrast to other Er doped semiconductors. In Er implanted silicon numerous attempts have been made to identify the location, site symmetry and nearest neighbors of the Er impurity, with use of such methods as channeling, EPR, and EXAFS. None of the methods, however, can distinguish between optically active and inactive centers, moreover, centers dominant in photoluminescence are not necessary those ocurring at the highest concentration. The only technique that can yield unambiguous information on the microscopic structure of the PL active centers in Si is the Zeeman effect. Unfortunately, owing to the great multiplicity of centers usually formed in silicon by Er implantation, with often overlapping PL spectra, no observation of the Zeeman effect has been so far possible. The situation is different in a sublimation MBE-grown sample, consisting of 400 interchanged Si and Si:Er layers of a few nanometer thickness, where a preferential formation of a single type of center has been observed. The extremely narrow linewidth ($<$10 μeV) made a successful observation of the Zeeman effect on Er^{3+}-related photoluminescence possible. A clearly resolved splitting of 4 major spectral components was observed in magnetic fields up to 5.5 T. The Zeeman effect was also investigated for the "hot" line appearing in the PL spectrum upon temperature increase. Based on the analysis of the data the symmetry of the dominant optically active center was conclusively established as orthorhombic C_{2v}, with g% $_{\parallel} \approx 18.4$ and $g_{\perp} \approx 0$. The fact that $g_{\perp} \approx 0$ explains why EPR detection of the Er-related optically active center in silicon may be difficult.

2:00 PM I7.2
REVERSED QUANTUM CONFINED STARK EFFECT OBSERVED FOR SPATIALLY INDIRECT TRANSITIONS IN Si/Ge QUANTUM DOTS. M. Larsson, P.-O. Holtz, A. Elfving, G.V. Hansson, and W.-X. Ni, Dept. of Physics, Linköping University, Linköping, SWEDEN.

We report on the quantum confined Stark effect (QCSE) for the spatially indirect transition in the Si/Ge quantum dot system. Photoluminescence measurements were performed on reversed biased p-i-n and n-i-p diodes in order to probe the QCSE in both field directions. Ten Ge dot layers, each separated by a 60 nm thick Si spacer, were incorporated in the intrinsic region. The lateral size of the dots is 20-30 nm and the heights are about 2-3 nm. The Si in the vicinity of the dot is tensile strained, which causes a notch potential for the electrons in the Si at the Si/Ge interface. Hence, the Si/Ge quantum dot system exhibit a type-II band lineup, the holes are in the Ge dot while the electrons are located in the notch potential of the surrounding Si. Consequently, any optical transition will be spatially indirect. We observe a blue-shift of this spatially indirect transition with increasing electric field, in sharp contrast to what is observed for type-I systems where the QCSE causes a red-shift of the transition energy. This reversed QCSE is shown for both field directions i.e. for the p-i-n as well as the n-i-p structure. This is the first reported reversed QCSE in the Si/Ge quantum dot system. At high electric fields the PL is quenched due to electron tunneling out of the notch potential. Different quenching-rate for the p-i-n and n-i-p structures implies an asymmetric energy band lineup. Our results indicate that there is a deeper potential well for the electrons above the dot than underneath. Higher strain in the embedding Si above than underneath the Ge dots could provide such an asymmetry.

2:15 PM I7.3
AUGER QUENCHING IN Si:Er INVESTIGATED WITH NEAR- AND SUB BANDGAP EXCITATION SPECTROSCOPY. M.A.J. Klik and T. Gregorkiewicz, Van der Waals-Zeeman Institute, University of Amsterdam, THE NETHERLANDS; A. Yablonsky, B.A. Andreev, Institute for Physics of Microstructures, Nizhny Novgorod, RUSSIA.

We have investigated the excitation of Er ions in an Er doped MBE grown Si/Si:Er superlattice by using a pump laser with photons of energy comparable to or lower than the bandgap of crystalline Si. Although for band-to-band excitation of these systems the intensity of photoluminescence from Er generally increases with increasing photon flux of the exciting laser, we measured a decrease for very high fluxes. The decrease is related to the (high) laser generated free-carrier concentration in the investigated sample. These carriers participate in an Auger process where the energy of the excited Er ion is transferred to the free carrier. This quenching mechanism reduces the maximum photoluminescence that can be obtained from these systems. Because the number and effective temperature of the carriers will depend on the photon energy and flux used to excite the sample, the magnitude of the Auger quenching process will also depend on these parameters. Indeed, such dependence has been measured in the present study. Highly effective excitation was found for photon energies near the bandgap of the host, where the effects of Auger quenching are severely reduced. In addition, sub-bandgap excitation reveals new details on the Er excitation mechanism under optical pumping.

2:30 PM I7.4
ENHANCED SOLUBILITY OF OPTICALLY ACTIVE ERBIUM IN SILICON DUE TO HYDROGENATION. Gudrun Kocher, Wolfgang Jantsch, Leopold Palmetshofer, Inst. Halbleiterphysik, Johannes Kepler Universitaet Linz, AUSTRIA; Alexander Ulyashin, Fernuniversitaet Hagen, GERMANY.

We investigate the effect of hydrogenation (both via plasma enhanced CVD and ion implantation) on the photoluminescence of Si:Er,O. We find a significant enhancement of the luminescence yield after hydrogenation. In addition, the luminescence of the hydrogenated samples show the five line pattern of the cubic center whereas reference samples prepared identically but without hydrogen exhibit only the eight line spectra due to Er-O complexes. SIMS measurements show a strong migration to the surface of erbium and oxygen after hydrogenation and annealing. Removing this surface layer leads to only a small reduction (less than 10%) of the luminescence yield in spite of the fact, that more than 80% of the incorporated erbium were thus eliminated. Life time measurements together with studies of excitation power dependence (saturation behavior) show that the remaining number of optically active erbium centers is higher than in reference samples. The total number of incorporated erbium according to SIMS is smaller in the hydrogenated samples, though. These findings show that the solubility of the isolated optically active erbium in silicon can be enhanced by hydrogenation by an estimated 1500%.

2:45 PM I7.5
GREEN-BLUE LIGHT EMISSION OF SILICON NANOSTRUCTURES EMBEDDED IN SILICON-OXIDE FILMS PREPARED BY RF CO-SPUTTERING. P.T. Huy, N.V. Toan and N. Duc Chien, International Training Institute for Materials Science (ITIMS), Hanoi, VIETNAM.

In the last few years, photoluminescence from nanocrystalline silicon embedded in dielectrics, such as amorphous silicon and silicon oxide, prepared by various techniques, has been extensively studied. As a result of these studies, intense PL in a range of energy from red to blue emitted at room temperature from these materials has been observed. This provides the possibility to incorporate the optoelectronics function in silicon integrated circuits. In this paper we report on strong and stable green-blue photoluminescence, visible to the naked eye under 365 nm ultra-violet excitations, observable from samples of silicon nanostructures embedded in SiO_2 matrices. The samples have been fabricated by rf co-sputtering followed by an annealing in nitrogen atmosphere. The effects of annealing temperature, annealing time, silicon concentration and film thickness on the PL intensity and energy have been measured and are discussed.

3:30 PM *I7.6
PHOTONICS IN GROUP IV SEMICONDUCTOR ALLOYS AND NANOCRYSTALS. Harry A. Atwater, R.J. Walters, J.S. Biteen, T. Feng, J. Casperson, Thomas J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, CA and Harvard University, Cambridge, MA; R. Ragan, HP Quantum Structures Research Laboratory, Palo Alto, CA; and A. Polman, FOM

Institute for Atomic and Molecular Physics, Amsterdam, THE NETHERLANDS.

In this talk, I will discuss optoelectronics of Si, Ge and Sn alloys and nanocrystals and potential research directions in photonic group IV nanostrucures. The narrow gap semiconductor alloys SnGe and SnSi offer the possibility for engineering tunable direct energy gap Group IV semiconductor materials. For pseudomorphic SnGe alloys grown on Ge (001) by molecular beam epitaxy, an indirect-to-direct bandgap transition with increasing Sn composition is observed, and the effects of misfit on the bandgap analyzed in terms of a deformation potential model. Key results are that pseudomorphic strain has only a very slight effect on the energy gap of thin SnGe alloys grown on Ge (001); for thicker SnGe alloy films, a strain and composition-driven growth instability leads to the formation of a dense array of pseudomorphic Sn-rich nanowires along the growth direction. In the SnSi system, ultrathin pseudomorphic epitaxially-stabilized cubic SnSi alloys are grown on Si (001) substrates by conventional molecular beam epitaxy. Coherently strained cubic Sn quantum dots are formed within a defect-free Si (001) crystal by phase separation of the thin SnSi layers embedded in Si (001) Attenuated total reflectance infrared absorption measurements indicate absorption features which are consistent with direct interband transitions in cubic Sn embedded in Ge and Si matrices. The photophysics and electronic properties of silicon nanocrystals have now been studied for more than ten years and still continue to yield surprises. I will discuss the dependence of nanocrystal luminescence on electronic charge state, and survey potential applications for silicon nanocrystal arrays in nonvolatile memory devices, photodetectors, novel optical memory devices, and future possibilities for silicon nanocrystals in photovoltaic devices.

4:00 PM I7.7
PROGRESS IN DIAMOND OPTOELECTRONICS.
Richard B. Jackman, Oliver A. Williams, Haitao Ye, Damianos Troupis, Stephane Curat, Olivier Gaudin, Electronic and Electrical Engineering, University College London, London, UNITED KINGDOM.

Early predictions that CVD diamond would lead to a new generation of high performance electronic devices were undermined by the apparent difficulties growing high quality material and in identifying effective dopants. Despte this, we were able to produce highly effective photoconductive devices based on free standing polycrystalline CVD grown diamond films, through the use of post-growth defect passivation treatments. In this manner, highly wavelength selective deep UV detectors were produced, which displayed high levels of gain, low dark currents and could be operated at frequencies in excess of a MHz. These optoelectronic devices became one of the first examples of an active CVD diamond device to be commercially exploited, with industry producing similar detectors under license to us. Since this time, further improvements in material quality, and the discovery that hydrogen terminated surfaces become p-type with little thermal activation, has enabled us to construct even more effective UV detectors based on photodiode and phototransistor designs. 1-D and 2-D imaging arrays have also been produced. A particularly exciting recent development is the use of low cost black diamond substrates with homoepitaxial layers to fabricate large area deep UV detectors at little extra cost to silicon structures. This paper will review the current state-of-the-art of diamond photodetector fabrication and performance and will report opon our latest devices fabricated with homoeptaxial layers which have been specifically designed for 126, 157, 172 and 193nm operation. The first use of phosphorus doped n-type diamond for detector fabrication will also be described.

4:15 PM I7.8
OPTICAL PROPERTIES OF β-$FeSi_2$ MICROCRYSTALLINE FILMS GROWN ON POROUS SILICON.
Yasuo Takigawa and Mayumi Tode, Osaka Electro-Communication Univ, Dept of Electronics, Osaka, JAPAN; Masato Ohmukai, Akashi College of Technology, Dept of Electrical Engineering, Hyogo, JAPAN; Kou Kurosawa, Miyazaki Univ, Dept of Electrical Engineering, Miyazaki, JAPAN.

β-$FeSi_2$ has attracted a great deal of attention as a direct-transition semiconductor with the capability of light emission (Eg=0.88eV) and an environmental-friendly semiconductor at the same time. We challenged to form β-$FeSi_2$ microcrystallites in such a way that iron was deposited on porous silicon instead of silicon wafers, followed by a thermal annealing. We report the structural and optical properties of β-$FeSi_2$ microcrystalline films.

4:30 PM I7.9
BANDGAP ENERGIES AND REFRACTIVE INDICES OF $Pb_{1-x}Sr_xSe$.
A. Majumdar, H.Z. Xu, F. Zhao, L. Jayasinghe, S. Khosravani, X. Lu, V. Kelkar, Z. Shi, Department of Electrical Engineering, University of Oklahoma, Norman, OK.

PbSe and lead-alkaline-earth-chalcogenide materials Pb(1-x)Sr(x)Se have attracted considerable attention in optoelectronic applications especially in the mid-infrared (mid-IR) lasers and mid-IR/UV detectors. The bandgap energies and the refractive indices of this material system vary widely with the change of Strontium composition. While PbSe has a direct band transition at L points, SrSe is reported to have an indirect L - X energy bandgap. Thus, the alloy goes through a transition from direct bandgap to indirect bandgap at a certain composition. In this research, we have grown epitaxial layers of Pb(1-x)Sr(x)Se by molecular beam epitaxy, on < 111 > BaF2, with more than ten different Sr compositions (x) ranging from zero to one. The crystal growth is characterized by high-resolution X-ray diffraction measurements and the Sr composition is determined by assuming a linear change of lattice parameter. Transmissions, in the wavelength range mid-IR to UV, were measured at different temperatures. The refractive indices and absorption coefficients of Pb(1-x)Sr(x)Se with different Strontium composition were determined. Bandgap energies of all different Sr compositions are calculated by fitting the absorption coefficients to theoretical models of either direct or indirect bandgap. A distinct bandgap inversion from the direct to the indirect is observed at x $\sim$0.15. While the direct bandgap of SrSe calculated from our experiments agreed closely with that from reported photoluminescence measurements, the lowest bandgap of SrSe is observed to be $\sim$1.82 eV, contradicting previously published results where the results were obtained only theoretically. These data are first hand and could have significant impact on device design and fabrication.

4:45 PM CLOSING REMARKS - Philippe Fauchet