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E-MRS 2005 Spring Meeting
May 31 – June 3, 2005

SYMPOSIUM C

Rare earth doped photonic materials

Symposium Organizers :

Yasufumi Fujiwara, Osaka University, Japan

Anthony J. Kenyon, University College London, U.K.

Bernard Moine, CNRS, Université Lyon, France

Pierre Ruterana, SIFCOM-ENSICAEN, Caen, France

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E-MRS 2005 Spring Meeting

SYMPOSIUM C

Tuesday, May 31, 2005
Mardi 31 mai 2005

Morning
Matin

Session I : Compound semiconductors Session chairs : T. Kenyon, P. Ruterana

- C-I.01** 9:00 -Invited- STRUCTURE AND ELECTRICAL ACTIVITY OF RE DOPANTS IN SEMICONDUCTORS
R. Jones
- C-I.02** 9:30 EXCITATION CROSS SECTION OF Er-2O LUMINECENT CENTER IN Er,O-CODOPED GaAs GROWN BY ORGANOMETALLIC VAPOR PHASE EPITAXY
Y. Fujiwara(a), T. Tokuno(a), H. Ichida(b), A. Koizumi(c), Y. Takeda(c) and Y. Kanematu(b), (a)Department of Materials Science and Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan, (b)Venture Business Laboratory, Center for Advanced Science and Innovation, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan, (c)Department of Crystalline Materials Science, Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
We have systematically investigated electrical and optical excitation cross sections of an Er-2O center, an Er atom located at the Ga sublattice with two adjacent O atoms, formed selectively in Er,O-codoped GaAs (GaAs:Er,O). In GaInP/GaAs:Er,O/GaInP double heterostructure (DH) light emitting diodes (LEDs) fabricated by organometallic vapor phase epitaxy (OMVPE), 1.5 mm electroluminescence (EL) due to the Er-2O center has been successfully observed under forward bias at room temperature. The injection current density dependence of the EL intensity and its dynamics revealed extremely large excitation cross section of $1-3 \times 10^{-15} \text{ cm}^2$. However, the excitation cross section decreased with increasing active layer thickness [1]. In GaAs:Er,O under optical excitation, on the other hand, the excitation cross section was estimated to be $3-6 \times 10^{-16} \text{ cm}^2$ from static and dynamical measurements on photoluminescence (PL) properties, which was smaller than the electrical excitation cross section ($\sim 10^{-15} \text{ cm}^2$) in a GaAs:Er,O homostructure LED.
[1] A. Koizumi, Y. Fujiwara et al., Physica B 340-342, 309 (2003).
- C-I.03** 9:45 TEMPERATURE DEPENDENT PAC STUDIES WITH THE RARE EARTH 172-Lu IN ZnO
R. Nédélec, R. Vianden, HISKP Universität Bonn, Nußallee 14-16, 53115 Bonn, Germany and the ISOLDE Collaboration, CERN, 1211 Genève 23, Switzerland
Wide band-gap semiconductors have recently emerged as important base materials for applications in optoelectronics and in high power, high temperature electronics. In combination with various Rare Earth (RE) electroluminescence throughout the whole visible spectrum has been observed. Our samples were implanted at the ISOLDE facility at CERN. In order to recover the sustained implantation damage the samples were treated adequately in an rapid thermal annealing furnace (RTA). This process has been optimized in earlier experiments and PAC results show that it is actually possible to recover a large part of the implantation damage.
In a first attempt to measure the temperature dependence of the electric field gradient (EFG) at the site of Lu in ZnO a large jump in the EFG frequency was observed between measurements at room temperature and 200°C. Above 200°C the frequency only changed very little. In order to explain this strange behaviour we prepared another sample and studied the temperature range between room temperature and 200°C more in detail. Both results match perfectly. Moreover, they show a smooth increase of the EFG frequency from about 146 MHz at room temperature to almost 400 MHz at 400°C. We discuss possible interpretations of these results and compare them to results obtained with the PAC probe 181-Hf.
- C-I.04** 10:00 PHOTOLUMINESCENCE PROPERTIES OF Eu-DOPED II-VI SEMICONDUCTOR NANOCRYSTALS
A. Ishizumi, Graduate School of Materials Science, Nara Institute of Science and Technology, Ikoma, Nara 630-0192, Japan and Y. Kanemitsu, Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan
Recently, there have been many studies on the optical properties of semiconductor nanocrystals doped with luminescence centers because they exhibit efficient luminescence even at room temperature. It is expected that they will become new nanophosphors with high luminescence efficiency. In this work, we have fabricated ZnO and CdS nanocrystals doped with Eu ions and have studied their photoluminescence (PL) properties.
The Eu-doped ZnO (ZnO:Eu) nanocrystals were fabricated by a microemulsion method. The transmission electron microscope and x-ray diffraction observations show that the ZnO:Eu nanocrystals have the rod-like shape and their crystal structure is hexagonal. The ZnO:Eu nanorods show the sharp PL lines due to the intra-4f transitions of the trivalent Eu ions. The

Eu-doped CdS (CdS:Eu) nanocrystals and CdS:Eu nanocrystals with thin CdS layers (core/shell structure) were fabricated by a reverse micelle method. The Eu-related PL is observed in the core/shell CdS:Eu nanocrystals, while we cannot observe the PL due to the Eu ions in CdS:Eu nanocrystals without the surface CdS layers. It is considered that the Eu ions are located at the surface of CdS nanocrystals without the overcoated CdS layers, and exist within the nanoparticles in core/shell CdS:Eu nanocrystals. The process of the Eu-related PL in the semiconductor nanocrystals will be discussed.

C-I.05 10:15

DOPING EFFECTS ON 1.54 μ m PHOTOLUMINESCENCE FROM Er-CONTAINING ZnO

Zhen Zhou(a,b), Toshitaka Komori(a), Tatsuya Ayukawa(a), Atsushi Koizumi(b), Noriaki Matsunami(c), Yoshikazu Takeda(b), Masahiko Morinaga(a), (a)Department of Materials Science and Engineering, Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8603, Japan, (b)Venture Business Laboratory, Ecotopia Science Institute, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8603, Japan, (c)Division of Energy Science, Ecotopia Science Institute, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8603, Japan

Erbium (Er)-doped semiconductors are expected as one of the promising optoelectronic materials, because the Er intra-4f shell transition causes a 1.54 μ m photoemission. Many semiconductors have been investigated as host materials for Er, such as Si, GaAs, GaN, etc. Recently a new host semiconductor, ZnO, has been proposed.

In this investigation, in order to modify the local structure around Er³⁺, N, or P or metal impurities were introduced into Er-containing ZnO specimens, and the doping effects were investigated on the photoluminescence (PL) spectra around 1.54 μ m at room temperature. N doping was found to increase the PL intensity around 1.54 μ m by about 40 times, and also the strongest peak position was shifted from 1.534 μ m to 1.539 μ m. Nitrogen was detected in the specimen by means of the ¹⁴N(d, ⁹⁴5);¹²C nuclear reaction analysis. Moreover, the Ne⁺ irradiation and subsequent annealing did not increase the PL intensity. Also, the PL performance changed greatly due to P and metal impurity doping. The N doping was proved an effective method to enhance 1.54 μ m PL intensity from the Er-containing ZnO at room temperature.

10:30

BREAK

Session II : RE in bulk crystals

Session chairs : J. Shin, B. Moine

C-II.01 10:45

MODEL BASED OPTIMIZATION OF SOME GROWTH PROCESS PARAMETERS OF A Nd:YVO₄ CYLINDRICAL BAR GROWN BY EDGE-DEFINED FILM-FED GROWTH (E.F.G.) METHOD IN THE PRESENCE OF THE PRESSURE

L. Braescu(a), A.M. Balint(b), R. Szabo(a), S. Balint(a), (a)Department of Applied Mathematics, West University of Timisoara, Blv. V. Parvan 4, 300223 Timisoara, Romania, (b)Department of Physics, West University of Timisoara, Blv. V. Parvan 4, 300223 Timisoara, Romania

The purpose of this paper is to find those values of the radius r_0 of the outer edge of the die, pulling rate v , melt temperature T_0 at the meniscus basis and pressure p in the furnace, which assure the growth of a Nd:YVO₄ monocrystal cylindrical bar with prescribed radius r_f and for which the surface non-uniformity of the bar, due to small uncontrollable oscillations of v and T_0 is minimum. Numerical results are given for a Nd:YVO₄ cylindrical bar of 2.5 (mm) radius, grown in a furnace in which the vertical temperature gradient is $k=33$ (K/mm) for four type of uncontrollable oscillations: O1= ($v=\pm 0.001$ (mm/s) and $T=\pm 1$ (K)), O2= ($v=\pm 0.01$ (mm/s) and $T=\pm 10$ (K)), O3= ($v=\pm 0.02$ (mm/s) and $T=\pm 20$ (K)), O4= ($v=\pm 0.001$ (mm/s) and $T=\pm 30$ (K)), respectively. For a smooth surface the parameters r_0 , v and T_0 has to be chosen as follows: - $r_0=2.6$ (mm), $p=0.002$ (atm), $v=0.0011$ (mm/s), $T_0=2102$ (K) in the case O1; - $r_0=2.6$ (mm), $p=0.002$ (atm), $v=0.0101$ (mm/s), $T_0=2100$ (K) in the case O2; - $r_0=2.7$ (mm), $p=0.002$ (atm), $v=0.0201$ (mm/s), $T_0=2111$ (K) in the case O3; - $r_0=2.7$ (mm), $p=0.002$ (atm), $v=0.0011$ (mm/s), $T_0=2118$ (K) in the case O4.

C-II.02 11:00

DIODE-PUMPED INFRARED AND UPCONVERSION EMISSIONS IN Er³⁺-DOPED AND Yb³⁺-CO-DOPED PLZT CERAMICS

J.A. Eiras, A.S.S. de Camargo, E.R. Botero, D. Garcia, Univ. Federal de São Carlos, Rod. Washington Luiz Km 235, 13565-905, São Carlos – SP, Brazil and L.A.O. Nunes, Univ. de São Paulo, CP 369, 13560-970, São Carlos – SP, Brazil

Diode-pumped erbium doped solid state laser materials emitting at 2.8 and 1.55 μ m are of recognizable technological importance in medicine and telecommunications. Traditionally, these materials are in the glassy or crystalline forms but transparent ceramics are emerging as a very advantageous and cost-effective alternative. An extensive transmission window in the infrared and the absence of OH- absorption band around 3.0 μ m allowed the observation of these emissions with high intensity in optical quality Er³⁺-doped lead lanthanum zirconate titanate (PLZT) transparent ferroelectric ceramic. Under the same pumping conditions, intense upconversion emission in the green (0.54 μ m) spectral region was also observed. Radiative properties were analyzed using the Judd Ofelt theory and fluorescence quantum efficiencies higher than those of the commercial YAG:Er³⁺ crystals were obtained. The effect of Yb³⁺-co-doping the samples was investigated and it was verified that Yb³⁺ (r) Er³⁺ energy transfer processes favor Er³⁺ upconversion while being detrimental to the efficiency of mid-infrared emissions. The interesting spectroscopic characteristics and excellent thermal and mechanical properties point out PLZT:Er³⁺ (co-doped or not with Yb³⁺) as very promising laser active media in both, mid-infrared and visible spectra.

C-II.03 11:15**INFLUENCE OF Yb³⁺ AND Ce³⁺ DOPING ON THE STRUCTURE AND LUMINESCENCE OF Er³⁺-DOPED TRANSPARENT GLASS-CERAMICS**

G. Dantelle, M. Mortier, D. Vivien, Laboratoire de Chimie Appliquée de l'Etat Solide, CNRS-UMR 7574, ENSCP, 11 rue Curie, 75005 Paris, France and G. Patriarche, Laboratoire de Photonique et Nanostructures, CNRS-UPR20, route de Nozay, 91460 Marcoussis, France

Transparent glass-ceramics possess high thermal and mechanical properties, easy shaping allowing fibers elaboration and easy synthesis. However, previously studied Er³⁺-doped glass-ceramics do not appear efficient enough for optical amplification at 1.5 micron in the telecommunication window. So, the addition of two other doping ions Yb³⁺ and Ce³⁺ was performed.

Oxyfluoride glasses (GeO₂-PbO-PbF₂) doped with ErF₃, YbF₃ and CeF₃ were prepared and heated above glass transition temperature to obtain transparent glass-ceramics. Such treatment brings about the precipitation of fluorite-type nanocrystallites embedded into an amorphous oxide phase. Differential Thermal Analysis and Transmission Electron Microscopy show evidence that ErF₃, YbF₃ and CeF₃ act as nucleating agents for the β-PbF₂ phase. Nonetheless, CeF₃ has higher nucleation efficiency than both others. Energy Dispersive X-ray microanalysis and unit cell parameter study show a segregation of the three rare-earth ions inside the fluorite crystallites, forming a solid solution Pb_{1-x-y-z}Er_xY_yCe_zF_{2+x+y+z}. The influence of Yb³⁺ and Ce³⁺ ions on the luminescence characteristics of Er³⁺-doped glass-ceramics was evaluated. Firstly, Yb³⁺ ions improve the absorption characteristics around 980 nm and, through an efficient energy transfer, allow a better excitation efficiency of Er³⁺ ions. Secondly, CeF₃ enables to decrease dramatically the up-conversion fluorescence of Er³⁺. The study of the lifetimes of the 4S_{3/2}, 4I_{11/2} and 4I_{13/2} levels of Er³⁺ reveals a cross-relaxation process between Er³⁺ and Ce³⁺. Hence, the presence of Ce³⁺ enables to decrease the Er³⁺ up-conversion fluorescence at the benefit of the fluorescence of interest at 1.5 μm, which is strongly enhanced.

C-II.04 11:30**LUMINESCENT CHARACTERIZATION OF LEAD TUNGSTATE CRYSTALS DOPED WITH EUROPIUM, PRASEODYMIUM, AND YTTERBIUM IONS**

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Tungstate crystals are widely doped by the RE ions in order to change luminescence and scintillation characteristics of these crystals. It is well known that doping of the lead tungstate (PWO) crystals by the RE ions improve significantly the PWO characteristics such as: induced transmittance in 330-450 nm region; decreasing of emission decay time; increasing of radiation hardness of the crystal.

Physical mechanism of the noted effect of the RE impurities is still under discussion. There are several models for description of the RE centers in the PWO crystal. The most known ones are consider that three valence impurities decrease concentration of the own matrix defects and uncontrolled impurities or they play role of electron donor in the crystal lattice. In our opinion peculiarities of this effect could be studied by investigation of the PWO crystals doped with the RE ions that are characterized by photoluminescence. Spectral characteristics of the Pr, Yb, and Eu doped PWO crystals were studied in a wide temperature region at the different excitation and registration wave length. In the investigated crystals excitation of emission of the impurity ions is possible in the region of the intrinsic absorption of the RE ions as well as in the region of the matrix absorption. The next conclusions were made. The noted ions are incorporated in crystal lattice of the PWO as triple charged ions. These ions influence on proper matrix emission. Luminescence properties of the ions are sensitive to the nearest crystal surrounding in the investigated matrix. At least two types of luminescence centers on the basis of the RE ions are formed in the PWO crystal lattice. Evaluation of energy level positions for the praseodymium ion was made. This work is supported by STCU Project 2042.

C-II.05 11:45**PROBING INTERACTIONS BETWEEN RARE-EARTH IONS IN A Cs₂NaY_{1-x}Er_xF₆ CONCENTRATION SERIES, A MODEL SYSTEM FOR WIDE-BANDGAP SOLIDS**

H. Vrielinck(a,b), I. Izeddin(a), T. Gregorkiewicz(a), H. De Cooman(b), F. Loncke(b), F. Callens(b), J. Lauwaert(b) and P. Clauws(b), (a)University of Amsterdam, Van der Waals-Zeemaninstitute, Valckenierstraat 65, 1018 XE Amsterdam, The Netherlands, (b)Ghent University, Department of Solid State Sciences, Krijgslaan 281-S1, 9000 Gent, Belgium

Interactions between dopant ions often play an important role in rare-earth (RE) based optical devices, either limiting their performance (e.g. via concentration quenching) or offering new possibilities (e.g. upconversion luminescence). In practical systems, the mechanisms behind these interactions cannot be easily studied, as several conformations of interacting rare-earth aggregates occur simultaneously and for each of them the interaction consists of several contributions, e.g. from lowering the crystal field symmetry, magnetic dipole and exchange interactions. Cs₂NaYF₆, with the cubic elpasolite crystal structure, is in this respect a good host model system, because RE³⁺ ions can only be incorporated on Y³⁺ sites, which are all equivalent, have Oh symmetry and are at a large distance from one another (0.7 nm for nearest neighbors). As a result, only a limited number of RE³⁺ aggregate centers need to be considered in models for describing interactions between them. Moreover, due to the structural similarity between Y³⁺ and most of the RE³⁺ ions, the effects of lowering the site symmetry by neighboring RE³⁺ ions are expected to be small.

In Cs₂NaY_{1-x}Er_xF₆ (0 < x < 1) crystals, considered as a model system for, e.g., GaN:Er, systematic changes in the photoluminescence spectrum at 1538 nm are observed as a function of the Er³⁺ concentration. There is also a pronounced and unexpected influence on the lifetime of the 4I_{13/2} and 4I_{11/2} excited states, as determined from time-resolved luminescence experiments. In order to reveal the physical mechanisms behind these effects, electron paramagnetic resonance and Fourier-transform infrared absorption measurements have been performed on these crystals as well.

HYPERFINE STRUCTURE OF Tm³⁺ IN YAG FOR QUANTUM STORAGE APPLICATIONS

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Quantum storage consists in a coherent transfer of the quantum state of a photon into and from matter, where other quantum processing could take place. It has been shown theoretically that quantum storage can be obtained with three-level Λ systems [1]. Up to now, experimental studies have been performed in gas systems or suffer from significantly different probabilities on the optical transitions of the Λ system [2]. The possibility to control the relative strength of transition probabilities of a Λ system in condensed matter is therefore very attractive and can be obtained with the hyperfine levels of rare earth ions in crystals under a magnetic field [3, 4].

Rare earth doped crystals are commonly used to perform coherent spectroscopy experiments, like hole burning and photon echo. This is explained by the long lifetime (up to minutes) of the hyperfine levels at low temperature ($< 4K$). Moreover, they can also exhibit dephasing time (T_2) of the order of several milliseconds which suggests that they could be used for quantum manipulations such as quantum storage. Tm³⁺ is especially interesting in this respect since its $^3H_6(0) \rightarrow ^3H_4(0)$ transition falls in the spectral range of semiconductor lasers that can be stabilized easily to sub-kHz linewidth and jitter [5]. This is necessary to match the long optical coherence lifetime of rare earth ions in single crystals.

We have determined, from crystal field calculations, the hyperfine structure of Tm³⁺ in YAG under an arbitrary magnetic field orientation [4]. These calculations show that it should be possible to relax the selection rules on nuclear spin projections and therefore build a three level Λ system. These predictions are compared with the hyperfine splittings measured by holeburning spectroscopy. Population transfer between hyperfine levels has also been observed, confirming that the selection rules are efficiently released by the magnetic field.

[1] M. Fleischhauer and M. D. Lukin, Phys. Rev. Lett. 84 (2000) 5094.

[2] A.V. Turukhin, V. S. Sudarshanam, M. S. Shahriar, J. A. Musser, B. S. Ham, P. R. Hemmer, Phys. Rev. Lett. 88 (2002) 023602

[3] Ph. Goldner and O. Guillot-Noël, Mol. Phys. 102 (2004) 1185

[4] O. Guillot-Noël, Ph. Goldner, E. Antic-Fidancev, J.L. Le Gouët, Phys. Rev. B, accepted for publication

[5] V. Crozatier, F. de Sèze, L. Haals, F. Bretenaker, I. Lorgeré and J.-L. Le Gouët, Opt. Commun. 241, 203(2004)

12:30

LUNCH

Session III : GaN I
Session chairs : Y. Fujiwara, R. Mahiou

- C-III.01** 14:00 -Invited- IMPACT OF AlGa_N ON LUMINESCENCE CAPABILITY OF RARE-EARTH IONS IN AlGa_N
A. Wakahara, Toyohashi University of Technology, Toyohashi 441-8580, Japan
Effects of AlN molar fraction on the luminescence properties of rare-earth (RE) impurities in Al_xGa_{1-x}N (x=0~1) have been investigated using cathodoluminescence and time-resolved photoluminescence to clarify the energy-transfer and/or back-transfer processes.
Eu, Tb, and Er were introduced into AlGa_N epi-layers using ion implantation method. The ion implantation was carried out at room temperature with the acceleration energy of 200keV. The dose of RE ions was in the range of 1-10E14 1/cm². The project range and peak concentration estimated by TRIM were 100nm and 3-30E19 1/cm³, respectively. Implantation damage was recovered by using rapid thermal annealing (RTA) in N₂ at 1400°C for 60s. PL intensity due to inner-shell transitions of Eu, Tb, and/or Er increased super linear as increasing the AlN molar fraction at first, then tend to saturate. The line width became broad at the AlN molar fraction around 0.5. These results indicate that local structure, such as ordering or disordering of group-III elements, affect the electronic structure of RE ions. Temperature dependence of PL properties revealed that the thermal quenching became small as increasing the Al contents, and also became small as the major emission lines of RE became longer, i.e., from Er (408nm) to Eu (620nm). The TRPL supported that the improvement of PL capability is caused by improvement of energy transfer efficiency and reduction of energy-back-transfer process.
- C-III.02** 14:30 TEM INVESTIGATION OF Tm IMPLANTED GaN, THE INFLUENCE OF HIGH TEMPERATURE ANNEALING
T. Wojtowicz, F. Gloux, P. Ruterana, SIFCOM UMR 6176 CNRS-ENSICAEN, 6, Boulevard du Marechal Juin, 14050 Caen Cedex, France, K. Lorenz and E. Alves, Instituto Tecnológico e Nuclear, EN10, 2686-953 Sacavém, Portugal
In rare earth (RE) doped GaN, by changing the RE, one can obtain luminescence covering the visible light spectrum. As a wide and direct band gap semiconductor with high electric field properties efficient excitation of the RE is achieved and thermal quenching of the RE luminescence is significantly reduced as compared to semiconductors with small band gaps. Ion implantation is one of the techniques that can be used for doping GaN. In this work transmission electron microscopy (TEM) structural characterization of GaN implanted with Tm ions is carried out. Our aim is to assist in determining the optimal implantation and annealing conditions by studying the effect of the various treatments on the microstructure. We have investigated samples implanted with different energies (150-300 keV), fluences (3-8x10¹⁴ - 8x10¹⁵ Tm/cm²) and implantation temperatures (20-500°C) as well as annealing from less than 1000°C to 1300°C with the protection of an AlN cap at the highest temperatures. The influence of the dose, energy and temperature on the structural quality of the layers will be discussed in detail.
- C-III.03** 14:45 DEPENDENCE OF GROWTH CONDITION ON THE PROPERTY OF EU-DOPED GAN FILMS PREPARED BY RADIO FREQUENCY MAGNETRON SPUTTERING
Shinji Yudate, Ryo Sasaki, Takashi Kataoka, and Sho Shirakata, Electric and Electronic Engineering Department, Bunkyo-choh 3, 790-8577/Matuyama, Ehime Japan
The Eu-doped GaN thin films (GaN:Eu) were deposited on the c plane of sapphire substrate by radio frequency magnetron sputtering method. As a target, the GaN compound powder target mixed with the EuN powder (2 mol %) was used. X-ray diffraction (XRD) and high resolution photoluminescence spectra (PL) of GaN:Eu films were studied under different growth conditions at substrate temperatures ranging from 300 to 550 degree. GaN:Eu films deposited at low temperature (350 to 400 degree) exhibited preferred oriented to c-axis. PL spectra exhibited a series of sharp PL lines related to Eu³⁺ center based on the wavelength. The PL intensity of 622 nm line (dominant PL line for the 5D₀-7F₂ transition) tends to be maximum at substrate temperature of 400 degree. Dependence of PL spectra on growth temperature indicated the existence of the optimum temperature at which the formation of the luminescent Eu³⁺ center is promoted. Furthermore, GaN:Eu films deposition was carried out with the target containing the EuN powder of 1,2 and 5 mol%. The PL intensity of 622 nm line tends to be maximum 2 mol%. Finally, GaN:Eu films were deposited on the undoped GaN films (Previously, this buffer layer was deposited on the sapphire substrate at 400 degree). Using buffer layer the PL intensity of 622 nm line was enhanced by three times.
- C-III.04** 15:00 OPTICAL PROPERTIES OF A SINGLE Er CENTER IN GaN
V. Glukhanyuk, H. Przybylinska, A. Kozanecki, Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02668 Warsaw, Poland and W. Jantsch, Institut für Halbleiter- und Festkörperphysik, Johannes Kepler Universität, Altenbergerstr. 69, 4040 Linz, Austria
Photoluminescence (PL) spectra near 1.5 μm of Er³⁺ implanted into GaN are usually very complex, due to the number of different centers formed depending on Er concentration, annealing conditions as well as residual or intentional impurities. However, by implanting low Er doses into a high purity material we found it possible to obtain a single optically active center with extremely sharp PL lines. With use of high resolution resonant optical spectroscopy, including Fourier Transform Infrared spectroscopy, we were able to determine the Stark splitting of the ground J=15/2 state as well as, at elevated temperatures, that of three levels belonging to the J=13/2 state. The wide (3.5 eV) forbidden gap of GaN allowed

us also to perform PL excitation spectroscopy and hence to determine the splitting of the $J=9/2$ and $J=11/2$ energy levels, as well. The large number of Stark split energy levels obtained in this way (23 in total) allowed us to perform reliable model calculations and determine the crystal field parameters. The results show that the Er^{3+} center formed at low implant doses has C_{3v} site symmetry, as expected for Er substituting gallium in the GaN lattice.

C-III.05 15:15

Er^{3+} EMISSION AND LOCAL STRUCTURE OF Er ATOMS IN BULK GaN

S.B. Aldabergenova, H. Mendel, M. Albrecht, G. Frank and H.P. Strunk, Department of Materials Science and Engineering, Institute of Microcharacterization, Erlangen-Nürnberg University, Cauerstr.6, 91058 Erlangen, Germany, M. Bockowski, J. Borysiuk and S. Porowski, High Pressure Research Center, Polish Academy of Sciences, ul. Sokolowska 29/37, 01-142 Warsaw, Poland

We report on Er^{3+} luminescence at room temperature in the visible and infrared regions in bulk crystalline GaN doped with different Er concentration. Crystals with small concentration of Er shows typical features of the n-type GaN. The Raman scattering measurements show four phonon modes of GaN: E2 (high) at 569 cm^{-1} , E1 (TO) at 561 cm^{-1} , A1 (TO) at 532 cm^{-1} and A1(TO) at 730 cm^{-1} . The photoluminescence spectra are dominated by a broad green-yellow emission from host crystal, centered at around 530 nm. This emission band exhibits well-pronounced shoulders at 660, 520, 476 and 455 nm which can be assigned to the characteristic Er^{3+} emission lines. With increasing of Er concentration in the liquid solution the structure of the crystals and the Er^{3+} luminescence drastically change. We observe strong and sharp Er^{3+} luminescence peaks corresponding to the $4S_{3/2} - > I_{15/2}$ transitions in the visible region and a strong Stark splitting of the characteristic Er^{3+} emission in the 1530-1580nm range ($4 I_{13/2} - > I_{15/2}$ transitions). We discuss, based on photoluminescence, cathodoluminescence, micro-Raman and transmission electron microscopy measurements the local structure of the Er surroundings and mechanisms of their incorporation during crystal growth.

C-III.06 15:30 -Invited-

HIGH TEMPERATURE ANNEALING OF RARE EARTH IMPLANTED GaN-FILMS: STRUCTURAL AND OPTICAL PROPERTIES

K. Lorenz(a), U. Wahl(a), E. Alves(a), E. Nogales(b), S. Dalmaso(b), R. W. Martin(b), K.P. O'Donnell(b), T. Wojtowicz(c), P. Ruterana(c), S. Ruffenach(d), O. Briot(d), (a)Instituto Tecnológico e Nuclear, EN10, 2686-953 Sacavém, Portugal, (b)Department of Physics, University of Strathclyde, Glasgow, G4 0NG, U.K., (c)SIFCOM, UMR 6176, CNRS-ENSICAEN, 14050 Caen, France, (d)GES, Université de Montpellier II, 34095 Montpellier, France

Rare earth doped GaN is widely studied with respect to applications in electroluminescent devices. Ion implantation is a technique to realize the rare earth doping of planar substrates with the facility of lateral patterning. However, for efficient damage removal and optical activation, post-implant annealing at temperatures well in excess of 1000°C is required. In particular the dissociation of GaN at high temperatures and the regrowth of amorphised layers remain open questions.

GaN epilayers grown by MOCVD were implanted with Er, Tm and Eu under different implantation conditions (varying fluence, temperature, energy). Rutherford backscattering spectrometry in the channelling mode, transmission electron microscopy and room temperature cathodoluminescence were used to study structural and optical properties of the samples. We found that the presence of a thin AlN cap protects the sample during post-implant high temperature annealing and also prevents the formation of an amorphous surface layer during the implantation. After annealing, sharp emission lines were observed due to intra-4f-shell transitions of the rare earth ions. The emission intensity is highly dependent on the annealing temperature and best results were achieved for annealing up to 1300°C using a 10 nm thick single crystalline AlN capping layer to protect the surface. Eu-related cathodoluminescence at room temperature increases by one order of magnitude within the studied annealing range between 1100 and 1300°C. For fluences larger than $2 \times 10^{15} \text{ at/cm}^2$ the cap itself is damaged and the dissociation of GaN and an out-diffusion of the implanted rare earth ions are observed for annealing at 1300°C. Nevertheless, even those damaged samples show strong but inhomogeneous luminescence.

16:00

BREAK

Session IV : GaN II

Session chairs : A. Wakahara, A. Kozaneki

C-IV.01 16:15 -Invited-

RARE EARTH DOPED InGaN AND GaN QUANTUM DOTS

B. Daudin, T. Andreev, X. Biquard, D. Jalabert, N.Q. Liem, Y. Hori, E. Monroy, B. Gayral, M. Tanaka, O. Oda and Le Si Dang

C-IV.02 16:45

Nd^{3+} DOPED Sc_2O_3 WAVEGUIDING FILMS PRODUCED BY PULSED LASER DEPOSITION

Yury Kuzminykh, Andreas Kahn, Günter Huber, Institut für Laser-Physik, Luruper Chaussee 149, 22547 Hamburg, Germany

Optically active waveguide is one of important elements for integrated optical devices. Sesquioxides and scandia (Sc_2O_3) in particular are well suited and effective host materials for rare earth doping. Laser operation has been demonstrated for Tm, Yb and Nd doped Sc_2O_3 crystals.

We report on the growth of neodymium doped Sc_2O_3 films by pulsed laser deposition. The films have been deposited on (0001) sapphire substrates, which provide only 2.5 % lattice mismatch for (111) plane of Sc_2O_3 . A number of films with thicknesses from 100 nm up to

3 μm have been produced. Films are proved to be crystalline and textured in the [111] direction. The films are doped with 2 at.% of neodymium. Spectroscopic investigations have been performed. Emission spectra of the films resemble a spectrum of the bulk material, emission lines are slightly broadened, the deviations in the intensities of the lines has been observed. Waveguiding experiments with a 3 μm Sc_2O_3 film has been performed. A 1.5 μm thick Al_2O_3 superstrate has been deposited on top of the film. Passive waveguiding is achieved when light of a blue laser diode at 397 nm is coupled into the film. Possible application of neodymium doped scandia films as an amplifier or a waveguide laser will be discussed.

C-IV.03 17:00

TEM OBSERVATION OF Eu DOPED GaN AND FABRICATION OF n-GaN/Eu:GaN/p-GaN STRUCTURE

J. Sawahata, H. G. Bang, J. W. Seo, K. Akimoto Institute of Applied Physics, University of Tsukuba, Japan

Structural properties of Eu doped GaN with the Eu concentration of about 2 at% was studied by cross sectional TEM observation, and electrical and optical properties of n-GaN/Eu:GaN/p-GaN structure was discussed.

The Eu doped GaN was grown by ammonia MBE on sapphire (0001) substrate. The source materials are metallic Ga and Eu with the purity of 7-nine and 99.9%, respectively. From the TEM observation of Eu doped GaN, in addition to a small portion of cubic phase of GaN, high density of stacking fault which was hardly observed in undoped GaN was detected. The generation of the stacking fault may be the result in the relaxation of strain caused by the incorporation of large atomic radius of Eu. The n-GaN/Eu:GaN/p-GaN structure was grown with the electron and hole concentration of $6 \times 10^{17} \text{ cm}^{-3}$ and $4 \times 10^{16} \text{ cm}^{-3}$ for n- and p-layers, respectively. The Eu doped GaN layer showed electrically high resistive. The electrical rectification characteristics were obtained with the threshold voltage of 2.5V in the forward bias condition, however, luminescence was obtained not from the Eu doped later but from p-GaN layer. These results suggest that the hole mobility in Eu doped GaN is extremely low probably due to the high density of stacking fault.

C-IV.04 17:15 -Invited-

EXCITATION AND QUENCHING MECHANISMS OF RARE-EARTH DOPED GaN

A. Braud, L. Bodiou, J-L. Doualan, R. Moncorge, CIRIL-ENSICAEN, 6 Bd Maréchal Juin, 14000 Caen, France; K. Lorenz, E. Alves Instituto Tecnológico e Nuclear, Estrada Nacional 10, PT-2685-953 Sacavém, Portugal; B. Pipeleers, A. Vantomme, Instituut voor Kern-en Stralingsfysica Departement Natuurkunde, Celestijnenlaan 200 D, 3001 Leuven, Belgium

Rare-earth doped GaN is being widely studied for its various applications in optoelectronics. Nevertheless, the mechanisms underlying the excitation of rare-earth ions in this host as well as the quenching processes impairing the luminescence of rare-earth ions are still unclear.

Photoluminescence (PL), Photoluminescence excitation (PLE), time-resolved PL and two laser experiments are used to investigate the excitation and quenching mechanisms affecting rare-earth ions embedded in a GaN host. Each of these experiments yields clues about the exact nature of the excitation paths leading to the luminescence of rare-earth ions. At least three types of rare-earth excitation mechanisms are clearly identified and divided in two categories: direct and indirect. The direct excitation is resonant with intra 4f shell transitions while indirect excitation processes involve energy transfer from electron-hole pairs towards neighboring rare-earth ions. Indirect excitation mechanisms are of two types: above and below bandgap. In some cases there is a clear evidence that these three types of excitation affect rare-earth ions occupying different sites while in some other cases the excitation appears to lead to the same rare-earth ions. The study of these different cases in relation to the GaN growth and doping conditions is discussed. Quenching processes affecting the rare-earth luminescence are also of great importance. Among them one can distinguish the thermalization of deep traps and Auger processes in which the rare-earth ion transfers its energy to free or trapped carriers. It is shown that in a given rare-earth doped GaN sample these quenching processes affect differently the rare-earth ion depending on its local environment.

C-IV.05 17:45 -Invited-

RE DOPED NITRIDES CHARACTERISED USING CATHODOLUMINESCENCE AND ELECTRON BEAM MICROANALYSIS

R.W. Martin, E. Nogales, D. Amabile, K. Wang, V. Katchkanov, K.P. O'Donnell, C. Liu, I.M. Watson, K. Lorenz, E. Alves, V. Matias, B. Pipeleers, A. Vantomme, O. Briot, S. Ruffenach

POSTER SESSION I

Tuesday, May 31, 2005
18:15 – 19:30

- C/PI.01** Withdraw
- C/PI.02** GEOMETRY RELAXATION IN THE EXCITED STATES AND ITS EFFECTS ON THE ELECTRONIC PROPERTIES OF THE $\text{Er}(\text{8-HYDROXYQUINOLATE})_3$ COMPLEX
M. Ottonelli(a), G.M.M. Izzo(a), G.F. Musso(a), G. Dellepiane(a), F. Rizzo(a) and R. Tubino(b), (a)Università di Genova, Dipartimento di Chimica e Chimica Industriale, Via Dodecaneso 31, 16146 Genova, Italy (b)Università di Milano Bicocca, Dipartimento di Scienza dei Materiali Via Cozzi 53, 20126 Milano, Italy
The understanding of the nature of the energy transfer process that occurs in organo-lanthanide complexes is still under investigation from both the experimental and the theoretical points of view with the aim to design and synthesize novel molecules with suitable photophysical properties such as large Stokes shifts, emission in target regions of the spectrum or long emission lifetimes. In this respect the electronic properties of the excited states play a central role, and it is of particular importance to take into account their variation due to relaxation effects, considering that some states, e.g. the triplets, have long lifetimes.
Taking into account quantum chemical relaxation effects in the first excited singlet and triplet states of the model system $\text{Er}(\text{8-hydroxyquinolate})_3$ complex, we will show that the energy transfer process occurs, at least in this case, via an energetically favourable channel which allows for an interaction with the manifold of the atomic levels of the Er^{3+} ion.
- C/PI.03** SOME PROPERTIES OF POLYIMIDE FILMS MODIFIED BY RARE-EARTH COMPOUNDS
A. Valozhyn, Institute of Electrical Engineering of Technical University of Szczecin, Szczecin Poland, E. Schab-Balcerzak, B. Jarbek, Centre of Polymer Chemistry, Polish Academy of Sciences, Zabrze, Poland, D. Tsirkunov, Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus, M. Tsvirko
Polyimide doped with compounds of erbium, terbium and europium are one of the most promising type of polymeric materials for application in electro-optical modulators due to their luminescence properties, excellent thermal stability, high mechanical and dielectrical properties and glass transition temperature ($T_g > 250^\circ\text{C}$). We prepared three series of polyimide doped with compounds of Er, Tb and Eu. These polymer thin films were formed and their mechanical, electrical, optical properties were investigated. These films may use in different application in electronic industries such as luminescent layer for displays, optical converter, etc.
- C/PI.04** PHOTOLUMINESCENT PROPERTIES OF Eu^{3+} COMPLEX INTO PC/PMMA BLENDS
R. Bonzanini, E.M. Giroto, E.C. Muniz, and A.F. Rubira, Departamento de Química, Universidade Estadual de Maringá, Av. Colombo 5790, 87020-990 Maringá, Paraná, Brazil, J.M.A. Caiut, and S.J.L. Ribeiro, Instituto de Química, Unesp, CP 355, 14801-970 Araraquara, São Paulo, Brazil
Spectroscopic properties of blends formed by bisphenol A polycarbonate (PC) and poly(methyl methacrylate) (PMMA) doped with Europium (III) acetylacetonate $[\text{Eu}(\text{acac})_3]$, have been studied by photoluminescent (PL) spectroscopy, 5D0 level emission lifetime, and emission quantum efficiency (h). Narrow bands assigned to ${}^7\text{F}_0(\text{r})5\text{L}_7$, 5D_4 , and 5H_3 Eu^{3+} transitions appear superimposed in a broad band extending from 280 to 400 nm together with the excitation from the matrix due to the acetylacetonate ligands (antenna effect). The five emission bands in the spectrum correspond to the characteristic Eu^{3+} transitions, suggesting a statistical distribution of different sites available for Eu^{3+} in the polymeric matrix. Emission concentration quenching was also observed. Higher light intensity outputs are obtained with the increase in the relative PMMA content. By comparing the values obtained for the precursor complex and the doped blends, increasing lifetimes were observed for the polymeric systems. Since the main non-radioactive channel of the complex must be due to water ligands, the observed increase in decay time must be related to the substitution of ligand groups from the polymeric matrix for the water molecules at the Eu^{3+} coordination shell. All h values of the doped blends are higher than those of the pure Eu complex ($h = 32.6\%$). In addition, the 20/80 blend doped with 2% $[\text{Eu}(\text{acac})_3]$ presented the highest quantum efficiency, $h = 66.9\%$, suggesting that the polymeric matrix also acts as a sensitizer, facilitating the energy transfer from the acetylacetonate ligand to the Eu^{3+} ion.
- C/PI.05** THE MICROSTRUCTURE OF LOW DOSE IMPLANTED GaN USING Cr, Er, Eu, Yb IONS
F. Gloux, P. Ruterana, SIFCOM UMR 6176, CNRS-ENSICAEN, 14050 Caen, France, Z. Zavada, ARL, Durham, U.K.
In GaN, by changing the RE, one can obtain luminescence covering the visible light spectrum. In this wide and direct band gap semiconductor, an electric field can be used to efficiently excite the RE^{3+} ions and the thermal quenching of the RE luminescence is significantly reduced. The optimisation of ion implantation is one of the challenges for use in GaN doping as this technique is well suited for device processing.
In this work, transmission electron microscopy (TEM) structural characterization of GaN implanted with Cr, Yb and Eu ions is carried out. Our aim is to assist in determination of the optimal implantation and annealing conditions by investigating the effect of the various treatments on the microstructure. We analyze samples implanted at different energies with fluences around 10^{14} / cm^2 and at room temperature. Typical defect structure have been determined and will be discussed in detail.
- C/PI.06** SYNTHESIS AND OPTICAL PROPERTIES OF Eu^{3+} AND Tb^{3+} DOPED GaN NANOCRYSTALLITES
Marcin Nyk(a), Robert Kudrawiec(a), Wieslaw Streck(b), Jan Misiewicz(a), (a)Institute of Physics, Wrocław University of Technology, Wrocław, Poland, (b)Institute of Low Temperature and Structure Research Polish Academy of Science, Wrocław, Poland
The synthesis and optical properties of pure and Eu^{3+} as well as Tb^{3+} doped GaN nanocrystallites are investigated in this paper. The GaN powders were obtained by simple thermal decomposition of pure and doped gallium nitrate followed by nitridation with ammonia. The evolution of phase composition, structure and morphology was studied. X ray diffraction reveals that the GaN powders are of single-phase wurtzite structure. Optical properties were investigated using photoluminescence (PL) and cathodoluminescence (CL). For pure GaN

nanocrystallites a broad emission band with a maximum in the red (~650 nm) and a weak band with a maximum in the UV region (~380 nm) have been observed. For doped GaN nanocrystallites PL emission related to GaN matrix as well as Eu³⁺ (Tb³⁺) ions have been observed. In addition, it has been found that the emission related to GaN matrix strongly depends on the excitation source. For example CL spectra do not show the broad emission at 650 nm which is observed in PL and is related to GaN nanocrystallites. Briefly the mechanism of energy transfer from GaN matrix to ions of rare earths is discussed.

C/PI.07 LATTICE ORDER IN THULIUM DOPED GaN EPILAYERS: IN SITU DOPING VERSUS ION IMPLANTATION

S. Hernández(a), R. Cuscó(b), L. Artús(b), E. Nogales(a), K.P. O'Donnell(a), R.W. Martin(a), O. Briot(c), G. Halambalakis(c), K. Lorenz(d), E. Alves(d); (a)Depart. of Physics, Univ. of Strathclyde, Glasgow G4 0NG, U.K., (b)Inst. Jaume Almera, CSIC, Barcelona, Spain, (c)Univ. of Montpellier, France, (d)Instituto Tecnológico e Nuclear, Sacavem, Portugal

Rare earth elements incorporated into GaN crystals give rise to sharp characteristic optical emission lines which have their origin in intra-4f-shell transitions. The emission efficiency depends strongly on the crystalline quality as well as on the symmetry of the site occupied by the dopants. Here, we compare by means of Raman scattering the crystalline quality of GaN:Tm epilayers doped in situ during MBE growth and MOCVD GaN layers doped by ion-beam implantation and subsequently annealed at 1000 °C for 120 s.

Wavelength dispersive x-ray analysis yields Tm concentrations in the 0.1-0.25 % range for the implanted samples, whereas Tm concentrations are in the 0.5-1.7 % range for the MBE layers. The Raman spectra of the MBE doped samples exhibit just the E₂ and the A₁(LO) phonons characteristic of GaN samples. In contrast, Raman spectra of the implanted samples display additional peaks possibly related to local defects and a low frequency broad band associated with disorder-activated modes. This result clearly shows that the standard annealing processes do not achieve full lattice recovery of GaN. Thus, Raman scattering measurements allow us to conclude that, despite the higher Tm concentration of the in situ doped layers, the lattice order is higher for MBE doped layers than for the implanted samples.

C/PI.08 LUMINESCENCE OF Eu DOPED InGaN QUANTUM DOTS

T. Andreev(a), N.Q. Liem(b), Y. Hori(a,c), E. Monroy(a), B. Gayra(a), M. Tanaka(c), O. Oda(c), Le Si Dang(a) and B. Daudin(a), (a)CEA/CNRS/UJF group Nanophysique et Semiconducteurs, 17 rue des Martyrs, 38054 Grenoble, France, (b)Institute of Materials Science, Vietnamese Academy of Science and Technology, 18 Hoang Quoc Viet –Cau Giay– Hanoi, Vietnam, (c)NGK Insulators, LTD 2-24 Sudacho, Mizuhoku, Nagoya, Japan

The combination of rare earth (RE) luminescence with the wide band-gap of (In)GaN is a promising solution for full color devices. To overcome the problems derived from the high dislocation densities in GaN layers we propose to combine the confinement properties of QDs with the RE luminescence. Eu- and Tm-doped GaN QDs in AlN matrix have been demonstrated, but RE-doped InGaN QDs grown on GaN are a preferable choice for current-injection devices.

With this motivation we have studied the optical properties of MBE grown Eu-doped InGaN QDs embedded in GaN matrix by PL and PLE spectroscopy for various emissions from the 5D₀ → 7F₂ transition. We found that most Eu ions are located inside the InGaN QDs, which is inferred from the PLE spectrum exhibiting a low energy tail up to 410 nm, due to the size distribution of the InGaN QDs. In addition, the line-width of the 5D₀ → 7F₂ Eu³⁺ ion emission from InGaN QDs is as narrow as 0.3 nm indicating the high quality of the grown material. The temperature-dependent PL carried out from 5 to 380 K showed that the luminescence originating from Eu³⁺ ions inside InGaN QDs is more stable than that from the GaN spacer or from GaN thick layers. We have also succeeded to directly excite the 4f electron shell of Eu atoms in InGaN QDs, even at room temperature.

C/PI.09 STUDY OF EXCITATION PATHS IN Eu IMPLANTED GaN

L. Bodiou, A. Braud, J-L. Doualan, R. Moncorge, CIRIL-ISMRA, 6 Bd Maréchal Juin, 14000 Caen, France, K. Lorenz, E. Alves, Instituto Tecnológico e Nuclear, Estrada Nacional 10, 2685-953 Sacavém, Portugal

Rare-earth-doped wide-bandgap semiconductors, and especially gallium nitride, are being intensively investigated for their potential use in optoelectronic devices. However questions still remain about the fundamental understanding of the mechanisms underlying the excitation of rare-earth ions in GaN. In order to deepen our understanding of the incorporation of rare-earth ions in GaN and the excitation processes of the 4f-shell, we recorded photoluminescence (PL) spectra of the Eu³⁺ 5D₀ to 7F₂ transition of Eu-implanted GaN samples. The samples were excited either above or below bandgap using cw and pulsed laser sources. The Eu PL intensity was specifically studied as a function of the annealing temperature. An AlN cap layer was grown on top of the GaN samples in order to allow annealing at high temperature (up to 1300°C). Annealing at 1300°C leads, under above band gap illumination, to an increase of the europium luminescence by one order of magnitude compared to annealing at 1100°C. PL experiments carried out as a function of temperature, excitation density and excitation wavelength enable us to identify two main different Eu incorporation sites in implanted GaN. These two europium species are present in all samples and are coupled to two distinct excitation paths which are investigated for above and below bandgap excitations. Both Eu species contribute to the PL spectrum under above bandgap excitation while below band gap measurements show that one species is selectively excited, the second one being hardly excited. Moreover the luminescence related to one species is drastically quenched as the temperature is raised to 300K while the PL signal of the second species remains almost unaffected.

C/PI.10 RAMAN STUDY OF IMPLANTATION DAMAGE RECOVERY FROM Er-IMPLANTED GaN AND AlGaN

A.P. Vajpeyi and S.J. Chua, Singapore-MIT Alliance, National University of Singapore, Singapore, S. Banerjee, Saha Institute of Nuclear Physics, Kolkata, India, S. Tripathy, Institute of Materials Research and Engineering, 3 Research Link, Singapore

We report a systematic Raman study to probe vibrational properties of Er-implanted GaN and AlGaN layers. Wurtzite GaN and Al_xGa_{1-x}N (x = 0 - 20%) layers were grown on sapphire (0001) substrates by metal organic chemical vapor deposition (MOCVD). Er-ions were implanted at 200 keV with a dose of 10E15 cm⁻² at room temperature and the implanted layers were subsequently annealed under N₂ ambient within a temperature range 700 - 1000 oC to facilitate recovery from implantation-induced damage. The surface morphology of the annealed layers was investigated using atomic force microscopy (AFM). Room-temperature micro-Raman measurements carried out on the as implanted and annealed samples show that implantation damage can be removed using high temperature annealing process. Apart from host optical phonon peaks of GaN and AlGaN, we have also observed implantation-induced disorder-activated Raman peaks from samples annealed at different temperature. High-temperature annealing also leads to the observation of Er-related local vibrational mode in GaN. In addition, Raman technique has been used to estimate the stress in these implanted layers subjected to various annealing

steps. From such micro-Raman analyses, we can determine the optimized annealing conditions to activate Er-related luminescence transitions in GaN and AlGaIn.

C/PI.11

EXTENDED X-RAY ABSORPTION FINE STRUCTURE STUDIES OF GaN EPILAYERS DOPED WITH Er
V. Katchkanov(a,b), K.P. O'Donnell(a), J.F.W. Mosselmans(b), S. Hernandez(a), E. Nogales(a), R.W. Martin(a), A. Steckl(c), D.S. Lee(c), (a)Department of Physics, Strathclyde University, 107 Rottenrow East, Glasgow G4 0NG, U.K., (b)Synchrotron Radiation Department, CCLRC Daresbury Laboratory, Daresbury, Warrington WA4 4AD, U.K., (c)Nanoelectronics Laboratory, University of Cincinnati, Cincinnati OH 45221-0030, USA

Rare-earth (RE) doped semiconductors attract much interest due to the possibility of integrating intense narrow-band emission in infra-red and visible spectral regions with existing semiconductor devices. A wide and direct bandgap, good chemical and thermal stability and excellent high field transport properties make GaN a promising host crystal for RE ions [1, 2]. In spite of the solubility of rare-earth ions being much higher than in any narrow gap semiconductor [3], formation of REN phase has been observed at high doping levels in GaN [4]. The observation of phase decomposition raises the question about critical concentrations beyond which rare-earth ions tend to form precipitates. We report Extended X-ray Absorption Fine Structure studies of GaN epilayers doped with Er in situ during Molecular Beam Epitaxy growth. The consequent formation of ErGaN, ErGaN clusters with locally high Er content and ErN phase was observed when the Er concentration was increased from 0.15 at.% to 0.60 at.%. The influence of phase decomposition on the emission properties of GaN:Er will be discussed.

[1] A. J. Steckl et al., *Materials Science and Engineering B* 81, p 97 (2001) [2] M.J. Garter and A.J. Steckl, *IEEE Transactions on Electron Devices* 49, p 48 (2002) [3] R. Birkhahn, R. Hudgins, D.S. Lee, A.J. Steckl, A. Saleh, R.G. Wilson, J.M. Zavada, *MRS Internet Journal of Nitride Semiconductor Research* 4S1, G3.80 (1999). [4] D.S. Lee, J. Heikenfeld, A.J. Steckl, U. Hommerich, J.T. Seo, A. Braud, J. Zavada, *Appl. Phys. Lett.* 79, 719 (2001).

C/PI.12

STRUCTURAL AND ELECTRICAL CHARACTERIZATION OF Eu IMPLANTED GaN

V. Matias, M. Mamor, A. Vantomme, Instituut voor Kern- en Stralingsfysica, K.U.Leuven, Celestijnenlaan 200 D, 3001 Leuven, Belgium, A. Colder, P. Marie, P. Ruterana, SIFCOM UMR 6176, CNRS-ISMRA, 6, Bld Maréchal Juin, 14052, Caen, France, L. Wu, F. D. Auret, Dept of Physics, University of Pretoria, Pretoria 0002, South Africa

Rare earth elements are being investigated for their properties as optical dopants in nitrides. Red, green and blue emission has been demonstrated in these semiconductors by Eu, Er and Tm implantation, respectively, as a relevant application for colour display technology.

Doping by ion implantation has the advantages of overcoming the solubility limit, patterning and depth control of the implanted species. The disadvantage resides in the damage introduced in the lattice. This damage along with the implanted species alter the crystalline periodicity introducing energy levels in the bandgap. In the case RE-doped GaN, these levels may both be harmful or beneficial to the optical properties. It is thought that they are responsible for non-radiative de-excitations, competing with the radiative de-excitation of the RE, but they can also be involved in the process of the RE excitation and radiative de-excitation. Understanding these mechanisms is crucial for device performance, but until this moment, little has been done on the electrical characterization of RE:GaN. We have recently investigated the electrical properties of Eu implanted GaN. Besides the usual traps attributed to N vacancies and NGa anti-sites, there is an electron trap at energy (Ec-0.36 eV), not been previously observed. It is believed to be a Eu related defect. In this work, we further investigate this new defect and its relation to Eu and the implantation damage. For this purpose, we have implanted Eu in GaN at fluences from 1E14 to 5E15 Eu/cm² both along the c-axis and 10° off this direction. Structural characterization was performed by RBS/C and HRXRD. DLTS with optical excitation was used to scan the entire band-gap and electrically characterize the samples.

C/PI.13

CATHODOLUMINESCENCE MEASUREMENTS AND THERMAL ACTIVATION OF RARE EARTH DOPED (TB, DY, TM, EU) A-ALN THIN FILMS PREPARED BY REACTIVE RF-SPUTTERING

R. Weingärtner, O. Erlenbach, A. Winnacker Department of Materials Science 6, University of Erlangen, Martensstr. 7, 91058 Erlangen, Germany, H. Mendel, H.P. Strunk, Department of Materials Science 7, University of Erlangen, Cauerstr. 6, 91058 Erlangen, Germany

We present comprehensive cathodoluminescence measurements from thin amorphous AlN films doped with rare earths (RE). The a-AlN films were prepared by reactive rf-sputtering using a high purity (5N) aluminum disk in high purity nitrogen/argon atmosphere (6N, flux ratio 1:3, pressure ca. 1.3 mbar). The rare earth doping (Dy, Tm, Tb or Eu, concentrations vary between 1 and 3%) was performed by placing respective RE metal pieces of appropriate size onto the aluminum disk. The rare earth ion emissions cover the colors yellow (Dy), blue (Tm) green (Tb) and red (Eu). The optical and related structural properties of the films are correlated by means of transmission electron microscopy (TEM) in combination with cathodoluminescence measurements in a scanning electron microscope. In addition, the corresponding compositions are determined by EDS and EELS. The cathodoluminescence spectra of the RE³⁺-ions are recorded in the visible for temperatures between 10K and 300K in the as-grown condition and after annealing treatments in the temperature range from 400K to 1000K in steps of 100K. The anneal-related changes in the emission of the cathodoluminescence spectra and in the microstructure of the films at each annealing step are recorded and different activation models are discussed. Conditions for optimal RE emission are derived.

C/PI.14

OPTICAL AND STRUCTURAL PROPERTIES OF Tm DOPED MBE GaN

I.S. Roqan, E. Nogales, K.P. O'Donnell, R.W. Martin, C. Trager-Cowan, Dept. of Physics, University of Strathclyde, Glasgow G4 0NG, U. K.; G. Halambalakis, O. Briot, Groupe d'Etudes des Semiconducteurs, Université Montpellier II, 34095 Montpellier, France

Rare earth-doped GaN has received considerable attention because of its applications in full colour light emitting devices. In this work the structural and optical properties of in situ doped MBE grown GaN:Tm films obtained at different growth temperatures have been investigated. The surface morphology of the films was characterized by atomic force microscopy (AFM). Simultaneous topography, wavelength dispersive X-ray spectroscopy (WDX) and room temperature cathodoluminescence (CL) mappings were performed in an electron probe microanalyser. Differences in the CL spectra, morphology and Tm concentration were observed when moving from the edge of each sample to the centre. The films show a high density of circular pits (8-15 microns diameter and ~200 nm depth) in a large region close to their edges. WDX reveals higher Tm concentration in this region than in the centre giving rise to intense sharp blue (477 nm) and infrared (805 nm) emissions due to intra 4f(n)-shell electron transitions associated with Tm³⁺ ions. On the other hand, a lack of Tm content inside the pits is correlated with the loss of its typical sharp emissions in favour of GaN related luminescence. Large Ga and small Tm metallic inclusions are found in several of these pits. Possible reasons for the formation of these features are discussed.

High Tm concentration and intense Tm³⁺ luminescence are found in a non-pitted transition region between the pitted and the low Tm concentration ones.

C/PI.15 HOW TO OPTIMIZE RARE EARTH EMISSION IN THIN AMORPHOUS NITRIDE LAYERS BY ANNEALING

H. Mendel, S.B. Aldabergenova, G. Frank, H.P. Strunk, Universität Erlangen-Nürnberg, Institut für Werkstoffwissenschaften VII, Mikrocharakterisierung, Cauerstr. 6, 91058 Erlangen, Germany and D. Kovalev, Physik-Department E16, Technische Universität München, James-Franck-Str. 5, 85747 Garching, Germany
The luminescence due to rare earth ions in Al and Ga nitride thin layers can be increased by proper structural tailoring. We report on the photoluminescence of a variety of rare earth ions (Eu, Sm, Tb, Tm and Ce) that are contained in films prepared by DC magnetron sputtering of Ga or Al targets with additional rare earth pellets in a nitrogen atmosphere. Thermal annealing of these samples results in significant improvement of the photoluminescence by factors up to several tens in intensity. Interestingly enough, optimum intensity is achieved with annealing temperatures in a window between approximately 500 °C and 750 °C in all cases. This finding indicates similar excitation and emission processes based on structural properties of the layers that will be analyzed by transmission electron microscopy.

C/PI.16 OPTICAL PROPERTIES OF HIGH TEMPERATURE ANNEALED EU-IMPLANTED GaN

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A 10nm thick epitaxially grown AlN cap is used to protect the surface of a GaN epilayer both during Eu ion implantation and the following high temperature annealing. The 16k photoluminescence (PL) intensity of the intra-4f Eu transition increases by two orders of magnitude when the annealing temperature is increased from 1000 to 1300°C. High resolution PL spectra reveal that the emission lines due to the 5D₀-7F₂ transition exhibit different dependence on the annealing temperature in the studying annealing range. PL excitation measurements demonstrate band edge absorption of GaN host at 356nm, together with a broad excitation band centred at ~384nm. The PL spectra of the 5D₀-7F₂ transition selectively excited by above band-gap absorption and by this broad excitation band are noticeably different. The first peak at 620.8nm is suppressed when exciting below the GaN band gap. This demonstrates differing energy transfer processes for the different Eu luminescent peaks and this is a direct evidence of at least two kinds of different Eu sites in the host with distinct optical activation.

C/PI.17 SPACE HETEROGENEITY OF DISTRIBUTION OF RARE-EARTH ELEMENTS AND THE KINETICS OF MINORITY CARRIERS IN WURTZITE CRYSTALS GaN DOPED BY Eu, Sm, Er, Tm

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The aim of this work is the determination of the effect of space correlation between the states of rare-earth ions (REI) and the concentration defects in native semiconductor matrix GaN on the kinetics of nonequilibrium carriers in GaN crystals doped by REI, which was affected by transport of charge carriers in native and doped GaN crystals. Stationary and time-resolved (with wide variation of time delay) spectra of photoluminescence (PL) and Mossbauer spectra were investigated at various temperatures. Diffusion technique for doping of GaN crystals with REI at various defects concentration was used. Intracentral f-f transitions of REI (typical for Eu, Sm, Er, Tm) were observed in stationary PL spectra, the intensity of these PL spectra lines depended on defects concentration in the native crystals. Additional illumination with wavelength of 5145 Å on the evolution of time-resolved spectra of near-edge PL for GaN crystals with various Fermi-level was evaluated. From the analysis of the time-resolved spectra it was found that in all GaN crystals independently of defects concentration the native matrix contain metastable-level which delivers the holes to the valency band. The process of the self-organization in wurtzite GaN crystals doped by REI and space heterogeneity were discussed.

C/PI.18 LUMINESCENT PROPERTIES OF Eu²⁺-ACTIVATED (Ba,Sr)₃MgSi₂O₈ PHOSPHOR UNDER VUV IRRADIATION

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The blue-emitting phosphor, BaMgAl₁₀O₁₇:Eu²⁺ (BAM) has been used in PDP due to its high emission efficiency. However, it is known that the degradation in emission intensity is resulted by the baking process for panel preparation and long exposure to VUV radiation. Thus, we have thought that a novel blue component instead of a conventional BAM phosphor is needed. In this work, (Ba,Sr)₃MgSi₂O₈:Eu²⁺ phosphors with a Merwinite structure were synthesized for application as a blue phosphor for PDP. The photoluminescence properties of the these phosphors were investigated under 147nm VUV-ray excitation. The central wavelength in the spectrum of (Ba,Sr)₃MgSi₂O₈:Eu²⁺ phosphor was blue-shifted with increasing Ba content. The optimum Eu²⁺ concentration exhibiting the maximum emission intensity was 0.5 mol%. On the other hand, the decrease in emission intensity of this blue phosphor by baking process was lower than that of a conventional BAM phosphor.

C/PI.19 THE SYNTHESIS OF EuF₃ MONODISPERSED NANOPARTICLES COVERED WITH TOPO

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In the present study the synthesis of EuF₃ nanoparticles covered with TOPO (trioctyl-phosphine oxide) shell by the decomposition of dehydrated flour-containing complex of europium Eu(CF₃COO)₃ was carried out. The influence of the preparation conditions (decomposition temperature and concentration of the complex) on the particle size and luminescent properties was investigated. These nanoparticles are highly promising as novel luminescent materials because of the possibility of energy transfer from trioctylphosphine oxide shell to the f-states of europium. However adsorption of pure fluorides is very low, thus the application of sensibilisation techniques is of great interest. Furthermore, the possibility to obtain phosphors with visible quantum efficiencies higher than 100% upon VUV excitation which can be realized in Rare Earth fluorides is of particular interest. The presence of oxygen in the system forbids the cascade process of two photons generation, but our technique allows preventing pyrolysis and contamination of fluoride with the oxygen atom. This work is supported by 'Universities of Russia' (grant no. 06.02.001).

C/PI.20**MODIFIED POLYELECTROLYTE DEPOSITION OF NANOPARTICULATE ZnS THIN FILM**

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Much of the research in nanotechnology today is based upon the utilization of the quantum mechanical properties exhibited by nanomaterials for various applications. Methods of smart assembly of synthesized nanoparticles play an important role in the development of novel devices. The assembly of nanoparticles in two dimensions results in thin films of nanoparticles on a substrate called self-assembled monolayers.

Conventional techniques utilized to generate thin films, including chemical vapor deposition and sputtering, typically require expensive substrates and complex vacuum environments. Alternatively, we report the development of a modified polyelectrolyte deposition technique for synthesizing thin films of manganese doped ZnS nanoparticles. The entire process is carried out at room temperature and atmospheric pressure, lowering the cost and complexity of the deposition process. We have achieved the growth of multilayers of ZnS interspersed with layers of polyacrylic acid (PAA) by alternatively dipping a functionalized substrate (glass or ITO coated glass) in PAA and doped ZnS nanoparticles. Capping the surface of the nanoparticles with poly-cationic biopolymer chitosan facilitates their electrostatic attachment to the negatively charged PAA. In this paper, a modified polyelectrolyte deposition technique is presented for the growth of multifunctional nanoparticulate ZnS thin films. Optical characterization of these multilayer films via transmission and ellipsometry measurements are also presented. The tunable electroluminescence characteristics of doped ZnS make these thin films ideal for use in display devices.

C/PI.21**PREFERENTIAL SITE SUBSTITUTION IN SOL-GEL DERIVED RARE-EARTH DOPED LU₂SIO₅ : A COMBINED STUDY BY X-RAY ABSORPTION AND LUMINESCENCE SPECTROSCOPIES**

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Inorganic scintillators find various applications in medical imaging, non destructive testing and high energy physics. Numerous rare-earth doped oxides materials have made their way through to final applications. These materials are usually produced as single crystals at very high temperature by classical solid state chemistry. Sol-gel chemistry is an interesting alternative route which is particularly convenient for the preparation of oxides. Among the numerous advantages offered by sol-gel chemistry, one can note the lower preparation temperature, the very high homogeneity of the final materials associated with the use of molecular precursors in solution, the high versatility in terms of composition (matrix and doping ion) and the possibility to produce both powders and thin films with a control of the morphology on the nanoscopic scale.

Various rare earth doped borates, phosphates, aluminates and silicates have been prepared in our laboratory using sol-gel process and this poster will focus on Lu₂SiO₅ (LSO) which is recognized as the most promising material for Positron Emission Tomography scanners. Original results have been found for this material and in particular, the possibility to prepare Eu³⁺ doped LSO has allowed addressing an important and long time debated issue in the field of scintillators concerning the substitution of rare earth ions in LSO. A combined study by X-Ray Absorption and luminescence spectroscopies has been performed. The refinement of the XAFS spectra obtained both at Lu and Eu LIII edges showed a preferential site substitution in the higher coordination site labeled 1 in the corresponding ICSD card. De-convolution of room temperature 7F₀-5D₀ excitation spectrum gives the respective populations: 63 % in site 1 and 37 % in site 2.

C/PI.22**HIGHLY EFFICIENT Mn²⁺ DOPED ZnS NANOPARTICLES**

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II-VI semiconductor nanocrystals, like CdSe or doped ZnS have potential applications including bio-labels and phosphors for display devices due to their tunable fluorescent properties. Organic dyes used for bio-labeling have the disadvantage of a narrow range of excitation wavelengths, which are close to the emission wavelengths, reducing the visibility of the sample. CdSe nanocrystals have a broad excitation band, and have recently become commercially available for bio-labeling applications. These nanocrystals have a bio-compatible ZnS coating due to the toxicity of both Cd and Se. However, a recent study shows that Cd diffuses out of the ZnS coating, rendering the bio-compatibility of these commercially available Quantum Dots questionable.

We report the synthesis of manganese doped ZnS nanoparticles, which show strong orange-red (590 nm) emission upon excitation with a low power UV lamp. As a preliminary study on the feasibility of their use as bio-labels, we attached these nanoparticles to the cell walls of bacilli. Excitation of these nanocrystals under a fluorescent microscope (excitation wavelength of 350 nm) clearly showed the morphology of the cell walls, indicating that these nanoparticles can be used as bio-labels akin to CdSe nanocrystals. Selectivity in attachment to specific species of bacilli requires specific surface modification of the nanoparticles, which is currently being pursued. Doped ZnS is also reported to show electroluminescent properties making it applicable as the phosphor layers for display devices. Attempts are being made to synthesize a self assembled monolayer of Mn²⁺ doped ZnS nanoparticles for future applications in field emission display devices which have the advantage of better viewing angles over conventional LCD screens.

C/PI.23**SYNTHESIS AND PHOTOLUMINESCENCE PROPERTIES OF DOPED WITH PRASEODYMIUM AND EUROPIUM DOUBLE ALUMINUM/INDIUM PHOSPHATES**

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Photoluminescence (PL) of Na(Al/In)P₂O₇ crystals doped with the praseodymium and europium ions (RE) is investigated. Synthesis of the Na(Al/In)P₂O₇ crystals was made by a method of spontaneous crystallization from homogeneous solution in melt of phosphate systems Na₂O- Al_2O_3 - In_2O_3 - RE_2O_3 at slow cooling in a temperature interval from 1000 down to 600 K. The set of solid solution Na(Al/In)_{1-x}RE_xP₂O₇ where value x was varied in regions from 0.02 up to 0.95 was obtained.

PL spectra of doped Na(Al/In)P₂O₇ crystals are characterized with wide "blue-green" bands in the 450 - 600 nm diapason and by several sharp lines that arise on their backgrounds and in the red region of light. The wide short wave length bands are complex and consist of two components at least. These bands are significantly narrowed when temperature decreases from 300 to 4.2 K, and the spectra of PL excitation of these bands are complex too. Positions and contour of the bands and lines depend on the temperature of the samples, concentration of the impurity ions, and excitation wave length as well. Complex structure of luminescence spectra is caused

by a superposition of own matrix emission and radiation of different PL centers formed by triple charged RE ions. The attention is paid to discuss the possibility of the impurity ions arrangements into different positions of the crystal lattice. Two types of the PL centers based on the RE ions are formed in the investigated compounds. Undoubtedly, one of them is formed by the RE ions those replace matrix Al^{3+} cations. Double phosphate compounds are perspective photonic materials as they offer possibility to easily change their luminescence properties on the base of the same compound by varying its composition.

C/PI.24 FLUORESCENCE OF NANOSTRUCTURED EU:Y₂O₃ AND EU:LU₂O₃ FILMS FABRICATED BY PULSED LASER DEPOSITION

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A modification of the fluorescence of rare earth ions included in oxide crystals is observed when the crystallite size decreases to some nanometers. It induces additional features, which are generally attributed to surface ions. Eu³⁺ doped Y₂O₃ and Lu₂O₃ nanocrystallized films were prepared by Pulsed Laser Deposition (PLD) as well as Eu³⁺ doped Y₂O₃ and Lu₂O₃ nanolayers or nanoparticles embedded in alumina waveguiding thin films. Depending on the deposition conditions (temperature and oxygen pressure), varying crystal size in the nanometric range were obtained according to TEM and X ray diffraction measurements. The spectral and dynamic fluorescence characteristics have been measured by time resolved site selective spectroscopy and attributed to Eu³⁺ ions in cubic crystalline environment, with increasing distortion as the crystal size decreases, and to Eu³⁺ ions in an amorphous phase induced at the alumina interface.

C/PI.25 LUMINESCENT CHARACTERIZATION OF SODIUM ORTHOPHOSPHATE CRYSTALS DOPED WITH NEODYMIUM, SAMARIUM, DYSPROSIUM, AND PRASEODYMIUM

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The paper presents results of luminescence investigation of sodium titanium orthophosphates doped with rare-earth elements such as neodymium, samarium, dysprosium, and praseodymium. These crystals can be used for creation of active solid state laser media. Therefore, it is important to understand peculiarities of processes in their absorption and emission centers. Therefore previous investigation of powerful ultraviolet and x-ray irradiation effect on spectral properties (luminescence and additional absorption) of the activated crystals were carried out. Investigation of the spectral-kinetic properties of the crystals was carried out in 4,2 - 300 K temperature region. Luminescence bands and decay kinetic of matrix emission and of inner emission of the RE ions were observed. Luminescence spectra of pure compound consist of two main bands in the green and red spectral regions. Maximum positions of the bands depend on the crystal composition and temperature of the samples. Linear luminescent spectra were observed on background of the matrix emission. The data on spectroscopy of the RE ions enables to assign the observed linear emission spectra of the investigated crystals to inner transitions in the respective RE ions. Obtained peak positions and numbers of spectral lines for these crystals agree with data on luminescent properties of triple-charged RE ions. Observed lines are caused by intrinsic radiation transitions in the 4f(n) shells of the RE ions. The crystal field theory has been used to explain the obtained results. Effect of the RE impurities on matrix emission was also studied.

C/PI.26 LUMINESCENT CHARACTERISTICS OF NANOCRYSTALLINE TiO₂:Eu³⁺ PHOSPHORS

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Synthesis of narrow-dispersed nanocrystalline TiO₂:Eu³⁺ phosphors has been investigated by reverse micelles and solvothermal synthetic method in toluene solutions. Different concentrations of europium nitrate pentahydrate (5.0, 10.0, 20.0 and 25.0 mole %) were dissolved in water. After the solution was thermally treated at 250°C for 20h in an autoclave, low-dispersed TiO₂:Eu³⁺ nanocrystalline particles with average size of < 5nm were synthesized. X-ray diffraction (XRD) measurements have identified TiO₂:Eu³⁺ particles at the anatase phase. Transmission electron microscopy (TEM) micrographs show that nanoparticles have polyhedral-shaped morphologies and good electron diffraction patterns, which indicates that they have good crystallinity. It was expected that the nucleation and growth of nanocomposites were composed of TiO₂ shell with Eu₂O₃ cores. However, any evidence was not obtained from XRD and TEM, whether the nanoparticle has core-shell structure or europium oxide is formed a colony of aggregates or Eu ions are dispersed in the TiO₂ solution. Luminous properties of TiO₂:Eu³⁺ phosphors were investigated by time resolved laser spectroscopy in the temperature range of 15 ~ 400 °K. The radiation was dominated by the red emission peak at 616 nm and the highest emission intensity was observed with TiO₂:Eu_{0.2}, whose brightness was increased by a factor of 1.9 in comparison with that of TiO₂:Eu_{0.05}. The life time, ~0.3 msec, of radiation was shorter than that of Eu-doped bulk phosphors and independent of the temperature. The photoluminescence and excitation spectra show the similar behavior as a function of Eu concentration.

C/PI.27 SOL-GEL DERIVED METAPHOSPHATES Ln(PO₃)₃(Ln=Y,La): SYNTHESIS AND CHARACTERIZATION

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Recent developments of new type of lamps and displays have introduced the need for improving phosphors mostly in shape of controlled size distribution powders or films. The sol-gel process which involves the use of molecular precursors as starting materials is well known to be an efficient method to provide phosphors, notably oxides, exhibiting enhanced optical properties [1,2].

Among the oxide based phosphors, rare earth activated metaphosphates Ln(PO₃)₃ (Ln = Y, La) show very promising properties. Purity and morphology of sol-gel derived powders were checked respectively by X-ray diffraction (XRD) and scanning electron microscopy (SEM). Besides, the crystallization process was analyzed by infrared (IR) spectroscopy and thermal analysis (TG-DTA). Local characterization was completed using laser induced fluorescence of Eu³⁺ doped samples. [1] D. Boyer, G. Bertrand-Chadeyron, R. Mahiou, C. Caperaa and J.C. Cousseins, J. Mater. Chem. 9 (1999), 211. [2] G. Li, M. Nogami, Y. Abe, Solid State Ionics 83 (1996), 209.

- C/PI.28** OPTICAL AND STRUCTURAL INVESTIGATION ON RARE-EARTH-DOPED ALUMINOPHOSPHATE GLASSES
M. Elisa(a), I. Cristina Vasiliu(a), Cristiana E.A. Grigorescu(a), Bogdan Grigoras(b), Horatiu Niciu(b), Daniela Niciu(b), Aurelia Meghea(c), Nicoleta Ifitimie(c), Maria Giurginca(c), J.H. Trodahl(d), M. Dalley(d), (a)Department for Advanced Materials, National Institute of Optoelectronics-INOE 2000 Atomistilor Str. 1, P.O.Box MG - 5, RO-77125, Com. Magurele, Romania, (b)National Institute of Glass, Department for Laser Glass Technology, Th. Pallady Str., nr.47, Bucharest, Romania, (c)Faculty of Industrial Chemistry, University Politehnica of Buchaest, Applied Spectroscopy Laboratory Polizu Str, 1, Bucharest, (d)School of Chemical and Physical Sciences, Victoria University Semicond.Laboratory, PO Box 600, Wellington, New Zealand
A wet non-conventional method for preparing phosphate glasses is presented. Aluminophosphate glasses belonging to the oxide system $\text{Li}_2\text{O}-\text{BaO}-\text{Al}_2\text{O}_3-\text{La}_2\text{O}_3-\text{P}_2\text{O}_5$, un-doped and doped with rare-earth metal ions (Ce^{4+} , Nd^{3+} , Pr^{3+} , Sm^{3+} , Yb^{3+} , Er^{3+} , Eu^{3+}) were obtained and characterized. The influence of the doping ions on the optical properties of the phosphate glasses has been investigated in relation with micro-structural and local electronic phenomena The optical behaviour of $\text{Li}_2\text{O}-\text{BaO}-\text{Al}_2\text{O}_3-\text{La}_2\text{O}_3-\text{P}_2\text{O}_5$ glasses un-doped and doped with 3% mol.rare-earth ions has been studied by ultra-violet-visible-near-infra-red (UV-VIS-NIR) spectrometry. Structural information via optical phonons was provided by infra-red (IR) absorption spectra in the range 400-4000 cm^{-1} . Fluorescence spectra in the visible range of some rare-earth-doped aluminophosphate glasses were obtained by laser excitation. The dependence of the refractive index versus wavelength is presented.
- C/PI.29** EFFICIENT BLUE EMITTING PHOSPHORS BY QUANTUM CUTTING MECHANISM IN RARE-EARTH DOPED MATERIALS.
L. Beauzamy, B. Hautefeuille and B. Moine, Laboratoire de Physico-Chimie des Matériaux Luminescents, UMR 5620 du CNRS Université Claude-Bernard LYON University, 03041, Geroiv Oborony st., Kyiv, Ukraine
- C/PI.30** THE LUMINESCENT PROPERTIES OF Ce AND Eu DOPED $\text{Sr}_4\text{Al}_{14}\text{O}_{25}$ PHOSPHORS
Sang Hyuk Han(a), Sung Mook Chung(b), Young Jin Kim(c); (a)R&D Div., Phosphor Team, DAEJOO Electronic Materials, Kyonggi-Do, Korea; (b)Organic EL Devices Team, ETRI, Deajeon 305-350, Korea; (c)Department of Materials Science and Engineering, Kyonggi University, Suwon 443-760, Kyonggi-do, Korea
- C/PI.31** UV AND VIS UPCONVERSION EMISSION IN Er^{3+} DOPED SOL-GEL $\text{SiO}_2-\text{LaF}_3$ GLASS-CERAMICS
J. Del-Castillo(a), A.C. Yanes(a), V.D. Rogriguez(b), J. Mendez-Ramos(b), M.E. Torres(a) and J. Peraza(a), (a)Dpto. Física Básica, Universidad de La Laguna, 38206 La Laguna, Tenerife, Spain, (b)Dpto. Física Fundamental y Experimental, Electrónica y Sistemas, Universidad de La Laguna, 38206 La Laguna, Tenerife, Spain
- C/PI.32** SYNTHESIS, CHARACTERIZATION AND LUMINESCENT PROPERTIES OF TRANSPARENT NANOSTRUCTURED Eu^{3+} DOPED SOL-GEL $\text{SiO}_2-\text{LaF}_3$ GLASS-CERAMICS
J. Del-Castillo(a), A.C. Yanes(a), V.D. Rogriguez(b), J. Mendez-Ramos(b), M.E. Torres(A) and J. Peraza(a), (a)Dpto. Física Básica, Universidad de La Laguna, 38206 La Laguna, Tenerife, Spain, (b)Dpto. Física Fundamental y Experimental, Electrónica y Sistemas, Universidad de La Laguna, 38206 La Laguna, Tenerife, Spain

Session V : Devices I
Session chairs : J. Coffe, C. Ronda

- C-V.01** 14:00 -Invited- 470 nm LED-PUMPED OPTICAL WAVEGUIDE AMPLIFIER BASED ON NANOCLUSTER-Si SENSITIZED, Er-DOPED SILICA
Jinku Lee, Hak-Seung Han, and **Jung H. Shin**, Dept. of Physics, KAIST, 373-1 Guseong-dong, Yuseong-Gu, Namkyoo Park, Daejeon 305-701, Korea and Hansuek Lee, Optical Communication Systems Laboratory, School of EECS, Seoul National University, 151-742 Seoul, Korea
The method of sensitizing Er-doped silica with nancluster Si (nc-Si) for broad-band, top-pumped optical amplification is reviewed. We first describe the mechanisms of nc-Si sensitization of Er. A detailed examination of the composition and structure of the nc-Si sensitized, Er-doped silica thin film necessary to obtain the optimum performance is then given. Finally, we demonstrate optical gain from such a film top-pumped with an array of commercial, visible light emitting diodes. An analysis of the possible performance of such an optical amplifier is presented, along with the discussion of the possible future developments.
- C-V.02** 14:30 SHORT RANGE ORDER AROUND Er IN SILICA WAVEGUIDES CONTAINING Al, Ti AND Hf
N.D. Afify and G. Dalba, INFN and Department of Physics, 38050 Povo (Trento), Italy, C. Armellini, M. Ferrari and **F. Rocca**, IFN-CNR Section of Trento, 38050 Povo (Trento), Italy, A. Kuzmin, ISSP, University of Latvia, Riga Latvia
Aim of this paper is to characterise the nearest and next nearest neighbours of Er ions in silica waveguides containing different modifier oxides (Al₂O₃, TiO₂ or HfO₂). Er(3+)-doped waveguides were prepared using the sol gel method and dip-coating processing; optical studies on these systems has been presented in previous papers by M. Ferrari et al. Here, we present a characterisation of the local environment around Er(3+) ion, as determined from the Er L₃-edge X-ray Absorption Spectra measurements (EXAFS) performed at BM08 of ESRF (France). The first coordination shell is composed of 5-6 Oxygen atoms in octahedral coordination at distances ~2.32-2.34 Å, slightly varying as a function of modifier oxide. On the contrary, this nearest distance does not show significant compositional dependence. Outer shells analysis shows significant differences: Al-doping (less than 2% mol) induces an ordering of the second shell, probably due to the substitution of Si atoms around Er by Al atoms; for TiO₂ doping (7-15% mol) it is impossible to distinguish between Si and Ti atoms in the second coordination shell; for HfO₂ (from 10 to 50% mol) there is a very clear evidence of Er-Hf coordination already at the lowest Hf content, but still in an amorphous environment.
- C-V.03** 14:45 EFFICIENT ELECTROLUMINESCENCE FROM Tb-IMPLANTED SILICON METAL-OXIDE-SEMICONDUCTOR DEVICES
J.M. Sun, W. Skorupa, T. Dekorsy, and M. Helm, Institute of Ion Beam Physics and Materials Research, Forschungszentrum Rossendorf, POB 510119, 01314 Dresden, Germany, L. Rebohle and T. Gebel, Nanoparc GmbH, Dresden, Germany
Strong green electroluminescence with brightness up to 2800 cd/m² was obtained from indium-tin-oxide/SiO₂:Tb/Si metal-oxide-semiconductor devices. The SiO₂:Tb gate oxide was prepared by thermal oxidation followed by Tb⁺ implantation and annealing. Electroluminescence and photoluminescence properties were studied with variations of the Tb³⁺ ion concentration and annealing temperatures. The optimized device has a high external quantum efficiency of 16 % and a luminous efficiency of 2.1 lm/W. The excitation process of electroluminescence can be attributed to the impact excitation of the Tb³⁺ luminescent centers by hot electrons and the subsequent cross-relaxation from the 5D₃ to 5D₄ levels. Light emitting devices with micrometer size were demonstrated by the complementary metal-oxide-semiconductor technology.
- C-V.04** 15:00 Er³⁺ DOPED Ge-Ga-Se GLASSES FOR SHORT LENGTH OPTICAL AMPLIFIERS
S.O. Kasap, K. Koughia, M. Munzar, D. Tonchev, Department of Electrical Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, SK, S7N 5A9 Canada and C. Haugen, R. Decorby, J.C. McMullin, 2TRLabs, 7th Floor, 9107 - 116 Street N.W., Edmonton, AB, T6G2V4, Canada and Department of Electrical and Computer Engineering, University of Alberta, Edmonton, AB, T5K 2P7, Canada
Optical and thermodynamical properties of Ge-Ga-Se(S) glasses heavily doped with Er³⁺ prepared by melt quenching technique have been investigated as a function of chemical composition and Er concentration. The glasses were doped using Er₂S₃. A strong correlation between the Er³⁺ and Ga concentrations (C_{Er} and C_{Ga}) and the properties of these glasses has been observed. High C_{Ga}/C_{Er} > 10 ensures the homogeneous distribution of Er³⁺ in the host volume. The optimum Ga concentration was found to be 10-12 at.% while higher C_{Ga} destroyed the glass structure. Up to 1.5 at.% of Er may be dissolved homogeneously without the formation of clusters and precipitates. The best results have been observed in glasses with stoichiometric compositions with subsequent annealing. We have studied the photoluminescence (PL) of a wide range of heavily Er³⁺ doped chalcogenide glasses pumped by laser diodes operating at various wavelengths from 530 up to 980 nm and showed that the broadening of PL line at higher excitation wavelengths may be connected with the absorption - re-emission of emitted photons. We were able to prepare the

homogeneous thin films of desirable composition by pulse laser deposition of bulk glasses. We compare the PL spectra of Er³⁺ doped bulk samples and thin films.

C-V.05 15:15

FABRICATION CONDITIONS AND SPECTROSCOPIC PROPERTIES OF RF-MAGNETRON DEPOSITED AND MICROSTRUCTURED YB-DOPED SILICA GLASS FILMS FOR WAVEGUIDE LASER APPLICATION

A-S. Jacqueline(a), V. Petit(b), F. Gourbilleau(a), P. Camy(b), J-L. Doualan(b), R. Moncorgé(b), R. Rizk(a),(a)SIFCOM, UMR 6176, CNRS-ENSICAEN, 6 bd. du maréchal Juin, 14050 Caen cedex, France, (b)CIRIL, UMR 6637, CNRS-CEA-ENSICAEN, 6 bd. du Maréchal Juin, 14050 Caen cedex, France

This paper describes the fabrication in planar technology of high refractive index n Yb-doped silica glass planar waveguides for laser applications. The thin films were prepared by RF magnetron sputtering of a pure silica target topped by TiO₂, Ge, and Yb₂O₃ pieces. The deposition parameters (substrate temperature, RF power, nature of the plasma...) were accurately adjusted to optimize both thickness and n values of the layers. The value of n is an essential parameter and should be large enough (>1.5) to reach good optical confinement in terms of coupling efficiency and laser brightness. Specific post-deposition thermal treatments (temperature, gas nature) were used to optimize the Yb³⁺ fluorescence lifetime whose value must be maximized for high pump energy storage and laser efficiency.. The obtained values, scaled from 70 to 700 μs, are comparable with those usually reported for Yb-doped silica glass fibers. The films were subsequently photolithographed and ionically etched to fabricate the waveguide laser whose spectroscopic properties are presented and commented.

C-V.06 15:30

PHOTOLUMINESCENCE FROM Er-DOPED SILICON OXIDE MICROCAVITIES

A. Hryciw, C. Blois, and A. Meldrum, Department of Physics, University of Alberta, Edmonton, Alberta T6G 2J1, Canada; T. Clement and R. DeCorby, Department of Electrical and Computer Engineering and TRILabs, University of Alberta, Edmonton, Canada; Q. Li, Department of Physics, Science Centre North Block, The Chinese University of Hong Kong, Shatin, NT, Hong Kong

Er-doped silicon nanocomposite glasses have been extensively studied due to the favourable optical properties of erbium in the presence of Si nanoparticles. However, most studies have annealed specimens at temperatures on the order of 1000 °C to form nanocrystals; such high temperatures are undesirable from an integrated optoelectronics perspective. In this study, Er-doped silicon oxide (SiO:Er) thin films with Er concentrations ranging from 0.04 to ~2.5 at% have been deposited on SiO₂ and Si substrates by co-evaporation of SiO and Er₂O₃ under high vacuum. Electron energy loss spectroscopy and the corresponding elemental mapping suggest the presence of amorphous Si nanoclusters surrounded by a ~SiO₂ matrix. Photoluminescence (PL) from these films was investigated with respect to annealing temperature and process gas. The 1.5 μm emission was highest for a 0.17-at%-Er specimen annealed at 500 °C in 95% N₂+5% H₂. To further narrow and tune the Er emission, we have incorporated SiO:Er into planar microcavities with metal mirrors. The low thermal processing temperatures permitted the demonstration of a simple-to-fabricate graded wavelength-selectable optical microcavity with intensified and directional emission in the 1480-1610 nm range. The results suggest that SiO:Er emitters based on the processes described might be integrated with existing microelectronics technologies.

C-V.07 15:45

FABRICATION OF Er/Yb-DOPED GeO₂ CHANNEL WAVEGUIDE AMPLIFIER

Iku Endo, Nobuhiro Onouchi, Hideyuki Yamaguchi, Atsushi Shinbori, Satoru Matsumoto Keio University, Japan

Erbium(Er)-doped semiconductors are attracting much attention because it involves emitting light at 1.54μm. We have used cathode-luminescence equipment to excite the erbium ion from the 4I_{15/2} ground state to 4I_{13/2} excited state to attain a populated inversion state resulting in fundamental luminescence. Er-doped GeO₂ material has exhibited strong luminescence property compared to Er-doped SiO₂ by two orders of magnitude and no other research have been reported. We have investigated the luminescence property by varying Er and Yb concentrations. Er concentrations were chosen carefully so that no concentration quenching would occur for each sample. By co-doped Yb to Er-doped GeO₂, the luminescence intensity increased by a factor of 2～3 for Er concentrations (0.24mol%, 0.27mol%, 0.4mol%). This is considered that energy migration to Er occurs easily due to higher absorb cross section of Yb, resulting in a increase in luminescence intensity at 1.54μm. The fabrication of a single mode channel waveguide is followed by the given procedures: First the lower refractive index cladding layer(SiO₂)is deposited on the CZ-Si(100)substrate using reactive ion sputtering technique. Later, the Rare-earth elements (Er/Yb) were simultaneously doped into Ge using co-sputtering and reactive sputtering technique under O₂ ambient resulting in an Er/Yb-doped GeO₂ active layer. The sample was then annealed under N₂ ambient at 700℃　using rapid thermal annealing (RTA) system to optically activate Er ion. Using standard photolithographic technique, the waveguide pattern was formed with selective etching. After depositing an upper cladding layer(SiO₂), the structure of a channel-type waveguide amplifier is then completed. The gain estimation of this device is in progress.

16:00

BREAK

Session VI : Devices II

Session chairs : F. Priolo, M. Fujii

- C-VI.01** 16:15
- FABRICATION OF OPTICAL PLANAR AND CHANNEL WAVEGUIDES IN Yb³⁺ DOPED KY(WO₄)₂ BY HE-ION IMPLANTATION
C.N. Borca, F. Záh, C. Schneider, R.P. Salathé, M. Pollnau, Advanced Photonics Laboratory, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland and P. Moretti, Laboratoire de Physico-Chimie des Matériaux Luminescents, Université Lyon 1, 69622 Villeurbanne Cedex, France
- Light ion implantation can be regarded as a universal tool for fabricating low-loss waveguide structures in optically active oxide materials. We have fabricated planar optical waveguides in KY(WO₄)₂:(2%)Yb³⁺ crystals by implanting He⁺ ions at 1.5 MeV, with doses ranging from 1 to 3x10¹⁶ ions/cm². An optical barrier with a decreased effective refractive index was created at the end of the ions' tracks, situated approximately 3.5 μm below the surface. The change in refractive index with respect to the bulk value and its stability to thermal treatment were investigated by dark m-line spectroscopy. Surface channel waveguides were obtained by writing sidewalls into the planar guiding layer by implantation through a slit. The sidewalls were produced by keeping the ion energy fixed and varying the incident angle of implantation. Channel waveguides of 5-μm width and 4-μm depth were obtained in the regions between the implanted sidewalls. Beam-propagation parameters were measured by investigating the output profile of end-coupled, fundamental-mode laser light at 980 nm. The results of loss measurements will be presented at the conference.
- C-VI.02** 16:30
- PUMP-PROBE EXPERIMENTS ON ER COUPLED Si-NANOCRYSTALS RIB-LOADED WAVEGUIDES
N. Daldosso, D. Navarro, M. Melchiorri, L. Pavesi, INFN and Department of Physics, Università di Trento, Via Sommarive 14, 38050 Povo (Trento), Italy, C. García, P. Pellegrino, B. Garrido, EME Departament d'Electrònica Universitat de Barcelona, Martí i Franquès, 1, 08028 Barcelona, Spain and F. Goubilleau, M. Carrada, R. Rizk, SIFCOM-ENSICAEN, 6 Boulevard Maréchal Juin, 14050 Caen, France
- Rib-loaded silica waveguides containing Er ions and Si nanoclusters (Si-nc) were grown by reactive magnetron co-sputtering on a 10 mm-thick SiO₂ layer deposited on a Si wafer. The annealing time has been varied to control Si-nc nucleation and their size, and thus changing the refractive index. The rib-loaded structure of the waveguides was fabricated by photolithographic and reactive ion etching processes, with patterned rib widths ranging from 2 to 10 μm. Efficient light propagation was observed when end-fire coupling a probe signal in the rib waveguide both at 1310 nm and in the range 1500-1600 nm, with attenuation losses as low as 1 dB/cm at 1600 nm. Insertion losses measurement as a function of the wavelength in the Er absorption region has permitted to estimate the Er absorption cross section at 1.535 μm in the order of 10-21 cm², contrary to other values reported in the literature. Pump and probe experiments at 1310 nm show increased absorption as the pump power (either at 488 or 532 nm) is increased due to excited state absorption of the Si-nc. Pump probe experiments at 1535 nm, which are affected by the negative role of carrier absorption too, have been performed and the signal enhancement measured has been discussed in terms of direct and indirect excitation of Er. The negative role of confined carrier absorption has been reduced by varying the annealing conditions thus showing an internal gain of about 0.5 dB/cm at low pumping power density (50-100 W/cm², 532nm).
- C-VI.03** 16:45
- PREFORMS AND FIBER LASERS FROM RARE-EARTH DOPED SOL-GEL GLASSES
M. Locher, V. Romano, D. Michel, U. Pedrazza, R. Renner, W. Lüthy, Th. Feurer Institute of Applied Physics, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland
- Mainly driven by the advent of photonic bandgap fibers, fiber production has gained further importance and is seeing the implementation of a large variety of novel fiber concepts. With its versatility the sol-gel method very well complements some of the needs of these new fiber concepts, mainly in the case, where rare-earth doping is desired. The sol-gel process starts from liquid metal alkoxide precursors at room temperature and allows to reach high dopant concentrations with considerably less effort than traditional glass production methods. The process further offers a high degree of compositional flexibility with respect to dopants as well as matrix components. It also facilitates to achieve high homogeneity - down to the molecular level - even in cases when several dopants at the precursor level are involved. In this work we have produced several fiber preforms; their rare-earth activated core material (Neodymium, Ytterbium, Terbium) was deposited by sol-gel technique and co-doped with Aluminum to prevent clustering of the rare-earth ions. Titania co-doping was used to enhance the refractive index from 1.46 to 1.73 and showed not to adversely affect the long fluorescence lifetime of the doped materials. The properties of the produced core materials (fluorescence spectra, lifetime and refractive index) as well as the laser properties of the fibers drawn from the sol-gel preforms are presented.
- C-VI.04** 17:00 -Invited-
- RARE-EARTH-DOPED III-N SEMICONDUCTORS: THIN FILM GROWTH AND PROSPECTS FOR LASER DEVICES
A. J. Steckl, NanoLab, University of Cincinnati, Cincinnati OH 45221-0030, USA

Session VII : Thin films

C-VII.01 17:30

SENSITISATION OF ERBIUM LUMINESCENCE IN ERBIUM-IMPLANTED ALUMINA

A.J. Kenyon, University College London, U.K., C.E. Chryssou, Southampton Photonics, U.K., T.M. Smeeton and C.J. Humphreys, University of Cambridge, U.K., D.E. Hole, University of Sussex, U.K.

Experimental evidence of an efficient broadband sensitisation mechanism in erbium-implanted alumina is presented. Alumina thin films were deposited by plasma-enhanced chemical vapour deposition. The as-grown films were implanted with erbium. Photoluminescence excitation spectra showed that erbium-implanted alumina thin films exhibit 1.53 μm luminescence even when pumped at wavelengths outside Er^{3+} absorption bands. The samples were analysed structurally using Transmission Electron Microscopy and Electron Energy Loss Spectroscopy. We postulate that the sensitising species is either small nanoclusters of aluminium or pairs of aluminium ions.

C-VII.02 17:45

INFRARED-TO-VISIBLE CW FREQUENCY UPCONVERSION IN $\text{Er}^{3+}/\text{Yb}^{3+}$ CO-DOPED ALUMINA-SILICA XEROGELS PREPARED BY SOL-GEL ROUTE

K. Tran Ngoc, G.D. Sorarù Dipartimento di Ingegneria Università di Trento, via Mesiano 77, 38050, Trento, Italy, L. Zampedri, M. Montagna, Dipartimento di Fisica, Università di Trento, CSMFO group, via Sommarive 14, 38050 Povo, Trento, Italy, H. Phan Thanh, C. Nguyen Duc, ITIMS-Hanoi University of Technology, No 1, Dai Co Viet, Hanoi, Vietnam, G.C. Righini CNR-IFAC Istituto di Fisica Applicata, "Nello Carrara", Optoelectronics and Photonics Department, via Panciatichi 64, 50127 Firenze, Italy, Y. Jestin, M. Ferrari, A. Chiasera, C. Armellini, CNR-IFN Istituto di Fotonica e Nanotecnologie, CSMFO group, via Sommarive 14, 38050 Povo, Trento, Italy

Several $\text{Er}^{3+}/\text{Yb}^{3+}$ codoped alumina-silica monolithic xerogels were prepared with the same concentration of 2000 Er/Si ppm and 6000 Al/Si ppm. The Yb/Si content was varied from 0 to 4000 ppm. Densification of the samples was achieved by thermal treatment in air at 950°C for 120 hours with a heating rate $0.1^\circ\text{C}/\text{min}$. Photoluminescence excitation spectra were obtained using a Ti:Sapphire laser tuned over the wavelength ranges of 880 - 1010 nm, spanning the energy range of the $\text{Yb}^{3+} 2F_{7/2} \rightarrow 2F_{5/2}$ and $\text{Er}^{3+} 4I_{15/2} \rightarrow 4I_{11/2}$ absorption bands. The observed wavelength was set to 1533 nm. The NIR-to visible upconversion luminescence has been investigated upon continuous wave (CW) excitation at 980 nm. The samples exhibit red, green and blue upconversion emission. At high Yb^{3+} co-doping concentration, a further upconversion emission band characteristic of Yb^{3+} - Yb^{3+} cooperative upconversion is observed at 20400 cm^{-1} . The dependence of upconversion luminescence intensities on pump power has been evaluated and experimental data were fitted to a power law, $I \propto P^n$. It is found that intensity of upconversion luminescence is increased with increasing Yb^{3+} doping concentration. Based on the experimental results, a model has been proposed for energy transfer and upconversion emissions, which consist of two and three photons excitation process.

C-VII.03 18:00

IMPROVING EMISSION PERFORMANCE FROM Er-Tm CODOPED Al_2O_3 THIN FILMS

Zhisong Xiao, R. Serna, C. N. Afonso, Instituto de Optica, CSIC, Serrano 121, 28006 Madrid, Spain and I. Vickridge, Groupe de Physique des Solides, UMR 7588 du CNRS, Université de Paris 6 et 7, 2, Place Jussieu, 75251 Paris Cedex 05, France

Rare earth (RE) doping of dielectrics allows to prepare suitable materials for integrated gain devices in planar waveguides. In order to obtain a broad emission band from a single material one interesting route to explore is the possibility of profiting from emission of more than one type of RE ion. The challenge is to obtain thin films with high enough rare-earth concentration, and with an efficient luminescent response.

In this work it will be shown how to obtain an efficient broad band emission from Er-Tm codoped Al_2O_3 thin films by controlling the concentration quenching effects through a suitable choice of the Er/Tm concentration ratio and nanostructuring the Er and Tm respective distribution. Two series of Er-Tm Al_2O_3 codoped thin films have been prepared by pulsed laser deposition (PLD). All the films show a broad emission band in the range 1400-1700 nm with two peaks located at 1540 and 1640 nm. However, in one series the Er^{3+} concentration was kept constant, and as the Tm^{3+} concentration was increased, both the PL intensity and lifetime at 1640 nm decreased due to concentration quenching. In the other series the Tm^{3+} concentration was also increased while keeping the $\text{Tm}^{3+}/\text{Er}^{3+}$ concentration ratio constant and in this case the quenching of the 1640 nm emission was substantially reduced. It will also be shown how adjusting the Er/Tm concentration ratio the 1400-1700 nm bandwidth of the PL response of Er-Tm codoped Al_2O_3 films can be controlled.

19:00

AWARD CEREMONY

The symposium organizers and the candidates to the graduate student award are requested to attend.

CONFERENCE RECEPTION

Session VIII : Phosphors I

Session chairs : P. Goldner, J. Evans-Freeman

C-VIII.01 9:00 -Invited-

LUMINESCENT MATERIALS: PAST, PRESENT AND FUTURE

C. Ronda, Philips Research Laboratories Aachen, 52072 Aachen, Germany and Utrecht University, Ornstein Laboratory, P.O. Box 80.000, 3508 TA Utrecht, The Netherlands

C-VIII.02 9:30

UNUSUAL FULL-COLOR PHOSPHORS: Na₃RESi₃O₉

D. Ananias(a), L.D. Carlos(b), J. Rocha(a), (a)Department of Chemistry, CICECO, University of Aveiro, 3810-193 Aveiro, Portugal, (b)Department of Physics, CICECO, University of Aveiro, 3810-193 Aveiro, Portugal

Luminescent materials, or phosphors, are found in a wide range of applications, such as emissive displays, fluorescent lamps, infrared amplifiers, and X-ray detectors. Different applications pose diverse requirements on the emitted light: pure colours may be needed, while in other cases a bright white light source is necessary. The development of new and efficient emitting devices is one of the main present challenges in display and lighting technology.

Na₃YSi₃O₉ possesses a mixed octahedral-tetrahedral framework, where the YO₆ octahedra are isolated from each another by SiO₄ tetrahedra (quantum dots on an insulating matrix, so to say). The Y³⁺ ion may be (totally or partially) replaced by one or more Ln³⁺ ions, such as Eu³⁺, Tb³⁺, Tm³⁺ and Er³⁺. Na₃ErSi₃O₉ is a new C-band infrared emitter with unusual optical properties [1]. Na₃(Y1-aTba)Si₃O₉ (a=0-1) materials are efficient X-ray phosphors [2]. The Tm-based material displays both broad room-temperature infrared emission, and blue emission with excellent colour purity [3]. Here we show the integration of the blue (Tm³⁺), green (Tb³⁺) and red (Eu³⁺) emissions on Na₃(Y,Eu,Tb,Tm)Si₃O₉ samples, which are full-colour phosphors with (x,y) CIE colour coordinates (0.324, 0.364), corresponding to a white emission. [1] D. Ananias, J. P. Rainho, A. Ferreira, M. Lopes, C. M. Morais, J. Rocha, L.D. Carlos, Chem. Mater. 2002, 14, 1767. [2] D. Ananias, A. Ferreira, L.D. Carlos, J. Rocha, Adv. Mater. 2003, 15, 981.

C-VIII.03 9:45

DEGRADATION MECHANISM OF PHOSPHORS BY VACUUM ULTRAVIOLET EXCITATION

B. Moine and G. Bizarri, Laboatoire de Physico-Chimie des Matériaux Luminescents, UMR 5620 du CNRS, Université Claude-Bernard Lyon 1, France

The mechanism of luminance decrease of phosphors excited by a Xe plasma discharge has been studied. It is shown experimentally that the aging process is mainly due to the Vacuum UltraViolet excitation (VUV). It is demonstrated that the degradation mechanism can be accelerated by using an 193 nm laser excitation. Based on excitation, reflectance, thermoluminescence spectra and aging or bleaching processes by laser excitation, the main causes of the degradation are demonstrated. The aging process can be separated in two different processes depending on the temperature: A first one, at low temperature, corresponding to the autoionisation of luminescent centers; and a second one, at high temperature, linked to the formation of traps in the phosphor. These traps induce a perturbation of the energy migration in the phosphor. The relevant parameters of the creation of traps are highlight: density of the VUV excitation, temperature, atmosphere and pressure surrounding the phosphor.

C-VIII.04 10:00 -Invited-

SOL-GEL SYNTHESIS AND LUMINESCENCE PROPERTIES OF FLUORIDE-BASED PHOSPHORS

S. Lepoutre, D. Boyer and R. Mahiou, Laboratoire des Matériaux Inorganiques, UMR CNR 6002, Université Blaise Pascal & ENSCCF 24, Avenue des Landais, 63177 Aubière Cedex, France

Since recent years, a great interest has been focused on the fabrication and luminescence properties of a variety of sol-gel based oxide materials in order to provide efficient phosphors for flat panel displays devices or free-Hg fluorescent lamp sources. In such applications luminescent materials have widely been based on powders, or on planar waveguide geometries which play the more significant role in photonic devices. Advantages gained by preparing materials through the sol-gel process have appeared sufficiently important to investigate the development of more efficient materials by this way. Fluorides show in comparison with oxides, specific optical features: low phonon frequencies, high transparency upon UV radiation. Nevertheless, there are some problems arising from the shaping techniques in particular to achieve fluoride thin film. Sol-gel chemistry can offer a convenient and efficient route for such purpose. The sol-gel preparation of fluorides can be classified in two major methods: post fluorination of sol-gel derived oxide material and in situ fluorination [1]. Fluorides of LiLnF₄ type (Ln = Y and lanthanide ions) have been investigated. These compounds are of great interest because of their ability as quantum cutter upon VUV radiation [2]. The synthesis way described is a one-step process involving fluorination reagent. Heating treatment under F₂ reactive atmosphere was carried out to prevent any oxygen contamination. The presentation is focused on the production of sol-gel powders and films and on the luminescence properties of derived materials.

[1] S. Fujihara, "Recent Research Developments in Materials Science", Vol.3 (2002), pp.619-631. [2] R.T. Wegh, H. Donker, E.V.D. van Loef, K.D. Oskam, A. Meijerink, J. Lumin. 87-89 (2000) 1017.

C-VIII.05 11:00

PHOSPHOR POWDERS ELABORATED BY SPRAY-PYROLYSIS:
CHARACTERIZATIONS AND POSSIBLE APPLICATIONS

N. Joffin(a,b), B. Caillier(c), A. Garcia(d), P. Guillot(c), A. Fernandes(a), R. Mauricot(a), J. Dexpert-Ghys(a), (a)CEMES-CNRS, 29 rue Marvig BP 94347, 31055 Toulouse Cedex, France, (b)DGTec, 178 rue de Mayoissard, Cent'alp, 38430 Moirans, France, (c)CPAT-UPS, 118 route de Narbonne, 31062 Toulouse Cedex, France, (d)ICMCB, 87 av Dr Schweitzer, 33608 Pessac, France

Several well known phosphors compositions have been synthesized by spray-pyrolysis and additional thermal treatments. The particles are spherical, the average diameter is around 2 micrometers, with a relatively narrow spreading. These powders have been characterized by various techniques, their nano- and micro-structurations investigated. The phosphors luminescence properties have been measured, especially under VUV excitations for which two dedicated experiments have been built. These characteristics are compared to those of commercial phosphors measured in the same conditions.

The present work will emphasize on : -the description of the results and critical comparison with analogous datas found in the literature; - the interpretation of some of the observed luminescence characteristics in relation with the phosphors morphologies; - the discussion on the possibilities and limits of the spray-pyrolysis technique for the synthesis of phosphor powders.

C-VIII.06 11:15 -Invited-

PHOTON MANAGEMENT WITH LANTHANIDES

A. Meijerink, R. Wegh and P. Vergeer, Debye Institute, Dept. of Chemistry, Utrecht University, The Netherlands

Session IX : Organic and related materials

C-IX.01 11:45

RED OLEDs FABRICATED BY Eu TERNARY COMPLEXES WITH CONDUCTING SECONDARY LIGANDS

M.K. Lam(a), S.K. So(a), J.B. Yuan(b,c), L.M. Leung(b), M.L. Gong(c), (a)Department of Physics and Centre for Advanced Luminescence Materials, Hong Kong Baptist University, Hong Kong, China, (b)Department of Chemistry and Centre for Advanced Luminescence Materials, Hong Kong Baptist University, Hong Kong, China, (c)State Key Laboratory of Optoelectronic Materials and Technologies, School of Chemistry and Chemical Engineering, Sun Yat-sen University, Guangzhou 510275, China

A series of Eu ternary complexes with charge conducting secondary ligands were examined as potential light-emitting materials for organic light-emitting diodes (OLEDs). The Eu complex contains imidazole-based secondary ligand and is electron-conducting. Very simple heterojunction OLEDs can be fabricated with a structure ITO/CuPc/TPD/Eu complex/Ca. where CuPc=copper (II) phthalocyanine TPD =N, N'-diphenyl-N,N'-bis(3-methylphenyl)(1,1'-biphenyl)-4,4'-diamine. The Eu complex plays the dual role of electron-transporting and light-emitting layer. Sharp red emission can be observed at about 610 nm. The OLEDs has a current efficiencies of about 0.5 cd/A (at about 20 mA/cm²) and a maximum luminance between 150-200 cd/m². The OLEDs performance was further examined by co-evaporating Eu with TPD, and PBD as the emitting layer. A trend between the current efficiency and the doping concentration can be found and the result was compared with the photoluminescence. The effects of various substituted imidazole moiety on the light-emitting properties will be addressed.

C-IX.02 12:00

NATURE OF THE STATES EU ATOMS IN ORGANIC SEMICONDUCTORS

V.V. Krivolapchuk, M.M. Mezdrogina., V.L. Berkovits, E.I. Terukov, Ioffe Physico-Technical Institute, J.V. Kozhanova, P.P. Seregin, E.C. Chuzakulov, S-Pb State Polytechnical University, T.A. Jurre, A.V. Zimanin, S-Pb State Technological University, St. Petesburg, Russia

Mossbauer spectroscopy of the ¹⁵¹Eu isotope have been applied to identify valence state of Eu atoms in structure of organic compound semiconductors. Mossbauer spectra of the crystalline phtalozianin (I) and crystalline acetilacetate (II) of europium at 295K and at 80K reveal only single broaden line with half-width of 2.9±0.1 mm/s for spectrum I and of 3.3±0.3 for spectrum II. The value of isomer shift of the line with respect to E2O3 in both compounds does not depend on temperature and was measured to be -0.33±0.02 mm/s for spectrum I and -0.36±0.07 mm/s for spectrum II. Such value corresponds to Eu³⁺ state in spite of the fact that the Eu - atoms have in their local surroundings only oxygen atoms in the compound I and only nitrogen atoms in the compound II. Mossbauer spectra of thin films the same compounds (I and II) also reveal single line with the same parameters as were found for crystalline samples. This fact indicates obviously a complete equivalence of valence and coordination states of the Eu atoms in crystals and in films. Photoluminescence, adsorption, and reflectance anisotropy spectra spectra were measured at T= 77, 300K. Correlation of the obtained optical data with Mossbauer spectra is discussed.

C-IX.03 12:15

MOLECULAR DESIGN OF OPTICALLY ACTIVE NANOCOMPOSITES

Sanjay Mathur(a), Hao Shen(a), Eva Hemmer(a), Christian Cavelius(a), Christian Petersen(a), Nicolas Lecerf(b) and Aivaras Kareiva(c), (a)CVD Division, Leibniz Institute of New Materials Saarland University Campus, Im Stadtwald PO box 50 11 63, 66041 Saarbruecken, Germany, (b)SINTEF Materials Technology, Ceramics Group PB 124 Blindern, 0314 Oslo, Norway, (c)Department of General and Inorganic Chemistry Vilnius University, 2006 Vilnius, Lithuania

Optical materials in which lanthanide ions or their phases are dispersed in an isotropic matrix provide an avenue to modulate the properties of the components as well as to design novel nano-composites. To increase the efficiency of optical nanocomposites, the positional fixity of optical centers is important in order to restrict the movement of Ln³⁺ species and

resulting formation of interaction clusters, which are detrimental for the luminescence quantum yield. However, a homogeneous dispersion of the optical component in the supporting phase remains a challenging task, which makes an undesired phase separation or element segregation commonly observed feature. Our concept is based on the chemical anchoring of lanthanide ions in the host matrix so that they are not physically suspended in the matrix. Specifically, heterometallic Ln-Al alkoxides (Ln = lanthanide element) containing single and isolated lanthanide center surrounded by optically silent aluminium atoms have been used in wet (sol-gel) and dry (chemical vapour deposition) chemical processing to obtain Ln-containing nanocomposites as powders and thin films, respectively. Nanoscaled composites of LnAlO₃ (Ln = any lanthanide element) in inorganic (SiO₂, Al₂O₃) and polymer (e.g., polystyrene, methyl methacrylate) matrices were produced by controlled hydrolysis or pyrolysis of Ln-Al alkoxide clusters with different Ln: Al ratios. Given the technical potential of lanthanide ions or their phases incorporated in isotopic matrices (solid-state lasers, phosphores, optical amplifiers, etc.), we fabricated tailored nanocomposites by shining laser (Nd:YAG) on [Ln-O-Al]_n films. A brief overview of our activities in the molecular level synthesis of optical nanocomposites will be presented.

12:30

LUNCH

Session X : Silicon and related nanostructures I
Session chairs : A. Steckl, A. Meijerink

- C-X.01** 14:00 -Invited- PHOTONIC PROPERTIES OF Er-doped Si MULTI-NANOLAYER STRUCTURES
T. Gregorkiewicz, N.Q. Vinh, M.A.J. Klik, S. Minissale, Van der Waals-Zeeman Institute, University of Amsterdam, The Netherlands and B.A. Andreev, A.N. Yablonsky, Institute for Physics of Microstructures, Nizhny Novgorod, Russia
Si/Si:Er multi-nanolayer structures grown by sublimation MBE technique exhibit unusual optical properties which make them very interesting for photonic applications. In particular, our recent investigations have proven that a specific type of an Er-related optically active center is preferentially formed in this material. Consequently, emission from the nanolayers does not suffer from inhomogeneous broadening and is characterized an ultra-narrow linewidth of 10 ± 0.1 meV (at $T = 4.2$ K).
In the contribution, we will review properties of Er-related optical centers formed in the multi-nanolayer structures as revealed by high-resolution time-resolved photoluminescence, excitation and magneto-optical spectroscopies. Particular attention will be given to the microscopic structural details of the optical center and the percentage Er³⁺ ions participating in its formation. Also effective excitation cross-section and its variation with excitation wavelength (band-to-band vs. sub-bandgap pumping) and mode (cw vs. pulsed) will be presented. Finally, optically induced quenching of Er-related emission upon illumination with a free-electron laser will be demonstrated, and its origin discussed.
- C-X.02** 14:30 MICROSCOPIC THEORY FOR EXCITATION OF ERBIUM IONS VIA SILICON NANOCRYSTALS IN SILICON DIOXIDE
I.N. Yassievich, A.S. Moskalenko, A.A. Prokofiev, Ioffe Physico-Technical Institute of RAS, Politekhnikeskaya 26, 194021 St.Petersburg, Russia
In this work we present the results of microscopic calculation for the probability of excitation of Er ions by electron-hole pairs confined in Si nanocrystals surrounded by silicon dioxide. For simplicity at first we consider the case of low pumping of nanocrystals when we may take into account only one electron-hole pair inside of a single nanocrystal. We have found the probability of Er ion excitation in three principally different cases for the location of the Er ion relatively to the nanocrystal: i) Er ion is situated inside of the nanocrystal, ii) Er ion is situated at the boundary of the nanocrystal or very close to the boundary, and iii) Er ion is situated at the considerable distance from the nanocrystal so that the tunneling of electrons and holes may be neglected. Our calculation is based on the wave functions of electrons and holes confined in Si nanocrystals recently obtained in [1]. In the case of higher pumping there is a high probability for the appearance of an additional electron-hole pair inside of the nanocrystal before the radiative transition of the excited Er ion takes place. In this case effective de-excitation assisted by an electron (a hole) intraband transition could take place. We produce the calculation of the probability this de-excitation process. In the end, we shortly discuss other possible excitation and de-excitation processes, which become important for the case of higher pumping. [1] A.S. Moskalenko and I.N. Yassievich, Phys. Sol. State 46, 1508 (2004).
- C-X.03** 14:45 SILICON-BASED LIGHT EMISSION FROM RARE EARTH ION-IMPLANTED SILICON DIOXIDE
W. Skorupa(a,b), J.M. Sun(a), T. Dekorsy(a), M. Helm(a), L. Rebohle(b), T. Gebel(b), A.N. Nazarov(c), I.P. Tjagulski(c), I.N. Osiyuk(c), S. Prucnal(d), J. Zuk(d), (a)Inst. of Ion Beam Phys. and Mat. Res., Forschungszentrum Rossendorf, Dresden, Germany, (b)nanoparc GmbH, Dresden, Germany, (c)Inst. of Semicond. Phys., Kiev, Ukraine, (d)Maria Curie-Sklodowska-Univ., Lublin, Poland
Thermally grown silicon dioxide layers free of silicon nanoclusters were doped with a wide variety of rare earth luminescence centers (Gd³⁺, Tb³⁺, Eu³⁺, Ce³⁺, Tm³⁺, Er³⁺) using ion implantation. These layers were integrated into a purpose-designed MOS capacitor with CMOS based technology. Indium-tin oxide was used as transparent top electrode material. The whole spectrum of light between UV an IR was extracted as efficient electroluminescence from such devices.
Electroluminescence properties were analysed regarding luminescence spectra, decay time, impact excitation cross relaxation, and power efficiency. Top values of the efficiency of 0.2 % corresponding to external quantum efficiencies well above the percent range were reached. The electrical properties of these devices such as carrier injection, charge-to-breakdown, charge trapping characteristics, and operation lifetime for dedicated applications will also be reported. Although former works showed that for a reliable operation of such devices silicon nanoclusters are needed in the silicon dioxide matrix it will be shown that with the advanced MOS capacitors an increase of the operation lifetimes by a factor of 100-1000 is possible. This allows an analysis of the electro-optical and electrical properties at higher current densities than before without any degradation problem. The recently demonstrated worldwide first ultraviolet silicon-based light emitter [1] was produced with the device type presented here. Finally application prospects in the field of biosensing will be shown. [1] J.M. Sun, W. Skorupa, T. Dekorsy, M. Helm, L. Rebohle, T. Gebel, Appl. Phys. Lett. 85, 3387 (2004)
- C-X.04** 15:00 CAVITY-RINGDOWN SPECTROSCOPY OF THE ER³⁺ INTRA-4F ABSORPTION CROSS SECTION AT 1.5 μ m IN SI-RICH SiO₂
H. Mertens and A. Polman, Center for Nanophotonics, FOM-Institute AMOLF, Kruislaan 407, 1098 SJ Amsterdam, The Netherlands; I.M.P. Aarts, W.M.M. Kessels, and M.C.M. van

de Sanden, Department of Applied Physics, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

We present measurements of the optical absorption cross section of the 4I15/2 - 4I13/2 transition at 1.5 μm of Er³⁺ ions embedded in pure SiO₂ as well as Si-rich SiO₂ using cavity ringdown spectroscopy on thin films.

It has recently been suggested that silicon nanoclusters would enhance the cross section of the 4I15/2 - 4I13/2 transition of Er³⁺ embedded in SiO₂ by 1-2 orders of magnitude. This presumed enhancement was derived from optical absorption spectroscopy in linear waveguides, and it has been invoked to explain the high signal enhancement in Er³⁺-doped Si-rich oxide linear amplifiers. If true, the cross section enhancement would have a broad impact on Er amplifier and laser technology as it implies an enhancement of the optical gain coefficient by the same 1-2 orders of magnitude. We have measured the Er³⁺ 4I15/2 (r) 4I13/2 absorption cross section spectrum by a direct and ultra-sensitive method: cavity ringdown spectroscopy. This method has recently been adapted for measurements on thin films. The cross section measurements we present are the first ones of rare-earth-doped materials using this technique. We find a peak absorption cross section for Er³⁺ embedded in Si-rich oxide (10 at.% excess Si) of $(8 \pm 2) \times 10^{21}$ cm² at 1536 nm. This value is similar to the values measured for Er embedded in SiO₂. The data imply that the silicon nanoclusters incorporated in Si-rich oxide do not enhance the cross section of the Er³⁺ 4I15/2 - 4I13/2 transition by 1-2 orders of magnitude, contrary to what has been reported in earlier work.

C-X.05 15:15

MULTIPLICATION OF ER-RELATED ELECTROLUMINESCENCE SIGNAL IN MULTIDIODE Si/Si:Er STRUCTURES

M.V. Stepikhova, A.M. Sharonov, Z.F. Krasil'nik, Institute for Physics of Microstructures, Russian Academy of Sciences GSP-105, 603950 Nizhny Novgorod, Russia, V.P. Kuznetsov, Physico-Technical Research Institute, Nizhny Novgorod State University, Gagarin Ave. 23, 603950 Nizhny Novgorod, Russia

In this contribution we present a new type of light-emitting diode structures on Si:Er basis realizing the principle of impact excitation of rare earth impurity. There are considered the multilayered periodic-type diode structures representing a series of p-n-n⁺ junctions with the Er impurity positioned in n-type layers. It will be shown that the realization of such type of structures allows to increase substantially the operating active area and as a consequence the luminescence efficiency of Si:Er LEDs. The theoretical analysis and results of room temperature electroluminescence studies carried out for such type of structures will be presented. The structures containing 5 p-n-n⁺ periods with the varied thickness of n⁺ layers were grown in one growth cycle applying the method of sublimation MBE. We will show that depending on the thickness of n⁺ layers both the breakdown voltage and luminescence intensity of the periodic-type structures increases and reach its saturation at the thickness, where the "spatial separation" of p-n-n⁺ diodes takes place. Comparing the periodic-type structures at the point, where all p-n-n⁺ junctions operate separately, with the one-period Si:Er structures one can show that the luminescence intensity of the first ones is substantially higher being proportional to the total thickness of Si:Er layers introduced in the active area of the operating diode pairs.

This work was partially supported by the RFBR (grant #04-02-08240 ofi_a) and INTAS (grant #03-51-6486).

C-X.06 15:30 -Invited-

ENERGY TRANSFER FROM SILICON NANOCRYSTALS TO ERBIUM IONS

Minoru Fujii, Department of Electrical & Electronics Engineering, Faculty of Engineering, Kobe University, Japan

Si nanocrystals act as an efficient photosensitizer for Er ions. By doping Si nanocrystals into Er doped silica glasses, effective excitation cross-section of Er ions is strongly enhanced. We have studied in detail the energy transfer mechanism by controlling the size of Si nanocrystals in a wide range, and revealed that there are two energy transfer processes. The first one is a trap-mediated process similar to that observed for Er doped bulk Si crystals, and the other one is direct Coulombic interaction between excitons and Er ions. The dipole-dipole interaction results in sharp resonant quenching bands in inhomogeneously broadened PL bands of excitons. The analysis of the quenching bands provides valuable information for electronic structures of Si nanocrystals. The energy transfer rate as well as radiative recombination rates of excitons in Si nanocrystals and Er ions can be modified if metal surfaces exist in the vicinity of the coupled system. By systematically changing the distance between metal films and Er and Si nanocrystals doped silica thin films, and analyzing rising and decaying parts of luminescence decay curves of Er ions after pulsed excitation, we will discuss how the energy transfer rate is modified by metal surfaces.

16:00

BREAK

Session XI : Silicon and related nanostructures II

Session chairs : **R. Jones, L. Tessler**

C-XI.01 16:15 -Invited-

OPTICAL AND ELECTRICAL ACTIVITY OF DEFECTS IN RARE EARTH IMPLANTED SILICON

J.H. Evans-Freeman, K.D. Vernon-Parry and N. Abdulgader, Materials and Engineering Research Institute, Sheffield Hallam University, Sheffield S1 1WB, U.K.

A common technique for introducing rare earth atoms into Si and related materials for photonic applications is ion implantation. It is compatible with standard Si processing, and also allows high, non-equilibrium concentrations of rare earths to be introduced. However, the high energies often employed mean that there are collision cascades and potentially severe end-of-range damage. This paper reports on studies of this damage, and the competition it may present to the optical activity of the rare earths. Er- and Yb-implanted Si samples have been investigated, before and after anneals designed to restore the sample

crystallinity. The electrical activity of defects in as-implanted Er and Yb doped Si has been studied by Deep Level Transient Spectroscopy (DLTS) and the related, high resolution technique, Laplace DLTS (LDLTS), as a function of annealing. Er-implanted Si, regrown by solid phase epitaxy at 600 degrees C and then subject to a rapid thermal anneal, has been studied by time-resolved photoluminescence (PL). The LDLTS studies reveal that there are clear differences in the defect population as a function of depth from the surface, and this is attributed to different defects in the vacancy-rich and interstitial-rich regions. These defects may provide the precursors for larger structural defects in annealed layers. The time-resolved PL, in combination with electron microscopy, shows that the emission at 1.54 microns, is a combination of emission from Er and that due to the well-known PL dislocation line, D1.

C-XI.02 16:45

STUDY OF THE Si-NC TO ER³⁺ ENERGY TRANSFER DYNAMICS USING A DOUBLE-PULSE EXPERIMENT

M. Falconieri, ENEA,C.R Casaccia, via Anguillarese 301, 00060 Roma, Italy, E. Borsella, L. De Dominicis, ENEA,C.R. Frascati, via E. Fermi 45, 00044 Frascati (Roma), Italy, F. Enrichi, INFN, Dip. Fisica Univ. Padova, via Marzolo 8, 35131 Padova, Italy, G. Franzò, F. Priolo, INFN, Dip. Fisica e Astronomia Univ. Catania, via S. Sofia 64, 95123 Catania, Italy, F. Iacona, CNR-IMM, Stradale Primosole 50, 95121 Catania, Italy, F. Gourbilleau, and R. Rizk, ENSICAEN, SIFCOM CNRS UMR 6176, 6 Bd Marechal Juin, 14050 Caen, France
Indirect excitation of Er³⁺ ions through energy transfer from Si quantum dots (Si-nc) attracts strong interest because of its relevance for the fabrication of broadly pumpable Er-doped waveguide amplifiers operating at 1.54 μm . However, an exhaustive picture of the sensitization process is still to be established. The occurrence of a very fast energy transfer channel was postulated but only indirectly assessed (1) and the expected dependence of the energy transfer dynamics on the sensitizers morphology is far from being well understood. To get a deeper insight into the excitation dynamics, a nearly degenerate double-pump-pulse experiment was set-up. The first powerful ns pulse (at 375 nm) excites the majority of Si-nc, thus initiating the chain of processes leading to Er³⁺ excitation and PL emission at 1.54 μm . The second ns pulse (at 355 nm) produces an increase of the PL intensity at 1.54 μm if and only if the Si-nc are de-excited and there are still active Er³⁺ ions to be excited. The PL increase due to the second pulse was recorded as a function of the delay after the first pulse, giving direct information on the recovery of sensitization in the time interval from a few ns to ms. Investigated samples were produced either by Er implantation in SiO_x grown by PECVD and annealed to precipitate Si nanoaggregates or by reactive magnetron co-sputtering of Er₂O₃-SiO₂ targets followed by an appropriate annealing. We obtained direct evidence for the presence of a fast energy transfer channel occurring in few hundreds ns, and for the dependence of the energy transfer mechanism on the sensitizers morphology. Data analysis by a rate equation model allows the determination of parameters highly relevant for device modeling. (1) M. Fujii et al. J. Appl. Phys. 95, 272, (2004).

C-XI.03 17:00

A FRACTION OF EXCITABLE ER³⁺ IONS IN SILICON-RICH-SILICON-OXIDE

D. Kuritsyn, Institute for Physics of Microstructures, Russian Academy of Sciences, GSP-105, Nizhny Novgorod 603950, Russia, A. Kozanecki, H. Przybylinska, Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland, and W. Jantsch, Institute für Halbleiterphysik, J. Kepler Univeristy, 4040 Linz, Austria
A detailed investigation of the excitation mechanisms of the 4I13/2 - 4I15/2 intra-4f-shell luminescence of Er³⁺ ions near 1.5 μm in silicon-rich silicon oxide (SRSO) is reported. SRSO:Er was produced by high dose implantation of Si⁺ ions into SiO₂ layers grown on silicon, followed by Er⁺ implantation at an energy of 800 keV. Samples were thermally annealed up to 1100°C to create different types of defects and Si-nanoclusters (Si-nc). Photoluminescence excitation (PLE) spectra were obtained using optical parametric oscillator (OPO) and Ti:Sapphire laser in the range 420-680 and 720-830 nm, respectively. We suggest that the dominant factors, which limit the excitation efficiency of Er³⁺ in SRSO, are a) distance dependence of the transfer rate and b) little spectral overlap between localized in Si-nc (or Si-nc/SiO₂ interface) e-h pairs and 4f-states of Er³⁺. Assuming dipole-dipole interaction between localized in Si-nc carriers and Er³⁺ ion and taking into account distributions of distances between Si-nc and Er³⁺ ion and band gaps in Si-nc ensemble (due to dispersion of sizes), it was estimated, that a fraction of approx. 10-4 of Er³⁺ ions is excited via energy transfer from Si-nc, whereas resonant excitation is entirely suppressed. Analyzing the dependence of the Er³⁺ emission intensity on excitation duration we show that in average for one electron-hole pair being generated by excitation pulse one nc-Si can excite only one or less of Er³⁺ ions in its vicinity.

17:30-19:00

POSTER SESSION II

POSTER SESSION II
Thursday, June 2, 2005
17:30 – 19:00

- C/PII.01** **OPTICAL PROPERTIES OF ND-ENRICHED SILICON NANOPARTICLE GLASSES**
A.N. MacDonald, A. Hryciw and A. Meldrum, Department of Physics, University of Alberta, Edmonton T6G 2J1, Canada, Q. Li, Department of Physics, Science Centre North Block, The Chinese University of Hong Kong, Shatin, NT, Hong Kong
The photonic properties of nanoscale silicon have attracted great research interest in recent years. At the same time, Nd-doped glass has been widely established as an effective lasing medium due to the transition at ~1060 nm in trivalent Nd. However, there have only been a few investigations into the properties of Nd-doped glasses containing silicon nanoclusters. Effective energy transfer from silicon nanoparticles to the rare-earth ions provides an important sensitizing mechanism that has been widely investigated in the case of erbium doped silicon nanocomposites. In the present work, we aim toward a systematic investigation of the optical properties of silicon nanocomposites doped with different concentrations of Nd. We show that effective nonresonantly-pumped emission from neodymium ions can occur for thin film specimens produced at processing temperatures of 500 °C or lower. We will discuss the emission intensities of the most important Nd transitions at wavelengths of ~800 nm, ~900 nm, ~1060 nm, and ~1350 nm (all these bands are strongly crystal-field split and are therefore quite broad). We also plan to discuss our first attempts at the synthesis of optical microcavity structures containing Nd ions and silicon nanoparticles in order to obtain control over the directionality and intensity of the emission at the desired wavelengths.
- C/PII.02** **MICROSCOPIC THEORY OF ERBIUM ION DE-EXCITATION PROCESSES IN SILICON**
A.A. Prokofiev, I.N. Yassievich, Ioffe Physico-Technical Institute, 26 Polytechnicheskaya, 194021 St.Petersburg, Russia
In recent years a great progress has been achieved in the understanding of main processes controlling the excitation and de-excitation processes of Er-ions in silicon. There are some evidences that Er related optically active centers in silicon form donors with binding energy about 150-200 meV and the excitation of erbium occurs in a result of Auger recombination process of the electron bound at the donor and a free hole or bound exciton. It is supposed that there are two effective de-excitation processes: i) back transfer process to recombination of electron-hole pair and ii) collision with free electrons.
A microscopic theory of these two processes is presented. As the back transfer is multi-phonon assisted process and demands an activation energy, its probability increases dramatically with temperature rising. The collision with free carrier is the dominating de-excitation process at low temperature. It was shown that the perturbation of wave function of free electron by Coulomb center associated with Er ion increases its probability in about 20 times. The Auger de-excitation process, in which the energy from Er ion is consumed by electron going from Er related donor to the conduction band, has been investigated as well. Our calculation has demonstrated the probability of the process to be 10000 times higher than the probability of radiative transition from the first excited into the ground state of Er. So the life time of excited erbium ion might be determined by free carrier capture probability at the donor associated with Er.
- C/PII.03** **CHARGE TRAPPING IN SiO₂ LAYERS IMPLANTED WITH RARE EARTH AND Ge IONS**
S. Prucnal, Maria Curie-Skłodowska University, Pl. M. Curie-Skłodowskiej 1, 20-031 Lublin, Poland; J. Sun, W. Skorupa Institute of Ion Beam Physics and Materials Research, Forschungszentrum Rossendorf e.V., POB 510119, 01314 Dresden, Germany; A. Nazarov, I. Osiyuk, I. Tyagulski, V. Lysenko Institute of Semiconductors Physics, National Academy of Sciences of Ukraine, Prospect Nauki 45, 03028 Kyiv, Ukraine
Metal-oxide-silicon (MOS) structures containing different rare earth and germanium ions exhibit strong luminescence from 300-1540 nm. This emission is very interesting from the viewpoint of the silicon-based light-emitting devices formation. Charge trapping behaviour in Ge and rare earth (Ce, Eu, Gd, Tb, Er and Tm) enriched SiO₂ during high field electron injection corresponding to operation of the light-emission devices has been studied. Employing of constant current injection regime and high frequency C-V characteristics it was shown that embedment of rare earth impurities into dioxide matrix results in formation of similar system of charge traps with following capture cross section 2.3×10^{-15} cm² for electron and $>1 \times 10^{-14}$ cm² for holes. In various rare earths doping the amphoteric charge traps with distributed capture cross section in range from 1×10^{-15} to 1×10^{-17} cm² is observed. Observed system of the traps is considerable different from one in the Ge implanted structures. For distributed traps an increase of injected current into the dielectric results in increase to positive charge trapping. Model of charge trapping in the defect shell located around rare earth inclusions inside of dioxide matrix is discussed.
- C/PII.04** **PHOTOLUMINESCENCE FROM Er-DOPED Ge NANOCRYSTALS IN SiO₂ PRODUCED BY CVD AND MAGNETRON SPUTTERING**
T. L. Pedersen, Jesper Skov Jensen, Pia Bomholt, Jacques Chevalier, Arne Nylandsted Larsen, Brian Bech Nielsen, Institute of Physics and Astronomy, University of Aarhus, 8000 Aarhus C, Denmark, Ole Hansen, MIC-Department of Micro and Nanotechnology, DTU, 2800 Kgs. Lyngby, Denmark
Nanocrystals have attracted considerable attention in recent years because of their potential applications as a light source in Si technology. By doping the nanocrystals with rare-earths such as Er, Yt or Th, the light emission can be shifted from near-infrared to infrared wavelengths. In this study, we have investigated Er-doped Ge nanocrystals in PE-CVD deposited and magnetron sputtered SiO₂. The nanocrystals were structurally characterized by RBS and TEM. In photoluminescence studies, we have found that the presence of Ge nanocrystals is crucial to obtain efficient light emission from the Er-ions around 1540 nm. The intensity of the light emission has been studied as a function of the size of the Ge nanocrystals and the Er concentration.
- C/PII.05** **OPTICAL PROPERTIES OF THE Er-1 CENTER IN Si/Si:Er MULTILAYERS**
S. Minissale(a), N.Q. Vinh(b), M.A.J. Klik(a), Z.F. Krasil'nik(c) and T. Gregorkiewicz(a), (a) Van der Waals-Zeeman Institute, University of Amsterdam, Valckenierstraat 65, 1018 XE Amsterdam, The Netherlands, (b)FOM Institute for Plasma Physics "Rijnhuizen" P.O. Box 1207, 3430 BE Nieuwegein, The Netherlands, (c)Institute for Physics of Microstructures, GSP-105, 603600 Nizhny Novgorod, Russia
Research on optical properties of Si continues to be spurred by prospects of integration of electronic and photonic components.

In the presented study, we carried out a detailed investigation of excitation mechanisms of sandwich structures of interchanged Si/Si:Er nanolayers, with different thickness of both Si and Si:Er layers. A unique optically active Er center with a very small linewidth of ≈ 1508 Å, Er-1, was found in these materials in previous investigations. The experiments have been performed at low temperature under pulsed and cw excitation, in a wide range of flux and wavelengths of the exciting light. The emission intensity from a nanolayered structure containing spacers of undoped Si is much stronger than from one thicker layer. The decay characteristics of the PL intensity at $\lambda = 1538$ nm for a pulsed excitation at a wavelength of 520 nm feature a fast and a slow component with the ratio of relevant amplitudes increasing with the flux. This can be interpreted in terms of the Auger process with free carriers. The excitation cross section of Er-1 center was determined to be in the order of $\approx 6 \times 10^{-15}$ cm², value in agreement with the one determined under pulsed excitation. By varying the wavelength, the excitation cross section was found to scale with the absorption cross section of Si. In fact the Er-1 excitation process remains the same, while only the number of generated e-h pairs changes. The percentage of optical active Er atoms has been estimated and we concluded that up to 32 % of Er atoms present in the sample form Er-1 centers and contribute to PL. Eventually, formation of Er-1 centers represent a conceivable way to improve low temperature photonic properties of Si:Er.

C/PII.06

ELECTRO-OPTICAL MEMORY EFFECT FOR 1.54 MKM ELECTROLUMINESCENCE OF ER DOPED SI DIODE

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

Since more than ten years ago Er-doped silicon attracts considerable interest as a promising material for silicon photonics. In the present paper we report on the investigation of the electroluminescence (EL) from the n⁺-Si/n-Si:Er/n-Si/p⁺-Si structures with the active (Er-doped) layer placed within the spacecharge region. For these structures kinetics of EL in the regime of forward bias for the temperatures from 4.2 to 300 K have been investigated. Dominating role of the Auger-interaction with nonequilibrium free carriers in Er deexcitation during the electrical pumping of the forward biased diodes has been shown. We have also observed for the first time the erbium EL under the reverse bias below the breakdown voltage applied after the forward bias pulse with up to 100 ns delay. The observed electrooptical effect is an experimental evidence of a long-term memory effect in the investigated structures. It supports the idea that the Si:Er/Si structures can be used as electrooptical converters and memory elements with electrical inputting and optical (at 1.54 μm) outputting information.

The work was supported by RFBR (04-02-17120, 04-02-08240), INTAS (01-0194, 03-51-6486).

C/PII.07

THE EFFECT OF ANNEALING CONDITIONS ON THE CRYSTALLIZATION OF ER-SI-O FORMED BY SOLID PHASE REACTION

K. Masaki, H. Isshiki and T. Kimura, Department of Electronic Engineering, Univ. of Electro-Communications, Tokyo 182-8585, Japan

Er-Si-O crystal is one of the promising materials for Si-based opto-electronic devices. Er-Si-O is crystallized by solid phase reaction of amorphous matrix which consists of Er-O and Si-O bonds. However detailed crystallization mechanism is not clear. In this study, three types of PL spectrum fine structures were obtained under different annealing conditions. This result indicates that the control of oxygen partial pressure is important for forming Er-Si-O crystal.

Sol-gel method was used to prepare the amorphous matrix. The samples were then annealed at 1250 °C in Ar for the solid phase growth of Er-Si-O crystals. However some types of XRD patterns and the PL spectra were obtained from Er-Si-O crystals. It was thought to be the effect of residual oxygen. To study the effect of residual oxygen, during solid phase growth three processes were applied, which were the process putting the Si wafer on the sample to reduce the influence of the atmosphere and the process additionally putting the carbon sheet as oxygen getter on the sample covered with Si and the process with no capping. Three kinds of XRD patterns and three kinds of PL spectrum fine structures were observed. These results indicate that Er-Si-O crystals are sensitive to residual oxygen during the solid phase growth.

C/PII.08

ERBIUM-DOPED SILICON QUANTUM DOTS GROWN BY R.F. SPUTTERING METHOD. COMPETITION BETWEEN OXYGEN AND SILICON TO GET ERBIUM

M.F. Cerqueira(a), M. Stepikhova(b), M. Losurdo(c), A. Kozanecki(d), T. Monteiro(e), (a)Departamento de Física, Universidade do Minho, Campus de Gualtar 4710-057 Braga, Portugal, (b)Institute for Physics of microstructures, RAS, 603600 Nizhny Novgorod, GPS-105, Russia, (c)Institute of Inorganic Methodologies and Plasmas, IMIP-CNR, Via Orabona 4-70126 Bari, Italy, (d)Polish Academy of Sciences, Institute of Physics, 02668 Warsaw, (e)Departamento de Física, Universidade de Aveiro, Campus de Santiago, 3700 Aveiro, Portugal

During the last 15 years, modern growth techniques have shown the ability to fabricate semiconductor nanostructures of typical size < 10 nm, with spatial confinement of electrons in all three dimensions. These systems are of considerable current interest because of the new physics involved and potential device applications. One of these applications can be Si-based optoelectronics. Erbium doped silicon (Si:Er) is a recognised candidate to become the material for emitters and detectors to be used in optical communication systems. However, there is a problem with efficient energy transfer from the Si matrix to the Er centres. The use of Er-doped Si nanocrystallites can help to solve this problem. Studies of the photoluminescence of Er-doped nanocrystalline silicon constitute an important probe for these applications.

Erbium doped nanocrystalline silicon (nc-Si:Er) thin films were grown by r.f. reactive magnetron sputtering in an Ar/H₂ atmosphere on ordinary glass substrates under several different conditions. We have grown 3 groups of samples changing basically the amount of oxygen and hydrogen present in the structure. In particular, we have grown samples without oxygen, samples with more oxygen than hydrogen and in the last series the samples have a little bit more hydrogen than oxygen. For each group we obtain samples with different structural parameters by varying the experimental parameters. The film structure was studied using X-ray diffractometry, Raman spectroscopy and spectroscopy ellipsometry. The chemical composition was determined using RBS technique. Our samples show sharp photoluminescence (PL) spectra of Er centres with the strongest peak positioned at the wavelength 1.536 μm and full width at half maximum (FWHM) of about 8 nm. Our results indicate that the formation of Er-silicide or Er-oxide depending on microstructure, this means that the kind of matrix where the nanocrystals are embedded influences strongly the erbium emission.

- C/PII.09** RARE-EARTH DOPING OF SILICON NITRIDES AND OXYNITRIDES FOR CARRIER-MEDIATED EXCITATION OF VISIBLE LUMINESCENCE
Hoon Jeong, Daigil Cha, Kwan-Sik Cho, and Jung H. Shin Dept. of Physics, KAIST, 373-1 Guseong-dong, Yuseong-Gu, Daejeon, Korea
Rare earth (RE) doping of semiconductors represent a great opportunity to realize stable, pure luminescence at many technologically important wavelengths without having to engineer the bandgap of the semiconductor. In particular, doping of RE ions into wide-bandgap semiconductor thin films represent a possible alternative path to obtaining full-color flat panel displays. This concept was demonstrated by previous reports of luminescence from RE-doped of GaN. In this paper, we present the results of using inductive-coupled plasma enhanced chemical vapor deposition of Tb-doped silicon nitrides and oxynitrides to obtain visible luminescence in a wide-area, CMOS-compatible thin film. We obtain strong green photoluminescence due to the intra-4f transition of doped Tb, excited via photocarriers. The maximum Tb intensity is obtained from films with low O content after an anneal at 950 oC and subsequent hydrogenation. At optimum, the Tb luminescence lifetime at room temperature is 0.8 msec, comparable with Tb doped into silica, which indicates a high luminescence efficiency. Comparison with the intrinsic defect luminescence from oxynitride films indicates that excitation of Tb occurs in competition with the defect luminescence, and that the Tb luminescence efficiency can be higher than that of the defect luminescence. The possibility of electrical excitation, as well as doping other rare earth for full RGB display, will be discussed.
- C/PII.10** ER-DOPED SILICON NANOPARTICLES FROM SPUTTERED SIOX THIN FILMS
Danilo Mustafa and Leandro R. Tessler, IFGW, Unicamp, 13083-970 Campinas, SP, Brazil
- C/PII.11** A COUPLING OF EUROPIUM IONS WITH CHALCOGENIDE NANOPARTICLES: EFFECTS UPON THE LUMINESCENCE WITHIN SILICA MATERIALS
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Semiconductor nanoparticles exhibit a number of challenging features in optics due to strong light absorption managed by particle size, concentration within matrices and various effects of interaction with other components of a system. In the contact with rare earth elements the nanoparticles are expected to be capable to excite them through transfer of an absorbed energy. This effect can make much wider the luminescence excitation spectrum (including up-conversion) and enhance the quantum yield of rare earths. In the work we present recent results on studies of photoluminescence of Eu(III) incorporated into silica sol-gel materials (both films and glasses) containing CdS(CdSe) or CuxSe nanoparticles. Composition of films and glasses and state of nanoparticles were characterized with XRD, TEM, Raman spectroscopy and optical absorption. The experimental data indicate that nanoparticles alter noticeably the features of europium luminescence. The energy transfer effect between chalcogenides and Eu(III) is proposed to be responsible for this phenomenon. The systems under study can be of considerable significance to develop efficient luminescent materials as well as laser active media based on modified quantum dot properties.
- C/PII.12** OPTIMIZATION OF THE OPTICAL PROPERTIES OF Er-DOPED Si-Rich SiO2/SiO2 MULTILAYERS OBTAINED BY REACTIVE MAGNETRON SPUTTERING
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Er-doped Si-rich SiO2/SiO2 multilayers (MLs) were been fabricated by reactive sputtering with two-silica-target configuration, bare and covered with Er2O3 pellets, alternatively sputtered under pure Ar or Ar+H2 mixture. Such a structure offers the double advantage of (i) growing the Si nanograins (Si-ng) close to the Er ions, and (ii) controlling their size through the thickness of the Er-doped Si-rich SiO2 sublayer. Different annealing treatments (temperature, duration, gas nature) were carried out to maximize the coupling rate between the ng-Si and the Er ions, in relation with the size effects of the Si-ng. In addition of the processing conditions allowing optimum optical properties in terms of emission intensity and lifetime, the results point out the effects of Si-ng size on the sensitizing action towards Er3+ through an abrupt drop of the PL when the size exceeds 4 nm. The PL experiments performed between ambient and 10K have showed little thermal quenching for both intensity and lifetime, suggesting a size effect lying in some loss of quantum confinement rather than energy backtransfer expected to occur for Er within the large grain. The evolution of the lifetime with the sublayer thickness reflects some impact of the non radiative interfacial centers.
- C/PII.13** PHOTOCROMIC PROCESS IN BaFCl:Sm2+ WITH AN BLUE SEMICONDUCTOR LASER
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BaFX(X=Cl, Br) doped with rare earth ions has been investigated in fundamental and applied physics for more than a decade. From the fundamental physics point of view, Sm2+-doped BaFCl is well known as the first material demonstrating photon-gated spectral hole-burning. From the applied physics point of view, Eu2+-doped BaFBr is now marketed as an imaging plate.
It had been known that the absorption due to F(Cl-) centres increases in Sm2+-doped BaFCl when it is irradiated by X-rays or VUV light. The mechanism is that electrons are excited to the conduction bands with the high energy laser and are released from the Sm2+ ions. These free electrons migrate into F+ centres (Cl- ion vacancies), yielding colour centres. In this work, we found that at room temperature, when Sm2+-doped BaFCl was irradiated with an blue semiconductor laser, absorption between 450 and 600nm due to F(Cl-) centres increased. On the other hand, when the sample was irradiated with 632nm light from a He-Ne laser, the absorption decreased. And also it was found that this process is reversible and repeatable. This photochromic effects look similar to the above phenomenon. However, the mechanisms seem to be different from each other, because the energy of the blue laser (about 3eV) is much lower than the energy gap between conduction bands and valence bands of BaFCl (above 7 eV). We will discuss the mechanism of these reversible photochromic effects in BaFCl:Sm2+, which has possible applications in optical data storage.

C/PII.14**Ce-Zr-Al-O SYSTEM WITH HOST-GUEST INTERACTIONS: PECULIARITIES OF THE OPTICAL PROPERTIES**

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The Ce³⁺ doped glasses have a potential application in a variety of luminescent materials, such as phosphors, detectors and active media for blue lasers. Since zirconia is a low-phonon matrix, which minimizes non-radiative quenching, dopants have a higher probability for radiative transitions, and thus are attractive for investigations. Recently it was found that coupling rare-earth ions with Al³⁺ provides an increase in fluorescence intensity and even can effectively reduce rare-earth ions through the sol-gel process itself without any deoxidizing heat-treatment or post-processing. Herein we report the temperature and structure dependent, photoluminescence behavior of the successfully prepared Ce-Zr-Al-O material by totally inorganic sol-gel technique.

The optical investigation of the obtained material together with ESR data indicate the appearance of the bulk Ce³⁺-defects ($g_1 = 1.962-1.967$, $g_2 = 1.938-1.940$, assigned to 4f1 state). The significant PL intensity (broad band emission at 510-540 nm under 300 and 350 nm excitation) rising at elevated temperature was related to spontaneous increasing of Ce³⁺ concentration as well as an unexpected formation of intra-band gap states in sol-gel samples during thermal treatment of xerogels. Those intra-band-gap states (the Hubbard's zones) was manifested in UV-Vis and XPS spectra and attributed to the oxygen related defects that contribute to PL signal. The work was supported by INTAS (grant 01-2162).

C/PII.15**QUALITY CHARACTERIZATION OF Nd:YAG RODS BY MEANS OF SYNCHROTRON RADIATION**

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Yttrium Aluminium Garnet crystal (Y₃Al₅O₁₂) doped with Nd³⁺ is the most widely used active medium in solid state lasers, with a wide variety of applications in medicine and material processing because of its mechanical and thermal properties, high degree of transparency and isotropy. Nd:YAG ensures good laser efficiency and extremely high output power in pulsed mode. The growing methods are very sensible to create high efficient rods. Optical analysis of such material are still a mandatory task, to improve the industrial applications. Synchrotron radiation was used to study the optical properties of Nd:YAG crystal samples grown by Czochralski method at room temperature and 8.4 K. These excitation permits to reveal the stark component emission of Nd³⁺ ions. Low temperature spectra show the quenching of stark component emission. In order to gain a better understanding of stark components temperature dependence, time resolved luminescence measurements have been performed. Moreover luminescence efficiency has been measured in the temperature range from 8 K to room temperature.

C/PII.16**OPTICAL BISTABILITY IN YTTERBIUM-DOPED CRYSTALS**

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Optical Bistability (OB) generates much interest mainly due to its potential application for optical computing or optical switching for telecommunications. Generally speaking, a system is bistable if it exhibits two stable output responses R (for example the absorption of light) for a single input signal or perturbation P (for example the frequency or the light intensity). This property manifests itself by an hysteresis loop in the curve R = f(P) which reveals a different response of the system for upward and downward sweep of the perturbation. Two ingredients are necessary to generate a bistable phenomenon: i) a feedback loop and ii) a non linear process. Recently, OB has been observed in the near infrared and visible luminescence of Yb³⁺-doped halide matrices: Cs₃Y₂Br₉:Yb³⁺ [1], Cs₃Lu₂Br₉:Yb³⁺ [2], CsCdBr₃:Yb³⁺ [3]. However, the origin of the feedback loop is not yet understood. We propose a theoretical approach of the OB using an effective spin-Hamiltonian and the density-matrix operator. A discussion on the physical conditions that a system has to fulfill to present a bistability response to an external parameter is proposed. The validity of this approach is demonstrated in the microwave range for the case of magnetic bistability of conduction electrons in semi-conductor. We discuss the possibility to obtain this phenomenon in the infrared or visible range with two optical rare-earth ions coupled in pairs. This approach explains some of the results obtained recently in the ytterbium doped halide matrices. New results will be presented in rare earth-doped crystals. [4]

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C/PII.17**Eu DOPED (Lu/Sc)2O3 THIN FILMS GROWN BY THERMAL EVAPORATION**

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The sesquioxides Y₂O₃, Sc₂O₃ and Lu₂O₃ are well known hosts for rare-earth-ions e.g. Eu:Y₂O₃ as red phosphor or Tm:Sc₂O₃ as solid state laser. Sesquioxide thin films on alpha-Al₂O₃ substrates allow fabrication of crystalline optical coatings, waveguide lasers and photonic structures.

We report on the growth of Eu-doped (Lu_{0.19}Sc_{0.81})₂O₃ thin films on alpha-Al₂O₃ by electron beam evaporation (EBV). The properties of the films are compared with EBV- and PLD-deposited Y₂O₃ films. In contrast to EBV-deposited Y₂O₃ films, the (Lu/Sc)₂O₃ films are chemically stable. The lattice mismatch to the substrate is -1,5% whereas it is 4,7% for Y₂O₃. This leads to films textured along the <111> direction. The grain size and quantum yield of the fluorescence is considerably larger than in polycrystalline Y₂O₃ films of similar thickness. The local symmetry of the Eu³⁺ centres is identical to the symmetry in (Lu/Sc)₂O₃ bulk crystals. Spectral modifications due to surface effects dominate only when the average film thickness is about 5nm or less. Burying the films below an Al₂O₃ cover layer prevents spectral changes and increases the fluorescence quantum yield. The (Lu/Sc)₂O₃ films resemble PLD-deposited Eu:Y₂O₃ films in crystal structure as well as in spectroscopic properties and in quantum yield of the fluorescence. Since EBV is a much simpler - and cheaper - technique than PLD, EBV-deposited (Lu/Sc)₂O₃ films might be favourable for the fabrication of waveguiding and photonic structures for future commercial applications.

- C/PII.18** A CONTROL PROCEDURE FOR THE SHAPE OF A Nd:YAG AND Nd:YVO4 CYLINDRICAL BAR GROWN BY EDGE-DEFINED FILM-FED GROWTH METHOD WHEN THE PRESSURE IN THE FURNACE OSCILLATES
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 The main purpose of this paper is to give a model based proof of the fact that the effect of the variations of the pressure p in the furnace can be compensated by an adequate variation of the pulling rate v in order to assure a constant diameter of a Nd:YAG and Nd:YVO4 cylindrical bar, grown from the melt by E.F.G. method.
 Using a nonlinear model, those pulling rate v and pressure p couples are found for which the system of differential equations, which governs the evolution of the crystal radius $r=r(t)$ and the meniscus height $h=h(t)$, has asymptotically stable steady-state solution (r^*, h^*) . By interpolation the dependencies $r^*=r^*(p, v)$, $h^*=h^*(p, v)$ and the curves S of those couples (p, v) for which $r^*(p, v)=r_f$ (where r_f represents the desired radius) are determined. Using the curves S , for a given variation of the pressure (during the growth) an adequate variation of the pulling rate is found which assures that the crystal radius constantly equal to r_f . Numerical results are given for a Nd:YAG and Nd:YVO4 cylindrical bar of $r_f=2.0$ (mm) radius, grown in a furnace in which the vertical temperature gradient is $k=33$ (K/mm).
- C/PII.19** PECULIARITIES OF PHOTOTRIGGER PHENOMENON IN LAMINAR MONOCRYSTALS OF A3B6 COMPOUNDS, DOPED BY RARE ELEMENTS
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 In the present study, we report on the influence of doping by rare elements (RE) of gadolinium (Gd), holmium (Ho) and dysprosium (Dy) on the phototrigger phenomenon in laminar crystals of A3B6 compounds (n-InSe and p-GaSe).
 Studied crystals of A3B6<RE> were grown by the method of slow cooling at constant temperature gradient along the ingot. Their doping by RE with various percentage were realized by introduction of maximum crushed doping agent into the furnace, before the synthesis.
 The measurements were carried out in two interperpendicular crystallographic directions (in direction perpendicular to natural layers - along the "C" axis of the crystal and along the natural layers) at various temperatures ($77 < T < 400$ K) and at influence of light with various wavelength (0.30 ((3.50 (m) and intensity (down to $F=102$ lx).
 The dark and light current-voltage characteristics (CVC) were investigated at various conditions of T , F and percentage of the doping agents (NRE = 0; 10-5; 10-4; 10-3; 10-2; 10-1 at.%). On the base of obtained results were constructed graph of dependence main parameters of the phototrigger phenomenon on the NRE.
 It's find out that effect of doping by RE on the phototrigger phenomenon in laminar monocystals of A3B6 compounds is determined by the percentage of doping agent atoms, but not it's material. Moreover, it is established that by the doping of A3B6 compounds with rare elements of Gd, Ho and Dy maybe control the characteristics and parameters of phototrigger phenomenon in these semiconductors. In which connection by choosing optimum value of NRE one can take laminar monocystals of A3B6<RE> with more stabile photoelectric, including phototrigger properties. The results obtained by this way allows to suppose a model, qualitative explaining the mechanisms of implantation of a RE atoms to laminar monocystals of A3B6 compounds and also revelation of motive of dependence of spatially disarrays in this materials on the doping level by RE.
- C/PII.20** INFLUENCE OF Pr IMPURITIES ON THE ELECTRONIC STRUCTURE OF DIELECTRIC OXIDE CRYSTALS AWO4 (A = Cd, Zn)
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 Properties of intrinsic luminescence of self-activated lead PbWO4 and cadmium CdWO4 tungstates are in great measure determined by the structural defects and uncontrolled impurities [1]. Among all kinds of defects and impurities in these crystals studied up to now, the rare-earth ions possess particular importance. Recently it was shown that impurities of some rare-earth elements which occupy the cationic sites of oxide crystals decrease absorption of the crystals in the region of fundamental absorption edge and suppresses slow components of their luminescence decay [2]. This agrees with understanding of the fact that self luminescence of AWO4 crystals originate from localized centres with radius of a few unit cells. In order to confirm this view we performed calculations of the electronic structures of the set of small clusters in which Pr impurities were modelled.
 The sets of AWO4 clusters (A = Cd, Zn) (from 12 to 100-110 atoms) are ab-initio calculated by the Restricted Hartree-Fock (RHF) method using GAMESS package [3] considered. It is investigated how the partial densities of electronic states distributions for the atoms which surround the Pr3+ impurity depend on the cluster size. The results of calculations for different clusters of the same crystal are compared each to other and to experimental data on luminescence, excitation and absorption of corresponding AWO4 crystals. Positions of the Pr and the nearest atoms energy states in the forbidden gaps of the crystals are characterized. [1] Nedelko S.G., Kushnirenko I.Ya., Moroz Z.T., et al. // Ukrainian Phys. Journ. 37, 976 (1992) [2] Kobayashi M., Usuki Y., Ishii M., Itoh M. // Radiat. Meas. 38, 385 (2004) [3] Schmidt M.W., Baldrige K.K., Boatz J.A., et al. // J. Comput. Chem. 14, 1347 (1993).
- C/PII.21** NEAR-INFRARED SPECTROSCOPY AND ENERGY TRANSFER IN Tm3+-DOPED LEAD LANTHANUM ZIRCONATE TITANATE (PLZT) TRANSPARENT CERAMICS
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 The search for rare-earth doped laser materials remains an open subject. Recently, ceramic laser materials have emerged with many advantages, such as lower cost fabrication and flexibility in tailoring optical properties, as compared to crystals and glasses. Among the most interesting rare earth ions is Tm3+ due to its near-infrared emissions at 1.8 μ m (3F4 (r) 3H6 transition) and 1.44 μ m (3H4 (r) 3F4), which find important applications in medicine for the cut and ablation of biological tissues or in telecommunications for the construction of optical amplifiers. Transparent Tm3+-doped lead lanthanum zirconate titanate (PLZT) ferroelectric ceramics have been successfully obtained and its absorption and emission spectra studied as a function of doping concentration. The emissions efficiencies, while pumping with low cost diode lasers at 0.8 μ m, are dependent on energy transfer processes among Tm3+ ions, being the 3H4, 3H6 (r) 3F4, 3F4 cross relaxation the major excitation mechanism of level 3F4. Studies of the probability of these processes were done using the Dexter formalism of multipolar

interaction. Furthermore, radiative properties were evaluated by the Judd Ofelt theory. The results indicate that PLZT:TM3+ presents high potential as a laser active medium.

C/PII.22

OPTICAL PROPERTIES OF ERBIUM DOPED POROUS SILICON PLANAR WAVEGUIDES

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Recently, Planar optical waveguides (WG) based on oxidized porous silicon (PS) were demonstrated. It was shown that are compatible with the conventional microelectronic technology. Oxidized porous silicon waveguides (OPSWG) are presently passive devices and incorporating Erbium (Er) into these WG's offers a way to realize optical planar WG amplifiers operating at the third telecommunication window (i.e. 1.55 μm). Planar PSWG are prepared from p+-type silicon substrate by two-step anodisation process. Er has been introduced in PSWG by the electrochemical method in $\text{ErCl}_3:\text{C}_2\text{H}_5\text{OH}$ solution. Two-step thermal oxidation at air was performed: (i) pre-oxidation at 300°C for one hour to stabilise pore structure against heat treatment at high temperature, (ii) oxidation at 1000°C for optical activation of Erbium and for complete oxidation of the porous layer to reduced optical losses. The morphology of the Er-doped PSWG before and after oxidation was analysed by Scanning Electron Microscopy (SEM). Erbium concentration was determined by Energy Dispersive X-ray (EDX) analysis performed on SEM cross section. Erbium concentration profile in the oxidised PSWG and luminescence intensity are studied versus current density of doping condition. Optical loss measurement was investigated by measuring the light streak scattered out of the upper surface of the WG.

C/PII.23

THE EFFECT OF B-DOPING ON THE FLUORESCENCE OF Er-DOPED Ge-SiO₂ WAVEGUIDE FILM

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A PLC(Planar Lightwave Circuit) type optical amplifier is an integrated optical device applicable to access networks in optical communication. Because of its compact physical size, easy mass-production, and integrability into monolithic multi-functional optical devices, this device is expected to be a key element in the next generation of optical communication network.

In the material viewpoint, the major difference between conventional fiber amplifier and waveguide amplifier is the chemical composition of host glass, especially B₂O₃.

B₂O₃ is inevitably incorporated into waveguide film to reduce the processing temperature, which is limited to below 1400°C due to Si substrate. Therefore, it is essential to investigate the effect of B₂O₃ addition on the basic amplification characteristics to fabricate the efficient waveguide amplifier.

In the study, Er³⁺-doped bulk glasses were prepared and tested for the basic amplification characteristics to investigate the influence of B-doping. According to the results of the fluorescence and lifetime, we could confirm the depression of the concentration quenching of Er ions and increase of the lifetime by the addition of B₂O₃.

C/PII.24

OBSERVATION OF THE POPULATION INVERSION OF ERBIUM ION STATES IN Si/Si_{1-x}Ge_x:Er/Si STRUCTURES UNDER OPTICAL EXCITATION

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Photoluminescence (PL) of Si/Si_{1-x}Ge_x:Er/Si structures grown by the sublimation MBE has been investigated at high excitation conditions. The structures of such type are considered as good candidates for a laser on Si:Er basis. The structures are characterized with the thickness of SiGe layer of 0.1-1.1 μm and Ge content of 10-30%. Depending on Ge content the refraction index of SiGe layers could be varied in high extend enabling the strong localization of optical modes (confinement factor up to 0.92). Despite the relaxation of Si_{1-x}Ge_x:Er layers the structures presume high luminescence efficiency. The PL response at 1.54 μm measured at 10 K exceeds that for the standard c-Si:Er samples (external quantum efficiency ~0.4%). The relative number of the ions being in the first excited state (4I_{13/2}) is estimated as the ratio of PL rise and decay times at 1.534 μm . For this purpose we analyze the PL transients excited by chopped light of a Cu-laser (0.51-0.58 μm). The population inversion of the Er³⁺ states is found to be achieved at the pump intensity of 0.1 W/cm². The pumping with 1 W/cm² results in the strong population inversion (~80% of the total amount of the optically active ions), which is promising for lasing realization.

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C/PII.25

PHOTOSENSITIVE GaSe<Dy> CRYSTALS AND HETEROJUNCTIONS ON THEIR BASE

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The anisotropy of some semiconductors can be used in many aspects of application. In particular, GaSe (E_g=2.0 at 300 K) crystals with the layered crystalline structure make possible to create on their base qualitative heterojunctions with mismatched lattice parameters of their components. It is important from the point of view of creation of new type heterojunctions. At the same time GaSe crystals have the natural photopleochroism and therefore can be used in analyzers of the polarized and laser radiation.

Active doping the above named crystals can result in a change of their anisotropic properties. Doping with dysprosium (Dy) in doses 0.01, 0.1, and 0.5 wt % made possible to establish the some regularities of the behavior of the rare-earth impurity in the layered matrix. The typical feature is that the impurity is localized mainly in the interlayer spaces making intercalation of the crystal. The more is impurity concentration the higher is intercalation level. As a result, electrical parameters of GaSe along the different crystallographic axes are essentially changed. Some heterojunctions in which GaSe<Dy> substrates are the base component were prepared. It is established that due to doping with dysprosium, the photoelectric parameters such heterojunctions become essentially improved.

- C/PII.26** Nd³⁺ DOPED Sc₂O₃ WAVEGUIDING FILMS PRODUCED BY PULSED LASER DEPOSITION
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 Optically active waveguide is one of important elements for integrated optical devices. Sesquioxides and scandia (Sc₂O₃) in particular are well suited and effective host materials for rare earth doping. Laser operation has been demonstrated for Tm, Yb and Nd doped Sc₂O₃ crystals.
- We report on the growth of neodymium doped Sc₂O₃ films by pulsed laser deposition. The films have been deposited on (0001) sapphire substrates, which provide only 2.5 % lattice mismatch for (111) plane of Sc₂O₃. A number of films with thicknesses from 100 nm up to 3 μm have been produced. Films are proved to be crystalline and textured in the [111] direction. The films are doped with 2 at.% of neodymium. Spectroscopic investigations have been performed. Emission spectra of the films resemble a spectrum of the bulk material, emission lines are slightly broadened, the deviations in the intensities of the lines has been observed. Waveguiding experiments with a 3 μm Sc₂O₃ film has been performed. A 1.5 μm thick Al₂O₃ superstrate has been deposited on top of the film. Passive waveguiding is achieved when light of a blue laser diode at 397 nm is coupled into the film. Possible application of neodymium doped scandia films as an amplifier or a waveguide laser will be discussed.
- C/PII.27** THE EFFECT OF AN ADDITIONAL R.F. DISCHARGE ON THE PROPERTIES OF Pr:GGG FILMS FABRICATED BY PULSED LASER DEPOSITION
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 Pr doped Gd₃Ga₅O₁₂ (Pr:GGG) is an interesting material for laser application because of the possibility of infrared emission at about 1.3 μm and of orange-to-blue and infrared-to-blue wavelength upconversions. Pulsed Laser Deposition (PLD) technique is very useful to grow complex oxide waveguiding films. Pr:GGG waveguiding films, deposited with the same deposition conditions, either by conventional PLD or by PLD combined with an additional radiofrequency (r.f.) discharge, were compared. The attention was paid to the relation of the r.f. discharge parameters (r.f. electrode alignment, r.f. power and DC bias) to the crystalline structure (examined by X-ray diffraction) and surface morphology (observed by Scanning electron microscopy) as well as to the optical and fluorescence properties. A strong dependence of the crystalline grain size was found on the DC bias of the r.f. electrode, when the substrate was placed on it. The strong bombardment of the surface of the growing films, due to the DC bias, caused the creation of additional crystallisation centres and prevented the growth of large crystals. By using the additional r.f. discharge with different DC bias and at different substrate temperatures, the size of the crystalline grains was varied from some nanometres up to hundreds of microns.
- C/PII.28** OPTICAL AND LUMINESCENT PROPERTIES OF TERBIUM DOPED Y₂O₃ PLANAR WAVEGUIDE
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 The Tb doped Y₂O₃ planar waveguides were elaborated using sol-gel process by three different doping materials, i.e. Tb(NO₃)₃, pure Tb₂O₃ and [Y₂O₃ : 50% Tb] nanoparticles, respectively. The chemical and nanostructural properties were analyzed by infrared spectroscopy and X-ray diffraction. The Tb³⁺ luminescence properties were studied as a function of the temperature, the atmosphere of thermal treatment and the Tb³⁺ concentration. The emission intensities corresponding to the quenching mechanisms, such as the Tb³⁺→Tb⁴⁺ transformation and the -OH groups, were studied according to the appropriate thermal treatments. The 5D₄ emission intensity was effectively enhanced for the all three different doping systems after annealing at 700°C under reduced atmosphere. Excellent luminescence efficiency was obtained using the [Y₂O₃ : 50% Tb] nanoparticles in comparison with the other two systems. Finally, the optical propagation losses of the Tb doped Y₂O₃ planar waveguides related to the doping sources and Tb³⁺ concentration were presented.
- C/PII.29** CaGdAlO₄, AN Yb³⁺ MULTI-SITE MATERIAL FOR TUNABLE SOLID STATE LASER AND HIGH POWER LASER APPLICATIONS
 Johan Petit, Philippe Goldner, Bruno Viana, Laboratoire de Chimie Appliquée de l'Etat solide, Ecole Nationale Supérieure de Chimie de Paris, 11 rue P et M Curie, 75231 Paris cedex 05, France
 In high power laser domain, the crucial issue is to control the heat production. So, good thermal properties, like high thermal conductivity and low thermal expansion values are required. Another way to reach high power is to reduce the heat load inside the crystal. The quantum defect can be reduced by decreasing the emission wavelength. However, the laser material must have appropriate optical spectroscopic properties to tune emission wavelength close to absorption wavelength.
 CaGdAlO₄, called CALGO, is doped with ytterbium ions. The thermal conductivity was measured on this sample. The thermal expansion coefficients were also measured by X-ray diffraction. Absorption and emission cross sections were determined in pi and sigma polarizations. These spectra are very broad and a plateau is observed between 990 nm and 1050 nm with relatively high emission cross section values which gives good expectation to obtain ultra-short pulses. The fact that this compound owns broad absorption and emission bands is due to Yb³⁺ occupancy in Ca²⁺ and Gd³⁺ crystallographic sites presenting different size and cationic charges. Optical characterization was done at low temperature to determine the energy level diagram and Yb³⁺ laser parameters. The 2F_{5/2} level lifetime of the 2%Yb:CALGO was measured. Due to the broad emission bands, tuneable laser oscillation was expected from 1000 nm to 1050 nm. Laser experiments were performed on a 2%Yb:CALGO sample without anti-reflection coating using Ti:sapphire. A laser oscillation was obtained from 1050 to 1016 nm with laser threshold around 300 mW of input power. The slope efficiency reached 40% with regard to incident pump power at 1016 nm. Consequently, the quantum defect value is as low as 3.5%.
- C/PII.30** ANOMALOUS Tb³⁺ LUMINOUS SPECTRUM IN THE TiO₂ NANOCRYSTALS
Jung Hwan Kim and Haeyoung Choi: Dept. of Physics, Dongeui University, Busan, 614-714, Korea. Byung Kee Moon and Jung Hyun Jeong: Dept. of Physics, Pukyong National University, Busan, 608-737, Korea. Soung-soo Yi: Dept. of Photonics, Silla University, Busan, 617-736, Korea
 Nanosize terbium oxide embedded in the TiO₂ nanocrystal was produced using a reverse micelles and solvothermal method in toluene solution. High resolution transmission electron microscopy (TEM) and X-ray diffraction measurements have identified particles with a size of 6.9~10.2 nm in the anatase phase. The TEM micrographs show that nanoparticles have polyhedral-shaped morphologies and good electron diffraction patterns, which indicates that they have good crystallinity. It was expected that the nucleation and growth of

nanocomposites is composed of TiO₂ shell with Tb₂O₃ cores. However, any evidence was not obtained from XRD and TEM, whether the nanoparticle has core-shell structure or terbium oxide is formed a colony of aggregates or Tb ions are dispersed in the TiO₂ solution.

Although many investigators tried to find out luminescence of Tb³⁺ in the titania, they failed. It is considered that Tb³⁺ ions were dispersed in titania for their samples. But, the strong emissions from 5D₄ level of Tb³⁺ ions have been observed from our samples, and the luminous spectra that has very strong emission band due to the transition of 5D₄ → 7F₂ was anomalous. It was ascribed to two kinds of energy migration among Tb³⁺ ions (5D₄ - 7F₆ and 5D₄ - 7F₂) in terbium oxide nanoparticle. The excitation energy corresponding to the transition of 5D₄ → 7F₂ may be able to migrate among Tb³⁺ ions for a long time, since the quenching centers operate upon higher excitation energy than that of this migration. It is inferred from the results of PL measurements that one or several cores of Tb₂O₃ nanoparticle are embedded in the TiO₂ nanocrystal.

C/PII.31

RARE-EARTH-DOPED GVO FILMS GROWN BY PULSED LASER DEPOSITION

Sebastian Bär, Hanno Scheife, Günter Huber, Institute of Laser-Physics, Luruper Chaussee 149, 22761 Hamburg, Germany

Bulk crystals of the vanadates YVO₄ and GdVO₄ are well-known hosts for lanthanide ions and have been widely used in solid-state lasers as well as in phosphors. Using these materials as thin films not only compact waveguide laser devices can be envisaged, but one can think also of thin crystalline vanadate films as surface coatings and heat sinks in the thin-disk laser setup, where the active medium is Nd:YVO₄.

We report on the thin film growth of rare-earth-doped GdVO₄ by pulsed laser deposition. These films were grown either nearly homoepitaxially on YVO₄-substrates or heteroepitaxially on alpha-Al₂O₃-substrates. The first spectroscopic results of an Eu-doped GdVO₄ film grown on YVO₄ with a film thickness of 100nm clearly indicate crystalline growth as the resulting emission and excitation spectra correspond well with the spectra from the bulk system. For first experiments, Eu³⁺ was chosen as a probe ion as the 5D₀ level reacts very sensitive to the crystal field. In the future Eu will be replaced by Yb or Nd. To confirm in more detail the structure of the films, X-ray diffraction measurements as well as atomic force microscopy will be performed. Apart from the homoepitaxially grown films, which can be used as efficient heat sinks or hard crystalline coatings, GdVO₄-films have been grown on sapphire for waveguide applications, since in this case the index step between substrate and film is 0.22 while for homoepitaxy the difference is only 0.014.

C/PII.32

1.53mm PHOTOLUMINESCENCE FROM ER-DOPED SOL-GEL DERIVED IN₂O₃ FILMS EMBEDDED IN POROUS ANODIC ALUMINA

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Er-related 1.53 mm light emission correspond to minimal dispersion and absorption in silica glass fibers. However, Er ions characterized with low excitation efficiency. Increase of the excitation efficiency can be achieved by transfer of the excitation energy from organic dyes, metal or semiconductor nanoparticles. On the other hand, it can be enhanced by increasing the scattering of exciting light by using porous materials.

Thus, porous anodic alumina (PAA) covered with spin-on erbium-doped In₂O₃ xerogel films has been investigated by photoluminescence (PL) and photoluminescence excitation (PLE). PL exhibited well-resolved at room temperature peak at 1.55 mm associated with 4I_{13/2} - 4I_{15/2} transitions of Er³⁺ ions. The PL intensity associated with this transition increase with the annealing temperature about seven times in range from 300 up to 1000 oC. Absence of the Er-related emission peaks for excitation energy beneath absorption edge of In₂O₃ xerogel suggest energy transfer from xerogel to erbium-related luminescence center. Role of xerogel and porous anodic alumina matrices in enhancement the 1.53mm light emission from xerogel/porous anodic alumina structure is discussed.

C/PII.33

OPTICAL PROPERTIES OF ERBIUM-DOPED XEROGELS EMBEDDED IN POROUS ANODIC ALUMINA

N.V. Gaponenko, G.K. Malyarevich, D.A. Tsyrukunou E.A. Stepanova, A.V. Mudryi, Belarusian State University of Informatics and Radioelectronics, P. Browki St.6, 220013 Minsk, Belarus, O.B. Gusev, E.I. Terukov, Ioffe Physicotechnical Institute, Russian Academy of Sciences, St. Petersburg, Russia, M.V. Stepikhova, L.V. Krasilnikova and Yu.N. Drozdov, Institute for Physics of Microstructures, Russian Academy of Sciences, Nizhny Novgorod, Russia

The structures comprising erbium-doped titanium oxide xerogel/porous anodic alumina show the strong photoluminescence at 1.54 μm originated by the 4I_{13/2}-4I_{15/2} transitions of Er³⁺ ions in xerogel. Two phases of erbium-doped titanium oxide xerogel - anatase and rutile mesoscopically confined in porous anodic alumina were detected with X-ray analysis, depending on the annealing conditions. Photoluminescence excitation spectra for 1.54 μm emission line are characterized by 10 bands of intra-shell transitions of Er ions, where the dominating band at 524 nm coincides with the 4I_{15/2}-2H_{11/2} transitions. The photoluminescence lifetime of 1.54 μm emission line is 1.8 ms.

Influence of the shape of the porous anodic alumina film grown on aluminum foil or silicon wafer as well as the role of chemical content of xerogel matrix on light emission at 1.54 μm are discussed.

C/PII.34

Li-DOPING EFFECT ON ENHANCEMENT OF PHOTOLUMINESCENCE IN Gd₂O₃:Eu³⁺ FILMS

Soung-soo Yi, Dept. of Photonics, Silla University, Busan 617-736, Korea, Hyun Kyong Yang, Byung Kee Moon, Sung Boo Kim and Jung Hyun Jeong, Dept. of Physics, Pukyong National University, Busan 608-737, Korea, Jung Hwan Kim, Dept. of Physics, Dongeui University, Busan 614-714, Korea

Luminous properties of Gd₂O₃:Eu³⁺ and Li-doped Gd₂O₃:Eu³⁺ thin films were investigated by time resolved laser spectroscopy in the temperature range of 15 ~ 400 °K. The films were grown by pulsed laser deposition method on Al₂O₃ (0001) substrates under different substrate temperature and oxygen pressures. It has been suggested by several authors that the enhanced photoluminescence brightness by Li doping results from improved crystallinity and reduced internal reflections caused by rougher surfaces. Comparing to Gd₂O₃:Eu³⁺ films, the brightness of Li-doped Gd₂O₃:Eu³⁺ films was increased by a factor of 1.5 at 15 °K, and 2.3 at room temperature. In this presentation, it is suggested that the highest optical phonon energy of Li₂O introduced Li to Gd₂O₃:Eu³⁺ is another important factor of improving brightness at higher temperature. Exciting the Gd₂O₃:Eu³⁺ films at its band gap or higher energy level of Eu³⁺ ions with 266 nm excitation results in cascading multi-phonon relaxation to the emitting state of Eu³⁺ ions (5D₀), luminescence of Eu³⁺ ions takes place. The optical phonon having the highest energy plays an important role in multi-phonon relaxation process. The photoluminescence intensity was increased with increasing temperature under 266 nm excitation. However, when the films were excited at the

emitting state of Eu³⁺ ion (5D₀), photoluminescence intensity was not increased with increasing temperature regardless of Li-doping.

C/PII.35

NANOCRYSTALLINE ER:YAG THIN FILM PREPARED BY PULSED LASER DEPOSITION

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Thin films of erbium doped yttrium aluminum garnet (Er:Y₃Al₅O₁₂) were grown by pulsed laser deposition (PLD) followed by high temperature annealing. Such thin films are very appropriate for planar waveguide lasers, useful in medical or telecommunication applications. Crystals of Y₃Al₅O₁₂ - doped with triple ionized ions of erbium are well-known laser materials that can emit in the infrared and visible range.

PLD experiments were performed both with a KrF excimer laser source ($\lambda=248$ nm) and with an ArF excimer laser source ($\lambda=193$ nm) in high vacuum chambers in oxygen atmosphere on silica, sapphire or silicon substrates. We studied the depositions from single crystalline Er:YAG targets as compared with those from nanocrystalline Er:YAG targets. After deposition, some of the films were annealed at temperatures as high as 1100°C. Influence of growth and annealing conditions on structural, morphological, optical and fluorescence properties were studied by optical spectroscopy, X-ray diffraction, scanning electron microscopy and fluorescence spectroscopy.

C/PII.36

LUMINESCENCE PROPERTIES OF ERBIUM DOPED MIXED ALUMINA YTTRIA THIN FILMS

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The development of the optical telecommunication components requires the realisation of active optical materials especially as thin films. In contrary to the fibers applications, for integrated devices a high efficiency of the optical amplification is required. This is obtained with a high rare earth concentration. But the classical rare earth doped silicate glasses are strongly limited by the clustering effect. In order to avoid this phenomenon, crystalline host materials such as alumina or yttria have been proposed as amplifying media. This kind of material exhibit a low level of phonon losses. As a new deposition approach this paper reports the growth of erbium doped alumina-yttria mixed thin films by an aerosol atmospheric CVD process. By using aluminium, yttrium and erbium acetylacetonates dissolved in butanol, erbium doped alumina-yttria mixed thin films were deposited between 350°C and 550°C. The deposition rate reached 300nm/h around 500°C. The refractive index and the density of the films increased with the deposition temperature. At low deposition temperature a contamination was revealed by FTIR measurements. This contamination corresponded to the organic ligand of the organometallic precursor and to hydroxyl group. As deposited the films did not exhibit luminescence properties due to the contamination. By annealing the films after deposition at 900°C, the luminescence was observed. The spectroscopic and crystallographic properties were discussed according to the deposition conditions, the films compositions and the post annealing temperature. In order to improve the luminescence properties, the deposition under UV lamp irradiation was evaluated. At 450°C the hydroxyl and organic contamination is lowered as revealed by FTIR.

C/PII.37

LUMINESCENT RARE EARTH DOPED LAPONITE XEROGELS AND FILMS

Rogéria Rocha Gonçalves(a), Jairo Tronto(a), Sidney José Lima Ribeiro(b), João Barros Valim a), (a)Departamento de Química, Faculdade de Filosofia Ciências e Letras de Ribeirão Preto, Universidade de São Paulo, Av. dos Bandeirantes 3900, 14.040-901, Ribeirão Preto, SP Brazil, (b)Departamento de Química Inorgânica, Instituto de Química de Araraquara, Universidade Estadual Paulista, R. Francisco Degni, s/n, 14.800-090, Araraquara, SP Brazil

Laponite, a synthetic hectorite clay with nominal composition Na_{0.7}[(Si₈Mg_{5.5}Li_{0.4})O₂₀(OH)₄]-0.7, can be promising material for optical applications due mainly of its high transparency and small crystallite size.

Eu³⁺ and Er³⁺ doped Laponite xerogels and films were prepared from colloidal dispersion. Thick films were deposited on soda-lime and quartz substrates. Homogeneous, crack-free and transparent single layers could be obtained with thickness up to 30 micra. Structural properties were analysed using X-ray diffraction, luminescence spectroscopy and excited state lifetime measurements. Luminescence spectra in the visible and near-infrared region, for Eu³⁺ and Er³⁺ ions respectively, were obtained and discussed as a function of thermal treatment. Relative intensity, line widths and stark splitting of the 5D₀→7F_J transitions of the Eu³⁺ ions are used for monitoring the structural evolution in the sol, gel, xerogel and thick films.

C/PII.38

THE EFFECTS OF SUBSTRATES AND DEPOSITION PARAMETERS ON THE GROWING AND LUMINESCENT PROPERTIES OF Y₃Al₅O₁₂:Ce THIN FILMS

Joo Won Kim(a), Sang Hyuk Han(b), Young Jin Kim(a) (a)Dept. of Materials Science and Engineering, Kyonggi University, Suwon 443-760, Korea, (b)R&D Div., Phosphor Team, DAEJOO Electronic Materials, Kyonggi-Do, Korea

To investigate the effects of the substrates and the sputtering parameters on the growing and the luminescent properties, YAG:Ce thin films were deposited on quartz glass substrates and sapphire single crystals by rf magnetron sputtering at the various sputtering conditions. The compositional ratio of Y/Al and the crystallinity strongly depended on the sputtering gas ratio O₂/(Ar+O₂) as well as substrate temperatures and rf powers. YAG:Ce thin films that had almost stoichiometric composition and high quality crystallinity could be obtained at the gas ratio of O₂/(Ar+O₂) = 0.5, which also showed the highest yellow emission at 550 nm after annealing process. The films deposited on c-plane sapphire substrates exhibited higher PL intensity than those on quartz substrates due to the superior crystallinity.

C/PII.39

SURFACE MORPHOLOGY DEPENDENT PHOTOLUMINESCENCE CHARACTERISTICS OF Eu-DOPED YVO₄ THIN FILMS

Byung Chun Choi(a), Kyoo Sung Shim(a), Byung Kee Moon(a), Jung Hyun Jeong(a), Jong Seong Bae(b), Soung-soo Yi(c), Jung Hwan Kim(d), (a)Department of Physics, Pukyong National University, Busan 608-737, Korea, (b)Basic Science Research Institute, Pukyong National University, Busan 608-737, Korea, (c)Department of Photonics, Silla University, Busan 617-736, Korea, (d)Department of Physics, Dong Eui University, Busan 614-714, Korea

High-quality YVO₄:Eu³⁺ thin-film phosphors have been deposited on an Al₂O₃ (0001) substrates using pulsed laser deposition method. The films were grown at the various substrate temperatures and the different oxygen pressures. The substrate temperatures were changed from 500 to 700 °C and the range of oxygen pressures was

100 - 300 mTorr. The crystallinity and surface morphology of the films were investigated using X-ray diffraction (XRD) and atomic force microscope (AFM), respectively. The results of XRD showed that YVO₄:Eu³⁺ films had zircon structure and AFM study revealed that the films consisted of homogeneous grains ranging from 100 to 300 nm depending on the deposition conditions. Photoluminescence spectra were measured at room temperature using a luminescence spectrometer and excitation by a broadband incoherent ultraviolet light source with a dominant excitation wavelength of 254 nm. The crystallinity, surface morphology and photoluminescence spectra of thin film phosphors were highly dependent on the deposition conditions, in particular, the oxygen pressure and substrate temperature. The surface roughness and photoluminescence intensity of the films showed similar behavior as a function of oxygen pressure and substrate temperature. The emitted radiation was dominated by the red emission peak at 619 nm and this phosphor is promising for applications in flat panel displays.

Session XII : Silicon and related nanostructures III
Session chairs : W. Skorupa, T. Kimura

- C-XII.01** 9:00 -Invited- THE IMPACT OF ERBIUM ON THE STRUCTURE AND PHOTOPHYSICS OF SILICON-GERMANIUM NANOWIRES
Jeffery L. Coffey and Ji Wu, Department of Chemistry, Texas Christian University, Fort Worth TX 76129, USA
Crystalline alloys and layered structures comprised of silicon (Si) and germanium (Ge) possess a number of fundamentally-useful properties that translate into significant advantages in state-of-the-art device platforms. Depending on composition, bonding, and local structure, the presence of Er³⁺ into these nanowires can enhance the photophysical utility of the SiGe. This presentation outlines a strategy designed to fabricate a family of SiGe nanowire platforms that incorporate the rare earth ion erbium (III) into a given structure. By probing the effect of average erbium location in the structure along with its first coordination sphere, we propose to elucidate and tune the optical behavior of these Group IV nanostructures grown via a bottom-up synthetic process. The fundamental issue of size dependent charge carrier confinement along the width of the wire is an intriguing tunable parameter to be explored here as well.
A number of experimental tools will be described which determine the structure and physico-chemical characteristics of the above. These include scanning electron microscopy (SEM), conventional TEM imaging, high resolution transmission electron microscopy (HREM), energy dispersive x-ray analysis (including mapping), extended x-ray absorption fine structure measurements (EXAFS), vibrational spectroscopies (micro-Raman), as well as photoluminescence (PL) and photoluminescence excitation (PLE) spectroscopies.
- C-XII.02** 9:30 ENERGY TRANSFER TO AND FROM Er³⁺ IN SiO₂ DOPED WITH Si NANOCRYSTALS
I. Izeddin(a), V.Yu. Ivanov(a,b), M.A.J. Klik(a) and T. Gregorkiewicz(a), (a)Van der Waals-Zeeman Institute, University of Amsterdam, Valckenierstraat, 1018XE Amsterdam, The Netherlands, (b)Institute of Physics, Polish Academy of Science. Al.Lotnikow 32/42, 02668 Warsaw, Poland
Energy transfer between silicon nanocrystals (Si-nc's) and Er³⁺ is of paramount importance for understanding the sensitization of Er [1]. Its related transfer time, estimated in the order of microseconds, is decisive for the number of excited Er³⁺ ions per nanocrystal [2]. In the present contribution we have studied excitation and decay kinetics of Er³⁺ in a set of SiO₂ samples doped with Si-nc's, for which the fast transfer time was reported [3] and simultaneous PL from both subsystems (nc's and Er³⁺) can be observed. The PL experiments have been performed using a tunable Nd:YAG-pumped OPO as excitation source; the detection system (spectrometer and a photomultiplier tube) allowed recording time-resolved PL. In order to investigate the energy transfer time we set up an experiment where the sample is excited by a sequence of two high power pulses from Nd:YAG lasers, of which the initial one leads to saturation of Er³⁺ PL, and whose delay can be adjusted to the energy transfer time. In the decay kinetics transients for the Er³⁺ PL two different components have been recorded: a fast initial followed by a slower one, with identical shape for their partial integrated PL. The fast component has the same decay time and similar excitation flux dependences as the PL from the Si-nc's. This suggests strong coupling between Er³⁺ ions and Si-nc's. These findings can be rationalized considering energy back transfer from Er³⁺ to Si-nc's, leading to additional Si-nc's PL. Such a reversal of the excitation process has not been reported before for the SiO₂:Er³⁺, Si-nc system. [1] F. Priolo et al., J. Appl. Phys. 89, 264 (2001) [2] M. Wojdak et al., Phys. Rev. B 69, 233315 (2004) [3] M. Fujii et al., J. Appl. Phys. 95, 272 (2004)
- C-XII.03** 9:45 1.54- μ m LUMINESCENCE FROM ER-DOPED AMORPHOUS SI QUANTUM DOT FILM
Nae-Man Park, Tae-youb Kim, Kyung-Hyun Kim, Gun Yong Sung, Future Technology Research Division, Electronics and Telecommunications Research Institute, Daejeon 305-350, Korea, Kwan Sik Cho, Jung H. Shin, Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 305-701, Korea, Baek-Hyun Kim, Seong-Ju Park, Department of Materials Science and Engineering, Gwangju Institute of Science and Technology, Gwangju 500-712, Korea, Jung-Kun Lee and Michael Nastasi, Materials Science & Technology Division, Los Alamos National Laboratory, NM 87545, USA
Er-doped silicon nanocrystals, showing efficient light emission attracts greatest interest because of its promising future in the development of light-emitting diodes and lasers operating at the wavelength 1.54 μ m. The amorphous Si quantum dot (a-Si QD) has stimulated interest in the control of dot size in a small dimension compared to nanocrystals and theoretical calculation also showed the efficient radiative property [1, 2]. In a recent report [3], the density effect of a very small a-Si cluster on Er PL in Si-rich SiO₂ was investigated, where a high density of a-Si clusters enhanced PL efficiency compared to Si nanocrystals. In this work, we will present the effects of the size of a-Si QDs and the hydrogenation on Er luminescence, where the samples were classified into three groups, referred to as large-, medium-, and small-dot samples in accordance with dot sizes of 2.5, 1.8, and 1.4 nm. Er³⁺ ions were implanted with a dose of 1¹⁰21/cm³ into the films. References [1] N.-M. Park, C.-J. Choi, T.-Y. Seong, and S.-J. Park, Phys. Rev. Lett. 86, 1355 (2001). [2] K. Nishio, J. Koga, T. Yamaguchi and F. Yonezawa, Phys. Rev. B 67, 195304 (2003). [3] G. Franzò et al., Appl. Phys. Lett. 82, 3871 (2003).

C-XII.04 10:00

NEODYMIUM EMISSION AND SHORT-RANGE ORDER IN AMORPHOUS SiNx

D. Biggermann(a), S.B. Aldabergenova(b), H.P. Strunk(b), L.R. Tessler(a), (a)"Gleb Watagnin" Institute of Physics, State University of Campinas, CP 6165, 13083-970 Campinas, Brazil, (b)Department of Materials Science and Engineering, Institute of Microcharacterization, Erlangen-Nürnberg University, Cauerstr. 6, 91058 Erlangen, Germany

We study the structure of Nd-doped amorphous silicon nitride SiNx ($x = 0,43; 0,65; 1,0; 1,15$) thin films prepared by RF co-sputtering by means of transmission electron microscopy techniques. As prepared SiNx samples were carefully annealed at different temperatures to enhance the characteristic Nd³⁺ emission in the infra-red region. The best Nd³⁺ emitting samples after optimal annealing show the structure of fine dispersed crystalline grains with sizes of 2-5 nm embedded in an amorphous matrix. Cathodoluminescence measurements, directly in high resolution transmission electron microscope, in optimally annealed samples show broad emission spectra that cover the whole visible region ranging from 430 upto 750 nm. This emission is related to the SiNx matrix and plays an important role in the excitation of the Nd³⁺ ions.

C-XII.05 10:15

ON THE ROLE OF YB IMPURITY IN EXCITATION OF ER³⁺ EMISSION IN SILICON-RICH SILICON OXIDE

A. Kozanecki, Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland, D. Kuritsyn, Institute for Physics of Microstructures, Russian Academy of Sciences, GSP-105, Nizhnyi Novgorod, 603950, Russia and W. Jantsch, J. Kepler Univeristy, 4040 Linz, Austria

In this work we study the role of Yb impurity in excitation of the 4I13/2 - 4I15/2 emission of Er³⁺ ions at 1.54 μm in silicon-rich silicon oxide (SRSO). Yb is a well known sensitizer of Er³⁺ emission in glasses, as its absorption cross-section for 2F7/2 - 2F5/2 transition is a factor of 20 higher than that of 4I15/2 - 4I11/2 of Er³⁺ transition. We intend to check if Yb³⁺ ions can be used as sensitizers in SRSO, as it is known that most of Er atoms in SRSO locate in silica phase rather than in silicon clusters. To answer this question we performed measurements of photoluminescence excitation (PLE) of Er³⁺ emission in a wide range of excitation wavelengths. The PLE spectra in a 420-650 nm range were excited using an optical parametric oscillator. We show that in Er+Yb implanted silica an absorption band related to Yb impurity exists for wavelengths shorter than 530 nm, similarly like for SRSO doped with Er only. We could exclude radiation defects as absorbing species in Er+Yb implanted silica. In SRSO as-implanted with Er+Yb the presence of Yb enhances the PL of Er, however in annealed SRSO absorption by Yb is entirely suppressed by absorption of silicon clusters, which appeared to be much more efficient sensitizers than Yb in the visible. As a result we conclude that Yb doping of SRSO:Er does not improve the PL efficiency of Er³⁺ in comparison with SRSO:Er.

10:30

BREAK

Session XIII : Silicon and related nanostructures III

C-XIII.01 11:00

OPTICAL ACTIVATION OF SEMICONDUCTOR NANOWIRES WITH RARE-EARTH DOPED, SOL-GEL DERIVED SILICA

Kiseok Suh and Jung H. Shina) Department of Physics, KAIST, 373-1 Guseong-dong, Yuseong-gu, Daejeon, Korea, Oun-Ho Park and Byeong-Soo Bae, Laboratory of Optical Materials and Coating (LOMC), Department of Materials Science and Engineering, KAIST, 373-1 Guseong-dong, Yuseong-gu, Daejeon, Korea, Jung-Chul Lee, Materials science and Technology Division, KIST, P.O. Box 131, Cheongryang, Seoul 130-650, Korea, Heon-Jin Choi, School of Advanced Materials Science and Engineering, Yonsei University, 120-749 Korea

Rare earth (RE) doping of semiconductors represent a great opportunity to realize stable, pure luminescence at many technologically important wavelengths without having to engineer the bandgap of the semiconductor. Unfortunately, the optical activity of RE ions in semiconductors are generally low, preventing development of practical devices. Excellent optical properties can be obtained when RE ions are doped into oxides and then sensitized by semiconductor nanocrystals. However, the need to isolate nanocrystals inside the oxide matrix makes current injection difficult, resulting in poor electrical properties. Such problems may be solved by using nanowires (NWs) instead, since they provide a continuous current paths in a nm-scale structure. However, due to the limited solubility of RE in semiconductors, direct growth of RE-doped NWs can lead to defective growth with low optical activity. In this letter, we report on the results of using Er-doped, sol-gel derived silica thin films to coat Si- NWs instead of doping them directly. We find that by separating NWs growth and optical activation step, we can achieve both high crystalline quality of Si-NWs and high RE optical activity at the same time. We observe strong room temperature 1.54 μm luminescence by the Er ions in sol-gel derived silica excited via carriers in nearby Si-NWs, with a luminescence lifetime of 6.9 ms and a nearly complete suppression of the temperature quenching of the Er luminescence, indicating that such nanocomposite material can provide high quality electrical and optical properties at the same time. Results of extending the NWs-RE combination to obtain visible luminescence will be presented, along with the possibility of electrical excitation of RE ions.

C-XIII.02 11:15

TOWARDS EPITAXIAL GROWTH OF ErSiO NANOSTRUCTURED CRYSTALLINE FILMS ON Si SUBSTRATES

H. Isshiki, M. Masaki, K. Ueda, K. Tateishi and T. Kimura, University of Electro-Communications, Chofugaoka, Chofu, Tokyo 182-8585, Japan

Growth of ErSiO nano-structured crystalline films with a preferred orientation was attempted on Si substrates, by sol-gel, Er doping of porous silicon and MOMBE (metal

organic molecular beam epitaxy). Er-Si-O self-aligned nanostructured crystalline composites which were reported by H.Isshiki et al. contain Er as the constituent element and show fine structured 1.54 μ m photoluminescence at room temperature (the main peak at 1.528 μ m with FWHM less than \sim 7nm). The epitaxial growth of micrometer thick ErSiO films on Si substrates is strongly required to develop silicon based optical devices operating at 1.54 μ m. The key to obtain nanostructured ErSiO films is the ratio of Er:Si at 1:2 in the starting materials, the solid-phase growth process at high temperatures, typically 1250°C, and controlled oxygen content. The electrochemical Er doping of thick porous silicon layers with fine pores of several ten nanometers in diameter forms the micrometer thick Er-Si-O films very easily. The sol-gel method on Si(100) forms thick and uniform ErSiO films aligned to the Si(100) surface with a controlled Er:Si ratio at 1:2. The MOMBE growth of ErSiO on Si substrates 15° off from Si(100) towards [011] using TEOS and Er(TMOS)₃ at 900°C successfully resulted in the formation of Er-Si-O nanostructured films which are strongly aligned 3.5° away the substrate surface orientation. This result indicates a possibility of epitaxial growth of ErSi-O nanostructured films on Si substrates at a moderate growth temperature.

C-XIII.03 11:30 -Invited-

LIGHT EMITTING DEVICES BASED ON RARE EARTH DOPED Si NANOCCLUSERS

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In the last decade, rare earth doping of Si nanoclusters (nc) has been shown to be one of the most promising method to bypass the poor light emission from Si. Si nc are very efficient sensitizers for the Er luminescence (PL) at 1.54 μ m. Recently, higher PL signals have been obtained in samples with Er and amorphous Si clusters, demonstrating that both amorphous and crystalline Si nc can be efficient sensitizers for Er. We will demonstrate that room temperature light emission from MOS devices based both on Er, Tm and Yb doped Si nc can be achieved. Si nc dispersed in the active layer allows for a good current injection in the otherwise insulating matrix and determine an efficient rare earth excitation. In particular, an effective excitation cross section 2 orders of magnitude higher if compared to optical pumping has been measured under electrical excitation. Due to the high excitation cross section and to the efficient current injection, internal quantum efficiencies of the order of 1% have been estimated. In order to increase the external efficiency, we coupled the emitting system with a 2D photonic crystal structure opportunely fabricated to efficiently couple the emitted radiation to the free space vertical modes, thus reducing the total internal reflection of the emitted light and increasing the overall emission yield. These data will be presented and discussed.

12:00

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