



Strasbourg (France)

E-MRS Spring Meeting 2003
June 10 - 13, 2003

SYMPOSIUM E

Ion beams for nanoscale surface modifications

Symposium Organizers:

Alain Claverie, CEMES-CNRS, Toulouse, France

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E-MRS 2003 SPRING MEETING

SYMPOSIUM E

Tuesday, June 10, 2003
Mardi 10 juin 2003

Morning
Matin

- 9:00 OPENING
- E-I.1** 9:15 -Invited- NANOMETRIC PHASE TRANSFORMATION OF MATERIALS UNDER ENERGETIC HEAVY IONS
M. Toulemonde(a), E. Balanzat(a), K. Hjort(b), C. Trautmann(v) and A. Weidinger(f), (a)CIRIL lab., CEA-CNRS- ISMRA, BP 5133, 14070 Caen Cedex 5, France, (b)The Ångström lab., Uppsala Univ., Box 534, 75121 Uppsala, Sweden, (v)MF/GSI, Planck Str. 1, 64291 Darmstadt, Germany, (f)HMS/HMI, Glinicker Str, 100, 14109 Berlin, Germany
The state of art of nanometric amorphization of materials induced by dense electronic excitation following the slowing down of swift heavy ion will be presented. After a description of experimental observations and track quantifications, it will be shown that swirl heavy ions are very efficient to induce the phase transformations at a nanometric scale in many different materials. The correlation between the nanometric observations and the chemical and physical properties of the irradiated materials will be described. We will focus in particular on the creation of tracks with magnetic properties, conducting Hacks in insulators, nanoscopic change of the geometrical shape of material, lithography with high aspect ratio, etching of nanochannels suitable as templates for growth of metallic nanowires including multi-layer systems.
- E-I.2** 9:45 -Invited- ION BEAM MANUFACTURING OF SURFACE NANOSTRUCTURES
U. Valbusa, INFN, Università di Genova, Dipartimento di Fisica, Via Dodecaneso 33, 16146 Genova, Italy
Ion sputtering of crystalline or amorphous surfaces produces periodic structures of nanometer dimension which can be easily controlled by changing a few macroscopic parameters like dose, energy, incident angle and flux of the ion beam or surface temperature. The effect, which has previously been viewed as an annoying artifact in some surface processing techniques (e.g. SIMS), can be seen as a versatile method of nanostructuring surfaces. When this method is applied on magnetic films, the ability to tune the morphology of nanoscale artificial patterns by means of ion sculpting combined with the quantitative determination of magnetic anisotropy, allows to determine the relative importance of surface and magnetostatic contributions. In the case of Co films on Cu(001), for instance, the formation of nanoscale ripples deeply affects the magnetic properties of the Co film. A surface-type uniaxial magnetic anisotropy with easy axis parallel to the ripples is observed. The origin of the magnetic anisotropy has been identified with the modification of thermodynamic-step distribution induced by ripple formation. At higher ion doses, when Co ripples detach and crystalline nanowires form, a strong enhancement of the magnetic anisotropy due to shape contribution is observed. The paper will report on a series of experiments performed by using Scanning Tunneling Microscopy (STM), Real-Time Grazing-Incidence Small-Angle X-ray Scattering (RT-GISAXS) and Magneto-Optical Kerr Effect (MOKE) measurements to determine morphology and magnetic anisotropy of nanostructured magnetic surfaces.
- 10:15 BREAK
- E-II.1** 10:45 -Invited- THE SHAPE AND ORDERING OF SELF-ORGANIZED NANOSTRUCTURES BY ION SPUTTERING
B. Ziberi, F. Frost, T. Höche and B. Rauschenbach, Leibniz-Institut für Oberflächenmodifizierung e. V., Permoserstrasse 15, 04318 Leipzig, Germany
The formation of periodic ripple structures on surfaces bombarded with ions under oblique (off-normal) incidence is a well-known and intensely studied phenomenon. In contrast to these long standing investigations, a new self-organization phenomenon was noticed for ion sputtering under oblique ion incidence with simultaneous sample rotation. Due to the rotation induced abolishment of the anisotropy in the evolution of the surface topography, naturally given by the direction of the ion incidence, the formation of nanometer-sized islands (dimension < 100 nm) can be observed. For prolonged sputtering, these island or dot structures are characterized by relatively uniform size distribution and a strikingly large degree of spatial ordering.
This contribution focuses on the specific role of the angle of ion incidence and temperature on the dimension, geometrical shape and the spatial arrangement of the arising nanostructures during low energy ion sputtering. Scanning force microscopy (AFM) and high resolution transmission electron microscopy (HRTEM) are used to investigate the evolution of the surface topography and morphology of these self-organised crystalline nanostructures. Depending on the ion incidence and temperature, these nanostructures show hexagonal or square ordering with cone-, spherical- or spike-like shape. New experimental results for dot formation on InP, GaSb, InSb and InAs surfaces will be presented.

- E-II.2** 11:15 **ENERGETIC CLUSTER ION IMPACT OF SURFACES: NANOHILLOCK FORMATION**
Eleanor E.B. Campbell, V. Popok, S. Prasalovich, Dept. of Experimental Physics, School of Physics and Engineering Physics, Göteborg University and Chalmers, 41296 Göteborg, Sweden
 Energetic cluster ion impact has been shown to be an interesting alternative to atomic ion implantation for a number of reasons. In particular it is possible to reduce the impact energy considerably without having problems associated with space charging since much more dopant atoms are associated with one positive charge. Also the implantation dynamics are different with strong non-linear processes occurring on impact. This serves to reduce the implantation range and to provide a means of controllably modifying surfaces within a range of a very few nanometres. In this contribution we present a new apparatus designed to study the effects of energetic cluster ion bombardment of surfaces. We will present results involving cluster ions from gaseous precursors (argon, oxygen, nitrogen) impacting on surfaces such as graphite, silicon and quartz. Interesting nanohillocks are formed from this cluster impact at energies of a few kV per cluster. The formation of these nanohillocks will be discussed and model scenarios presented. The dependence of the structure formation on cluster size and composition as well as impact energy will be presented and discussed.
- E-II.3** 11:30 **THICK ELEVATION OF SILICON ON PATTERNED STRUCTURE USING ION IMPLANTATION INDUCED SELECTIVE ETCHING**
M.O. Huda and K. Sakamoto, Nanoelectronics Research Institute, National Institute of Advanced Industrial Science and Technology, Central 2, 1-1-1 Umezono, Tsukuba 305-8568, Japan
 Elevation of silicon on patterned SiO₂/Si structure has been achieved by non-selective epitaxial growth followed by ion implantation induced selective etching. 100 nm thick epitaxial layer was grown on patterned structures by a conventional Low Pressure Chemical Vapor Deposition (LPCVD) system at 700 °C. As grown polysilicon layer on the oxide region, as well as the epitaxial silicon layer showed small etching rates in a solution of HF: HNO₃: CH₃COOH. The etching selectivity was achieved by an Argon implantation at 140 keV with a dose of 2x10¹⁴/cm². Implantation orientation was aligned in vertical <100> channeling direction to keep damage in the epitaxial silicon region in a minimum level. Damage in polysilicon layers due to the implantation was found to be strong with consequent enhance in the etching rate. A short annealing at 420 °C was used for damage recovery of the epitaxial silicon. Damage in poly-silicon layer, on the other hand, showed only a small recovery by the same annealing. The annealed layers of poly-silicon and silicon showed etching rates of 20 nm/min and 1 nm/min respectively. The selectivity over an order of magnitude was used to etch the poly-silicon layers, leaving the elevated silicon region unaffected. Pattern edges, representing gate sidewalls in CMOS devices, showed no sign of residual poly-silicon. Our approach of silicon elevation does not depend on isolation/sidewall materials, and is not bound by thickness limits, or faceting effects.
- E-II.4** 11:45 **ION ENERGY AND POLARITY DEPENDENT SPUTTERING INDUCED ALTERATION OF 6H-SiC{0001} SURFACE**
M. Menyhard, A. Ster, A. Sulyok, G.Zsolt, Research Institute for Technical Physics and Materials Science, Budapest, 1525 P.O.Box 49, Hungary
 Recently we have found that the steady state surface compositions (measured by AES) of the polar faces of 6H-SiC {0001} are different if the energy of various sputtering ions is lower (depending on the projectile) than some threshold value [1].
 To avoid the problem connected to the changes of the Auger peak shapes due to the changing atomic binding, the experiment was repeated by applying elastic peak electron spectroscopy (EPES). The backscattering intensity does not depend on the chemical binding and thus EPES allows a more quantitative determination of the altered layer chemistry. The dependencies observed by EPES were similar to those detected by AES. The concentrations determined by EPES are compared with results of crystal TRIM simulations. Reflected electron energy loss spectra (REELS) were also measured. It turns out that the energy of the bulk loss depends on the sputtering energy and different for the polar faces. This later finding will be explained by the different electronic structure of the surface close region of the polar faces formed during ion sputtering. It will be shown that this steady state condition of the surface does not depend on the prehistory of the sample (oxidized, mixed by ions of high energy etc.) provided that the layer produced by those processes are removed. I. G. Battistig, J.L. Lábár, S. Gurbán, M. Menyhard, A. Sulyok, I. Vickridge, E. Szilagyí, J. Malherbe, Q. Odendaal, Sur. Sci. Lett. in print
- 12:00 **LUNCH**

Tuesday, June 10, 2003
Mardi 10 juin 2003

Afternoon
Après-midi

E-III.1 14:00 -Invited-

ION-BEAM INDUCED DEFECTS AND NANOSCALE AMORPHOUS CLUSTERS IN SILICON CARBIDE

William J. Weber and Fei Gao, Pacific Northwest National Laboratory, P.O. Box 999, Richland WA 9352, USA

Atomic-level simulations have been employed to study the defects and nanoscale disordering induced in 3C-SiC by Si and Au ions with energies up to 50 keV. Energetic Si ions primarily produce interstitials, vacancies, antisite defects, and small defect clusters directly during the collision cascade. The overlap of Si cascades produces nanoscale disordered clusters. In the case of energetic Au ions, topologically disordered nanoscale domains are produced directly within the Au cascade along with point defects and smaller clusters. In about 25% of the 50 keV Au cascades, one or more of the nanoscale clusters produced in the subcascades exhibit a structure that is consistent with an amorphous state. Structural image simulations of the Si and Au induced damage states are used to obtain atomic-level insights into the interpretation of experimental high-resolution TEM images. Additional simulations on self-interstitial diffusion in SiC provide insights into controlling the formation and growth of nanoscale disorder in SiC. These simulations indicate that it is possible to fabricate nanoscale disordered domains with uniquely different properties in SiC using the ion-beam-induced order-disorder transformation.

E-III.2 14:30

EFFECT OF SUBSTRATE ORIENTATION ON DEFECT GENERATION AND ANNEALING BEHAVIOUR IN CARBON IMPLANTED SILICON

M. Häberlen, J.K.N. Lindner, B. Stritzker, Universität Augsburg, Institut für Physik, Universitätsstrasse 1, 86135 Augsburg, Germany

Amorphization of semiconductors, in which the amorphous phase has a significantly reduced atomic density compared to the crystalline state, is frequently observed to be accompanied by the formation of a self-organized crystalline/amorphous lamella structure on the nanometer-scale. For example, 180 keV high-dose carbon implantation at temperatures between 150°C and 250°C into (100)-oriented silicon has been shown to result in the formation of a buried amorphous layer covered with a crystalline Si top layer containing a self-organized array of nanometric, amorphous SiC_x inclusions. Depending on the implantation temperature the c-Si top layer above predominantly contains point defects (Ti=150°C) or dislocations on {111} planes (Ti>150°C). In this presentation it is shown by cross-sectional TEM (XTEM) that self-organized structures of amorphous SiC_x inclusions can also be observed after implantation into (111)-oriented wafers. In contrast to (100)-oriented samples dislocations are observed by XTEM and RBS channelling at temperatures as low as 150°C indicating different stress relief mechanisms in the different substrates. Annealing experiments near the crystallization temperature of a-Si:C show further effects of the substrate orientation: Whereas crystallization of SiC is negligible in (100)-oriented samples, annealing of {111} samples leads to the formation of two textured bands of polycrystalline SiC within the buried amorphous layer.

E-III.3 14:45

ATOMISTIC MODELING OF ION BEAM INDUCED AMORPHIZATION IN SILICON

Lourdes Pelaz, Luis A. Marques, Maria Aboy, Juan Barbolla Dept. Electronics, University of Valladolid, Spain

The low implant energies and high doses required for the fabrication of nanoscale electronic devices leads to the amorphization of the near surface area. Pre-amorphizing implants are also carried out to achieve electrical activation of dopants at lower temperature. Therefore, it is essential to develop ion beam induced amorphization models, compatible with process simulators, which are able to capture the features of the crystal-amorphous transition. We have developed an atomistic model that extends the atomistic approach to the modeling of amorphous pockets and continuous amorphous layers. The model is based on the so called bond defect or interstitial-vacancy pair, which is a local distortion of the lattice without any excess or deficit of atoms. This defect alone is not stable at room temperature. However, agglomerates of bond-defects or amorphous pockets are formed during ion beam irradiation. These amorphous pockets or extended areas of disorder surrounded by crystalline Si start the recrystallization by the interfaces in contact with more crystalline material. The larger the number of surrounding crystalline atoms the faster the recrystallization. As we will show, the fact that the stability of amorphous pockets increases with the presence of surrounding amorphous material explains the cooperative nature of the amorphization process and the critical nature of amorphous/crystalline transition.

E-IV.1 15:00 -Invited-

ION BEAM INDUCED DEFECTS IN CRYSTALLINE SILICON

F. Cristiano, N. Cherkashin, B. de Mauduit, E. Scheid, A. Claverie, Pôle Implantation Ionique CEMES/LAAS-CNRS, 7 av. Col. Roche, 31077 Toulouse, France and B. Colombeau, University of Surrey, Guildford, U.K.

Extended defects in ion implanted silicon result from the precipitation of the large amounts of interstitials and vacancies generated during the implantation process. The interactions between the defects and the implanted dopants are at the origin of the diffusion and activation anomalies which are among the major obstacles to the realisation of future generation devices. The work presented in this paper addresses the crucial issues of the understanding and the physical modelling of defect evolution during annealing and provides a unified picture explaining their formation under different experimental conditions.

In the first part, we will recall the structure of the various types of defects and present an extensive TEM study of their thermal behaviour. We will show that all these defects grow following an Ostwald ripening process whereby they exchange Si atoms and evolve in size and type to minimise their formation energy. This mechanism is at the basis of the model that we have developed to predict the defects formation and evolution during annealing. Some applications to a variety of experimental conditions will be presented, including the case of ultra low implantation energies. In the last part we will focus on some recent experiments on the structure and the kinetics of small cluster defects generated after ultra low energy, high dose Boron implantation. These clusters are known to prevent the full electrical activation of Boron in low dimensional CMOS devices. We will show that they are of the Boron-Interstitial type and that, similarly to the defects formed after lower implantation doses, they also evolve following an Ostwald ripening mechanism.

E-IV.2 15:30

THE LASER ANNEALING INDUCED PHASE TRANSITION IN SILICON: A MOLECULAR DYNAMICS STUDY

Luis A. Marqués, L. Pelaz, M. Aboy and J. Barbolla, Universidad de Valladolid, E.T.S.I., 47011 Valladolid, Spain

Ion implantation and a subsequent thermal annealing is the standard procedure to fabricate shallow junctions in silicon. However, as the device sizes shrink, this method shows several drawbacks regarding the dopants, such as transient enhanced diffusion, channeling and deactivation. Recently it has been shown that implantation of the dopant in pre-amorphized silicon, followed by laser annealing, can produce very shallow junctions without the inconveniences cited. These promising results indicate that this technique could be used to fabricate ultra shallow junctions and meet the downscaling industry requirements. During the laser annealing stage the silicon sample overcomes a phase transition from amorphous to liquid. The changes in the properties of silicon as a consequence of the phase transition could influence the subsequent recrystallization and thus the activation of the dopants. In this work we have used the molecular dynamics simulation technique to study the physics of the amorphous-to-liquid transition in silicon. The changes in density, internal energy and diffusion behavior suggest that it is second order. We show as well that for temperatures between the amorphous and crystal melting points there exists an intermediate phase which shares some of the properties of the amorphous and liquid silicon.

E-IV.3 15:45

THE INFLUENCE OF OXYGEN ON THE THERMAL EPITAXY OF Rb-ION AMORPHISED QUARTZ

S. Gasiorek(a,b), S. Dhar(a), K. P. Lieb(a), T. Savajaara(c), J. Keinonen(c), (a)II. Physikalisches Institut, Universität Göttingen, Bunsenstr. 7-9, 37073 Göttingen, Germany, (b)The Henryk Niewodniczanski Institute of Nuclear Physics, ul. Radzikowskiego, 31-342 Krakow, Poland, (c)Accelerator Laboratory, University of Helsinki, 00014 Helsinki, Finland

The Solid Phase Epitaxial Growth (SPEG) of 175 keV Rb-ion-irradiated quartz was studied during thermal annealing in an ^{18}O atmosphere up to 1170 K. In an attempt to optimize the SPEG process, the influence of the gas pressure and annealing time was investigated. The evolution of the damage in the matrix and the Rb depth profile was examined via Channeling Rutherford backscattering spectroscopy (RBS-C). The role of the ^{18}O - ^{16}O exchange between the annealing gas and the matrix was monitored via time-of-flight elastic recoil detection analysis (TOF-ERDA). The recrystallisation rate was found to increase for increasing annealing time and to depend strongly on the oxygen pressure. The observed planar epitaxy of the amorphised SiO_2 , the ^{18}O - ^{16}O exchange and the out-diffusion of the implanted Rb are highly correlated and explained in terms of the SiO_2 -network topology. The new data will be compared with those previously obtained after Li-, Na- and Cs-ion implantations in quartz [1,2].

[1] F. Roccaforte, F. Harbsmeier, S. Dhar, K. P. Lieb, Appl. Phys. Lett. 76 (2000) 3709.

[2] F. Roccaforte, W. Bolse, K. P. Lieb, J. Appl. Phys. 89 (2001) 3611.

BREAK

- E-V.1** 16:30 -Invited- **DAMAGE ACCUMULATION AND DOPANT MIGRATION IN LOW DOSE SHALLOW As AND Sb IMPLANTATION INTO Si**
M. Werner, **J.A. van den Berg**, D.G. Armour, Joule Physics Laboratory, Institute of Materials Research, University of Salford, Salford, M5 4WT, U.K., W. Vandervorst, IMEC, 3001 Leuven, Belgium, E.H.J. Collart and R.D. Goldberg, Applied Materials, Horsham, W Sussex, RH13 5PX, U.K., P. Bailey and T.C.Q. Noakes, CLRC Daresbury Laboratory, Daresbury, WA4 4A, U.K.
The damage evolution and concomitant dopant redistribution as a function of ion fluence during ultra shallow, heavy ion implants has been investigated using medium energy ion scattering (MEIS) and secondary ion mass spectrometry (SIMS). These studies involved As and Sb implanted into Si at room temperature, at energies between 2 and 5 keV to doses from $3 \times 10^{13} \text{ cm}^{-2}$ to $1 \times 10^{16} \text{ cm}^{-2}$. MEIS is capable of detecting both the displaced atom and implant profiles with sub nano-metre depth resolution. These studies show that for doses up to $1 \times 10^{14} \text{ cm}^{-2}$ (sufficient to produce an amorphous layer) the damage build up does not follow the energy deposition function, but proceeds through the initial formation of a $\sim 4 \text{ nm}$ wide amorphous layer immediately under, that grows inwards into the bulk with increasing dose. A mechanism that takes account of the closely overlapping vacancy and interstitial distributions (as shown by TRIM) and involves point defect accumulation at the surface / oxide sink is discussed. Although for doses $\sim 4 \times 10^{14} \text{ cm}^{-2}$ the As depth profiles agreed well with TRIM calculations, for lower doses As was observed to have a narrower profile, nearer to the surface. This behaviour is ascribed to dopant movement towards the near surface amorphous layer (probably mediated by point defect migration) in which the larger dopant appears more easily accommodated. Comparative MEIS studies of preamorphised Si confirmed these observations. The dose dependence of the damage and implant profiles of Sb implants which showed a similar behaviour will also be presented.
- E-V.2** 17:00 **THE INFLUENCE OF ION BEAM ENERGY ON THIN FILM GROWTH: Co ON Si(111)**
Koen Vanormelingen, Bart Degroote, Hugo Pattyn and André Vantomme, Katholieke Universiteit Leuven, IKS, Celestijnenlaan 200D, 3001 Leuven, Belgium
Properties of thin films often depend on the deposition method used. Frequently this dependence is due to a difference in the energy of the deposited atoms, e.g. Chemical Vapor Deposition (absorption), Molecular Beam Epitaxy (10-100 meV) or sputtering (10 eV). We studied the energy dependence systematically, with special interest in the initial layer growth. We compared the growth of an ultra-thin Co film on a Si(111) substrate for two techniques: Low Energy Ion Deposition (LEID) and MBE. In LEID, an isotopically pure ion beam with energy of 50 keV is produced. This beam can be decelerated in an electrostatic lens to well defined energies between 0 and 200 eV. Prior to Co deposition, the samples were cleaned with a two-step silicon flux method to achieve the Si(111) 7×7 reconstruction. After deposition the samples were transported through vacuum to an in situ scanning tunneling microscope. For low coverage ($\sim 0.3 \text{ ML}$) we observe that the periodicity of the 7×7 structure degrades with increasing deposition energy. These early stages of the layer formation are expected to influence the growth of thicker films. For higher coverage ($\sim 2 \text{ ML}$) we investigated the influence of the deposition energy on the island density on the surface. Depositions with LEID show a higher cluster density and a lower surface roughness compared to MBE depositions, where the size of the clusters is of the order of half the size of a 7×7 unit cell. Plausible explanations for this behavior will be discussed.
- E-V.3** 17:15 **NITROGEN DISTRIBUTION DURING OXIDATION OF LOW AND MEDIUM ENERGY NITROGEN IMPLANTED SILICON**
D. Skarlatos(a), C. Tsamis(a) and D. Tsoukalas(a,b), M. Fanciulli(c), M.Perego(c) and S. Ferrari(c), (a)Institute of Microelectronics, NCSR 'Demokritos', 15310 Aghia Paraskevi, Greece, (b)Faculty of Applied Mathematical and Physical Sciences, National Technical University of Athens, 157 80 Athens, Greece, (c)INFN-Laboratorio MDM, Via Olivetti2, 20041 Agrate Brianza (Milano), Italy
As the dimensions of modern electron devices decrease the need for even thinner and good quality gate dielectrics becomes more demanding. One of the methods developed during the last years is the oxidation of nitrogen - implanted silicon, which reduces the oxidation rate increasing in parallel the reliability of the resulting oxides. On the other hand a great disadvantage of the method is the formation of extended defects in the silicon substrate. We performed a systematic study of the influence of nitrogen implantation energy on oxide growth in order to achieve ultra thin oxides on extended defect - free silicon substrates. Nitrogen was implanted in a wide range of energies (3-150 keV) and oxidations were performed at a variety of temperatures (800 - 900 $^{\circ}\text{C}$) and time intervals. We observed that the reduction of the oxidation rate decreases as the implantation energy decreases and nitrogen is implanted closer to the silicon surface. The greater difference in oxide growth is observed between the 3 and 25 KeV nitrogen implants. Responsible for the above phenomenon is nitrogen out-diffusion, which is more effective as nitrogen has been placed closer to the surface. SIMS analysis was performed in order to reveal the final distribution and the remaining concentration of nitrogen at the SiO_2/Si interface and the silicon substrate. On the other hand we observed that very low energy nitrogen implantation offers the advantage of the full absence of extended defects in the silicon substrate, a key point for modern device performance. Combination of the above results can give us a process "window" for industrial applications.

beta-SiC HETERO EPILAYER WITH SMOOTH SURFACES FORMED USING
HYPERTHERMAL IONS: A LOW TEMPERATURE EPITAXY PROCESS

N. Tsubouchi, A. Chayahara, Y. Mokuno, A. Kinomura, Y. Horino, National Institute of Advanced Industrial Science and Technology, Laboratory of Purified Materials, 1-8-31 Midorigaoka, Ikeda, 563-8577 Osaka, Japan

We aim to develop a method for lower temperature epilayer formation using hyperthermal particles, in order to produce beta-SiC hetero-epilayers with a smooth surface and high quality compared to conventional methods, e.g., MBE and CVD.

beta-SiC is an important candidate material for achieving high-temperature, high-frequency, high-power as well as radiation-hard transistors. So far, ~0.1 eV thermal species have been mainly employed for beta-SiC epilayer formation on MBE and CVD. A nearly equilibrium growth process with such species requires high epitaxial growth temperatures, e.g., 1000°C. Such high temperatures, however, induce high activity of atom migration on surfaces, resulting in surface roughness. Furthermore, high temperature growth processes are not suitable for electric device production. In this paper, we present an approach for heteroepitaxial beta-SiC growth on Si(100) by means of mass-separated hyperthermal ions; step growth consisting of carbonization as a first step using only 60 eV CH₃⁺ beam and subsequent SiC layer formation as a second step using both 50-60 eV C⁺ and Si⁻ ion beams, has been carried out. The process temperature, ~670°C of both carbonization and SiC epilayer formation is quite lower than that in CVD and MBE with nearly equilibrium processes, resulting in surface smoothness of the grown beta-SiC epilayers, i.e., RMS<0.4 nm. Such lower growth temperature probably ascribes to a far equilibrium and subplantation film growth process provided by hyperthermal species.

N. Tsubouchi et al., Appl. Phys. Lett. 77(2000)654. N. Tsubouchi et al., J. Vac. Sci. Technol. A19(2001)1882. N. Tsubouchi et al., Jpn. J. Appl. Phys. 41(2002)7353.

Wednesday, June 11, 2003
Mercredi 11 juin 2003

Afternoon
Après-midi

E-VI.1 14:00 -Invited-

Si SELF-INTERSTITIAL DIFFUSION AND CLUSTERING WITH IMPURITIES IN CRYSTALLINE SILICON

S. Mirabella, F. Giannazzo, A. Terrasi, F. Priolo, INFN and Dipartimento di Fisica e Astronomia, Università di Catania, via S. Sofia 64, 95123 Catania, Italy, V. Raineri, CNR-IMM Sezione Catania, Stradale Primosole 50, 95121 Catania, Italy, D. De Salvador, E. Napolitani, G. Bisognin, M. Berti, A. Camera, A.V. Drigo, INFN and Dipartimento di Fisica, Università di Padova, Via Marzolo 8, 35131 Padova, Italy

In this work the diffusion of ion beam injected self-interstitials (I) and their interaction with impurities in crystalline Si are presented. In particular, the I penetration into a molecular beam epitaxy (MBE) grown Si structure was studied by means of diffusion effects induced on B spikes, analyzed by a developed simulation code. Trapping effects at sample- surface and bulk are evidenced and modeled. Moreover, the B markers approach was extended to the two dimensional I (2D) diffusion occurring as a consequence of I ion beam injected through a sub-micron dimension oxide mask. I source- size effects on the I penetration depth have been found and modeled and a quantitative description of the 2D I- evolution has been obtained. The I-substitutional carbon (C) interactions have been also studied, showing the C ability to retain a certain amount of I into small C-I precipitates. The I- trapping mechanism was quantitatively studied by the simulation code, showing that one I is able to deactivate about two C traps by means of I- trapping and C- clustering reactions. Finally, the interaction between I and B leading to the B precipitation into small B-I clusters (BIC) has been experimentally investigated. The dissolution kinetics of BIC was studied in detail at different temperatures, directly using experimental concentration profiles and an opportunely developed diffusion simulation code. The activation energy for BIC dissolution and the BIC stoichiometry are extracted and given.

E-VI.2 14:30

DEPTH DEPENDENCE OF DEFECT EVOLUTION AND TED DURING ANNEALING

Benjamin Colombeau(a), Nick Cowern(a), Younes Lamrani(b), Pascal Calvo(b), Alain Clavier(b), Evelyne Lampin(c) and Fuccio Cristiano(b), (a)Advanced Technology Institute, University of Surrey, Guildford GU2 7XH, U.K., (b)Ion implantation group, CEMES-LAAS, Toulouse, France, (c)IEMN-Dpt. ISEN, BP 69, 59652 Villeneuve d'Ascq cedex, France

A key issue in Transient Enhanced Diffusion (TED) modelling and simulation is the way in which extended defects evolve and dissipate due to the loss of the self-interstitial atoms which they contain. Self-interstitials are lost from extended defects by emission of single interstitial atoms and their subsequent diffusion to other defects (Ostwald ripening) or to the silicon surface (dissolution). However, two important issues remain unclear. It is not accurately known how the depth distribution of defects in the defect band evolves with time, and how it relates to the source of interstitials during TED. To this purpose, Si implants at two different energies and doses were performed into Si substrate containing B marker layers epitaxially grown by CVD. After implantation the samples were annealed in nitrogen gas using furnace and/or rapid thermal annealing for various times/temperatures. Defect evolution was investigated using plan-view and cross section TEM. B profiles were measured by SIMS. TEM analysis for the highest energy/dose shows that {113} defects evolve into dislocation loops whilst the defect depth distribution remains unchanged as a function of annealing time. For the lowest energy/dose, {113} defects evolve and dissolve while the defect band shrinks preferentially on the surface side. At the same time, extraction of boron TED as a function of defect depth shows a decrease of the supersaturation towards the surface, starting at the location of the defect band. The study clearly shows that in these systems the defect source coincides with the defect band and the principal sink for interstitials is the silicon surface. The results provide reliable data and physical parameters, which will allow the improvement of physical models of defect evolution and TED.

E-VI.3 14:45

COUPLING OF ATOM BY ATOM CALCULATIONS OF EXTENDED DEFECTS WITH B KICK-OUT EQUATIONS: APPLICATION TO THE SIMULATION OF BORON TED

E. Lampin, IEMN, Av. Poincaré, 59652 Villeneuve d'Ascq, France, F. Cristiano, Y. Lamrani, Ion implantation group, CEMES-LAAS, Toulouse, France, B. Colombeau, Univ. Surrey, Guildford, Surrey GU2 7XH, U.K.

The diffusion of boron is intimately linked to the Si interstitials (Si(int)s) by the kick-out mechanism. When extended defects form in the ultra shallow junction technologies, the Si(int)s behave differently and thus boron transient enhanced diffusion (TED) is observed. The extended defects nucleate and grow from a supersaturation of Si(int)s. As they grow, their geometry evolves from clusters to {311} to dislocation loops. This evolution requires a description atom by atom of the distribution of extended defects : $(n)Si + Si(int) \ll (n+1)Si$.

We present a coupling of an atom by atom calculation of the evolution of extended defects with the B kick-out equations implemented in a standard process simulator (IMPACT). The coupling is made through the transfer of the free Si(int)s supersaturation. The simulations are applied to an experiment of B delta doped layers. The comparison with SIMS of the B profiles for several annealing times shows a very good agreement. The overall strategy for simulating B TED is therefore validated.

- E-VII.1** 15:00
MODULATION OF THE ELECTRONIC TRANSITIONS OF SILICON LIGHT-EMITTING DIODES PRODUCED BY BORON IMPLANTATION
J.M. Sun, T. Dekorsy, W. Skorupa, B. Schmidt, A. Mücklich and M. Helm, Forschungszentrum Rossendorf e.V., Institut für Ionenstrahlphysik und Materialforschung, P.O. Box 510119, 01314 Dresden, Germany
 Two asymmetric electroluminescence bands with tunable maxima at around 1.044-1.065 and 0.90-1.00 eV are observed at low temperature in silicon pn diodes prepared by boron ion implantation and subsequent high temperature annealing. The intensity of the two bands increases strongly with increasing the boron concentration above the solubility. A large blue shift of the two bands with increasing the injection carrier concentration was attributed to the three-dimensional confinement of holes in p-type δ -doped spikes localized on a nanometer scale. They are produced by the boron clustering at the end of range defects close to the pn junction. The two bands with a smaller binding energy is attributed to the spatially indirect recombination of the excitons confined around the strain-free p-type δ -doping spike. The band with a higher binding energy is associated with highly strained p-type δ -doping spikes around dislocations. A significant enhancement of the room temperature electroluminescence efficiency of the silicon diode is observed which is attributed to the spatial modulation of the band structure around these p-type δ -doped spikes.
- E-VII.2** 15:15
ATOMISTIC ANALYSIS OF THE ION BEAM INDUCED DEFECT EVOLUTION
Maria Aboy, Lourdes Pelaz, Luis A. Marqués and Juan Barbolla, University of Valladolid, Electricidad y Electronica, Campus Miguel Delibes, Valladolid, Spain
 Kinetic Monte Carlo simulations are used to analyze the role of surface in {311} defect dissolution, and its influence on transient enhanced diffusion of dopants in silicon. The ripening and dissolution of {311} defects is studied in terms of the probabilities of emitted interstitials being recaptured by other defects or in turn, being annihilated at the surface. These two probabilities are related to the average distance among defects and their distance to the surface, respectively. In the model the surface is considered as a perfect sink for point defects. We show that this is compatible with experiments, which indicate that during a period of time interstitials are mostly exchanged among defects, with a minimal loss to the surface. Only when defects grow to larger sizes and their concentration decreases, the loss of Si interstitials through diffusion to the surface prevails, causing their dissolution. The presence of large and stable defects near the surface is also possible in low energy implants if the dose is high enough. Transient enhanced diffusion of dopants occurs in the presence of a supersaturation of Si self-interstitials, which are available during both ripening and dissolution of defects. Therefore the correlation between the duration of the anomalous diffusion and the dissolution of defects must take into account the ripening stage of defects. In all cases, the dissolution time of interstitial clusters and the time constant of the TED are clearly correlated.
- E-VII.3** 15:30
ANNEALING BEHAVIOR OF HIGH TEMPERATURE IMPLANTED Fe IMPURITIES IN n-InP
T. Cesca and A. Gasparotto, INFN and University of Padova, Physics Dept., Via F. Marzolo 8, 35131 Padova, Italy, B. Fraboni, INFN and University of Bologna, Physics Dept., V.le Bertoni-Pichat 6/2, 40137 Bologna, Italy, F. Priolo, INFN and University of Catania, Physics Dept., Corso Italia 57, 95129 Catania, Italy
 The introduction of active Fe impurities in InP is of technological importance for both electrical (n+-to-semi-insulating conversion to create current blocking layers in high-speed devices) and optical (mid-IR luminescence due to Fe-related intracenter d-shell transitions) applications. In both cases, high concentrations of Fe atoms have to occupy substitutional positions in the InP lattice. Thanks to its non-equilibrium character, high temperature ion implantation is the suitable incorporation technique: by this method, indeed, we recently demonstrated that it is possible to introduce active Fe concentrations well above the Fe solubility limit in InP, with a limited damage production. Nonetheless, several important questions remain to be addressed, mainly concerning the mechanisms leading to the final location of the Fe atoms after the implant and the annealing treatments, and the interaction of Fe with the host-atoms and the implant-induced defects. In this work we present a phenomenological model developed to describe the temperature evolution of the Fe incorporation in high-symmetry sites of the InP lattice; the measurements are performed by means of the PIXE-channeling technique. The model takes into account the thermal vibrations and the Fermi-level and allows to evaluate the activation energy for the escape process of Fe atoms from high-symmetry sites towards low-symmetry positions. The connection with other structural and electrical results will be also discussed.

E-VII.4 15:45

ANNEALING OF BaTiO₃ THIN FILMS AFTER HEAVY ION IMPLANTATION

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Single crystalline BaTiO₃ films have been grown by pulsed laser deposition on SrTiO₃. Radioactive ¹¹¹In ions were implanted with energies of 60 keV and 400 keV, resp. The lattice site of ¹¹¹In has been determined by emission channeling of conversion electrons emitted after the nuclear decay to ¹¹¹Cd. Besides a large random fraction, 10 % of the events show that In substitutes Ti-sites directly after the implantation. The recovery of the lattice after the implantation has been monitored in the direct vicinity of the probes by perturbed angular correlation spectroscopy (PAC) in a wide temperature range. After annealing in air at a temperature of 1350 K for 10 min, PAC spectroscopy yields a unique electric field gradient at the site of the ¹¹¹In(¹¹¹Cd)-probe with a quadrupole coupling constant of 30.0(2) MHz and a frequency distribution with a width of 4.1(2) MHz. The film starts to degrade at a temperature of 1520 K. SEM and EDX investigations are used to monitor the degradation.

This work has been supported by the BMBF (05 KK1TSA/7) and FCT (CERN-FIS-43725-2001).

16:00

BREAK

16:15-19:00

POSTER SESSION I

E/PI.01

NANOCRYSTALLINE PARTICLES OF ZnTe FORMED BY ION IMPLANTATION IN SiO₂ ON SILICON

R. Chemam, Laboratoire LPR, Département de Physique, Faculté des Sciences, Université de Annaba, BP 12 Annaba 23000, Algérie, A. Bouabellou, Laboratoire Couches Minces et Interfaces, Université Mentouri de Constantine, 25000, Algérie, J.J. Grob, D. Muller, Laboratoire PHASE (UPR 292 du CNRS), 23 rue du Loess, 67037 Strasbourg Cedex 2, France and G. Schmerber, Institut de Physique et de Chimie des Matériaux de Strasbourg, laboratoire GEMME, 23 rue du Loess, 67037 Strasbourg Cedex 2, France

Ion implantation is a very simple and suitable way to form nanometric precipitates in materials compatible with the silicon technology. The successive high dose (3-5x10¹⁶/cm²) implantations of tellurium and zinc ions have been performed in a 250 nm thick SiO₂ layer thermally grown on <111> silicon. Their respective energies (180 and 104 keV) have been chosen to produce 5 to 10 at.% profiles overlapping at a mean depth of about 80 nm. Subsequent thermal treatments (800 to 1100 °C) lead to the formation of nanometric precipitates of the compound semiconductor ZnTe. Their size, crystalline structure and depth distribution have been studied as a function of annealing temperature using X-ray diffraction, Transmission Electron Microscopy and Rutherford Backscattering Spectrometry. For the highest temperatures, the nanoparticles progressively redistribute in two bands located close to the surface and the interface. Their mean diameter is then about 30 nm.

E/PI.02

CO AND DY FOCUSED ION BEAM IMPLANTATION IN GaAs

A. Melnikov, S. Gök, S. Ünlübayir, P. Schafmeister, R. Wernhardt, D. Tichonov*, K. Westerholt*, D. Reuter, and A.D. Wieck, Angewandte Festkörperphysik, Festkörperphysik*, Ruhr-Universität Bochum, Universitätsstrasse 150, 44780 Bochum, Germany

Focused ion beam (FIB) implantation of Co and Dy in GaAs (100) with energies of 100 and 200 keV employing a range from 1E14 to 2E17 cm⁻² was investigated. AuSiDy and CoDy liquid alloy ion sources were developed to perform Co and Dy ion implantation. After implantation, a rapid thermal annealing step in forming gas atmosphere at temperatures from 700 to 830 °C was performed. Implanted regions with different sizes down to 0.3µm were investigated by atomic force microscopy (AFM) and raster electron microscopy before and after annealing. For both types of ions, formation of nanoscale precipitates was detected after annealing. The size of the precipitates depends on the dose and the annealing conditions and can reach 300 nm. For Co implantation, the composition of the clusters could be determined to CoAs. At implantation doses higher than 8E15 cm⁻², GaAs sputtering is detected. It is shown that it is possible to control the number of the clusters by decreasing the size of the implanted region. Magnetic characterization by superconducting quantum interference device reveals room-temperature ferromagnetism in implanted and annealed GaAs. Potentials for fabrication of nanoscale elements for spinelectronic with the FIB implantation of magnetic ions are discussed.

E/PI.03

FORMATION OF Cd AND CdSe NANOCCLUSERS IN MgO BY ION BEAM SYNTHESIS

M.A. van Huijs, A. van Veen, H. Schut and S.W.H. Eijt, Interfaculty Reactor Institute, Delft University of Technology, The Netherlands

CdSe nanoclusters are created in MgO by means of co-implantation of 280 keV, 1E16 Cd ions cm⁻² and 210 keV, 1E16 Se ions cm⁻² in single crystals of MgO(001) and subsequent thermal annealing. Other MgO crystals are implanted with Cd only in order to create Cd nanoclusters. Optical absorption spectroscopy and Doppler broadening positron beam analysis are employed to follow nanocluster formation and defect evolution during thermal annealing. The structural properties and the orientation relationship between the CdSe and the MgO are investigated using cross-sectional transmission electron microscopy (XTEM).

- E/PI.04** STRUCTURAL CHARACTERIZATION OF MgO CRYSTALS IMPLANTED WITH TRANSITION METALS
J.V. Pinto(a), B. Fernandes(b), E. Alves(a,c) ,R.C. da Silva(a,c), (a) Dep. Física, ITN, E.N. 10, 2686-953 Sacavém, Portugal, (b)CENIMAT, Quinta da Torre, Monte da Caparica, 2829-516 Caparica, Portugal, (c)CFNUL, Av. Prof. Gama Pinto 3, 1649-003 Lisboa, Portugal
 Colloidal dispersion of metallic precipitates is known to produce important modifications of some physical properties of insulators. Selective absorption of radiation and data storage are examples of applications permitted by the presence of colloids in ionic crystals.
 In this work we have implanted MgO single crystals with Cobalt, Nickel and Copper at different energies in order to study their lattice site location and interactions with defects in the host, as a function of annealing temperatures. Cobalt, Nickel and Copper preferred charge states are isoelectronic of Magnesium, and yet they behave quite differently. Apparently Co segregates to the surface with increasing annealing temperature and shows no orientation correlation with the MgO structure. On the other hand, RBS-channeling measurements indicate that Ni and Cu form structures with some degree of alignment with the host. For the Ni implanted MgO data shows that this correlation is not affected by the annealing treatments while for Cu, increasing the annealing temperature leads to an enhancement of channeling. The RBS-channeling results are presented in comparison with X-Ray diffraction data in order to clarify the formation and evolution of the metallic precipitates, and compare with MgO crystals doped with the same ions during growth.
- E/PI.05** NUCLEATION OF NANOCLUSTERS IN COBALT-IMPLANTED SILICON: MODELING OF IN-SITU TRANSMISSION ELECTRON MICROSCOPY OBSERVATIONS
V.A. Borodin, RRC Kurchatov Institute, 123182 Moscow, Russia, M.-O. Ruault and H. Bernas, CSNSM, Univ. Paris-Sud, bat. 108, 91405, Orsay, France
 Precipitation of impurity clusters is an important stage ion beam surface modification. When clusters nucleate under implantation, new clusters appear while clusters formed earlier grow simultaneously. The post-nucleation cluster size distribution must be taken into account in rationalizing the experimental observations.
 We present an analytical model of impurity clustering for the case where the critical size of clusters is very small (for our case of CoSi₂ precipitation in Co-implanted silicon the critical size constitutes only 3-4 cobalt atoms). The model is formulated in terms of time-dependent kinetic equations describing both direct encounters of freely migrating cobalt atoms and monomer capture by clusters. We describe cluster evolution both at the cluster nucleation and growth stages. This is crucial for adequate comparison to experimental data: in-situ transmission electron microscopy only tracks particles larger than 1.5-2 nm, so clusters become visible well after the nucleation stage is over. The model describes the visible cluster kinetics in experiments on CoSi₂ precipitation at different fluxes and temperatures, and explains dependence of the cluster density on implantation parameters. At high implantation doses, the analytical results are compared to the full measured cluster size distribution. Compared to usual approaches in terms of average cluster size kinetics, our work provides more detailed information about the laws of cluster growth.
- E/PI.06** FABRICATION OF n-ZnO/p-Si PHOTODIODES FULLY ISOLATED BY ION-IMPLANTATIONS
C.H. Park, I.S. Jeong, H.S. Bae and S. Im, Institute of Physics and Applied Physics, Yonsei University, 134 Shinchon-dong, Seodaemooon-gu, Seoul 120-749, Korea
 We report on the fabrication of a new heterojunction photodiode for the visible range that consists of a transparent insulating ZnO overlayer and a transparent semiconducting n-ZnO layer on p-Si. For device isolation we implanted B⁺, O⁺, and Si⁺ ions into the n-ZnO layer with varying doses. We have obtained wide-range spectral responsivity and quantum efficiency curves for our isolated photodiodes. They exhibited an efficiency drop at 380 nm near ultra-violet because the ZnO layers absorbed the photons of higher energy before they would reach p-Si. The ion-beam-induced isolation considerably reduced dark leakage currents in our devices with varying the dose of ions. More details on the reduction of dark current, such as the effects of ion species, are to be discussed.
- E/PI.07** VIS-FUV AND FTIR REAL TIME SPECTROSCOPIC ELLIPSOMETRY STUDIES OF POLYMER SURFACE MODIFICATIONS DURING ION BEAM BOMBARDMENT
A. Laskarakis, C. Gravalidis, S. Logothetidis, Department of Physics, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece
 The continuously increasing application of polymeric materials to many scientific and technological fields has motivated an extensive use of polymer surface treatments, which modify the physical and chemical properties of polymer surfaces leading to surface activation and promotion of the surface adhesion. Fourier Transform IR Spectroscopic Ellipsometry (FTIRSE) and MultiWavelength Ellipsometry (MWE) in the IR and Vis-FUV spectral regions respectively have been employed for in-situ and real-time monitoring of the structural changes on the polymer surface obtained by Ar⁺ ion bombardment. The polymers were industrially supplied Polyethylene terephthalate (PET) and Polyethylene naphthalate (PEN) membranes. The Ar⁺ ion bombardment has found to change the chemical bonding of the films and especially the amount of the C=O, C-C and C=C groups. The detailed study of the FTIRSE spectra reveals important information about the effect of the Ar⁺ ion bombardment on each of the above bonding groups. Also, the modification of the characteristic features, attributed to electronic transitions in specific bonds of PET and PEN macromolecules, has been studied using MWE. The above methodology proves the potentiality of real-time and in-situ diagnostic techniques towards the optimization of surface treatment procedures in order to improve the adhesion of polymer membrane surfaces.
- E/PI.08** MICROSTRUCTURE OF b-FESI₂ BURIED LAYERS SYNTHESIS BY ION BEAM IMPLANTATION
 R. Ayache, Pharmacy Department, University of Batna, Algeria, E. Richter, Forschungszentrum Rossendorf, Institut für Ionenstrahlphysik und Materialforschung, Postfach 510119, 01314 Dresden, Germany, A. Bouabellou, Laboratoire des Couches Minces et Interfaces, Université de Constantine, Route de Ain El-Bey, Algeria
 A buried layer of iron disilicide was synthesized by ion beam implantation in (111)Si p-type maintained at 500°C using 195 keV Fe ions with a dose of 2x10¹⁷ at./cm², followed by annealing in a N₂ atmosphere at 850°C for 90 min. The investigation of the phase composition is carried out by Rutherford backscattering spectrometry (RBS), whereas the structural characterization is obtained by means of both X-ray diffraction (XRD) pole figure and cross-section high resolution transmission electron microscopy (HRTEM). The precipitates favor epitaxial growth with respect to (111)Si planes with epitaxial relationships (202)b-FeSi₂:(111)Si and/or (220)b-FeSi₂:(111)Si. A mixture of b-FeSi₂ and a-FeSi₂ silicides is observed in the as-implanted state. After annealing of the samples at 1000°C, the XRD pole figures show the transition from b-phase to a-phase.

- E/PI.09** PHYSICAL PROPERTIES AND STRUCTURE OF THIN ION-BEAM MODIFIED POLYMER FILMS
M. Guenther, G. Gerlach, G. Suchanek, Dresden University of Technology, Institute for Solid State Electronics, Mommsenstr. 13, 01062 Dresden, Germany, K. Sahre, K.-J. Eichhorn, Institute of Polymer Research Dresden, Hohe Str. 6, 01069 Dresden, Germany and S. Duvanov, Institute of Applied Physics, National Academy of Sciences, Petropavlovskaya Str. 58, 40030 Sumy, Ukraine
 In order to increase the sensitivity to moisture uptake of the polyimide (PI) and polyethersulfone (PES) films applied in bimorphic humidity sensors, 140 and 180 keV boron ions with irradiation doses between 1013 and 1016 B+/cm² were implanted. A complex investigation of the following features has been carried out: chemical changes in the surface regions by X-ray photoelectron spectroscopy (XPS); density and Young's modulus by surface acoustic waves (SAW); conductivity of modified polymer films. It was shown, that the partial destruction of chemical bonds under ion bombardment leads to the creation of amorphous carbon islands, which increase the surface film conductivity by several orders of magnitude from an insulating to a semiconducting region and enhance the sensitivity of these polymer films to moisture uptake. The radiation-induced cross-linking results in an enhancement of the Young's modulus of the polymer layers up to a factor of 6-9. The density of the modified films increases from an as-prepared value of 1.37-1.44 g/cm³ to 1.8-2.2 g/cm³. The changes in structure and physical properties of polymer films are discussed in dependence on irradiation conditions for the PI and PES films. Conditions for optimal sensor properties were evaluated.
- E/PI.10** PHOTOLUMINESCENCE SPECTRA OF POROUS SILICON LAYER FORMED ON THE (111) ORIENTED SILICON WAFER WITH BURIED HEAVILY DAMAGED THIN LAYER
Z. Swiatek, E. Bielanska, W. Baliga, Institute of Metallurgy and Materials Science, Polish Academy of Sciences, 30-059 Krakow, 25 Reymonta Str., Poland, I.M. Fodchuk, Chernivtsi State University, 274012 Chernivtsi, 2 Kotsyubynsky Str., Ukraine, A. Bonchuk, Institute for Applied Problems of Mechanics and Mathematics of NASU, 3b Naukova Str., 79601 Lviv, Ukraine, F. Krok, Regional Laboratory for Physicochemical Analyses and Structural Research, Jagiellonian University, 30-060 Krakow, 3 Ingardena Str., Poland
 Photoluminescence spectroscopy, transmission electron microscopy, and non-contact atomic force microscopy were used to study of photoluminescence mechanism in porous silicon (PS) layer formed on the n⁺-type, (111)- oriented Si wafer with buried heavily damaged (BHD) thin layer. The BHG layer was produced by the ion implantation process of phosphorous at energy 180keV and at dose 1015cm⁻² followed by thermal treatment in nitrogen atmosphere, while the PS layer was formed by electroless chemical etching in solution containing concentrated HF, HNO₃ and same surface active additives. We show that complex, broad band (~400 - 700nm) can be decomposed into seven elementary bands. On the basis of the results obtained, the model of structural changes in the the near-surface layers of the Si wafer as well as the mechanisms of the elementary bands in photoluminescence spectra are analysed.
- E/PI.11** IRON DISILICIDE FOMED IN a-Si: Fe THIN FILMS BY MAGNETRON CO-SPUTTERIG
V.Kh. Kudoyarova, E.I Terukov, O.I. Konkov, O.B. Gusev, V.Yu. Davidov, G.N. Mosina, Ioffe Physicotechnical Institute, Russian Academy of Sciences, 194021 St.Petersburg, Russia
 Formation of Si-based structures emitting in the 1.5 μm region (transparency window of silicon and silica optical fibers) has attracted much interest over the last 10 years. One of the main approaches for the formation of buried layers of low-defect, emitting b-FeSi₂ is an iron-beam synthesis (IBS) i.e. high-dose Fe⁺ implantation in Si with subsequent high-temperature and long-duration annealing.
 In this work the formation iron disilicide (b-FeSi₂) nano-precipitates in amorphous silicon has been observed at low temperature without implantation Fe. Amorphous silicon films doped with Fe (a-Si: Fe) have been prepared by magnetron co-sputtering. Subsequent short-time annealing results in the transformation of amorphous silicon doped with Fe into microcrystalline one and the production of b-FeSi₂ nano-precipitates. The phase composition of the films was studied by Rutherford backscattering spectrometry (RBS). The microstructure of the layers was studied using Raman spectroscopy and transmission electron microscopy (TEM). TEM data show the precipitate sizes to be in the range 20-25 nm. It is shown that the synthesized layers are able to emit at λ > 1.5 μm at 100K.
- E/PI.12** ORDERED HELIUM NANOBUBBLES AND Si NANOCRYSTALLITES IN AMORPHOUS SILICON INDUCED IN THIN Si CRYSTALS BY LOW-ENERGY He⁺ IMPLANTATION
 V.F. Reutov, A.S. Sokhatsky, Joint Institute for Nuclear Research, Flerov Laboratory of Nuclear Reactions, Joliot-Curie 6, 141980, Dubna, Moscow region, Russia
 Thin transparent in transmission electron microscope (TEM) self-carried silicon (001) plates were irradiated in the direction to their (110) butt surface by low-energy helium ions in the fluence interval from 5E16 to 4.5E17 cm⁻², at room temperature. These samples were analyzed by TEM as-irradiated and after annealing. The obtained results show that the amorphous layers (a-Si) form in the most damaged regions of thin Si crystals. The amorphization of the silicon takes place when the ratio of defects production rate to the rate of helium atoms implantation exceeds 90 displacements per atom of He, provided the He⁺ ions fluence exceeds 1017 cm⁻². The helium bubbles of 2-5 nm in diameter with the density under 3E17 cm⁻³ form on the whole width of a-Si layers. The nanobubbles are linearly ordered in the form of regular chains oriented in the direction of the ions motion. Thermal evolution of the bubble microstructure at post-irradiation annealing depends significantly on the dynamics of thermal treatment. As a result of heating with high constant rate of 15K/s up to 875 K (in nitrogen flow) increasing of volume of bubbles in a-Si conserved layer takes place due to a capture of the solved helium atoms in nonmoving bubbles. However, conventional heating of samples up to 850 K, results in no changes in the distribution of bubbles in a-Si layer. At the same time in a-Si conserved with ordered nanobubbles appeared small-dispersible crystallites of 1-2 nm in size.

- E/PI.13** DOSE AND ENERGY EFFECTS IN THE THERMAL GROWTH OF He NANOCAVITIES IN Si
 R. Delamare, C.L. Liu, E. Ntsoenzok, CNRS/CERI, 3A rue de férollerie, 45071 Orléans, France, M.O. Ruault, C.S.N.S.M./CNRS, 91405 Orsay Campus, France, L. Vincent, A. claverie, CNRS/CEMES, 29 rue Jeanne Marvig 31055 Toulouse, France, G. Regula, TECSEN, case 151, Faculte des Sciences St-Jerome, 13397 Marseille, France, A. Van Veen, IRI, Delft University of Technology, Mekelweg 15, 2629 JB Delft, The Netherlands
 Silicon samples were implanted with energies ranging from 10 keV to 1.55 MeV helium 3 with various doses but higher than the minimum required to form He cavities in silicon. After implantation thermal treatments, up to 900°C, were applied. Thermal evolution of cavities were then studied by the means of TEM. Helium dose was chosen in order to have roughly the same helium peak concentration for the three main energies used: 1.45, 2.83, 5'1016 3He/cm² for 10 keV, 50 keV and 1.55 MeV implantation respectively. These three doses induce a maximum helium concentration peak of about 1021He/cm³ according to SRIM simulation. Our results show that after a 400°C annealing only platelets are observed in sample implanted with 10 keV while small bubbles/cavities can be measured for the two others energies. From 700°C to 900°C annealing, it can clearly be stated that the total volume occupied by cavities increases with the implanted depth. Only the loss of vacancies at the surface can explain such an evolution which is very important between 1.55 MeV and 10 keV. Also the diameter of cavities increases with helium energy. In all cases studied, the 900°C annealing results in a quasi-monolayer of cavities. The paper will discuss on the growth model which can be extracted from all these data and the role of helium in that growth. Fast Oswald Ripening process might be predominant in the growth of He-cavities for the two lowest energies while the highest energy would predominantly consists on a slow Oswald Ripening process .
- E/PI.14** ONSET OF BLISTERING IN ION IMPLANTED AND HYDROGEN PLASMA TREATED SILICON
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 The onset time for surface blistering at different temperatures was studied for n and p-type Cz Si implanted by H or He ions (100 keV, doses 1015 - 1016 cm⁻²) and then hydrogenated from a plasma at 150-400 °C. The surface blistering process was studied by optical and scanning electron microscopy (SEM) as a function of annealing temperature and annealing time. Raman spectroscopy was used for the investigation of the evolution of Si-H bonds after the post hydrogenation annealing. It was found that the release of the hydrogen from the sub-surface layer and accumulation in buried defect region during the annealing is responsible for the onset of blistering for low-dose H/He implanted and then hydrogen plasma treated samples. It was found also that process of blistering is controlled by the hydrogenation and the post-hydrogenation annealing parameters. The onset of blistering for ion implanted and then hydrogenated samples was observed at doses of about 5'1015 cm⁻² which of about one order magnitude less than those observed in case of only H implantation. The mechanism of the hydrogen gettering on buried defect layer and the possibility of hydrogen-induced exfoliation of silicon layers at low dose implantation with following hydrogenation ("Soft-cut") is discussed.
- E/PI.15** NUCLEATION, GROWTH AND DISSOCIATION OF He BUBBLES IN SAPPHIRE Al₂O₃
 M.A. van Huis, A. van Veen, A.V. Fedoroy, F. Labohm and H. Schut, Delft University of Technology, Interfaculty Reactor Institute, Mekelweg 15, 2629 JB Delft, The Netherlands
 The formation and dissociation of helium bubbles and helium desorption is investigated in sapphire Al₂O₃ implanted with 30 keV He ions to four different doses of 0.1, 0.3, 1.0 and 2.0E16 ions cm⁻². The samples were annealed isochronally up to 1850 K in steps of 100 K. The techniques of Doppler broadening positron beam analysis (PBA) and neutron depth profiling (NDP) were used to investigate defect evolution and helium retention, respectively, during the annealing procedure. It was observed that the maximum bubble volume is found after 1250 K annealing, after which a process of bubble shrinkage sets in. Helium is released mainly at a temperature of 1750 K. The desorption curve is discussed by means of a permeation model. The bubble size is determined by means of transmission electron microscopy (TEM).
- E/PI.16** GISAXS COMPARATIVE STUDY OF H AND D IMPLANTED Si
B. Pivac(a), P. Dubcek(a), O. Milat(b), S. Bernstorff(c), R. Tonini(d), F. Corni(d) and G. Ottaviani(d), (a)Rudjer Boskovic Institute, POBox 180, 10000 Zagreb, Croatia, (b)Institute of Physics, Bijenicka 46, 10000 Zagreb, Croatia, (c)Sincrotrone Trieste, SS 14km163,5, 34012 Basovizza(TS), Italy, (d)Dipartimento di Fisica, University of Modena, Via Campi 213a, 41100 Modena, Italy
 The grazing incidence small angle X-ray scattering (SAXS) technique was used to study monocrystalline silicon samples implanted with H₂ and D₂ ions at energy of 32 keV and to the dose of 1E16 ions/cm². Samples were annealed isochronally at different temperatures in the range from 100 to 900 C. Although the H depth distribution was expected to be smooth initially, nanosized features, like agglomerates of defects have been detected (minor correlation peak observed in implanted but not annealed sample). Annealing destroys this feature due to the relaxation of defects structures, i.e. redistribution of vacancies and hydrogen. Above 300 C a well defined film with highly correlated borders is formed on the edge of the layer rich in defects, whose thickness is slowly decreasing from 17 to 12 nm with increasing annealing temperature. Moreover, defects as well as hydrogen are migrating towards the surface with increasing annealing temperature, as indicated by the increase in surface roughness. We will present a model for the film structure changes obtained by data evaluation based on the distorted wave Born approximation. The differences between the H and D ions effect on Si substrate are shown and discussed.
- E/PI.17** POSITRON DEPTH PROFILES IN HELIUM IMPLANTED CUBIC ZIRCONIA
S. Sauté, R.I. Grynszpan, DGA/DCE/CTA/LOT/L+, 94114 Arcueil, France (& LCMTR-CNRS-UPR-209-ISCSA-IFR-1780), W. Anwand, G. Brauer, Forschungszentrum Rossendorf, 011314 Dresden, Germany, J.J. Grob, Y. Le Gall, PHASE-CNRS-UPR-292, 67037 Strasbourg, France
 Zirconia is an attractive material for the confinement of both nuclear fuel and nuclear waste, owing to its high radiation stability and its weak neutron cross-section. To complement previous studies on radiation damage production during low energy ion implantation [1], we characterized the nature and thermal stability of open-volume defects induced by 50 keV helium ions (projected range : 220 nm), using Slow Positron Implantation Spectroscopy. Up to 2.1017 He/cm², the Doppler broadening parameter S exhibits a dose dependence similar to that observed for other noble gas ion implantation [2]. Isochronal annealing results tend to indicate the presence of at least two types of defects introduced by the implantation.
 [1] K.E. Sickafus et al., J. Nucl. Mater., 274 (1999) 66.
 [2] J. Fradin et al., Nucl. Instr. Meth. B, 175 (2001) 516.

- E/PI.18** HELIUM DIFFUSION IN METALS INVESTIGATED BY NUCLEAR REACTION ANALYSIS
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 The $d(3\text{He},p)^4\text{He}$ resonance reaction offers the possibility of monitoring helium depth profiles in metals, as it results in the emission of ~ 14 MeV protons, easily discriminated from other reaction by-products. In the present work, we followed the change, induced by thermal treatment, in a sub-micron width distribution of helium-3 implanted in Au(Ag). Emitted protons spectra were collected and analyzed while scanning the d-energy. Results show that, whereas the distribution width is not affected by low temperature isothermal annealing, helium profiles depart from a Gaussian distribution after high temperature treatments, i.e. the diffusion does not follow Fick's law. This seems to unveil two helium behaviors, one which allows diffusion towards the surface and the other indicating a possible stabilization via bubble formation.
- E/PI.19** GRAZING INCIDENCE SMALL ANGLE X-RAY SCATTERING STUDY OF He IRRADIATION INDUCED DEFECTS IN MONOCRYSTALLINE SILICON
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 Structural defects in monocrystalline silicon samples, irradiated with a dose of 2×10^{16} He ions per square centimeter at 77K and annealed at temperatures in 100 - 800 oC temperature range, were investigated using grazing incidence small angle X-ray scattering. Apart from the scattering intensity shape typical for this surface roughness, all the samples showed fringes in scattering intensity from the topmost, implantation unaffected layer.
 Apart from the step-down from nonimplanted to implanted sample, the critical angle is slowly decreasing with the annealing temperature increasing up to 600oC, when it starts to rise again. This results from redistribution of defects, and is indicating bubbles formation onset. Some of the induced defects are lost due to the diffusion towards the surface. This increases surface roughness, and causes the sample density to rise slowly and is detected as lowering of intensity of the reflected primary beam and the change of the shape of reflection. It is believed that the bubbles start to form at 600oC, and this is the temperature at which film thickness and the change in critical angle reverse their dependence on temperature of annealing..
- E/PI.20** HYDROGEN MOLECULE FORMATION IN LOW ENERGY HYDROGEN IMPLANTED CZOCHRALSKI SILICON
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 The formation of H₂ molecules in voids/plateles in Czochralski (Cz) Si (100) oriented p- and n-type wafers during the low-energy hydrogen implantation by immersion in a DC plasma was investigated. Implantation was done at 250 and 400 °C for 1 and 2 hours. The energy of implantation was 1, 2.5 and 5 keV. The Raman spectroscopy, the spreading resistance probe (SRP) measurements and the scanning electron microscopy (SEM) were used for the analysis. It was found that the H₂ molecules in voids/plateles can be formed in both n- and p-type Si unlike for the case of a remote plasma hydrogenation. The maximum concentration of the H₂ molecules was found at 250°C temperature of hydrogenation. This fact shows, that the formation of voids/plateles is more effective at 250 °C than at 400 °C. The SRP profiling for 400 °C hydrogen implanted samples shows the formation of thermal donors at depths of 100-200 μm which indicates the release of hydrogen from subsurface layer and the hydrogen penetration into the Si bulk at this temperature. Results of a DC hydrogen plasma implantation in Cz Si are compared with the case of a HF hydrogen plasma treatment. The mechanism of the hydrogen induced voids/platelets formation is discussed as well as possible applications of this phenomenon
- E/PI.21** RED ELECTROLUMINESCENCE EMITTED FROM THIN SiO₂ IMPLANTED BY Ge IONS RED ELECTROLUMINESCENCE EMITTED FROM THIN SiO₂ IMPLANTED BY Ge IONS
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 Ge ions of 80 keV were implanted with doses of 1×10^{16} cm⁻² and 5×10^{15} cm⁻² into a 120 nm-thick SiO₂ layer on p-Si at room temperature. Postannealing was subsequently performed at 500 oC and 1100 oC, to investigate the luminescence from radiative defects induced to the SiO₂. Violet photoluminescence (PL) and intense red electroluminescence (EL) were observed under an ambient light from the samples annealed at 500 oC while the samples annealed at 1100 oC exhibited no luminescence. The strong EL was observed only under a reverse bias applied to Au/Ge-implanted SiO₂/p-Si structures where the Ge-implanted SiO₂ had been annealed at 500 oC
- E/PI.22** DOPING OF Si NANOCRYSTALS BY P ION IMPLANTATION
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 New effects in quantum-sized Si structures and downscaling of the electron devices require the detailed knowledge on the ion-beam modification of Si nanocrystals (Si-ncs). Here we present the study of P ion implantation in Si-ncs, preliminarily synthesized in SiO₂ by implantation of 10^{17} cm⁻² Si ions at 140 keV followed by annealing at 1000 or 1100oC for 2 hours. Then P ions were implanted at 150 keV with the doses of 10^{13} - 10^{16} cm⁻². Post-implantation anneals were carried out at 600-1100oC for 30 mins. Photoluminescence (PL), Raman, FTIR and XPS spectroscopy were used for characterizations. Raman data shown 1100oC are more efficient for Si-ncs formation than 1000oC. On the other hand, low temperature synthesis makes the nanostructures much more sensitive to P implantation. Thus, strong increases in the PL intensity over the as-synthesized level were observed after the lowest P dose and for very high P concentrations. The first effect was found to be due to the instant crystallization of Si nano-inclusions under single impingements of P ions. The second one was ascribed to the impurity enhanced crystallization. The last feature pointed to a presence of P atoms inside the Si-ncs and the XPS spectra indicated penetration of P in Si. However, the theoretically predicted effect of Auger recombination on PL due to excess free electrons and optical absorption by them were not observed. The behavior of the excess carriers in doped Si-ncs is considered.

E/PI.23 THE INFLUENCE OF INTERFACE STATES ON THE LUMINESCENCE OF SiO₂:nc-Si AND a-Si:nc-Si SYSTEMS FORMED BY ION IMPLANTATION

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The question about the nature of the red-near-IR luminescence (700-1000 nm) of Si nanocrystals (nc-Si) is discussed on the base of original experimental data for SiO₂:nc-Si and a-Si:nc-Si systems formed by Si⁺ ion implantation into thermal SiO₂ layers and by ion irradiation of c-Si, respectively. The influence of annealing temperature and additional phosphorus doping on the optical transmission, electron spin resonance (ESR) and photoluminescence (PL) of SiO₂:nc-Si system is investigated. Some peculiarities are established. They can be explained by the influence of interface states, if we assign the main PL peak (at ~ 800 nm) to the band-to-band transitions inside nanocrystals. In particular, the second PL peak at ~ 900 nm (its occurrence depends on the annealing conditions) is observed. This peak is interpreted to be caused by the interface states. The double-mode PL of a-Si:nc-Si system is attributed to the emission both in nc-Si and in surrounding a-Si matrix (the peaks at ~ 750 and ~ 950 nm). The change of PL spectra with dose of ion irradiation and annealing temperature is discussed from the standpoint of evolution of two-phase a-Si:nc-Si system electron spectra. The model of a-Si and nc-Si mutual sensibilization is suggested. The correlation between the dose dependencies of nc-Si PL and ESR (caused by Si broken bonds localized in a-Si layer and in a-Si/nc-Si interfaces) is established.

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E/PI.24 TIME-RESOLVED PHOTOLUMINESCENCE FROM SiO₂ FILMS AFTER Si-AND C-COIMPLANTATION

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In this contribution we explore the white emission properties of thermally grown SiO₂ layers co-implanted with silicon and carbon ions to high doses. This white emission results from the convolution of at least three bands, located in the IR-red, yellow-green and blue spectral regions. While the IR-red emission is coming from Si nanocrystals in the regions close to the main C-implanted peak, the other two photoluminescence bands have been assigned to graphitic C and amorphous SiC. This attribution has been established by PL intensity-versus-depth profiles and by correlations with microstructural analysis. For each implanted dose the PL-rise and decay measurements have been measured as a function of the emitted wavelength. We have estimated the lifetime and capture cross section of each PL structure as a function of the implanted dose. The red emission shows no significant difference in capture and emission parameters respect to reference samples containing only Si nanocrystals, implying that the C-implantation has any effect on the radiative recombination inside the nanocrystals. The C-related structure presents a dominant, very fast relaxation, of about 5 ns, and a slower component, of the order of 1 ms. The origin of these two recombination mechanisms are discussed as a function of the emission wavelength and sample processing parameters. Moreover, by means of these measurements we resolved the fine structure of the spectra, providing the correct interpretation of the apparent shifts in the visible emission, observed when varying the C content in the layers.

E/PI.25 OPTICAL STUDY OF Si NANOCRYSTALS IN Si/SiO₂ LAYERS BY SPECTROSCOPIC ELLIPSOMETRY

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Since the discovery of a visible photoluminescence from porous silicon at room temperature, several researches were consecrated for applications of this silicon to optoelectronic devices. This exciting discovery has stimulated growing experimental and theoretical interest in understanding the optical properties of semiconductor structures with reduced dimensions like silicon. Si ion implantation into thermal SiO₂ films on Si substrate and subsequent high temperature annealing is a well-known process of making Si nanocrystals. A lot of optical studies of Si nanocrystals have been carried out using luminescence methods. However, few optical properties have been studied by reflectance and ellipsometry spectroscopy (SE). The aim of the work is to show that SE is a powerful method suitable for investing the optical properties of nanostructures. Multi-layer analyzed were performed, and each layer of the corresponding system consists of a mixture between silica and Si nanocrystals. The Bruggeman effective medium approximation (EMA) combined with Fourouhi-Bloomer model have been used to predict the values of layers thickness, and optical indices of Si nanocrystals, and volume fractions of each component. A significant change of optical indices and optical gap as a function of growth temperature were found.

E/PI.26 Co GROWTH ON NANOSTRUCTURED Cu(110) SUBSTRATES

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We have studied the growth of Co films on Cu(110) substrates nanostructured by ion sputtering by means of surface X-ray diffraction at the ESRF ID3 beamline. On the flat Cu(110) substrate at temperatures around 230 K the cobalt islands grow elongated in the {1-10} direction and above a coverage of 15 ML the development of mounds with well defined (111) facets is observed in the rod scans. This behaviour is in close analogy to the case of Al(110) homoepitaxy where the formation of nano-pyramids bound by (111)facets was observed, and suggests that significant upward mass transport to the mounds is occurring also for fcc Cobalt. When Co growth is performed on the nanostructured Cu(110) substrate (rectangular mounds elongated in the <1-10> direction [1]) the Co capping film does not cover the Cu mounds in a conformal way but strongly prefers to develop steep (111) facets. Surprisingly, even when ripples elongated in the <100> direction are formed by ion sputtering on the Cu(110) substrate [1], the Co clusters growing on the ridges of the ripples are able to develop dominant (111) facets. The implications of these results for possible magnetic applications will be discussed.

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E/PI.27 PATTERN FORMATION AND ATOMIC SCALE SMOOTHING ON QUARTZ GLASS SURFACES DURING ION BEAM EROSION

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The surface topography of quartz glass after low-energy Ar⁺ ion beam sputtering was studied using scanning force microscopy. In detail the influence of the ion incidence angle, ion energy, ion flux, sample temperature, and sputter time (equivalent to the total ion dose or ion fluence) were evaluated. It is shown that, for ion incidence angle between 50 and 70 degree surface topography of quartz glass was dominated by regular ripple structures with an orientation perpendicular to the ion beam direction. Whereas for an angle of 50 degree the wavelength of the ripple structures is still growing for extended sputter times, the ripple wavelength saturates for angles of 60 and 70 degrees and, additionally, a destroying of the rippled topography is seen, after passing a cross over time. The ripple wavelength increases with ion energy but it is constant with respect to the ion flux and sample temperature. In contrast, at incidence angles less than 50 degrees extremely smooth surfaces are created, offering the possibility of surface smoothing by ion beams down to a sub-Angstrom level.

Further, the surface evolution with simultaneous sample rotation was investigated. The rippled surface topography disappears under this condition in the range of ion incidence angles, where surface smoothing can be observed, increases. These results are discussed within the framework of existing continuum models for surface erosion by ion sputtering including different relaxation mechanisms.

E/PI.28 REPORT ON THE TIME EVOLUTION OF {113} DEFECTS DURING TED

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Modelling of TED requires solid data on {113} defects evolution during annealing under well defined conditions.

For this work, different substrate types were implanted with either 40 keV 6*10¹³/cm² or 100 keV 2*10¹⁴/cm² Si ions then annealed at 650, 700, 740 and 850°C for various times under N₂. After 100 KeV implants, the {113} defects grow in size and finally evolve into dislocation loops following a conservative Ostwald ripening. After the 40 KeV implants (lower dose and energy), the {113} defects grow in size until their density suddenly drops down: they dissolve. In this case, the growth of {113} defects is a non-conservative Ostwald ripening process and the time variation of the fluxes of Si interstitial atoms towards the surface has been measured. Significant differences have been found in the kinetics of defect dissolution between substrates of different types. These results definitely prove that the dissolution of {113} defects is not an intrinsic characteristics of these defects but reflects the competition between atomic interchange between defects and diffusion to, recombination at, the surface. These results are used to test recent simulations of TED and defects evolution describing Ostwald ripening of defects in presence of a sink.

E/PI.29 ION-BOMBARDMENT INDUCED MORPHOLOGY MODIFICATIONS ON SELF-ORGANIZED SEMICONDUCTOR SURFACES

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For III-V semiconductors it has been demonstrated that ion erosion may result in well-ordered dot patterns on the nanometer scale [1]. Attempts to obtain a similar effect on the technological most relevant silicon surfaces failed with one exception [2]. To explore the reasons for this deviating behavior we used atomic-force microscopy to investigate the morphology evolution under Ar ion bombardment (100 eV ? 1 keV) of Si(001) covered by various self-organized SiGe films. In most of the cases a significant smoothening of the surface was observed. However, for a checkerboard array of {105} pyramids and pits [3] the nanopattern could indeed be transformed into the Si substrate. For ion energies below 750 eV the pyramidal pits transform into shallow troughs before smaller craters are formed. The details of the surface modifications and their dependence on ion energy are discussed in the framework of current theories of ion bombardment induced pattern formation. From the results routes are predicted for ion bombardment assisted nanopatterning of pure silicon surfaces.

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E/PI.30 SURFACE STRUCTURE DEPENDENCE OF IMPACT PROCESSES OF GAS CLUSTER IONS

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Gas cluster ion beam technique provides irradiation of large clusters with those sizes ranging from several tens to several tens thousand, and is expected to be applied to high-performance surface modification process such like high-yield sputtering and surface smoothing. When such a large cluster impacts on a solid target, large number of collisions between cluster and surface atom occur. As a result, several thousands of surface atoms are moved and a large crater-like damage is formed on the surface with only one cluster impact. Because of such dynamic deformation of surface structure in nano-scale, it is expected that the collisional processes and surface modification effect with clusters are different depending surface structures.

In this study, molecular dynamics simulations of large Ar cluster impact on Si(100) with sine-curve structure were performed. It was found that the deformation process of surface morphology was different depending on impact point. For example, when an Ar₂₀₀₀ cluster accelerated with 20keV impacted on the convex point of the surface the hill was compressed and the impact area was smoothed. At the impact on concave point, however, a deeper crater was formed compared with the impact on flat surface. From these results by computer simulations, characteristic surface modification effects with cluster irradiations will be discussed.

This study is supported by the new energy and industrial development organization (NEDO) in Japan.

- E/PI.31** SURFACE SMOOTHING WITH LARGE CURRENT CLUSTER ION BEAM
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 A cluster is an aggregate of a few to several thousands atoms. When many atoms constituting a cluster ion bombard a local area, high-density energy deposition and multiple-collision processes are realized. Because of the interactions, cluster ion beam processes can produce new surface modification effects, such as surface smoothing, high rate sputtering and very shallow implantation. Especially, the cluster ion beam can smooth surfaces of diamond films that are very hard materials and difficult to machining with usual ion processes. High ion dose is needed to realize the nano-level smoothing and etching of hard materials using cluster ion beam and large current is needed to increase the productivity of processing. In order to achieve large current cluster ion beam, the cluster generation, ionization and ion transportation were studied and the beam current reached 600 μ A. The cluster size is a unique and important parameter for the efficient surface modification with cluster ions. It is important to measure and control the size distributions of cluster beams. The size distributions of large current Ar cluster ion beams were measured using compact Time-of-Flight (TOF) system. The system can be set in the cluster irradiation machines and used for the cluster size monitor. Each cluster size distribution had a peak at size of 2000-30000 and it can be controlled by the source gas pressure and ionization condition.
 This work is supported by Ministry of Economy, Trade and Industry (METI) and New Energy and Industrial Technology Development Organization (NEDO).
- E/PI.32** LOW HIGHLY CHARGED IONS FOR NANOSCALE SURFACE MODIFICATIONS
 L. Großmann(b), U. Kentsch(a), St. Landgraf(a), V.P. Ovsyannikov(b), M. Schmidt(a), X. Tyrroff(c), F. Ullmann(b), G. Zschornack(a,c), (a)TU Dresden, Institut für Kern- und Teilchenphysik, Mommsenstraße 13, 01062 Dresden, Germany, (b)Leybold Vakuum Dresden GmbH, Zur Wetterwarte 50, 01109 Dresden, Germany, (c)Forschungszentrum Rossendorf, Institut für Ionenstrahlphysik und Materialforschung, PF 510119, 01314 Dresden, Germany
 Molecular dynamics simulations have been used to obtain the three-dimensional distribution of interfacial mixing and cascade defects in TiPt multilayer system due to series of single 1 keV Ar⁺ impacts at grazing angle of incidence. The calculated ion induced mixing profile is not sensitive to the heat of mixing. Therefore the thermal spike model is not fully supported in this system. Instead we found that the majority of mixing occurs after the thermal spike in the relaxation process. These are supported by liquid, vacancy and adatom analysis. The interfacial mixing is in various aspects anomalous in this system: the time evolution of mixing is leading to a phase delay for Ti as well as Pt exhibits an unexpected double peaked mixing evolution. The possible reasons are discussed.
- E/PI.33** NON - ELASTIC PROCESSES OF ION FORMATION AT SPUTTERING OF IONIC CRYSTALS UNDER ELECTRON AND MULTICHARGED ION BOMBARDMENT
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 Using the method of secondary ion mass-spectrometry the yield of positive ions from LiF, KCl, KBr, SiC, MgO has been investigated during the bombardment by electrons and Ar ions with the charge q=1-6 with in the range of energy E=0.02-1 KeV.
 It has been shown that the increase in q and E of bombarding ions gives the rise in the yield of cations M⁺, anions X⁻ and slightly affects the yield of molecular ions (MnXn)⁺. Inelastic sputtering has its hold on charge and occurs at q> 2. Potential energy of MCI is spent on the formation of neutrals X and double - ionized anions X⁻. Double - ionized ions M2⁺ have not been found in the mass-spectra for all the initial values of the charge q. During the electron bombardment of alkali-halide crystals the multiple - charged ions M2⁺, X2⁻, M3⁺, X3⁻ have been found together with atomic and molecular ions. Their occurrence is connected with the Auger effect as a result of excitation of inner shells of cations and anions. The rise of the MCI share results in the yield of one-charged ions. From the comparison of ion emission taking place under the action of the both beams, it has been concluded that ionization of the lattice atoms by electrons is more effective than by ions.
- E/PI.34** SPUTTERING OF BINARY CRYSTAL SURFACE UNDER GRAZING ION BOMBARDMENT
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 Application of grazing angles of incidence of ions on the solid surfaces opens new perspectives in their modification and polishing by ion beams.
 In present work the peculiarities of sputtering processes on Cu₃Au(100), GaP(100) and GaAs(100) surfaces at grazing 1-5 keV Ne, Be and Se ion bombardment have been investigated by computer simulation. The used code is based on the binary collision approximation. The sputtering has been simulated in the primary knock-on regime. The energy, angular and spatial distributions of sputtered particles and their yields, subdivided into sputtering by each both components and surface layers of compounds for a range of grazing angles of incidence have been calculated. It was shown that at grazing ion bombardment the projectile ions generate the low energy primary knock-on atoms from several nearest to surface atomic layers. In the main the energies of these ejected particles are lower than 10 eV. These recoil atoms are ejected with preferential escape direction in space. It was found that the optimum for layer-by-layer sputtering of the binary single crystal surface are observed within the small angle range of the glancing angles near the threshold sputtering angle. The features of preferential sputtering of the binary single crystal components have been studied carefully. It has been shown that the possibility of preferential sputtering of one component essentially depends on the bombardment angle. At small glancing angles the preferential sputtering of heavy component atoms is possible.

E/PI.35

ROUGHNESS EVOLUTION OF SOME X-UV REFLECTIVE MATERIALS INDUCED BY LOW ENERGY (<1 keV) ION BEAM MILLING

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Ion beam figuring (IBF) is an advanced technique used since more than 10 years as a final step in optical manufacturing to improve the figure of optics. One disadvantage of the technique is the potential increase of the optical surface roughness induced by ion beam milling.

The roughness evolution of various optical materials used in our IBF applications has been measured with an interferometric profilometer microscope. Mostly analysis get on electroplated nickel, PVD gold and CVD silicon carbide smooth samples are presented. These materials are often used in X-ray and UV applications, but a few information exist in the literature about they behaviour during ion milling. The measurements have been performed at different level of etching depth, with a maximum of 5 microns which is largely enough for main IBF applications. The damaged surfaces were also observed with a scanning electron microscope. Different inert gases (Argon, Krypton and Xenon) and ion energies (200 - 900 eV) have been tested, mainly at normal incidence. Two different kinds of ion sources (Kaufman and end-Hall source) have been used for this work. The results show in general a strong increase of the roughness for electroplated nickel, a slight decrease for PVD gold and a slight increase for CVD silicon carbide. Results are discussed in relation to previous related works and sputtering considerations.

Thursday, June 12, 2003
Jeudi 12 juin 2003

Morning
Matin

E-IX.1 9:00 -Invited-

ION BEAM SYNTHESIS AND OPTICAL PROPERTIES OF SILICON NANOCRYSTALS

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We present the correlation between the structural (average size and density) and optoelectronic properties (band-gap, PL and EL) of Si nanocrystals embedded in SiO₂, which is an essential issue to understand their emission mechanism/s. The Si nanocrystals were obtained by ion implantation of Si in SiO₂ plus annealing. By varying the time of annealing in a large time scale we have been able to track the nucleation, pure growth and ripening stages of the nanocrystal population. The optical properties on the different growth regimes are assessed and some valuable conclusions for application in devices are set up. The ability of surface passivation to enhance the PL emission is also tackled with emphasis on the identification of the interface defect responsible of quenching the PL. Besides, PL lifetimes and absorption cross-sections of Si nanocrystals as a function of size, surface passivation and pumping wavelength are introduced. These provide a fundamental insight on the emission mechanism and their knowledge is essential to engineer devices with optimised light emission, optical amplification or energy transfer to rare earths in co-doped systems. From highly luminescent Si nanocrystals, LEDs consisting of MOS capacitors were fabricated. Stable red EL has been obtained at room temperature and the current is related to a pure tunnelling process. Finally, some recent results on the co-implantation of Si and C in SiO₂ are presented and discussed.

E-IX.2 9:30

ELECTROLUMINESCENT DEVICES BASED ON Tm-DOPED Si NANOCCLUSERS

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We have studied the structural, electrical and optical properties of MOS devices, where the dielectric layer consists of a substoichiometric SiO_x ($x < 2$) thin film deposited by plasma enhanced chemical vapor deposition. After deposition the films were annealed at high temperature to induce the separation of the Si and SiO₂ phases with the formation of Si nanoclusters (nc) embedded in the insulating matrix. When the devices are polarized, a strong light emission at a wavelength of about 900 nm has been observed at room temperature. It is possible to change the wavelength of the light emission by doping Si nc with rare earth ions. In particular, we present the properties of devices based on Tm-doped Si nc. To fabricate the devices the SiO_x films have been implanted with Tm ions and annealed at 900 °C in N₂ atmosphere to activate Tm and to induce the separation of the Si and SiO₂ phases. We have investigated the charge transport in the layers containing the Tm-doped Si nc and we have observed that high current densities are obtained at relatively low voltages, due to the presence of Si nanoclusters dispersed in the SiO₂ matrix. Due to the efficient carrier injection, Tm is efficiently excited producing two different room temperature electroluminescence peaks at 780 nm and 1650 nm. The EL properties as a function of the current density and temperature have been studied. Moreover we have studied the radiative and non-radiative de-excitation properties of the system.

E-IX.3 9:45

OPTIMIZING NANOCRYSTAL SYNTHESIS FOR MULTI-DOT FLOATING GATES OF NOVEL NON-VOLATILE MEMORIES

T. Müller, K.-H. Heinig, Research Center Rossendorf, Dresden, Germany

The synthesis of a single monolayer of nanocrystals (NCs) with a maximum density but no in-plane electrical percolation paths is a challenging task. Such layers are required for the fabrication of multi-dot nonvolatile memories. Here, compared to the conventional nonvolatile memory, the floating gate is replaced by a layer of Si NCs allowing for distributed charge storage and, therefore, lower operation voltages, faster programming, etc. These advantages are lost at too high NC densities when NC's charge can spread over neighboring NCs by electron tunneling, i.e. due to electrical in-plane percolation paths.

In this contribution, studies on the synthesis of Si NCs by low energy Si⁺ implantation into thin gate oxides of NC memories are presented. Using a kinetic 3D lattice Monte Carlo code, the nucleation, growth and Ostwald ripening of the Si NCs in Si supersaturation is simulated [1]. On the basis of these simulations, the dependence of the Si NC density, the distribution of the NC spacing as well as the threshold for extended electron tunneling paths are predicted. Thus, process conditions could be identified, where NCs align in a thin layer at high density but sufficient electrical isolation.

[1] T. Müller, K.-H. Heinig, W. Möller, Appl. Phys. Lett. 81 (2002) 3049.

- E-IX.4** 10:00 RELIABLE FLASH EEPROM MEMORIES BASED ON ARRAYS OF SI NANOCRYSTALS EMBEDDED IN SiO₂
O. Gonzalez, B.Garrido, A. Cuadras, S. Cheylan, A. Pérez-Rodríguez, J.R. Morante, ept. Electronics, University of Barcelona, Martí i Franquès 1, 08028 Barcelona, Spain
In the field of non-volatile memories, the introduction of nanocrystals as charge storage elements embedded in silicon oxide is becoming a very attractive challenge. Memories with nanocrystals present fast writing and long retention times. Moreover, they work at low injection voltages so that degradation due to hot electrons decrease enormously.
In this work, we study the memory effects and figures of merit of MOS capacitors with Si-nanocrystals for different tunnel oxides and density of nanocrystals. The control of the tunnel oxide is achieved by changing the thickness of oxide or by an oxidation step after nanocrystal formation. Nanocrystals have been fabricated using ion implantation, which allows an accurate control of the nanocrystals size, density and position in the oxide. Thermal oxides of 20-40 nm have been implanted with Si doses from 10¹⁵ to 2x10¹⁶ cm⁻² at 15 keV. An annealing at 1100 °C leads to the complete precipitation of the Si excess as nanocrystals. Strong memory effects are found from the reversible shift of the high frequency capacitance-voltage characteristics after constant voltages stress. Direct tunnelling of electron and holes towards/from nanocrystals to the substrate are responsible of this shift. The optimum implantation dose is at least 10 % of Si excess. The additional oxidation step provides a tunnel oxide free of nanocrystals and provokes a dramatic increase of retention times. These dependencies will be discussed in detail.
- E-IX.5** 10:15 COMPARISON OF THE CHARGE STORAGE PROPERTIES OF ION BEAM SYNTHESIZED SI AND GE NANOCLUSTERS IN THIN GATE OXIDES
V. Bever(a), J. von Borany(a), K. Knobloch(b), A. Mücklich(a), (a)Forschungszentrum Rossendorf, Institute of Ion Beam Physics and Materials Research, P.O. Box. 51 01 19, 01314 Dresden, Germany, (b)Infineon Technologies Dresden, Königsbrücker Str. 180, 01099 Dresden, Germany
Semiconductor nanoclusters (NCs) embedded in thin gate dielectrics are of fundamental interest for future integrated memory concepts. In this contribution we compare the properties of Ge and Si NCs embedded in thin SiO₂ films (d = 20 nm) with respect to their charge storage behaviour. Those NCs were prepared by ion beam synthesis combining low energy ion implantation (6-18 keV, 5x10¹⁵-2x10¹⁶cm⁻²) with subsequent rapid thermal processing (950 or 1050°C, 30-120 s) choosing identical ion ranges and peak concentrations for both elements. Electrical characterization based on CV, IU, pulsed Ct and It measurements were performed at MOS capacitors. The investigations reveal significant differences for Ge and Si NC containing gate oxides. Ge NCs near the Si/SiO₂ interface are characterized by fast charging / discharging and a flatband voltage shift of several volts. In contrast, Si implanted oxides show memory effects with a smaller flatband voltage shift, but considerably improved data retention. In both cases charging is possible for electrical field strength of 4-6 MV/cm, well below the Fowler-Nordheim tunnelling region. The varying electrical properties correlate with differences in the spatial distribution of ion beam synthesized Ge and Si NC in thin SiO₂ films, which were investigated by XTEM and RBS. The change of spatial distribution during annealing is due to different thermodynamics of NC evolution and chemical processes especially in thin SiO₂ films.
- 10:30 BREAK
- E-X.1** 11:00 -Invited- NANOCRYSTALS FABRICATION BY ULE IMPLANTATION FOR NON-VOLATILE MEMORIES
P. Normand E. Kapetanakis, P. Dimitrakis, D. Tsoukalas, IMEL/NCSR "Demokritos", 15310 Aghia Paraskevi, Greece, K. Beltsios, Department of Materials Science and Technology, University of Ioannina, Greece, C. Bonafos, G. Ben Assayag, A. Claverie, CNRS/CEMES, 29 rue Jeanne Marvig, 31055 Toulouse, France, J. Van Den Berg, Physics Department, University of Salford, Salford M5 4WT, U.K., V. Soncini, ST Central R&D Agrate, Via Olivetti 2, 20041 Agrate Brianza, Italy, A. Agarwal, M. Ameen, Axcelis Technologies, Inc., 55 Cherry Hill Drive, Beverly MA 01915, USA, M. Perego, M. Fanciulli, Laboratorio MDM - INFN, Via C. Olivetti 2, 20041 Agrate Brianza (MI), Italy
Memory cells made of a single metal-oxide-semiconductor (MOS) field-effect-transistor with nanocrystals (NCs) embedded in the gate oxide are a subject of intense research activity aiming at high-density low-voltage memory applications. Among the different techniques leading to the development of semiconductor NCs (e.g. Si, Ge) within silicon dioxide layers, the ultra low-energy (ULE) ion beam synthesis (IBS) is of substantial interest as it allows for the formation of a two-dimensional array of Si NCs in thin SiO₂ layers at relatively low doses and at a location tunable through the choice of implantation energy. Our recent research on NC memories obtained by using the ULE-IBS technique led to attractive results suggesting that further elaboration on the technological routes may lead to structures of substantial potential impact for mainstream microelectronics. The effect of implantation and post-implantation process parameters on the evolution and arrangement of silicon NCs in thin SiO₂ layers will be presented and correlated with the electrical properties of MOS devices incorporating such implanted oxides. An important point of concern in the use of the ULE-IBS technique is related to the damage induced by implantation that strongly affects the integrity of the oxide, and thus, the memory characteristics of the devices. This major issue will be discussed as well as the fabrication options allowing for an effective healing of the oxides. Finally, the memory characteristics (programming time and voltage, endurance and retention time) of NC floating-gate MOS devices fabricated through the use of the ULE-IBS technique will be analyzed and compared to those of conventional floating-gate memory cells.

- E-X.2** 11:30 POST-IRRADIATION PENETRATION OF H₂¹⁸O HUMIDITY INTO NANOSCALE SiO₂ FILMS
K.-H. Heinig(a), B. Schmidt(a), T. Müller(a), M. Fanciulli(b), M. Perego(b), (a)Research Center Rossendorf, Dresden, Germany, (b)Laboratorio MDM-INFM, Agrate, Italy
 It is well-known that irradiation of dielectrics produces a variety of bulk and interface defects. For this reason it is commonly presumed that ion irradiation of the gate oxide of MOS transistors has to be avoided. However, in special cases, the fabrication of advanced MOS devices requires ion implantation through or into gate oxides. An example is the novel process of nanocluster formation in gate oxides of multi-dot nonvolatile memories by ion beam synthesis. The post-irradiation thermal treatment required for nanocluster formation anneals these defects.
 Recently, another ion-irradiation-induced surface modification of SiO₂ has been found [1]. Humidity penetrates into ion-bombarded thin SiO₂ films, which might cause more problems to nonvolatile memory fabrication than implantation-induced defects. Here, using the isotope ¹⁸O as a tracer, we present a direct study of humidity penetration into damaged SiO₂. After 75keV Si⁺ irradiation through 15 and 100nm thick Si¹⁶O₂ layers in vacuum, the implantation chamber was filled with an artificial atmosphere of N₂ containing 45% relative humidity of H₂¹⁸O. This artificial atmosphere simulates standard clean room ambient (air, 45% relative H₂¹⁶O humidity, 22°C). For different Si⁺ doses, ¹⁸O depth profiles of as-implanted and annealed samples were determined by ToF SIMS. The consequences of penetration of ambient humidity on the fabrication of non-volatile memories will be discussed.
 [1] B. Schmidt, D. Grambole, F. Herrmann, Nucl. Instr. and Methods B 191 (2002) 482.
- E-X.3** 11:45 STUDY OF CHARGE TRAPPING AND BLUE ELECTROLUMINES-CENCE IN HIGH-DOSE Ge IMPLANTED SiO₂ LAYERS
A.N. Nazarov, I.N. Osiyuk, V.S. Lysenko, Institute of Semiconductor Physics, 03028-Kyiv, Ukraine, T. Gebel, Nanoparc GmbH, 01328 Dresden, Germany and W. Skorupa, Institute of Ion Beam Physics and Material Research, Forschungszentrum Rossendorf e.V., POB 510119, 01314 Dresden, Germany
 This work addresses electron and hole trapping in Ge implanted and rapid thermal annealed (RTA) SiO₂ layers of the Al-SiO₂-Si structures during high-field electron injection both from the Si substrate and the Al electrode. Using of constant current regime of the electron injection and studying of change of applied bias and shift of C-V characteristics allowed to find parameters of electron and hole traps created by high-dose Ge implantation (D=6.5x10¹⁶ ions/cm²; E=50 keV) and to determine the hole traps location.
 It has been shown by RBS technique that in thin SiO₂ layer (near 80 nm) increase of RTA duration (from 3 to 150 s) resulted in the Ge atom diffusion towards the SiO₂/Si interface and decrease of the Ge atom concentration inside of the oxide. A good correlation between concentration of the electron traps possessing of capture cross-section above then 10-14 cm² with Ge atom concentration inside of the oxide has been revealed. It has been found, that intensity of the blue electroluminescence (EL) measured on the similar structures with semi-transparent ITO electrodes also decreased with increase of the RTA duration. Positive charge generation in the SiO₂/Si interface during the electron injection has been shown to be associated with the anode hole injection mechanism at small RTA duration and the trap creation mechanism after 150 s RTA. Connection of the charge trapping and the blue EL intensity has been considered.
- 12:00 LUNCH

Thursday, June 12, 2003
Jeudi 12 juin 2003

Afternoon
Après-midi

E-XI.1 13:30

CRYSTALLINE NANOSYSTEMS DEVELOPED IN TiO₂ BY "CONVENTIONAL"- AND "PATTERNED"- AU-ION IMPLANTATION

R. Fromknecht(a), G. Linker(a), K. Sun(b), S. Zhu(b), L.M. Wang(b), A. van Veen(c), M.A. van Huis(c), T. Weimann(d), J. Wang(d), J. Niemeyer(d), F. Eichhorn(e), T. Wang(e), (a)Forschungszentrum Karlsruhe, Institut für Festkörperphysik, Germany, (b)The University of Michigan, Dept. of Nucl. Eng. and Rad. Science, USA, (c)Interfaculty Reactor Institute, Delft University of Technology, The Netherlands, (d)Physikalisch-Technische Bundesanstalt Braunschweig, Germany, (e)Forschungszentrum Rossendorf, Institut für Ionenstrahlphysik und Materialforschung, Dresden, Germany

Au-ions were "conventionally" implanted into TiO₂-single crystals with doses ranging from 2x10¹⁶Au⁺/cm² to 6x10¹⁶Au⁺/cm² at RT and thermally annealed at temperatures of 550K to 1550K. The Au-atoms precipitate to nanocrystals already during implantation at RT with an average particle size of 1.5nm. HRTEM investigations revealed that the Au-nanocrystals, embedded in amorphous TiO₂-regions, have a broad size and range distribution varying from large sizes in the near surface region to smaller sizes at larger depths. In the annealing process a reorientation of the Au-nanocrystals is observed, with the main effect of a decrease of the (111)-peak and an increase of the (200)-peak in the XRD spectra. After annealing at 1000K the particle size of the textured Au-implant was evaluated to ~6nm; this means that during annealing the particles grow, leading to a partially coherent orientation in the disordered TiO₂-matrix. "Patterned" implantation at RT performed through a metal mask with holes of 120µm diameter resulted in an almost equidistant arrangement of the Au-nanocrystals with a narrow size distribution of 2-6nm in the near surface region. When the "patterned" Au-ion implantation was performed through an e-beam resist mask (50nm x 50nm squares), with an order of magnitude reduced ion dose at RT and annealed at 1000K, a periodic structure of the Au-nanocrystals with a narrow size distribution was achieved in a crystalline TiO₂-matrix.

E-XI.2 13:45

CHARACTERIZATION AND ROOM-TEMPERATURE FERROMAGNETIC PROPERTIES OF CO-DOPED TiO₂ FILMS PREPARATION BY COBALT IMPLANTATION

K.H. Cheng, K.W. Lo, Y.W. Lai, M.F. Chiah, W.M. Tsang, N. Ke, W.Y. Cheung, S.P. Wong, Department of Electronic Engineering, The Chinese University of Hong Kong Shatin, N.T., Hong Kong, China

We have performed cobalt implantation using a metal vapor vacuum arc (MEVVA) ion source into TiO₂ thin films prepared by RF sputtering onto thermally grown silicon dioxide layers on Si substrates. The MEVVA implantation was performed at an extraction voltage of 65 kV to doses ranging from 1.4x10¹⁶ cm⁻² to 1.4x10¹⁷ cm⁻². Annealing was performed in vacuum at 600°C for 2h. The cobalt composition and distribution in these implanted Ti(1-x)Co(x)O₂ films was studied using Rutherford backscattering spectrometry. The crystal structure was studied using x-ray diffraction. The optical properties were studied using spectroscopic ellipsometry in the wavelength range from 350 to 700 nm. The magnetic properties were measured by vibrating sample magnetometry. We observed clear room-temperature ferromagnetic properties for all the as-implanted and annealed samples prepared under the above conditions. Our preliminary results showed that both the saturation magnetization M_s and coercivity H_c seemed to exhibit an oscillatory dependence on the implantation dose. We speculate that this could be an indication of the separation dependence of magnetic interaction between isolated Co atoms, in analogy to the oscillatory dependence on spacer thickness shown in the giant magneto-resistance effect in magnetic multilayer structures. The measured M_s values ranged from 0.5 µB/Co atom to 2.1 µB/Co atom and the coercivity values ranged from 200 Oe to 500 Oe. The correlation between the optical properties, the magnetic properties and their structures will be discussed.

This work is supported in part by the Research Grants Council of Hong Kong SAR (CUHK4221/00E).

E-XI.3 14:00

PRECIPITATION OF SILICON AND METAL PARTICLES IN TRIETHOXY-SILANE UNDER ION IRRADIATION; OPTICAL AND MAGNETIC APPLICATIONS

J.C. Pivin, C.S.N.S.M., Bât 108, 91405 Orsay Campus, France

Gel and polymeric coatings are easily transformed in glasses by ion irradiation, with much less tendency to cracking and a stronger hydrogen depletion than those submitted to treatments at high temperatures. Among them, triethoxysilane (TH: SiH(OC₂H₅)₃) is an attractive precursor of composite materials with optical and magnetic applications. First, both types of treatments lead to the formation of silicon nanoparticles in TH. Their optical excitation can be used for enhancing the infrared luminescence of Er or Nd, introduced by addition of a salt to the precursor or by ion implantation, as evidenced in this paper. Beside that, the reduction ability of the hydrido group for metallic salts permits to obtain nanoparticles of metals. This reduction is achieved more easily under ion irradiation than by treating the films in vacuum at high temperatures and the particles exhibit a narrower range of sizes in the irradiated films (characteristics which is researched for electromagnetic applications). Examples presented in this contribution are the synthesis of Cu clusters, with a noticeable plasmon resonance in the visible useful in non-linear optics, and of Fe, Ni clusters, with a superparamagnetic behavior. The precipitation kinetics is studied by means of TEM and optical measurements. The optical resonance or the magnetization of particles are compared in irradiated and heat treated films.

- E-XI.4** 14:15 STRUCTURAL AND MAGNETIC PROPERTIES OF FE-AL SILICA COMPOSITES PREPARED BY SEQUENTIAL ION IMPLANTATION
C. de Julián Fernández, G. Mattei, C. Sada, V. Bello and P. Mazzoldi, Dip. Fisica, INFN Univ. Padova, via Marzolo 8, 35131 Padova, Italy, M.A. Tagliente and L. Tapfer, ENEA-CR Brindisi, SS.7 Appia km. 714, 72100 Brindisi, Italy, C. Maurizio, INFN - GILDA, ESRF, Rue J. Horowitz, BP 200 Grenoble, France, G. Battaglin, INFN Dip. Chimica-Fisica, Univ. Venezia, Calle Larga Santa Marta 2137, 30123 Venezia, Italy and C. Sangregorio and D. Gatteschi, LAMM - Dip. Chimica, Univ. Firenze, via della Lastruccia 3, 50019 Sesto Fiorentino, Italy
 Fe_xAl_{1-x}SiO₂ (x = 0.55, 0.5, 0.45) composites have been prepared by sequential ion-implantation technique. A nanostructural and magnetic characterization has been realized to determine the alloy formation at nanoparticle level. The role of the Fe/Al composition and of the ion implantation order are investigated. TEM studies show the presence of a heterogeneous nanostructure in the implanted region, which is characterized by the existence of dispersed nanoparticles with a particle size distribution of 2 to 10 nm. The Fe/Al in-depth concentration ratio measured by SIMS and RBS is not uniform in the implanted region. GI-XRD and SAED studies indicate that, depending on the Fe/Al implanted ratio and on the implantation order, different percentages of three crystalline nanophases are present in the samples: fcc Al, bcc Fe and another bcc phase, which can not be indexed as a Fe-Al alloy nanophase having a lattice parameter smaller than the one of the α -Fe. Magnetic measurements confirm the formation of the Fe-alloy based nanoparticles. Indeed, magnetic moments and Curie temperatures smaller than those of pure-Fe samples have been obtained. Low temperature hysteresis loops do not saturate at high field (6 T) and show low coercive fields, indicating the presence of magnetic frustration effects. Also, ZFC-FC measurements indicate that nanoparticles exhibit superparamagnetic behavior with a blocking temperature distribution that depends on the Fe/Al ratio and on the implantation order.
- 14:30 BREAK
- E-XII.1** 15:00 A POSITRON BEAM STUDY OF HYDROGEN CONFINED IN NANO-CAVITIES IN CRYSTALLINE SILICON
H. Schut, H. van Gog, A. van Veen, M.A. van Huis and S.W.H. Eijt, Interfaculty Reactor Institute, Delft University of Technology, Mekelweg 15, 2629 JB Delft, The Netherlands
 Helium and hydrogen ion implantation and Positron Beam Annihilation (PBA) techniques (Doppler Broadening (DB) and Two Dimensional Angular Correlation of Annihilation Radiation (2D-ACAR)) have been applied to study the behavior of hydrogen confined in nanometer-size cavities in crystalline silicon. In particular, our interest is focussed on the choice of the implantation parameters (dose and energy) and the subsequent annealing treatments leading to a transition of hydrogen from the gas phase into the solid phase. Cavities were created by He ion implantation at 33 keV to a dose of 3×10^{16} cm⁻², followed by an anneal in vacuum at 800C for 30 minutes. As observed by PBA the annealing leads to the formation of cavities in a 150 nm wide band starting at a depth of approximately 230 nm below the surface. Next, the samples were implanted with hydrogen ions at 28 keV to doses of (1, 3 and 9) $\times 10^{16}$ cm⁻² followed by annealing from 200C to 1000C in steps of 100C. Results for the low dose H implantation show two main features. For annealing up to 600C a gradual filling of the cavities is derived from the reduction in DB-parameter and the p-Ps contribution in the 2D-ACAR spectra. For temperatures above 600C a release of H is observed. The results obtained for the intermediate and high dose are discussed in terms of the intensity and the width of the p-Ps signal and will be correlated to the outcome of swelling and Thermal Desorption Spectroscopy measurements.
- E-XII.2** 15:15 THERMAL EVOLUTION OF He-CAVITIES IN VACANCY-RICH SILICON
C.L. Liu, E. Ntsoenzok, M. F. Barthe, P. Desgardin, CNRS/CERI, 3A, rue de férollerie, 45071 Orléans, France, D. Alquier, LMP, 16 Rue Pierre et Marie Curie, B. P. 7155, 37071 Tours Cedex, France, S. Ashok, Electronic Materials and Processing Research Lab, Pennsylvania State University, University Park PA 16802, USA, M.O. Ruault, C.S.N.S.M./ CNRS, 91405 Orsay Campus, France
 CZ p-type Si (100) samples were first implanted with 2 MeV Si ions at a dose of 1×10^{16} /cm², which introduces vacancies in excess of the equilibrium concentration in the region close to the surface, as confirmed by positron annihilation spectroscopy (PAS) measurements. All these samples were then subjected to 50 keV He ions at doses ranging from 5×10^{15} to 5×10^{16} He/cm². Thermal evolution of He-cavities was then studied by cross sectional transmission electronic microscopy (XTEM) and compared with reference samples (silicon implanted only by He). Our results show that the presence of vacancies can significantly influence the formation of He-cavities. For the dose of 2.83×10^{16} He/cm², more cavities are formed. These cavities are less faceted than reference ones. However, when increasing dose to 5×10^{16} /cm², the cavity band seems to shift toward the surface. Meanwhile the mean size of cavities is much smaller than that obtained in the reference sample. The results are qualitatively interpreted in combination with PAS and RBS/c results.

E-XII.3 15:30 **COMPARISON OF THERMALLY AND MECHANICALLY INDUCED SI LAYER TRANSFER IN HYDROGEN-IMPLANTED SI WAFERS**
T. Höchbauer(a), A. Misra(a), M. Nastasi(a), K. Henttinen(b), T. Suni(b), I. Suni(b), S.S. Lau(c), W. Ensinger(d), (a)Los Alamos National Laboratory, Los Alamos NM 87545, USA, (b) VTT, Center of Microelectronics, Tekniikantie 17, 02150 Espoo, Finland, (c)University of California San Diego, La Jolla CA 92093, USA, (d)University of Marburg, Dept. Chem., Hans-Meerwein-Str., 35032 Marburg, Germany
Hydrogen ion-implantation into Si and subsequent heat treatment has been shown to be an effective means of cleaving thin layer of Si from its parent wafer. This process has been called smart-cut (TM) or ion-cut. We investigated the cleavage process in H-implanted silicon samples, in which the ion-cut was provoked thermally and mechanically, respectively. A <100> oriented p-type silicon wafer was irradiated at room temperature with 100 keV H₂⁺-ions to a dose of 5*10¹⁶ /cm² and subsequently joined to a handle wafer. Ion-cutting was achieved by two different methods: (1) thermally by annealing to 350 °C and (2) mechanically by insertion of a razor blade sidewise into the bonded wafers near the bond interface. The H-concentration and the crystal damage depth profiles before and after the ion-cut were investigated through the combined use of elastic recoil detection (ERD) analysis and Rutherford backscattering spectroscopy (RBS). The location at which the ion-cut occurred was determined by RBS in channeling mode and cross-section transmission electron spectroscopy (XTEM). The ion-cut depth was found to be independent on the cutting method. The gained knowledge was correlated to the depth distribution of the H-platelet density in the as-implanted sample, which contains two separate peaks in the implantation zone. The obtained results suggest that the ion-cut location coincides with the depth of the one H-platelet density peak located at a larger depth.

E-XII.4 15:45 **BURIED SILICON DIOXIDE IN SI FORMED IN A PRECURSOR NANOCAVITY LAYER**
A. van Veen, H. Schut, A. Rivera, H. van Gog, S.W.H. Eijt, Interfaculty Reactor Institute, Delft University of Technology, The Netherlands
Internal Thermal Oxidation (ITOX) of a buried porous layer in silicon is a new successful method to fabricate SOI material. The porous layer consists of helium induced nanocavities and the oxygen permeates through the top silicon layer and forms oxide starting at the internal surfaces of the cavities. In the present work buried oxide layers are produced by implantation of silicon with helium ions. The helium energy is chosen at 100 keV in order to create a band of nanocavities stretching from 700 to 900 nm below the surface. In a few cases multi-energy implantation with 80 and 140 keV was employed to widen the cavity band. Doses were of the order of 5 10 16 cm⁻² per chosen energy. The implantation was followed by annealing to 800°C in order to convert helium bubbles into nanocavities. Oxidation was carried out at temperatures varied from 1000-1200 C. Depth profiles of the layered oxide/top silicon/buried oxide/substrate silicon system were made by Positron Beam Analysis (PBA). The thickness of the different layers was determined and the defect population in the silicon was measured. The quality of the ITOX produced buried oxide was compared with that of standard SIMOX and Unibond oxide.

16:00-19:00 **POSTER SESSION II**

E/PII.01 **A DC HF CVD PROCESS TO GROW CARBON NANOSTRUCTURES (DIAMOND, NANOTUBES, FIBERS, ...)**
CS Cojocaru(a), M. Larijani(a), F. Le Normand(a), P. Veis(b), (a)IPCMS, UMR 7504 CNRS, BP 43, Bat 69, 23, rue du Loess, 67034 Strasbourg Cedex, France, (b)Dept. of Plasma Physics, Faculty of Mathematics Physics and Informatics, Comenius University, Mlynska dol. F2, 84248 Bratislava, Slovakia
We will describe a new DC HF CVD process that is quite convenient to grow carbon nanostructures (diamond, nanotubes, fibers, ...) with a high selectivity. The process is designed in an ultra high vacuum chamber directly connected to a surface analysis chamber provided with XPS, AES, ELS probes and surface cleaning and deposition tools (ion beam, thermal vacuum evaporation, ...). The DC HF CVD process combines the activation of a gas mixture (either C₂H₂:H₂:NH₃ or CH₄:H₂ including a carbon source) both by a plasma created between two electrodes and by hot filaments. Thus both ions and neutral radicals are obtained at a high density, probed by emission of the light in the visible, and focussed onto the substrate. This process was tested for the elaboration of two kinds of carbon materials : the nucleation of diamond, where a strong density of diamond nuclei were obtained after very short nucleation times, and the growth of aligned carbon nanotubes on a SiO₂/Si(100) substrate where a dispersion of metallic particles (Co, Ni) was preliminary performed.

E/PII.02 **PLASTICITY EFFECT OF ION IMPLANTED ALUMINA CERAMIC**
Caroline Legrand-Buscema, Pascal Aubert, Stéphane Coindeau, Laboratoire d'études des Milieux Nanométriques (LMN) University Evry-Val d'Essonne, Bd F. Mitterrand, 91025 Evry, France, Jacek Jagielski*, Anna Piatkowska, Z. Librant, Institute of Electronic Materials Technology, Wolczynska 133, 01-919 Warszawa, Poland *also with The Andrzej Soltan Institute for Nuclear Studies, 05-400 Swierk/Otwock, Poland
Alumina ceramic present attractive mechanical properties for numerous engineering applications. Tribological properties of this material can be improved accordingly to Tabor and Bowden theory which predicts a diminution of the friction coefficient of a substrate recovered by a thin, soft surface layer formed via, e.g., an ion implantation process. The aim of this study is to analyze the effect of high plasticity discovered recently in irradiated alumina. Mechanical properties were studied by nanoindentation. Typical forces used are 1 mN for a depth indentation inferior to 100 nm. Ion implantation of a noble gas ions (Ar⁺ and Kr⁺) with an energy of 150 keV and a dose ranging from 1 10¹⁵ atom/cm² up to 1 10¹⁷ atom/cm² were used. The decrease of the hardness of the surface layer correlating with the increase of radiation damage is the first effect observed. The substrate reveals a typical hardness equal to 22 GPa, the hardness progressively decreases with the radiation damage caused by the irradiation with noble gas ions. The lowest hardness (2.7 GPa) was measured for the sample in which the radiation damage reached the highest value used of 174 dpa. In the beginning of the unload part, the different displacement curves present an increasing slope with the increasing radiation damage. This effect is related to the increase of the samples surface plasticity.

- E/PII.03** MECHANICAL PROPERTIES OF PULSED LASER-DEPOSITED HYDROXYAPATITE THIN FILM IMPLANTED AT HIGH ENERGY WITH N⁺ AND AR⁺ IONS
PART I: NANOINDENTATION WITH SPHERICAL TIPPED INDENTER
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Hydroxyapatite (HA) is extensively studied for various applications in bone implantology. Applied as coatings and thin films, HA increase the biocompatibility of the titanium-based prostheses, showing excellent bioactivity and osteoconductivity. However, the mechanical properties (hardness and elastic modulus) of these structures are generally poor. These low characteristics are related to the poor intrinsic mechanical characteristics of the HA material, but also to the lack in density of the produced films. High energy ion-beam implantation was proved to be an appropriate tool for surface modification and densification of materials. Therefore, the mechanical resistance of the HA films can be increased by ion bombardment. We report here a comparison between the effects of an ion beam implantation treatment on the mechanical characteristics of HA films grown by pulsed laser deposition. We used for deposition a KrF* excimer laser. Crystalline and stoichiometric HA films were grown on Ti-5Al-2.5Fe alloy substrate, previously coated with a TiN buffer layer. After deposition, the film were implanted with ions of N⁺ and Ar⁺ of high energy (1-1.5 MeV range) and dose set at 1016 at cm⁻². The hardness and elastic modulus were determined by nanoindentation tests using a spherical tipped nanoindenter with a 2 μm-tip radius. >From the load-displacement curves, we put into evidence an enhancement of the mechanical characteristics of the HA films after implantation, especially for those implanted with N⁺ ions [...] This improvement of the mechanical characteristics is related to the changes of surface morphology and the densification of the HA layer after ion treatment.
- E/PII.04** MECHANICAL PROPERTIES OF PULSED LASER-DEPOSITED HYDROXYAPATITE THIN FILM IMPLANTED AT HIGH ENERGY WITH N⁺ AND AR⁺ IONS
PART II: NANO-SCRATCH TESTS WITH SPHERICAL TIPPED INDENTER
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Hydroxyapatite (HA) ceramics are continuously studied in order to develop a new generation of bioactive and osteoconductive bone prostheses. HA are currently produced in form of thin films on titanium alloys corps of prostheses. In spite of an excellent biocompatibility, these films suffer from poor mechanical properties (hardness, elastic modulus and adherence). In this study, we report a method to improve the adherence of the HA films, using an ion beam implantation treatment. Crystalline HA films were grown by pulsed laser deposition method (PLD), using an excimer KrF* laser. Films were deposited at room temperature in vacuum on Ti-5Al-2.5Fe alloy substrates, previously coated with a ceramic TiN buffer layer, and then annealed in ambient air at 500°C-600°C. After deposition the films were implanted with N⁺ and Ar⁺ ions accelerated at high energy (1-1.5 MeV range) at a fixed dose of 1016 at.cm⁻². The intrinsic mechanical resistance and adherence to the TiN buffer layer of the implanted HA films have been evaluated by nano-scratch tests. We used for measurements a spherical indenter with a tip radius of 2 μm. Different scratch tests have been performed on implanted and unimplanted areas of films, to put into evidence the effects of N⁺ and Ar⁺ ion implantation process. Tests were performed, first at constant load, and then with increasing load during the test. Results show an enhancement of the dynamic mechanical properties in the implanted zones and influence of the types of the implanted species. The best results are obtained for films implanted with nitrogen. The modes of failure of the films under the tip charge are described.
- E/PII.05** INFLUENCE OF IMPLANTATION OF AL IONS ON OXIDATION OF COPPER
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Copper film was deposited by vacuum evaporation on oxidized single crystalline silicon substrate. The copper film was implanted by aluminum ions using the Heavy Ion Cascade ion implanter of the KFKI Campus in Budapest. The Al implantation was done using 140 keV and nominal dose of 1.4x10¹⁷ ion/cm². Ex situ and in situ spectroellipsometric investigation of room temperature oxidation of ion-implanted copper surface was performed. It was found that the native oxide layer formed earlier on the surface of the copper was sputtered off during the aluminum ion implantation (evaluations give a rather low thickness value (0.08 nm and 0.04 nm of CuO and Cu₂O)). This made possible the in situ study of the growth of the newly formed native oxide layer on the ion implanted surface. Evaluations of spectroellipsometric measurements performed on the same sample after 11 days later give layer thicknesses 2.2 nm and 1.5 nm. The thickness values of oxidation film of the unimplanted sample are 5.7 and 4.0 nm.
- E/PII.06** DIRECT EVIDENCE OF THE RECOMBINATION OF SILICON INTERSTITIAL ATOMS AT THE SURFACE
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Transient enhanced diffusion (TED) is strongly influenced by the thermal evolution of extrinsic defects which form when annealing ion implanted silicon. Recent simulations have shown that boron (B) TED is due to a time-decaying interstitial supersaturation located on the defects and a flux towards the wafer surface. However, no experiments have clearly demonstrated such dependence. To this purpose, Si implant at 100 keV, 2x10¹⁴ ions/cm² was performed into Si substrate containing four lightly-doped B marker layers epitaxially grown by CVD. After implantation the samples were annealed in nitrogen gas at 850°C using rapid thermal annealing (RTA) for different times. B profiles were analysed by SIMS. Extraction of boron TED as a function of time and depth was performed using a kick-out method. Our results clearly show a time decrease of the interstitial supersaturation, and, for the first time, a decrease of the supersaturation towards the surface. Subsequently, we have simulated our experimental results by developing a physical model describing interactions between point defects, extended defects and dopants upon annealing. The agreement between the simulations and experimental data clearly demonstrates that the recombination of silicon interstitials at the surface has to be taken into account.

- E/PII.07** FORMATION AND DISSOLUTION OF BORON-INTERSTITIAL CLUSTERS
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 Boron is the primary p-type dopant in Si device fabrication. It was largely demonstrated that in presence of a high self-interstitials (I) supersaturation (typically produced by ion implantation and subsequent annealing) and a high boron concentration (above 10^{18} B/cm³), B and I's tends to co-precipitate in immobile and electrically inactive clusters (BIC). This fact severely hinders the scaling-down of Si microelectronic devices, which requires very high B concentration fully active. While this topic is widely investigated both theoretically and experimentally, some open questions still remain about the stoichiometry and the dissolution kinetics of BICs. In this work we have investigated the stoichiometry of BICs produced in a MBE-grown B box by Si implantation and annealing. Low concentration B delta doping were used to quantitatively monitor the I diffusion. A stoichiometry ratio of about 1:1 between B and I was found for the BICs formed at 815°C. The BIC dissolution kinetic was investigated by analysing the concentration profiles at different temperatures and times with a simulation code able to deconvolve the processes of B diffusion and B release from clusters. A thermal activation energy of 3.2 ± 0.4 eV was found for the boron release from the clusters.
- E/PII.08** DIFFUSION OF ION BEAM INJECTED AUTO INTERSTITIAL DEFECTS IN SILICON LAYERS GROWN BY MOLECULAR BEAM EPITAXY
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 Silicon auto interstitial (I) defects have a key role in dopants and impurities behavior in crystalline Si, thus the understanding of I diffusion properties is fundamental for Si-based microelectronic devices. Molecular Beam Epitaxy (MBE) grown Si presents a particular behavior due to the presence of a significant background of intrinsic I traps. The common believing is that I's diffuse in MBE materials remaining in dynamic equilibrium with traps through a trapping/de-trapping mechanism, leading to an effective I diffusion coefficient, which is significantly lower than in pure Si. We performed a large set of experiments on the diffusion of ion beam injected I's in MBE Si with boron delta superlattices showing a quite different and complex scenario: a) the traps appear to be a true sink for I's, being the de-trapping mechanism significant only for long annealing times; b) the I recombination at the surface, contrarily to many previous works, has to be considered. All the physical parameters needed to quantitatively model the I diffusion in MBE Si (concentration of intrinsic traps, surface evaporation length, de-trapping characteristic time, diffusion length of B in deltas) have been evaluated at different annealing temperatures, and the results have been compared to existing literature data.
- E/PII.09** A SIMPLE MODEL FOR BORON TRAPPING BY HE-IMPLANTATION EXTENDED DEFECTS IN SI: THE ROLE OF BORON DIFFUSIVITY
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 High dose Helium implantation leads to the formation of extended defects, such as cavities and dislocations. These defects strongly interact with impurities like metal and dopant, affecting significantly their final profile. The detailed mechanisms governing the B gettering on these defects are still unclear as defects formation and gettering occur at the same time. However, it is crucial for an industrial device fabrication, which integrate the He-gettering technique, to have a predictive simulation tool. In this paper, we will propose a simple model that accounts for experimental observations, i.e., diffusion and trapping of B with the He-induced extended defects. The model was tested using two sets of experiments. Highly-doped (1×10^{18} B/cm³) P-type <111> wafers were used as well as B implanted N-type <111> wafers. In both cases, a well-defined defect band was created by a He implantation at 40 keV for a dose of 5×10^{16} He+/cm² followed by Furnace Annealing for various times ranging from 15min to 8h and temperatures in the range of 650°C up to 1000°C. Secondary Ion Mass Spectrometry (SIMS) was used to follow the dopant profile. Numerical parameter extraction, using PROMIS 1.5 code, provides the evolution of the B diffusion coefficient with regard with the defect band. This work sheds light on the impact of diffusivity variation on the gettering phenomenon and clarify the interaction of B with He-induced extended defects.
- E/PII.10** UPHILL-DIFFUSION MODELING OF BERYLLIUM IMPLANTS IN GAINAS : COMPARISON BETWEEN SEVERAL P-TYPE DOPANT DIFFUSION MODELS
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 In order to improve MHB technology (Metal Heterojunction Bipolar Transistor), phosphorus and beryllium have been coimplanted in InGaAs.
 Transient and uphill-diffusion of Be in GaInAs is studied and modeled for annealing temperatures of 745°C through 826°C with time duration of 15 to 120s. The redistribution of implanted ions during activation annealing was measured by Secondary Ion Mass Spectrometry (SIMS). To explain the observed depth profiles, kick-out models of the substitutional-interstitial diffusion mechanism which involves neutral Be interstitial species and positively charged group III self-interstitials, are proposed and compared with an other published model based on substitutional-interstitial diffusion mechanism which include dopant-point-defect interactions developed. So the roles of extended defects and nonequilibrium point defects in the implanted Be anomalous diffusion behaviour are taken into account to explain the diffusion phenomenon. Model parameter extractions have been discussed. Uphill-diffusion modeling of p-type dopant in GaInAs and GaAs have been compared. The role of extended defects in InGaAs after P and Be implantation has been discussed.

- E/PII.11** **DIFFUSION MODEL OF BORON IMPLANTED AT LOW-ENERGY IN CRYSTALLINE AND AMORPHOUS SILICON**
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 Several models have been proposed for the simulation of boron diffusion during annealing after implantation in silicon. It has been shown that Transient Enhanced Diffusion (TED) leads to disappear at sub-keV implant energies. Since boron concentration in silicon is higher than the boron solubility limit value, precipitation phenomena occur. Extended defects ($\{311\}$, EOR, ...) formation and boron precipitation affect both the redistribution during the annealing and activation of the boron. For these reasons, we have investigated the diffusion of low-energy boron implanted in crystalline and amorphized silicon and developed a simulation program which takes into account, on the one hand, the Ostwald Ripening of EOR defects which reduces the efficiency of the defects as a source of self-interstitials and, on the other hand, the effects of type I defects as a sink for self-interstitials and of boron precipitation. Experimental results have been simulated and consistent parameters have been found to fit the data. Boron Enhanced Diffusion effect has been studied. Model parameters extractions have been discussed and compared with the existing boron diffusion models.
- E/PII.12** **INDENTATION-INDUCED NANOSCALE PHASE TRANSFORMATIONS IN ION-AMORPHISED SILICON**
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 We have found that ion amorphised silicon undergoes intriguing phase transformations under nanoindentation testing. Furthermore, the deformation behaviour of the silicon depends dramatically on the nature of the amorphous silicon, whereby as implanted silicon deforms plastically without phase transformation, whereas annealed relaxed amorphous silicon undergoes a transformation to a high pressure metallic (β -Sn) crystalline phase on indentation loading and further transformations to Si-III or Si-XII crystalline phases on unloading.
 The silicon was amorphised using silicon ions of energy 30-600 keV to generate amorphous layers of a few tens of nanometres to over a micron. Indentation has been performed with ultra-small spherical indenters and analysis carried out using transmission electron microscopy, Raman spectroscopy and atomic force microscopy. A novel in-situ electrical measurement method has been used to probe the transformations during indentation and the thickness of the amorphous layer varied to probe the depth of the transformation as a function of indentation load. Models for the transformation behaviour in ion amorphised silicon are presented.
- E/PII.13** **THE INFLUENCE OF IN-SITU PHOTOEXCITATION ON A DEFECT STRUCTURE GENERATION IN AR+ IMPLANTED SI (111) CRYSTALS**
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 The influence of in-situ photoexcitation on the defect structure generation in Si(111) crystals implanted by Ar⁺ ions with energy of 100 keV and doses of (1-8) $\times 10^{16}$ cm⁻² was studied by high-resolution X-ray diffraction. The damage depth profile in the implanted layers was reconstructed from the diffraction curves obtained by the high-resolution X-ray diffraction in non-dispersive triple-crystal arrangement (n ; $-n$; n) with Bragg symmetrical reflections. The damage depth profile is described by both strain and static Debye-Waller factor profiles that can be determined from the shape of the diffraction curve. To reconstruct the profiles an autofitting procedure, based on a genetic algorithm, was used. The in-situ photoexcitation is found to contribute for the annihilation of Frenkel pairs that decrease the residual concentration of radiation induced point defects (RPD). The amorphisation of the damaged layer proceeds by a generation and a growth of RPD clusters. The vacancy- and interstitial-type clusters are spatially separated: the former are located closer to the surface than the latter ones. The influence of photoexcitation on the cluster growth with the dose increase is nonmonotonic.
- E/PII.14** **ION BEAM INDUCED COHERENT DISPLACEMENT IN Al ON Au SYSTEM**
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 Molecular dynamics has proven to be successful in studying ion beam induced complex surface effects, such as collision cascades and sputtering. Implanted ions lose energy as they penetrate the target material. If there is a thin layer of some other material on the surface of that target material, the ions lose different amount of energy per unit length while penetrating the system. The stopping power is different in these two materials. This may trigger an effect called coherent displacement, which produces planar nanoclusters on the thin surface layer. We have studied this phenomena by simulating the implantation of Au ions into a system of a thin layer of Al on the surface of Au bulk with molecular dynamics. The goal was to find irradiation conditions where most surface damage is produced by coherent displacement, and not other methods which produce less ordered surface structures.
- E/PII.15** **MICROSTRUCTURE OF N⁺ ION BEAM INDUCED EPITAXIAL CRYSTALLIZED Si**
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 Ion Beam Induced Epitaxial Crystallization (IBIEC) is being widely studied since it offers several advantages over thermally induced solid phase epitaxy. Moreover the potential applications of recovering MeV ion induced damage are becoming important in device technology to fabricate novel and three dimensional structures. In this paper we present the efficiency of IBIEC to recover thick (300 - 500 nm) amorphous layers produced by MeV heavy ions in Si (100) and discuss the changes in its microstructure. IBIEC has been carried out using 1.2 MeV N⁺ ions at substrate temperatures of 200, 300, and 400 °C. The micro-Raman technique indicates the epitaxial recovery of crystalline structure and the formation of nano-crystalline Si embedded inside the crystalline layer. The AFM measurement show the surface morphology and reconstruction of Si. The thickness of the regrown layer is determined by Rutherford backscattering channeling measurements. The regrowth rate shows an Arrhenius behaviour with an activation energy of 0.21 eV. These results will be discussed in the light of the mechanisms proposed.

- E/PII.16** DAMAGE SURFACE STUDY ON THIN AMORPHOUS SILICON OXIDE UNDER MEDIUM ENERGY ION IRRADIATION
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 The change in the surface topography of amorphous SiO₂/Si structure after heavy ion irradiation (in normal and grazing incidence) will be investigated by AFM.
 By using different ion species at different energies, a large range of electronic stopping power was covered (from 1 to 25 keV/nm). The used fluences were 5*10⁹ and 1*10¹⁰ ions/cm² in order to avoid the overlap of tracks. Two kinds of nanostructures have been observed on the surface after irradiation: hillocks in the case of a normal incidence irradiation and a specific track (a hole followed by a hillock in the irradiation direction) in the case of grazing incidence irradiation. These results will be compared to insulators irradiated in the same conditions (in normal incidence) (CaF₂ [1], quartz SiO₂[2], Al₂O₃[3] showing hillocks and amorphous SiO₂ showing holes[4]). Some possibilities for the origin of the tracks (in normal and grazing incidence) will be discussed.
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 [3] S.M.M.Ramos et al. , Nucl.Instr. and Meth.in Phys. Res.B 143 (1998) 319
 [4] S.M.M.Ramos et al. , Nucl.Instr. and Meth.in Phys. Res.B 191 (2002) 456
 The work is financed by European Commission through the Human Potential program Network EuNITT, Contract No. HPRN-CT-2000-00047.
- E/PII.17** COMPARATIVE ANALYSIS OF THE IMPLANTATION-INDUCED STRUCTURAL MODIFICATIONS IN GaAs AND Ge
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 Ion implantation introduces a variety of defects, disorder and damage into the material. The goal of this extensive study was to separate the effects of micro-structural modifications due to the implantation-induced damage from the effects arising from incorporation of foreign species into the lattice, especially important for very high ion doses. Three types of experiments have been performed, monitored and analyzed with Raman spectroscopy, and Rutherford backscattering:
 GaAs monocrystals were implanted in a wide range (3x10¹² to 3x10¹⁶ /cm²) of ion doses, using an equal total dose of 69Ga and 75As ions to preserve stoichiometry. For quantitative disorder assessment, the LO phonon peak in RS was analyzed within the 'spatial correlation' model. These results have been compared with a study in which monocrystalline GaAs was implanted with 30Si⁺ ions, ranging in doses from 8x10¹² to 3x10¹⁶ /cm², as well as with C, Co and Sn ions. While similar conclusions have been reached for smaller fluences, the microstructure of the amorphous network responded differently to the highest doses. To assess the differences between the binary and simple semiconductors, the results obtained on GaAs were compared with the analogous study on monocrystalline Ge implanted with 3x10¹² to 3x10¹⁶ /cm² 74Ge ions. Contrary to GaAs, in all implanted Ge samples, beyond the amorphization threshold dose (>10¹⁴ /cm²), a pronounced, dose dependent evolution of the amorphous matrix could be followed in RS.
- E/PII.18** TEM STUDY OF SOLID-PHASE EPITAXIAL GROWTH BEHAVIOUR OF NORMAL AND ANGLED Si IMPLANTED GATE STACK STRUCTURE
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 The addition of germanium to the source and drains of pMOSFETs creates a heterojunction between the silicon germanium source and the silicon channel. The subsequent valence band offset can reduce the off state leakage current and suppress parasitic bipolar action. This can be done by implanting Ge into the source and drain regions of the MOSFET. However, such Ge implants also create end of range (EOR) defects close to the source and drain junctions. The EOR defects can be moved deeper into the substrate by amorphizing the top layer of the wafer by implanting high energy Si into the part processed wafers after the Ge implant.
 Thermally induced solid phase epitaxial growth (SPEG) of the amorphous layer was examined by transmission electron microscopy (TEM) on a 200nm wide gate structure after various anneal times. Because the Si implant was made after the creation of the gate stack structure, a curved amorphous / crystal (a/c) interface was created below the gate electrode. EOR defects (dislocations) developed from the tip of the curved a/c interface during SPEG and extended to the gate after full regrowth. Annealing at 700°C for 20 minutes gave a fully re-crystallized structure with the gate returning to a polycrystalline structure. To make a defect-free region under the gate after annealing, two silicon implants were made at an angle of 30 degrees into each side of the gate stack. This resulted in a flat a/c interface below the gate electrode and eliminated defects under the gate electrode after regrowth.
- E/PII.19** LUMINESCENCE OF ALPHA-QUARTZ AFTER HOT GE IRRADIATIONS
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 We have studied cathodoluminescence (CL) in α -quartz irradiated at 900 °C with 120 keV Ge⁺ ions at fluences between 1x10¹⁴ and 1x10¹⁶ ions/cm² using the Göttingen 500 kV ion implanter IONAS. Rutherford backscattering channeling analysis with 900 keV He⁺⁺ revealed that the thickness of the amorphous layer decreased with decreasing Ge fluence. CL measurements were performed using a 5 keV electron beam at an incident angle of 60°. Four bands were observed at 289 nm (4.3 eV), 385 nm (3.2 eV), 515 nm (2.4 eV), and 621 nm (2.0 eV), respectively. At room temperature the 385 nm violet luminescence intensity is dominant and increases with decreasing the Ge fluence. But at 10 K measuring temperature, the same samples showed blue luminescence (453 nm). The transition from blue to violet occurred around 200 K. Results are also been obtained for various implantation temperatures and ion fluxes. The origin of the luminescence and type of defects will be discussed.
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- E/PII.20** NANOSIZED MORPHOLOGY AND PHOTOEMISSION OF ARSENIC IMPLANTED GERMANIUM FILM
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Germanium film of 140 nm thickness was deposited onto Si substrate and was implanted by As ions with 70 keV energy, 2.5×10^{14} ion/cm² dose. The morphology of the implanted film was determined by Rutherford Backscattering (RBS) and Cross Sectional Transition Electron Microscopy (XTEM). The distribution of contaminations (O,C) in the implanted layer were detected by SIMS and O16(He4,He4)O16 reaction. The depth dependence of the valence band density of states (DOS) was investigated by the measurements of the energy distribution of photoelectrons (EDC's) using Ar ion etching for profiling. The morphology of As implanted film was dominated by nanosized (10-100 nm) Ge islands separated by empty bubbles in 20-50 nm depth under the surface. At 0-20 and 70-140 nm depth range, the morphology of the as evaporated Ge film was not modified. Up to 20 nm from the surface and at larger thickness than 70 nm, the photoemission spectra were equivalent to the well-known results for evaporated Ge film. On the contrary in a depth of 20-50 nm the photoelectron spectra were similar to those data obtained for amorphous state of Ge induced by heavy ion (Sb) implantation II a-Ge. The depth profile of the morphology and the photoemission data indicate correlation between the morphology and valence band density of states of the ion implantation induced a-Ge (II a-Ge). As this regime was formed inside of an evaporated film isolated from environment, any environmental effect (contamination etc) can be excluded. The depth distribution of ion implanted amorphous Ge (II a-Ge) shows that the atomic displacement process can not be the origin of the II a-Ge.
- E/PII.21** ION BEAM SI SURFACE MODIFICATIONS FOR APPLICATIONS IN OPTOELECTRONICS AND PHOTOVOLTAICS
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Medium energy ion implantation combined with subsequent post-implantation thermal treatment leads to a nanoscale Si layered system inserted within a single-crystal matrix. The particular role of heterointerfaces and their transition zones produces unexpectedly good Si performance. For example, combined effects realisable in such a structure: built-in fields (strain and electric), band gap engineering, crystalline defects and nano engineering open new potentialities in optoelectronics and photovoltaics.
New effects have been shown experimentally taking into account, among other things, the i) spectral response, ii) c-Si and equivalent a-Si absorption coefficient (measured independently by two methods), iii) thickness of the frontal dead zone (obtained by EBIC), iv) depth and thickness of the amorphized layer (by X-TEM), and v) depth of the PN junction (by SIMS and SRP profiles). The synergy of the several effects required sufficiently developed structures which have been formed around a buried amorphization [APL 81,2002,4853]. The data obtained on test devices have been interpreted using recent developments of carrier collection theory and self-consistent calculations. Two of the most interesting results consist of a strong enhancement of strained zone photon absorbance and low energy carrier multiplication. It is shown that more than one electron per absorbed short-wavelength photon is collected in the active zone close to the crystalline/amorphous heterointerface.
- E/PII.22** THE RESEARCH OF THE MECHANISMS OF DISORDERING IN TWO-DIMENSIONAL THIN FILM Ni₃Al
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The mechanisms of disordering taking place in two-dimensional hexagonal thin film of Ni₃Al intermetallide were studied by the method of molecular dynamics. The intervals of thermoactivation temperature of vacancies migration were determined. It was found, that the temperature of vacancies activation in the sites of Ni atoms was lower than the temperature of vacancies activation in Al site. Main thermoactivating transformations, taking place at the migration of atoms by vocational mechanism, were investigated.
The character of interaction of PSD and vacancy depended on the distance and the position of the studying point defects. Temperature of the process activation increased with the growth of the distance between vacancy and PSD. At relatively low temperatures and keeping of stoichiometry conditions, the process of migration taking place by vocational mechanism could occur with the annihilation of PSD. The number of the additional PSD, caused by migrating vacancy increased with the growth of temperature. It was determined the role of divacancies in the processes of disordering. It was shown, that divocational complex was more mobile in comparison with single vacancies.
- E/PII.23** COOPERATIVE DYNAMICAL WAVES OF ATOMIC DISPLACEMENTS IN 2D CRYSTAL, CONTAINING POINT DEFECTS
M.D. Starostenkov, G.M. Poletaev, J.V. Patzeva, General Physics Department, Altai state technical university, Lenin st 46, Barnaul, 656099, Russia
Structure-energetical transformations in 2D crystal, containing vacancies and point defects of substitution, and displacement in the dependence on temperature, time and concentration of point defects were studied by the method of molecular dynamics. 2D nanocrystal was presented by the packing of the plane [111] of FCC lattice of pure metals Ni and Al and intermetallid Ni₃Al. Dynamical nanocrystals were characterized by the relative turns of atomic packing in comparison with start orientation in 2D crystal. The sizes of dynamical nanoblocks depended on temperature, concentration of point defects and their types. With the growth of temperature and concentration of point defects, the relative sizes of dynamic nanostructures and the boundary between the separate nanocrystal blocks decreased.

- E/PII.24** **LOW TEMPERATURE GROWTH OF CARBON NANOTUBES BY DIRECT ION BEAM DEPOSITION**
 V. Kopustinskas, S. Meskinis, V. Grigaliunas, S. Tamulevicius, G. Niaura, Institute of Physical Electronics, Kaunas University of Technology, Savanoriu 271, Kaunas, Lithuania
 Carbon nanotubes have been intensively investigated since first report about these nanomaterials in 1991. List of the possible applications of the carbon nanotubes is very impressive. In particular carbon nanotube emitters are purported to be ideal candidates for the next generation of field emission flat displays as well as for X-Ray and E-Beam Tube and lighting applications. Low temperature carbon nanotube synthesis is desirable for use of these nanomaterials in field emission display applications. It enables direct deposition of carbon nanotube emitter onto the glass that commonly is used as a low-cost substrate for display panels.
 In this study research on the low temperature catalytic growth of carbon nanotubes by low energy direct hydrocarbon ion beam is presented. The influence of substrate temperature, catalytic layer preparation, gas precursors and ion energy on the geometry and structure of the nanotubes was investigated. Raman spectroscopy and X-ray photoelectron spectroscopy (XPS) was used to investigate the synthesized nanostructures.
- E/PII.25** **ION BEAM ELABORATION AND MODIFICATION OF NANOPARTICLES: A MONTE-CARLO SIMULATION**
C. Cerruti(a), J.P. Stoquert(b), C. D'Orléans(b,c), C. Estournès(c), J.J Grob(b), J.L. Guille(c), F. Haas(a), D. Muller(b), M. Richard-Plouet(c), (a)IreS, 23 Rue du Loess, 67037 Strasbourg, France, (b)Laboratoire PHASE, 23 Rue du Loess, 67037 Strasbourg, France, (c)IPCMS-GMI, 23 Rue du Loess, 67037 Strasbourg, France
 The experimental study of Co nanoparticles, formed in silica layers by ion implantation and their evolution during irradiation, has shown some specific features(1,2). The size of the nanoparticles depends on the implantation fluence, temperature and flux. After implantation, their shape can be modified by irradiation with energetic heavy ions.
 Simulation of cluster's growth and deformation has been performed using a kinetic 3D lattice Monte-Carlo method, similar to that developed by Strobel and coworkers(3). The following improvements have been introduced in the model:
 - The layer structure is explicitly taken into account
 - a realistic Lennard-Jones interaction potential between Co atoms is used
 - ion induced local temperature changes are considered.
 The experimentally observed features are qualitatively understood within this approach.
 1. C. d'Orleans et al., Nucl. Instr. Meth. Phys. Res. In press
 2. C. d'Orleans et al., submitted
 3. M. Strobel et al., Nucl. Instr. Meth. Phys. Res B147 (1999)343
- E/PII.26** **STRESS AND ION-IRRADIATION INDUCED RELAXATION IN METALLIC THIN FILMS AND MULTILAYERS DEPOSITED BY ION BEAM SPUTTERING**
 F. Martin, G. Abadias, C. Jaouen, J. Pacaud, A. Debelle, A. Michel, Laboratoire de Métallurgie Physique, UMR 6630 CNRS, Université de Poitiers, Av. M. et P. Curie, 86962 Futuroscope-Chasseneuil, France
 The physical and especially the mechanical properties of thin films depend strongly on their intrinsic stress state and, in some cases, this stress can reach values near the theoretical shear strength, an effect that leads to the creation of significant defects such as delaminating or crack formation. For this reason, the ability to control the stress level is of prime importance, either in situ during the film growth, or ex situ, through thermal treatment or, in a more subtle way, by post-irradiation with energetic ions.
 Although the origin of the strain in thin films deposited by thermal evaporation is now thought to be well understood, this is definitely not the case for ion beam sputtering deposition, where large in-plane compressive stress can be observed. Data from X-ray diffraction analysis illustrate the specific strain and stress state in Mo thin films, as well as Mo/Ni multilayers epitaxially grown on Al₂O₃ [11-20] substrates. The state of stress in the multilayers is non biaxial, as expected from epitaxial growth due to the different symmetries of the (110) Mo and (111) Ni growth planes. The study continues by examining the evolution of the stress state in the Mo layers during irradiation with 400 keV Ar ions at low fluence. The results show that the coherency stress in the multilayers is combined with a hydrostatic type of stress that is the first to be relaxed, via the formation of defect clusters. The exact origin of this hydrostatic stress is yet to be resolved and additional experiments are currently undertaken. The presented results demonstrate the importance of ion beam irradiation as a tool for a controlled modification of thin films, thus giving insight in the physical processes that take place during the film growth.
- E/PII.27** **FINITE SIZE EFFECTS IN PHASE TRANSFORMATION KINETICS IN THIN FILMS AND SURFACE LAYERS**
Vladimir I. Trofimov, Institute of Radioengineering & Electronics of RAS, 11 Mokhovaya Street, 101999 Moscow, Russia
 In studies of phase transformation kinetics in thin films, until recent time is widely used familiar Kolmogorov-Johnson-Mehl-Avrami (KJMA) model despite it is applicable only to an infinite medium. In this paper, we present a modified KJMA model that takes into account finite size effects generated by a finite film thickness. The main concept of the model is a survival probability for any random point during transformation. Two model versions are explored: volume induced transformation (VIT) when new phase nuclei are formed in a film volume and surface induced transformation (SIT) when they are formed only on an interface or external film surface, and two nucleation mode are considered: instant nucleation at onset of transformation (IN) or continuous one during transformation process (CN). For these model versions (IN-VIT, CN-VIT, IN-SIT and CN-SIT), the time evolution of the transformed volume fraction and its distribution across a film, the overall grain density and its distribution is derived. The finite size effects lead to interesting peculiarities of the VIT-process: the thinner film the slower it proceeds and the more fine microstructure with highly dispersed subsurface layer is formed. The VIT- kinetics in a thin film obeys the extended KJMA-equation with a time exponent n varying with a film thickness between two limit values: n=2 (IN), n=3 (CN) in limiting thin film and n=3(IN), n=4 (CN) in limiting thick film predicted by the 2D and 3D KJMA-model, respectively.

E/PII.28 COMPOSITION AND ELECTRONIC PROPERTIES OF LOW-SIZED PHASES, FORMED ON EPITAXY FILMS OF SILICON UNDER ION IMPLANTATION

D.A. Tashmukhamedova, B.E. Umirzakov, E.U. Baltaev, Tashkent State Technical University, 700095 Tashkent, Uzbekistan

In development micro- and nanoelectronics thin semiconductor films with low-sized chip are of special interest. Such crystals possess to absolutely new unique properties that enable to use them of construction new devices for solid-state electronics. In particular Si epitaxy films with silicides low-crystals can be used in creation the transistors with metallic and permeable base. For obtaining of such systems possible use the method of low energy ion implantation. In this work are presented experimental results on formation as from separate cluster phases to continuous film on near surface of area of Si (111) film at irradiation Ba⁺, Na⁺, Mg⁺ and Co⁺ ions with $E=1-10$ keV energy and $D=10^{14}-10^{17}$ cm⁻² dose. The researches were conducted with use the methods: AES, UPES, HEED and REM. The determinate that at low energy high dose implantation of Ba⁺ ions till dose $D=(2-6)\times 10^{15}-10^{18}$ cm⁻² occurs formation of separate low-sized clusters. At annealing of this films are formed islet disposed monocrystalline BaSi₂ silicides, which crystallize in cubic lattice. However parameters of lattices BaSi₂ and Si sharply differ from each other. Evidently last result in appearance of decomposition layer on interfacial a film - target. At obtained of CoSi₂ chips not formation of strongly decomposition layer on interfacial CoSi₂ - Si. This conditioned conformity of parameters of their lattice. The value of constant lattice CoSi₂ is 5.40 Å, and Si - 5.43 Å. The investigations in this direction are continue.

E/PII.29 EFFECT OF LOW-ENERGY ION IRRADIATION ON THE ELECTROPHYSICAL PARAMETERS OF SI-SiO₂ INTERFACE

V.M. Popov, M.I. Gorodiskiy, Y.M. Shustov, A.P. Pokanevich, A.S. Klimenko, Research Institute for Microdevices, Physical & Technol. Res. Certif. Center, 3 Severo-Syretskaya, 04136 Kiev, Ukraine

Modifications of the electrophysical properties of Si-SiO₂ interface after irradiation of insulator-semiconductor (IS) and metal-insulator-semiconductor (MIS) structures by low-energy ions have been studied. The primary ion beam of SIMS (6-10 keV) was used for selective irradiations of the surface of IS(MIS) structures with different oxide thickness. The irradiated areas were in the range $2\times 10^{-6}-5\times 10^{-3}$ cm². The behaviour of fixed oxide charge Q_{ss} , surface state charge Q_{st} , surface generation velocity S_g and bulk generation life-time of minority carriers τ_g have been investigated by means of dynamic unsteady-state current voltage characteristics (DUCVC) of MIS structures. Application of the DUCVC method provides accurate determination of Q_{ss} , Q_{st} , S_g and τ_g values. Special technique for elimination of surface state charging current from the total generation current in DUCVC analysis was used for correct S_g definition in irradiated samples with high surface state density. We have shown that electrophysical parameters of Si-SiO₂ interface under irradiated surface are strongly modified and depend on the type of the structure (IS or MIS), the conditions of experiment in the case of MIS structures (floated or grounded gate), the dose of irradiation and its rate. Formation of electrically active defects with extremely high generation rate of minority carriers was revealed in the region of Si-SiO₂ interface.

E/PII.30 COMPOSITIONAL AND STRUCTURAL EVOLUTION OF METAL ALLOY NANOCLUSTERS IN SiO₂ UPON ION IRRADIATION

V. Bello, G. De Marchi, C. Maurizio, G. Mattei, P. Mazzoldi, M. Parolin, C. Sada, INFN - Univ of Padua, Dept of Physics, Padua, Italy, G. Battaglin INFN - Univ of Venice, Dept of Physical Chemistry, Venice, Italy

Sequential ion implantation in glass has been used to obtain composite materials made by metal alloy nanoclusters embedded in SiO₂. The interest on such systems stems from their peculiar nonlinear optical properties which are function of the cluster size and composition. A crucial issue for controlling such properties is the stability of the nanoclusters upon post-implantation treatments. In this work we report on the use of ion beam irradiation to induce either compositional or structural transformations on noble metal nanoclusters in SiO₂. An elemental selective de-alloying in bimetallic Au-Cu and Au-Ag nanoclusters has been found upon irradiation with light ions. In the Au-Ag system, irradiation with He, Ne, Ar or Kr ions promotes a preferential extraction of Au from the alloy, resulting in the formation of Au-enriched "satellite" nanoparticles around the original Au_xAg_{1-x} clusters. The role played by the irradiation parameters (i.e., dose, dose-rate, energy of the implanted ions) has been systematically investigated. A correlation between the nuclear component of the energy released by the irradiating ions and the size of the satellite clusters is found. For comparison, thermal annealing in oxidizing atmosphere on the same samples is found to promote preferential extraction of the less noble metal: in the case of the Au-Cu system, the incoming oxygen interacts with copper promoting Cu₂O formation in the early stages of oxidation, therefore extracting Cu from the alloy.

E/PII.31 NANOMETER SCALE INTERFACE STRUCTURE FABRICATION IN THIN FILMS USING ION BEAM TECHNOLOGY

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The formation of interface structure with different physical properties on either side of the interface is quite common for many solid state electronics devices. The reduction in physical size in semiconductors is mainly driven by the desire to integrate as many single interface structures into the limited space as possible. However, in superconductor electronics device based on the Josephson effect, the formation of nanometer scale interface structure is due to the intrinsic short coherence length of superconductors. In the past five years, we have explored the fabrication of nanometer interface structure in high temperature superconductor thin films using proton beam irradiation damage with high resolution and high aspect ratio metal masks. The design and fabrication of various metal mask structures have been guided by substantial simulation on the formation of irradiation damage profile under various ion irradiation conditions. Very high quality single Josephson junctions and junction arrays have been fabricated with both single crystalline YBCO and polycrystalline MgB₂ thin films. In contrast to the well defined irradiation damage mechanism in YBCO, the damage process in MgB₂ is still not very clear. This has been subjected to experimental studies and simulation. The suppression in superconducting phase transition temperature T_c upon ion irradiation is very likely to be associated with the degradation of the MgB₂ grain size, as our recent ion beam synthesised MgB₂ nanometer particles only exhibit much suppressed T_c . In addition to superconducting thin films, we also explored the nanometer scale physical property modification in multiple layered magnetic thin films.

- E/PII.32** ION-BEAM INDUCED MODIFICATION OF NANOPOROUS ARRAY IN ANODIC ALUMINA
N.N. Cherenda, V.V. Ugloy, Belarusian State University, F. Scorina av. 4, 220080 Minsk, Belarus, G.V. Litvinovich, A.L. Danilyuk, Belarusian State University of Informatics and Radioelectronics, P. Brovka av. 6, 220027 Minsk, Belarus
Nano-channel array materials have attracted considerable attention due to their potential utilization in magnetic, electronic and optoelectronic structures and devices. Porous anodic alumina films belong to this type of materials and are used now as a template for the fabrication of nanometer scale composites. Due to a considerable stress induced by intensive ion beams pores arrangement in an alumina film can be changed. In this work Mo ions were chosen for implantation. Implantation was carried out using a MEVVA impulse ion source. The initial anodic alumina films had pores with a diameter of 20 nm. The pores length was approximately equal to the sample thickness ≈ 0.2 mm. It was found that implantation led to the formation of new types of an alumina porous array. One of them contained oblong shaped pores with a diameter of 20 nm and a length of 300 nm. Another one contained almost spherical pores with a diameter of 40-70 nm and so on. The size and shape of pores depended on the implantation conditions. The thickness of the layer with the modified pores array was 0.03-0.04 mm, it substantially exceeds the calculated mean projected range of Mo ions ≈ 44 nm. The implantation also led to the change of the alumina films crystalline structure. When implanted an amorphous film transformed into gamma alumina, while gamma alumina \approx into an amorphous film. In all cases the presence of theta alumina inclusions after implantation was observed.
- E/PII.33** VISIBLE PHOTOLUMINESCENCE FROM Si ION BEAM MIXED SiO₂/Si/SiO₂ LAYERS DEPOSITED BY E-BEAM EVAPORATION
J.H. Son(a), H. B. Kim(1), C. N. Whang(a), M.C. Sung(a), K. Jeong(a), K.H. Chae(b), (a)Atomic-scale Surface Science Research Center and Institute of Physics & Applied Physics, Yonsei Univ., Seoul 120-749, Korea and (b) Div. Of Mater. Sci. Engin., Korea Institute of Science and Technology, Seoul 130-650, Korea
In this experiment, the samples with the same structure were prepared by e-beam evaporation method. No PL spectra around 700 nm were observed from these samples when the same processes were performed.
The PL related to Si nanocrystals was obtained after an annealing process was carried out before ion beam mixing process. In the case of the sample made by e-beam evaporation method, why is a pre-annealing process required to get the PL around 700 nm? We will discuss the PL characteristics from the samples.

Friday, June 13, 2003
Vendredi 13 juin 2003

Morning
Matin

E-XIV.1 9:00 -Invited-

RADIATION DAMAGE IN NANOCRYSTALLINE METALS

M. Samaras(a), P.M. Derlet(a), **H. Van Swygenhoven**(a), M. Victoria(b), (a)Paul Scherrer Institute, 5232 Villigen-PSI, Switzerland, (b)CRPP-Fusion Technology Materials, EPFL, 5232 Villigen-PSI, Switzerland

It is well known that grain boundaries can strongly influence the damage produced by irradiation in metals. Experiments in ion-irradiated samples have shown that the defect production is smaller than in its polycrystalline counterpart, with the nc rapidly saturating in terms of dose.

This contribution discusses the role of the grain boundary during cascade evolution within nc-Ni. Large-scale molecular dynamics of cascade production of the primary damage state have been performed in nc-Ni with average grain diameters of 5nm to 20nm. Primary Knock-on Atoms (PKA) with kinetic energies ranging from 5keV to 30keV have been investigated.

The simulations show that GBs acts as a strong sink for self interstitial atoms/clusters (SIAs) via two possible mechanisms: replacement collision sequences and 1D/3D motion. Careful analysis on the atomic scale allows the determination of the key role played by the structure of the grain boundaries in terms of misfit areas, excess free volume, GB dislocations and internal stresses in qualifying the sink strength of the GBs. Truncated stacking fault tetrahedra (SFT) are more easily formed during cooling of the vacancy-rich core of the cascade and these SFT's can act as an additional sinks for SIAs during cascade overlap. The results will be discussed in the framework of recent irradiation experiments on nc-Ni.

E-XIV.2 9:30

ATOMIC MECHANISMS OF GRAIN GROWTH IN NANOCRYSTALLINE NICKEL INDUCED BY ION IRRADIATION

Wolfgang Voegeli, Karsten Albe und Horst Hahn Institute of Materials Science, Darmstadt University of Technology, Petersenstr. 23, 64287 Darmstadt, Germany

In this study we have investigated the atomic mechanisms responsible for ion irradiation-induced grain growth in nanocrystalline Ni by means of molecular dynamics simulations. Collision cascades of 5 keV were calculated in bulk nc-Ni samples generated by a Voronoi tessellation method. We find that the cascade position relative to the GB areas is decisive for stimulating ion-beam induced grain growth. Using bicrystal geometries we have therefore investigated the role of the GB orientation on grain growth in more detail. For certain symmetric grain boundaries we find growth that can be explained by means of a simple geometrical model, while for others almost no grain growth can be observed. We find that the atomic area density in the crystalline layers adjacent to the GB has a decisive influence on grain growth. In the case of asymmetrical boundaries this can lead to preferred growth in one direction.

E-XIV.3 9:45

ION-INDUCED INTERFACIAL MIXING IN TI/PT AT KEV ENERGY: A MOLECULAR DYNAMICS STUDY

P. Saule, M. Menyhard, K. Nordlund, MTA-MFA, Surface Physics, Konkoly Thege M. 29-33, Budapest-1125, Hungary

Molecular dynamics simulations have been used to obtain the three-dimensional distribution of interfacial mixing and cascade defects in TiPt multilayer system due to series of single 1 keV Ar⁺ impacts at grazing angle of incidence. The calculated ion induced mixing profile is not sensitive to the heat of mixing. Therefore the thermal spike model is not fully supported in this system. Instead we found that the majority of mixing occurs after the thermal spike in the relaxation process. These are supported by liquid, vacancy and adatom anal analysis. The interfacial mixing is in various aspects anomalous in this system: the time evolution of mixing is leading to a phase delay for Ti as well as Pt exhibits an unexpected double peaked mixing evolution. The possible reasons are discussed.

E-XIV.4 10:00

MODIFICATION OF MAGNETIC PROPERTIES BY LIGHT ION IRRADIATION

S. Poppe, J. Fassbender, B. Hillebrands, Fachbereich Physik, Universitaet Kaiserslautern, Erwin-Schroedinger-Str. 56, 67663 Kaiserslautern, Germany

Nanopatterned thin films are of crucial importance for magnetic storage technology. Ion irradiation based techniques exhibit the potential to manufacture improved storage media, since it becomes possible to tailor the magnetic parameters on a nanometer scale without modification of the surface topography. Also for position sensing devices simplified fabrication processes are currently tested, which rely on ion irradiation of magnetic films.

One of the key results is the ion induced modification of magnetic exchange bias bilayers. These bilayers consist of a ferromagnetic (FM) and an adjacent antiferromagnetic (AFM) layer. The hysteresis loop of the FM layer is shifted by the so-called exchange-bias field with respect to the applied field due to the exchange coupling to the AFM layer. It has been shown that the magnitude and direction of the exchange bias field can easily be tailored using 5 keV He ions. Recent experiments show that also the sample temperature during the irradiation process is of crucial importance.

- E-XIV.5** 10:15 **MAGNETIC MODIFICATION OF THIN CoFe FILMS BY Ne+, Xe+, AND Au+ ION IRRADIATION**
Ratnesh Gupta, G.A. Müller, P. Schaaf, M. Uhrmacher, K. Zhang and K.-P. Lieb, Universität Göttingen, Zweites Physikalisches Institut und SFB 345, Bunsenstrasse 7/9, 37073 Göttingen, Germany
 Co₅₀Fe₅₀ (CoFe) has a high positive magnetostriction coefficient and has been extensively used in spin-valve structures and magnetic tunnel junctions. Magnetic field assisted ion beam irradiation has been used to study the magnetic modification of 75 nm thick CoFe films deposited on Si(100). Irradiations have been done at room temperature with Ne+, Xe+ and Au+ ions, keeping the penetration depth of the ion inside the film constant. The films were analyzed by Rutherford backscattering, X-ray diffraction and Magneto-optic Kerr effect (MOKE). Initially, the lower fluence of Ne ions enhances the coercivity of the film while higher ion masses reduces the coercivity of the film. In-plane MOKE results suggest that a uniform four-fold anisotropy has been induced because of ion irradiation and the value of induced anisotropy depends on the ion species. We find that the magnetic modification is sensitive to the ion species and the fluence. # on leave from Inst. of Instrumentation, D.A. University, Khandwa Road, Indore-452017, India.
- 10:30 **BREAK**
- E-XV.1** 11:00 -Invited- **ION IRRADIATION OF CARBON NANOTUBES AND RELATED PHENOMENA**
A. Krashennnikov, K. Nordlund, and J. Keinonen, Accelerator Laboratory, P.O. Box 43, 00014 University of Helsinki, Finland
 The rising interest in irradiation effects in carbon nanotubes (CNTs) is triggered by recent observations of fascinating irradiation-induced phenomena like irradiation-induced coalescence and welding of CNTs, tunnel barrier formation, just to mention a few. Experiments also show that ion bombardment and CNTs may be employed for fabricating metal nanowires using multi-walled nanotubes as masks.
 Using various atomistic models, we systematically study the fundamental physics of ion-irradiation-induced effects in CNTs. By simulating impacts of energetic ions, we examine production of defects in nanotube bundles and individual CNTs. We further study the annealing of main defects--vacancies and carbon interstitial atoms, which can migrate over the CNT surface. The latter issue is also of great importance for understanding the CNT growth mechanisms. In order to ascertain the limitations of using CNTs as masks against irradiation, we simulate ion irradiation of multi-walled nanotubes. We derive an equation which for a given nanowire material allows one to estimate the theoretical limit on the minimum width of the wire. We further study ion bombardment of crossed CNTs as a technique to join them. We demonstrate that ion irradiation should result in welding of crossed CNTs, both suspended and deposited on substrates. We discuss various experimental aspects of this method which may potentially be used for developing complicated networks of joined CNTs.
- E-XV.2** 11:30 **ELLIPSOMETRIC SPECTROSCOPY STUDY OF Ar ION BEAM MIXED SiO₂/Si/SiO₂ LAYERS**
H.B. Kim(a), J.H. Son(a), C.N. Whang(a), S.J. Kim(b), S.Y. Kim(b), and K.H. Chae(c), (a)Atomic-scale Surface Science Research Center and Institute of Physics & Applied Physics, Yonsei Univ., Seoul 120-749, Korea, (b)Depart. Of Physics, Ajou Univ., Suwon 442-749, Korea, and (c)Div. of Mater. Sci. Engin., Korea Institute of Science and Technology, Seoul 130-650, Korea
 The intense photoluminescence from the samples fabricated by various methods has been reported. Especially, ion beam mixing method is one of strong candidates to get the Si nanocrystal in the sample and this technique has a merit that the position of Si nanocrystals in the perpendicular direction to the sample can be controlled.
 SiO₂/Si/SiO₂ layers were deposited by ion beam sputtering method and energetic Ar ions were irradiated into the sample to break Si layer between SiO₂ layers into pieces and mix the Si layer with SiO₂ layers. Then, the annealing at high temperature was carried out under N₂ ambient to make Si nanocrystals along the Si layer between SiO₂ layers.
 Photoluminescence associated with the defects induced by Ar ion beam mixing and Si nanocrystals formed during the annealing was observed from the samples. The ellipsometric spectroscopy study will be discussed about these samples with transmission electron microscopy, infrared absorption, and x-ray spectroscopy.
- E-XV.3** 11:45 **ELONGATED Co NANOPARTICLES INDUCED BY SWIFT HEAVY ION IRRADIATIONS**
C. D'Orléans, J.J Grob, D. Muller, J.P. Stoquert, Laboratoire PHASE, 23 Rue du Loess, 67037 Strasbourg, France, C. Estournès, J.L. Guille, M. Richard-Plouet, IPCMS-GMI, 23 Rue du Loess, 67037 Strasbourg, France, C. Cerruti, F. Haas, IReS, 23 Rue du Loess, 67037 Strasbourg, France
 Due to their large surface/volume ratio, metal nanoparticles embedded in matrices exhibit optical, magnetic and chemical properties different from those of the bulk material. We have demonstrated the power and versatility of ion implantation for elaboration of magnetic nanoparticles in silica layers with size and density controlled by implantation parameters (dose, energy, temperature) and observed a prolate deformation of nanoparticles under high fluence irradiation with energetic heavy ions. Here we report on a systematic study undertaken in order to determine the critical parameters controlling the deformation. Nanoparticles were elaborated by implantation of Co ions at 160 keV in SiO₂ at fluences of 2e16, 5e16 and 1e17 at.cm-2. For each fluence, implantations have been performed at 77, 295 and 873 K. Elongations have then been determined for samples irradiated with swift heavy ions at 200 MeV at fluences from 1e11 to 1e14 ions.cm-2 at room temperature, and have been characterized by RBS, TEM, XPS and magnetic measurements.
- 12:00 **LUNCH**

Friday, June 13, 2003
Vendredi 13 juin 2003

Afternoon
Après-midi

E-XVI.1 13:30 -Invited-

SURFACE SMOOTHING WITH GAS CLUSTER ION BEAMS FROM FUNDAMENTAL CHARACTERISTICS TO INDUSTRIAL APPLICATIONS

N. Toyoda, Laboratory of Advanced Science and Technology for Industry, Himeji Institute of Technology, 3-1-2 Kouto, Kamigori, Hyogo 678-1205, Japan

Recently, gas cluster ion beam (GCIB) are beginning to be used for surface smoothing in various industrial applications. As the energy per atom of GCIB can be easily reduced to several eV, GCIB is very useful for low-damage processing. Although the energy per atom is low, the energy density of the impact point becomes extremely high. This dense energy deposition realizes high-pressure and high-temperature conditions at the impact point of a cluster ion, as a result, chemical reaction enhancements occurs without heating the target itself. The most interesting characteristic of cluster ion impact is so called 'lateral sputtering'. When cluster ion hits a surface, sputtered particles are preferentially ejected in lateral directions, which cause a significant surface smoothing with cluster ion beams at normal incidence. With a lot of efforts for GCIB equipment development, now the gas cluster ion beam current becomes adequate for various industrial applications with a sufficient throughput. Semiconductor wafers, magnetic films or optical substrates are now processed with gas cluster ion beam equipments. In this paper, we will summarize the characteristics of gas cluster ion beam from fundamental impact kinetics and sputtering process to industrial applications.

E-XVI.2 14:00

STUDY OF THE NUCLEATION AND GROWTH OF AG CLUSTERS IN SILICA GLASSES UNDER ION IRRADIATION

J.C. Pivin, CSNSM, Bât. 108, 91405 Orsay Campus, France and D.K. Avasthi, NSC, PO Box 10502, New Delhi 110067, India

The processes of nucleation and growth of silver clusters are investigated independently by using different type of films in which no cluster exist or on the contrary all the metal is precipitated before the irradiation. The studied films are prepared by means of sol-gel chemistry, co-sputtering of SiO₂ and Ag, ion-exchange of Ag with Na in glasses and in gel coatings. They are irradiated with He or Au ions of energy in the range of 1 to 100 MeV. The nucleation is assessed by combining measurements of the luminescence of solute ions and of the optical absorption in the clusters after irradiation with incremented ion fluences. The analysis of optical absorption spectra on basis of Mie theory permits also to estimate the size of the clusters, more accurately than TEM images because they are very small in the studied films.

The two processes of nucleation and growth are found to be correlated with the energy deposited in electronic excitations by the ions and the nuclear collisions have little effect. The growth kinetics is ascribed to a process of desorption/re-adsorption of Ag atoms at the surface of the clusters. The desorbed atoms remain neutral according to the measured yields of luminescence. Their fast diffusion on short distances induces the ripening of the biggest clusters at the expense of smaller ones in the distribution of cluster sizes when the desorption rate is limited. But the clusters are dissolved instead of growing when the density of electronic excitations exceeds a threshold value.

E-XVI.3 14:15

FORMATION AND CHARACTERISATION OF Zn NANOCCLUSERS IN MgO

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In order to create Zn nanoclusters, MgO(001) single crystals were implanted with 1E17 Zn ions cm⁻² at an energy of 140 keV. After thermal annealing at 1100 K, an optical absorption band appears caused by Mie plasmon resonance. Due to the optical properties of metallic Zn, the absorption peak is present at a rather low wavelength, with the centroid at 290 nm. From the width of the absorption peak, the mean nanocluster size is estimated at 2 nm using Doyle theory. The evolution of implantation damage is monitored with Doppler broadening positron beam analysis (PBA); the location and depth distribution of the Zn is investigated by means of Rutherford backscattering spectrometry (RBS). Transmission electron microscopy (TEM) investigations reveal that the nanoclusters have an fcc crystal structure rather than the usual hcp crystal structure. This reduces the lattice mismatch with the MgO, and therefore the interface energy. The Zn nanoclusters dissolve after annealing at 1350K.

14:30

BREAK

E-XVII.1 15:00

COMBINATORIAL ION IMPLANTATION - A SMART TECHNIQUE APPLIED TO SYNTHESIZE CdSe-NANOCRYSTALS

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The understanding, discovery and optimization of new complex functional materials requires combinatorial synthesis techniques and suitable fast screening and analysis methods. This approach to catch the wide field of possible parameter combinations is state of the art in various sectors of science. To introduce this idea for ion implantation, we developed an implanter target end station, equipped with two computer controlled apertures, to synthesize on a 4 inch wafer a rectangular pattern of distinct dose and stoichiometry combinations of the optically active II-IV compound semiconductor CdSe. A computer controlled measuring station combined with an optical cryostat for photoluminescence (PL) measurements add up to a fast screening method.

The two elements are implanted in thermally grown silicon dioxide on silicon. Afterwards the wafers are subsequently annealed in a rapid thermal processor, so that a band of CdSe nanocrystals near the surface is formed. The findings show strong dependency of the PL intensity on the variation of dose and stoichiometry. Furthermore different structures in the PL signal, which are linked with the mentioned parameters, are visible. Samples with e.g. excess of Cd show only a single narrow PL peak, whereas a lack of Cd results in a bulk like, broad spectrum. In addition, measurements at different temperatures and with different excitation powers were carried out. For a closer analysis of the observed effects selected samples were then investigated by SIMS, RBS, XRD and TEM.

E-XVII.2 15:15

ION BEAM SYNTHESIS AND PROPERTIES OF LEAD SULFIDE NANOCRYSTALS IN SILICA

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Synthesizing low band-gap compound semiconductor nanocrystals in waveguide materials is of interest for applications in photonics devices. Several groups are involved in the design of ion implantation and post-implant annealing techniques in order to provide a means of forming the compound as well as controlling nanocrystal densities and depth distributions in shallow waveguides. We have studied the synthesis of PbS in pure silica by double implantation. RBS, SIMS and transmission electron microscopy experiments show that the growth dynamics and final cluster depth distribution both strongly depend on the implant sequence (the chemical affinity and species mobility play a major role). The nanocrystal growth and irradiation-induced damage evolution were monitored via spectroscopic and photoluminescence experiments.

E-XVII.3 15:30

DIRECT ION BEAM SYNTHESIS OF II-VI NANOCRYSTALS

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Compound semiconductor nanocrystals were formed in amorphous substrate directly implantation of sufficiently high doses of constituent elements at room or even liquid nitrogen temperature. Nanocrystals of CdS, ZnTe, CdTe and PbTe were produced in SiO₂ by this procedure. Grazing incidence small angle x-ray scattering (GISAXS) was applied to study the synthesis of produced nanocrystals. The two-dimensional GISAXS patterns comprised of quasi-isotropic half-rings with an interference maximum related to spatial correlation between isolated II-VI nanoclusters. The analysis of these patterns was performed by using Guinier approximation as well as the local mono-disperse approximation (LMA), in which the nanocrystal ensemble was treated as a sum of mono-disperse subsystems. The analysis provided an estimate of the nanocrystallite average size and interparticle distance, the size and distance distributions, depth distributions of average size and distance, the shape of nanocrystals, as well as the fraction of implanted atoms that synthesized into nanocrystals. Comparison is made with samples, in which a similar average size of nanocrystals was obtained by lower-dose implantation and subsequent high-temperature annealing. It has been found that a narrower size distribution can be obtained by high-dose implantation, with no or only low temperature subsequent annealing, i.e. when the high-temperature sample processing was avoided.

15:45

CLOSING