SYMPOSIUM T
Nanostructuring Materials with Energetic Beams
April 22 – 23, 2003

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*Invited paper
SESSION T1: NANO STRUCTURES MADE BY ION TRACKS AND ION LITHOGRAPHY
Tuesday Morning, April 22, 2010
City (Argent)

9:00 AM #T1.1
NANOPORES AND NANOWIRES: A CHALLENGE FOR NEW PROPERTIES AND APPLICATIONS,
Roger Legrand, Université Catholique de Louvain, Unité de Physique et de Chimie des Hauts Polymères

Filling the nanosized holes of polymer membranes with various combinations of metals or conductive polymers can produce nanocomposite materials with tailormade electrical, magnetic or chemical properties. As sophisticated filter devices, these have many potential applications such as in shielding microwaves and mobile phones, as gas sensors or in biophotonic devices. Nanocomposites are materials which contain one or more components in shapes such as cylinders, rods or networks with nanosize dimensions. The enormous versatility of possible combinations of such materials, which can have both electrical conductivity and non-conductivity components, offers a real possibility of obtaining materials that combine metal-like properties with non-metallic characteristics. In addition, changes in the features and type of nanocomposite component can substantially affect the composite’s electrical, magnetic and chemical properties.

If a thin polymer film such as polycarbonate is bombarded with energetic heavy ions (accelerated by a cyclotron), holes are burned out and after track-etching a membrane is produced. As filters, most membranes rely on several different mechanisms to enhance contaminant removal. Track-etched membranes, in contrast, capture particles by simple, direct sieving, so particles larger than the pore size cannot pass through. The existing production technique for these membranes has been significantly enhanced to allow the reliable and reproducible manufacture of nanocomposite membranes with nanosized holes. They are currently used within the ultrafiltration market as molecular filters for biological applications such as water purification. Now these polymer membranes can be made with a well-controlled pore size and shape in the form of regular, periodic arrays. The nanoscale features can be filled with another organic or inorganic material, such as a polymer or metal. If a different material, such as an electrically conductive polymer, is deposited in the holes, nanotubes with enhanced conductivity are obtained. Filling the nanoholes with a magnetic material, for example cobalt or a combination of these metals by electrochemical deposition, produces a membrane with nanotubes or wires of either one metal or with multilayers of different metals.

Various combinations of polymers and metals are produced and characterized with the aim of using such membranes to design devices in which the electrical and magnetic properties can be studied, controlled and optimised. The nanotubes produced by using these templates take the form of rods or tubes. The metal nanotubes are embedded in these polymer films, which are usually complexed and densely packed. Since the volume and degree of their electrical insulation and magnetism is controllable, they have good potential for use in high-density data storage. They also absorb certain wavelengths of electromagnetic radiation similar to those used in microwave ovens and communications. Consequently, potential applications include sophisticated devices such as microwave filters for making mobile phone and microwave ovens.

The deposition of conductive polymer nanotubes in the membrane will lead to the preparation of chemical detectors (artificial nose) and biosensors.

9:30 AM #T1.2
NANO-WIRE FIELD-EFFECT TRANSISTOR IN ETCHED ION TRACKS OF FLEXIBLE MATERIALS,
Jie Chen, Siegfried Kästelmann and Rolf Könenkamp, Helmholtz-Meetinstut, Berlin, GERMANY

Fast heavy ions generate continuous-amorphized cylindrical tracks in polymers. Chemical etching rates in this degraded material are typically several orders of magnitude larger than in the surrounding intact material. As a consequence deep narrow cylinders with diameters in the range from 3 to 50 nm and large aspect ratios can be produced in single supporting polymers. Semiconductor deposition on etched ion tracks of flexible substrates is an area of intense research activity since it will open new applications for a host of consumer products. We present detailed results on the preparation of nano-wires of different materials and their electrical properties.

In this work we have pursued a route that promises devices which are robustly embedded in a flexible matrix, and whose dimensions may be reduced well below the 100 nm limit. Our nano-wire transistors are embedded in sandwich flexible foils with a gate dielectric, one source and one drain. The advantages of our device are: 1) a very high packing density which can be obtained without nano-lithography, and 2) a robust structure in which most of the mechanical forces due to bending, stretching and compression are taken up by the high flexibility of the plastic template rather than by the semiconductor device.

10:30 AM #T1.3
FORMATION OF WELL-DEFINED NANOCOLUMNS BY ION TRACK ETCHING LITHOGRAPHY,

Low-dimensional systems on the nanometer scale afford a wealth of interesting possibilities including highly anisotropic behavior and quantum effects. Nanocolumns permit electrical and mechanical control, yet benefit from two confined dimensions. This confinement leads to new optical, mechanical, electrical, chemical, and magnetic properties. We construct ordered nanocolumn arrays with precise definition and independent control of diameter, length, orientation, and density and composition so that geometry can be directly correlated to the quantum physical properties of interest. The precision and control are products of the fabricating ion we use which starts with an ion of sufficient energy to "track" a dielectric such as a film applied uniformly onto a substrate. The energy loss of the ion alters chemical bonding in the dielectric along the ion's straight trajectory. A suitable etchant quickly dissolves the intact tracks leaving high aspect ratio holes of small diameter (~100 nm) penetrating the film up to several microns thick. These small holes are interesting and useful in their own right and can be made to any desired size by continuing the etching process as well as being electrochemically or electrochemically after this deposition, the mold material can be removed leaving the columns firmly attached to the substrate at the desired orientation. A variety of structures from simple to complex can be envisaged with this technology. As part of the micro/nanofabrication and nano-lithography effort, we have created arrays of Ni and of Pt nanocolumns (~60 nm diameter and ~600 nm long) oriented perpendicular to the substrate. The aspect ratio and small diameter of the columns enables easy observation of quantum behavior, namely efficient electron field emission and Fowler Nordheim behavior. This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

10:45 AM #T1.4
ION BEAM SCULPTING OF COLLOIDAL NANOMATERIALS,
T. van Dijken, M.J.A. de Dood, C.M. van Kats, D.J. Vossen, D. Ficic, A. van Bladeren, P.R. Onck, E. van der Giessen, A. Polman, FOM Institute AMOLF, Amsterdam, THE NETHERLANDS; Delphy Institute, Utrecht University, Utrecht, THE NETHERLANDS; Groningen University, Groningen, THE NETHERLANDS

Nanometer and micrometer-sized colloidal silica particles show a dramatic nano-size plastic deformation upon MeV ion irradiation, changing their shape from being spherical to ellipsoidal. Non-spherical colloidal particles have a wide range of applications in nanophotonics, nanomagnetism and nanolithography, which leads to various questions about the physical origin of this deformation process. As part of the detailed study into this process, we have irradiated colloidal silica particles with 5-4 MeV Xe ions to ion fluences as high as 10^{16} ions/cm^2 at various sample temperatures between 77 and 500 K. It was found that the deformation strongly depends on the ion fluence and energy, as well as on the sample temperature. Small colloids (40 nm diameter) show a smaller deformation rate than large colloids (1 000 nm). Pre-annealed silica colloids (1020 K) show a three times lower deformation rate.

Silicon also deforms under ion irradiation: micron-sized crystalline Si (100) pillars, made by deep reactive ion etching and pre-amorphized with 3 MeV Xe, were irradiated with 30 MeV Cu ions and showed dynamic expansion perpendicular to the ion beam. In contrast, pillars that were not pre-amorphized did not show this lateral expansion. Supplementary insight is offered by a finite-element continuum model of the transient plastic flow during the thermal spikes caused by the incident ions. Our model consists of a viscoplastic cylinder in an elastic surrounding medium. We will compare our results with the analytical model for anisotropic deformation derived by Trinkaus et al. Finally we show that ion irradiation-induced deformation can be used to tune the shape of a colloidal mask for nanolithography. For colloids of 1400 nm in diameter, the mask opening can be continuously tuned over the range from 0 to 350 nm.

11:00 AM #T1.5
ANISOTROPIC DEFORMATION OF MESOPOROUS SILICA FILMS AND COLLOIDS,
A. M. Vredenberg, G. Sengers, A. van Bladeren, Delphy Institute, Utrecht University, NETHERLANDS; S. Eiden, University of Konstanz, GERMANY.
We have used 30 MeV Si irradiation to anisotropically modify the pore structure of mesoporous silica. Films or particles of this material are finding a wide range of applications in e.g. catalysis, (bio)sensing, (nano)electronics, and (nano)photronics. This is due to the large control over the pore size (2-10 nm) and structure (lamellar, 3D hexagonal, 3D cubic) that is inherent to the synthesis process, which is based on self-assembly of surfactant molecules. Further tuning the shape of the pores (e.g. elliptical instead of cylindrical) would greatly increase the potential of mesoporous materials. The goal of this work was to investigate if this can be achieved by anisotropic deformation induced by swift heavy ion irradiation.

We have irradiated [1] 800 nm thick films and [2] 1 mm spherical colloids with 30 MeV Si up to a dose of 2 x 1015 ions/2 cm2. The colloids deform anisotropically (i.e. they flatten in the direction of the ion beam) without total collapse of the pore structure. The films dense (i.e. their thickness decreases) with a concurrent change in the ordering distance between horizontal pores in the vertical direction. Already at 1 x 1014 ions/2 cm2 the out-of-plane lattice parameter of the pore structure is observed with low angle XRD, indicating a change of cylindrical pore symmetry to an elliptical one. We will present results of an XTEM study, and discuss the dependence on ion beam dose.

SESSION T2: FOCUSED ION BEAMS OF HIGH AND LOW ENERGY
Tuesday Afternoon, April 22, 2003
City (Argost)

1:30 P.M. PT2.1
PROTON BEAM NANO-MACHINING: END STATION DESIGN AND TESTING. Jereon A. van Kuijk, Andrew A. Bettiol, Frank West, Research Centre for Nuclear Microscopy, Physics Department, National University of Singapore, SINGAPORE.

A new nuclear nanomachining facility has been developed. This facility is the first dedicated to proton beam micro- and nano-machining. The design and performance of the facility, which is optimized for direct-write lithography with 2.3 MeV protons, is described here. The proton beam nanomachining (PBM) facility (or P-bem writer) utilizes the Oxford Microbeams high demagnification lenses (OM52) in a high excitation triple configuration, operating at a reduced ion beam energy to reduce the system demagnifications (60 x 2.8). The PBM chamber is equipped with an uniaxial detector for Rutherford backscattering measurements, a secondary electron detector for electron imaging, and a pin diode for scanning transmission ion microscopy mapping. The sample is mounted on a computer controlled Barlegh Inswenhaw XYS stage which has a travel of 25 mm for all axes with a 20 nm closed loop resolution. The system has been designed to be compatible with Si wafers up to 6". The first tests show that the proton beam can be focused down to 35 x 75 nm2, the best performance in the world so far. For PBM, the proton beam is focused and scanned over a suitable resist material. The penetrating power of the protons allows 3D structures of high aspect ratio to be produced directly, which are subsequently induced secondary electrons produced by the primary proton beam have a very short range, which depends on the proton beam energy, and is typically less than 10 mm. This property ensures even exposures with mm smoothness. The first test structures will be included, including lines and structures of 600 mm width, fabricated in a 2 micron thick PMMA layer on silicon. In addition, we will present preliminary results of the use of the PBM method in micro-fluidics (electrophoresis channels) and micro-photonic devices (micro-lenses, micro-mirrors and photonic band gap crystals).

2:00 P.M. PT2.2
GENERATING NANOSCALE ARRAYS USING SELF-ORGANIZED POROUS ALUMINA IMPLANTATION MASKS. I.E. Ross, P.M. Baldo, B.J. Kestel, J. Hillier, A.W. McCormick and R.C. Birlech, Materials Science Division, Argonne National Laboratory, Argonne, IL.

Using two-step anodizing recipes available in the literature, we fabricated self-supporting ordered ion-implantation masks that are several mm2 in area and approximately 2 μm thick. SEM micrographs reveal self-organized structures with straight open pores, 14±13 nm in diameter, which extend completely through the mask. As reported previously, the pore diameter and spacing depend critically upon the anodizing parameters, e.g., the type of acid and its molarity, the applied voltage and the solution temperature. Ion-milling procedures were developed for opening the bottoms of the anodized pores. The resulting implantation masks appear quite robust during exposure to ion beams of 1 MeV He, Ne, and Kr. The steps necessary to fabricate the implanted samples, including the SEM characterization, will be described. Measurements of the angular dependence of the transmitted ion current will be reported; these results are consistent with the physical dimensions of the opened pores. Alignment procedures will be discussed, and TEM images of implanted arrays will be shown. This research was supported by the U.S. Department of Energy, Office of Scientific and Technical Information, BES-Materials Science, under Contract No. W-31-109-Eng-38.

2:15 P.M. T2.3

Pt nanowires have been produced by the deposition of Pt thin films in a commercial (30 keV) ion beam (FIB) system, followed by cross-sectional sputtering to form electron transparent Pt nanowires. The thermal stability of the FIB manufactured Pt wires on Si has been investigated by in-situ thermal cycling in a TEM. The Pt wires recrystallized with heating in vacuum, and real-time videos of the in-situ nucleation, growth and coarsening of Pt nanocrystals are presented. The influence of Ga impurities in the Pt wires from the FIB processing is discussed.

2:30 P.M. T2.4
ULTRA-RAPID NANO-SCALE PATTERNING OF PMMA USING A Ga4+ FOCUSED ION BEAM: TOPOGRAPHIC CONTROL AS A FUNCTION OF SPUTTERING TEMPERATURE. Yaying Liu, Timothy Herley, Robert Hull, Department of Materials Science & Engineering, University of Virginia, Charlottesville, VA.

A 30 keV Ga4+ focused ion beam (FIB) is used to create nano-scale topographic patterns in Polymethyl methacrylate (PMMA) thin films at speeds up to 5 x 106 features/second. The patterned features are about 60 nm in diameter and 5 nm deep using a 1 pA beam with a diameter of 10 nm. TEM observation of the irradiated material did not show material densification, indicating that the material removal rate is much faster than the beam dwell time. The material removal rate has been measured under different conditions and observed sputtering rates remain at least one-two orders of magnitude higher than typical values (i.e. 0.1 - 1 μm3/nC) with the substrate held at room temperature. A more significant effect was observed in varying the substrate temperature from -80 to 200°C. When the substrate temperatures are lower than the glass transition temperature of the PMMA, depressed features (i.e. holes) are created with anomalously high sputtering yields. When the substrate temperatures are higher than the glass transition temperature of the PMMA, the ion-exposed regions then become raised hillocks with similar lateral dimensions to the holes created at lower temperatures. We speculate that ion-enhanced chemical modification and unzipping reactions are responsible for these complex topographies. In any event, these observations enable FIB-generated topographical patterns to be created at rates of magnitude faster than previously envisioned. Using this approach we have successfully demonstrated high-density fabrication of topographical patterns as masters for micro-contact printing (μCP), with resolution comparable to molding from conventional inorganic masters.

SESSION T3: NANO-STRUCTURES AND NANO-STRUCTURE SURFACES
Tuesday Afternoon, April 22, 2003
City (Argost)

3:15 P.M. T3.1
NANO-PHASE FORMATION UNDER ION BEAM: RADIATION EFFECTS VERSUS ION IMPLANTATION. Lumin Wang, University of Michigan, Dept of Nuclear Engineering & Radiological Sciences, Ann Arbor, MI.

Nanomaterials obtained with ion beam processing can be divided into two general types, i.e., those that are obtained from deposited implanted ion species and those that are not. Nanomaterials of the latter type are the result of radiation effects. Various kinds of nanomaterials have been produced in ceramic and semiconducting materials under energetic ion beam irradiation as results of radiation effects rather than the implanted species. Irradiation of single crystalline materials with energetic particles can result in microstructures composed of nanophases (nanomotes, nanolayers, nanodots, or three-dimensional nanocrystals), either with the original composition and crystal structure or with altered structures and compositions. The phenomenon has been observed with ion implantation, electron microscopy during ion beam
irradiation in all kinds of materials including metals, semiconductors and ceramics. Nanostructures may be induced by radiation effects with ion fluxes several orders of magnitude lower than those typically required for ion implantation based method, thus resulting in much smaller local strain and stress. Examples of nanostructure formation with both methods in either crystalline or amorphous materials will be demonstrated. Possible mechanisms responsible for the formation of radiation induced nanostructures include radiation-induced defect accumulation, recrystallization, structural order and disordering, chemical segregation and decomposition, etc. These mechanisms will be discussed with examples of experimental observations.

3:45 PM **T3.2**

**Abstract Withdrawn.**

**4:00 PM** **T3.3**

**ION-BOMBARDMENT INDUCED PATTERN TRANSFORMATION ON SELF-ORGANIZED SEMICONDUCTOR SURFACES. S. Ahlersmann, T. Teichert, C. Hofer, Institut für Physik, Universität Stuttgart, GERMANY**

Self-organization of nanostructures in semiconductor heteroepitaxy has been established as an efficient route towards large-scale nanoscale patterning of surfaces [1]. Recently, it has been demonstrated that ion erosion of compound semiconductors may also result in well ordered dot patterns [2]. Here we use atomic-force microscopy to explore the ion bombardment induced morphological evolution of self-organized SiGe films grown on Si(001) under subsequent ion bombardment. Whereas in most of the cases a smoothing of the surface is observed, for a checkered array of (105) pyramids and pits [3] the nanostructures could be transformed into the Si substrate. The details of the pattern transition and its dependence on ion energy are discussed in the framework of current theories of ion bombardment induced pattern formation. Research supported by the FWF, Austria (No. P14005-PHE). [1] C. Teichert, Phys. Rep. 365, 335 (2002) [2] S. F. F. K. et al. Science 285, 1551 (1999); F. Frost, et al., Phys. Rev. Lett. 85, 4110 (2000) [3] C. Teichert et al., Thin Solid Films 380, 28 (2000).

4:15 PM **T3.4**


The physical properties of the probe are integral to scanning probe microscopy (SPM). In metrology applications, the geometry and stiffness are particularly important. In many cases the tip-sample interface affects the measurement as well. Diamond is a favorable material for SPM probes because of its high stiffness and wear-resistance. Furthermore the chemically inert surface is usually desirable to minimize tip-sample interaction. To achieve the sharp geometries needed for high aspect measurements, focused ion beam (FIB) milling is often the preferred method for diamond. However, the FIB process leaves a damage layer consisting primarily of amorphous carbon, compromising the probes stiffness and wear-resistance, and altering its surface chemistry. Removing the damage layer enables a new process for producing pure nanoscale diamond structures of practically any geometry. Nicke acid etch has previously been reported for top-down FIB-milled diamonds used for conductive SPM[1]. Reactive oxygen plasma etching offers an alternative removal method with potentially greater control. We present transmission electron microscopy and SPM data characterizing the performance of untreated and plasma-etched FIB-milled diamond tips. These tips represent a more complex geometry necessary for critical dimension metrology.


**SESSION T4: POSTER SESSION**

**ION AND ELECTRON BEAM INDUCED NANOSTRUCTURES**

Tuesday, Evening, April 22, 2003

**8:00 PM**

Golden Gate (Marriott)

**T4.1**

**Abstract Withdrawn.**

**T4.2**

**POTENTIALITIES OF FORMATION OF ANNULAR AND THERMAL SPKRES FROM SWIFT HEAVY IONS. Alexander E. Valkov, Michael V. Sorokin, Denis N. Korotev, Institute of General and Nuclear Physics, Russian Research Centre, Kurchatov Institute, Moscow, RUSSIA.**

Decay of solid solutions of impurity atoms in metals [1] and dielectrics [2] irradiated with swift heavy ions (SHI, E>1MeV/amu) results in nanoscale precipitate nucleation, which correlates with the value of the electronic energy loss of the penetrating ions. For such high energies, the primary damage occurs mainly in the electronic subsystem of material and the damage produced by elastic recoil is of secondary importance. This effect manifests a new possibility of the monitoring of the precipitate formation and can be interesting as some alternative in manufacturing of low-dimensional nanostructures. Subsequent energy transfer from the excited electrons to target atoms can result in surface nanoscale temperature increase (thermal spike) at the surface and in the bulk of irradiated material in nanometric region the vicinity SHI trajectory. Temperature dependence of the nucleation times of precipitates and shalms has generally an abrupt minimum at the characteristic temperatures depending on the system parameters. A decrease for the precipitation appears when the material/surface heating in SHI track results in those temperature values, where the nucleation time becomes shorter than the track cooling down time. We indicate the values of parameters of matrixes, surface, impurity atom, projectiles, and irradiation conditions favorable for precipitations in the bulk and on the surface caused by SHI. It is shown that the region, where the maximum nucleation rates are possible, can be shifted from the track center. Initial inhomogeneity may result in appearance of nanoscale tubular heterostructures along the projectile trajectories and/or ring-shaped nanocluster distribution on the surface near ion ions. 1. Barbu A. P. K. J. Jacques V., Nuclear Inst. Meth. B146, 728 (1998) 2. Valentin E. Bormas H., Ricoleau C., Criquet F., Phys. Rev. Lett. 86 99 (2001).

**T4.3**

**MILLING, GROWING AND MOLDING WITH A FOCUSED ION BEAM. Paul F.A. Alkemade, Valerie G.M. Sivel, Henk W. Zundelbergen, Delft Univ. of Technology, Dept of Nanoscience, Delft, THE NETHERLANDS.**

Increasing knowledge of the physics and chemistry of materials at sub-micrometer length scales and rapid instrumental developments drive developments in nanotechnology. Nowadays charged particle beams of nanometer widths are available for shaping materials. The physical processes that underlie this technique are ion milling, ion beam assisted growth, and ion beam molding. In this presentation I will elaborate the interplay of ion beam milling, ion beam assisted growth and molding. Besides sputtering and ion assisted decomposition, crucial aspects are defect production, amorphisation, and viscous flow. To illustrate these processes, I will show examples of nanostructures shaped with a focused Ga beam in a dual-beam FIB instrument. In particular, I will show that there is not a direct one-to-one relation between processing and shape. In order to find distinct nanostructures, one must make clever use of the physics.

**T4.4**

**ION INDUCED DISPLACEMENT OF GOLD NANO Particles IN CORE-SHELL COLOIDS. Sjoerd Roerdink,1,2 Teun van Dillen,1,2 Joan Penninkhof,1,2 Bart Kooi,3 Jeff de Hoon,2 Christian Graß,4 Alfons van der Kraan,2,4 Alfons van der Kraan,2,4 Albert Pettersson for the Amsterdam and Molecular Physics, Amsterdam, THE NETHERLANDS. 1University de Montreal, GCM, Département de physique, Montréal, CANADA; 2University of Groningen, Groningen, THE NETHERLANDS; 3Utrecht University, Utrecht, THE NETHERLANDS.**

It is well known that irradiation of amorphous materials with swift heavy ions leads to shape deformations known as ‘hammering’, a mechanism that has been attributed to Coulomb explosions, viscoelasticity, or momentum transfer. Distinguishing between the different alternative explanations is not clear-cut because the predicted dependence of the deformation on projectile mass, energy, and incident angle is quite similar for each model. In this work, core-shell colloidal particles, were irradiated with 30 MeV heavy ions. The core-shell colloids consisted of a 1.5 nm diameter gold core surrounded by a silica shell of typically 70 nm thickness. The gold core, which normally is located at the centre of the particle, has moved to a new position downstream from its original position. This movement can be as large as 15 nm and is due to surface sputtering, creep, or flow of the silica, although these phenomena do occur to some extent. The shift in position of the gold core is always in the direction of the ion beam and attributed to the force exerted by the ions on the gold core as they slow down, thus providing support for the momentum transfer model.

**T4.5**

**Abstract Withdrawn.**

**T4.6**

**ION-NOISE AND ELECTRICAL TRANSPORT STUDIES ON...**
The effect of 200 MeV Ag ion irradiation on the electrical transport and 1/f conduction noise properties of pulsed laser deposited epitaxial thin films of Li0.64Ce0.36MoO3 have been studied. The electrical transport measurements show sharp metal-insulator transition at 282K and magneto-resistance around 30% at 1T magnetic field in the pristine film. The well characterized thin films were irradiated with 200 MeV Ag ions for various values of fluence in the range 5x10^8 to 1x10^12 ions/cm^2 using 15U Octagon Polaronix at Nuclear Science Centre, New Delhi. The electrical transport and the conduction noise as a function of temperature and frequency of un-irradiated and irradiated thin films in the spectral density S(f), (V^2/Hz) of conduction noise show 1/f dependence through the temperature range in the low frequency range up to 100Hz for un-irradiated as well as irradiated samples. The systematic variation of transition temperature and resistivity has been observed as a function of ion fluence. For fluence value of 5x10^10 ions/cm^2 the transition temperature is increased to 284K and with further irradiation it decreased and remain higher than the unirradiated sample upto the fluence of 1x10^12 ions/cm^2. The S(f) (V^2/Hz) of irradiated thin films is an order of magnitude higher than the unirradiated thin film. Whereas, the temperature coefficient of resistivity (TCR) values for irradiated films are higher by factor of 3 than that of the unirradiated thin film. The observed TCR values in the pristine and irradiated films are consistent with the general expectation concerning the effect of heavy ion induced lattice defects.

T4.7 ELECTRON BEAM INDUCED EFFECTS IN COPPER DOPED CHALCOGENIDE THIN FILMS J.S. Romero and A.G. Fitzgerald, Carnegie Laboratory of Physics, Department of Electronic Engineering and Physics, University of Dundee, Scotland, UNITED KINGDOM

Copper migration and surface expansion of irradiated areas is observed in copper doped amorphous germanium based chalco-genide thin films examined by TEM and X-ray diffraction. The migration of copper ions in focused pulsed or continuous electron beams is focused on the surface of these bilayers. Both phenomena can be explained using a simple model in which the population of D centers is increased by the irradiation. The increase in the population of D centers is envisaged as a result of the bond-breaking nature of electron radiation and the conformation of the charge in the irradiated regions. Expansion of the surface ranging between 30-40% of film thickness has been achieved and dry patterning in one step of patterns with micron and submicron dimensions on chalco-genide thin films has been demonstrated.

T4.8 CHEMICAL ENHANCED ELECTRON BEAM INDUCED DIRECT PATTERNING. Jiunn Weng, Kunning University of Science and Technology, Kunming, Yunan, P.R. CHINA; D.P. Griffis, R. Garcia, P.E. Russell, Analytical Instrumentation Facility, North Carolina State University, Raleigh, NC

Maskless or direct patterning of electronic material is an interesting topic when considering structures with nanometer sized feature. Ebeam is also a promising tool for mask repairing to remove copake defects. This work demonstrates the ability of electron beam direct writing on silicon oxide, C, film and TaN film. With the help of XeF2 well defined pattern and profile can be obtained on these materials used for mask making in semiconductor industry. The writing process was revealed by controlled dose and after AFM images. Influence of electron beam energy, beam current, and gas supply on patterning rate was studied. Create depth increases linearly with dose. Electron beam induced gas supply shows etching effect. Electron beam with energy of 5kev is more efficient than 1kev, but for Cr film, it is opposite.

T4.9 DISCOVERY OF NANOBOULDERS AT THE SURFACE OF ELECTRON BEAM ANNEXED LOW-ENERGY CARBON IMPLANTED SILICON Andrew Bedroom, A. Deakin and W. Trompeter, Institute of Nuclear and Nuclear Sciences, Lower Hutt, NEW ZEALAND; Horst Baumann, Institute for Nuclear Physics, J.W. Goethe University, GERMANY

The combination of an electron beam annealed low-energy carbon implanted silicon (EBA) was studied by fast secondary electron microscopy. The average energy of the beam was 5 to 20 keV in crystalline silicon at room temperature to create new structures with distinct properties. To form these nanostructured surfaces and thin films, a 20 keV electron beam was used. The beam was scanned over the implanted regions using beam control and a computer-controlled feedback system. The specimen was annealed for a few seconds at typically 1100°C (temperature gradient 5°C/s) under high vacuum conditions. Depending on the ion flux and the implantation process, structurally different features have been produced by irradiating with gaseous ions. In this contribution, we report for the first time, high dose 10 keV ion-energy implantations of carbon (3×10^16) + ions to crystalline silicon using EBA. The implanted regions have a height of up to 150 nm. Additionally, an enhanced boundary layer around the implanted area was observed. The ion beam analysis (IBA) measurements using the high sensitive 14C(14C,α) 8He reaction at 750 keV revealed that the implanted carbon is still present in the annealed specimen. The SEM and HRTEM images have been presented providing evidence for the discovery of the nano-boulders on the surface of implanted and annealed silicon substrates.

T4.10 SELECTIVE NANOSCALE ELECTRON BEAM STIMULATED ETCHING. P.D. Ruck, S. Randolph, J. Kim, J. Fowlkes, Y. Choi, and David C. Joy, Department of Materials Science and Engineering, Department of Biochemistry and Cellular and Molecular Microbiology, The University of Tennessee, Knoxville, TN

The ability to manipulate materials at the nanoscale is critical for the nanotechnology revolution that is occurring. Current techniques to selectively deposit or etch microscale features utilize ion beam deposition and etching, laser ablation etching using far field and near field optics, and mechanical ablation using a fine microtip. As an alternative approach to these techniques we are exploring nanoscale electron stimulated deposition and etching. In this paper we will focus on our recent progress on nanoscale electron stimulated etching. The experimental set-up consists of a scanning electron microscope modified with a gas delivery system. To date we have achieved a variety of materials (Si, SiO2, Si3N4, Ta, W, Al, Cr, C, Cu, low dielectric constant SILK and Black Diamond, and photoresists) using fluorinated chemistries. Beam energy studies of a single etching reveals increased etching yield and an increase in the effective beam size at lower beam energies. These results are in qualitative agreement with the increased inelastic scattering cross-sections for dissociation and ionization at lower beam energy. Silicon dioxide trends are similar, however the process is believed to be facilitated by an oxygen electron stimulated desorption process. In this paper selective etch results will be presented and the relevant electron-solid, electron-gas, and gas-solid interactions will be discussed.

T4.11 NANOSCAE SCALE STRUCTURES GENERATED BY COMBINED CHEMICAL AND RADIATIVE EXPOSURE OF SOLID SURFACES. Tom Dickinson, Khin Nwe, and Steve Langford, Dept. of Physics, Washington State University, Pullman, WA

Novel nanometer scale structures on insulating inorganic materials with wide bandgaps can be generated by simultaneous exposure with laser and electron beams plus reactive gases. Here we present our current research on the mechanisms involved in modification of surfaces of inorganic crystals following exposure to UV excimer laser light, keV electron beams, and relatively low pressures of water vapor. Dramatic synergies are observed due to bond weakening which arises from localized chemisorption. We are able to model single crystal surfaces of alkali halides and calcium phosphates/carbonates either at the single atomic layer level or, with higher intensities, at the level of several microns. Arrays of cones and frustal structures with unique optical properties can readily be generated. Mechanisms for the material removal, redeposition and restructuring are observed. Finally, we show that in the presence of water vapor, the rates of both laser and electron beam induced decomposition/desorption increase by as much as an order of magnitude. We present evidence that this is a highly localized, defect mediated mechanism. We suggest that point defect clusters lead to atomic dimention step structures (e.g., kinks) that peel off due to bond weakening from sorbed water derived radicals. Supporting evidence from spectroscopic and microscopic data exposed surfaces will be presented. The consequent sequences of irradiating hydrated crystals will also be discussed.

T4.12 NANOSTRUCTURE OF GOLD NANOWIRE FORMED BY ELECTRON BEAM IRRADIATION IN HIGH RESOLUTION TRANSMISSION ELECTRON MICROSCOPE. Yu Zhang, Kathleen Dunn, and Alan E. Kakhiyev, University of Alabama in Birmingham, SUNY, Albany, NY.
In this study, self-supporting nanowires were fabricated from electron-transparent gold films irradiated in a JEOL 2010F high-resolution transmission electron microscope (HRTEM). The gold films were prepared either by thinning a 100 nm evaporated gold film to 5 nm via low-angle sputtering with 2 keV Ar+ ions while cooling the specimen to 77 K, or by evaporating a 5 nm gold film on a copper grid coated with amorphous carbon membrane. Both approaches resulted in films of suitable thickness for high-resolution imaging and subsequent melting by the electron beam in situ. To accomplish this, the films were exposed to high current densities (∼10^5 A/cm²) by converging the electron beam to a diameter of ~10 nm for brief intervals in order to locally melt the gold film. Images were acquired between irradiations with a diverged electron beam. Strategic placement of such holes resulted in the formation of self-supporting bridges of gold within one grain or between two grains. Wires with diameters less than 10 nm and aspect ratios of 1:3 were fabricated. Bridges which were longer or had higher aspect ratios (length/width) were subject to amorphization and breakage. The orientation of the crystal planes within the bridges appeared to rotate relative to the axis of the wire, suggesting that there may be a preferred low-energy orientation for nanowires.

T4.13
SILICON MICRO MAGNETIC NANO STRUCTURES PRODUCED BY ELECTRON BEAM DIRECT WRITING ON CO AND Co(Tc) SYSTEMS
Y. Zhou, Data Storage Institute, SINGAPORE, ISML, ECE Department, National University of Singapore, SINGAPORE; T.J. Zhou, Data Storage Institute, SINGAPORE; J.P. Wang, Department of Electrical and Computer Engineering, JNTU, University of Minnesota, Minneapolis, MN; T.C. Chong, Data Storage Institute, SINGAPORE, ISML, ECE Department, National University of Singapore, SINGAPORE.

We present a novel method to produce magnetic nanostructures by EB-beam irradiation induced nano-scale phase transition. Non-magnetic Co-C and Co(Tc) films were patterned by electron-beam direct writing and the 20nm magnetic dot/line array were produced. This method of magnetic patterning has the potential application for nanoscale solid magnetic devices. The Co films with thickness of 30nm and Co concentration of 45% ~ 50% were co-sputtered under room temperature. The magnetic measurement shows that the films with the cobalt concentration less than 60% were non-magnetic. After annealing under 400°C for two hours, both He and Mo of all the films increased significantly and the highest coercivity reached when Co content equaled to 60%, Fig. 1. However, such coercivity is somewhat low for applications in magnetic recording. Ta was selected to improve the magnetic properties of the films because it can enhance the segregation of Co and C. It was found that the film with 3% Ta doping (Fig. 2.), Magnetic patterning of the Co20Ta20 was achieved by subjecting them to electron beam radiation using a focused 30keV-E-Beam with a current of 7.1mA and a dwell time of 0.75-15.2 seconds. As shown in Fig. 3., for Co-C films, the magnetic dots were formed within the dwell time increased from 0.75 to 15.2 seconds. However, for Co(Tc) films, the weak magnetic line was produced with the dwell time of 0.75 seconds, and the stripe domain was very clear when the dwell was 1.9 seconds. It is obvious that the time of magnetic patterning (Co20Ta20) is much shorter than that of patterning Co20C20 films thus more practicable in use.

SESSION T5: POSTER SESSION
NANOTUBES AND NANO CRYSTALS
Tuesday Evening, April 22, 2005
8:00 PM
Golden Gate (Marriott)

T5.1
ATOMISTIC SIMULATION OF RADIATION DAMAGE TO CARBON NANOTUBES
Zhao, Y. Wang, J. Cui, D. F. Shih, Inst. of Materials Science and Engineering, Tsinghua Univ, Beijing, CHINA

Damage carbon nanotube upon energetic irradiation has been modeled with molecular-dynamics simulations. The angular dependence of the threshold energy of the primary knock on atom (PKA) escaping from the tube is investigated in the initial PKA directions spanning half space. The average value of the threshold energy is 1.19 keV. The detailed picture of the damaging processes, in which four mechanisms were revealed. The interactions between carbon atoms are described with the Tersoff mode modified to match a screened Coulomb potential at short range.

T5.2
ABSTRACT WITHDRAWN

T5.3
ABSTRACT WITHDRAWN

T5.4
CATALYST NANOPARTICLES SYNTHESIZED WITH ION IMPLANTATION IN SILICON AS TEMPLATE FOR CARBON NANOTUBES GROWTH

The growth of carbon nanotubes (CNTs) in chemical vapor deposition (CVD) process strongly depends on the properties (size, location, density etc.) of catalyst particles and their interactions with substrates. In this work, we investigated the role of catalyst nanoparticles prepared by ion implantation in the CVD growth of CNTs. Nanoparticles of catalyst [nickel] embedded in silicon are prepared by Ni ion implantation followed by annealing. The implanted doses of Ni were varied between 1e15 e17 cm-2. Post-implantation annealing between 600-1000°C produced nanometer crystals of nickel silicide in Si. As the second step, CNTs were grown on these Si substrates containing Ni nanoparticles, by CVD through decomposition of hydrocarbon. The morphology and various properties of the resultant CNTs were examined with a number of techniques including transmission electron microscopy (TEM), scanning electron microscopy (SEM), x-ray diffraction (XRD) and x-ray photoelectron spectroscopy (XPS). We discuss the effects of different parameters, e.g., the size and density of nanoparticles and their embedding substrates, on the formation of CNTs.

T5.5
HIGH-ENERGY PROTON IRRADIATION OF SINGLE-WALLED CARBON NANOTUBES
Vladimir A. Barinik, Kensei Kobayashi, Takeo Kuroki, Yokohama Natl Univ, For of Engineering, Dept of Chemistry and Biototechnology, Yokohama, JAPAN; Elena V. Barinik (Goncharova Dzhambulova) and Jos M. Sangor, Universidade Nacional Autonoma de Mexico, Centro de Ciencias Aplicadas y Desarrollo Tecnologico, Mexico D.F., MEXICO; Yoichi Negishi, Yokohama Natl Univ, Instrumental Analysis Center, Yokohama, JAPAN.

Effects of different kinds of irradiation on carbon nanotubes (CNTs) are of interest from two main points of view: (1) for modifying their physical and chemical properties, by introducing structural defects into the side walls; (2) for defining to what extent CNT materials can be used under harsh radiation environments, associated with their possible use for nuclear applications and under open space conditions. Effects of electron and heavy ion irradiation on CNTs already received attention in recent publications. The aim of this work is to present one more important type of high-energy charged particles, namely protons. Their size is intermediate between that of electrons and of heavier positively charged ions, so that any information on CNT irradiation with protons would be a significant addition to our knowledge of the whole spectrum of radiations effects on this important class of materials. We report on TEM observation of morphological changes in single-walled carbon nanotubes (SWNTs) caused by their bombardment with 3 MeV protons, in a wide range of irradiation doses. Evident morphological alterations were observed at > 0.1 mC, such as curling of the nanotubes, a loss of their straight shape and formation of short pieces. During further irradiation (doses approaching 1 mC) SWNTs degraded into an amorphous material, although a significant fraction of them was present as pieces of different lengths. This means a loss of the nanotube physical integrity, and thus puts an upper limit of proton irradiation doses where SWNT materials can be used, regardless of their particular application. This limit, however, is very high if to compare flux values in our case and for those typical for near-Earth space conditions during "quiet Sun" periods. Even upon a direct exposure to proton space irradiation, SWNTs will undergo no detectable alterations for practically unlimited time.

T5.6
THE LUMINESCENT PROPERTIES OF THE ION IMPLANTED-FABRICATED SiO2 nanoscale Si NANOSTRUCTURES ANNEALED AT HIGH TEMPERATURES
Dawid Tetebulem, Oleg Gornoknov, Alexander Kuznetsov, Nanomaterials Dept., Max Planck Institute for Solid State Research, Stuttgart, GERMANY; Olga Gornoknov, Physico-Technical Research Institute of University of Nizhny Novgorod, Nizhny Novgorod, RUSSIA; Daria Gaponova, Institute for Physics of Microstructures of Russian Academy of Science, Nizhny Novgorod, RUSSIA.

The luminescent properties of the ion implanted-fabricated SiO2 nanoscale Si nanocrystals annealed at high temperatures were investigated. The samples were implanted with 1MeV Si+ ions with doses from 1e15 to 1e18 ions/cm² and then annealed at temperatures from 700°C to 1200°C. The emission spectra were recorded in the wavelength range from 300 to 800 nm. The results showed that the luminescence intensity and peak position were dependent on the ion implantation dose and annealing temperature. The luminescence intensity increased with increasing ion implantation dose and decreasing annealing temperature. The peak position of the emission spectra shifted to longer wavelengths with increasing ion implantation dose and decreasing annealing temperature. The luminescence intensity and peak position were also influenced by the substrate material and its thickness. The luminescence intensity was higher for Si substrates with a smaller thickness, and the peak position shifted to longer wavelengths with decreasing substrate thickness. The results have potential applications in the development of luminescent materials for optoelectronic devices.
The SiO$_2$-no-Si structures are extensively investigated in connection with a good prospect of their utilization in the silicon-based optoelectronic devices. However, rather little attention is paid to the influence of the variation of the annealing temperatures $T_{\text{ann}}$ (at high ones) on the luminescent properties of this system. It was recently revealed that even rather small variation of the $T_{\text{ann}}$ (1000-1100°C) strongly affects the optical behavior of the SiO$_2$-no-Si samples. Therefore, the results of the further investigation of this item are presented. The elevation of the $T_{\text{ann}}$ from 1000°C (2h) to 1100°C and higher ones leads to a sharp lowering Si$^4+$ dose for which the maximum photoluminescence yield in the visible region is reached. The behavior of the system at the additional doping with phosphorus is also different for $T_{\text{ann}} = 1000°C$ and $T_{\text{ann}} \geq 1100°C$, respectively. In the first case, the strong phosphorus-induced increase of the PL intensity takes place, whereas in the second case the increase is not so pronounced. The pointed out difference is interpreted on the base of the model which takes into account the Ostwald ripening. Their role is sharply enhanced with the $T_{\text{ann}}$ elevation. It is shown that the model permits to explain the observed change in the PL intensity. The stability of the new phase was studied by x-ray diffraction measurements. The heavily irradiated samples (fluences of about $1 \times 10^{17}$ ions/cm$^2$ and above) showed a thermal stability up to the sintering temperature, whereas samples irradiated with lower fluences showed only a residual amount of this phase of about 5 vol% at temperatures of 1000°C. No significant change in the grain size of both phases could be observed. The grain size of the monoclinic phase was approximately 60 nm, and that of the tetragonal phase about 20 nm. Beside the thermal stability of the tetragonal phase an ageing stability within a time period of several years was also observed.

T5.7 EFFECT OF ANNEALING ON THE CHARACTERISTICS OF SILICON IMPLANTED NANO-TAP MEMORY

T. S. Kalier, Microelectronics Research Laboratory, University of Colorado, Colorado Springs, CO; Nick Craner, Elliot Philofsky and Lee Kummerlin, Applied Ceramics Research, Colorado Springs, CO.

Silicon nano-crystal and nano-tap memories are attracting the attention of many investigators because of lower programming voltage, longer retention time and improved endurance. In this paper, we are presenting the results of silicon nano-tap memory fabricated by implanting low energy high dose silicon into gate oxide thickness 300 A. The gate oxide was grown by dry oxidation. Capacitance versus Voltage (CV) characteristics of MOS (metal oxide silicon) structures with silicon implanted samples annealed in nitrogen environment at a temperature of 950°C show a memory window depending on the applied DC bias voltage. A memory window of 3V was obtained for an applied bias voltage between $-400$ V and $-100$ V. Annealing of the MOS structures in a furnace at a temperature of 800°C for 30 minutes in oxygen resulted in complete loss of memory window. Annealing the samples rapidly thermal in oxygen environment at 800°C for 30 seconds resulted in a memory window of about 3V for a programming voltage of plus or minus 14 volts with improved CV characteristics.

The characteristics of implanted silicon nano-tap MOSFET non-volatile memory devices.

T5.8 EFFECT OF ENERGETIC BEAMS ON Si NANOSTRUCTURES IN SiO$_2$

Gregory Kudrin, Svetlin Vanevsky, Vladimir Volodin, Anton Gratkowski, Institute of Semiconductor Physics, SO RAN, Novosibirsk, RUSSIA.

The influence of ion, electron and intense light beams on Si nano-crystals embedded in SiO$_2$ layers, was studied using HREM, photoluminescence and Rams spectroscopy. The Si-nano-crystals were formed by implantation of ~$10^{15}$ cmm$^{-2}$ Si ions in thin SiO$_2$ layers followed by annealing at 1100°C. Due to the quantum-size confinement, the pre-prepared Si nano-crystals emit red strong light under 488 nm laser excitation. Subsequent irradiations of the samples with the keV-range He and B ions and with 400 eV electrons resulted in structural transformations quite different from that of bulk Si. Single atomic displacement cascades, presumably due to the light energetic particles, created an increase in Si-nano number in the layers. That was the case only when the post-implantation annealing temperatures exceeded 1000°C. Further irradiation with the light ions and fast electrons annihilated Si nano-crystals, presumably by accumulation of mobile point defects by the Si nano-crystals boundaries. Amorphization occurred when about 20% of atoms were displaced due to elastic losses while the ionization losses did not play any role. Unlike bulk Si, more than 1000°C annealing was required by low doses of light energetic particles. Si-nano-crystals may be formed by annealing of Si-implanted SiO$_2$ layers with the intense light pulses of sea- and micro-duration, which provided the samples heating up to 1200-1400°C. However, the subsequent implantation of Si ions at 800°C led to a destruction of mobile Si nano-crystals, as revealed by HREM and Rams data. All the observed peculiarities are related to the strong influence of the Si nano-crystals boundaries and their surface tension on the structural transformation processes. The Si nano-crystals do not disappear, even under the most intensive ion and electron irradiation, followed by high-temperature thermal processing showing a broad and evenly intense PL band. The light emission, centered in the near infrared and extending well into the visible part of the spectrum, has potential applications for the development of photo-sensors based on nano-crystals. Here, we report on our attempts to...
create luminescent arrays of Si nanoparticles. Silicon microprobes containing embedded silicon nanocrystals were formed by ion implantation and annealing of commercially produced wafers with a nominal diameter of 5 micrometers. Arrays of luminescent microprobes were successfully fabricated, without significant degradation or destruction of the silicon spheres. However, a substantial deformation of the surface of the spheres that occurred during the high-flux implantation prevented the development of resonant cavity modes in the luminescence spectra. Resonant modes could clearly be observed for pre-implanted and annealed SiO2 spheres with a layer of pores microspheres that were subsequently created on the inner surface. These combined results suggest that at lower ion fluxes, the development of luminescence microprobes superlattices, with novel optical properties due to resonant mode coupling to the light emission from silicon nanocrystals, may be possible if the deformation effects can be reduced or eliminated.

SESSION T6: METALLIC AND MAGNETIC NANOSTRUCTURES
Wednesday Morning, April 23, 2003
City (Argus)

9:00 AM *T6.1
METAL-SEMICONDUCTOR PHASE TRANSITION IN NANOSCALE VANADIUM DIOXIDE PRECIPITATES FOR MEDICAL APPLICATIONS
R. Lopez,1,2, L.A. Bocner,1 L. C. Feldman,1,2, R. H. Hylton, Jr.1 and T.E. Haynes1
1Vanderbilt University, Nashville, TN; 2Oak Ridge National Laboratory, Oak Ridge, TN.

The study of solid-state phase transitions at nanometer length scales provides new insights into the effects of size on the mechanisms of structural transformations. Such research also opens the door to new applications since the physical properties of nanoparticles change with particle size or through the interaction of the nanoparticles with a surrounding host matrix. For applications such as optical memories, the hysteresis that is characteristic of the phase transition is particularly relevant. Here, we describe the formation of vanadium dioxide precipitates in silica and sulphide substrates by stoichiometric ion implantation and thermal processing. We observe 10-100 nm-size VO₂ nanoparticles with shapes that vary from spheroids to needles. The metal-semiconductor transition of VO₂ precipitates shows features that differ in each substrate. The effects of nanocrystal morphology, size, and host interaction on the phase transition were characterized by transmission electron microscopy, x-ray diffraction, Rutherford backscattering, infrared optical measurements, and doping experiments.

Of particular interest are the enhanced size-dependent hysteresis and the surface plasmon resonance induced by dielectric confinement when the particles reach the metallic state. This resonance amplifies the optical contrast in the range of newly-formed optical transmission wavelengths. The VO₂ nanoparticles in Al₂O₃ present a ‘rounded’ and narrow hysteretic transition, while the nanoparticles embedded in SiO₂ exhibit a sharper transition with up to 50 K of hysteresis—one of the largest values ever reported for this transition. This hysteresis and the transition temperatures are correlated with the size of the precipitates; this size dependence can be understood within the framework of the Bloch-Slater model. Dopplng the particles with ions such as tungsten and titanium alters the transition temperatures and the hysteresis width over a wide range of values, and provides further clues to the mechanism of the phase transition. Nonlinear and ultrafast optical measurements on VO₂ films have shown that the semiconducto-metal transition is the fastest known solid-solid transformation. The VO₂ nanoparticles will be shown to retain this bulk property, transforming in times shorter than 150 fs.

9:30 AM *T6.2
STRUCTURES OF ENERGETIC ION IRRADIATED CARBON NANOTUBES

Carbon nanotubes (CNTs) have unique structures and hence a range of fascinating properties. If the structures can be controllably tailored by post-synthesis techniques such as irradiation, for example, by introducing controlled number of defects, it may lead to better control in electronic applications. Ion irradiation offers a unique way to investigate defects structures of CNTs and their influence on CNTs' various properties. The understanding of energetic ion beam effects on CNTs is of great technological importance, since CNTs are promising for applications in space exploration. However, there is only limited experimental work on ion irradiation and most of this focused on electron irradiation. In this work we study radiation effects of energetic ions (proton and Ar⁺) on CNT structures and multi-walled carbon nanotubes (SWNTs) and multi-wall nanotubes (MWNTs) were irradiated with ions of energy in keV-MeV to doses in the range of 1e14-1e16 cm⁻². A comparison in CNT structures and chemical environments between the un-implanted and ion-implanted samples was made based on x-ray photoelectron spectroscopy (XPS) and x-ray diffraction (XRD). The amount of defects (e.g. vacancies) created in the irradiated samples was correlated with the nuclear and electronic energy loss of ion beams. Effects of post-irradiation annealing on defect structures of CNTs were also examined.

9:45 AM *T6.3
ION BEAM MANIPULATION OF NANO-SIZED ARTIFICIAL SOLID-STATE MICROSTRUCTURES IN SOME IMMISCIBLE BINARY METAL SYSTEMS
Z.C. Li and B.X. Liu, Tsinghua University, Dept of Materials Science and Engineering, Beijing, CHINA.

We developed a new scheme namely ion beam manipulation, i.e., interface-assisted ion beam mixing, for fabricating artificial solid-state microstructures in the metal-metal multilayers, in which the individual layer thickness was down to about 2 nm, different from typical thickness of 5-8 nm in the conventional ion beam mixing [1].

In the scheme, the interfacial free energy was a controllable parameter and designed to be adequate for elevating the multilayers up to a highly energetic level. Another controllable parameter was the ion irradiation dose, which was executed with fine intervals for tracing the detailed structural evolution, prior to the formation of the new microstructure. We report, in this paper, some examples observed in the equilibrium immiscible Ag-Co, Ag-Ni and Pb-Ru systems in this scheme. The nanocomposite scheme was indeed unique because it could control a large number of two adjustable parameters. In the Ag-Co system, a highly energetic ordered layered structure was obtained and identified to consist of two overlapping for lattices, corresponding to a new magnetic state of Co atoms with an average magnetic moment of 2.84 μB, which was about twice of the equilibrium value and probably the largest one ever observed. Interestingly, the similar ordered layered structure was reproduced in the Ag-Ni system [2]. In the Ru-Pd system, unique structural evolution was observed with increasing the irradiation dose, i.e., the initial polycrystalline Pd and Ru first transformed gradually into a single crystalline for phase, and then turned into a well grown ordered structure, which, however, showed an apparent tendency to transform back to the same for phase upon over-irradiation [3].

10:30 AM *T6.4
MAGNETIZATION DYNAMICS OF IRRADIATION-FABRICATED PERPENDICULARLY MAGNETIZED DOTS INSIDE A SOFTER MAGNETIC MATRIX
T. Devolder, M. Belmegueni, C. Chippert, Institut d'Electronique Fondamentale, UMR CNRS 8622, Universite Paris-Sud, Orsay, FRANCE; H. Bearnas, Centre de Spectrometrie Nanoarime et de Spectrometrie CAES, UMR-CNRS 8622, Universite Paris-Sud, Orsay, FRANCE; Y. Suzuki, National Institute of Advanced Industrial Science and Technology, Electronics Institute, Tsukuba, JAPAN.

Obtaining reproducible magnetization switching within the sub-micron regime and the deep sub-micron range is currently one of the most challenging tasks in nanomagnetism. We have previously shown that temperature-sustained helium ion irradiation is a very powerful tool to tune the magnetic properties of thin films, notably their magnetocrystalline anisotropy. Helium ion irradiation through nanofabricated masks has also been used to produce sub-micron planar nanostructures. We have recently tested perpendicularly magnetized dots in a matrix of weaker magnetic anisotropy. Static magnetometry measurements and Magnetic Force Microscopy showed that magnetization reversal in these dots is nucleation-free and proceeds by a very specific domain wall injection from the magnetically ‘soft’ matrix, which acts as a domain wall reservoir for the ‘hard’ dot, thus inducing a remarkably weak coercivity dispersion. We now generalize this approach by a new type of irradiation-fabricated magnetic device, designed to achieve high switching speeds, typically below 100 ps. The speed is obtained through the use of a very high effective magnetic field, and high resolution precision femtosecond pulses. During magnetic rewritting, the effective field incorporates a significant exchange field, storing energy in the form of a domain wall surrounding a high magnetic anisotropy nanostructure’s region of interest. Promising applications to magnetic storage are anticipated.

11:00 AM *T6.5
ION BEAM STABILIZATION OF FE PS-NANOPARTICLE ARRAYS FOR MAGNETIC STORAGE MEDIA
J.L. Johnson, A.J. Miller, W. Volkman, IBM Almaden Research Center, San Jose, CA; S. Sun and C.B. Murray, IBM T.J. Watson Research Center, Yorktown...
SESSION T7: NANOCRYSTALS IN SILICA
Wednesday Afternoon, April 23, 2003
City (Argentina)

1:30 PM T7.1
ELECTRON TRANSPORT IN METAL NANOPARTICLE PHASMAON WAVEGUIDES. Stefan A. Mozer, Pieter G. Kik, and Harry A. Atwater, California Institute of Technology, Thomas Watson Laboratory of Applied Physics, Pasadena, CA; Sheffer Meltzer, Ehlad Harf, Bruce E. Koel, and Ari A. Guirad, University of Southern California, Laboratory for Molecular Robotics, Los Angeles, CA.

The ultimate miniaturization of optical devices to spatial dimensions approaching the molecular scale will require structures of the electromagnetic energy with lateral confinement below the diffraction limit of light, which is not possible using conventional dielectric optical or photonic crystal waveguides. We have shown theoretically that arrays of closely spaced metal nanoparticles can work as plasmon waveguides that guide electromagnetic energy on the nanoscale. Such structures could potentially be fabricated and their optical properties tuned using ion beam irradiation methods. We report on FDTD calculation of energy guiding in locally excited plasmon waveguides consisting of spherical noble metal nanoparticles. The simulations allow the determination of the dispersion relation and group velocities for energy transport and quantitatively confirm the results of point-dipole calculations. Using ellipsoidal nanoparticles with a 3:1 aspect ratio, group velocities up to 0.2c are predicted for longitudinal excitations in waveguide geometries that can be fabricated using electron beam lithography. We also present the results of optical characterization of the guiding properties of plasmon waveguides consisting of closely spaced gold and silver nanoparticles fabricated using electron beam lithography. Far-field spectroscopy confirms the existence of longitudinal and transverse collective modes of excitation and allows for the estimation of the dispersion relation and group velocities. Measurements of the polarization-dependent absorption confirm that the collective modes arise from near-field optical interactions. Using the tip of a near-field optical microscope as a local excitation source and fluorescent polystyrene nanobeads as detectors, we present experimental evidence for energy transport over a distance of about 0.5 micron for plasmon waveguides consisting of silver rods with 3:1 aspect ratio and a center-to-center distance of 80 nm. This is the first direct evidence for localized energy transport in nanoparticle plasmon waveguides.

2:00 PM T7.2
THE OPTICAL PROPERTIES OF SELENIUM NANOCRYSTALS FABRICATED BY ION IMPLANTATION. D.O. Henderson, R. Mis, M.H. Wu, A. Ueda, Chemical Physics Laboratory, Department of Physics, Fisk University, Nashville, TN; A. Melnick, Dept. of Physics, University of Alberta, Edmonton, CANADA; C.W. White, Oak Ridge National Laboratory, Solid State Division, Oak Ridge, TN; M. Jukic, Rudjer Boskovic Institute, Zagreb, CROATIA; B. Vlahovic, Department of Physics, North Carolina Central University, Durham, NC.

Silicon windows were implanted with selenium at an energy of 330 KeV with doses ranging from 1x10^16 to 1x10^17 ions/cm^2. Rutherford backscattering measurements were performed to determine the depth profiles for implanted substrates. The implanted substrates were annealed in an atmosphere consisting of 5% H2 and 95% Ar and temperatures from 400° to 1000°C. The optical transmission spectra of implanted substrates showed a continuous red shift in the band edge as the annealing temperature increased from 400° to 1000°C. Specifically, at a transmission level of 75%, the unannealed sample implanted with 1x10^16 ions/cm^2 indicated an absorption corresponding to 3.0 eV while the sample annealed at 1000°C showed an absorption corresponding to 2.7 eV. The annealing induced red-shift is attributed to the formation of Se nanocrystals with a size range that affects quantum confinement of the excitation. This interpretation is qualitatively consistent with the transmission electron microscopy measurements which showed that the nanocrystals increased in size from <5 nm for a sample annealed 600°C to ~10 nm for the sample annealed at 1000°C. Moreover, the band edge showed a decrease with increasing ion dose, which is also consistent with size dependence on ion dose, i.e., increasing the ion dose renders larger size particles.

2:15 PM T7.3
A NEW PATHWAY FOR SI NANOCRYSTAL OXIDATION REDUCTION INDUCED BY IMPURITY IMPLANTATION. L.C. Cocke, J.K. Lee, D.W. Cooke, M. Nastasi, M.E. Hawley and D.W. Cooke, Materials Science & Technology Division, Los Alamos National Laboratory, Los Alamos, NM; A.R. Zaman, Instituto de Fisica de Sao Carlos, Universidade de Sao Paulo, Sao Carlos, SP, BRAZIL.

In this work we show the feasibility of producing silicon nanocrystals by means of a new method based on the oxidation-reduction of silicon dioxide induced by the presence of an impurity. The choice of
magnesium as the impurity relies on its thermodynamic behavior since it has a high probability of forming an oxide while the formation of Si, for example, is unlikely. The low energy ion implantation into silicon dioxide with a dose of 1 \times 10^{15} \text{ Me}/\text{cm}^2 and then annealed at 900°C to 250°C. Rutherford backscattering spectrometry (RBS) provided the actual depth distribution as well as the amount of implanted Me. For the 300° annealed sample, Raman scattering spectroscopy showed a sharp peak at 523 cm^{-1}, suggesting the existence of large Si nanocrystals. No Raman peak was observed in the case of 2h annealing. The presence of Si nanocrystals is also supported by the presence of an absorption band around 340 nm that corresponds to the Si nanostructures. In a direct transition. Photoluminescence (PL) results show a broad band centered around 700 nm with negligible PL intensity for low energy or low energy that is a fingerprint for the presence of Si nanocrystals. The analysis of the PL data in the framework of quantum confinement theory shows the existence of large (10-30 nm) Si nanocrystals.

**2:30 PM T2.4**

**LUMINESCENCE EFFICIENCY OF SILICON NANOCRYSTALS IN SiO2 EFFECTS OF EXCITATION SPECTRUM** A. Hrycik, K. Chow, A. Mekrum, Dept. of Physics, University of Alberta, Edmonton, AB, CANADA, C.W. White, Solid State Division, Oak Ridge National Laboratory, Oak Ridge, TN.

Silicon nanocrystals formed by ion implantation and annealing of fused silica wafers show a strong, broad photoluminescence (PL) peak, typically centered at a wavelength between 720 and 850 nm. This luminescence has been extensively investigated and trial device structures based on these materials have been fabricated. However, relatively few studies also report the optical absorption spectra. In fact, the absorption of these specimens is typically quite low (often < 10%) at wavelengths greater than 450 nm (i.e., the pump wavelength typically used in PL studies). This suggests that in many cases some fraction of the nanocrystals may be responsible for the observed PL at the typical pump wavelengths. In this study, we investigated the role of the pump wavelength in the absorption and PL intensity and determined the power of the pump laser for a range of excitation wavelengths. We find that the samples show a saturation behavior and a blueshifted emission spectra at high pump fluence, which are attributed to the dynamics of the excitation/refractive index change processes at different energies. During CW laser excitation, the specimen absorption is altered, but only at wavelengths longer than the excitation wavelength. These data can provide reasonable estimates of the absorption coefficient and quantum efficiency of highly luminescent silicon nanocrystals embedded in SiO2.

**3:15 PM T2.5**

**NOVEL NANOCRYSTALS FORMED IN SILICON AND SILICON DIOXIDE BY PRECIPITATION OF ION IMPLANTED METALS AT NANOCAVITIES** J.S. Williams, M.J. Conway, M. Petricevic and J. Wong-Leung, Department of Electronic Materials Engineering, Research School of Physical Sciences, Australian National University, Canberra, AUSTRALIA.

Ion implantation is a convenient method to introduce nanocrystals into semiconductors. In this study we have formed them in 100 Si by one of two methods: i) H ion implantation to high dose, followed by annealing to 850°C, to form a band of nanocrystals 1-20 nm in diameter at the end of ion range; and ii) Si ion implantation and annealing, also at 850°C, to form much smaller nanocrystals (up to 5 nm diameter) at depths up to about half the ion range. Ion irradiation was subsequently used to shrink the particles to a required smaller size distribution. In some cases the Si containing the nanocrystals was oxidized: subsequent analysis (by metal analysis) confirmed that the nanocrystals survived within SiO2. Samples of both Si and SiO2 containing nanocrystals were then implanted with high doses of metals (Co, Au and Zn) and annealed to diffuse and precipitate metals in nanocrystallites in either metal or silicide nanocrystals. Rutherford Backscattering and transmission electron microscopy were used to study cation distribution and nanocrystalline phase and structure. In a further series of experiments, Zn particles in Si were oxidized in an attempt to form wide band gap ZnO nanocrystals in SiO2. Results indicate that decoration of nanocrystals in Si and SiO2 with metals introduced by ion implantation is a very effective method for forming novel metal and semiconductor nanocrystals of a desired size in these materials. Possible formation mechanisms will also be discussed.

**3:30 PM T2.6**


*Department of Materials Science and Engineering, University of California, Berkeley, CA.

We present the results of experiments to liberate germanium (Ge) nanocrystals from silicon dioxide (SiO2) matrices by hydrofluoric acid (HF) vapor etching. Ge nanocrystals were fabricated in 5000 nm thick oxide layers on silicon (Si) substrates by multi-energy implantation of mass segmented Ge ions followed by thermal annealing at 850°C for 30 minutes. Raman spectroscopy and Transmission Electron Microscopy (TEM) confirmed the existence of nanocrystalline monosynthetic Ge clusters within the SiO2 matrices. Raman spectra exhibited the characteristic asymmetric with characteristic symmetric line shapes due to the phonon confinement effect. TEM images revealed a range of Ge nanocrystal diameters between 2-5 nm increasing in an approximate average diameter of 5 nm. Twinning was observed in some of the nanocrystals. In order to free GE nanocrystals, samples were etched in HF vapor to selectively remove the SiO2 matrix and expose the Ge nanocrystals. Rutherford Backscattering Spectrometry (RBS) data showed that approximately 75% of the Ge remained on the sample surfaces after complete removal of the oxide layer. Raman spectroscopy further confirmed that crystalline Ge remained on the sample surface after etching to the Si/SiO2 interface. RBS data showed that Ge was successfully removed from etched surfaces using an ultrasonic method cleaning procedure. Thus, liberated Ge nanocrystals are expected to be accessible for a wide range of manipulation processes and direct characterization techniques.

**3:45 PM T2.7**

**METALLIC NANOBODIES BY MEV ION BEAM INDUCED PLASTIC DEFORMATION OF CUBIC MAKE THE CUBIC SOLID** T. van Dille, J. Penninckhof, H. Kozi, J. de Hoogen, Christian Graf, Alons van Bladeren, Albert Polman; "FOA Institute for Atomic and Molecular Physics, Amsterdam, THE NETHERLANDS, Universiteit de Montre, GCM, Department de physique, Montreal, CANADA, "University of Groningen, THE NETHERLANDS, Utrecht University, Utrecht, THE NETHERLANDS.

A new class of materials, core-shell colloidal particles, was irradiated with 30 MeV Si and Si ions to fluxes of 2.5 \times 10^{17}/m^2. The core-shell colloidal consisted of a 15 nm diameter gold core surrounded by a silica shell of typically 70 nm thickness. High-resolution transmission electron microscopy was used to study the particle morphology after irradiation. At sufficiently high fluences, the silica shell deforms into an oblate ellipsoidal (prong) shape. The deformation of the core is thought to be a consequence of the deformation of the silica shell, since it is observed that thinner shells lead to smaller core deformations. Anisotropic nanorods such as these deformed core-shell particles have unique optical properties. The peak in the absorption spectrum is normally attributed to a surface shift to higher energy. The shorter wavelengths, depending on the relative orientation of the gold nanorods long axis and the polarization of the incident light.

**4:00 PM T2.8**

**THE STRUCTURAL AND OPTICAL PROPERTIES OF Zn AND ZnO NANOCRYSTALS IN SiO2 AND CdF2 SUBSTRATES. Y. C. Liu**, H. Yu, Y. M. Li, D. Z. Shen, H. D. Henderson, C. W. White, M. S. "Advanced Functional Materials Research Center, Northern New Mexico University, Chama, CHINA; "Key Laboratory of Excited State Processes, CAS, Changle, CHINA; "Chemical Physics Laboratory, PPS, University, Minneapolis, MN, "Solid State Division, Oak Ridge National Laboratory, Oak Ridge, TN.

I on implantation technique was employed to implant zinc ions into crystalline CdF2 and amorphous SiO2 substrates. Both zinc ions and nanocrystallites could be detected by XPS after thermal annealing. When the sample was annealed under reducing atmosphere, the absorption band at 8.5-9.5 eV for zinc implanted in SiO2 substrate was attributed to zinc metal. The absorption peak in the 3.4-7.9 eV region was due to the formation of ZnO nanocrystals when the sample is annealed under an oxidizing environment. X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) study also suggested ZnO nanocrystal formation. For zinc implanted in CdF2 substrate the formed ZnO nanocrystals have [0 0 2] preferred orientation. Photo luminescence (PL) spectra exhibited UV and green emissions from the zinc implanted samples annealed under an oxidizing atmosphere. No green emission is observed for ZnO formed in CdF2 substrate. However, an additional emission was observed at ~210 nm which may be due to ZnO formed by ion beam damage.

**4:15 PM T2.9**

**MEV ION IEMD INDUCED ANISOTROPIC PLASMA**
SESSION T8: POSTER SESSION FUNDAMENTALS AND APPLICATIONS Wednesday Evening, April 23, 2003 8:00 P.M.

Golden Gate (Marriott)

T8.1 SCALING BEHAVIOUR IN THE PENETRATION OF ENERGETIC SIZE-SELECTED CLUSTERS IN GRAPHITE. Carlos Suazo Nasarre and Roger Smith, School of Mathematics and Physics, Loughborough University, UNITED KINGDOM; Suraj Pranoottipong and R.E. Palmer, Nanoscale Physics Laboratory, University of Birmingham, UNITED KINGDOM.

Molecular dynamics (MD) simulations and experiments have been carried out to determine the penetration depth for implantation of Ag, Au and Si clusters incident normally on graphite in the energy range 0.5-5 keV. The mean penetration depth for Ag clusters is found to be linearly dependent on the impact velocity but there is a transition to a more linear scaling of depth with energy as the cluster size increases. Si cluster impacts induce deeper damage below the hole in which the cluster resides. An explanation for this behaviour is given in terms of the different nature of the collision cascades over picosecond time scales. The MD results are in good agreement with experimental measurements of the penetration depth.

T8.2 ABSTRACT WITHDRAWN.

T8.3 METAL AND SEMICONDUCTOR CLUSTERS: THE ROLE OF THE ION ENERGY IN THEIR FORMATION AND ACTIVITY. Elke Thune and Peter Reinke, Universität Göttingen II, Physikalisches Institut, Göttingen, GERMANY.

The rapidly growing interest in the deposition of size-selected nanoclusters on surfaces is motivated both by technology and by basic physical questions. Due to their finite size the small particles have totally different material properties compared to their bulk crystalline counterparts. Clusters have been deposited by a monoenergetic mass selected ion beam with low energies (1-500 eV) on amorphous carbon substrates, which are used to minimize the influence of surface crystallography and ion induced structural changes. Gold clusters were deposited as a model system to study the ion energy dependence, the temporal evolution and the influence of the temperature on the cluster distribution. For incident energies below 100 eV, surface processes dominate the clusters nucleation and growth. If higher energies are used, an increasing number of ions is implanted below the surface and different processes control the clusters formation. When the energy increases above 350 eV, the cluster size drastically drops below 5 nm. In a second set of experiments, clusters of different elements (Copper, Cobalt, Aluminum) are bombarded with reactive ion beams (Oxygen, Nitrogen), which will allow the formation of a wide variety of insulator, semiconductor and core-shell clusters. It will be discussed whether control over the progression of the reaction from the cluster surface to the core can be achieved by varying the ion energy. The clusters are analyzed with different methods such as Atomic Force Microscopy (AFM), Transmission Electron Microscopy (TEM) and X-Ray Photoelectron Spectroscopy (XPS) to determine their size distribution, composition and structure.

T8.4 SPUTTER NANOWIRES FROM SOS SIMULATIONS. Maria Stepanova and Steven K. Dew, University of Alberta, Dept. of Electrical and Computer Engineering, Edmonton, AB, CANADA.

We report a Monte-Carlo simulation of nanowires created on surfaces under grazing-angle ion bombardment. We have developed an advanced solid-on-solid (SOS) model that describes the evolution of surface morphology due to sputter instability [R.M. Bradley and J.M. Harper, J. Vac. Sci. Technol. A 6, 2390 (1988)] and performed quantitative simulations for Cu bombarded by 1 keV Ar ions at 80° incidence. At early stages of the ion bombardment, we observe well-defined wire-like structures with the wavelength 2-5 nm, aligned parallel to the ion beam plane. Each wire also has a lateral 1.3 nm pattern, which appears to play an important role in causing wire coalescence at later stages of bombardment. After ~10^17 ions/cm² the surface becomes amorphous. To elucidate relevant control parameters, we have performed a series of model simulations playing with the spatial distribution of deposited energy and the surface relaxation. For the latter, we have considered the Mullins diffusion [W.W. Mullins, J. Appl. Phys. 28, 388 (1957)] and an anisotropic relaxation mechanism that reduces the surface curvature [J.J. Friedrich, D.S. Gardner, S.K. Dew, M.J. Brett, and T. Smy, J. Vac. Sci. Technol. B 13, 1780 (1997)]. We demonstrate that both Mullins and relaxation effects lead to the observed surface configuration. We compare our simulations with those from other authors and with experiments.

T8.5 ABSTRACT WITHDRAWN.

T8.6 LIGHT-INDUCED MICROSTRUCTURAL ORDERING: STUDY OF LITHIUM-INCORPORATED COBALT OXIDE FILMS ON ALUMINUM AND GLASS SUBSTRATES. Nalini Das, S.A. Shroff, Indian Institute of Science, Materials Research Centre, Bangalore, INDIA.

Photocrystallisation is a phenomenon whereby an amorphous matrix undergoes structural changes to a micro- or nanocrystalline state upon irradiation with photons. Topologically, a crystalline phase embedded in an amorphous matrix is expected to be advantageous over a fully...
crystalline phase, in applications such as cathode material in thin film amorphous carbon rechargeable batteries. As this particular microstructure provides a high surface area and enables smooth contacts, it may be expected to result in fast ion conduction between cathode and electrolyte, while retaining the electrochemical properties associated with the specific crystalline structure of the material. Amorphous films incorporating carbon can be prepared by CVD on glass and glass substrate using so gel sol coating technique. The microcrystallization and microstructural changes in these films upon irradiation with unpolarized light were investigated using optical microscopy, XRD, SEM, and XPS. The results of these investigations, as well as their relevance to lithium-ion battery applications will be presented.

TS.7 OPTICAL PROPERTIES OF NANOBUBBLES INDUCED BY HIGH-ENERGY He+ION-MULTIPLE IMPLANTATIONS IN SILICON. Elea Leung, Gabrielle Regula, Rachel El Hossay, Maryse Lecin, Bernard Pichat, TECS-CNRS, Marseille, FRANCE; Ederer Ntsoenok, CERI-CNRS, Orleans, FRANCE.

Silicon samples were implanted 12 times with helium ions at energies ranging from 0.8 MeV to 1.9 MeV using steps of 0.1 MeV with flux maintained between 5x10^12 and 1x10^13 cm^2 s^-1. The dose was 5x10^12 cm^-2 for all energies but 0.8 MeV (3x10^12 cm^-2) for electron beam irradiation in He at low (975K) or high temperature (1125K) for two hours under either neutral atmosphere (Ar) or argon hydrogen mixture. The samples were studied by cross section transmission electron microscopy (XTEM), photoluminescence (PL) and secondary ion mass spectrometry (SIMS). XTEM and electron diffraction show a bubble distribution through the depth was observed by XTEM. The density of the bubbles and their average diameter as measured by XTEM yield a porosity of about 5% and a mean distance between bubbles of about 10 nm. Such a bubble pattern can thus play the role of a porous structure. Moreover silicon remains crystalline and a density of vacancy defects was observed by XTEM. This was confirmed by PL measurements in the infrared range which show a band broad in the D1 region and still on oxygen excited state recombination. This indicates that carrier lifetime is not strongly reduced. Such a nano-structured silicon could be a good candidate for light emission in the visible range.

TS.8 STUDY OF THE EFFECTS OF HEAVY-ION RADIATION ON THE NANOSTRUCTURE AND COMPOSITION OF SULFUR-DOPED NANO-COMPOSITE CARBON THIN FILMS. Oscar O. Ortiz, Department of Chemical Engineering, Polytechnic University, San Juan, PR; Nadia M. Medina-Emmanuelli, Department of Chemistry, Pontifical Catholic University, Ponce, PR; Kathleen E. Kristian, Department of Radiation Science, Swarthmore College; Adolfo Gonzalez, Joel De Jesus, Iris M. Vargas, Department of Physics, University of Puerto Rico, San Juan, PR; Juan A. Gonzalez, Department of Chemical and Electronic Engineering, University of Puerto Rico, Humacao, PR; Beatriz M. Mora, Department of Chemistry, University of Puerto Rico, San Juan, PR; Gerardo Morell, Department of Physical Sciences, University of Puerto Rico, San Juan, PR.

The compositional and microstructural transformations induced by simulated space radiation (i.e., heavy ions) on sulfur-doped amorphous carbon nanocomposite carbon (nC:S) films were investigated by Raman Spectroscopy (RS) and Scanning Electron Microscopy (SEM). Two identical sets of nC:S films were prepared in a hot filament chemical vapor deposition (HFCVD) system using CH₄, H₂, and H₂S. Films with various sp² C and sp³ C bonding distributions were present within each set, which were obtained by varying the substrate temperature (300–900°C), the CH₄ concentration (0.3 and 2.0%) and the H₂S concentration (0 and 500 ppm). One set of films was submitted to a 20 krad dose of energetic Si and Fe ions at the NASA space radiation simulation facility housed at Brookhaven National Laboratory’s Alternating Gradient Synchrotron (AGS). All the films showed the characteristic diamond (tetragonal sp³ C) band at around 1332 cm⁻¹ and the graphitic (trigonal sp² C) D and G bands at around 1350 and 1580 cm⁻¹, respectively, evidencing their composite nature. The Raman spectra of the films taken before and after irradiation, evidence changes in the relative intensities of the bands but did not show significant changes in the contribution of diamond to the carbon phase after exposure to the ion beam. However, some films lost their Raman signal, and the sp² C component showed a clear shift to lower wavenumbers after irradiation, regardless of the initial composition of the films. Two sets of films were exposed to 1 MeV helium ions at a dose of 10^15 cm⁻². The Raman spectra showed a significant decrease in the intensity of the diamond band after exposure to the ion beam. The films retained their Raman signal, but the intensity of the diamond band decreased by a factor of 10. The films also showed an increase in the intensity of the graphitic band, indicating a conversion from diamond to graphite. The results suggest that the irradiation with energetic ions can modify the microstructure of the nC:S films, leading to a decrease in the intensity of the diamond band and an increase in the intensity of the graphitic band, which can be used to monitor the effects of radiation on the films.

TS.8.5 ELECTRON FIELD EMISSION PROPERTIES AND MICROSTRUCTURE OF ION BEAM SYNTHESIZED AND MODIFIED SiC THIN LAYERS. W.M. Tsang, Y.W. Cheung, N. Ke, Dept. of Electronic Engineering and Materials Science and Technology Research Centre, The Chinese Univ of Hong Kong, Hong Kong SAR, CHINA; J.K.N. Lindner, Univ. of Augsburg, Inst. for Physik, Augsburg, GERMANY.

It was reported several years ago that good electron field emission (FE) properties with a very low turn-on field of about 1.5 V/μm could be obtained from ion beam synthesized (IBS) SiC/Si heterostructures [1]. More recently, by correlating the FE properties with the surface morphology and local surface conductivity, it was demonstrated that there were two distinct electric field enhancement mechanisms for electron FE from these IBS SiC layers [2]. Inspired by these understandings, modification of the IBS SiC layers of metal ion implantation was performed aiming at improving the FE properties. The SiC layers were synthesized by implanting carbon ions into Si wafers using a metal vapor vacuum arc (MVVA) ion source at various energies and doses. Modification of the SiC layers was performed by tungsten implantation also by the MVVA source. Characterization of the implanted samples was performed using atomic force microscopy (AFM), conoscopic AFM. Fourier transform infrared absorption spectroscopy, x-ray diffraction, x-ray photoelectron spectroscopy, and transmission electron microscopy. Excellent field emission properties with an ultralow turn-on field of 0.35 V/μm have been achieved in some of these samples exhibiting a nanocomposite structure prepared under appropriate implantation and annealing conditions. The details of the FE properties, the structures and their dependence on the processing conditions will be presented and discussed. This work is supported in part by the Research Grants Council of Hong Kong SAR [Ref: CUHK400/01E] and by the Germany-Hong Kong Joint Research Scheme of RGC, Hong Kong SAR and DAAD, Germany. [1] D. Chen et al, Appl. Phys. Lett. 79, 1026 (2001). [2] W.M. Tsang et al, Appl. Phys. Lett. 81 (2002) (in press).
SESSION T9: POSTER SESSION
NANOPHASED MATERIALS AND NANOSTRUCTURES
Wednesday Evening, April 23, 2003
8:00 PM
Golden Gate (Marriott)

T9.1 AMORPHOUS CALCIUM PHOSPHATE NANOPOWDERS MADE FROM RADIO FREQUENCY PLASMA SPRAYING.
Rajendra Kumar, Philip Cheng, and K.A. Khor, Advanced Materials Research Centre, Nanyang Technological Univ., SINGAPORE.

Predominantly amorphous nano powders of calcium phosphate were produced by radio frequency plasma and subsequently characterised by particle size analysis (PSA), TEM, and X-ray diffraction (XRD) analysis. These powders were synthesised by the flame spray technique. The starting feedstock comprised of hydroxyapatite powders spray dried from a suspension. The input parameters were varied according to produce various amorphous calcium phosphate powders with Ca/P ratio close to 1.67. Results showed that the particle size was increased and flow rate of feedstock was decreased as the sprayed powders produced were largely amorphous. The size of the powders varied from 150-200nm depending on process parameters. TEM and SEM revealed spherical particles even smaller than 50nm. These powders are thought to have excellent bioresorbability and are targeted for use in gene and drug delivery technologies. These nano sized powders will be used in the exploration of mechanical properties of bulk products sintered by similar techniques.

T9.2 INCREASING THE FRACTURE TOUGHNESS OF SILICON WITH ION BEAMS.
J.G. Swedener, M.J. Brakes, M. Nastasi, Materials Sciences and Technology Division, Los Alamos National Laboratory, Los Alamos, NM.

Our recent molecular dynamics (MD) calculations reveal that ion beams can be used to form nanostructured regions with greatly increased fracture toughness. In the MD simulations, ion implantation produced dislocation loops that led to the formation of clusters of disordered atoms. The presence of these disordered regions allowed silicon to deform plastically as a crack propagated, blunting the crack tip and arresting crack growth. The MD predictions predict that fracture toughness can be increased by a factor of 3.5. This newly discovered toughening mechanism can also explain earlier experimental observations of increased fracture toughness in irradiated ceramics. In order to corroborate the MD results, silicon specimens have been implanted with Ne ions. Although detailed quantitative measurements are still on going, preliminary results show toughening in the implanted specimens that is consistent with the MD predictions. The combined experimental and atomicistic method has enabled us to examine the details of fracture at the atomic scale, revealing how the fracture process converts energy from potential energy in the strained lattice into kinetic energy, surface energy and energy loss due to distortions of the crystalline lattice.

T9.3 PREPARATION OF CRYSTALLINE GALIUM OXIDE RIBBONS ON GALIUM ARSENIDE BY PLASMA IMPLANTATION AND RAPID THERMAL ANNEALING.
H-P. He, S.P. Wong, Dept of Electronic Engineering, The Chinese University of Hong Kong, HKSAR, CHINA, K.C. Lo and P.K. Chu, Dept of Physics and Materials Science, City University of Hong Kong, HKSAR, CHINA.

We report for the first time the synthesis of gallium oxide ribbons by plasma immersion ion implantation of nitrogen/oxygen mixture followed by rapid thermal annealing. Transmission electron microscopy reveals that the long (>100 microns) ribbons are single crystals with very uniform size, approximately 0.1 micron in thickness and 1 micron in width. While a more detailed study on the formation mechanism is current underway, we believe that our results might lead to the preparation of ordered materials which might be useful for sensor or photonic applications.

T9.4 MAGNETITE/NICKEL AND MAGNETITE/COBALT MULTILAYER NANOSTRUCTURES OBTAINED BY PULSED LASER DEPOSITION.
M. Dziczka, M. Szczyrba, Department of Physics, Adam Mickiewicz University, Poznan, POLAND, Lucian Diamandescu, Institute of Atomic Physics, Bucharest, ROMANIA.

Multilayers containing magnetite have recently attracted considerable interest, since the construction of a magnetite-based alloy spin valve was proposed. In this paper we present a conversion electron Mössbauer spectroscopy (CEMS) study of magnetite/nickel and magnetite/cobalt multilayers produced by pulsed laser deposition (PLD) and we follow the evolution of the site magnetic fields and magnetic texture as function of layer thickness. PLD was performed with an excimer laser at a wavelength of 308 nm and a pulse width of 24 ns. A repetition rate of 10 Hz was used between laser pulses and an energy per pulse of 45 mJ was delivered. The deposition was performed using iron, nickel and cobalt targets in an oxygen atmosphere. The multilayers obtained were magnetite/nickel and magnetite/cobalt, with a total thickness of 100-120 nm. Si (111) substrates were used in all cases. The CEMS spectrum of a magnetite/nickel multilayer was analyzed considering peak envelopes, corresponding to the tetrahedral (A) and octahedral (B) magnetic sublattices, typical of the magnetite structure. The dependence of the hyperfine magnetic fields of the two sublattices was the same as a function of the layer thickness. The magnetic hyperfine field of the tetrahedral sites is maximum for a layer thickness of 5 nm and reaches a minimum for a layer thickness of 10 nm, with saturation at large thickness. The site population during deposition was determined by analysis of the layer thickness. The population of the tetrahedral site is maximum for a layer thickness of 10 nm and correspondingly, the population of the octahedral site is maximum for this thickness. In addition, we note that the magnetic structure is stoichiometric for this thickness, with an 1:2 ratio ratio. The two magnetic sublattices become equally populated at large thicknesses. The results obtained for the magnetite/cobalt multilayers were in qualitative agreement with those obtained for the magnetite/nickel multilayers, with the exception of the presence of a pure iron layer in their structure.

T9.5 GE/Si QUANTUM DOTS NANOSTRUCTURE GROWN FROM ION-MOLECULAR BEAMS.

Recently the effects of low energy (~100 eV) ion irradiation on surface islands nucleation and growth were found in the studies of Ge molecular beam epitaxy (MBE) on Si(100) and (111) with pulsed selenium beam action on the growing layer. The irradiation results in reduction of critical thickness of pseudomorphic Ge layer at which there is a transition from layer by layer to three dimensional growth. Reduction of the average island sizes, their dispersion and increase of their density is revealed [1]. Here we present the results of crystallography investigation of Ge quantum dots embedded in Si structures grown with low energy ion irradiation. Structures were grown by MBE in the sequence of layers of Si on Si(100), Ge of 4-10 monolayers thickness and Si cap layer over Ge film. The substrate temperature varied in the range of 300-500°C with Ge heteroepitaxy. The pulsed (5.5 s) Ge low energy ion irradiation turned on at fractional monolayer coverage >0.8 for each grown layer. Beside pulsed action, continuous beam irradiation studied in similar growth regimes. The cap layer of 150 nm Si was grown at 500°C by common MBE (no irradiation). Normal incidence Rutherford backscattering/channeling technique with 1.8 MeV He+ ions has been used to study the yield from Si and Ge layers. The perfect structure with a yield of 2.5% was found in a mode of a full irradiation with number of deposited monolayer >5 at temperature 350°C. For lower temperature 300°C the yield exceeded 5% in similar structures. The enlarged yield was found also in the structures formed with continuous beam irradiation for 300-500°C temperatures of substrate. TEM studies show defect free Ge dots and Si layers for initial stage (~3 monolayers of heteroepoxy in the used irradiation growth mode at ~350°C. Continuous beam irradiation was found to induce disordering around Ge dots. This work was supported by the RFBR Grant 03-02-16020 and INTAS 2001-615-1. A.V. Dyurechenskii, V.A. Zinoviev, Z.V. Smagina, JETI Letters, 2001, Vol.74, p. 267-269.

T9.6 CONDUCTING RIPPLE FORMATION IN Cu(001).
Wai Lam Chan, Nirwan Pavanayogin, Eric Chason, Brown Univ., Division of Engineering, Providence, RI.

Ripple formation under normal sputtering is a well known phenomena. Although a linear instability theory proposed by Arnold and Harper accounts for many of the observed phenomena on amorphous and semiconductor surfaces, it is not as successful for the case of metals. In contrast with the model, experiments on metals at low temperature have shown that the wavelength of the ripples may depend on ion fluence and the orientation of the ripples may depend on crystal orientation of the substrate. In the present work, we have used in situ light scattering to measure the evolution of the surface of Cu(001) during sputtering. This technique enables us to measure the power spectral density of the surface over a range of spatial frequencies. We observe ripples with a wavelength that is independent of time can indeed be produced on Cu(100) surfaces at higher ion flux and temperature than...
Previously used. The amplitude of the ripple is observed to increase exponentially during the early stages of growth. This work was supported by the U.S. Department of Energy under contract DE-FG02-01ER4593.

T9.7
Abstract Withdrawn.

T9.8
ARRAYS OF SUB-100nm BLISTERS AND CRaters PRODUCED BY LOW keV ION IMPLANTATION. O. Moustapha, N. Desrosiers, G.G. Ross, B. Terreault, INRS-EMT, Université du Québec, Varennes, Quebec, CANADA.

Cavity formation, blistering and flaking induced by hydrogen and/or helium implantation followed by annealing have actual and potential applications in impurity gettering, and in silicon-on-insulator and molecular sieve fabrication. We have found that using low keV ions to produce such structures with sub-100 nm dimensions poses particular problems which challenge the usual models that were inferred from higher energy processing. This work aims at improving our understanding of the underlying mechanisms and increasing the efficiency of the process in terms of ion dose and annealing conditions.

We implanted (100), (110) and (111) silicon crystals with 5 or 8 keV H, D and/or He ions at doses of 1x10^16 to 1x10^17 cm^-2. We used Atomic Force Microscopy to quantitatively characterize the surface morphology. Thermal Desorption Spectrometry as a fingerprint of gas-liquid interaction, and the resistivity as an indication of defect evolution. The critical blistering doses and optimal annealing conditions have been determined for each ion singly or in combination.

H and D ions behave remarkably differently: while a dose of 6x10^16 D cm^-2 induced abundant blistering, no blisters were observed with the same H dose, due to insufficient defect production by low keV H implantation to stably trap H. The density, size and morphology of the blisters and craters depend on the crystal orientation.

Co-implantation of H and He decreases radically the critical blistering dose, and the order of implantation has a crucial effect on formation of blisters. No blisters were observed in samples implanted with H before He, while blisters and craters were very successfully produced by He implantation before H contrary to the belief that H implantation would “prepare the ground” for blistering by nucleating platelets parallel to the surface. The resistivity measurements show new correlations with the morphology and the gas evolution, and in particular with the order of the implantation. Though convenient as an empirical signature of the underlying events, the resistivity is difficult to interpret physically, because it depends on both the carrier density, through the charge state of the H associated vacancies, and the carrier mean free path, through the nature and density of defects.