SYMPOSIUM L

Fundamental Mechanisms of Low-Energy-Beam-Modified Surface Growth and Processing

November 29 – December 2, 1999

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Cornell University

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* Invited paper

TUTORIAL

FTL: LOW-ENERGY ION AND HYPERTHERMAL NEUTRAL BEAMS FOR SEMICONDUCTOR, METAL, AND CERAMIC FILM GROWTH

Monday, November 29, 1999
8:30 am - 12:00 p.m.
Salon H/I (M)

Low-energy (10-100 eV) ion and hyperthermal neutral atom irradiation during film growth from the vapor phase are used to increase dopant incorporation probabilities by orders of magnitude during MBE Si and SiGe. They also provide new chemical reaction pathways, modify film growth kinetics, and, hence, controllably alter film properties. For example, during low-temperature epitaxial growth from hyperthermal Si beams, critical epitaxial thicknesses can be increased by up to an order of magnitude over those obtained with MBE due to enhanced interlayer mass transport and more effective filling of interisland trenches. For heteroepitaxial SiGe growth on Si(001), AFM and XTEM studies show that strain-induced roughening, which occurs at elevated growth temperatures, is strongly suppressed at growth temperatures between 300 and 400 C, with no indication of kinetic roughening. Low-energy ion irradiation during UHV magnetron sputter deposition of epitaxial TiN(001) exhibits a relatively small barrier to adatom migration over descending steps but a large barrier to adatom diffusion along island edges – the latter leading to 2D dendritic growth. This type of irradiation was found by *in situ* STM combined with post-deposition x-ray reflectivity and HR-TEM to decrease kinetic roughening leading to surface aspect ratios (surface width divided by the lateral correlation length) which are much smaller than those of Si(001).

The use of low-energy primary-ion beam sources – in which ion energy and ion/neutral flux ratios can be varied independently – during the growth of Al, Cu, Pt, Ti, CrN, ScN, and TiN epitaxial and polycrystalline layers has been shown to provide dramatic differences in nucleation rates, epitaxial thicknesses, mosaicity, preferred orientation, strain, and microstructure evolution. The use of secondary ion-assisted sources has a similar effect. Mechanisms, simulations, and modeling will be discussed in detail in this tutorial.

Instructor: Joe Greene, University of Illinois

SESSION L1: BEAM-INDUCED SURFACE GROWTH AND MODIFICATION

Chairs: Albert-Laszlo Barabasi and David J. Srolovitz
Monday Afternoon, November 29, 1999
Salon H/I (M)

1:30 PM *L1.1
HYPERDYNAMICS AND PARALLEL-REPLICA DYNAMICS STUDY OF COPPER GROWTH VIA THERMAL AND ENERGETIC PARTICLE DEPOSITION. Arthur F. Voter and Timothy C. Germann, Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM.

Applying recently developed methods for accelerating the dynamics of infrequent events, we study the growth of copper on a Cu(100) face. While molecular dynamics simulations are limited to nanoseconds, these methods (hyperdynamics and parallel replica dynamics) allow us to reach the much longer time scales necessary for the activated processes between deposition events, without any presumptions about the microscopic mechanisms. We use an embedded atom method (EAM) interatomic potential that was fit to bulk and diatomic properties, but which has been found to give a good description of surface diffusion barriers. Each deposition event, either thermal or hyperthermal, is simulated using regular molecular dynamics for a few ps. Hyperdynamics combined with parallel replica dynamics are employed for the remainder of the time until the next deposition. With a 72-atom per-layer simulation cell, we have been able to grow at deposition rates as slow as 1 monolayer per 72 microseconds. We observe rough growth below about 300K, and the onset of reentrant layer-by-layer growth as the temperature is raised. We find the activated events are dominated by nonstandard mechanisms, such as interlayer smoothing via 3-atom exchange and 3- and 4-atom row sliding. As expected, hyperthermal deposition leads to smoother growth.

2:00 PM L1.2
NOVEL DEFECTS AND ANISOTROPIC VACANCY DIFFUSION ON RECONSTRUCTED SURFACES. O. Rodríguez de la Fuente, M. A. González, J.M. Rojo, Dpto. de Física de Materiales, Universidad Complutense, Madrid, SPAIN.

Low energy beam surface modification is becoming increasingly more important for scientific and technological purposes. In order to understand at an atomic scale the mass transport processes underlying that modification, a better knowledge of surface vacancy motion is required. Moreover, surface self-diffusion which controls other processes such as two-dimensional island decay can occur in some cases by vacancy, rather than by adatom, diffusion[1]. In a recent paper[2] we have proposed that the defects found with Scanning Tunneling Microscopy on reconstructed 5x20 Au(001) following low dose, 600 eV Ar^+ ion irradiation are two-dimensional dislocation dipoles. In the present work we present further evidence of that assignment and show that these defects appear as the result of anisotropic vacancy diffusion. Molecular dynamics simulations show that vacancies and vacancy clusters randomly distributed on the reconstructed Au(001) surface (as a result of Ar^+ sputtering) quickly migrate to the top of the reconstruction furrows, where they are energetically more favourable. Once there, their diffusion is shown to be predominantly along the reconstruction direction, i.e. highly anisotropic. The clustering of these vacancies forming chains and their relaxation is shown to give rise to the dislocation dipoles. Diffusion mechanisms and rates are also discussed. Our results show that reconstruction plays a fundamental role in surface vacancy diffusion and explain why defects other than vacancies and vacancy clusters are experimentally observed after low energy ion irradiation. [1] J.B. Hannon, C. Klünker, M. Giesen, H. Ibach, N.C. Bartelt, J. C. Hamilton, Phys. Rev. Lett. 79 (1997) 2506. [2] M.A. González, J. de la Figuera, O. Rodríguez de la Fuente, J.M. Rojo, Surf. Sci. Lett. 429 (1999) 486.

2:15 PM L1.3
OBSERVATION OF ION-ERODED Au(111) BY SCANNING TUNNELING MICROSCOPY (STM). A. Couture, E. Butler, J. Pomeroy, M.V. Ramana Murty*, J.P. Sethna, B.H. Cooper, Department of Physics and Cornell Center for Materials Research (CCMR), Cornell University, Ithaca, NY. *currently at Argonne National Labs, Advanced Photon Source.

The final surface morphology of ion-eroded Au(111) can be controlled by changing the experimental conditions of the erosion (temperature, fluence, flux, beam incidence angle, etc.). We have studied the development of surface morphology at atomic length scales using an STM. An initially smooth Au(111) surface is sputtered with 500eV Ar+ ions at different temperatures. At sub-monlayer doses, the presence of pits disrupts the herringbone surface reconstruction. In addition, at longer erosion times multi-layer surface features develop, and the spacing between features is observed to grow with power law size scaling. We have characterized the complex structure of these surface features, which include mounds, pits, and a network of connecting channels. The surface morphology is composed of mainly mounds during low temperature erosion, while at high temperature pits are dominant. Research supported by grants NSF-DMR- 963-2275 and Air Force F49620-97-1-0020

2:30 PM L1.4
THERMAL RELAXATION OF ION ERODED Au(111) MONITORED BY X-RAY SCATTERING. Evelyn N Butler, A. Couture, B.H. Cooper, Dept. of Physics, Cornell University ; R.L. Headrick, CHESS, Cornell University, A.Woll, School of Eng. and Appl. Physics, Cornell University, Ithaca, NY.

We are studying the thermal relaxation of surfaces using real-time X-ray diffraction. We are interested in how the Au(111) surface, patterned during sputter-roughening, evolves back to its initial, smooth state. Eroding the surface with 500 eV argon ions near room temperature produces a morphology of mounds and pits. These surface features are spatially correlated, separated by a characteristic distance that can be tuned with ion fluence. We have monitored the decay of these nanometer sized features using time-resolved measurements of the diffuse component of the scattered X-ray intensity; specifically the FWHM of the scattered intensity vs the in-plane momentum transfer. The relaxation of the surface, characterized by this lateral correlation length, is found to follow a power law.

3:15 PM *L1.5
ATOMIC LEVEL MODELS OF SPUTTER DEPOSITION OF DIFFUSION BARRIER LAYERS. G.H. Gilmer, J. Dalla Torre, D. Windt, F.H. Baumann and R. Kalyanaraman, Bell Labs, Lucent Technologies, Murray Hill, NJ; H. Huang, T. Diaz de la Rubia, Lawrence Livermore National Laboratory, Livermore, CA.

Atomistic Monte Carlo simulations of the deposition of thin films provide a powerful method for examining the different mechanisms operating under various conditions. In this talk we focus on the sputter deposition of refractory materials such as Ti, and Ta, but compare the results with those for films of Cu and Al. Direct comparisons with experiments on sputter deposition provide model validation; these films are characterized using X-Ray reflectance, atomic force microscopy, and high-resolution transmission electron microscope pictures. We discuss the influence of the deposition conditions on the microstructure of the film; i.e., porosity, grain morphology, grain orientations or texture, and surface roughness. Among the factors considered in the modeling are the substrate orientation and geometry, the surface mobility of atoms on the film and substrate, the film-substrate wetting, the magnitude of the Ehrlich-Schwoebel barrier, grain boundary energies, and the angular distribution of the impinging atoms. Modifications in the film structure and step coverage resulting from the application of low energy ion beams are also discussed. The sensitivity of the film morphology to model parameters is also studied using the kinetic Monte Carlo simulations. Atomic level parameters are derived mainly from molecular dynamics and *ab initio* calculations, and the sensitivity information is used to estimate the effect on the film structure resulting from the uncertainties in these parameters.

3:45 PM L1.6
GROWTH OF Co ON Ag(100): A COMPARISON OF ULTRA LOW ENERGY ION BEAM DEPOSITION AND THERMAL DEPOSITION. Bart Degroote, Johan Dekoster, Hugo Pattyn, André Vantomme, Guido Langouche, Stefan Degroote, K.U. Leuven, Instituut voor Kern- en Stralingsfysica, Leuven, BELGIUM.

We have investigated the growth of Co deposited on Ag(100) with ultra low energy ion beam deposition and thermal deposition. The preferred sites of nucleation, the island densities and heights are determined with scanning tunneling microscopy. Submonolayers of Co were ion beam deposited at 300 K using energies between 5 and 30 eV. Preferential growth of islands on the upper side of the monoatomic Ag steps (i.e. step decoration) is observed for deposition energies of 5 and 15 eV. In addition, 3-4 ML deep holes are formed in the Ag substrate for deposition at 5 eV. At higher deposition energies, the number of holes per surface area decreases. In contrast, for thermal deposition of submonolayers of Co at 300 K, the islands are spread randomly over the terraces. For deposition at 350 K, islands are decorating the Ag steps on the upper side. At 425 K the Co and Ag form a surface alloy: no islands are observed on top of the surface and small depressions in the terraces indicate the presence of Co islands in the first surface layer. The competition between island growth and formation of a surface alloy is interpreted in terms of the surface free energy and the heat of mixing.

4:00 PM L1.7
MOLECULAR DYNAMICS SIMULATIONS OF ENERGETIC FULLERENE IMPACTS ON SILICON (100)-(2 × 1) SURFACES. Xiaoyuan Hu, Karsten Albe, Robert S. Averback, Materials Research Laboratory, University of Illinois, Urbana-Champaign, IL.

C_{60}-molecules exhibit a unique stability against surface induced defragmentation. Therefore the investigation of fulleren interactions with solid substrates has become a field of active research in recent years. Especially, the study of fulleren interaction with semiconducting materials, where covalent bonds can be formed with the cluster, is of particular interest.In this study the collision dynamics between C_{60} clusters with energies of 100 eV to 60 keV and Si (100)-(2 × 1) substrates are investigated by classical molecular-dynamics simulations using cells containing 52880 to 114464 silicon atoms. A diverse behavior depending on the impact energy is observed and several significantly different regimes are identified: Below 100 eV the molecule is chemisorpted on the bare Si(100) surface. Between 100eV - 500 eV reactive collisions occur and the fullerene penetrates a few silicon monolayers, while the cage structure is still preserved after the collision with the surface. Between 500 eV and 1500 eV the cluster partially decomposes and cohesive caps of carbon are embedded in the surface. Between 1500 eV and 12 keV, complete decomposition occurs and an amorphous zone is formed. Above 12 keV sputter effects get significant and craters are formed in the substrate. It is found that projectile temperature and substrate temperature are of minor influence on the collision dynamics. The resulting structures are carefully analyzed before and after additional annealing runs. The specifics of energetic cluster impacts are discussed and contrasted with results for single atom impacts.

4:15 PM L1.8
EFFECTS OF TRANSIENT DIFFUSION IN PVD SIMULATION. Gwang-Soo Kim[1], Uwe Hansen[1,2] and Klavs F. Jensen[1]; [1]Department of Chemical Engineering, Massachusetts Institute of Technology Cambridge, Massachusetts, [2]Physik-Department and Walter Schottky Institut, Technische Universität München, Garching, GERMANY.

With shrinking feature dimensions the typical size of trenches and vias will be only some hundred lattice constants in the near future. Thus for reliable metalization an understanding of atomic scale phenomena is becoming more and more important. We present detailed molecular dynamics calculations elucidating the effects of transient diffusion during physical vapor deposition. Our calculations reveal that for near grazing incidence Cu atoms can transverse fairly large distances on Cu surfaces after their initial impact. We predict diffusion lengths as a function of the incident energy and angle. In addition the effect of surface roughness is studied by performing MD calculations for stepped surfaces.

4:30 PM L1.9
SURFACE SMOOTHING UPON DEPOSITION OF NANOPARTICLES ON SINGLE CRYSTALLINE SUBSTRATES. C.G. Zimmermann, M. Yeadon, J.M. Gibson, R.S. Averback, Materials Research Laboratory, University of Illinois, Urbana, IL; U. Herr, K. Samwer, Institut für Physik, Universität Augsburg, Augsburg, GERMANY.

Surfaces with artificial roughness were generated by deposition of nanoparticles on single crystalline substrates. Nanoparticles with an average size ≈ 15 nm were produced by inert gas condensation and deposited in-situ on the substrate mounted inside a modified ultra high vacuum (UHV) transmission electron microscope (TEM). We investigated the smoothing behavior on annealing based on the difference in surface energies between cluster and substrate and their heat of mixing. The cluster substrate combinations Co/Cu(100) and Co/Ag(100) were chosen as model systems in which the cluster has a significantly higher surface energy than the substrate. Upon deposition at 600 K, the clusters do not remain on the surface, but rather burrow into these substrates. They also reorient to assume the substrate orientation. Deposition at room temperature on the other hand failed to show either burrowing or reorientation. Responsible for this new mechanism of surface smoothing are the extremely large capillary forces associated with nanoparticles. We developed a model to estimate the rate at which the particles burrow into the substrate. Clusters in the system Ge/Si(100) in contrast have a lower surface energy than the substrate. A large fraction of the clusters assumed the substrate orientation around 600 K before they started to wet the substrate at 900 K. Details of this "inverse Stranski-Krastanow" growth will be discussed. Finally the system Ti/Si(111), which is also characterized by clusters with a lower surface energy than the substrate, was studied, however this is a reactive system and Ti-Si phases form at temperatures as low as 500 K. This prevents wetting and it determines the surface morphology.

4:45 PM L1.10
ETCHING AND SURFACE SMOOTHING WITH GAS CLUSTER ION BEAMS. David B. Fenner, Richard P. Torti, Lisa P. Allen, Allen R. Kirkpatrick, and James A. Greer, Epion Corp, Billerica, MA; Noriaki Toyoda, Massachusetts Institute of Technology, Cambridge, MA.

There are potentially many devices in the electronics and photonics industries that would benefit from a processing tool having the capability to smooth surfaces to nearly an atomic scale utilizing all-dry vacuum methods. Specific materials include: silicon, compound semiconductors, gate and high-k dielectrics, ceramic wafers and films, thin metal and ferromagnetic films, and electro-optics. Energetic-ion processes are in wide use for etching and thinning in manufacturing as well as for depth-profiling in analytic instruments, however in general, sputtering causes damage and accumulated roughness. The unique physics and chemistry of sputtering with ion beams composed of small droplets (i.e., clusters) of condensed gas was recognized some years ago. Such gas-cluster ion-beam (GCIB) systems make possible improved surface sputtering and processing for many types of materials. We report etching and smoothing of the surfaces of sapphire, alumina and gold films, silicon (wafer, SOI and poly), and permalloy. The argon clusters (few thousand atoms each) are injected into vacuum, singly ionized, accelerated (10-30 kV), focused, magnetically filtered, electrostatically scanned, and impact with near-normal incidence. GCIB has been found to simultaneously etch and smooth surfaces (to roughness as low as 0.1 nm rms, by AFM analysis) without accumulating roughness or damage. A physical model consistent with etched-surface evolution is presented which suggests that the clusters are solid nanoparticles (at impact), with the ion charge a delocalized hole in the valence band, and substantial intra-cluster cooperative effects (e.g., hard-sphere repulsion) that result in a highly inelastic collision, breakup of the cluster, and anisotropic (non-cosine) sputtering, despite the low energy per atom. Subsurface damage and implantation essentially do not occur for cluster energy not too far above the sputtering threshold, and the etch rate increases linearly in this regime, unlike that of monomer argon-ion etching (square root of energy). Supported by NIST-ATP.

SESSION L2/O2/II4: JOINT SESSION:
BIAXIALLY TEXTURED SUBSTRATES FOR
HIGH-Tc COATED CONDUCTORS
Chairs: Ron Feenstra and James M.E. Harper
Tuesday Morning, November 30, 1999
Room 200 (H)

8:30 AM *L2.1/O2.1/II4.1
HIGH-J_c, YBCO CONDUCTORS FABRICATED BY EPITAXIAL DEPOSITION OF YBCO ON ROLLING ASSISTED BIAXIALLY TEXTURED SUBSTRATES (RABiTS). A. Goyal, R. Feenstra, M. Paranthaman, F.A. List, D.F. Lee, D.P. Norton, P.M. Martin, D. Verebelyi, X. Cui, E.D. Specht, D.B. Beach, T. Chirayil, C. Park, D.M. Kroeger and D.K. Christen, Oak Ridge National Laboratory, Oak Ridge, TN.

Progress made in the fabrication of Rolling assisted biaxially textured substrates (RABiTS) and epitaxial deposition or formation of HTS on such substrates is reported. Significant progress has been made in the fabrication of non-magnetic, strengthened, biaxially textured metal templates, deposition of oxide and other buffer layers and in the fabrication of long length substrates and superconductors. Ni-Cr alloy substrates fabricated using thermomechanical processing show a single orientation cube texture (~100%) with sharp in-plane and out-of-plane textures, essentially identical to that obtained for pure Ni. High J_c's exceeding 1 MA/cm^2 have been demonstrated on epitaxially grown YBCO films on RABiTS using Ni-Cr as the starting template. Tensile tests and magnetic hysteresis and susceptibility measurements show that the substrates have greatly reduced magnetic properties compared to Ni, and are significantly stronger. In the area of buffer layer development, significant progress has been made in the formation of single orientation oxide buffer layers on Ni using sol-gel processes. A variety of Re_2O_3 type materials have been fabricated in this manner. The buffer layers are dense and crack-free and electron backscatter diffraction patterns show that the films have a high crystalline quality. High J_c's exceeding 1 MA/cm^2 have been demonstrated on such substrates using intermediate vapor deposited buffer layers. Progress made in the area of long length deposition using both vapor deposition and sol-gel will be reported. Efforts are underway to fabricate longer length superconductor samples exceeding l0cm and results obtained will also be summarized.
*Research sponsored by U.S. Department of Energy under contract DE-AC05 96OR22464 to Lockheed Martin Energy Research Corporation.

9:00 AM *L2.2/O2.2/II4.2
INCLINED SUBSTRATE DEPOSITION BY EVAPORATION OF MAGNESIUM OXIDE FOR COATED CONDUCTORS. Markus Bauer, Ralf Metzger, Robert Semerad, Paul Berberich, Helmut Kinder, Technische Universität München, Physik Department, Garching, GERMANY.

Thin films of $YBa_2Cu_3O_7$ (YBCO) must be highly textured in order to have good superconducting properties. One way to achieve this is to grow textured buffer layers on arbitrary polycrystalline substrates by inclined substrate deposition (ISD). This was first proposed by Hasegawa et al. using pulsed laser ablation. We use evaporation techniques to make the ISD process scalable to large areas and high production rates. Buffer layers of MgO are deposited at very high rate either by e-beam or simply by thermal reactive evaporation on substrates of hastelloy or stainless steel inclined by typically 40°. This leads to columnar growth with biaxial texture, improving with thickness up to 2 μm. YBCO films grown on these buffers are highly textured with FWHMs around 8°. The CuO_2 planes of the YBCO are typically tilted with respect to the surface by 20° towards the direction of vapor incidence. Therefore the critical current density is anisotropic, with lower j_c along the vapor direction and twice as much across. This direction must be chosen along the tape for coated conductors. The highest j_c we have reached so far is 0.8 MA/cm^2, resistively measured. To understand the texturing mechanism we have carried out Monte Carlo simulations. These confirm the columnar growth mode. We find that the preferred orientation arises from two effects, namely biased hopping of the particles due to their initial momentum, and mutual shadowing of the colums selecting the fastest growing orientation. Issues of magnetic anisotropy, production rate, upscaling of tape length, and cost will be addressed.

9:30 AM *L2.3/O2.3/II4.3
ION BEAM INDUCED GROWTH STRUCTURE OF FLUORITE TYPE OXIDE FILMS FOR BIAXIALLY TEXTURED HTSC COATED CONDUCTORS. Yasuhiro Iijima, Mariko Kimura, Takashi Saitoh, Fujikura Ltd., Material Technology Lab., Tokyo, JAPAN.

The achievement of sharp biaxial alignment of Yttria Stabilized Zirconia (YSZ) films by off-normal ion-beam-assisted deposition (IBAD) produced a hopeful application as flexible HTSC coated conductors using metallic substrates. Quite high-J_c values were successfully achieved by removal of intergranular weaklinks in Y-123 films on the YSZ templates. Till now 2-3 m length Y-123 tapes were fabricated using random polycrystalline Ni-based alloy tapes coated with textured YSZ layers. Ar^+ ion bombardment had significant effects on the crystalline structure of the YSZ films; to align a $< 100 >$ axis with the substrate normal, and a $< 111 >$ axis with the bombarding beam axis. Those two effects were induced simultaneously at room temperature and resulted in peculiar biaxially textured structure without epitaxial relationship to substrates. This paper discuss the alignment mechanism with the structural properties of several fluorite or related type oxide films including YSZ, CeO_2, Y_2O_3, etc., based on several proposed models. Films were formed on polycrystalline Ni-based alloy by dual ion beam sputtering method. Growth structures were characterized by X-ray diffraction (XRD), transmission electron microscopy (TEM), atomic force microscopy (AFM) etc. Peculiar structural evolution of the crystalline orientation was observed and its development was well described by an exponential equation which agreed with Bradley's selective growth model. It could be explained as a collaboration among in-plane and out-of-plane anisotropic growth of surface crystallites, and also homoepitaxial growth onto crystalline surface beneath, both induced by Ar^+ ion bombardment. Very smooth surfaces were observed by AFM imaging with a roughness of 2-3 nm and a peculiar ripple structure. The surface topographic structure was discussed by relating to Ressler's surface binding energy model without using ion channeling. Because the energy of assisting ions were too low as 200 - 300 eV, the origin of azimuthal aligning effect is still under controversy.

10:30 AM *L2.4/O2.4/II4.4
BIAXIALLY TEXTURED BUFFER LAYERS ON LARGE-AREA POLYCRYSTALLINE SUBSTRATES. H.C. Freyhardt[1,2], J. Dzick[1,3], S. Sievers[1,3], J. Hoffmann[1], K. Thiele[1], F. Garcia-Moreno[1,2], A. Usoskin[2] and Ch. Joss[1]; [1]Institut fuer Materialphysik, Universitaet Goettingen, Goettingen, GERMANY, [2]ZFW: Zentrum fuer Funktionswerkstoffe GmbH, Goettingen, GERMANY, [3]Kabelmetal Electro GmbH, Hannover, GERMANY.

Biaxially textured buffer layers on polycrystalline metallic or ceramic substrates are required as templates for high-current-carrying HTS films, particularly coated YBCO films. In this contribution we report on our present understanding of the mechanisms governing the ion-beam-assisted deposition (IBAD) process employed for the preparation of textured YSZ as well as CeO_2 and Gd-doped CeO_2. On Ni, Hastelloy, SS as well as on ceramic tapes IBAD buffers could be produced with high-quality in-plane textures characterized by a FWHM of considerably smaller than 20°. Two systems were used, one with two 11 cm sputter sources and a 21 cm Kaufman ion source for the assisting beam and a second one with 11 cm sources for sputtering and the assisting beam. Furthermore, the IBAD process is now developed to an extend to allow the coating of large-area substrates (up to 20 cm x 50 cm) with well textured buffer films. Maximum current densities of PLD-YBCO layers on IBAD-buffered substrates reach values up to 2 MA/cm^2.
In parts supported by the German BMBF, kabelmetal electro GmbH and Siemens AG under grants 13 N 6924/6 and 13 N 6482, respectively.

11:00 AM *L2.5/O2.5/II4.5
METHODS EMPLOYED FOR PRODUCING HIGH-QUALITY ION-BEAM DEPOSITED CUBIC OXIDE TEMPLATE FILMS ON METAL SUBSTRATES. P.N. Arendt, J.R. Groves, S.R. Foltyn, Q.X. Jia, H.H. Kung, T.G. Holesinger, E.J. Peterson, P.C. Yashir, M.R. Fitzsimmons, R.F. DePaula, J.Y. Coulter, Y. Fan and M. Ma, Los Alamos National Laboratory, Los Alamos, NM.

Ion-beam assisted deposition was used to fabricate biaxially aligned cubic zirconia or magnesia films on flexible metal substrates. These films are used as templates for heteroepitaxially deposited YBCO films. The quality of the crystalline texture of the template films has a direct influence on the superconducting properties of the final YBCO films. We describe our efforts to fabricate high-quality templates on small-area substrates processed in stationary mode and meter-long substrates processed in continuous mode. Cubic zirconia templates were deposited on the meter-long substrates and magnesia templates were deposited on the small-area substrates. Our best phi scan FWHM values for the films on the meter-long tapes are 12.6 degrees for the template and 6.1 degrees for the overcoated YBCO. This meter-long tape had self-field, 75 K, superconducting critical current of 122 amps. Our best phi scan FWHM values for the films on small area substrates are 5.6 degrees for the template and 3.6 degrees for the overcoated YBCO. We will also describe x-ray grazing incidence measurements of the topmost layers of the template films as well as TEM measurements of the film microstructure.

11:30 AM L2.6/O2.6/II4.6
LEVEL SET SIMULATION OF ION BEAM ORIENTED MgO GROWTH. Xingquan Li, Dept. of Physics, University of Michigan, Ann Arbor, MI; Peter S. Smereka, Dept. of Mathematics, University of Michigan, Ann Arbor, MI; David J. Srolovitz, Princeton Materials Institute, Princeton University, Princeton, NJ; Giovanni Russo, Dept. of Mathematics, University of L'aquila, L'aquila, ITALY.

We have developed a general purpose algorithm for the growth of faceted thin films from the vapor based upon the level set method. In the present simulations, we focus on the growth of polycrystalline MgO from the vapor in the presence of a low energy ion beam, which is used to establish in-plane texture. While out-of-plane texture {100} forms naturally, the ion beam selects grains which are oriented in a channeling direction with respect to the oblique beam. Growth rates of individual grains vary with grain orientation. We determine the polycrystalline microstructure, grain size and the width of the orientation distribution as a function of ion beam properties.

11:45 AM L2.7/O2.7/II4.7
QUANTITATIVE RHEED ANALYSIS OF BIAXIALLY-TEXTURED POLYCRYSTALLINE MgO FILMS ON AMORPHOUS SUBSTRATES GROWN BY ION BEAM-ASSISTED DEPOSITION. R.T. Brewer, J.W. Hartman and Harry A. Atwater, California Institute of Technology, Dept of Applied Physics, Pasadena, CA.

We have developed a computer simulation based on analytic calculation of RHEED patterns in the kinematic approximation for mosaic polycrystalline films for given values of electron beam incidence angle, polycrystalline texture, in-plane orientation distribution, and grain size. Although RHEED is most accurately modeled using a dynamical scattering model, the computational efficiency of kinematical scattering lends itself to development of a model suitable for real time control of biaxially-textured film growth by ion beam-assisted deposition (IBAD). Using the simulation results, we can quantitatively determine how RHEED spot shapes and relative intensities depend on the mosaic film characteristics. RHEED patterns taken at 15 keV with incidence angle in the range 1-5 degrees from 10 nm thick nominally [100]-textured MgO films grown on amorphous Si_3N_4 films by IBAD were analyzed by comparing experimental RHEED spot shapes and relative intensities with those predicted by the simulation results. For some films, an additional 200 nm thermally-grown MgO homoepitaxial layer was grown on top of the IBAD MgO layer. Results are also compared to X-ray rocking curve film analysis, and the quantitative correlation between biaxial texture and model-based RHEED analysis will be discussed.

SESSION L3: POLYCRYSTALLINE FILMS – MICROSTRUCTURE AND TEXTURE
Chairs: Tomas Diaz de la Rubia and Arthur F. Voter
Tuesday Afternoon, November 30, 1999
Salon H/I (M)

1:30 PM *L3.1
ION BEAM CONTROL BOTH IN- AND OUT-OF-PLANE TEXTURE DURING FILM GROWTH. D.J. Srolovitz, Princeton Materials Institute and Dept. of Mechanical and Aerospace Eng., Princeton University, Princeton, NJ; L. Dong, Dept. of Materials Science & Eng., University of Michigan, Ann Arbor, MI; G.S. Was, Q. Zhao, Dept. of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI; A.D. Rollett, Dept. of Materials Science & Eng., Carnegie Mellon University, Pittsburgh, PA.

We present both computer simulation and experimental evidence for the simultaneous establishment of both out-of-plane and in-plane texture during the ion beam assisted deposition of aluminum. The molecular dynamics simulations and experiments show that the channeling effects yields both an orientation dependence of the sputtering yield (and hence growth rates) and damage. Using an ion beam at 60° from the normal, we employ the dominant $< 110 >$ channels to change the dominant out of-plane orientation from the thermodynamically preferred {111} orientation to {220}. Since the ion beam has a components of the momentum in the plane of the film, the 60° ion beam also aligns $< 220 >$ directions that are normal to the film. We present similar results for the case of MgO grown on an amorphous substrate. Measured x-ray pole figures confirm the presence of a strong out of-plane texture and the presence of two main in-plane texture components. Analysis of these pole figures shows that these two in-plain texture components are twin related. We show theoretically that it is not possible to completely control both the in-plane and out-of-plane texture with a single ion beam in high symmetry crystals (without twin related components) and propose a two ion beam method that will guarantee complete texture control.

2:00 PM L3.2
MICROSTRUCTURAL EVOLUTION OF ION BOMBARDED COPPER THIN FILMS. Dietmar Mueller, Thomas Wagner, Max-Planck-Institut fuer Metallforschung, Stuttgart, GERMANY.

The effect of low-energy bombardment on the microstructure of copper films will be described. The copper films have been deposited by magnetron sputtering with a simultaneous bombardment of low-energy argon ions and than annealed at 450°C in HV. The bombardment leads to a stronger and sharper (111) texture of the as-deposited films. The difference in texture changes the evolution of the microstructure during annealing. After annealing the ion bombarded films have a significantly smaller grain size than films produced without ion bombardment. This point is reflected in the strength of the films tested by wafer curvature. The experimental results will be discussed connecting the texture of the as-deposited film with the mean grain size obtained after annealing. Details will be given as to how the microstructure of Cu films can be tailored using low-energy argon ion bombardement.

2:15 PM L3.3
MICROSTRUCTURAL EVOLUTION DURING OBLIQUE FILM DEPOSITION: A FRONT TRACKING SIMULATION APPROACH. Fnu Paritosh, Dept. of Chemical Engineering, University of Michigan, Ann Arbor, MI; David J. Srolovitz, Princeton Materials Institute, Princeton University, Princeton, NJ.

Microstructures grown with the deposition flux or ion beam at a non-zero angle with respect to the substrate normal exhibit microstructures that are characterized by tilted columns and void incorporation. If the deposition angle is alternated, a zig-zag microstructure can be produced. We examine these shadowing effects by tracking the evolution of the growth surface of a faceted polycrystalline film using a front tracking method. These simulations predict the temporal evolution of the microstructure, morphology and texture of the polycrystalline film. We present the results of the evolution of mean grain size, grain size distribution, surface roughness, crystallographic texture as a function of deposition angle. When the deposition angles become large, shadowing effects cut off the deposition flux to many surfaces and voids are formed. Additional simulations are performed for the case of ion beam assisted deposition, where the ion beam is oblique and the deposition flux is normal. In this case, the relative growth rates of different facets depends on the orientation of the ion beam with respect to channeling directions. When the ion beam angle gets large, the fastest growth rates occur for surfaces that are completely shadowed from the ion beam. This yields interesting microstructures. Finally, we examine the effects of angular dispersion in the deposition flux and/or ion beam.

2:30 PM L3.4
THE EFFECTS OF GRAIN GROWTH ON SURFACE STRUCTURE EVOLUTION OF SPUTTER DEPOSITED POLYCRYSTALLINE Al THIN FILMS. Adriana E. Lita, John E. Sanchez, Jr., University of Michigan, Dept of Materials Science and Engineering, Ann Arbor, MI.

We report the first observation of dynamic scaling for sputter deposited polycrystalline Al film surfaces. We have characterized the development of surface structure of sputter deposited Al and Al-0.5wt.% Cu thin films during growth from 0.01 μm to 1.6 μm thickness by atomic force microscopy (AFM). In addition film microstructure (grain size and crystallographic texture) was determined by transmission electron microscopy (TEM) and x-ray diffraction pole figure (XPF) analysis. Surface evolution was correlated to the development of microstructure as grain growth leads to preferred crystallographic texture in the films. Imaging of the surface structure reveals growth hillocks scattered randomly at average separation larger than the median grain size, identifiable grains with boundary grooves, and periodic ridge features extending uniformly over the surface of individual grains. These features indicate that surface structure and roughness evolve on distinct length scales specified by different mechanisms acting during growth. The characteristic lengths determined by power spectral density (PSD) analysis represent the transitions between distinct regimes of growth dynamics during film growth. The median grain size represents the transition between a self-affine region (α=0.2-0.3) at length scales smaller than the grain size and a randomly rough region with uncorrelated features (hillocks) at length scales corresponding to several grain diameters. The ridge separation represents the transition between the above self-affine region and a surface diffusion dominated self-affine region ($\alpha \geq 1$) at smaller length scales. The initial stages of surface and microstructure evolution in sputter deposited Al-Cu thin films were characterized before and after island coalescence. The roughness decrease after coalescence illustrates the effect of the competitive grain growth process that affects surface structure as well as grain size and crystallographic texture. We emphasize grain growth as a significant process which contributes to surface structure evolution in polycrystalline thin films.

3:15 PM *L3.5
MODIFICATION OF THIN FILM GROWTH USING GLANCING-ANGLE IONS. Scott A. Barnett, Kurt C. Ruthe and Paul M. DeLuca, Northwestern University, Dept of Materials Science and Engineering, Evanston, IL.

This paper reviews the use of glancing-angle ions for modifying surfaces and thin film growth processes. Ions impinging on a flat surface at oblique incidence angles are mostly reflected without penetrating, providing very low sputtering rates along with minimal damage and implantation. They also provide a unique selectivity, where ion energy is coupled to defects or rough portions of the surface, while flat portions are essentially unaffected. This allows one to clean contaminated surfaces and smoothen rough surfaces, both with essentially no ion damage. In addition, recent results indicate that the ion energy couples directly to adatoms during epitaxial growth of GaAs(001). This was observed by a decrease in the time required for diffusion across terraces on a vicinal GaAs surface, as the glancing-angle Ar ion current was increased. It was also found that ion-enhanced diffusion shifted the growth mode from two-dimensional island nucleation to step-flow growth, and resulted in flatter growth surfaces. Finally, the use of glancing-angle ions to introduce a biaxial texture into polycrystalline GaAs films will be described.

3:45 PM L3.6
PHASE CONTENT AND DEPOSITION KINETICS IN ULTRA-THIN SPUTTERED TANTALUM FILMS. J.F. Whitacre, University of Michigan, Department of Materials Science & Engineering, Ann Arbor, MI, Z.U. Rek, Stanford Synchrotron Radiation Laboratory, Stanford University, Stanford, CA, S.M. Yalisove and J.C. Bilello, University of Michigan, Department of Materials Science & Engineering, Ann Arbor, MI.

The influence of adatom kinetics on phase content and residual stress development in extremely thin sputtered Ta films was examined. The adatom kinetic energy distribution at the substrate during growth was manipulated by controlling the sputter gas (Ar) pressure. Calculations show that at low Ar pressures (less than 5 mTorr), arriving adatoms have kinetic energies on the order of 10 eV as they impinge upon the substrate. At pressures greater than 15 mTorr, the energy distribution shifts to the thermal regime, where all atoms have energies less than 1 eV. For this experiment, Ta films 25 to 5000 Å in thickness were DC magnetron sputter deposited using Ar pressures ranging from 2 to 20 mTorr. The films were analyzed using a synchrotron x-ray source (SSRL beamline 7-2) in conjunction with a four-circle diffractometer aligned in the grazing incidence x-ray scattering (GIXS) geometry. The stress in these films was calculated using double crystal diffraction topography (DCDT, a wafer curvature method) data. Film nanostructure was directly examined using cross-section high-resolution transmission electron microscopy (HRTEM). Phase content was determined by modeling ideal polycrystalline x-ray diffraction patterns and comparing them with corrected (for air, Compton, and substrate scattering) diffraction data. These x-ray results compare favorably with the HRTEM analysis. It was found that films grown at progressively higher pressures displayed a systematic increase in amorphous content. Film grown using 20 mTorr of Ar were fully amorphous to thicknesses as great as $\sim$150Å. Residual stress analysis showed that all films less than 100 Å thick had compressive stresses on the order of -2 GPa. These results are discussed in context of a model that relates adatom kinetics, surface diffusion, and grain development during the early stages of film growth. Work supported by ARPA under contract No. DAAH-04-95-1-0120. Work done (partially) at SSRL, which is operated by the Department of Energy, Office of Basic Energy Sciences.

4:00 PM L3.7
THIN FILM GROWTH AND ION-BEAM MODIFICATION: MD SIMULATIONS GOING BEYOND SIMPLE SYSTEMS. Edwin F.C. Haddeman, Bouke S. Bunnik, and Barend J. Thijsse, Delft University of Technology, Dept of Materials Science, Center for Research on Ion-Solid Interactions and Surfaces (CRISIS), Delft, NETHERLANDS.

Molecular Dynamics simulations are becoming increasingly helpful in understanding the atomic-scale processes that are instrumental in thin film formation and ion-beam modification. However, in most cases only simple systems are studied, under more or less idealized conditions. The purpose of this work is to go one step further in complexity. After all, grain boundaries, textured surface patterns, and crystallographic mismatch at interfaces are just a few of the conditions that distinguish real-life applications from textbook films. We report MD simulations - employing Embedded Atom Methods - of thin film growth and ion beam modification in all these three cases. More in particular, the following subjects are examined: (1) Strong surface patterns develop when a Mo film is grown on a Mo(110) substrate, while they are absent for Mo on Mo(100). The causes of this difference in nanofaceting and the resulting difference in defect topology are discussed. (2) Depositing a Mo film on a substrate containing two (100)/(910) grain boundaries of different orientation leads to complicated film morphologies in the grain boundary regions. Dislocations, mosaic spread, and regions of fcc Mo are observed. (3) Cu films deposited on Mo substrate form a model system for the latest metallization technologies in IC manufacturing. The influence of the fcc/bcc interface mismatch on the Cu film properties is analyzed for thermally evaporated and IBAD films.

4:15 PM L3.8
ARSENIC ION IMPLANTATION INDUCED TEXTURE MODIFICATION IN C_{60} THIN FILMS. K.L. Narayanan and M. Yamaguchi, Toyota Technological Institute, Nagoya, JAPAN.

Ion Implantation in C_{60} thin films has been a topic of interest since the researchers have started working on the doping studies of the fullerenes. Ion Implantation technique changes the structural, optical and electrical properties of the materials and hence the present studies are motivated towards the structural analysis of the arsenic ion implanted C_{60} thin films. C_{60} thin films deposited on Si (001) wafer were implanted with positive arsenic ions and they were characterized using Atomic Force Microscopy(AFM) and X-ray Diffraction (XRD) along with the X-ray Photo electron spectroscopy(XPS). XPS results indicate the formation of arsenic buried layer within C_{60} film leading to the anisotropy stress in the film. XRD results reveal the preferential orientation of the film along the (531) plane on implantation and it can be due to the re-alignment of the grains as evidenced by our AFM measurement. AFM measurements also reveal the reduction in the grain size and the surface roughness of the films by arsenic ion implantation.

4:30 PM L3.9
IMPROVEMENT OF TFT CHARACTERISTICS BY USING CONTROLLED GRAINS. Fumiyo Takeuchi, Katsuyuki Suga, Yasuyoshi Mishima, Nobuo Sasaki, Fujitsu Laboratories Ltd., LCD Lab., Kanagawa, JAPAN.

We fabricated poly-Si TFTs on a glass substrate by excimer laser crystallization with silicon oxide capping layer exactly on the channel regions. TFT characteristics and their uniformity are greatly improved compared with conventional excimer laser crystallized p-Si TFTs, because the patterned capping layer of narrow width makes nucleation control and produce rectangle grains aligned along the pattern. Amorphous-Si films (50nm) and silicon oxide capping layers (50nm) were deposited by PECVD on a glass substrate. The capping layer was patterned into tiny islands of 2-micron width, which exactly correspond to the successively fabricated channel regions. Crystallization was performed by XeCl excimer laser (308nm) scanning. After removing the capping layer, 120nm gate insulator was re-deposited and TFTs were fabricated below 450°C. It is observed by SEM that 1 micron-long rectangular grains are grown along the edge of patterned capping layer and aligned regularly; the grains by the conventional crystallization show polygon-like shape of various size due to random nucleation. This capping method results in the improvement of uniformity of TFT characteristics, although the average mobility of $80cm^2/Vs$ is equal to that of conventional TFTs. The coefficient of variation(σ/mean) of mobility in the 300mm x 300mm glass substrate is decreased to 10% from 20% of the conventional TFTs. The average S-value is improved from 0.5 to 0.3 V/decade. Raman spectra show that peak frequency of the Si band of the Si-film by capping method, about $518cm^{-1}$, is higher than that of conventionally crystallized film, about $516cm^{-1}$. The surface roughness is also reduced into one-half by the capping method. In conclusion, uniformity of mobility is improved by using patterned capping layer just on the channel regions to control grain shape and location, that is, the variation is suppressed into one-half. S-value is also improved by this method owing to the grain size and quality.

4:45 PM L3.10
PULSED ELECTRON BEAM $CuInSe_2$ PROCESSING. Serghei Malkov, Academy of Science-Moldova, Kishinev, MOLDOVA.

A pulsed electron beam processing has been applied for preparation and annealing of as-grown $CuInSe_2$ thin films. This technology method is concerned to be analogous to UV-laser deposition, but at the same time, it can be related to plasma induced techniques like sputtering. The $CuInSe_2$ processing was implemented by a high current and magnetically self-pinched electron beam produced in a low pressure channel spark camera at the following conditions: voltage - 7-18.5 kV, pulse duration - 100 ns, repetition rate - 1-5 Hz, power density $< 300\ MW/cm^2$, argon pressure - 1-3 Pa, substrate temperature - 100-500C. The $CuInSe_2$ films were established to have a strong preferential (112) orientation, chalcopyrite structure, columnar grain microstructure, and specular surface morphology consisting of a smooth background of closely arranged grains as well as precipitates and spherical particulates disposed on the film surface. The Cu/In ratio in the films was found to be substrate temperature dependent and in a range of 0.

SESSION L4: POSTER SESSION: BEAM-MODIFIED FILM GROWTH AND SURFACE PROCESSING

Chair: James M.E. Harper
Tuesday Evening, November 30, 1999
8:00 P.M.
Exhibition Hall D (H)

L4.1

GROWTH BY ION BOMBARDMENT ON Al(111). Carsten Busse, Henri Hansen, Thomas Michely, I. Physics Institute, RWTH-Aachen, Aachen, GERMANY.

As ion bombardement causes sputtering of surface atoms, one expects an irradiated surface to retract due to this erosion process. In contrast to this expectation, low energy ion bombardement of Al(111) by Ne^+, Ar^+ and Xe^+ causes an initial surface growth as observed by STM. For 1 keV Xe^+ bombardement the amount of grown material saturates at about 2 ML at a fluence of 7×10^{18} ions/m^2 and not till higher fluences the surface starts to receed. In order to account for the material balance, it must be concluded that at saturation an amount of vacancies corresponding to 4.4 ML of material resides below the surface. This scenario is observed for all temperatures up to 375 K (0.4 reduced melting temperature), while previous studies of e^- and fast neutron irradiation damage show complete annealing of the defects at about 200 K. The observed behaviour is explained on the basis of the thermal spike model. It is argued that the growth with a rate of up to 40 atoms by one 1 keV Xe^+ impact is due to the flow of molten Al onto the surface, leaving stable vacancy clusters in the bulk. The large vacancy clusters form only for energy deposition near the surface but not for cascades in bulk Al. STM annealing measurements in agreement with measurements of quenched Al support the presented view.

L4.2

NANOPARTICLE EJECTION FROM AU INDUCED BY SINGLE Xe ION IMPACTS. R.C. Birtcher and S.E. Donnelly*, Materials Science Division, Argonne National Laboratory, Argonne, IL. *Joule Physics Laboratory Research Institute, University of Salford, Salford, UNITED KINGDOM.

Sputtering of Au thin films has been determined for Xe ions with energies between 50 and 600 keV. In-situ transmission electron microscopy was used to observe sputtered Au during deposition on a carbon foil near the specimen. Total reflection and transmission sputtering yields for a 62 nm thick Au thin film were determined by ex-situ measurement of the total amount of Au on the carbon foils. Individual Xe ions eject Au particles as large as 7 nm in diameter with an average diameter of approximately 3 nm. Particle emission correlates with crater formation due to single ion impacts. Particle emission contributes as much as 15% to the total sputtering yield for Xe ions in this energy range in either reflection or transmission geometry.

L4.3

ION-ENHANCED DRY ETCHING OF MAGNETIC MULTI-LAYERS: POST-ETCH CLEANING AND EFFECTS OF UV ILLUMINATION. H. Cho, K.P. Lee, K.B. Jung and S.J. Pearton, Department of Materials Science and Engineering, University of Florida, Gainesville FL; F. Sharifi and J. Marburger, Department of Physics, University of Florida, Gainesville, FL.

Patterning of magnetic multilayer structures of the type used for MRAMs (e.g. NiFeCo/CoFe/Cu/CoFe/NiFeCo) is generally performed with ion milling, but this can degrade the coercivity of small (micron-size) MRAM elements and lead to sidewall redeposition. In high ion density reactive plasmas (Cl_2/Ar) it is possible to produce ion-enhanced desorption of otherwise involatile halogenated reaction products, and achieve practical etch rates (~600$\AA$/min) for the multilayers. However removal of the chlorinated etch products from the feature sidewalls is critically important to avoid corrosion. We have used de-ionized water rinsing or in-situ exposure to H_2, O_2 or SF_6 plasmas for removal of these etch residues. Some slight degradation in magnetization was observed in O_2 plasma treated structures, but the other cleaning procedures produced no change in magnetic properties and excellent long-term stability. UV illumination of the sample surface during etching is also found to enhance etch rates, as has been reported previously for room temperature etching of Cu [(1)]. [(1)] K. S. Choi and C. H. Han, J. Electrochem. Soc. 145 L37 (1998).

L4.4

THE EFFECT OF ION BEAM ETCHING ON THE SURFACE ROUGHNESS OF AlTiC. Danielle S. Hines, Kurt Williams, Sudhi Sant, David Sampson, Veeco Instruments, Plainview, NY.

AlTiC, a composite of alumina and titanium carbide, is used as the substrate for most hard drive recording heads. Because the cavities that control the aerodynamic properties of the recording head are etched into this material, control over the surface roughness of AlTiC is critical to proper head performance. In this study, the effects of ion beam angle of incidence, ion beam power and etching duration on AlTiC surface roughness have been explored. It has been found that surface roughness varies greatly with ion beam angle of incidence, with the roughness minimized at an angle of 45 degrees. In addition, roughness increases linearly with duration of etching, regardless of the ion angle of incidence. It is proposed that this surface roughness arises from the difference in the etching rates of the component materials of AlTiC, alumina and titanium carbide.

L4.5

SELF-ORGANIZING PROCESSES INDUCED BY LOW-ENERGY ION IRRADIATION IN SOLIDS. I.V. Tereshko, V.I. Khodyrev, B.B. Glushchenko, A.M. Tereshko, Mechanical Engineering Inst, Mogilev, BELARUS.

The present paper is aimed at studying nonlinear effects induced by interaction of low-energy ions with the surface of solids. The computer simulation experiment was made by a molecular dynamics method. We chose the Morse potential as the potential of atomic interactions. Having decomposed it into the Taylor series we write the system of equations for the chain of coupled oscillators. The coefficients of elasticity and quadratic and cubic nonlinearity and coefficient of damping factors have been calculated using the parameters of the Morse potential for armco-Fe. A special model based on the classical dynamics equations has been developed for calculating lattices of different dimensions. The dependence of an atom displacement on time passed after stopping the external influence was investigated. The computer simulations showed that nonlinear oscillations were excited in the system of coupled atomic oscillators in irradiated solids, which resulted in the formation of new collective stable structural states in crystal lattices. Atomic clusters with irregular atom rearrangements, running and pulsing autosolitons, long-lived undamped oscillations in local ranges of lattices, and nanometer dimensions structures were formed. The specific kind of these new heterogeneous structures depends on the properties of the potential characterizing the atomic oscillator bonds and the magnitude of the external influence. The numerical simulation results have been verified by experiments. We showed by electron microscopy method that the low-energy irradiation leds to the increase in dislocation density up to 10 mm in depth from the irradiated surface. This is actually a bulk modification. This result was described independently as a long-range effect (LRE). The samples of armco-iron were exposed to gas discharge plasma under the voltage of 0.8-2.5 kV, samples being irradiated by ions of residual gases of vacuum. The ion energy depended on the voltage in the plasmagenerator and did not exceed 0,8-2,5 keV. These modifications in materials define the new physical and mechanical properties of irradiated materials.

L4.6

USE OF THE ARC DISCHARGE FOR THE SURFACE MODIFICATION. Vladimir A. Kovalenko, Physics Department, Michigan Technological University, Houghton, MI.

The steel surface saturation by nitrogen (nitriding) results in a high increase of surface hardness and a decrease of friction rate. This treatment is widely used for the increasing of the cutting tool life times and wearing parts in machines. A new approach of steel surface treatment by using the vacuum arc discharge in nitrogen is presented. The apparatus consists of two arc vacuum discharges. The first one is a metal vapor discharge and serves for both the cleaning- heating of the treated surface, and for the initiation of the second vacuum arc discharge in nitrogen. The technological source of metallic plasma allows for simultaneous implantation of additive metals and surface saturation by nitrogen. The developed arc vacuum discharge method shortens the nitriding time 2 to 3 times in comparison to the glow discharge technology. Usual tool steel containing ~6% of W and ~5% of Mo has hardness H_v^{300}=1000 kgf/mm^2 after nitriding in our apparatus for 20 minutes at the temperature of 550°C. The resulting thickness of the solid-solutions of nitrogen in a sample is 100 μm. After N_2 nitrogen and Cr chromium implantation, the tool steel described above reaches the surface hardness H_v^{300}=1200 kgf/mm^2. The developed technique of the surface treatment is suitable for wide variety of steels.

Supported in part by State of Michigan Research Excellence Fund

L4.7

KeV ION BEAM INDUCED SURFACE MODIFICATION OF SiC

HYDROGEN SENSOR. C.I. Muntele, D. Ila, E.K. Williams, Center for Irradiation of Materials, Alabama A&M University, Normal, AL; D.B. Poker, D.K. Hensley, Solid State Division, Oak Ridge National Laboratory, Oak Ridge, TN; David J. Larkin, NASA Lewis Research Center, Cleveland, OH.

Silicon carbide, a semiconductor, is used to fabricate efficient high temperature hydrogen sensors. Traditionally, when a palladium coating is applied on the exposed surface of SiC, the chemical reaction between palladium and hydrogen produces a detectable change in the surface chemical potential. Rather than applying a palladium film we have implanted palladium ions into the Si face of 6H, n-type SiC. Different ion energies and fluences have been studied at an implantation temperature of 500 C. After the implantation, their exposure to hydrogen while monitoring the current flow with respect to time, has revealed a completely different behavior than the samples that have Pd deposited as a surface layer (1, 2). On the coated SiC sensors the current rises in the presence of hydrogen at the room temperature as well as at elevated temperatures. In the case of implanted SiC, the current rises at room temperature in the presence of hydrogen, but decreases whenever the temperature is raised above a threshold value. Moreover, the threshold temperature is different for the direct and reversed bias voltage applied to the samples. These results were obtained for current measurement done using a Keithley model 595 IV/CV meter interfaced to a computer, for various temperatures in an alternated hydrogen/air closed environment. The temperature of the SiC samples was also monitored in order to correct for current fluctuations due to temperature changes. For this experiment, an H-Ar gas mixture was used.

References

1. G.W. Hunter, P.G. Neudeck, L.Y. Chen, D. Knight, C.C. Liu, Q.H. Wu, AIAA 95-2647, Joint Propulsion Conference and Exhibit, 1995, San Diego, CA.

2. L.Y. Chen, G.W. Hunter, P.G. Neudeck, D. Knight, C.C. Liu, Q.H. Wu, The 190th Meeting of the Electron Society, 1996, San Antonio, TX.

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L4.8

PECVD APPLIED TO EPITAXIAL SiGe GROWTH AT VERY HIGH RATES. C. Rosenblad[1], M. Kummer[1,2], E. Müller[1], A. Dommann[2], and H. von Känel[1]; [1]Laboratorium für Festkörperphysik, ETH-Zürich, Zürich, SWITZERLAND; [2]Interstaatliche Fachhochschule für Technik Buchs, Buchs, SWITZERLAND.

At low substrate temperature, the growth rate for epitaxial SiGe layers becomes very low using conventional growth techniques. For the SiGe relaxed buffer layer, where several μm of epitaxial material have to be grown, the deposition time is several hours, which is far above what is accepted by the industry. We have developed a new growth technique, called low-energy plasma enhanced chemical vapour deposition (LEPECVD), which uses a high current, but low voltage arc discharge to speed up the growth rate to values of at least 5 nm/s for a substrate temperature below 600°C. Due to the low ion energies involved in the hot cathode arc discharge plasma, the soft but intense ion-bombardment of the surface provides non-thermal energy to the surface reactions, without any accompanying ion damage. The potential of LEPECVD as a growth method for epitaxial semiconductor material will be discussed for the example of SiGe relaxed buffer-layers. High resolution X-ray diffraction reciprocal space maps in conjunction with cross-sectional transmission electron microscopy and defect etch pit counting, shows that the buffers are completely relaxed ($\epsilon_{||} < 0.1\%$), with etch pit densities below 10^{-5} cm^{-2}. To assess the potential of LEPECVD in different production environments, strained modulation doped Si channels were grown on the SiGe buffer layers either in the same growth run, on H-passivated buffers exposed to air for a few minutes, and on buffer layers stored several weeks before cleaning and overgrowing them with the active layer. The subsequent characterization of the electronic properties shows that in all cases the LEPECVD synthesized SiGe buffer layers are suitable virtual substrates.

L4.9

PATTERNED ZnS THIN-FILM GROWTH USING KrCl EXCIMER LAMP ON THE Zn NUCLEI. Masahiro Toda, Masataka Murahara, Tokai Univ, Dept of Electrical Engineering, JAPAN.

We are going to report a method of thin-filmed ZnS pattern growth above the Zn nuclei by KrCl Excimer lamp (222nm) which was formed on the Si substrate with single shot of KrF Laser at room temperature. To create thin-filmed ZnS pattern on the Si substrate, we were tested a method which is based on two major step process, such as nucleation of Zn on the surface and ZnS thin- filmed Pattern layer growth. The first step of this process is nucleation of Zn. Sealing material gas (DMS; Di- Methyl-Zinc, 0.5 Torr) in the reaction chamber and quick exhaust to absorb single molecules layer on the surface of the substrate. Then expose KrF laser (single shot exposure with 100mJ/cm^2 fluence) through masked pattern to form patterned Zn nuclei on the surface. The second step of this process is growth of thin-filmed ZnS pattern layer above of patterned Zn nuclei, which was formed by the first step. To form thin- filmed ZnS pattern, we used KrCl Excimer Lamp exposure (222nm; 10 min) into reaction chamber which is sealed DMZ Gas (0.5 Torr) H2S (5 Torr) to form ZnS. ZnS layer is formed only above patterned Zn nuclei, therefore, we can leave photo mask out from this step. As a result of our examination of this method, we could have 15um L/S (Line and Space) ZnS pattern on the Si substrate with the 500 A thickness. To Confirm of creation of ZnS, we examined this thin-film by XPS analysis there are peaks at 264eV and 166eV, which are known as ZnS characterization.

L4.10

A NOVEL LARGE AREA NEGATIVE SPUTTER ION BEAM SOURCE AND ITS APPLICATION. Minho Sohn, Steven Kim, Catherine Rice, SKION Corporation, Hoboken, NJ; Nam-Woong Paik, Daeil Kim, Physics and Engineering Physics Department, Stevens institute of Technology, Hoboken, NJ.

A large area negative metal ion beam source has been developed. The kinetic ion beam energy of the incident metal ions yields a whole new nucleation and growth phenomenon compared to the conventional thin film deposition processes. At the initial deposition step, the surface and interface can be engineered by tuning the energy of the incident metal ion beams. Smoothness and shallow implantation can be tailored according to the desired application process. Surface chemistry and the nucleation process is also controlled by the energy of the direct metal ion beams. Each individual metal ion beam with controlled energy undergoes hyper-thermodynamic reactions and nucleation. The degree of formation of tetrahedral sp^3 carbon bonding and beta-carbon nitride films directly depends on the energy of the ion beams. Formation of polycrystalline Si is obtained at temperatures lower than 500°C with controlled grain size by controlling the energy of the incident negative Si ion beams. The large area metal ion source combines the advantages of magnetron sputter sources and SKION's prior cesium-activated metal ion source. The ion beam source produces uniform amorphous diamond films over 6 inch diameter. The films are now being investigated for applications such as field emission display emitter materials, protective coatings for computer hard disks and heads, and other protective coatings. The performance of the ion beam source and recent applications will be presented.

L4.11

ION BEAM CHARACTERISTICS OF A NOVEL METAL ION BEAM SOURCE AND ITS APPLICATION ON NUCLEATION KINETICS. Daeil Kim, Dept. of Materials Science and Engineering, Stevens Institute of Technology, Hoboken, NJ; Steven Kim, SKION Corporation, Hoboken, NJ.

A novel metal ion beam has been developed. A negative metal ion beam is generated by sputtering with a primary positive cesium ion beam. The beam energy of the incident metal ions can be independently controlled from 5 eV to 500 eV. The energy spread has been found to be less than ± 10 % regardless of the beam energy. The flux of the secondary metal ion beam depends on the primary cesium ion beam as well as on secondary negative ion sputter yields. We have measured the secondary metal ion yields for C, Al, Si, Ni, Cu, Ta, and W, which are 27, 23, 22, 19, 14, 15 and 13 % respectively. The ratio of negative metal ions to neutral atoms has been measured, and it's approximately 25 % for carbon. One can obtain pure ion beams using a simple electrostatic deflector. The unique properties of the precise controlled incident energy and flux of the metal ion beam source allows us to investigate the kinetically controlled nucleation mechanism. A UHV Scanning Tunneling Microscope has been used to study the evolution of nucleation as functions of ion beam energy, substrate temperature and mass of incident ions.

L4.12

STUDY OF THE LOW ENERGY DIRECT ION BEAM DEPOSITION OF CARBON AND NICKEL AT ATOMIC SCALE. H.-A. Durand, K.Sekine, K.Ito, K. Etoh, I. Kataoka; Japan Aviation Electronics Industry Ltd, Central Research Laboratory, Advanced Research Department, Tokyo, JAPAN.

We have pursued investigations of surfaces bombarded by ions with kinetic energy ranging from a few ten eV to several hundred eV. The modification of highly oriented pyrolitic graphite surface under argon ion irradiation was studied using a ultra high vacuum scanning tunneling microscope at atomic resolution. We could experimentally observe several types of ion induced defects that were previously forecast by computer simulations, as well as the existence of a threshold energy before inducing vacancies in the crystallographic arrangement of the substrate. Furthermore, the influence of ion induced defects on the nucleation and growing interface morphology of carbon and nickel thin films were also observed and monitored using the scaling exponent of roughness computed from STM and AFM images.

L4.13
CUBIC BORON NITRIDE STRUCTURAL STABILIZATION USING LOW ENERGY ION ASSISTED BOMBARDMENT. Wilfredo Otano-Rivera, Cayey University College, Cayey, PUERTO RICO.

Several models have been proposed to explain the nucleation and growth of the cubic structure of boron nitride (cBN) and it is agreed that hyperthermal ion bombardment of the growing film is critical for its structural stabilization. The energetic bombardment during film growth, e.g., a high flux of ions with energies over approximately 50 eV, has been correlated with P/a, the total momentum imparted to the growing film per arriving boron atom. A window of stabilization for the cBN in terms of P/a has been established. It has been also suggested that this P/a dependence break down at lower energies (less than 150 eV). In order to test this hypothesis an End-Hall ion source was incorporated to an ion beam assisted deposition (IBAD) system in order to generate a high current, low energy beam (30-120 eV). Kaufman sources used in previous IBAD studies provide only about half the current of the End-Hall source. This limits the energy of the ions produced in the Kaufman sources to values over 200 eV in order to produce the P/a values necessary for the cBN stabilization. An End-Hall source, increasing the current by a factor of 2, and bombarding the growing film with ions of 100 eV should be able to produce the same energetic bombardment as a Kaufman source with ion energies of 400 eV. The use of the End-Hall source extends the study of the cBN stabilization to energies between 50-120 eV, while providing independent control of the sputtered atom flux, and the energy and flux of the bombarding ions. The end result is an accurate measurement and control of the parameters that define P/a. Details of this study and the implications for the stabilization of cBN films will be presented.

L4.14
STRESS FORMATION IN BORON NITRIDE FILMS PREPARED BY ION BEAM ASSISTED DEPOSITION. Bernd Rauschenbach, Stefan Sienz, Institut für Physik, Universität Augsburg, Augsburg, GERMANY.

The cubic boron nitride films prepared by low-energy ion beam assisted deposition are characterized by the small mean diameter of the crystallites, a substrate-film interlayer of sp^2-hybridized boron nitride (amorphous and/or hexagonal BN) and poor adhesion of the films. These properties and the formation of the cubic BN phase are often associated with large compressive stress. Therefore, measurements of stress and stress evolution dependent on deposition and ion irradiation conditions are important. Highly accurate and sensitive in-situ stress measurements were used to study the evolution of the stress during the N/Ar ion beam assisted deposition of BN-films. The c-BN content was determined by FTIR spectroscopy and the layered structure of the BN films by spectral ellipsometry and high-resolution transmission electron microscopy. The stress evolution is investigated in dependence on ion energy ($<$ 600 eV), substrate temperature ($<$ 400 °C) and ion-to-atom ratio. The influence of additional irradiation of UV-light on the stress relaxation is demonstrated. High tensile stress in the initial stage of the film growth, development of the compressive stress versus the film thickness and the relation between the stress and the c-BN content are discussed. A simple model is presented to predict the evolution of the stress during the film growth under simultaneous low-energy ion bombardment by a balance between the defect generation by ion bombardment and the defect annihilation stimulated by temperature during film deposition. It is assumed that the displaced atoms are responsible for the stress formation, i.e. the total number of displaced atoms corresponds to the build-up of compressive stress. The induced compressive stress is reduced by the temperature-dependent thermal diffusion, especially. The theoretically determined stress evolution is compared with results of in-situ measurements of the stress.

L4.15
MODIFICATION OF METAL SURFACE MORPHOLOGY AND STRUCTURE DUE TO LONG-TERM BOMBARDMENT WITH KEV ENERGY RANGE DEUTERIUM IONS. Vladimir G. Konovalov, Anatoli F. Shtan', Anatoli N. Shapoval, Sergei I. Solodovchenko, Vladimir S. Voitsenya, IPP NSC Kharkov Institute of Physics and Technology, Kharkov, UKRAINE; Vasily T. Gritsyna, Kharkov State University, Kharkov, UKRAINE; Alexandra F. Bardamid, Konstantin I. Yakimov, Taras Shevchenko Kiev University, Kiev, UKRAINE; Dorian V. Orlinskij, RRC Kurchatov Institute, Moscow, RUSSIA.

This paper presents results of experiments stimulating the fusion reactor (FR) environment effects on surface of in-vessel metal mirrors. These mirrors being plasma facing elements of diagnostic schemes will be exposed to different kinds of radiation. The most serious consequences will be due to bombardment with charge exchange atoms, CXA, (i.e., deuterons and tritons) of a very wide energy distribution, from tens eV up to many thousands keV. These atoms not only will sputter the mirror surface but will produce also different kinds of defects rather deeply in the near-surface layer. We compared the rate of degradation of mirrors fabricated of different metals (Be, Al, SS, Cu, Mo, Ta, W) and different crystalline structure (polycrystals, single crystals, metal film on metal substrate) when they were long-term bombarded with fixed or energy-spreaded (0.1-1.5 keV) ions of deuterium (or hydrogen) plasma. The surface morphology and structure were investigated with SEM and TEM, respectively, and reflectance at normal incidence was measured in the wavelength range 250-650 nm. There was observed that the rate of morphology change and reflectance deterioration rate depend strongly not only on the material itself and its crystalline structure but on the ion energy as well. The polycrystalline mirror became to have the step structure soon after beginning ion bombardment because of difference in sputter rate of grades with different orientation of crystalline planes. For two metals (polycrystalline copper and stainless steel), with thickness of sputtered layer as a parameter, the mean surface roughness increased with increasing ion energy. The step structure was not found on mirrors made of single crystal materials (W, Mo) and on film mirrors (Cu film on Cu, Be film on Cu, Rh film on Cu), but small holes of etching were observed which did not influence strongly the specular reflectance. Comparing SEM and TEM photos and reflectance of SS mirrors exposed to different energy ions it was concluded that reflectance can degrade not only due to increasing the surface roughness (as a result of long-term sputtering) but also because of changing the optical properties of metal due to evolution of defects (as a result of gradual accumulation of hydrogen isotopes in a near surface layer).

L4.16
ENHANCEMENT IN THE GROWTH OF TEXTURED HFCVD DIAMOND COATINGS ON MODIFIED Ti-6Al-4V SUBSTRATE BY EXCIMER LASER PROCESSING. Mikhail T. Galeev, M. Vedawyas, G. Sivanathan and Ashok Kumar Department of Electrical and Computer Engineering, University of South Alabama, Mobile, AL.

For a number of reasons, high quality diamond coatings are difficult to achieve on metal surfaces. In this work we address, the studies of enhancement in diamond growth on Ti-6Al-4V metal alloy by modifying the surface using the excimer laser ablation, prior to deposition of diamond by hot filament chemical vapor deposition method. Ti-6Al-4V substrate is chosen for its technological importance in aerospace industry, dental and bio-implant applications. Analysis of the structures of the film is done using x-ray diffraction, scanning electron microscopy and Raman spectroscopy. Ablation of the alloy by excimer laser pulses produces periodically hill/valley structures on the surface, thus increasing the density of diamond nucleation and film adhesion. The roughness of the alloy surface was measured to be in the 0.5mm - 1mm range with an average distance between peaks of the hill/valley structure measuring 1.5mm. The detailed processing parameters will be discussed to get the high quality textured diamond films on metal substrates This research was supported by Alabama NASA EPSCoR program.

L4.17
DEPOSITION OF CUBIC SiC THIN FILMS ON Si (111) USING MOLECULAR ION BEAM TECHNIQUE. Takashi Matsumoto, Kazuhiko Mimoto, Masato Kiuchi* and Seiichi Goto, Osaka Univ, Graduate School of Engineering, Plasma Physics Laboratory, Osaka, JAPAN, *Osaka National Research Inst, Osaka, JAPAN.

Cubic SiC thin films were formed on Si (111) substrates at temperature of 750-1000 °C using a molecular ion beam deposition technique with a precursor of dimetylsilane. CH_3Si^+ ions, generated from dimetylsilane $(CH_3)_2SiH_2$, were deposited on Si (111) substrates by a low-energy mass-selected ion beam deposition apparatus. As the ions have a stoichimetric ratio of Si/C and a dipole moment, a deposition of these ions is effective for the formation of SiC. The energy distributions of the ions were measured by a plasma process monitor with a cylindrical mirror analyzer (CMA) and a quadrupole mass spectrometer (QMS). The ions were transported at 25 keV and decelerated to 100 eV. In spite of the serial beam handling and fragmentation processes, the energy spread was very small ($\pm$1 eV). The chemical bond and the orientation of the deposited films were analyzed by Raman spectroscopy and reflection high-energy electron diffraction (RHEED). The Raman spectra of the films exhibit a peak at 800 cm^{-1} assigned to transverse optic (TO) phonon scattering of 3C-SiC, and a sharp peak at 510 cm^{-1} associated with the Si substrates. The RHEED patterns of the films exhibit the crystal lattice of 3C-SiC (111). The patterns were observed both the streaks and the spots. In conclusion, using a molecular ion beam deposition technique with a precursor of dimetylsilane, the formation of 3C-SiC (111) films is available on Si (111) substrates at very low temperature (750 °C).

L4.18

ECR PLASMA OXIDATION: DEPENDENCE ON ENERGY OF ARGON ION. S. Matsuo, M. Yamamoto, T. Sadoh, T. Tsurushima, *D. W. Gao, *K. Furukawa, *H. Nakashima, Kyushu Univ, Dept of Electronic Device Engineering, *Advanced Science and Technology Center for Cooperative Research, Fukuoka, JAPAN.

Effects of ion-irradiation on growth kinetics and electrical characteristics of silicon dioxide films formed at low temperatures (130°C) in argon and oxygen plasmas excited by electron cyclotron resonance (ECR) interaction were investigated. First, dependences of ion energy and flux of irradiated ions on the flow rate of argon and the microwave power were evaluated. It was shown that the total flow rate and the microwave power were key parameters for controlling the energy and the flux of irradiated ions, respectively. Second, growth kinetics of the oxide film was studied, and it was shown that the growth rate depended on the energy and the flux of incident argon ions to the silicon substrate, and the growth thickness increased proportionally to the root square of the oxidation time. Thus, the growth rate is limited by diffusion of oxidants enhanced by irradiation with argon ions. The electrical properties of the oxide films were improved by increasing the flow rate of argon and reducing the microwave power. On the basis of the dependences of the energy and the flux of argon ions on the gas pressure and the microwave power, it was concluded that reduction of the energy and the flux of argon ions was essential to improve the quality of the oxide films. The improvement is due to the reduction of damages on the surface of the substrate induced by the irradiation with ions at the initial stage of oxidation. We will show the effect of substrate bias on electrical properties of the grown oxide films.

L4.19

LAYER SPLITTING BY H-ION IMPLANTATION IN SILICON: LOWER LIMIT ON LAYER THICKNESS? Chao Qian and Bernard Terreault, INRS-Énergie et Matériaux, Université du Québec, CANADA.

The Smart-Cut^{TM} Silicon-On-Insulator process and its variants involve H and/or He ion implantation and annealing to neatly exfoliate a lyer of material as thin as the ion range. At the low implant energies (∼5 keV) reqired for layers <100 nm thick, several effects may compromise the process; one attractive recipe developed at ≥30 keV failed at 10 keV in an early test. We implanted undoped Si (100), (110) and (111) with 5 keV H or D ions at doses below (3-4x10^{160}/cm^2) or above (5.5x10^{16}/cm^2) the critical dose. H-implants were isochronally annealed in vacuum in three steps at 500°C for 60 min, 550°C for 120 min and 600°C for 120 min. D-implants were subjected to thermal desorption spectroscopy (TDS) with linear ramps of 7.5 K/min up to 500°C, 550°C and 600°C. Layer exfoliation (blistering) was observed by scanning electron microscopy (SEM). TDS of D-implants showed that the high dose samples had a low temperature peak (∼350°C), weak in the case of (110) samples, and a high temperature peak (∼550°)C); the low dose implants had a high temperature peak only. SEM of high dose samples showed the exfoliated area increasing with temperature, from 32% at 500°C to 50% at 600°C for Si (110), from 50% to 66% for Si (111), with Si (100) in between. H-implants showed little difference between the (111) and (100) samples, the exfoliated area being 45-55%, at any temperature. The (110) samples wrere only weakly exfoliated (7% at 500°C, 18% at 600°C). This is attributed to H ion channelling, a strong effect in the <110> direction at low energy (profile width approximately doubled); D channelling is less pronounced due to the larger energy transfer to Si atoms in elastic collisions.

L4.20

STUDY OF STRAIN RELAXATION IN EPITAXIAL STRUCTURE $Ge_{0.2}Si_{0.8}$/Si AT THERMO-IMPLANTATION TREATMENT BY ION BEAM CHANNELING. A.F. Vyatkin, V.K. Egorov, IPMT RAS, Chernogolovka, Moscow Dist., RUSSIA; E.V. Egorov, Metal Phys. Dept., Moscow Engineering Phys. Institute, Moscow, RUSSIA.

The reconstruction of the strain epitaxial structure $Ge_{0.2}Si_{0.8}$ (95 nm)/Si [100] by the action of thermo-implantation treatment are studied. The targets have been exposed to irradiation by ion beam Si^+ (E_o=200 keV) with total dose (4-8)*10^{13} ion/cm^2 at the temperature T_1=230°C. The goal of the investigation was to find the condition of the dislocationless relaxation of the strain state in the structure. The targets were prepared from P-type high resistance Si[100] with 0.5 mkm buffer sublayer by Low Temperature Molecular Beam Epitaxy at T_o=400°C. The relaxation mechanism of the strain was studied by RBS spectra at ion He^+ (E_o=0.98 MeV) beam channeling aligned [100] and [110] crystallographic directions. There was registrated that the thermo-implantation treatment with dose D≈6*10^{13} ion/cm^2 leads to formation of the dislocationless strainless structure with disorientation of [110] direction in Ge-Si film and Si substrate near 0.15° at preservation of the conformity along [100] axis. It is proposed that the dislocationless structure organized in consequence of the energy advantage of point defect generation.

L4.21

A MOLECULAR DYNAMICS STUDY OF ION-INDUCED DEFECTS IN A SILICON STEPPED SURFACE. A.M. Mazzone, C.N.R.-Istituto LAMEL, Bologna, ITALY.

Low-energy ion bombardment is a common technique used in many thin film applications. Ripples,bumps and cones are common effects of these implants and have been observed in amorphous materials, in metals and in germanium and silicon. The analysis of surface rippling indicates that there is a fundamental ambiguity on the role of implants as it is not clear if the impinging ions remove atoms or stimulate the growth of hillocks.
The purpose of this study is to investigate on the genesis of these phenomena by using computer simulations of the type molecular dynamics. A low energy displacement cascade (E_k ≤10eV) is generated on a silicon stepped surface and the evolution of the irradiated region is simulated with classical molecular dynamics using standard three-body potentials. Two main types of defects have been found. These are vacancies, generated by sputtering of dimers and of second layer atoms, and interplanar interstitials due to a transplantation of third layer atoms.
We analyze if the cascade shape shows some local dependence and if typical patterns arise from cascades launched near the step edge, or on the terraces. Furthermore we discuss if binding sites,similar to the ones contributing to film growth, are to be found on the path of the cascade atoms.

L4.22

GROWTH OF METAL NUCLEUS ON POLYIMIDE SURFACE WITH PHOTOCHEMICAL REACTION. Masaaki Tomita, M. Murahara, Faculty of Engineering, Tokai University, Kanagawa, JAPAN.

All aromatic group polyimide has advantages, which are chemical resistance and heat resistance than other plastics. Unfortunately, it is very difficult to have surface modification, because of these advanced properties. Laser-ablation and plasma treatment to modify the surface of polyimide are reported. There are known method to modify the surface of the plastics. We have been focused on photochemical treatment method using UV light source. We are interested in using all aromatic group polyimide, which is advanced in heat resistance rather than thermo-hardening polyimide. We succeeded to find a method to have Cu thin-film on the surface of all aromatic group polyimide using photochemical surface modification. This process is purely chemical binding Cu or Ni and Polyimide surface. Explain the experimental set up. $CuSO_4$ solution or $NiSO_4$ solution was applied to a polyimide surface and covered with a fused silica glass to make a thin liquid layer of the solution with capillary phenomena. The circuit patterned ArF excimer laser light which was homogenized were vertically irradiated on the surface through the window, the polyimide film and the thin layer. The experimental conditions were as follow; in the ArF laser fluence was 26-32mJ/cm^2, the ArF laser shot was 1, the concentration of $CuSO_4$ solution set up 0.25-1.4% and the thickness of the layer solution about 50μm. These treated samples were measured by ATR-FTIR spectrometer. As a result the peak of C=O decreased less than non-treated surface. I consider that double bonds of C and O were photodissociated and the copper atom was composed of C-O-Cu bonds. After that, photo-modified polyimide was immersed in an electoroless plating solution keeping temperature at 70Åand plating time was 30 minute. The Cu grow on the Cu metal film grow on the Cu or Ni nuclei by the electroless plating method.

L4.23

ELECTRON BEAM INDUCED PATTERN FORMATION BY SELF-DEWETTING OF METALLIC SURFACES. A.N. Roviglione, N. Mingolo, Y. Cesa and O.E. Martìnez, Universidad de Buenos Aires, Buenos Aires, ARGENTINA.

In this work the experimental evidence of self-dewetting of metallic surfaces is presented. Metallic alloy surfaces are melted by a pulsed electron gun and the subsequent fast cooling against its substrate gives rise to the formation of characteristic patterns that we attribute to the dewetting of the liquid film. Previous works have reported dewetting of metallic films deposited over dielectric substrates but this is the first time to our knowledge that it is observed that a material will tend to dewet from a substrate of the same composition. The patterns formed are similar to those obtained by spinodal dewetting, that is, when the dewetting action develops from a nonlinear instability on the liquid surface, although holes nucleation and coalescence could also be present.

L4.24
X-RAY STANDING WAVE ASSISTED DEPOSITION AND CRYSTAL GROWTH (XSWDG). Dirk C. Meyer, Peter Paufler, TU Dresden, Institut for Crystallography & Solid State Physics, Dresden, GERMANY.

We suggest a procedure for layer deposition and crystal growth to influence crystallographic parameters of the products on atomic scale. This procedure is characterised by the fact that during layer deposition or crystal growth on base of a number of different well-known procedures the formation of layer and crystal structure is affected by a superposition of X-ray standing wave fields, which are produced in an appropriate way and interact with the layer or crystal ranges in forming (German patent application DE 19726766.1 (1997)). This is what we suggest to call X-ray standing wave assisted deposition and crystal growth (XSWDG). The periodic local density distributions of energy of these X-ray standing wave fields can be constituted corresponding to interatomic distances of a desired crystallographic structure. Thereby, for instance, photo-fragmentation of precursor gases can be supported at definite lattice sites at the surface of substrates by suitable positioning of the X-ray standing wave field with respect to its orientation. In certain cases also a local distribution of the probability of desorption can be favourable to remove atoms from unwanted adsorption sites. A large number of growth processes is conceivable, which can be affected purposefully by a periodic energy distribution. Generally we want to point out that by this procedure non-thermal energy contributions are made available locally at the sub-nanometer range by which also a structuring on this scale can become possible. We discuss the base of production and application of such X-ray standing wave fields regarding the suggested procedure and show the results of theoretical computations of resulting periodic energy distributions on atomic scale at the example of typical materials.

L4.25
INVESTIGATION OF ELECTRONIC SURFACE STATES AND ITS CORRELATION TO SURFACE MODIFICATIONS IN FEMTOSECOND UV LASER TREATED n(100) GaAs T.A. Railkar, A.P. Malshe, and W.D. Brown*, Materials and Manufacturing Research Laboratory (MRL), Department of Mechanical Engineering, *Department of Electrical Engineering, University of Arkansas, Fayetteville AR; S.S. Hullavarad and S.V. Bhoraskar, Materials Research Laboratory, Department of Physics, University of Pune, Pune, INDIA.

Gallium arsenide (GaAs) is one of the most important materials among the III-V family, especially in view of its applicability to high-speed and optoelectronic devices. In this work, we have exposed crystalline n(100) GaAs surface to femtosecond (fs) excimer laser (wavelength, λ = 248 nm and pulse width, $t_p \sim$380 fs). Thermally stimulated exoelectron emission (TSEE) has detected the electronically active defect states introduced at the surface. The defect states have been correlated to the surface morphology as observed by scanning electron microscopy (SEM) and atomic force microscopy (AFM) and to the surface chemistry, by x-ray photoelectron spectroscopy (XPS) measurements. The effect of these defect states and of the laser treatment on device performance is discussed in the paper.

SESSION L5: ENERGETIC BEAM EFFECTS ON FILM GROWTH I

Chairs: Douglas H. Lowndes and Ramana M.V. Murty
Wednesday Morning, December 1, 1999
Salon H/I (M)

8:30 AM *L5.1
IMPORTANCE OF PURITY AND ION BOMBARDING ENERGY IN ION BEAM PROCESSES: CASES OF HIGH CORROSION RESISTANT Fe-IBD FILM FORMATION AND SEMICONDUCTING BETA-$FeSi_2$ ION BEAM SYNTHESIS. Kiyoshi Miyake, Dept. of Environmental Sci. & Human Eng, Saitama Univ. Urawa, JAPAN; Kenya Ohashi, Hitachi Research Laboratory, Hitachi Ltd, Hitachi, JAPAN; Yoshihito Maeda, Dept. of Materials Sciences, Osaka Pref. Univ, Sakai, JAPAN.

Ion beam processes have been developed during the last three decades in many industrial application fields. However, reasonable understanding and explanation of their processes have not yet been satisfactory. Firstly we show an importance of high purity and less damage layer information is essential in a case of high corrosion resistance Fe film formation by IBD (ion beam deposition). Mass-separated Fe ion bean was directly deposited on Si surface after deceleration from 20 keV to 50 eV. Higher ion energy (100 eV) bombardment resulted in poorer corrosion resistance compared with the 50 eV case in spite of the same order purity. Possible causes of this difference will be discussed. Then, we present a use of highly damaged continuous layer caused by triple ion implantation for forming large grained semiconducting beta-$FeSi_2$ crystals. Recently this material has been intensively studied in Japan as a candidate of Kankyo-Semiconductors, which are defined as ecologically friendly semiconducting materials and resource-stable materials. Some typical electrical properties of our beta-$FeSi_2$ will be presented.

9:00 AM L5.2
LOW ENERGY ION BEAM ASSISTED VAPOR DEPOSITION. Xiaowang Zhou, Haydn N. G. Wadley, Univ., of Virginia, Charlottesville, VA.

Advanced thin film materials such as giant magnetoresistive (GMR) multilayers require a minimization of surface roughness and chemical mixing during multielement deposition. Ion beam assistance can be easily implemented to modify surface roughness. However, traditional ion beam assistance based on ion energies above 50.0 eV is likely to cause chemical mixing during multilayer deposition due to an impact induced atomic exchange. Molecular dynamics method has been used to explore lower energy (below 20 eV) Ar- and Xe- ion assisted deposition of model Ni/Cu/Ni multilayers. The study revealed that as the ion to metal ratio exceeds about 2, ion impact probability is sufficiently high and the low ion energy induced local reconstruction of atomic clusters can result in the flattening of the surface. Low ion energies ($\sim$ 3 eV) are sufficient to flatten the relatively weakly bonded copper surfaces, and much higher ion energies (> 10 eV) are required to flatten the relatively strongly bonded nickel surface. Intermixing becomes significant at high ion energies, and its degree depends on the binding energy of the underlying materials. Significant mixing occurs at 9 eV ion energy during deposition of nickel on copper, but the mixing is negligible even at a higher ion energy of 12 eV during deposition of copper on nickel. The heavier Xe+ ions deposit a higher fraction of energy to the surface and hence generate more flattening effects. A modulated ion energy strategy in which the ion beam energy is reduced while depositing the first few monolayers of each new metal layer was found to successfully reduce both interfacial roughness and intermixing.

9:15 AM L5.3
THE EFFECT OF LOW-ENERGY NITROGEN IONS ON THE GROWTH MODES OF NITRIDES ON POYLMERS USED IN THE MICROELECTRONICS INDUSTRY. Peter Abramowitz, Michael Kiene, Paul Ho, University of Texas at Austin, Dept of Physics, Austin, TX.

The microelectronics industry needs to grow ultra-thin nitride layers on polymers to act as a diffusion or 'barrier' layer for the copper wiring. The barrier layers are generally titanium or tantalum nitride, and a homogeneous and amorphous layer only a few monolayers thick is sufficient to prevent diffusion. However, growing such a thin continuous material on a polymer is not achievable by standard reactive evaporation or RF-sputtering techniques. Low-energy ion deposition allows an opportuinity to understand what mechanisms influence the growth of these nitrides at the surface of the polymer. Our group has used in situ x-ray photoemission and ex situ transmission electron microscopy studies to examine the formation of nitrides grown in an ultra-high vacuum environment on top of a few industrially relevant polymers. The nitrides are grown by e-beam evaporating the metal, and concurrently bombarding the surface with nitrogen ions in the energy range of 100-1000eV. We have found that a low-energy ion beam alters the growth mode in a variety of ways. Not only can it break the initial metal/polymer bonds, but also it disrupts the initial polymer surface by breaking up the monomer units and implanting nitrogen into the polymer. However, the use of an ion beam allows the growth of a more uniform nitride layer that scales with ion energy. The changes in adhesion and microstructure from the use of an ion beam will also be discussed.

9:30 AM L5.4
MODELING Cu THIN FILM GROWTH UNDER IPVD CONDITIONS USING MOLECULAR DYNAMICS RATES IN A LEVEL SET APPROACH. Uwe Hansen[1,2], Seth Rodgers[2], Maria Nemirovskaya[2] and Klavs F. Jensen[2]; [1]Physik-Department and Walter Schottky Institut, Technische Universität München, [2]Department of Chemical Engineering, Massachusetts Institute of Technology Cambridge, MA.

In the near future the typical size of trenches and vias will be only some hundred lattice constants. Thus accurate simulations based on atomic level infomations is becoming increasingly useful. We present results of detailed molecular dynamics calculations elucidating the reactions taking place during Cu ionized physical vapor deposition. The data obtained at the atomic level is then used in a level-set approach to bridge the gap between the atomic and feature scale. We study the effect of beam collimation and beam energy on the resulting thin film morphologies and discuss the role of the dominant surface reactions leading to the predicted film topographies.

10:15 AM *L5.5
TIME-RESOLVED X-RAY SCATTERING STUDIES OF GaN NUCLEATION AND GROWTH WITH PLASMA-ASSISTED MBE. R.L. Headrick Cornell High Energy Synchrotron Source, Cornell University, Ithaca, NY; A.R. Woll, J.D. Brock, Dept of Applied and Engineering Physics, Cornell University, Ithaca, NY.

We have found that the use of a nitrogen plasma source in place of thermal ammonia dramatically changes the nucleation of GaN onto a variety of substrates. Using x-ray scattering techniques, we have studied the nucleation of GaN onto sapphire (0001) in detail. The results show a complex behavior. At least two different nitridation layers can be formed on sapphire during exposure to the plasma, which have an effect on the nucleation and strain relaxation of the GaN film. The x-ray scattering results during nucleation of GaN show evidence for a large barrier for interlayer transport. Both a 2D multilevel growth mode and a 2D plus island growth mode have been observed under different growth conditions. In contrast, use of thermal ammonia instead of the plasma source results in a 3D growth mode with no wetting layer. Finally, a significant difference in growth rate and morphology are observed for plasma-assisted growth relative to growth from thermal ammonia. Models will be presented to explain these results in terms of enhanced reactivity, nucleation rate, and gallium desorption caused by the low-energy nitrogen ions and radicals from the plasma source.

10:45 AM L5.6
STUDY OF LOW-ENERGY ION ASSISTED EPITAXY OF GaN FILMS: INFLUENCE OF THE INITIAL GROWTH RATE. J.W. Gerlach, D. Schrupp, R. Schwertberger, B. Rauschenbach, Universität Augsburg, Institut für Physik, Augsburg, GERMANY; A. Anders, Lawrence Berkeley National Laboratory, University of California, Berkeley, CA.

Although much research has been done on deposition techniques of the wide-band gap semiconductor material gallium nitride, only few investigations exist for ion assisted deposition of thin epitaxially grown GaN films. The purpose of this study is to investigate the effect of the initial growth rate on GaN that is epitaxially grown in a nitrogen ion assisted deposition process. Films are compared that have been prepared with and without growth rate variation. GaN films were grown on sapphire by evaporation of Ga from an effusion cell and irradiation with low-energy nitrogen ions delivered by a constricted-glow discharge plasma source. The ion energy was less than 25 eV. The substrate temperature was kept constant during the whole process. In the early phase of deposition process, the ratio of gallium and nitrogen fluxes was gradually increased from a low value to an optimized value, resulting in a growth rate ramp. Further deposition was conducted with the optimized flux ratio. This optimum value was determined by post-growth analysis of the films. Crystalline structure and texture, defect depth distribution, and surface topography of the GaN films were examined by XRD, channelling-RBS, and AFM, respectively. The results show that an initial isothermal growth rate ramp improves the crystalline quality of the films. Defect production due to the lattice misfit between film and substrate, and defect propagation are considerably reduced as shown by the decrease of the minimum backscattering yield in RBS. A phase selection is observed that suppresses the formation of the cubic GaN phase in favour of the hexagonal phase. Additionally, the film surfaces are found to be much smoother when a growth rate ramp was applied. The results are discussed in terms of gallium-rich versus nitrogen-rich GaN growth taking the additional energy input into the growing film by ion irradiation into account.

11:00 AM L5.7
ION BEAM PROCESSING OF CARBON NITRIDE THIN FILMS. Richard L.C. Wu, William C. Lanter, K Systems Corporation, Beavercreek, OH; Charles DeJoseph, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH.

There has been a growing interest in recent years in thin film growth, processing, and surface treatment by low energy ion beam technology. Carbon nitride thin films (CN_x) are of particular interest for applications in tribology, wear resistance and microelectonics. A large area ultra high vacuum system using a 20 cm diameter RF excited (13.56 MHz) ion gun has been employed for the growth of carbon nitride films by two different methods: (1) Direct ion beam deposition; and (2) Ion beam sputtering deposition. In the first technique, ions (CH_3^+, N_2^+, N^+, NH_4^+, NH_3^+, NH_2^+, HCN^+, CN^+ and $N_2H_2^+$) produced by gas mixtures of nitrogen and methane discharge were directly impacted onto the substrate surface. The effects of RF power, CH_4/N_2 gas ratio, total gas flow, pressure, and ion energy on the film properties and deposition rates were studied. In the second technique, a flux of energetic nitrogen ions (N_2^+, N^+), generated by N_2 and N_2/Ar plasmas, were used to directly sputter a graphite target. The effects of RF power, gas mixture (N_2, N_2/Ar), and ion energy on the film characteristics and deposition rates were compared with those films generated by direct ion beam deposition. A variety of techniques including Rutherford back scattering, ellipsometry, resisitivity, dielectric constant, as well as coefficient of coefficient and wear life in ultra high vacuum, dry nitrogen and humid air environments were used to characterize the films.
A quadrupole mass spectrometer and a total ion current monitor were utilized to monitor the ion beam compositions during the deposition process for quality control and process optimization. The correlation between process parameters and film properties will be presented and discussed.

11:15 AM L5.8
AlN THIN FILMS PREPARED BY REACTIVE ION BEAM COATING. L.L. Cheng[1], Y.H. Yu[1,2], B. Sundaravel[2], E.Z. Luo[2], S. Lin[2], Y.M. Lei[1], C.X. Ren[1], W.Y. Cheung[2], S.P. Wong[2], J.B. Xu[2], and I.H. Wilson[2]; [1]Ion Beam Laboratory, Shanghai Institute of Metallurgy, Chinese Academy of Science, Shanghai, CHINA; [2]Materials Science and Technology Research Center and Department of Electronic Engineering, The Chinese University of Hong Kong, Hong Kong, CHINA.

Aluminum Nitride (AlN) is a promising material for a variety of technological applications because it has many exceptional properties, such as wide band gap (WBG), negative electron affinity (NEA). The properties of the AlN thin films may be a function of the preparation conditions: nitrogen concentration in the gas mixture, the plasma energy and the incidence angle. We use the non-Rutherford backscattering (NBS) results to analyze the composition of the AlN thin films. On the other hand, we use X-Ray Diffraction (XRD), Atomic Force Microscopy (AFM) to study the structural and morphological properties of the AlN thin films. We succeeded in finding the optimum conditions to prepare smooth, nearly stoichiometric AlN thin films with high qualities.

11:30 AM L5.9
SYNTHESIS OF SiC ON Si BY SEEDED SUPERSONIC BEAMS OF FULLERENES. Giuseppe Ciullo, Tullio Toccoli, Salvatore Iannotta, CeFSA, CNR/ITC Research Center on the Aggregates Physics, Povo di Trento, ITALY; Paolo Milani, Alessandro Podesta, INFM, Milano ITALY; Stefano Gialanella, Dipartimento di Ingegneria dei Materiali, Universita di Trento, ITALY.

Despite the attracting features that make SiC ideal for high power, high frequency and hostile environments microelectronics, its use suffers of presents limitations inherent in its growth and in the synthesis of high quality crystalline films. As experimentally shown in hetero-epitaxial growth, precursor concentrations and substrate temperatures play an important role on the film morphology. Recently C_{60} has been proposed as precursor to lower reaction temperatures down to 850-950°C [1] and some groups carried out further experiments to have deeper insight on the carbidization and growing processes [2]. It is now recognized that a good control on substrate surface and precursor concentration is required. In this framework we developed an approach based on a supersonic beam of fullerene that allows a fine control on beam kinetic energy, up to tens of eV, and its dispersion, as well as on flux distributions. This is achieved thanks to our hyper-thermal supersonic beam (HSB) source[3]. The film synthesis is performed in a UHV environment under well-controlled beam conditions and substrate temperatures. The growing process is investigated and monitored in situ by means of different electron spectroscopies for elemental and morphological analysis and of LEED to qualify the crystallinity of the SiC layers during growth. Afterwards higher resolved analysis (SEM, AFM and TEM) are performed ex-situ. A direct evidence of dependence on beam parameters has been observed showing different morphologies and a wide range of ordering that can be controlled by deposition parameters. The observed lowering of temperature of the synthesis, due to the activation of the process by the kinetic energy of the beam, can be used to improve film quality.
[1] A.V. Hamza et al., Surf. Sci. 317 (1994) L1129. [2] C.-W. Hu et al., Appl. Phys. Lett. 68 (1996) 1253. [3] F. Biasioli et al., Chem. Phys. Lett. 270 (1997) 115.

11:45 AM L5.10
A COMPARISON BETWEEN THE CALCULATED AND EXPERIMENTAL EFFECTS OF ENHANCED PRECURSOR TRANSLATIONAL KINETIC ENERGY ON SiC GROWTH ON Si(100) AND (111) FROM HEXAMETHYLDISILANE. D.W. Beck, Q. Li, M.E. Kordesch, Department of Physics and Astronomy, Ohio University, Athens, OH.

Silicon carbide thin films were grown on Si(100) and (111) substrates at 1050 C using a pulsed supersonic beam of hexamethyldisilane (HMDS) in hydrogen. X-ray diffraction analysis shows that these films contain only the 3C cubic polytype, determined mainly by the (111) SiC peak at $2\theta = 35.6°$, the (200) SiC peak at $2\theta = 41.4°$, and the (220) SiC peak at $2\theta = 60.0°$. The silicon substrates were heated directly by means of a DC current through the substrate. The temperature was monitored with an optical pyrometer. The angle of incidence of the HMDS/hydrogen beam could be varied through an angle of 0 to 90° without displacing the specimen from the focal point of the beam. On Si(111), in order to monitor the growth texture of the films, the ratio of the (111)SiC to (220)SiC peak was measured for HMDS incidence angles of 0, 30, 45, and 60°. On Si(100) the SiC(111)/(200) ratio was monitored. The velocity of the incident HMDS molecules parallel to the surface can be increased by about a factor of 8 at the highest glancing angle. In this way, the effect of translational kinetic energy enhancement on growth can be examined. On Si(111), no significant effects were observed for the (111)/(220) peak ratio; some variation was observed for Si(100). Comparison with the molecular dynamics simulation of SiC homoepitaxy with supersonic molecular beams by Alfonso and Ulloa (APL 74 (1999) 55) will be made with our results, and aspects of the film morphology as observed with SEM and AFM, due to the angular variation of the incident beam, will be presented.

SESSION L6: ENERGETIC BEAM EFFECTS ON FILM GROWTH II

Chairs: Randy L. Headdrick and Kiyoshi Miyake
Wednesday Afternoon, December 1, 1999
Salon H/I (M)

1:30 PM *L6.1
CARBON FILMS DEPOSITED FROM CONTROLLED-LOW-ENERGY PULSED-LASER ABLATION AND METAL-ION BEAMS.
Douglas H. Lowndes[1], Vladimir I. Merkulov[1], L.R. Baylor[2], G.E. Jellison Jr.[1] and D.B. Poker[1], Oak Ridge National Laboratory, Oak Ridge, TN; Steven Kim and M.H. Sohn, SKION Corporation, Hoboken, NJ; and N.W. Paik, Physics and Engineering Physics Department, Stevens Institute of Technology, Hoboken, NJ. [1] Solid State Division [2] Fusion Energy Division.

Carbon films with variable sp^3-bonding fraction were deposited on n-type Si substrates by ArF (193 nm) pulsed-laser ablation (PLA) of a pyrolytic graphite target, and by direct metal ion beam deposition (DMIBD) using a primary Cs^+ beam to generate the secondary C^- deposition beam. The kinetic energy (KE) of the incident C atoms/ions was controlled and varied over the range from ~25 eV to ~175 eV. Earlier studies have shown that C films' sp^3-bonding fraction and diamond-like properties can be maximized near the center of this KE range. The PLA films are undoped while the DMIBD films are doped with Cs. The films' surface morphology, optical properties (Tauc energy gap), sp^3-bonding fraction, and Cs-content were determined as a function of KE using atomic force microscopy, spectroscopic ellipsometry, TEM/EELS and Rutherford backscattering measurements, respectively. Their electron field emission (FE) characteristics were measured using ~5 μm and ~25 μm diameter probes that were scanned with ~75 nm resolution in the x-, y-, and z-directions, in a vacuum chamber (~5 x 10^-7 torr base pressure) equipped with a video camera for viewing. FE from these very smooth doped and undoped films is compared and contrasted with FE from deliberately nanostructured carbon-based materials, including hot-filament chemical vapor deposition (HF-CVD) carbon films and carbon nanotubes grown by plasma-enhanced CVD. The effect of the scanned-probe diameter on FE measurements also is considered. The principal interests in this work are energetic-beam control of carbon-film properties and the roles of doping and surface morphology in FE. Models for the growth of both smooth and highly nanostructured carbon surfaces are briefly described. This research was sponsored by the Oak Ridge National Laboratory (ORNL), managed by Lockheed Martin Energy Research Corp. for the U.S. Dept. of Energy, under contract DE-AC05-96OR22464, and was partially supported by the Defense Advanced Research Projects Agency contract DARPA-MIPR-97-1357 with ORNL.

2:00 PM L6.2
INTERBAND ELECTRONIC EXCITATION-ASSISTED ATOMIC-SCALE RESTRUCTURING OF METAL SURFACES BY NANOSECOND PULSED LASER LIGHT.
Fabrice Charra, Ludovic Douillard, Hans-Joachim Ernst, CEA Saclay, DSM / Drecam / Srsim, Gif Sur Yvette, FRANCE.

Light absorbed by metals is usually transformed into heat within a few picoseconds because electronic excitations are short lived and delocalized. Structural changes on metal surfaces induced by light, often irreversible, have therefore been linked to temperature-induced melting or thermomechanical strain. It is shown that Cu single crystal surfaces can be patterned by laser light. Despite the low-temperature rise associated with the total energy put into the system, irradiation with green light produces adatoms and vacancies, which self-organize into nanoscale pyramids. This restructuring can be removed by annealing. In contrast to green light, infrared laser irradiation at equivalent absorbed energy density does not produce any structural change. The green light must therefore excite a long-lived, spatially localized electronic state that couples with nuclear motion, whereas this state is not accessible for infrared light.

2:15 PM L6.3
Abstract Withdrawn.

2:30 PM L6.4
CONTROLLING THE DIAMOND FILM MORPHOLOGY AND INTRINSIC STRESS BY LOW-ENERGY ELECTRON BOMBARDMENT.
Juan A. Gonzalez, O.L. Figueroa, University of Puerto Rico, Dept. of Physics; B.R. Weiner, University of Puerto Rico, Dept. of Chemistry; G. Morell, University of Puerto Rico, Dept. of Physical Sciences; Rio Piedras, PR.

We have studied the effects of low-energy electron bombardment over the microstructure of diamond thin films. In situ spectroscopic ellipsometry measurements were correlated with ex situ Raman, SEM, and XRD measurements in order to elucidate the mechanisms leading to the observed microstructural modifications. We have also employed the in situ ellipsometric measurements to monitor the film evolution from nuclei formation to film formation. This allowed us to start the electron bombardment at different points during the film deposition process and assess the bombardment effects over the various films formation stages. It was found that electron bombardment improve the film formation process and reduce the intrinsic stress provided it is kept at low energy values and is started only in the particle growth stage after nuclei formation. This parameter window leading to beneficial effects for diamond film deposition is rather narrow. However, if the purpose is to grow nanocrystalline diamond, a wider range of electron bombardment energies can be employed.

3:15 PM L6.5
SURFACE ROUGHNESS MEASUREMENTS OF FILMS GROWN USING HYPERTHERMAL Cu+ ON Cu(111).
J. Pomeroy, A. Couture, M.V. Murty[1], J. Jacobsen[2], J.P. Sethna, B.H. Cooper, Cornell Center for Materials Research, Cornell University, Ithaca, NY; [1]currently with Argonne National Laboratory, [2]currently with Haldor Topsöe, DENMARK.

The surface roughness of films grown by direct hyperthermal copper ion deposition on a Cu(111) crystal are compared with results from a hybrid kinetic Monte Carlo and molecular dynamics simulation (KMC/MD). The Cu+ ion beam energy is tunable from a few eV to greater than 1 keV with a FWHM of 3 eV in the region of interest. Surface roughness is measured using reflection high energy electron diffraction (RHEED) in the anti-phase scattering condition. At 80 K the simulation predicts that growth proceeds in a layer-by-layer manner within a narrow ion energy window near 25 eV, and that rough three dimensional growth results from using energies on either side of this window (Jacobsen, et. al. PRB **58** 23, 1998.) Films grown using this energy selected ion source will contribute to an understanding of how deposition energy influences surface roughness in an energy range relevant to sputter deposition.
Supported by CCMR (NSF-DMR-9632275) and AFOSR (F49620-97-1-0020).

3:30 PM L6.6
ACCELERATED MOLECULAR DYNAMICS SIMULATIONS OF THIN FILM DEPOSITION.
Timothy C. Germann and Arthur F. Voter, Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM.

Until now, most simulations of epitaxial surface growth have relied on one of two techniques: molecular dynamics (MD) or kinetic Monte Carlo (KMC). While MD is exact (for a given empirical potential energy function), its timescale is limited by the atomic vibrational period (femtoseconds), so that simulations as long as 1 μs require heroic efforts, while still falling several orders of magnitude short of typical deposition rates. On the other hand, KMC employs a tabulated "catalog" of possible diffusion events which may occur, so its timescale is determined by the fastest event in the catalog and simulation times on the order of seconds or minutes are not uncommon. However, the restriction of possible events to those in the predefined catalog raises questions about the potential importance of novel mechanisms which may have been omitted. Recently, two new methods have been introduced for accelerating the dynamics of rare events such as the diffusion processes which occur between deposition events. The first, hyperdynamics, modifies the potential energy surface by adding a bias potential in potential energy basins to accelerate the escape rate from these basins, while maintaining the correct relative escape rates for multiple channels, and allowing the elapsed time to be accumulated as a statistical property. The second,

parallel replica dynamics, involves running N independent trajectories on N processors until an event is detected on any processor, at which time all processors are notified and N new trajectories are started in the new potential basin. We will describe the combination of these two methods to study thermal and hyperthermal vapor deposition of Cu on a Cu(100) surface. Several unanticipated mechanisms have already been observed, including concerted events involving 3 or more atoms, diffusion on {111}-type microfacets, and the formation of bulk vacancies.

3:45 PM L6.7
DIRECT ION BEAM DEPOSITION OF POLY-SILICON: SIMULATION AND EXPERIMENT. Catherine E. Rice and Steven I. Kim, SKION Corporation, Hoboken, NJ; Ferdinand Orock, Stevens Inst. Of Tech., Dept. of Phys. and Eng. Phys., Hoboken, NJ.

The formation of crystalline silicon using a negative Si ion beam source has been investigated. Substrate temperature is one of the key variables in conventional CVD and PVD processes. In this work, the role of the incident kinetic energy of the Si^- beam has been investigated. In the low temperature range (from room temperature to 300°C), an amorphous phase is formed regardless of the ion beam energy. At an intermediate temperature range (350° to 450°C) partial crystallization, i.e., a mixture of crystallized and amorphous phases are observed. At higher temperature (450° to 600°C), fully crystallized silicon is obtained. Grain size was found to be dependent on ion beam energy. We will present data on the crystallization behavior of DMIBD silicon on glass substrates as a function of Si^- ion beam energy and substrate temperature. We will compare these data with the results of a molecular dynamics simulation of the Si on SiO_2 system.

4:00 PM L6.8
ION-ENHANCED SURFACE DIFFUSION: EXPERIMENT AND SIMULATION. R. Ditchfield, E.R. Blomiley, Z. Wang and E.G. Seebauer, Department of Chemical Engineering, University of Illinois, Urbana, IL.

Low-energy ion enhancement of thin film deposition has become an increasingly widespread technique for lowering growth temperatures and improving film properties. Systematic process optimization has remained difficult, however, because the beneficial effects of enhanced surface diffusion are often opposed by the deleterious effects of sputtering and ion embedding. Quantitative rate expressions for these processes are needed. We report for the first time direct quantitative measurements of low-energy (<70 eV) ion-influenced diffusion, using the Ge/Si(111) adsorption system with noble gas ions as the bombarding species. Experiments with second harmonic microscopy show two temperature regimes. Below about 750 C, only the pre-exponential factor for surface diffusion changes, rising with the square root of ion energy and mass up to a factor of about 10. These effects appear above a threshold energy of 15 eV. Above 750 C, both the activation and the prefactor decrease dramatically above an energy threshold of 25 eV. The decreases are so large that above about 850 C, the apparent ion-influenced diffusivity actually falls below the thermal value. Molecular dynamics simulations of this system show that enhanced diffusion in the low-temperature regime is dominated by increased hop lengths of adatoms due to billiard-ball-type collisions, while at high temperatures ion-induced adatom-vacancy pair formation dominates.

4:15 PM L6.9
ION IRRADIATION INDUCED CROSSLINKING EFFECTS ON MECHANICAL PROPERTIES OF PHOTORESIST FILMS. Irene T.S. Garcia, Curso de Pus-Graduaso em Cincia dos Materiais, UFRGS; D. Samios, Instituto de Quimica, UFRGS; F.C. Zawislak, J.A.H. da Jornada, Instituto de Fisica, UFRGS, Porto Alegre, BRASIL; C.E. Foerster, F.C. Serbena, Departamento de Fisica, UEPG, Ponta Grossa, PR, BRASIL; C.M. Lepienski, Departamento de Fisica, UFPR, Curitiba, PR, BRASIL.

We investigate the crosslinking process for the ion irradiated AZ1350J novolac-diazonaftoquinone photoresist. A film of 1.7 μ m was spin coated on clean silicon surface and irradiated with ions of He, Ar, I and Bi at different fluences and energies ranging from 100 keV to 4 MeV. Various techniques (RBS, NRA, ERDA, IR, Raman, SEM and nanoindentation) as well as density and solubility measurements have been used to determine the film thickness, composition, density, gel content, hardness, Young modulus, thermal stability and morphology as function of the ion beam deposited electronic and nuclear energy densities. The hardness and solubility variation with the increasing fluence of He show clearly the onset, the growing and the saturation of the crosslinking mechanism. On the other side the IR and Raman spectra and the density measurements show that for larger fluences and for heavier ions, the photoresist transforms into an amorphous carbon layer. The most efficient and effective crosslinking of the polymeric chains is obtained with an irradiation of 10^{15} $He.cm^{-2}$, depositing an average electronic energy density of $\simeq 2$ eV/Å^3 to the whole volume of the film. At this fluence the hardness and the Young modulus are respectively 12 and 6 times larger than that of the pristine film, the thermal stability is improved considerably, the gel content reaches 90% and there is no significant damage of the polymeric structure.

4:30 PM L6.10
ATOMIC STRUCTURAL CHANGES OF A Br-CHEMISORBED Si(111)-7X7 SURFACE UNDER ELECTRON-STIMULATED DESORPTION. Kozo Mochiji, Masakazu Ichikawa, Joint Research Center for Atom Technology, Angstrom Technology Partnership, Tsukuba, Ibaraki, JAPAN.

Surface structural changes by electron-stimulated desorption (ESD) have not been studied in detail. The authors therefore developed a technique to irradiate a sample by a field emission (FE) electrons from the tip of a scanning tunneling microscope (STM) [1]. This technique can perform STM observation of the FE-irradiated area by using the tip. And we used it to investigate ESD of a bromine (Br)-chemisorbed Si(111)-7x7 surface. ESD of halogen-adsorbed Si surfaces is useful as an elementary reaction in electron-beam etchings. In the previous study of STM etching, we found that Si adatoms of Br-saturated Si(111) can be etched by field evaporation at a proximity gap between the tip and the sample [2]. In the present experiment, the tip is fixed at the distance of 65 nm from the sample. Irradiation with 30-eV electrons from the tip induces various desorptions depending on the initial Br coverage. At low coverage, only Br atoms desorb, but no atomic changes occur on the Si surface. At saturation coverage, Si adatoms desorb remarkably, but Br atoms more predominantly desorb from the adatom layer. The appearance of a four-Si atom structure instead of missing adatoms after the electron irradiation shows that the position of adatoms is shifted by multiple brominations and the Br atoms are preferentially removed by ESD. The desorption behavior obtained here is distinguished from that of field evaporation or thermal desorption. And the relationship between the desorption cross section and the lifetimes of the holes produced by the irradiation is shown to be the main influence on desorption behavior. This work was partly supported by NEDO. [1] M. Shibata, Y. Nitta, K. Fujita, and M. Ichikawa, Appl. Phys. Lett. 73 (1998) 2179. [2] K. Mochiji and M. Ichikawa, Jpn. J. Appl. Phys. 38, Part2 (1999) L1.

4:45 PM L6.11
KINETICS OF SEGREGATION DURING VAPOR PHASE GROWTH. Craig B. Arnold, Jonah Erlebacher, Michael J. Aziz, Division of Enginnering and Applied Sciences, Harvard University, Cambridge, MA.

Segregation during vapor phase growth is an important consideration when one tries to grow thin films with sharp interfaces or to control the composition profile. We show that a kinetic Monte Carlo (KMC) simulation with first nearest neighbor interactions can be used to model segregation during thin film growth from the vapor. The influence of temperature, deposition rate, and surface morphology on segregation are investigated. In particular, we focus on the differences between continuous and pulsed deposition modes which is relevant to Pulsed Laser Deposition of multicomponent thin films. Our results are compared to current analytic models of segregation based on interlayer transport processes and surface diffusion mechanisms.

SESSION L7: SURFACE MORPHOLOGY EVOLUTION WITH ENERGETIC BEAMS

Chairs: David G. Cahill and Thomas W. Michely
Thursday Morning, December 2, 1999
Salon H/I (M)

8:30 AM *L7.1
MORPHOLOGY OF ION SPUTTERED SURFACES. Albert-László Barabási, University of Notre Dame, Department of Physics, Notre Dame, IN.

There is abundant experimental evidence that sputter eroded surfaces develop a ripple morphology or undergo kinetic roughening. We have recently derived a nonlinear theory that can account for both ripple formation and predict the roughening process, depending on the parameters of the bombarding process [1]. Furthermore, this theory was also able to account for low temperature ripple formation [2]. However, little is known about the effects of the nonlinear terms on the ripple morphology and ripple orientation, and the interplay between the roughening process and the ripple structure. Here we present recent results on the numerical integration of the anisotropic noisy KS equation. We show that a number of morphological phases can exist on the surface, and that many features of these phases can be predicted analytically. We also discuss the effect of the nonlinear terms on the ripple stabilization and dynamics. This research is done in collaboration with R. Cuerno, H. Jeong, B. Kahng, M. Makeev, and S. Park. [1] R. Cuerno and A.-L. Barabási, Phys. Rev. Lett. 74, 4746 (1995). [2] M.A. Makeev and A.-L. Barabási, Appl. Phys. Lett. 71, 2800 (1997).

9:00 AM L7.2
THE ROLE OF ENERGY DEPOSITION IN THE NANOMETER TOPOGRAPHY OF ION-BEAM ERODED GRAPHITE SURFACES. Sönke Habenicht, Wolfgang Bolse, Ullrich Geyer, Fabrizio Roccaforte, Carsten Ronning, Klaus-Peter Lieb, II. Physikalisches Institut, Georg-August Universität Göttingen, GERMANY.

Scanning tunneling microscopy was used to study the surface evolution of graphite (HOPG) surfaces under low energy (2-50 keV) ion beam erosion. In agreement with the theoretical concepts of Bradley and Harper [1], ripple topograpies with nanometer scale (40-700 nm) were found when the ion beam is tilted to the surface normal. For comparison between theory and experiment, the distribution of deposited ion energy into the target was calculated using Monte-Carlo simulations (TRIM) of the recoil and vacancy distribution. With the help of this concept, the angular dependency of the ripple wavelength and the critical angle θ_C of ripple rotation found in the measurements was reproduced by the theory [2]. By variation of ion mass (Ar^+0-Xe^+) and energy a detailed overview of the projectile-target kinematics has been achived and allows a distinctive insight into ion tracks and damage cascades in the solid [3]. In particular this leads to direct size determination of the collision cascade, whose results can be verified by the observation of single ion impacts on graphite. With rising ion fluence a transition in the surface evolution from the linear (Bradley, Harper) to self-affine scaling (Kardar, Parisi, Zhang) can be observed [2]. [1] R.M. Bradley and J.M.E. Harper, J. Vac. Sci. Technol. A6 (1988), 2390 [2] S. Habenicht, W. Bolse, K.P. Lieb, K. Reimann and U. Geyer, Phys. Rev. B60(4), in press [3] S. Habenicht, K.P. Lieb, W. Bolse, U. Geyer, F. Roccaforte and C. Ronning, Nucl. Instrum. Methods B, submitted

9:15 AM L7.3
Abstract Withdrawn.

10:00 AM *L7.4
FROM MAGIC SLOPE TO PHASE SEPARATION: TEMPERATURE DEPENDENT MORPHOLOGICAL EVOLUTION OF PT(111) DURING ION EROSION. Thomas Michely, I. Physics Institute, RWTH-Aachen, GERMANY.

The analysis of the morphology of Pt(111) under 1 keV Xe^+ ion bombardment for removed amounts of up to 600 monolayers exhibits an unexpected change in the surface evolution with increasing erosion temperature, namely a phase separation of the surface into a rough and a flat phase. At temperatures below 700 K pit formation with an almost perfect slope selection on the entire surface is observed. The pit formation results from a significant diffusion bias of the vacancies created, whereas no evidence for the action of a curvature dependent sputtering yield is found. At about 700 K a flat phase nucleates at the bottom of the pits due to the onset of step atom detachment. The spreading of the flat phase at the expense of the rough phase at even higher temperatures causes a qualitative change in surface morphological evolution from pit to mound formation. The phase separation together with the transition from pit to mound formation is accompanied by a change in the roughness exponent from about 0.3 to 0.6. In the entire temperature range investigated, coarsening of the surface features with increasing erosion time is observed. Surprisingly the coarsening exponent is almost temperature independent and stays close to the value of 0.25. It turns out that coarsening is not due to a transport mechanism, which may be described as a function of the surface height, but due to step edge diffusion. It is critically discussed, how existing models for surface erosion may account for these findings.

10:30 AM L7.5
SURFACE MORPHOLOGY EVOLUTION DURING ION IRRADIATION AND ANNEALING. M.V. Ramana Murty and B.H. Cooper, Cornell University, Ithaca, NY.

Ion irradiation often leads to pattern formation with an approximately regular arrangement of mounds and pits. Subsequent annealing of such "patterned surfaces" results in a network of elevated regions with mounds and depressed regions with pits. While existing models (M.D. Johnson *et al.*, Phys. Rev. Lett. 72, 116(1994). can describe pattern formation, the same models fail to describe the surface morphology evolution in the absence of an ion flux. We will discuss a continuum equation that describes surface morphology evolution during both ion irradiation and annealing. Surface diffusion mediated relaxation is treated below the roughening temperature, a feature not present in previous models. Fast step edge diffusion (M.V.R. Murty and B.H. Cooper, Phys. Rev. Lett. 83, to be published) and the Ehrlich-Schwoebel barrier[1] are considered as sources of instability leading to pattern formation. The description of surface morphology and scaling laws according to the continuum equation will be compared with experimental observations from the literature. This work made use of the CCMR facilities which is supported by NSF under Award No. DMR–9632275, and the resources of the Cornell Theory center.

10:45 AM *L7.6
DEFECTS AND MORPHOLOGIES PRODUCED BY keV ION BOMBARDMENT OF Ge AND Si SURFACES. David G. Cahill, Jaichan Kim, K. Kyuno, and R. S. Averback; University of Illinois, Dept of Materials Science, Urbana, IL.

At keV energies, ion bombardment of a material surface generates a substantial density of bulk defects in the near surface region. The interaction of these bulk defects with the surface influences the evolution of morphology and microstructure during keV ion beam processing; e.g., sputter depth profiling and low energy ion implantation. We are using ultra-high vacuum scanning tunneling microscopy to probe the interactions of bulk defects with Ge(111), Ge(001), and Si(001) surfaces. Sputtering of Ge surfaces with 5 keV Xe ions at 500°C produces a nearly perfect surface even though the near surface region harbors a high density of nanometer-scale voids. Subsequent sputtering at lower temperatures induces a strong interaction of these voids with the surface and the rapid formation of surface pits. The pit-dominated morphology eventually gives way to pattern of surface mounds and valleys. Helium ion bombardment and STM imaging of Si(001) at 180 K reveals the motion and surface trapping of Si interstitials created within a few nanometers of the surface.

11:15 AM L7.7
MD SIMULATIONS OF GROWTH AND LOW-ENERGY ION POLISHING OF THIN MOLYBDENUM FILMS FOR XUV MULTILAYER MIRRORS. Peter Klaver, Wim Goedheer, Fred Bijkerk, FOM Rijnhuizen, Dept. of Laser Plasma & XUV Optics, Nieuwegein, THE NETHERLANDS; Barend J. Thijsse, Delft University of Technology, Dept. of Materials Science, Delft, THE NETHERLANDS.

We report on the simulation of the growth and subsequent krypton ion polishing of thin molybdenum films, required for XUV mirror production. We have used a comprehensive Molecular Dynamics code, principally enabling a simulation of the various processes of deposition, ion bombardment and annealing. Ion energies used are in the sub keV range. The effects of ion polishing on the surface roughness are discussed, as well as sputtering yields, ion penetration depths, trapping, increase in surface atom mobility, and krypton saturation. The results are compared with experimental data available and other simulation results. Also, the effects of ion polishing and short-time, high-temperature annealing of partially or fully amorphous films are investigated. Simulations show that the effects of ions of various sub keV energies are limited to a small area around the point of impact, in terms of both lateral spread and penetration depth. Increase of surface roughness, an unwanted effect for mirror production, is found to be strongly energy dependent. This is due to the indiscriminate character of these ions, which displace or sputter molybdenum surface atoms regardless of their surface binding energy. Varying the energy results in more selective displacing and sputtering. This work is part of the FOM/Philips programme on physics of thin film materials.

11:30 AM L7.8
APPLICATION OF CLUSTER ION BEAM SMOOTHING TO SURFACES. D. Fathy, O.W. Holland*, J.Y. Jin, QingMian Li, Wei-Kan Chu, Univ of Houston, Houston, TX.

The advantages of using cluster-ion beams for smoothing of rough surfaces, and its ability to produce surface height variations of less than nanometer-sized dimensions, has been previously demonstrated (a). Results of smoothing several materials will be reported using an Epion cluster beam system, which is capable of generating ion clusters of greater than 2000 atoms/cluster with cluster energies to 30 keV. Of particular interest in this study was the morphological instabilities in ion-implanted Ge. Regularly spaced columnar voids of 20-40 nm in diameter extending 180 nm from the surface into the amorphous layer are formed during heavy ion bombardment (b). A 25 keV, Ar+ cluster beam at a dose of 5 E15 clusters /Sqcm will be shown to displace 60 nm of the surface leaving a planar amorphous layer of <3 nm roughness at the surface. Thermal annealing removes this amorphous layer by solid-phase-epitaxial growth (SPEG) leaving a smooth crystalline layer at the surface that is doped with the implanted specie. Since ion implantation is an integral part of the manufacturing process for integrated-circuits, the ion-induced roughening of the surface may lead to reliability and performance problems. Not only can cluster beams be used to re-establish the original surface smoothness after the ion implantation, but also may be used to smooth localized regions. In addition to the Ge results, work related to smoothing of SiC will be discussed. a) (Smoothing of YBCO films by cluster beam bombardment), W.K. Chu, etal Appl. Phys. Lett. (1997) b) (Morphological Instabilities and Ion Beam Mixing in Ge), B.R. Appleton, etal. Nucl. Inst. and Methods in Phys. Research B7/8, (1985) 639-644.

11:45 AM L7.9
DIFFERENCES IN SURFACE MORPHOLOGY FOR GE HOMOEPITAXY IN PULSED LASER DEPOSITION AND MOLECULAR BEAM EPITAXY. Christian Stauter, M.H.M. Reddy, Craig B. Arnold, James W. McCamy*, Michael J. Aziz, Division of Engineering and Applied Sciences, Harvard University, Cambridge, MA; *Corning Inc., Corning, NY.

Thin films resulting from the deposition of a pulsed flux of energetic atoms as in Pulsed Laser Deposition (PLD) often exhibit different morphologies compared to those formed by a continuous flux of atoms with thermal energy as in Molecular Beam Epitaxy (MBE). We have used Reflection High Energy Electron Diffraction (RHEED) and AFM/STM to study the growth of germanium on Ge(001) for both PLD and MBE processes conducted in the same chamber at the same substrate temperature. Time-resolved RHEED intensity variations as well as RHEED diffraction profiles were used to infer the evolution of the morphology of the growing films. AFM/STM measurements performed on quenched samples were used to calibrate the RHEED analysis. The mechanistic sources of the morphological differences observed will be discussed.