



Strasbourg (France)

E-MRS Spring Meeting 2004
May 24-28, 2004

SYMPOSIUM T

Nanostructural substrates: self-assembling and
nanopattern formation

Symposium Organizers:

Isabelle Berbezier, CRMC2 – CNRS, Marseille, France

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Papers will be published in Superlattices and Microstructures

E-MRS 2004 SPRING MEETING

SYMPOSIUM T

Tuesday, May 25, 2004

Morning

Session I: Modelling of pattern formation and of self-assembling

Session chair: A. Pimpinelli

- T-I.01** 08:30 -Invited- NUMERICAL SIMULATIONS OF PATTERN-DIRECTED PHASE DECOMPOSITION IN STRESSED FILMS
William C. Johnson, University of Virginia, Charlottesville VA, USA, Stephen M. Wise and J.S. Kim, Department of Mathematics, University of California Irvine, Irvine CA, USA
Two- and three-dimensional simulations of the microstructural evolution of stressed, epitaxial, binary thin-films on a geometrically patterned substrate using a Cahn-Hilliard equation are presented. Substrate, film, and free surface are differentiated using a phase-field parameter and both epitaxial and compositional strains for an elastically heterogeneous system are considered. Numerical simulations show that arrays of nanoparticles can self-assemble in the decomposing film, especially near the film-substrate interface for film compositions near the spinodal. The size and spatial distribution of the precipitates in the film are sensitive to the geometry of the substrate interface, sign and magnitude of the compositional and epitaxial strains, the film composition and thickness, and the interfacial interaction of the film with the substrate and with the surface. The simulations show the possibility of creating particle spacings considerably smaller than the substrate pattern periodicity, allowing a "demagnification" below the resolution of the imposed pattern. This work is supported by the U.S. National Science Foundation through the Center for the Design of Nanoscopic Materials, Grant DMR0080016.
- T-I.02** 09:00 Si(001) SURFACE SELF-ORGANIZATION UNDER STRAIN FIELD INFLUENCE. 2D MONTE CARLO SIMULATION
Florin Nita(a,b), Alberto Pimpinelli(a), Hiroo Omi(c), (a)LASMEA, UMR 6602 CNRS, Blaise Pascal University, Clermont 2, 63177 Aubière Cedex, France, (b)Institute of Physical Chemistry, Romanian Academy, Spl. Independentei 202, Bucharest, Romania (c)NTT Basic Research Laboratories, NTT Corporation, Atsugi, Kanagawa, 243 – 0198 Japan
The morphology of vicinal and flat surfaces during relaxation and during growth in the presence of a strain field is studied by kinetic Monte Carlo simulation, using a model that was already used to study the decay of pyramidal nanostructures on Si(001) surface [1].
In the model we have taken into account only the deposition and diffusion events. The activation energy for the diffusion event is given by: $E_d = E_D + n_1 E_{a1} + n_2 E_{a2}$, where E_{a1} and E_{a2} are the lateral interaction energies in perpendicular, respective parallel direction relative to the dimer rows direction in the plain, and n_1 and n_2 are the numbers of nearest neighbours in these two directions. E_D is the energy barrier due to the interaction with the substrate and can have two different values, E_{D1} or E_{D2} , that depending on the dimer diffusion direction relative to the dimer rows direction on the substrate. We performed simulations using different strain field distributions taking into account different possibilities to produce such strain fields (ion implant or local surface deformation). For all cases we compare our simulation results with experimentally data.
[1] Scaling and crossovers in nano-island decay : a kinetic Monte Carlo study Florin Nita, Alberto Pimpinelli, accepted to be published in Surface Science
- T-I.03** 09:30 MONTE CARLO SIMULATIONS OF GE ISLANDS ON PATTERNED Si(001) SURFACES
A. Pascale(a), A. Ronda(b), I. Berbezier(b) and P.C. Kelires(a), (a)Foundation for Research and Technology-Hellas (FORTH), P.O. Box 1527, 711 10 Heraclion, Crete, Greece, and Physics Department, University of Crete, P.O. Box 2208, 710 03 Heraclion, Crete, Greece, (b)Centre de Recherche des Mechanismes de la Croissance Cristalline CRMC2-CNRS, Campus de Luminy, Case 913, 13288 Marseille, France
It has been recently observed [1] that during SiGe growth on vicinal Si(001) surfaces an anisotropic undulation takes place, depending on the miscut angle, which extends perpendicular to the direction of step edges. This is in contrast to the case of Si homoepitaxy on vicinal surfaces, in which the surface undulation, due to a step-bunching kinetic instability, is parallel to the step edges. We present here the results of extensive Monte Carlo simulations, which shed light onto the origin of this peculiar evolution of island morphology on vicinal Si(001). We concentrated on the Ge/Si(100) system. We investigated, as a function of the surface step density, the influence of step edges on the morphology and the stress state of Ge islands. Our approach is based on the analysis of the stress field inside the islands and at the island/substrate interface into atomic level stresses [2]. A key finding of our simulations is that the growth of elongated Ge islands on a patterned Si substrate, where each pattern consists of a number of steps, has a drastic effect on stress relaxation. Specifically, when the elongated island extends over three or more steps, stress is relieved to more than half compared to the stress of a regular island on a flat terrace. This opens up the possibility for weaker intermixing and higher Ge content in the islands, and so for a more effective quantum dot behavior. We shall show that the presence of two types of reconstructed domains on the Si(100) surface, namely (2x1) and (1x2), plays a very important role for this remarkable behavior.
[1] A. Ronda, I. Berbezier, A. Pascale, A. Portavoce, and F. Volpi, Mater. Sci. Eng. B 101, 95 (2003).
[2] P. Sonnet and P.C. Kelires, Phys. Rev. B 66, 205307 (2002).

- T-I.04** 09:45 **NANOISLAND NUCLEATION UNDER CONTINUOUS DEPOSITION OF MONOMERS**
Alexander E. Volkov and Michael V. Sorokin, Institute of General and Nuclear Physics, Russian Research Centre 'Kurchatov Institute', Kurchatov Sq.1, Moscow 123182, Russia
 Steady-state nucleation of 2D nanoislands is described analytically. This temporal stage may appear at low deposition rate/high temperatures due to the transient balance between generation of monomers at the surface and their annihilation at the island edges. Nearly constant nucleation rate and linear increase of the island density realize at this stage. The most part of the precipitates appears in the system at this time forming initial conditions for the subsequent kinetics. The steady-state is characterized by a small number of parameters that allows monitoring the nanoisland formations. Conditions of this stage appearance and this stage duration are estimated analytically. The model takes self-consistently into account the coupling between the kinetics of adatoms near the island edge with their generation at the surface and diffusion to islands. The dependencies of the steady-state nucleation rate on the temperature and generation rate of monomers are determined. Two limit cases are extracted: the reaction controlled case, when the nucleation is governed by the kinetics of adatoms near the island edge, and the diffusion controlled case, when nucleation is determined by adatom diffusion. In the last case the nucleation barrier considerably differs from that used in thermo-equilibrium approach and depends on diffusion parameters. This difference can be used to investigate governing mechanisms of the nanoisland nucleation from experimental and numerical data
- T-I.05** 10:00 **PHYSICO-CHEMICAL MODEL AND COMPUTER SIMULATIONS FOR EARLY STAGES OF SILICON NANOWIRES GROWTH**
A.A. Efremov, A.I. Klimovskaya, K.N. Grygoryev, Institute of Semiconductor Physics, 45 Nauki av., Kiev 03028, Ukraine and T.I. Kamins, Hewlett-Packard Labs, 1501 Page Mill Road M/S 1123, Palo Alto Ca 94304-1126, USA
 A phenomenological model for silicon nanowires growth on silicon substrate mediated by metallic particles in CVD process is developed. It takes into account molecular transport in gas phase, adsorption/desorption processes at the surface of ultra-small particles, behavior of Si and H adatoms on the surface with high average curvature and different mechanisms of Si adatoms incorporation into a growing nanocrystal. They are (i) "bulk-like" transport through metal particle to top of a whisker (ii) bypass surface diffusion of adatoms to Me/Si interface, (iii) direct adatom transport toward and along lateral surface of the wire; (iv) chemisorption of molecules on the lateral surface directly from gas phase. The former two mechanisms result in the wire length-growth and the latter two are responsible for radial growth of whisker. The temperature distribution caused by heat transport between substrate and gas phase were considered too. Different types of whisker growth kinetics in dependence on radius, temperature and concentration have been revealed. Excellent agreement of simulations with published data was found. Applicability of thermodynamically-kinetic approach to nanocrystal growth is discussed and possible ways of process control are considered.
- T-I.06** 10:15 -Invited- **CLUSTER DIFFUSION AND STEP FLUCTUATIONS ON METAL SURFACES: APPLICATIONS OF A SELF-TEACHING KINETIC MONTE-CARLO METHOD**
T. Rahman, Kansas State Univ., USA
- 10:30 **BREAK**

Session II: Spontaneous pattern formation: instabilities, stress fields

Session chair: J. Floro

- T-II.01** 11:00 -Invited- **SPONTANEOUS STRUCTURAL PATTERN FORMATION AT THE NANOMETER SCALE IN KINETICALLY RESTRICTED HOMOEPITAXY ON VICINAL SURFACES**
J. Ernst, CEA Saclay
- T-II.02** 11:30 **SPONTANEOUS PATTERN FORMATION; CARBON SPIRALS AND GRIDS ON SINGLE CRYSTALL SURFACE**
I. Sandu, I. Morjan, I. Voicu, R. Alexandrescu, F. Dumitrache, C. Fleaca, I. Soare, E. Popovici, M. Savoiu, L. Albu, National Institute for Lasers, Plasma and Radiation Physics, Laser Department, P.O. Box MG-36, 76900 Bucharest, Romania, E. Vasile, METAV, 16-18 Zapada Mieiilor St., 71529 Bucharest, Romania
 Carbon nanoparticles were obtained by laser pyrolysis technique of some gaseous precursors: ethylene, acetylene and benzene. Investigations performed on nanometric carbon soot shows that it consist (depending on the process parameters) in an almost spherical particles with diameters in the range 20 – 50 nm, having a turbostratic or fullerene like structure in which sp² C-C bondings are in 71% of the soot.
 Based on the property of carbon soot to float on some liquid's surface, in analogy with Langmuir-Blodgett technique, a method capable to deposited thin carbon films on different substrates was developed. These thin and homogenous films are formed by carbon nanoparticles that keeps them physical and chemical properties that they have like powder. Thin films composed by carbon nanoparticles in mixture with Ni(NO₃)₂ micro crystallites were obtained. Irradiated with a CO₂ IR laser in the range 50 – 200 W in different experimental conditions, the obtained carbon and Ni(NO₃)₂ thin films vanish. Optical microscopy's reveals that on the single crystal's surface used like substrate spontaneous patterns where formed: spirals like and grids. Analyses performed on these patterns shows that are formed by carbon and metallic nickel in which turbostratic carbon nanoparticles changes its structure in carbon like onion.
 Spirals like pattern have diameters in the range of 5 – 50 nm and width in the range of 2 – 5 nm. The carbon grids exhibit a 350-lines/mm density, on which light diffraction experiments were performed. Atomic force microscopy (AFM) and scanning electron microscopy (SEM) will be performed on the obtained patterns. A theoretical model of patterns formation mechanism is proposed.

- T-II.03** 11:45 MORPHOLOGICAL INSTABILITIES OF VICINAL FCC(001) METAL SURFACES INDUCED BY DIMER DIFFUSION
 Florin Nita(a,b), Alberto Pimpinelli(a), Ofer Biham(c), (a)LASMEA, UMR 6602 CNRS, Blaise Pascal University, Clermont 2, 63177 Aubière Cedex, France, (b)Institute of Physical Chemistry, Romanian Academy, Spl. Independentei 202, Bucharest, Romania, (c)Racah Institute of Physics, The Hebrew University, Jerusalem 91904, Israel
 The morphology of vicinal surfaces in the presence of dimer diffusion during epitaxial crystal growth is studied by kinetic Monte Carlo simulations of a model, that accounts for deposition and diffusion on FCC(001) metal surfaces [1].
 The model distinguishes between in-layer and inter-layer diffusion. For in layer diffusion, the activation energy is computed in the manner described in [1], manner which implies the formation and fast diffusion of dimers without any additional assumption. For interlayer diffusion the activation energy, E_d , is given by $E_d = E_D + (E_i - E_v)$, where E_i and E_v are the lateral interaction energies in the initial and in the final "virtual" site for an atom that is diffusing. As a matter of fact we consider an interlayer diffusion process as having two steps: firstly a diffusion to a virtual site, followed by a diffusion to the final site. The corresponding energy barriers are computed as $n_i E_a$ and $n_v E_a$ where n_i and n_v are the numbers of nearest neighbours corresponding to the initial and "virtual" site. The model obeys detailed balance and reproduces the morphology of a FCC(001) real system (step meandering and mounting instabilities) even in the absence of Schwoebel barrier. [1] H. Mehl, O. Biham, I. Furman, M. Karimi, Phys Rev B 60 , 2106 (1999)
- T-II.04** 12:00 NANOMETRIC SILICON SURFACE PATTERNING BY USING DIRECT WAFER BONDING
 F. Fournel, J. Mézière, P. Perreau, CEA-DRT, LETI/DTS, CEA/GRE, 17, rue des Martyrs, 38054 Grenoble Cedex 9, France, J. Eymery, P. Gentile, F. Leroy, CEA Grenoble, DRFCM/SP2M, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France
 In order to achieve density and size control of nanostructures, new substrates with a nanometric surface patterning are elaborated by direct bonding and preferential chemical etching.
 Due to the twist misorientation of two (001) silicon surfaces, the direct bonding produces square nanometric networks of dislocations localized nearby the bonding interface. Despite classical direct bonding which also produce unavoidable mixed dislocation network, an original process allows to eliminate this undesirable network and to accurately control the twist disorientation up to 0.001° . Using a thin film transfer technique, this grain boundary has been achieved on a full 100mm wafer size under an ultra-thin silicon film ($<10\text{nm}$). In order to nanopattern the "twisted" surface, a Yang-etch type mixture ($\text{HF}/\text{H}_2\text{O}/\text{CrO}_3$), for instance, has been used and revealed the periodicity of the quasi-perfect underground dislocation network. The ultra high vacuum STM measurement exhibits then a patterned surface highly correlated. This morphology has a fourfold symmetry consisting in a square network of trenches with a period exactly equal the underneath dislocation one, for instance 22nm. This nanometric surface patterning can be used for a lot of applications. Among them, the nanostructure Germanium growth with well define positions was demonstrated. In fact, this "twisted" substrates allow to produce patterning with a definition not easily reach by other lithographic techniques overall the full wafer surface.
- T-II.05** 12:15 THE DRIVING FORCE OF THE NANOFACETING OF CU VICINAL SURFACES INDUCED BY AG DEPOSITION
 A. Coati, J. Creuze, A. Zobelli, Y. Garreau, LURE, Bât.209D, Centre Universitaire Paris Sud, 91898 ORSAY Cedex, France
 The self-organisation of nanometric systems has been intensively studied in the last years due to their potential application for the fabrication of magnetic or catalytic nano-objects.
 We studied by Grazing Incidence X-ray Diffraction (GIXD) the periodic faceting of a set of Cu surfaces, vicinal to (111) planes, induced by the deposition of Ag atoms in the sub-monolayer regime. After the Ag deposition, the surface results in a hill-valley structure formed by a regular succession of bare Cu and Ag-covered facets. As a function of the Ag coverage, the period of the superstructure and the lateral dimensions of the stripes vary from few to tents of nm. The Ag-covered facets correspond to well definite Cu crystallographic planes, while the orientation of the bare Cu facets changes, for each deposition, in order to keep constant the macroscopic surface miscut angle. For low coverages, the Ag-covered facets are always constituted by Cu(211) planes and present a reconstruction $c(2 \times 10)$. To understand the origin of this faceting, we studied the epitaxy of Ag on a Cu(211) substrate [Y. Garreau et al. Phys. Rev. Lett. 91 (2003) 116101]. We find that the deposition of 1 ML exhibits a $c(2 \times 10)$ reconstruction, which structure was solved by means of Quenched Molecular Dynamics (QMD) simulations. This Ag layer presents $\{111\}$ steps, in contrast with the original $\{100\}$ steps in pure Cu, and can be viewed as the beginnings of a Ag(133) surface that will be the starting point for an epitaxial growth. This "magic" epitaxy is generated by the remarkable agreement between the Cu(211) and Ag(133) step period (which present a misfit of only 0.4%), in spite of the lattice parameter misfit between Cu and Ag (13%). This epitaxy is the driving force of the faceting of the vicinal substrate.

T-II.06 12:30

INSTABILITIES INDUCED IN COBALT NANOPARTICLES IRRADIATED WITH SWIFT HEAVY IONS

C. d'Orléans(a,b), J.-P. Stoquert(a), C. Estournès(b), J.-J. Grob(a), D. Muller(a), C. Cerruti(c), F. Haas(c), (a)Laboratoire PHASE (UPR 292 CNRS), 23 rue de Loess, 67037 Strasbourg, France, (b)IPCMS-GMI (UMR 7504 CNRS), 23 rue de Loess, 67037 Strasbourg, France, (c)IRES (UMR 7500, IN2P3 –CNRS), 23 rue du Loess, 67037 Strasbourg, France

We have undertaken a systematic study of the modifications induced by swift heavy ions in nanoparticles implanted in SiO₂. In a previous paper [1], we reported on the modifications of 10 nm cobalt nanoparticles irradiated with 127I ions at 200 MeV at fluences ranging from 10¹¹ to 10¹⁴ ions.cm⁻². We have evidenced the existence of two regions in which different types of modifications occur and that can be described by a model reported in [2]. For low irradiation fluences, the spherical growing of particles is observed, and for higher irradiation fluences, deformation of the particles has been observed in the direction of the irradiation beam. These two well-defined domains are separated by a region for which calculations do not apply corresponding to a shape instability characterizing the transition from spherical growth to prolate deformation. At very high fluences, an other transition region is expected, corresponding to a second type of shape instabilities due to limitations on large deformations. Here we report on a systematic studies of the intermediate and high irradiation fluences leading to instabilities in nanoparticles/SiO₂ systems.

[1]C. D'Orléans, J.P. Stoquert, C. Estournès, C. Cerruti, J.J. Grob, J.L. Guille, F. Haas, D. Muller, M. Richard-Plouet, Phys. Rev. B 67 (2003) 220101.

[2]C. D'Orléans, J.P. Stoquert, C. Estournès, J.J. Grob, D. Muller, J.L. Guille, M. Richard-Plouet, C. Cerruti, F. Haas, Nucl. Instr. and Meth. B xxx (2004) in press.

12:45

LUNCH

Tuesday, May 25, 2004

Afternoon

Session III: Surface functionalization

Session chair: P. Kelires

- T-III.01** 14:00 -Invited- GROWTH AND ASSEMBLY OF SEMICONDUCTOR NANOWIRES : NEW MATERIALS FOR PHYSICS AND APPLICATIONS
L. Samuelson, Lund Univ., Sweden
- T-III.02** 14:30 FROM NANOPATTERNING TO FUNCTIONALITY - SURFACE- AND BULKIMPRINTING FOR ANALYTICAL PURPOSES
P. Lieberzeit, C. Schirk and F. Dickert, Institute of Analytical Chemistry, Vienna University, Austria, H. Nannen, Volkswagen AG, 38436 Wolfsburg, Germany
For the design of sensor layers self-assembling strategies of organic and inorganic monomers around an analyte were performed by an imprinting process. Thus, suitable interaction centres with an adapted geometry allow the re-inclusion of the analyte by nanopatterning. Detection was performed by mass-sensitive devices (QCM, SAW), capacity measurements and surface-plasmon resonance.
Sol-gel processes based on silicon, titanium, zirconium compounds were used and long chain carbonic acids added as print molecules to form diffusion channels and cavities in the size of some nm. Heating yields structured ceramic materials which re-include these acids as FT-IR spectroscopy shows. The pre-polymerised solutions are applied by a "spin-off" process to QCM, SAW and SPR devices creating very homogenous layers in a height of several hundred nm. These sensors are capable of monitoring automotive oil quality. In going from fresh to waste oil a lowering of the QCM resonance frequency is observed, where the contributions due to chemical degradation in the oil exceed those of viscosity. Surface patterning is important both for very fast sensor responses as well as macromolecular compounds up to cells, since bulk diffusion is not possible for large particles. The quartz can be surface modified with a mixture of silyl-spacers having different length and shape. Thus, a surface modulation in a nanometer scale is realized for analyte incorporation. Using additional thin polymer layers, this strategy is even applicable for proteins, viruses and cells. A combination of QCM-, SPR-, dielectric and AFM- measurements reveals mobility of these particles on the nano-structured surfaces.
- T-III.03** 14:45 A THERMAL STABILITY STUDY OF ALKANE AND AROMATIC THIOLATE SELF-ASSEMBLED MONOLAYERS ON COPPER SURFACES
L. Carbonell(a), C.M. Whelan(a), M. Kinsella(a), K. Maex(a,b), (a)IMEC, Kapeldreef 75, 3001 Leuven, Belgium, (a)Electrical Engineering Department, Katholieke Universiteit Leuven, 3001 Leuven, Belgium
Self-assembled monolayers (SAMs) have been found to be effective corrosion inhibitors of Cu surfaces for interconnect metallization. Though, their stability during subsequent processing steps may limit their eventual application. To this end, Thermal Desorption Spectrometry (TDS) with Atmospheric Pressure Ionization was used to study the thermal stability of decanethiol (C10) and benzenethiol (BT) SAMs on metallic and oxidized Cu surfaces.
Decanethiol (C10) and benzenethiol (BT) SAMs exhibit low thermal stabilities on clean copper surfaces with a maximum in decomposition occurring between 100 and 150°C. However, the onset of desorption starts at around 50°C for C10 and 100°C for BT, limiting potential applications. The decomposition of both types of SAMs follows a similar mechanism with the simultaneous desorption of the head group as oxidized sulphur, evidenced by the detection of SO₂ (m/e=64) and organic fragments of the chain. Interestingly, H₂S desorption (m/e=34) is not observed suggesting that the decomposition pathway is not dominated by S-C bond scission. A TDS comparison of the oxidized and metallic Cu substrates shows desorption of species trapped in the porous structure of the CuO layer. Following SAM formation on the oxidized surface, only desorbed species specific to the SAM are detected, suggesting removal and/or reduction of the CuO layer. Higher intensities of the SAM related desorption peaks, as compared to those observed with clean copper substrates, are also an indication of an increased roughness of the oxidized copper surface. Interestingly, the thermal stability of the BT layers is independent of the oxidation state of the underlying substrate. Complementary XPS, SEM and AFM data confirm the TDS results.
- T-III.04** 15:00 OBSERVATION OF METASTABLE SELF-ORGANISED STRUCTURE DURING POROUS SILICON FORMATION
K. Skorupska, J. Jakubowicz, H. Jungblut, H.J. Lewerenz, Hahn-Meitner-Institut, Berlin, Germany
The initial processes leading from atomically flat Si surface to porous silicon formation are not well known and detailed surface analytical investigations on the dissolution steps are still lacking. By performing potentiostatic and chronoamperometric experiments in dilute ammoniumfluoride solutions at moderate pH value we are able to investigate the dissolution process from first pit formation to the formation of transitory mesa-type terraces on atomically flat n-Si(111) by atomic force microscopy (AFM). Mesa - type structures with flat extended terraces surrounded by strongly corrugated areas are observed after a variety of different conditioning procedures. The mesas exhibit terrace edges being aligned parallel or perpendicular to distinct preferred surface orientations which results in pentagonal, hexagonal or highly composed structures. The findings can be interpreted by side wall formation which exhibit only a limited number of crystal orientations: {111}, {110} and {113}. Because these faces can be electrochemically H-terminated in a 1x1 manner, we suggest that their stability accounts for the variety of observed structures.

T-III.05 15:15

SELF-ORGANIZATION OF Fe NANOPARTICLES ON MICROMETRIC SiO₂ AREAS BY COMBINING HOT EMBOSSED LITHOGRAPHY AND CHEMICAL FUNCTIONALIZATION

L. Ressler(a), C. Martin(a), J.P. Peyrade(a), O. Margeat(b), C. Amiens(b), B. Chaudret(b), J. Grisolia(a), M. Respaud(1), C. Vieu(c), (a)LNMO, INSA-département de Physique, 135 av. de Rangueil, Toulouse, France, (b)LCC, 205 route de Narbonne, Toulouse, France, (c)LAAS, 7 av. du Colonel Roche, Toulouse, France

Self-assembled nanoparticles (NPs) on solid substrates are at the basis of many promising applications for spin electronics. But, the main difficulty remains the accurate control of the localization and organization of such nano-objects. To take up this challenge, we propose to tune the local chemical affinity between a SiO₂/Si substrate and Fe NPs on specific micrometric areas by combining hot embossed lithography and functionalization of the substrate using a silane monolayer. This chemical affinity must be strong enough to guarantee that the NPs will stay on the desired areas patterned by lithography, but must also permit some surface recombination to get a good self-organisation. Our process consists in depositing a silane layer by chemical vapour deposition on a SiO₂/Si substrate patterned by hot embossed lithography. After lifting-off this layer, 1µm square arrays of silane monolayer are easily obtained on millimetric areas. A solution of 5nm Fe nano-cubes is then deposited on the whole surface, and the excess is removed by adequate cleanings. The NP organization has been studied using Atomic Force Microscopy, Scanning Electron Microscopy and Transmission Electron Microscopy observations. The efficiency of this process and the role of the tail group of the silane used will be presented and discussed.

T-III.06 15:30

SELF-ORGANIZATION OF ORGANIC MOLECULES ON METAL SURFACES AND ON INSULATOR THIN FILMS

L. Ramoino(a), S. Schintke(a), M. Von Arx(a), T.A. Jung(a,b) and H.-J. Güntherodt(a), (a)Institute of Physics, University of Basel, Klingelbergstr. 82, 4056 Basel, Switzerland, (b)Paul Scherrer Institute, Laboratory for Micro- and Nanostructures, 5232 Villigen, Switzerland

Single molecules on surfaces are promising objects to overcome the limits of present silicon based techniques. Molecular properties like self assembling and preferential adsorption are specially interesting in order to evolve from the present top-down manufacturing methods to bottom-up techniques. Formation of a wide variety of molecular self organized structures has been achieved on metal and semiconductor surfaces. Much less is known about the adsorption and self organization of organics molecules on insulating substrates. However, decoupling molecules from the conductive substrate and building up metal-insulator as well as semiconductor-insulator patterns is very interesting in the perspective of molecular electronics. It has been shown as STM and STS are profitable tools for the study of morphology and electronic structure of ultra-thin insulating structures on both metallic and semiconductor substrates. In addition, with such insulating films it should be possible to tune the molecule sample interaction by varying the thickness of the insulating layer. We are studying the growth of ultra-thin NaCl films on different metal surfaces. STM pictures clearly show the formation of ordered 2D islands between 1 and 3 monolayer thick and with a characteristic square shape. Their size can be reliably controlled in a range between a few and hundreds of nanometers. Self-organization of different organic molecules deposited on the NaCl/metal system, has been studied for various molecule substituents and surface coverages. The possible molecule-surface interactions leading to self-assembled molecular structures on ultra-thin insulators are discussed for the different molecules and coverages in comparison.

T-III.07 15:45

CO NANO-ELECTRODES FOR THE STUDY OF SPIN DEPENDENT TRANSPORT THROUGH NANO-OBJECTS

J. Grisolia(a), C. Martin(a), L. Ressler(a), M. Respaud(a), J-P. Peyrade(a), C. Vieu(b), E. Snoeck(c), (a)LNMO, INSA, Dpt. de Physique, 135 avenue de Rangueil, 31077 Toulouse, France, (b)LAAS, Toulouse France, (c)CEMES, Toulouse, France

The connection of a single or a few number of self-organised nano-objects (NOs) between two nano-electrodes (NEs) is a crucial issue to make well controlled magneto-transport experiments. The choice of the NE material and NO type allows the study of not only the charge effect but also the spin dependent effects. We have developed an horizontal approach for the study of spin dependent transport mechanisms. This goal requires the control of various techniques like Hot embossed Lithography (HEL), CVD chemistry and High Resolution Electron Beam Lithography (HREBL). A classical process for patterning these NEs consists in lifting-off a ferromagnetic layer deposited by ion beam assisted evaporation set-up into electrode shape patterns designed in a PMMA resist layer by HREBL. It presents the inconvenience to have a poor electrodes crystalline quality. Here we present a new method consisting in etching, through a PMMA mask patterned by HREBL, a continuous ferromagnetic layer deposited in optimal conditions (temperature, magnetic field, atmosphere...) by sputtering. The main advantage of this approach is to guarantee a better crystalline and magnetic quality of the NEs. However, it requires the inversion type of the positive electron sensitive PMMA layer by HREBL. All the key steps of this process will be described in details especially the impact of various parameters like the electron beam dose, the coded NE gap, the layer development, the inverted PMMA removal... Observations by Scanning Electron Microscopy and Atomic Force Microscopy reveal that a 270nC/cm is required to reverse the PMMA type and provide a strong etching mask. NE gap from 5nm to several tens of nm were obtained. The Co NEs magneto-transport and magnetic properties at the nanometer scale will be discussed.

16:00

BREAK

Session IV: Nanopatterning and nanolithography

Session chair: N.N.

T-IV.01 16:30 -Invited-

DIRECT PATTERNING OF NANOSTRUCTURES BY ELECTRON BEAM INDUCED DEPOSITION WITH A SUB-NANOMETER PROBE

K. Furuya, K. Mitsuishi, M. Shimojo, M. Song, M. Tanaka and M. Takeguchi, National Institute for Materials Science (NIMS), 3-13 Sakura, Tsukuba, Ibaraki 305-0003, Japan

Electron beam-induced (EBI) fabrication is one of the promising techniques, because of short wavelength which results in much smaller resolution limit than several 10 nm. We applied FE-SEMs and FE-TEMs to EBI chemical vapor deposition (EBI-CVD) for the fabrication of position and size controlled metal nanostructures. The electron microscopes used in this study were FE-SEM (JEOL JSM-6700F, 30 kV) and FE-STEM (JEOL JSM-2500SE, 200 kV). A gas introduction system with a nozzle and a reservoir of the gas source of tungsten hexacarbonyl, W(CO)₆ was installed at the specimen chamber of FE-SEM and -STEM. The gas sublimates slightly, and the measured value of the background pressure in the chambers did not change at this gas flux. EBI-CVD experiments were done with Ge disks, Si thin films and carbon grids at room temperature. The position and size control was successfully carried out by careful manipulation of the electron beam. The minimum diameter of the nanostructures was 20 nm with FE-SEM. Writing of nano-dots arrays, nano-lines, nano-character and so on was possible within a several seconds on Si thin films. The deposition using the FE-STEM produced annular dark field (ADF) images of dots about 3.5 nm in diameter. The clear Z-contrast appeared because of the large scattering of heavy W atom. The fabrication of nanostructures less than several nm is possible when the proper experimental conditions was achieved such like this study.

T-IV.02 17:00

SELF ASSEMBLY ON TEMPLATES PREPARED WITH X-RAY INTERFERENCE LITHOGRAPHY

H.H. Solak, C. Padeste, D. Grützmacher, J. Gobrecht, Laboratory for Micro- and Nanotechnology, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland, S.O. Kim, M. Stoykovich, P. Nealey, Dept. of Chemical Engineering and Center for Nanotechnology, University of Wisconsin, Madison WI 53706, USA

Self assembly processes offer advantages and opportunities for production of materials with nanometer-scale patterns. These so-called bottom-up processes are expected to enable large scale production with the quality and resolution not easily available with the top-down lithographic approaches. However the resulting patterns often possess some randomness, such as variations in the size and spacing of the features or lack of long range order. For many applications it is desirable to reduce these variations and position the assembled structures in a controlled way to be able to interact with other components, e.g. the read/write head of a magnetic storage device. Templated self assembly, in which the substrate surface is pre-patterned to guide the self assembly process, combines the top-down and bottom-up approaches.

X-ray Interference lithography (XIL) uses coherent x-rays from synchrotron radiation sources to create periodic patterns. Using XIL we have demonstrated the production of sub-50nm period patterns covering areas over several square millimeters with exposures taking less than one minute. The scale and the periodic nature of the patterns, as well as the available high throughput in comparison to the competing serial techniques, make XIL an attractive tool for templated self-assembly applications. This is the emphasis at the recently completed XIL facility of the Swiss Light Source where we pattern substrates as templates for assembly of Ge quantum dots on Si substrates and macromolecular systems such as block copolymers, grafted polymers, and proteins. We are going to introduce the patterning technique and present examples of assembled structures on XIL exposed templates including epitaxial alignment of block copolymer films and growth of polymer brushes.

T-IV.03 17:15

COLLOIDAL MASKS FOR NANOLITHOGRAPHY MODIFIED WITH OPTICAL TWEEZERS AND ION IRRADIATION

D.L.J. Vossen(a), **J.J. Penninkhof(a,b)**, D. Fific(b), T. van Dillen(b), A. Polman(b) and A. van Blaaderen(a), (a)Utrecht University, Utrecht, The Netherlands, (b)FOM-institute AMOLF, Amsterdam, The Netherlands

We present easy-to-use and inexpensive techniques that extend the use of colloidal masks in lithography. The size of the individual nanoparticles as well as the inter-particle distances and the symmetry of the array of nanoparticles can be precisely controlled. We create masks with single-particle control using optical tweezers and critical point drying. The use of optical tweezers extends the geometry of the masks from (self-organized) hexagonal to any desired symmetry. To achieve control over the hole size two methods were developed: 1) by MeV ion irradiation the colloids plastically deform, expanding in the plane perpendicular to the ion beam, thus shrinking the size of the holes, 2) using a wet chemical process a layer of silica can be grown on the mask. In this way the hole dimensions can be controlled with nm-precision and it is decoupled from the size of the colloidal particles in the mask. Evaporation of different materials at different angles with respect to the mask gives additional control over structure and inter-particle distances. The structures can be used for plasmonic applications such as wave guiding and switching and (single molecule) detection schemes. As examples we will show the fabrication of particle lines, corners and T-structures with both the nanoparticles dimensions and inter-particle distances down to tens of nanometers.

- T-IV.04** 17:30 ORDERED 2-D ARRAYS OF Ge QUANTUM DOTS EMBEDDED IN ULTRA THIN SiO₂ LAYERS
A. Olzierski(a), A.G. Nassiopoulou(a) and A. Travlos(b), (a)IMEL/NCSR Demokritos, 15310 Aghia Paraskevi, Athens, Greece, (b)IMS/NCSR Demokritos, 15310 Aghia Paraskevi, Athens, Greece
Ordered two-dimensional arrays of Ge quantum dots embedded in ultra thin SiO₂ layers were fabricated by e-gun evaporation of Ge on resist windows opened by electron beam lithography. After lift-off of the resist, the structures were annealed and a silicon layer was deposited on top, which was then oxidized in order to get the embedded Ge nanocrystals within SiO₂. The obtained structure constitutes a Ge nanocrystals MOS capacitor. Charging of Ge nanocrystals was investigated by capacitance-voltage measurements in view of their use in a Ge nanocrystals memory.
- T-IV.05** 17:45 FORMATION OF ORDERED PORE ARRAYS AT THE NANOSCALE BY ELECTROCHEMICAL ETCHING OF HIGHLY-DOPED N-TYPE SILICON
X. Badel, R.T. Rajendra Kumar, P. Kleimann, J. Linnros, Department of Microelectronics and Information Technology, Royal Institute of Technology Sweden, Atomic Physics Division, Stockholm University, Sweden, LENAC, Université Claude Bernard Lyon-I, 43 bd. du 11 Nov. 1918, 69622 Villeurbanne, France
Silicon electrochemical etching has been widely studied for the formation of macropore arrays at various scales. On one hand, ordered pore arrays of large dimension, up to 100 μm in diameter, has been reported while on the other hand, only the growth of randomly distributed pores with a diameter of about 200 nm has been reported. At this end the formation of ordered macropore arrays is limited by conventional lithographic techniques. In this paper, well-ordered pore arrays with diameters in the range of 200-300 nm and depths up to 30 μm are presented. These pores have been formed by electrochemical etching in (100)-oriented n-type silicon of low-resistivity (0.1-1 Ωcm). First a lithographic step was performed in order to define the pattern and to form inverted pyramids at each pore position. The lithography was made in a 250-nm thick thermally grown oxide using a stepper and dry oxide etching technique. Several pore opening and pitch sizes were tested. The smallest pore opening realised at this stage was 0.5 μm for a pitch of 1 μm. Inverted pyramids were formed in warm KOH, and finally electrochemical etching was performed using aqueous hydrofluoric acid electrolytes. An IR diode or a halogen lamp was used to photogenerate carriers. Stable pore formation was obtained in many cases. Further experiments involving e-beam lithography are in progress in order to increase the achievable aspect ratio and to reduce the pore diameter.
- T-IV.06** 18:00 SELF-PHASE MODULATED FRINGE PATTERNS IN SILICON NANOPARTICLES: A NONLINEAR PHENOMENON
Sudakshina Prusty, H.S. Mavi, S. Rath and A.K. Shukla, Department of Physics, Indian Institute of Technology, Hauz Khas, New Delhi-110016, India
Silicon nanoparticles are fabricated by laser-induced etching of a silicon wafer with a continuous-wave argon-ion laser. Laser-induced etching with different irradiation times results in thin films consisting of nanoparticles of different size distributions as measured by Raman spectroscopy. The reflected laser beam forms a concentric optical fringe pattern at the observation plane and is monitored for various laser intensities. When the etching process starts, a bright reflected spot is observed. It gradually transforms into a fringe pattern after 10 minutes of etching. The number of fringes depends on the incident laser intensity and the size distribution of the nanoparticles. The reflected laser beam is expected to undergo certain changes different from simple interference to produce fringe patterns. We explain the formation and evolution of the fringes by a theoretical model of spatial self-phase modulation of light. This indicates a change in the distribution of refractive index across the medium, which depends on both the incident laser intensity and the size distribution of the nanoparticles. Sizes are estimated using Raman and photoluminescence spectroscopy employing two-dimensional phonon and electron confinement models. The Raman data shows that onset of stimulated scattering occurs when nanocrystals sizes are in the range of 10-15 nm. Nonlinear phenomena appear when nanocrystallite sizes are below 8 nm. Our observations provide evidence for nonlinear properties of silicon nanoparticles.
- T-IV.07** 18:15 SPONTANEOUS PATTERN FORMATION ON SI SURFACES BY ION BEAM EROSION
Bashkim Ziberi, Frank Frost, Thomas Höche and Bernd Rauschenbach, Leibniz-Institut für Oberflächenmodifizierung e. V., Permoserstrasse 15, 04318 Leipzig, Germany
Spontaneous pattern formation during ion beam erosion of various surfaces offers a promising tool for the cost-efficient fabrication of large-area nanostructured surfaces. The underlying mechanism for this evolution of regular nanometer structures with typical dimension < 100 nm, is a self-organisation process caused by the interplay of roughening by curvature dependent sputtering and surface smoothing by different surface relaxation mechanisms (e.g., ion induced viscous flow or thermally activated surface diffusion).
In this study the self-organized pattern formation on Si surfaces during low-energy Ar⁺ ion beam erosion (ion energy 2000 eV) under normal and oblique ion incidence with and without sample rotation was investigated. It is shown that ordered nanodots are formed at normal ion incidence for ion energies > 1000 eV. In the case of simultaneous sample rotation during ion beam erosion and in the investigated ion energy range dot patterns were also formed at oblique ion incidence angles between 70° and 80° with respect to the surface normal. The dots formed under this conditions show a remarkable high degree of ordering comparable to dot patterns reported for different III/V compound semiconductors. In the case of no sample rotation highly ordered ripple patterns can be produced at ion incidence angles slightly deviating from normal ion incidence. These self-organised patterns were analysed by Scanning Force Microscopy (AFM) and High Resolution Transmission Electron Microscopy (HRTEM).

Wednesday, May 26, 2004

Afternoon

Session V: Local probe nanopatterning and other techniques

Session chair: H.J. Venables

- T-V.01** 14:30 -Invited- INTEGRATED SOLUTIONS FOR NANO-TECHNOLOGY HIGH RESOLUTION SEM/SAM COMBINED WITH STATE OF THE ART SPM TECHNOLOGY
M.D. Green, OMICRON NanoTechnology Ltd, U.K.
- T-V.02** 15:00 InP PATTERNING USING NON CONTACT MODE AND VOLTAGE MODULATION AFM LITHOGRAPHY FOR QUANTUM DOT LOCALIZATION
E. Tranvouez, G. Bremond, LPM UMR CNRS 5511, 69621 Villeurbanne Cedex, France, Gendry, P. Regreny LEOM UMR CNRS 5512, 69134 Ecully Cedex, France
The Stranski-Krastanov (SK) growth mode is an attractive way to elaborate quantum dots (QDs) which are small and of good crystalline quality. However, QDs for photonic applications require their size, density, uniformity and spatial localization to be optimized. This can be achieved by using controlled growth on patterned substrates to localize the nucleation of the QDs, for example on nanoholes. The AFM lithography process can provide patterned surfaces with the required resolution (nanohole diameter in the 10-30 nm range), with easy alignment and a relatively high velocity. This patterning can be completed by local information provided by near field characterization (EFM, SCM, TUNA...). In this work, we will demonstrate that using AFM oxidation and wet etching, we can produce patterned InP surfaces for the localization of InAs QD's. To reach the resolution that we need for this purpose, we have developed a new methodology combining an AFM intermittent contact mode with an alternating voltage. Optimizing the various parameters (vibration amplitude, voltage parameters...) allows us to produce patterned surfaces with a lateral resolution in the 10-20 nm range. We will discuss our results in terms of space charge behavior during lithography, of pattern aspect ratio and of possibilities for QD controlled growth.
- T-V.03** 15:15 ELECTRON TRANSPORT THROUGH A BARRIER PREPARED BY TIP INDUCED OXIDATION
J. Soltys, V. Cambel, R. Kudela and M. Mosko, IEE SAS, Dubravska cesta 9, 84104 Bratislava, Slovakia
Tip induced oxidation is an effective tool for preparation of nanometer-level structures. It can be used also for device definition in shallow AlGaAs/GaAs heterostructures. We have studied transport of a two-dimensional electron gas (2DEG) in such heterostructure prepared by metalorganic chemical vapour deposition (MOCVD). Using an atomic force microscopy (AFM) we have locally oxidized surface of a two terminal device. The oxidation depletes the area with the 2DEG below the oxide line and divides the device into two regions isolated by energy barrier. From the temperature dependence of the current-voltage (I/V) characteristics we have found that the barrier height is dependent on the AFM writing mode (contact or non-contact). In both cases is logarithm of the transport current linearly dependent on the root of applied voltage, which shows that the current is controlled by Schottky and/or Pool-Frenkel effect. The experimental results are compared with computer simulations of the I/V characteristics using ensemble Monte Carlo method with molecular dynamics included to encounter for the electron-electron interaction.
- T-V.04** 15:30 Si SUBSTRATE NANOPATTERNED AND Ge QDS SELF-ASSEMBLING Ge DOTS ORGANIZATION ON FIB PATTERNED SUBSTRATES
A. Karmous, A. Cuenat, A. Ronda and I. Berbezier, CRMC2-CNRS, Campus de Luminy Case 913, 13288 Marseille, France, S. Atha, R. Hull, Univ. of Virginia, 116 Engineers Way, Charlottesville VA 22904-474, USA
One of the major challenges for the reliable use of self-organization phenomena for devices applications is to accurately position quantum dots on the surface. For this purpose, use of pre-patterned substrates is promising. We use a combination of patterned holes on Si(001) substrates using Focused Ion Beam (FIB) and Ge self-assembled quantum dots formation to study the different mechanisms leading to an organized growth. This method could be scaled down to below the 10 nm range. It also allows studying the different physical mechanisms believed to influence the formation of the quantum dots.
We study the three different ways the FIB holes can influence the dots formation: i) presence of Ga atoms (from the FIB source) at the surface; ii) topographic effect, attributed to the creation of step bunches on the holes sides; iii) the stress field gradients induced by the holes which depend on the periodicity of the patterns. In order to determine the driving force for island nucleation and growth, we studied samples with different holes size, depth and periodicity and with Ga atoms removed from the surface or not. A cleaning process of the FIB patterned substrate has been developed in order to fully eliminate Ga contamination without removing the small holes. Concerning Ge island growth on FIB patterned substrate, we demonstrate that, for the correct set of parameters, quantum dots can be organized either in-between or inside FIB holes. At high temperature (700°C) the islands grow at the edges of the holes and when the latter are close enough they self-organize between them. At lower temperature (560°C) the islands self-organize inside the holes. By specific long term annealing experiments we show how the combination of kinetic and stress effects can explain these results.

T-V.05 15:45 NOVEL FOCUSED ION BEAM LITHOGRAPHY PROCESS FOR SUB-100nm TECHNOLOGY NODES
Khalil Arshak, Miroslav Mihov, Arous Arshak, Declan McDonagh, ECE Department, University of Limerick, Plassey Technological Park, Limerick, Ireland
 Focused Ion Beam (FIB) technology is commonly used nowadays into the IC's industry for failure analysis, prototype fabrication and device repair [1]. FIB lithography can be utilised for direct patterning of photoresist without using a mask. This technology has several advantages over other maskless lithography processes such as direct-write e-beam lithography. The advantages are mainly attributed to the higher resist sensitivity and much lower backscattering and proximity effects when ions are used instead of electrons to pattern the photoresist.
 This article follows the investigations into a novel dry developed FIB lithography process, the Negative Resist Image by Dry Etching (NERIME) [2]. This single layer resist scheme implements Ga⁺ FIB exposure of DNQ/novolac based resists, followed by near ultraviolet (NUV) flood exposure, silylation and oxygen dry etching. The main advantage of the process is that it could yield both positive and negative image formation. The NERIME process is also capable of achieving nanometer resolution (<100nm) and high aspect ratio of the processes patterns. Such process could be utilised for specific CMOS process steps for the next generation technology nodes, such as high resolution lithography over topographic surfaces.
 [1]. J. R. Gerlach, M. Utlaut, Proc. SPIE Charged Particles Detection, Diagnostics, and Imaging, Vol.4510, (2001), 96-106.
 [2]. K. Arshak, M. Mihov, D. Sutton, A. Arshak, S. Newcomb, Microelectronic Eng. 67-68, (2003), 130-139.

16:00

BREAK

Session VI: SiGe nanostructures self-assembling

Session chair: R. Hull

T-VI.01 16:30 -Invited- FORMATION OF HIGH QUALITY SiGe HETERO-STRUCTURES
Y. Shiraki, Department of Applied Physics, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
 SiGe hetero-structures are receiving a lot of interests not only from the point of view of device applications but also from the point of scientific view. Band modification due to the strain brings the increase of the mobility both of electrons and holes and the hetero-structures such as quantum wells and dots make it possible to realize light emitting devices even with indirect band-gap materials. It is obvious that these fascinating applications largely depend on the material growth, particularly control of surface reaction and formation of dislocations and surface roughness that strongly affect device performances. In this talk, we introduce several fabrication technologies of SiGe hetero-structures aiming at growth of high quality materials and structures and discuss physics and chemistry behind the process. The relaxation of strain of SiGe buffer layers grown on Si substrates is very important in this field, since many devices are formed on the strain-relaxed buffer layers which are sometimes called as 'virtual substrates'. So, the formation and properties of these layers are discussed too. To extend the possibility of SiGe, carbon incorporation is now studied, which is also very interesting from the point of view of material growth. The large lattice mismatch in this material system brings formation of misfit dislocation as well as dot formation. The latter is now one of the hottest topics in the semiconductor physics and technology and is discussed here. Some device applications are introduced to show how important these materials are in the real world.

T-VI.02 17:00 -Invited- STRIVING FOR FUNCTIONALITY: HETEROEPITAXIAL SELF ASSEMBLY OF CIRCUIT ELEMENTS THROUGH CONTROL OF KINETICS AND NANOPATTERNING
Jerrold A. Floro, Sandia National Laboratories, Albuquerque NM 87185-1415, USA, Jennifer L. Gray, Nitin Singh, Robert Hull and Dana M. Elzey, University of Virginia, Department of Materials Science and Engineering, Charlottesville VA 22904-4745, USA
 Strain-induced self-assembly during heteroepitaxial semiconductor growth can be used to produce quantum structures such as nanodots and nanowires. We manipulate the growth kinetics associated with molecular beam epitaxy of SiGe alloys on Si (001) to form more complex structures. By combining limited growth temperatures, elevated deposition rates, and interspersed annealing steps, we can simultaneously self-assemble 4-fold quantum dot molecules, quantum dots, and high aspect quantum wires. The quantum dot molecules are of interest as logic elements in quantum cellular automata schemes, the individual dots can serve as charge storage elements, and the wires could act as interconnects or resistors. This ability to self-assemble more complex structures is very promising, but significant challenges remain in order to produce a functional circuit via self-assembly. These challenges include shrinking of the feature size, electrical isolation, and precision placement of the various elements to form a circuit. We are addressing the latter by examining the effect of nanopatterns, generated using a focused ion beam, on the self-assembly process. In preliminary results we have been able to create uniform arrays of quantum dot molecules using nanoscale holes drilled into the substrate with the ion beam.
 This work was partially supported by the DOE Office of Basic Energy Sciences. Sandia is a multiprogram laboratory of the United States Department of Energy operated by Sandia Corporation, a Lockheed Martin Company, under contract DE-AC04-94AL85000.

- T-VI.03** 17:30 **GROWTH DYNAMICS OF Ge ISLANDS ON Si (001) AND (113) SURFACES**
W.-C. Yang and R.J. Nemanich, Dep. of Physics, North Carolina State Univ., Raleigh NC, 27695-8202, USA, M. Himmerlich, Institute of Physics, Technical University Ilmenau, Ilmenau, Germany
 The growth dynamics of Ge islands on both Si (001) and (113) surfaces is explored using ultra-violet photoelectron emission microscopy (UV-PEEM). Real time monitoring of the in situ growth of the island structures can allow us to study the evolution of the size and shape of the islands. The islands were prepared by in situ Ge deposition of ~ 10 ML with a growth rate of 0.1 – 0.6 ML/min at temperatures of 450 – 550C followed by annealing at temperatures up to 700C. For Ge deposition of ~ 3 ML, we observed island formation on both surfaces indicating a surface morphology transition from strained layer to island growth. On Si (001) circular islands formed and grew larger without new island nucleation during further deposition. During annealing at higher temperature, we observed island coarsening through Ostwald ripening, where smaller islands evolved into larger islands. In contrast, on Si (113) we observed the formation of elongated islands oriented along the [33-2] direction, which showed further growth in length during continuous deposition. However, annealing at a higher temperature led to the transition of the elongated islands into shorter islands with an indented shape. AFM images of the islands grown on Si (001) showed dome shaped structures while the islands on Si (113) displayed flat tops of (113)-orientation with multiple side facets. The shape evolution of the islands is discussed in terms of strain relaxation and kinetic effects.
- T-VI.04** 17:45 **NANOSTRUCTURE FORMATION ON ION-ERODED SEMICONDUCTOR SURFACES**
C. Hofer, S. Abermann, C. Teichert, Institute of Physics, University of Leoben, Austria, T. Bobek, H. Kurz, Institute of Semiconductor Technology, RWTH Aachen, Germany, K. Lyutovich, E. Kasper, Institute of Semiconductor Engineering, University of Stuttgart, Germany
 The successful application of low-energy ion-bombardment on III-V semiconductors generating well ordered dot-patterns [1] motivated the investigation of ion-eroded SiGe and Si surfaces. Two different substrate types were used: Si(001) covered with native oxide and self-organized silicon germanium (SiGe) films grown on Si(001). The latter sample exhibits a checkerboard-pattern of {105} faceted pyramids and pits due to an interplay of a dislocation network and formation of three-dimensional islands [2].
 We used AFM to investigate the morphology evolution under noble-gas bombardment (< 1 keV). For the SiGe substrates, two distinct energy regimes were found [3]. For ion energies above 500 eV smoothing mechanisms lead to a flat surface, as was also found for Si samples. For ion energies of 500 eV and below, it was possible to transform the checkerboard-pattern into the Si substrate. There we observed a transition from pyramidal pits to shallow troughs. With increasing sputter depth, a large number of smaller craters evolve between the troughs which are less uniformly arranged. The roughness evolution and the role of misfit dislocations on the size and distribution of the nanostructure array is compared for several different SiGe substrates. Research supported by FWF, Austria (P14009).
 [1] S. Facsko, et al. Science 285, 1551 (1999).
 [2] C. Teichert, et al., Thin Solid Films 380, 28 (2000).
 [3] C. Hofer, et al., Nucl. Instr. and Meth. B, available online 20 Dec. 2003.
- T-VI.05** 18:00 **Si SUBSTRATE NANOPATTERNED AND Ge QDS SELF-ASSEMBLING**
A. Ronda, I. Berbezier, CRMC2 - CNRS, Campus de Luminy, Case 913, Marseille, France
 New generation of electronic devices need the self-assembly of highly packed quantum dots. Of the main issues in the growth of such nanostructures is the lateral ordering of quantum dots. During the growth of Ge / Si, 3D islands naturally form under the effect of epitaxial stress and of kinetics. However, it is not possible to predict nor to control the nucleation sites of islands. We propose a two-step process that consists of substrate self-nanopatterning in a first step and Ge dots self-assembly in a second step.
 In a first part, the study aims at a perfect control of the formation and evolution of the periodic patterns. We particularly investigate the kinetic and stress driven kinetic instabilities that occur during the MBE growth of Si / Si and SiGe / Si respectively. The temperature regimes of the instabilities and the critical exponents describing the morphological evolution with time of the instability were determined. Illustration of large-scale patterns obtained using these growth instabilities is given. In particular, the different patterned Si substrates resulted from: 1) equilibrium faceting of Si(111) 1.5° off; 2) kinetic corrugation by means of Si/Si instability; 3) kinetically activated stress-driven growth instability of Si_{1-x}Ge_x/Si (001) 1.5° off or 10° off. In a second part, we investigate Ge dots ordering on the different patterns. The best ordering is obtained by using stress fields or chemical effects. Efficiency of step bunches is also evidenced on (111) surfaces but not on (001). SiGe undulations perpendicular to the step edges induced a very nice alignment of the Ge dots. In the end, we show that alignment can be further improved by combining stress and surfactant effects.
- T-VI.06** 18:15 **TRENCH FORMATION, STRESS RELIEF, AND INTERMIXING IN GE/SI(100) ISLANDS**
 Ph. Sonnet(A) and P.C. Kelires(b), (a)Laboratoire de Physique et de Spectroscopie Electronique, 4 rue des Freres Lumiere, 68093 Mulhouse Cedex, France, (b)Physics Department, University of Crete, P.O. Box 2208, 710 03 Heraclion, Crete, Greece, and Foundation for Research and Technology-Hellas (FORTH), P.O. Box 1527, 711 10 Heraclion, Crete, Greece
 One of the most interesting phenomena observed during Ge/Si(100) heteroepitaxy is the appearance of trenches (grooves of missing material) around the periphery of dome islands, grown at sufficiently high temperatures (T > 600 C). The morphology of these objects is well analyzed, but the physical origin of their formation is unclear, and the stage during growth at which they are nucleated is unknown. Also, the interplay between trench formation and intermixing as stress relief mechanisms is not well understood. Here, we present results of Monte Carlo simulations of stress buildup and relief, which shed light onto the physical origin of trench formation and identify the stage of their nucleation. By monitoring the stress evolution as the island grows layer by layer, we show that a trench is most likely being formed halfway during growth. The primary driving force for this phenomenon is the reduction of the concentrated stress below the edges of the island, but not the need to provide Si into it, as is widely believed. Thus, trench formation precedes intermixing. However, once the trench is formed, subsequent intermixing through it is enhanced, and nearly compensates the stress in the island.

Thursday, May 27, 2004

Morning

Session VII: Growth and self-assembling of semiconductor nanostructures

Session chair: A. Ronda

T-VII.01 08:30 -Invited- SELF-ASSEMBLED SEMICONDUCTOR QUANTUM DOTS GROWN ON EX-SITU AND IN-SITU PATTERNED SUBSTRATES

Oliver G. Schmidt, Max-Planck-Institut fuer Festkoerperforschung, Heisenbergstrasse 1, 70569 Stuttgart, Germany

One of the most interesting phenomena observed during Ge/Si(100)

heteroepitaxy is the appearance of trenches (grooves of missing material) around the periphery of dome islands, grown at sufficiently high temperatures ($T > 600$ C). The morphology of these objects is well analyzed, but the physical origin of their formation is unclear, and the stage during growth at which they are nucleated is unknown. Also, the interplay between trench formation and intermixing as stress relief mechanisms is not well understood. Here, we present results of Monte Carlo simulations of stress buildup and relief, which shed light onto the physical origin of trench formation and identify the stage of their nucleation. By monitoring the stress evolution as the island grows layer by layer, we show that a trench is most likely being formed halfway during growth. The primary driving force for this phenomenon is the reduction of the concentrated stress below the edges of the island, but not the need to provide Si into it, as is widely believed. Thus, trench formation precedes intermixing. However, once the trench is formed, subsequent intermixing through it is enhanced, and nearly compensates the stress in the island.

T-VII.02 09:00 METALLIC NANO DOTS REALIZED BY A SUBTRACTIVE SELF ORGANIZATION PROCESS
A. Lugstein, B. Basnar, and E. Bertagnolli, Vienna University of Technology, Floragasse 7, 1040 Vienna, Austria

We present a new approach for the generation of uniform metallic nano dots, which in contrast to conventional bottom up or top down processes is based on a subtractive self organization process relying on material decomposition induced by focused ion beam exposure and subsequent rapid thermal annealing.

First, we study the morphological evolution of the InAs, GaAs, GaP, GaSb surface due to FIB exposure by in-situ FIB-SEM combined with XRD and AFM. The chemical composition of the pattern was analyzed using high resolution AES. We completed these many-faceted experimental study with the morphological study of the FIB exposed surface subjected to RTA by optical microscopy, AFM and electrical measurements. Nanometer sized Ga droplets can be formed in a size and position controlled fashion on GaAs (100), and GaAs sputtered on Si (100) and SiO₂ substrates. The diameters of the dots ranges from 60 to 2000 nm. Two dimensional ordered arrays of embedded as well as freestanding metallic dots were fabricated by a site control technique relying on preformed craters and an irradiation mediated migration and agglomeration. The formation of these dots is discussed in terms of selective etching of arsenic due to the local energy injection by the gallium ions and further minimization of the excess free energy of the surfaces. In case of InAs as substrate FIB exposure leads to the formation of pure indium crystallites. As the mobility of indium determines the initial surface density of the crystallites, a lower energy injection for irradiation at 10 keV favors the formation of small crystallites with high density. Furthermore, this method is expected to apply to various metals apart from Ga and In.

T-VII.03 09:15 THE INFLUENCE OF GROWTH PARAMETERS ON SILICIDE NANODOT FORMATION
Koen Vanormelingen, Bart Degroote and André Vantomme, Katholieke Universiteit Leuven, IKS, Celestijnenlaan 200 D, 3001 Leuven, Belgium

The self-assembly of nanoscale structures on a surface critically depends on the conditions during growth. Parameters such as deposition rate, deposition temperature and surface reconstruction influence the surface morphology. We studied the influence of these parameters on the self-assembly of Fe-silicide nanodots on the Si(111) surface. The samples were grown using molecular beam epitaxy and low energy ion deposition (LEID). In LEID, an isotopically pure ion beam with an energy of 50 keV is decelerated to a well defined energy between 0 and 200 eV and consequently deposited onto the surface, allowing us to study the influence of the deposition energy. Moreover we used Ag as a surfactant to mediate the growth. Prior to deposition, the samples were cleaned using a two-step silicon flux method, resulting in a contaminant free surface. After deposition, the samples were measured with reflection high energy electron diffraction, scanning tunneling microscopy and conversion electron Mössbauer spectroscopy. Deposition of 1 Å Fe onto the Ag-passivated surface leads to small separate islands, consisting of a non-magnetic Fe-silicide. A systematic study of the influence of the deposition rate and temperature reveals an increasing island density as a function of decreasing temperature or increasing rate. This study, combined with theoretical calculations, shows that a specific morphology (e.g. step decoration) can be achieved by an appropriate choice of growth parameters.

T-VII.04 09:30

CLOSELY PACKED InAs QUANTUM DOTS GROWN BY MBE ON NANOPATTERNED GaAs (001) SUBSTRATES OBTAINED BY AFM LOCAL OXIDATION

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Different approaches are being tried for obtaining highly ordered InAs quantum dots (QDs) template layers. Important advances in controlling both size and spatial localization have been achieved by using prepatterned substrates. In this work we present a method to obtain highly ordered and closely packed InAs QDs arrays by tuning the value of the ratio between the diameter (f) and pitch (l), f/l , of nanometer size GaAs oxide dots. The dots have been fabricated by local oxidation nanolithography of GaAs (001) substrates.

The GaAs oxides were removed by using a thermal cracker hydrogen cell at low substrate temperature, $T_s < 500$ °C and a GaAs buffer layer of thickness d , was grown previously to InAs deposition. The dose of atomic H, the magnitude of T_s and d were optimized to obtain a clean and flat GaAs surface maintaining at the same time the 2D-arrays of nanoholes. Our experimental results show that when $f/l \sim 1$ is possible to obtain highly ordered and closely packed InAs QDs arrays by carefully adjusting the InAs deposited material. The QDs size can be controlled by changing f , the diameter of the GaAs oxide nanopattern. These results show a new way to produce high density and extremely uniform quantum dots arrays.

T-VII.05 09:45

NOVEL UNSTRAINED GaAs/AlGaAs QUANTUM DOTS BY HIERARCHICAL SELF-ASSEMBLY

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By means of an MBE equipped with an in-situ AsBr₃ etching unit we have grown GaAs/AlGaAs QDs through a series of self-assembly steps. We first grow Stranski-Krastanow InAs/GaAs(001) islands, overgrow them with GaAs and apply an etching step. This results in the spontaneous formation of nanoholes about 5-nm deep [1]. Nanoholes are then "transferred" to an AlGaAs surface by AlGaAs-overgrowth at $T_g=500$ °C and spontaneously fill up by deposition of a thin GaAs-layer followed by annealing. The GaAs-filled AlGaAs-nanoholes are then overgrown with AlGaAs to obtain QDs. Since GaAs/AlGaAs intermixing is negligible at T_g , the morphology of the QDs is that of the AlGaAs-nanoholes, which we determine by AFM and STM. The QD-optical-properties are investigated by photoluminescence (PL) spectroscopy and by single-QD m-PL and m-PLE (PL excitation). Our QDs show: (i) Tuneable size and light emission in the range of Si-CCD cameras; (ii) Ultranarrow inhomogeneous broadening with PL-FWHM down to 8.9 meV at low excitation intensity I_{exc} ; (iii) Clear excited states when I_{exc} is increased; (iv) Single QD spectra show resolution-limited narrow lines corresponding to excitonic, multiexcitonic and excited state recombination, witnessing the high quality of the structure. Nominal compositions and measured geometry are used as inputs to 8-band $k \times p$ theory calculations. With no further assumptions our calculations are able to interpret the main features of our PL and PLE spectra. Due to their properties and easiness of the fabrication process, these QDs can be used as a new playground for studying the fundamental properties of single QDs and possibly of laterally-coupled-QDs.

[1] R. Songmuang, S. Kiravittaya and O. G. Schmidt, Appl. Phys. Lett. 82, 2892 (2003).

T-VII.06 10:00

STRAIN-BASED MANIPULATION OF 3-D QUANTUM STRUCTURE

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We demonstrate the ability to manipulate self-assembled formation of quantum structures through the balance of lattice mismatch and surface migration. Using an AlGaAsSb metamorphic buffer layer (MB) grown on GaAs to alter the lattice constant of the growth matrix, we are able to form quantum dots(QDs) under highly strained conditions ($D_{ao}/a > 4\%$) and quantum dashes(Qdashes) under low strain conditions ($D_{ao}/a < 4\%$). Under low strain conditions, the asymmetric surface migration inherent in the [1-10] direction in zinc blende structures dominates the formation process forming Qdashes. Under high strain conditions, the reduction of strain energy(formation of 3-D structure) limits the surface migration along both directions and results in a symmetric QD. We vary the strain conditions of QD growth using a metamorphic buffer layer that increases the growth matrix, using step-graded Sb composition in AlGaAsSb superlattice, from GaAs to either $a_0 = 5.78\text{Å}$ (MB1) or $a_0 = 5.89\text{Å}$ (MB2). We study(a) InAs QDs grown on MB1 where $D_{ao}/a \sim 4.8\%$. The InAs Qdashes(b) are formed on a more aggressive MB2 where $D_{ao}/a \sim 3\%$. We can form QDs on MB2 (c) by increasing the lattice constant of the QD material: InGaSb QDs ($a_0 = 6.34\text{Å}$) are grown on MB2 to establish $D_{ao}/a \sim 7\%$. The QDs in(a) and (c) have 3-4 nm and 6 nm height, respectively, 30 nm diameters, and $5 \times 10^{10}/\text{cm}^2$ density. The greater aspect ratio of the QDs grown with higher strain is due to the larger strain energy that needs to be diffused by the surface curvature. The Qdashes have a 1.5- 2nm, 30nm width and a length that varies from 50 – 300nm. The ground-state emission wavelengths of the three ensembles are 1.6mm, 2.0 mm and 2.3mm, respectively - all on a GaAs substrate. Our ensembles are studied using AFM, PL, HRTEM, time-resolved PL and DLTS.

T-VII.07 10:15

SELF ORGANIZED SiC NANOSTRUCTURES ON SILICON

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Self-organization in a system with chemical interactions between substrate (Silicon) and deposit (Carbon) is demonstrated by growing SiC dots on silicon substrates. The large lattice mismatch between Silicon and SiC of 20% stimulates a three-dimensional nucleation on the substrate. This spontaneous formation of islands is a powerful tool for the formation of dots. However, the chemical interaction leads to an instability of the Si surface during the nucleation and the growth: The need of Si for the SiC formation as well as the Si evaporation results in a depletion of the area surrounding the SiC islands. As a result well-defined pyramids with a four-fold symmetry are formed on (001)Si substrates with SiC nuclei on the top. The nucleation sites were controlled by the formation of equally spaced monoatomic and biatomic steps on (001) and (111)Si, respectively. The resulting terraces promote an alignment of the SiC dots along the step edges. By applying atomic force microscopy we demonstrate a lateral ordering of SiC dots in linear chains and in dense dot arrays. Depending on the process conditions the SiC dot separation was adjusted between 20 and 500 nm. These SiC dots could be used as etch mask to create self-organized three dimensional silicon nanostructures. The mechanisms of their formation and possible applications in antidot systems and as field emitter will be discussed.

10:30

BREAK

11:00-12:45

POSTER SESSION 1

T/PL01

STRAIN ANALYSIS OF A QUANTUM-WIRE SYSTEM PRODUCED BY CLEAVED EDGE OVERGROWTH USING GRAZING INCIDENCE X-RAY DIFFRACTION

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Quantum wires (QWRs) have been fabricated by the cleaved-edge overgrowth (CEO) technique using tensile strain to confine the charge carriers to one dimension. The cleaved edge of a pseudomorphically strained InAlAs/AlGaAs superlattice (SL) is overgrown by a GaAs layer of 10nm thickness. The lateral charge carrier localization in the overgrown layer is induced by the periodic strain modulation of the SL.

Using grazing incidence x-ray diffraction (GID) we determine this strain state of the system. The strain modulation due to the overgrown superlattice occurs only within 3 microns of the total wafer thickness of 150 microns. The GID technique allows for a clear separation of the strain modulation in the cap layer and the superlattice underneath. We prove that the strain modulation in the GaAs cap layer is purely elastic and not of compositional origin. The strain profile obtained is confirmed by finite-element model calculations. The strain modulated CEO layer represents a pre-patterned substrates which can serve as a template for the self-organized ordering of InAs quantum dots.

T/PL02

FABRICATION OF HIGHLY ORIENTED MICRO- AND NANOSTRUCTURES OF FERROELECTRIC P(VDF-TrFE) COPOLYMER via DIP-PEN NANOLITHOGRAPHY

Qian Tang, San-qiang Shi, Limin Zhou, Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Dip-pen nanolithography (DPN), using an atomic force microscopic tip to transfer ink to substrate of interest, was developed in 1999 by Mirkin et al. It's a simple and cheap nanolithography method compared with electron beam lithography, ion beam etching and photolithography, etc. Poly(vinylidene fluoride-trifluorethylene) [P(VDF-TrFE)] exhibits the highest ferroelectric polarization and electromechanical response among known polymers, and superior coupling effect than poly(vinylidene fluoride). It is widely used in the ultrasound industry as acoustic sensors and transducers due to its flexibility and lower acoustic impedance than that of piezoelectric ceramics. Micro- and Nanostructures of ferroelectric P(VDF-TrFE) polymer on gold are constructed via DPN. The thickness of the structures is about 1 nm. The polymer molecules are well orientated according to all-trans conformation and hold ferroelectric property on the gold surface through electrostatic interaction. The size of the structures formed by DPN depends on temperature, humidity, intramolecular interaction of P(VDF-TrFE) and the interaction between [P(VDF-TrFE)] and the substrate. This work shows potential applications of P(VDF-TrFE) in micro and nanostructured sensors.

T/PL03

SURFACE SILICON NANOSTRUCTURING BY ULTRA-SHORT MONOPULSE ANODIZATION

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Different Si-based nanostructures (nanodots, nanowires, etc.) are studied because of their outstanding physical properties: intensive luminescence at room temperature, single-electron electrical transport, etc. Numerous techniques were elaborated to fabricate such nanostructures: CVD, precipitation in SiO_x (rich in Si) layers, laser pyrolysis, AFM-assisted lithography, etc. However, all these fabrication methods are relatively difficult from manipulation point of view, time consuming and very expensive. In our work we report on a self-assembling fabrication of Si nanostructures by ultra-short (1ms- 100 ms) current pulses (0,3 - 1 A/cm²) applied during anodization of monocrystalline Si surfaces in HF-based solutions. Nanoscale structural particularities, dimension distribution and surface density of the formed Si nanoparticles are studied as function of Si wafer doping level and of anodization parameters: current density, pulse duration, electrolyte composition.

- T/PL.04** ELECTRONIC COUPLING EFFECT ON CARRIER DYNAMICS IN InAs/GaAs VERTICALLY STACKED QD LAYERS
M. Hjiri(a), L. Sfaxi(a), F. Hassen(a), H. Maaref(a), M. Senes(b), X. Marie(b), T. Amand(b), (a)LPSCE-, Faculté des Sciences de Monastir, Avenue de l'Environnement, 5000 Monastir, Tunisia, (b)LPMC-INSA-CNRS, Complexe Scientifique de Rangueil, 31077 Toulouse, France
 We report an experimental study of the photoluminescence (PL) properties, of vertically coupled InAs quantum dots (QDs) in a GaAs matrix with a large number of QD stacks, after both pico-second and continuous-wave excitation has been studied. We show that for large numbers of QD deposition cycles ( 10 planes), in addition to vertical coupling, lateral coupling effects between the laterally neighboring QDs influence the electronic spectrum of the structure. Lateral coupling of vertically-coupled QDs result in an appearance of a new photoluminescence (PL) line associated with a radiative recombination of excitons via the states of laterally coupled QDs, which dominates the PL spectrum for large number (20 planes). A strong increase of the radiative lifetime has been observed for the laterally coupled QDs. Moreover, a strong temperature, power excitation and energy detection dependences of the PL decay time has been found in the laterally coupled QDs.
- T/PL.05** EFFECT OF INTERFACE ROUGHNESS ON THE MAGNETIC ANISOTROPY IN EPITAXIAL FE FILMS
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 We have grown by molecular beam epitaxy (MBE) 300Å Fe films on single crystal MgO(001) substrates with Ag buffer layer with a thickness varying from 0 to 150Å. The epitaxial growth and structure quality of films were verified by reflection high-energy electron diffraction (RHEED) and X-ray diffraction. Small angle X-ray diffraction revealed the dependence of interfacial roughness on the thickness of Ag buffer layer. In-plane magnetic anisotropy was determined by means of magneto-optic Kerr effect at room temperature. The analysis of hysteresis loops showed a dependence of uniaxial anisotropy energy K_u and coercive fields on the Ag buffer layer.
- T/PL.06** "CONSTRUCTIVE NANOLITHOGRAPHY" - A HIERARCHICAL FABRICATION APPROACH TOWARDS THE CONTROLLED ASSEMBLY OF COMPLEX NANODIMENSIONAL CIRCUITS
S. Hoeppener, R. Maoz, J. Sagiv, Dept. of Materials and Interfaces, Weizmann Institute of Science, 76100 Rehovot, Israel
 A main challenge in the fabrication of complex arrangements of different nanoobjects is their planned hierarchical assembly in a controllable manner. Thus metal nanowires and functional nanoobjects such as nanoparticles have to be reliably integrated into circuits that can be addressed via appropriate contact electrodes. Combining the SFM tip-mediated local electrochemical oxidation of terminal methyl groups of a self-assembled monolayer of n-octadecyltrichlorosilane (OTS) on silicon (which creates stable nanopatterns of chemically active surface groups) with further self-assembly and chemical derivatization routines provides generic tools towards the architecture of complex multicomponent assemblies. This approach, referred to as "Constructive Nanolithography", can be utilized to generate the required circuit components, such as nanoparticles positioned within conducting gap structures. The versatility and reliability of this approach originate from the high chemical selectivity of the derivatization procedures, that moreover allow the assembly of components consisting of different materials, such as metals and semiconductor particles, as well as from the structural and chemical stability of the resulting nanostructures. Examples will be presented demonstrating the hierarchical fabrication of well-defined metal nanogap structures with a controllable gap-size in the 10-100nm range and the subsequent integration of single semiconductor nanoparticles within the gap.
- T/PL.07** INFRARED-SPECTROSCOPIC INVESTIGATION OF GeO₂ – Ag⁺ NANOCOMPOSITES
S.V. Serezhkina, G.P. Shevchenko, S.K. Rakhmanov Physico-Chemical Research Institute, Belorussian State University, Leningradskaya 14, 220080 Minsk, Belarus
 Composite film coatings comprising nanodisperse silver are under investigation nowadays being of interest as promising electroconductive metal-polymer systems, nonlinear optical and luminescent materials. One way to fabricate silver-oxide films is the sol-gel method, which gives silver nanoparticles in oxide matrices formed by thermal treatment of silver-ion-containing films in a hydrogen flow or in air. This paper presents the results of the investigation of the structural and chemical transformations going on in GeO₂ – Ag⁺ nanostructured films when heated in the air by IR-spectroscopy. The new peaks at 722, 770 and 810 cm⁻¹ are shown to appear in the IR-spectra of the GeO₂ – Ag⁺ films heated at 600oC, while in powdered samples the same bands appeared at 500oC. These bands are present also in the IR spectrum of the silver germanate having the formula Ag₂Ge₄O₉ and may be assigned to Ge-O-Ag bonds vibrating. Based on these results one can conclude that both in films and powders the reason of Ag-nanoparticles formation in the air is the thermolysis of silver germanate, which is formed in the case of films at higher temperatures.
- T/PL.08** LONG WAVELENGTH VERTICALLY STACKED INAS/GAAS(001) QUANTUM DOTS WITH A BIMODAL SIZE DISTRIBUTION: OPTICAL PROPERTIES AND ELECTRONIC COUPLING
B. Ilahi, L. Sfaxi and H. Maaref, Laboratoire de Physique des Semiconducteurs et des Composants Electroniques, Faculté des Sciences, 5019 Monastir, Tunisia, G. Bremond, Laboratoire de Physique de la Matière (UMR CNRS 5511), INSA de Lyon, 69621 Villeurbanne, France, J. Dazord, Laboratoire Multimateriaux et Interfaces, UCB Lyon1, 69622 Villeurbanne, France
 Molecular beam epitaxy (MBE) grown vertically stacked InAs/GaAs(001) quantum dots (QDs) emitting at 1.3 μm at room temperature are investigated by photoluminescence (PL), polarized photoluminescence (PPL), photoluminescence excitation (PLE), and atomic force microscopy (AFM). The low temperature PL measurements show two well separated PL peaks arising from two QDs family with different dots. The AFM observation of the tenth QDs layer of uncapped sample confirms the former attribution. Furthermore, the large QDs are found to be elongated along the [1-10] direction. This structural information has been controlled in all the staking structure by PPL. By further increasing the excitation power, the high energy side peak keeps a Gaussian form and a constant energy position while a blue shift and an increase in the high energy asymmetrical broadening have been observed for the high energy side one. By varying the PLE detection energy, following the blue shift, we have evidenced lateral coupling between small size QDs and vertically coupled large size QDs in the upper layers. These results can help improve some fundamental properties understanding for optoelectronic applications.

- T/PL.09** NUCLEATION AND RIPENING OF METALLIC NANOISLAND
A.C. Powell, F. Silly and M.R. Castell, Department of Materials, University of Oxford, Parks Road, Oxford OX1 3PH, U.K.
Nanometre sized metal islands on oxide supports are used in diverse applications from catalytic materials to gas sensors. Interaction between the oxide support and the islands, the island shape, the temperature dependence of island ripening, and molecular interactions with the islands are all active areas of study. Through ultra high vacuum elevated temperature scanning tunnelling microscopy we have investigated the growth and ripening behaviour of Fe and Pd islands on single crystal SrTiO₃ (001) supports. The structure of the oxide substrate can be imaged at atomic resolution. When Fe is deposited on the substrate it grows epitaxially and forms nanometre scale islands. When imaged at elevated temperatures (400 C) we observe the Ostwald ripening of the islands. A more complicated relationship is exhibited for the Pd on SrTiO₃ (001) system. Pd initially forms nanometre scale epitaxial huts which upon ripening transform into pyramids. The epitaxial relationship for the huts and pyramids is (001) on the (001) substrate. Upon further ripening the islands change the crystallography of the interface and become (111) on the (001) substrate. We are currently investigating the origin of this shape change.
- T/PL.10** SPECTRAL MANIFESTATION FOR AGGREGATION AND NON-LINEAR OPTICAL PROPERTIES OF POLYMOLECULAR LAYERS BASED ON SPIROCUMARINPYRANS
V.A. Barachevsky, R.E. Karpov, I.A. Nagovitsin, G.K. Chudinova, Yu.P. Strokach, V.S. Miroshnikov. T.A. Chibisova, V.F. Traven', Photochemistry Center of RAS, Institute General Physics of RAS, L.I. Mendeleev Russian University of Chemical Technology, Moscow, Russia
For the first time it was found formation of the J-aggregates in solutions and polymolecular layers based on indoline spirocumarinpyrans. Aggregation efficiency of the merocyanine molecules for these compounds depends on solution polarity and the presence of the substituent into the indoline fragment. The spectra of these compounds in solution are characterized by the very narrow absorption (490 nm) and fluorescence (515 nm) bands. In the case of the polymolecular layers produced by the Langmuir-Blodgett technique maxima of these bands coincide very closely. The resonance fluorescence is observed. It is a strong demonstration of J-aggregate formation.
The prepared polymolecular layer were used for the study of the non-linear optical properties by measuring a relation between the intensity of second-harmonic generation and an angle of incidence for laser radiation. It was found efficient second harmonic generation depending on the J-aggregate structure. The above mention results may be used for the development of the devices for frequency transformation of laser radiation.
- T/PL.11** MORPHOLOGICAL AND STRUCTURAL STUDY OF ULTRA THIN METAL FILMS ON DIFFERENT SUBSTRATES
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Processes of nucleation and shaping of nanostructure of surface of substrates with different physical-chemical nature were investigated ultra thin metallic films (Al, Ni with thickness 20 – 100 nm) were deposited on polymer (PET) and quartz glass substrates by evaporation in vacuum. It is shown that the size of nanostructured formations can be changed by changing the evaporation rate and substrate temperature (essentially reaching the polymer glassing temperature region) XRD and AFM were employed to study structural and morphological changes of the films. In parallel optical transmittance and electrical properties (resistivity) of thin films were registered.
- T/PL.12** ELECTRICAL AND OPTICAL CHARACTERIZATIONS OF TiC/POROUS Si/Si STRUCTURES
N. Gabouze(a), K. Ait-Hamouda(a), S. Ouendadji(a), K. Henda(b), N. Saoula(b) (a)UDTS, 2 Bd Frantz-Fanon, B.P. 399 Alger-Gare, Algiers, Algeria, (b)CDTA, Haoche Loukil B.P 17 Baba-Hassen, Algiers, Algeria
In this paper, the electrical and optical behaviour of a new PS-based structure based on titanium carbide (TiC) covered PS structure has been studied. The layer of the titanium carbide was deposited by pulverisation RF of titanium under methane/argon atmosphere. A rectifying behaviour has been observed from the I-V curves of the structures, which suggests a Schottky-like junction. The change in the electrical parameters, such as the ideality factor, resistivity of the films, differential resistance etc, was attributed to the presence and the increase of hydrogen concentration when the TiC layer increases. The value of the refractive index of the TiC layers is close to that of Si₃N₄. The values of the extinction coefficient k indicate that TiC layers are transparent. Finally, spectral response measurements show that the TiC/PS/Si is transparent in the near infrared region.
- T/PL.13** FUNCTIONALIZATION OF OXIDIZED SILICON SURFACES WITH METHYL GROUPS AND THEIR CHARACTERIZATION
A. Schmohl, A. Khan and P. Hess, Institute of Physical Chemistry University of Heidelberg 69120 Heidelberg, Germany
By functionalization of surfaces with specific end groups, such as an organic monolayer, the surface properties can be controlled at the molecular level. Organic monolayers grafted on silicon are of increasing interest in advanced silicon technologies such as MEMS and sensor applications. Results are presented for the termination of oxidized c-Si and a-Si surfaces with chemically bonded methyl end groups. The trimethylsilyl (TMS) and pentamethyldisilyl (PMDS) terminated surfaces were prepared by silanization with suitable chloro compounds.
The functionalization was characterized by FTIR-ATR spectroscopy and thermal desorption spectroscopy (TDS). The IR spectra of the PMDS surface shows two CH stretching peaks at 2897.8 and 2954.7 cm⁻¹ with a FWHM of 21 cm⁻¹. The thermal desorption spectra indicate cleavage of Si-Si bonds and desorption of trimethylsilane. Among other peaks, broad peaks at m/z = 59 u/e [HSiCH₃]₂ and 73 u/e [Si(CH₃)₃] were observed around 350°C, confirming the expected chemical termination of the silicon surface. The wetting behavior, adhesion, and mechanical properties were studied by contact angle measurements and scanning force microscopy (SFM) and compared with the well-defined Si(111)-(1x1):H surface and a SAM terminated silicon surface with long hydrocarbon chains, prepared with octadecyltrichlorosilane (OTS). The water contact angle was 110° and 90° for TMS on amorphous and crystalline silicon surfaces, respectively, comparable to SAM surfaces, and 85° for PMDS. The friction force measured for TMS and PMDS was comparable and about 3 times higher than that of the H-terminated silicon and SAM surface and the friction coefficient showed a similar trend.

T/PL14

SELF-ASSEMBLING OF METAL NANOPARTICLES ON PATTERNED SEMICONDUCTOR SURFACES (Au/GaAs)

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Large scale patterning of semiconductor surfaces by spontaneous or artificial structuring is of special importance. As spontaneous pattern surface we used the anisotropically etched GaAs (100) surfaces with two types of microrelief: dendrite-like and quasi-grating-like. To obtain strictly periodic relief, we developed a holographic photochemical etching technology. In these ways we obtained diffraction gratings with periods varying from 1 up to 5 μm , as well as bigratings (a set of two gratings oriented in perpendicular directions). Gold film was produced using local electrochemical deposition from aqueous solution of AuCl₃ salt or vacuum deposition of gold. By varying the deposition conditions the technology allowed us to obtain isolated metallic nanoclusters (5 - 25 nm), as well as some fractal, chain-like structures including percolation threshold. The morphology and statistical geometric parameters of metal clusters and surface relief were examined by AFM and SEM. Atomic composition of surface film was investigated by energy dispersive X-ray analysis. Our results show that gold predominantly locates in the top of the relief. Since the surface roughness strongly affects the rate of metal deposition usage of microrelief GaAs surfaces allows design of nanostructure deposition and to obtain specific metal coating: quantum dots and wires. Nanostructures have been characterized by minima in reflection/absorption spectra in 300-900 nm region connected with surface polariton excitation.

T/PL15

NANOPATTERNING SURFACES BY SELFORGANIZED GROWTH OF ORDERED AND STRAINED EPITAXIAL LAYERS

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In recent years extensive efforts have been devoted to the formation of semiconductor nanostructures at the substrate surface. Stress and its appropriate management influence the properties of the resulting surface structure. Properties of In_xGa_{1-x}P epitaxial layers lattice matched to GaAs are strongly influenced by spontaneous ordering on the Ga/In sublattice. The degree of order in InGaP grown by MOVPE can be controlled by growth parameters, such as the growth temperature, V/III ratio, and growth rate. The surface roughness connected with the alternation of ordered domains and antiphase boundaries can reach 10 to 100 nm. In addition, the ordered domains are mostly oblong with their longer dimension parallel with the [110] direction. Under appropriate conditions strained and ordered InGaP epitaxial film forms a three dimensional system of small ridges and valleys, which may be used as a stencil to form nanoparticles or oriented nanowires from various magnetic materials as Co, Ni or diluted magnetic semiconductors technologically compatible with the GaAs material system (GaMnAs, InMnAs etc). In our paper we will present the influence of growth temperature and growth pressure on the formation of self-assembled surface nanoroughness of ordered and strained InGaP epitaxial layers. Undoped In_xGa_{1-x}P epitaxial layers were grown by a low-pressure MOCVD technique at 20 or 50 hPa. All epitaxial layers were grown on exactly (001)-oriented semi insulating GaAs substrates at growth temperatures T_g varied from 520 to 720 °C. This interval was chosen as a typical temperature range at which an evolution of the ordering effect can be achieved. The V/III ratio was kept constant at a value of 254, and the growth rate was close to 1000 nm/h.

T/PL16

OPTICAL CHARACTERIZATION OF Ge NANOCRYSTALS EMBEDDED IN SiO₂

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Ellipsometry is a very sensitive measurement technique that uses polarized light to characterize isotropic and anisotropic thin films, surfaces, and material microstructure. It derives its sensitivity from the determination of the relative phase change in a beam of reflected polarized light. This technique is based on the measurement of the parameters Psi and Delta named ellipsometric angles. Recently the spectroscopic ellipsometry (SE) was demonstrated as a powerful method suitable for investigating the optical properties of nanostructures. In this paper, we propose to study by SE the optical responses of Ge nanocrystals (nc-Ge) formed in SiO₂ matrix by ion implantation. The nc-Ge samples were obtained by implantation of Ge⁺ into SiO₂. The silicon was used as the substrate for the samples. SE measurements on the implanted samples were performed in air at room temperature by varying the angle of incidence. The comparison between the ellipsometric parameters of the implanted and unimplanted SiO₂ layers was discussed. The complex refractive index of Ge nanocrystals (nc-Ge) has been determined in the spectral range of 300 to 850 nm. A change in the optical properties of the nc-Ge was observed as the nanocrystal sizes were reduced. Surface layer on the Si substrate was treated as a mixture of nc-Ge and SiO₂ components by using Bruggeman effective medium approximation. The optical properties of nc-Ge were determined using the point by point inversion model. The optical model was selected by taking into account of the ions distribution implantation. So the implanted layer was divided into ten sublayers, and each sublayer is characterized by its nanocrystal concentration. The model used in this work yield the nanocrystal depth, but not the nanocrystal sizes.

T/PL17

ROOM TEMPERATURE FUSION OF THE ASSEMBLED METAL NANOPARTICLES BY PLASMA

Shin-ya Onoue(a,b,c), Junhui He(a) and Toyoki Kunitake(a), (a)The Institute of Physical and Chemical Research (RIKEN), Frontier Research System (FRS), Topochemical Design Lab., Hirosawa 2-1, Wako, Saitama, 351-0198, Japan, (b)R&D Department, Kyoritsu Chemical & Co., Ltd, Shiomi 5-1-2, Kisarazu, Chiba, 292-0834, Japan, (c)PRESTO, Japan Science and Technology Agency (JST), Japan

A simple method for low temperature gold molding in the nano-dimension was newly developed. Firstly, gold nanoparticles stabilized by organic protecting groups were uniformly and closely assembled by solution casting or by using organic templates in one- and two- dimensions. The thus closely-aligned gold nanoparticles were cured with plasma at room temperature. After the decomposition of organic moieties by plasma curing, the fusion between neighboring particles occurred and the original shapes of nanoparticles completely disappeared. This phenomenon was attributed not only to the prompt removal of the protective organic shell, but also to the promotion of atomic diffusion between particles by plasma. The combination of nanoparticle assembly and plasma curing permits the design of nano-sized architectures such as gold wires or films.

T/PL18

ELLIPSOMETRIC OPTICAL STUDY OF COBALT NANOCRYSTALS IMPLANTED INTO SILICA MATRIX

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Ellipsometry is a well-known method in interfaces and thin films physics. It allows to determine parameters such as refractive indexes and thicknesses with great accuracy. It is based on the measurement of the ratio between the reflection coefficient for parallel and perpendicular to incidence plane electric field. Spectroscopic ellipsometry can also be used to characterize more complex structures such as multi-layers devices, alloys or aggregates materials. Such materials are considered as mixes presenting an effective refractive index function of the refractive indexes and volume fractions of each of the components (Maxwell-Garnett or Bruggeman effective medium approximation).

In this paper we present an optical characterisation by spectroscopic ellipsometry of cobalt clusters embedded into SiO₂ matrix. Cobalt clusters in a nano-size range (2-10nm) are formed into a 250 nm thick thermal SiO₂ layer on Si substrate during Co⁺ implantation at an energy of 160 keV and at a fluences of 10¹⁷ ions/cm² at fixed temperature. Spectroscopic ellipsometry measurements are performed in the (250-850nm) spectral range. Experimental data are analysed and interpreted in terms of both nanostructures distribution in depth into the sample and optical properties of the nanostructures of cobalt. We use a multi-layers model where volume fractions and complex optical constants of the nanostructures can be varied. For more reliability in our modelling process we use measurements at different angles of incidence. Special attention is paid on optical behaviour differences between bulk and nanostructured Co, which could offer interesting possibilities of complete size characterisation of the clusters.

T/PL19

OPTICAL AND NANOMECHANICAL STUDY OF ANTISCRATCH LAYERS ON POLYCARBONATE LENSES

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The research on optical technology during the past two decades has made significant progress concerning the materials that will be used for the development of better optics, such as low weight lenses for eyewear applications. Polymeric materials are good candidates for such optical applications due to their low weight and transparency. However, the deposition of anti-scratch (AS) coatings on the polymer surfaces is essential for the improvement of the mechanical behavior of the lens. In this work, we present a detailed investigation of the optical and nanomechanical properties of a Polycarbonate (PC) based optical lens and coated by an AS coating as a protective overcoat. The study of the effect of the AS coating on the optical response of the PC lens has been performed by the use of Spectroscopic Ellipsometry (SE) in the IR spectral region where the characteristic features corresponding to the different bonding configuration of the PC lens and the AS coating were studied. Also, the nanomechanical study of the PC lens, before and after the deposition of the AS coating performed by Nanoindentation measurements revealed the significant enhancement of the mechanical response of the PC lens/AS coating system. More specifically, the PC lens coated system is characterized by increased values of hardness and elastic modulus. Finally, the use of AS coating has found to lead to the reduction of the friction coefficient (μ) of the PC lens.

T/PL20

VERTICAL AND LATERAL ALIGNMENT AND INTERDIFFUSION IN MULTILAYER In_xGa_{1-x}As/GaAs (100) NANOSTRUCTURES

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Using the HRXRD and Raman scattering, we studied In_xGa_{1-x}As/GaAs multilayer structures with $x = 0.20 \text{ ? } 0.50$. The strains and nonuniform profiles of In-content along the growth direction were obtained from X-ray diffraction rocking curves for the (400), (311), (200) and (224) reflections. For samples with QDs ($x > 0.28$) distinct satellite structure of x-ray diffraction patterns was observed due to vertical periodicity of the multilayer structures and lateral ordering of QDs. Thermal annealing (550 ? 7500?) did not affect the structure periodicity but resulted in QD-related peaks broadening which arise from the preferential lateral interdiffusion of In/Ga atoms. Resonant Raman spectra of initial QDs samples show up LO-phonon bands of In(Ga)As 2D layer and localized LO-phonons of QDs with increased In-content. The annealing result in variation of composition as well as strain in QD-layers. Strain-enhanced interdiffusion mechanism is discussed.

T/PL21

NANOSTRUCTURES PREPARED BY HIGH TEMPERATURE-PRESSURE TREATMENT OF SILICON IMPLANTED WITH HYDROGEN / HELIUM

A. Misiuk, Institute of Electron Technology, Al. Lotnikow 46, 02-668 Warsaw, Poland

Effect of the high temperature (HT, up to 1520 K)–high hydrostatic pressure (HP, up to 1.5 GPa) treatment (for up to 10 h) on Czochralski silicon, Cz-Si, implanted (at energy ≈ 200 keV) with hydrogen (Si:H, H doses, $D \approx 2.7 \times 10^{17} \text{ cm}^{-2}$), helium (Si:He, $D \approx 1 \times 10^{17} \text{ cm}^{-2}$) or hydrogen and helium (Si:H,He, total $D \approx 1 \times 10^{17} \text{ cm}^{-2}$) was investigated by numerous methods.

The treatment at ≈ 1070 K-HP results in a creation of buried nanostructured layers containing hydrogen / helium filled cavities / platelets and numerous point and extended defects. Depending on the treatment conditions such layers can be strongly enriched in oxygen originating from the Cz-Si bulk. Hydrogen out-diffusion from Si:H is retarded at HP; hydrogen diffusivity in Si:H,He depends also on initial spatial distribution of implanted H and He atoms. Mostly extended defects (dislocations) are created in the Si:H, Si:He and Si:H,He structures treated at ≈ 1270 K-HP, as evidenced by strong photoluminescence, PL, at about 0.81 eV and 0.94 eV (for excitation with Ar laser). Visible PL at 400 – 500 nm detected for the similarly treated Si:H ($D < 1 \times 10^{17} \text{ cm}^{-2}$, excitation with N₂ laser) can be related to the presence of nanometer-sized Si crystallites and / or of specific chemical compounds containing hydrogen and oxygen.

This work is currently supported (at 2002-2004) by the Polish Committee for Scientific Research, grant no. 4T08A 034 23.

Thursday, May 27, 2004

Afternoon

Session VIII: Physics of nanostructures

Session chair: I. Berbezier

T-VIII.01 14:00 -Invited-

ASSEMBLING OF METALLIC NANOPARTICLES ON OXIDE SUBSTRATES: CONTROL OF DENSITY, SIZE, SHAPE AND INTERPARTICLE DISTANCE

Claude R. Henry, CRMCN-CNRS, Marseille, France

Metallic nanoparticles supported on oxide surfaces are suitable model catalysts which can be studied by surface science techniques. However in order to understand the origin of size effects in heterogeneous catalysis it is important to control, not only the size and the density of particles, but also the particle shape. The last goal is to control the spacial distribution of the particles. In this lecture we will review results obtained in the recent years. Pd and gold particles (1-20 nm) have been grown on MgO(100) surfaces by condensing metal atoms under UHV. The nucleation and growth kinetics has been studied, in situ, by various techniques: He atoms diffraction, AFM and GISAXS and, ex situ, by TEM. A unique shape is obtained by growing the particles at high temperature in order to get the equilibrium shape. We have also investigated the possibility to grow regular arrays of metal nanoparticles. Two methods have been used. The first one, electron beam lithography, has been used to make Pt particles, down 10 nm, on silica thin films. The second method used growth of Au and Pd clusters on spontaneously nanostructured ultrathin alumina films obtained by oxidation of NiAl(111) surfaces.

T-VIII.02 14:30

INVESTIGATION OF SHAPE, STRAIN, AND INTERDIFFUSION IN InGaAs QUANTUM RINGS USING GRAZING INCIDENCE X-RAY DIFFRACTION

Michael Sztucki(a,b), Till Hartmut Metzger(a), Virginie Chamard(c), Anke Hesse(d), (a)European Synchrotron Radiation Facility, BP 220, 38043 Grenoble Cedex, France, (b)CeNS at Ludwig-Maximilians-Universität München, Geschwister-Scholl-Platz 1, 80539 München, Germany, (c)Laboratoire de Thermodynamique et Physico-chimie Métallurgique, UMR CNRS 5614, ENSEEG, INPG, BP 75, 38402 St Martin d'Hères Cedex, France, (d)Institute of Semiconductor Physics, University of Linz, Altenbergerstr. 69, 4040 Linz, Austria

The formation of nanoscopic InGaAs ring structures on a GaAs (001) substrate takes place when InAs quantum dots, grown by Stranski-Krastanov self-organization, are covered by a thin layer of GaAs. The shape transformation into rings is governed by strain, diffusion and surface tension, quantities which are of importance to understand magneto-optical and electronic applications of the rings.

In this work we report on the characterization of morphology and structural properties such as strain and chemical composition of the rings in three dimensions. To this end we applied grazing incidence small angle x-ray scattering (GISAXS) and grazing incidence diffraction (GID) and compared the results with AFM measurements. From GISAXS the shape is found to be of circular symmetry with an outer radius of 26 nm, a height of 1.5 nm, and a hole in the middle, in good agreement with AFM measurements. The most surprising results are obtained from intensity mappings in reciprocal space close to the (2 2 0) and (2 -2 0) reflection done in surface sensitive GID geometry. From a comparison of the intensity maps with finite-element model calculations the InGaAs interdiffusion profile in the ring is determined. It strongly depends on the crystallographic orientation. In the ring we find a maximum InAs concentration of more than 80% along [1 -1 0] while along [1 1 0] it is below 20%. This is explained by the preferred diffusion of InAs along [1 -1 0].

T-VIII.03 14:45

A COMPARATIVE STUDY OF Ag AND Cu ADHESION ON MgO(001) SURFACE

Yuri F. Zhukovskii and Eugene A. Kotomin, Institute for Solid State Physics, University of Latvia, Kengaraga str. 8, Riga 1063, Latvia, David Fuks, Mater. Eng. Dept, Ben Gurion University, Beer-Sheeva 84105, Israel, Simon Dorfman, Dept. of Physics, Technion, Israel Institute of Technology, Haifa 32000, Israel

The atomic and electronic structure of the metal-oxide interfaces is of great interest for the micro- and nanoelectronics. In this study, we employ thin 2D slabs for ab initio DFT modeling of transition (copper) and noble (silver) atoms deposited on the perfect (001) magnesium oxide [1]. One-side nanostructures of copper and silver atop MgO substrate were studied for a metal coverage varied from 1/4 monolayer (ML) to a 2 ML. To this end, we performed calculations for a 2x2 extended surface unit cell of MgO(001). We compare results for copper and silver atom positions over surface magnesium and oxygen ions. For all interfacial structures, we have carried out the optimization of the substrate lattice constant and the interfacial distance. The results for the atomic and electronic structure, total and partial DOS, charge transfer across the interface and relevant bond populations as a function of the metal coverage are carefully compared. We calculated and compared also the migration energy for the single Ag and Cu atoms on the defectless MgO surface, which is relevant for the kinetics of the metal atom clustering upon adsorption.

T-VIII.04 15:00

GOLD COATED PALLADIUM NANOPARTICLES DEPOSITED ON THE PORE WALLS OF NANOPOROUS ANODIC ALUMINA USING ELECTROLESS DEPOSITION

Anders Johansson, Tobias Törndahl, Jan-Otto Carlsson and Mats Boman, Uppsala University, Department of Materials Chemistry, Box 538, S-75121 Uppsala, Sweden

Gold coated palladium nanoparticles with a narrow size distribution were deposited along the pore walls of nanoporous anodic alumina (Whatman Anodisc) using an electroless deposition technique. The depositions were done by wetting the Anodisc membranes in a solution containing ions of the element chosen for deposition (i.e. Au³⁺ or Pd²⁺). After wetting the membranes they were quickly heated to 300-500°C using a hot air-stream. The membranes were subsequently cleaned in deionized water and dried in a 50°C air-stream. The above mentioned deposition process were cycled various numbers of time in order to obtain particles of different sizes. First palladium was deposited on the membrane pore walls secondly gold was deposited on the palladium particles using the same technique. Scanning electron microscopy was used for determination of the particles size distribution and particle density. X-ray diffraction confirmed that the particles consisted of metallic palladium and gold.

T-VIII.05 15:15

ELEMENTARY DIFFUSION PROCESSES FOR PREFERENTIAL NUCLEATION AND GROWTH OF Co NANOSTRUCTURES ON THE HERRINGBONE RECONSTRUCTION OF Au(111)

H. Bulou, C. Goyhenex, and C. Massobrio, IPCMS-CNRS UMR 7504, 23 rue du Loess, 67034 Strasbourg Cedex 2, France

The spontaneous formation of nanostructures by epitaxial growth of submonolayer films has raised considerable interest since ten years, due to their potentiel for numerous technological and fundamental applications.

A prominent example is metal deposition on reconstructed Au(111), where regular arrays of admetal islands can be formed by preferential nucleation at uniformly spaced dislocation sites of the reconstructed Au surface layer. If the preferential nucleation phenomena is now well understood in term of structural inhomogeneity of the gold substrate [1], the dynamical mechanism of the exchange at the kink of the reconstruction as well as the migration behavior of adatoms on inhomogeneous substrate are unknown. In this framework, we have investigated the effects of an inhomogeneous substrate on island nucleation using Molecular Dynamics. A system of about 50000 atoms has been used in order to reproduce the herringbone reconstruction of gold. The interatomic forces have been calculated in the framework of the Tight Binding Theory within the Second-Moment Approximation and Newton's equations of motion have been solved using a predictor-corrector algorithm with a time step of 1 femtosecond. The dynamical behavior of the system has been investigated at 400 K and 600 K on about 200 picosecond. The elementary diffusion processes and results concerning the diffusion anisotropy on such a surface are presented as well as exchange mechanisms at some selected location of the reconstruction. On the basis of these results, a screenplay for the preferential nucleation and growth of Co clusters on the herringbone reconstruction of Au(111) is put forward.

[1] H. Bulou and C. Goyhenex, Phys. Rev. B 65 (2002) 045407

T-VIII.06 15:30

Au-CATALYSED EPITAXIAL GROWTH OF ZnO NANORODS ON (100)Si BY THE VAPOUR-LIQUID-SOLID MECHANISM

P. Prete(a), N. Lovergine(b), A. Taurino(a) and A.M. Mancini(b), (a)IMM-CNR, Sez. di Lecce, Via Arnesano, 73100 Lecce, Italy, (b)Dipartimento di Ingegneria dell'Innovazione, Università di Lecce, Via Arnesano, 73100 Lecce, Italy

In the last few years the growth of one-dimensional (1D) semiconductor nanocrystals, such as nanowires and nanorods, has gathered considerable research interests due to their importance for both fundamental physics studies and potential applications in nanoscale electronics and photonics. ZnO is a semiconductor compound of great interest in reason of its attractive electronic properties: a wide band-gap energy of 3.37 eV at RT and an exciton binding energy of 60 meV, which is larger than the thermal energy at room temperature. In this regard, ZnO is an excellent material for fabrication of UV/blue light emitting diodes and laser diodes. The growth of 1D nanocrystals of ZnO allows to combine the material attractive properties with the benefits of reduced dimensionality.

For optoelectronic applications ZnO nanostructures and epilayers are usually grown on nearly lattice-matched substrates, such as sapphire. However, the use of Si wafers is very attractive as it may allow the integration of future ZnO-based nano-devices with existing Si technology.

In this paper we report on the Au-catalysed epitaxial growth of ZnO nanopillars on (100)Si by the Vapour-Liquid-Solid (VLS) mechanism. The process is based on the high temperature carbothermal reduction of ZnO powders by graphite to form Zn and CO/CO₂ vapours. The Zn and CO/CO₂ molecules thus formed are then transported by a pure N₂ flow into a lower temperature zone of a hot-wall reactor, where the growth of ZnO nanopillars is catalysed by Au nano-islands formed on Si through annealing of a Au-evaporated thin film.

In our experiments 1-6 nm of Au were evaporated on (100)Si substrates and annealed at 815°C under inert gas for 20 min. This process formed round-shaped Au nano-islands, whose diameter varied between 8 and 70 nm, depending on the initial thickness of Au film. The island density ranged around 10¹⁰ cm⁻². The growth of ZnO nanorods was realised by preparing a 1:1 molar mixture of ZnO and graphite. The carbothermal reduction was performed at around 910 °C, whilst the growth of ZnO nanorods was carried out at 750 °C for different growth times. As confirmed by the XRD pattern of as-grown samples, these conditions allowed the growth of wurtzite-phase ZnO nanorods, having their major dimension parallel to the crystal c-axis and perpendicular to the (100)Si substrate. The nanorod dimensions ranged between 40 nm and 100 nm in diameter and up to a few microns in length. Their density ranged between 10⁸ cm⁻² and 10¹⁰ cm⁻². The dependence of nanopillar structure along with their orientation and size on VLS growth parameters has been studied. The conditions for the enhancement of the Au-catalysed VLS growth against the vapour-solid mechanism will be also discussed.

Finally, the vapour composition inside the reactor during the growth was analysed and monitored by in-situ mass spectrometry. In particular, we studied the formation of CO and CO₂ during the carbothermal reduction of ZnO as a function of temperature and ZnO/C molar ratios and correlated with the nanorod growth rates and diameter-to-height ratios. The vapour composition was also monitored as a function of time to check for aging effects of the ZnO/C source.

15:45

BREAK

16:15-18:30

POSTER SESSION 2

T/PIL.01

XPS ANALYSIS OF THIOL-CAPPED GOLD AND SILVER SELF-ASSEMBLED NANOCCLUSERS

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Metal particles with few nanometers diameter size and controlled dimensions may possess properties quite different from those of the corresponding bulk material. Gold and silver thiol-capped nanoclusters have been widely considered as model systems to study these new properties. In the present paper dodecanthiol gold and silver nanoclusters were synthesized via a two phase synthetic route and were selectively precipitated with a solvent/non solvent method (exane/ethanol pair) giving rise to four different precipitates. The starting suspensions were characterized via HRTEM which indicates that the Au and Ag are polydispersed single crystal nanoparticles with average diameter of 2.89 ± 0.36 and 4.10 ± 0.82 nm, respectively. The XPS analysis carried out on the same samples and on the first and last size selected precipitate, indicates the presence of the Au-Au (Ag-Ag) and Au(Ag)-S bond in the particles. In the last gold NCs precipitate a further component rises on the C 1s peak, from the low binding energy side, indicating a differential charging in the alkyl chain of the thiol capping agent and therefore an inhomogeneous metal-gold arrangement in a certain area of investigation. This effect is not revealed onto Ag where the grain size distribution is quite coarse. The repeatability of the XPS measurements in different areas and their independence from the randomly drop deposition onto silicon substrates, were assessed repeating the experimental procedure at least three times for each suspension. The results suggest that the self-assembling process could be favored in NCs showing a smaller grain size distribution.

T/PIL.02

INFLUENCE OF WETTING PHENOMENA IN THE FABRICATION OF MATERIAL ARCHITECTURES WITH GRID ASSISTED DEPOSITION

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The development of technology based on molecular material requires the fabrication of three dimensional architectures onto different kind of substrates. Control of the final motif at micron or submicron lengthscale through cheap processes is an appealing goal in this field of research. Grid assisted deposition has proven to be both a versatile and easy method for the generation of periodic structures starting from molecules in solution [1]. We have shown in a previous work that relative affinity of the solution for the material of the grid can be tuned in order to force the material to aggregate in two different forms filling the holes or replicating the bars of the grid [2].

In this work we have investigated the influence of the wetting properties of the molecule in the final morphology of the material arising from molecule/surface interactions. We show how such wetting/dewetting phenomena drive the aggregation of the material and how we can control this physical process changing the amount of material deposited. Moreover we are able to switch wetting/dewetting properties tuning the surface free energy of the substrate, with a molecular primer grafted on it. In this way we can choose to obtain material arranged either in continuous rows or in separated dots with a periodicity imposed by the motif of the grid.

[1] M. Cavallini, F. Biscarini, M. Massi, A. Farran Morales, D. Leigh, F. Zerbetto, Nano Letters 2002, 2, 635.

[2] M. Massi, M. Cavallini, S. Stagni, A. Palazzi, F. Biscarini, Materials Science and Engineering C, 2003, 23, 923.

T/PIL.03

MORPHOLOGY AND STRAIN OF GE QUANTUM DOTS GROWN ON NANO-PATTERNED SI (001) SUBSTRATE

P. Gentile(a), J. Eymery(a), F. Leroy(a), D. Buttard(a), T. Schüllli(a) and F. Fournel(b), (a)CEA Grenoble, DRFMC/SP2M, (b)CEA-DRT - LETI/DIHS - CEA/GRE, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France

For epitaxial heterostructure grown on pre-patterned samples, the local surface curvature and the mechanical relaxations strongly influence the Quantum Dots (QDs) shape and position. In this paper, we used a method that can be applied on the full Si wafer to control the pattern periodicity at the nanometer-scale. First, two “twin” surfaces of Si(001) produced by the splitting of a single wafer are bonded together and thinned. Then, the samples are etched with strain dependent mixtures to transfer the interface structure (square network of screw dislocations) and to create the patterned surface. The surface morphology consists of very regular square array of Si bumps giving a template for further growth [1]. STM is used to study the morphology of the initial patterned surface corresponding to a 1° rotation (periodicity about 22nm) and the deposition of 9 Å of Ge at 490°C. The evolution of the QDs shape is studied as a function of post-growth annealing (500-725°C). GIXRD is used to measure the strain. Reciprocal space mapping of in-plane (220) and (440) reflections between the initial patterned surface and the deposited surface clearly gives the orientation of the QDs and the strain state which will be compared to standard growth on flat surface. The analysis of radial scans along the square dislocation network using anomalous effects near the $K\&\#61537$ -Ge absorption edge (11.1 keV) explains the Ge contribution to scattered intensity.

[1] F. Leroy et al., Surf. Sci. 545 (2003) 211.

T/PIL.04

SCALING PROPERTIES OF Si SURFACE PATTERNED BY SELECTIVE CHEMICAL ETCHING

G. Wisz(a), T.Ya. Gorbach(b), P.S. Smertenko(b), A. Blahut(c), K. Zembrowska(a), M. Kuzma(a), (a)Institute of Physics, Rzeszów University, Rejtana 16a, 35-309 Rzeszów, Poland (b)Institute of Semiconductor Physics, National Academy of Sciences of Ukraine, Prospect Nauki 45, Kiev 28, 03028 Ukraine, (c)Department of Physics, Rzeszów University of Technology, Wincentego Pola 2, 35-959 Rzeszów, Poland

Fractal patterns have been observed on (100) Si surface etched in HF: HNO₃. The microstructure of the surface was examined by scanning electron microscopy with consecutive magnification in the range x500 to 50000.

The fractal dimensions of patterns were determined using the box-counting method. The crystal structure of the surface was studied by reflection high energy electron diffraction. Electron diffraction patterns were compared with those obtained for mirror Si surface. A model of the chemical etching on the atomic level was proposed. Patterned Si surface is addressed as shaped by crystallographic planes of high Miller indices. Therefore such surfaces are predicted as promising surfaces for direct heteroepitaxy.

T/PII.05

FORMATION AND PROPERTIES OF SELECTIVELY GROWN GE/SI QUANTUM DOTS

Lam H. Nguyen, M. Halbwx, V. Yam, J-L Perrossier, F. Meyer, D. Débarre, and D. Bouchier, Institut d'Electronique Fondamentale, UMR-CNRS 8622, Université Paris-Sud, 91405 Orsay Cedex, France, V. Le Thanh, CRMC2-CNRS, Campus de Luminy, Case 913, 13228 Marseille Cedex 9, France

During the last few years, selective epitaxial growth (SEG) of Ge quantum dots (QDs) has attracted growing interest. Research in this direction has been motivated by the fact that SEG may allow the formation of well-arranged dots over the surface, compared to a random dot distribution observed from the self-assembled technique.

In this work, we study selective epitaxial growth of Ge QDs on patterned Si(001) windows. The growth of Si buffers is found to develop into a pyramidal shape formed by {113} facets. These facets grow until the (001) top layer disappears and are showed to be an additional parameter for the regulation of the nucleation process of Ge islands. By monitoring the facet formation during the growth of Si buffer layers, we show that it is possible to form one Ge dot per window even in the case that the window size is not favourable for the formation of a single island. We have investigated the formation of Ge dots both in a single layer and in stacked layers as a function of the window size. We show that by controlling the kinetic parameters, we can obtain only one dot per circular window and a high cooperative arrangement of dots on striped windows. Then, the optical and electrical properties of dots grown both by selectivity and self-assembly will be reported and discussed in connection with the dot formation process.

T/PII.06

BURIED POLYMER WAVEGUIDES: FABRICATION APPROACHES AND CHARACTERIZATION

N. Kehagias, S. Zankovych, A. Goldschmidt, R. Kian, D. Chigrin, C.M. Sotomayor Torres, Institute of Materials Science, Dept. of Electrical, Information and Media Engineering, University of Wuppertal, Gauss-str. 20, 42097 Wuppertal, Germany and O.S. Kaiser, A. Neyer, Microstructure Group, Dep. of Electrical Engineering, University of Dortmund, Friedrich-Woehler-Weg 4, 44221 Dortmund, Germany

The requirement to expand optical communication networks by optimising commercial prospects and functional optical devices, opens the way to polymer waveguide devices. Polymer waveguides are expected to meet this requirement because they can be fabricated using a low-cost process with a high-volume manufacturing production with feature sizes down to 100 nm. A main consequence of buried symmetrical waveguides is a low light leakage from guiding layer and, therefore, they are the best choice for waveguiding photonic crystal structures.

In this work we address key fabrication issues, specific to fabricating buried waveguide system. These are a control of adhesion between polymer layers and filling in the cavities on pre-patterned polymer substrates. We demonstrate two buried waveguides, namely PMMA/PDMS and polystyrene/Teflon, fabricated by means of electron beam lithography and or nanoimprint lithography. For both waveguides, it is possible to realize a low confinement of the waveguiding mode in the core due to the low refractive index contrast (around 0.05-0.1). Thus, this configuration gives flexibility to reduce waveguide optical losses if the losses of the core polymer are too high, which is usually the case in near infrared for all easily processed polymers. The fabrication of buried 1D and 2D photonic crystal waveguiding structures and characterization of these devices are in progress.

T/PII.07

EFFECT OF PHYSICO-CHEMICAL PARAMETERS ON THE MORFOLOGY, TEXTURE AND CRYSTALLINITY OF THE NANOSTRUCTURED CALCIUM HYDROXYAPATITE COATINGS GROWN FROM AQUEOUS SOLUTIONS

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The effect of various growth factors such as supersaturation, Ca/P concentration ratio, pH and duration of growth period on the phase composition, morphology, texture and crystallinity of hydroxyapatite (HAp) coatings grown on titanium substrates is studied. Heterogeneous crystallization phase diagram of CaCl₂-Na₂HPO₄-NaOH-H₂O system in Ca/P-S-pH coordinates is determined. It is shown that kinetics of HAp formation well agrees with Arrhenius theory. The evolution of the morphology, texture and crystallinity of HAp coatings during the growth process is studied by XRD and SEM. It is found that HAp crystalline grains mainly grow along (002) axis of HAp lattice, regardless of the parameters studied. Texture and degree of crystallinity of HAp coatings rise with increase of growth period. The changes in shapes and size of HAp grains are observed at pH variations.

T/PII.08

TOWARDS FABRICATION OF ORDERED GALLIUM NANOSTRUCTURES BY LASER MANIPULATION OF NEUTRAL ATOMS

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In recent years a progress towards the fabrication of nanostructures was made through the laser cooling and manipulation of neutral atomic beams (Atom Nano-Fabrication). The ultimate resolution limit in ANF is associated with the quantum-mechanical wave-like nature of atoms. It has been shown that highly collimated beams of laser cooled atoms can be realized with a typical de Broglie wavelength much smaller than the spacing between atoms in a solid. Thus ordered nanostructures can be grown at the single-atom scale. A breakthrough for applications will be the demonstration of ANF for technologically relevant materials like Ga or In that are among the key building blocks of modern semiconductor devices.

During ANF the atom-surface interaction plays a crucial role in determining the lateral resolution of the nanostructures. Indeed surface mobility of the adatoms can increase the structures width or in some cases even wash them out completely. Some materials (like Ga) can also form self assembled droplets preventing any direct observation of periodic nanostructures created through atom focusing. In the case of Ga, the formation of nanodroplets is related to deposition in partial wetting conditions i.e. in liquid growth mode that is very sensitive to substrate surface parameters. In order to have a better understanding of this film growth mode and to avoid or minimize the effect of self-assembling, we started a systematic study of gallium growth on different substrates and experimental conditions. Our target is to find the right substrate and the right process conditions in terms of substrate material, temperature and surface treatment to control the diffusion process in order to demonstrate the feasibility of gallium ANF directly, that is the final goal of our experiment.

- T/PII.09** NANO-PATTERNED SILICON SURFACE FOR THE SELF-ORGANISED GROWTH OF MAGNETIC AND METALLIC NANOSTRUCTURES
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The objective of this work is to obtain self-organised growth of magnetic and metallic nanostructures on nano-patterned silicon surfaces. In order to grow well-defined nanostructures with a narrow size distribution, clean crystalline interfaces and a controlled periodic arrangement, a promising and original method is to couple microelectronic processes which will provide a periodic surface pattern, with self-assembled growth on such a surface. The structured surface serves thus as template to control the position of the nanostructures obtained by self-organisation processes.
Regarding the silicon templates preparation, we want a periodicity of the same order of magnitude as the atomic diffusion length during subsequent growth. By optimising e-beam nanolithography and reactive ion etching, we elaborated nano-holes arrays of typically 50 nm diameter with a 50 nm spacing on vicinal silicon surfaces. An annealing by direct current flow under ultra-high vacuum is then performed in order to obtain a corrugated surface mimicking the lithography pattern. It also ensures the surface cleanliness after the technological steps. For the metal deposition, we choose as a model system the growth of Au on vicinal silicon surfaces presenting arrays of step bunches 10 to 50 nm apart. The Au-Si alloy is well-known and forms a liquid eutectic at $T_m = 363^\circ\text{C}$. We will discuss the formation of Au-Si islands on step edges during growth under and above T_m .
- T/PII.10** SUBMOLECULAR CHIRALITY AND TWO-DIMENSIONAL SUPRAMOLECULAR SELF-ASSEMBLY OF MONODENDRONS AT THE LIQUID/SOLID INTERFACE
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Surface chirality is gaining increasing attention recently. We report on the self-assembly of the enantiomers, racemic mixture, and achiral analogue of an alkylated monodendron at the liquid-graphite interface. We have investigated the effect of the stereogenic center on the two-dimensional pattern formation with STM, and show that despite the relatively small size of the stereogenic center with respect to the overall molecular size, two-dimensional chirality is expressed. The racemic compound undergoes spontaneous resolution at the liquid-solid interface. However, chiral and achiral compounds form completely different two-dimensional patterns. Moreover, in case of the achiral derivative, its two-dimensional assembly is solvent dependent, leading to complex two-dimensional structures and providing control for the distance between 'supramolecular containers'.
- T/PII.11** FREE-STANDING NANOSTRUCTURES PREPARED BY TIP INDUCED OXIDATION
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Recently, great progress has been achieved in patterning semiconductor nanostructures using atomic force microscope (AFM). One of the most common techniques used is local oxidation (LO) of substrates and thin films by applying electric signal to the AFM tip.
The purpose of this work is to prepare free-standing nanoscale structures – cantilevers, bridges, etc., utilizing such tip induced local oxidation. The technology is applied to GaAs/AIAs/GaAs heterostructure with thin GaAs layer at the top, and it combines two basic steps: a) Tip induced local oxidation, and b), selective etching of sacrificial layer (AIAs) via the oxide created within the first step. Free-standing quantum wells and quantum wires can be prepared using the technology, as well.
- T/PII.12** A NOVEL APPROACH FOR FAST NANOPATTERNING OF TWO-DIMENSIONAL PHOTONIC CRYSTALS BY ELECTRON BEAM LITHOGRAPHY
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We propose two non-conventional Electron Beam Lithography (EBL) techniques for patterning of PMMA in order to fabricate two-dimensional Photonic Crystal (2D-PC) devices. The first technique consists of a single exposure of a large defocused gaussian beam, instead of the conventional pixel-by-pixel mode, in which each feature is composed of an array of smaller focused spots. Advantages of our approach include higher (5 to 10 times) exposure speed and reusability of the same scan description for the definition of crystals with different filling-factor and same lattice period. Experimental results are provided, which show the accurate control of the hole size with the exposure time, for different values of defocusing length. Another technique is based on the use of Continuous Path Control (CPC) exposure mode. This approach, which is peculiar of the Leica Lion LV1 system used in this work, allows the realization of very long bezier lines without field stitching errors. The lines are exposed in a single scan by keeping the e-beam continuously on, while moving the substrate holder. The mechanical errors of the motorized stage are compensated by an electronic feedback on the beam deflection. The flexibility of this method and its speed gain make possible the definition of both pillars and holes in a dielectric slab. In this case 2D-PC structures can be fabricated by crossing two arrays of straight lines rotated by 90° (square lattice) or two arrays of straight lines rotated by 120° (triangular lattice). By this method, exposure times reduction of more than an order of magnitude in the definition of a 2D-PC over a square-millimeter area has been achieved. 2D-PC patterns having lattice period of 300nm and filling factors in the range of 0.1-0.4 have been realized in both cases.

T/PII.13**FOCUSED-ION-BEAM (FIB) WAY TO MICRO-NANO MAGNETISM: Fe PATTERNS ON MgO**

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Fe micro and submicro magnets prepared on MgO substrates by means of a Focused-Ion-Beam (FIB) represent a good combination between a widely investigated but still exciting model system and a new preparation technique, to address the dependence of the magnetic properties on the reduced lateral dimensions and on the different shape and arrangements of metallic patterns.

The morphologically sharp interface, the very reduced electronic interfacial interaction and the good epitaxial relationship between overlayer and substrate suggest the Fe/MgO system to be a good approximation of a self-standing, crystalline Fe nano-micro array. FIB approach has been recently used as an alternative, simple patterning procedure with respect to the more popular, well assessed but quite complex etching or lift-off lithography. It has been shown that area densities as high as ~200 Gbit inch⁻² can be reached by FIB sculpting. Fe films 10 nm in thickness were epitaxially grown on the (001) MgO surface, and covered with 10 nm MgO passivation layer. FIB has been subsequently used to selectively remove portion of the bilayer to produce set of single crystal Fe micro and submicro patterns, different in size, shape and orientation. A detailed morphological, structural and compositional analysis of these patterns has subsequently been performed by AFM, SEM and Energy Dispersion Spectroscopy to investigate the quality of the individual metallic elements and of the overall pattern, therefore to assess the ultimate performances of the FIB procedure. Finally, the magnetic behaviour of the patterns has been studied by means of Magneto Optical Kerr Effect analysis.

T/PII.14**NANOPATTERN REALIZATION BY COLD ATOM DEPOSITION**

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The possibility of producing nanopatterns by laser manipulated atom deposition is attracting a growing interest in the scientific community due to the peculiar features of the technique. Nanopatterns are produced through interaction of a neutral atom beam with a "light masks", a suitable configuration of stationary e.m. fields quasi-resonant with an atom transition. Such interaction leads to space segregation of the beam into regular arrays of atoms, which can be used either for direct deposition or to impress a particle sensitive resist. The process keeps the advantageous possibility of large-area patterning typical of conventional lithography, while using a virtually defect-free mask able to produce regular nanopatterns with interferometric precision. The apparatus developed in this work exploits a beam of cold cesium atoms, differently from standard apparatus where thermal sources are used, offering advantages in terms of atom/field interaction time. As the light mask we use a one-dimensional standing wave, with wavelength of 852 nm, that produces parallel lines spaced 426 nm with widths ranging from 30 to 100 nm, depending on the light mask parameters. A self assembled monolayer of thiols, grown on gold substrates, is employed as the resist. The produced patterns are investigated by ex-situ atomic force microscopy and in-situ scanning tunneling microscopy, presently in progress, to ascertain morphology and electronic properties of the nanopatterns.

T/PII.15**INFLUENCE OF SUBSTRATE ORIENTATION ON THE PHOTOLUMINESCENCE PROPERTIES OF Ge NANOSTRUCTURES IN Si/Si_{0.5}Ge_{0.5}/Ge SYSTEM**

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We have studied the correlation between the morphological characteristics and the photoluminescence (PL) behavior of Ge dots deposited by gas source molecular beam epitaxy (GS-MBE) on Si(100) surface and high index Si(118) vicinal surface. Ge nanostructure were confined on the top of undulation of the Si_{0.5}Ge_{0.5} template layer, according to the Stranski-Krastanov growth mode. Atomic force microscopy (AFM) and cross-section transmission electron microscopy (TEM) measurements reveals that the main effect of vicinal substrate is to transformed island domes on the nominal (001) substrate to large wire shaped islands. Photoluminescence spectroscopy investigations as a function of temperature and excitation power allowed to identify two broad lines, which are respectively attributed to the template layer and the islands emissions. We have observed a direct correlation between no spherical shape and polarization anisotropy of optical transitions in islands. The islands photoluminescence emission is partially (~25%) Polarized, for the substrate (118). Room temperature islands PL was observed for both samples, which is very promising for optoelectronic device application.

T/PII.16**Ge DOTS GROWN BY SELECTIVE EPITAXY IN SMALL SiO₂ HOLES OBTAINED BY FIB PATTERNING**

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Direct milling of small windows in SiO₂ layer by using Focus Ion Beam (FIB) is a good candidate to obtain precise positioning of Ge dots with a reduced lateral size in the range of 10nm. This could be important for applications in Si-based electronics and optoelectronics. The removing of the implanted Ga using RTA and HCl cleaning after FIB patterning was investigated by SIMS and RBS. Oxidized Si substrates were patterned with different FIB parameters and Ge dots were grown with a Si/Ge/Si layer sequence by selective epitaxy. The correlation of the FIB parameters with the properties of FIB holes and grown dots was investigated. AFM and SEM measurements were used for the shape investigation of both the FIB holes and the Si/Ge/Si dots. The change of dot shape by thermal oxidation and subsequent chemical etching of the oxide are presented.

T/PII.17**FORMATION OF MICRO- AND NANO-STRIATIONS AT (211)In FACETS DURING WET ETCHING OF InP IN HCl**

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It is generally observed that the anisotropic wet etching of InP crystal in HCl-based etchants leads to the spontaneous formation of nano-sized striations at certain side facets of patterned objects. It is a consequence of etch mask edge roughness linked with the specific dissolution mechanism of InP in HCl. This work investigates nano-sized striation formation at (211)In-related facets of [0 -11]-oriented mesa patterns in (100) InP during etching in xHCl : yH₃PO₄. It is shown that if artificial roughness is introduced in the form of regular corrugations along the wet-etch mask edge, regularly-spaced micro-sized or nano-sized striations can be formed along the (211)In-related facets. The formation of such artificial striations is investigated using SEM and AFM.

T/PII.18

GERMANIUM QUANTUM DOTS GROWTH BY ION-ASSISTED ION BEAM DEPOSITION

Hung-Chin Chung, Chuan-Pu Liu, Department of Materials Science and Engineering, National Cheng Kung University, Tainan, Taiwan

Germanium quantum dots have been deposited onto silicon (001) substrates by single and dual ion beam deposition. The structural properties of the as-deposited films have been characterized by atomic force microscopy and transmission electron microscopy. Germanium dot size, shape, size distribution and density are examined as function of ion energy flux and temperature. In particular, the evolution of island shape and assembly are studied with the incident angle of the assisted gun. The results show that, with increasing ion energy in the energy range of 0.8-1.5 keV, the germanium island size distribution becomes more uniform, the mean island size decreases while the island density increases. Thus, the island size as small as 10 nm can be achieved. Low-energy ion bombardment during deposition exerts a strong influence on the properties of the dots, particularly their size, orientation, and density. The increased island density is not a result of an increased island nucleation rate associated with defects produced in the Si substrate during ion beam-assisted deposition. In addition, for a fixed ion energy, an increased ion-to-atom flux ratio results in similar changes in microstructure distribution as is observed with increasing ion energy.

T/PII.19

PROPERTIES OF ISOLATED ISLANDS FORMED BY SELECTIVE GROWTH OF Ge IN SMALL WINDOWS OF ULTRA-THIN OXIDE

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Statistic investigation of the shape and size of isolated islands has been performed in comparison with the corresponding islands formed on large area. The isolated islands, i.e. not connected by wetting layer (WL), were obtained by selective epitaxy of Ge in small windows of ultra thin oxide (UTO) 1-2 nm thick. Voids in UTO with a broad range of size 30 – 600 nm have been obtained by in-situ partial desorption of the oxide layer. The size and shape of the islands were studied in function of void size and Ge deposition time. In voids smaller than 300 nm only one island is nucleated. Due to the absence of the island-island interaction and the reduced area of the WL the properties are different for isolated islands and for islands formed on large area. Height, width and aspect ratio of isolated islands increase continuously with void size and Ge coverage. In function of Ge coverage, there is a critical window size for the 2D -> 3D transition. In the case of low Ge thickness and windows narrower than 150 nm a metastable state of Ge much above the Stranski-Krastanov value was identified. For isolated islands, the Si interdiffusion is strongly reduced with decreasing void size.

T/PII.20

AB-INITIO STUDY OF THE ADSORPTION OF GERMANIUM NANOSTRUCTURES ON THE CLEAN AND HYDROGENATED Si(111) SURFACE

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Spontaneous formation of nanometric germanium islands is now currently observed. Nevertheless, the size distribution and density of these islands, determining for the collective and individual behavior of nano-objects, are not yet controlled. To obtain a homogeneous distribution of islands, one possibility is to use the 7x7 reconstruction of the Si(111) surface. This pre-patterning would then allow to control the nucleation sites of the germanium islands. On the other hand, a lot of experiments (STM, FIM, TPD,...) show that hydrogen presence modifies the adsorbates diffusion. In this way, new structures of germanium nanostructures may be stabilized. In an initial stage, we study, by mean of ab-initio calculations, the adsorption of several models of linear chains formed by hydrogen and germanium atoms in first, second and third neighbours positions. We particularly focus on the role of the hydrogen in the stability and shape of these nanostructures. Our first results emphasize the destabilizing role of hydrogen and the stabilizing role of the germanium clusters compacity.

Friday, May 28, 2004

Morning

Session IX: Synthesis and growth of nanostructures

Session chair: C. Henry

- T-IX.01** 08:30 -Invited- **MAGNETIC ANISOTROPY OF NANOSTRUCTURES AT SURFACES**
H. Brune, Institute of the Physics of Nanostructures, IPN, Ecole Polytechnique Fédérale de Lausanne, EPFL, Switzerland
The magnetic anisotropy energy K is one of the key quantities in the design of novel magnetic recording media as it defines the stability of the magnetization direction against thermal fluctuations and therefore the so-called superparamagnetic density limit where magnetic information becomes volatile. K is closely related to the anisotropy of the orbital magnetic moment Δm_L . Both quantities can be measured with X-ray magnetic circular dichroism (XMCD). In the gas phase transition metal atoms have large orbital moments given by Hund's rules ($m_L = 3 \mu_B$ for Co), whereas in the bulk m_L is almost entirely quenched due to the crystal field and electron delocalization ($m_L = 0.15 \mu_B$ in hcp Co), and therefore K is small ($40 \mu\text{eV/atom}$ for hcp Co). This comparison suggests spectacular magnetic properties for low coordinated atoms at surfaces.
We report on the evolution of K and m_L as a function of size starting from single atoms and going up in size almost atom by atom for Co on Pt(111) using XMCD measurements carried out *in-situ* to growth. Monomers have giant values of $K = 9.3 \pm 1.6 \text{ meV}$ and $m_L = 1.1 \pm 0.1 \mu_B$. These values strongly decrease as coordination goes up in dimers and trimers etc. The XMCD-results are complemented by Magneto-optical Kerr effect (MOKE) measurements for larger 2D nanostructures confirming a strong coordination effect on the anisotropy energy. For Co/Pt(111) and for Co/Au(778) we find $K = 0.9 \pm 0.1 \text{ meV}$ for the low-coordinated edge atoms favoring out-of-plane magnetization. We show the absence of mutual interactions between the monodomain particles up to densities of 26 Tera particles/in².
- T-IX.02** 09:00 -Invited- **TIME-DEPENDENT DIFFUSION FIELDS AND CAPTURE ON RECTANGULAR SUBSTRATES**
H.J. Venables* and P. Yang, Arizona State University, USA, (*also at University of Sussex, U.K.)
- T-IX.03** 09:30 **EFFECT OF INTERFACE ROUGHNESS ON THE MAGNETIC ANISOTROPY IN EPITAXIAL Fe FILMS**
F. Chemam(a), R. Boukhalfa(a), A. Bouabellou(b),(a) Institut des Sciences Exactes, Université de Tebessa, Tebessa 12000, Algeria, (b) Laboratoire LCMI, Université Mentouri de Constantine, Constantine 25000, Algeria
We have grown by molecular beam epitaxy (MBE) 300Å Fe films on single crystal MgO(001) substrates with Ag buffer layer with a thickness varying from 0 to 150Å. The epitaxial growth and structure quality of films were verified by reflection high-energy electron diffraction (RHEED) and X-ray diffraction. Small angle X-ray diffraction revealed the dependence of interfacial roughness on the thickness of Ag buffer layer. In-plane magnetic anisotropy was determined by means of magneto-optic Kerr effect at room temperature. The analysis of hysteresis loops showed a dependence of uniaxial anisotropy energy K_u and coercive fields on the Ag buffer layer.
Keywords: Fe; Ag; Epitaxy; Magneto-optic; Coercive field; Roughness, Anisotropy
- T-IX.04** 09:45 **SELF-ORGANIZED GROWTH OF AU NANOCUSTER ARRAYS ON A THIN ALUMINA FILM ON Ni3Al(111)**
G. Hamm, C.R. Henry, CRMCN-CNRS Case 913, Campus de Luminy, 13288 Marseille Cedex 9, France and C. Becker, Universität Bonn, Wegelerstr. 12, 53115 Bonn, Germany
Although gold is traditionally an inert element, a catalytic activity has been observed for small supported gold clusters on oxide supports [1]. In order to study the mechanisms that determine the catalytic activity, the production of well-ordered Au cluster arrays with a uniform size distribution would be very helpful. In the present case, we have used a thin alumina film as support, which was produced by oxidation of a Ni₃Al(111) surface at 1000 K. In accord with previous studies on this film using scanning tunneling microscopy (STM), two hexagonal superstructures with periodicities of 2.6 and 4.5 nm were imaged, depending on the applied bias voltage [2, 3]. Investigations of Becker et al. on the growth of different vapor deposited metals on the film have shown that both superstructures can act as a template for the production of ordered cluster arrays [4]. The template effect was used in the current project to study the growth conditions (substrate temperature, Au flux) for the growth of Au clusters with narrow size distribution in the range 1-5 nm where gold is catalytically active.
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- T-IX.05** 10:00 **FORMATION, STRUCTURE AND PROPERTIES OF Si/SiC NANOSTRUCTURES ON SILICON**
V. Palermo(a), A. Parisini(b), D. Jones(a), A. Le Donne(c), S. Binetti(c), S. Pizzini(c) (a)ISOF CNR, (b)IMM CNR, Via Gobetti 101, 40129 Bologna, Italy, (c)Dip. di Scienza dei Materiali, Università di Milano Bicocca, via Cozzi 53, 20125 Milano, Italy
 Silicon nanostructures can be formed on silicon surfaces through self-organisation using simple UHV thermal annealing techniques[1]. These silicon nanostructures can be nucleated by carbon-containing contaminants present on the silicon surface leading to the formation of SiC nanocrystals at their summit[2]. In this work a Scanning Tunneling Microscope (STM) was used to monitor the room temperature adsorption of selected organic molecules on silicon surfaces. Following UHV annealing and the formation of the nanostructures, the quantities, distribution and properties of the latter were examined in situ by STM. Sections through the Si/SiC nanostructures were then examined using Transmission Electron Microscopy (TEM) and showed a good degree of epitaxy between the SiC nanocrystals and the underlying silicon. Interesting optical properties of these nanostructures were also observed by photoluminescence spectroscopy in the UV-Visible and infrared.
- T-IX.06** 10:15 **GROWTH AND ARRANGEMENT OF GE QUANTUM DOTS ON NATURAL AND NANOSTRUCTURED Si(001) SURFACES BY SCANNING TUNNELING MICROSCOPY**
P.D. Szkutnik(a), A. Sgarlata(a), A. Balzarotti(a), N. Motta(b), A. Ronda(c), I. Berbezier(c), (a)INFM Dipartimento di Fisica, Università di Roma Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy, (b)INFM Dipartimento di Fisica, Università di RomaTre, via della Vasca Navale 84, 00146 Roma, Italy, (c)CRM-CNRS, Campus de Luminy, case 913, 13288 Marseille cedex 09, France
 Quantum dots (QDs) grown on semiconductors surfaces are actually the main researchers' interest for applications in the forecoming nanotechnology era. Novel approaches to form ordered patterns of homogeneous nanostructures consist of natural patterning induced by surface instabilities, as step bunching of Si(111) or misoriented Si(001) surfaces, and of nanolithographic techniques, as implantation of Ga⁺ ions by Focused Ion Beam (FIB) or in situ substrate patterning by Scanning Tunneling Microscopy (STM). Based on the analysis of STM images we report on growth and arrangement of Ge islands on Si(001) substrates nanopatterned using different techniques. The first is a natural method based on the study of Ge growth on Si(001) surfaces with different misorientation angles. The second considers the role on the heteroepitaxial growth of an array of holes produced by STM lithography. Several issues are discussed: substrate nanostructuring, wetting layer growth, transition up to 3D islands formation and arrangement of QDs. We find that Ge islands nucleate nearby the holes on STM nanopatterned surfaces. Concerning the growth on Si(001) misoriented substrates we observe that the shape of Ge islands depends on the miscut angle and that a transition from regular hut clusters up to ripples takes place.

10:30

BREAK

Session X: Physical properties of nanostructures and novel devices

Session chair: S. Nozaki

- T-X.01** 11:00 -Invited- **SINGLE-ELECTRON DEVICES FABRICATED BY MOS PROCESSES**
Hiroshi Inokawa, Yukinori Ono, Akira Fujiwara, Katsuhiko Nishiguchi, and Yasuo Takahashi, NTT Basic Research Laboratories, NTT Corporation, 3-1, Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-0198, Japan
 Current status of silicon single-electron devices is reported. We have developed a MOSLSI-compatible fabrication process for single-electron transistors (SETs) based on pattern-dependent oxidation (PADOX). The method uses special phenomena that occur during oxidation of one-dimensional Si nano-wires on SiO₂ (Fig. 1) and achieves 10-nm-size Si islands. Owing to stability of Si/SiO₂ interface, we cannot observe offset-charge instability that is one of the biggest obstacles to be overcome for SET application. One of the great advantages of SETs is that they have special features, such as multi-peak oscillatory characteristics and multigate capability. Another useful point is that we can combine SETs with MOSFETs. By using these features, we have demonstrated sophisticated functions, such as adders and multiple-valued applications. The functionality of SETs is advantageous not only for reducing power consumption and size, but also for opening up new circuit applications.
- T-X.02** 11:30 **CHARGE CONFINEMENT IN InAs/InP QUANTUM WIRES**
J. Maes(a), M. Hayne(a), Y. Sidor(b), B. Partoens(b), F.M. Peeters(b), L. González(c), D. Fuster(c), J.M. García(c) and V.V. Moshchalkov(a), (a)Laboratorium voor Vaste-Stoffysica en Magnetisme, Katholieke Universiteit Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium, (b)Departement Natuurkunde, Universiteit Antwerpen (Campus Drie Eiken), Universiteitsplein 1, 2610 Antwerpen, Belgium, (c)Instituto de Microelectrónica de Madrid (CNM-CSIC), C/Isaac Newton 8, 28760 Tres Cantos, Madrid, Spain
 The excitonic properties of InAs/InP self-assembled quantum wires are studied using photoluminescence in pulsed magnetic fields. For thin wires we show that the electron wave function extends into the InP barrier material in the wire height direction, and that this electron spill-over is inversely related to the wire height. These effects are due to the large confinement energy of the electron. As the wire becomes thicker, the decrease in confinement energy is reflected in a reduction of the electron wave function extent. A more detailed theoretical understanding is provided within the effective-mass approximation, with strain effects taken into account.
 This work is supported by the Belgian IUAP, the Flemish GOA, the FWO-VI, the VIS project of the UAntwerpen, and the Nanoself (TIC2002-04096-C03) and NANOMAT (G5RD-CT-2001-00545) projects. B.P. is a post-doctoral researcher with the FWO-VI.

- T-X.03** 11:45 **CONTROLLED SYNTHESIS AND OPTICAL PROPERTIES OF ALIGNED ZINC OXIDE NANOWIRE ARRAYS**
H.J. Fan, R. Scholz, F.M. Kolb, M. Zacharias and U. Gösele, Max-Planck-Institute of Microstructure Physics, Weinberg 2, 06120 Halle, Germany
 ZnO nanowires have recently attracted great attention due to their promising applications in room-temperature UV nanolasers and optoelectronic switches. For this purpose, fabrication of high quality ZnO nanowires with ordered orientation and controllable position is of importance. In our work, vapor phase synthesis of single-crystalline ZnO nanowire arrays on sapphire has been successfully achieved based on vapor-liquid-solid (VLS) mechanism. In order to control the distribution density and/or position of the nanowires, the catalytic Au nanoparticles on the substrate were deposited by thermal evaporation or electron beam lithography. In this manner, nanopatterning of the ZnO nanowire arrays can be achieved. Electron microscopy investigations show that the nanowires are aligned preferentially vertical to the sapphire substrates, with heights of up to 5 μm and diameters of 30-100 nm depending on growth conditions. The nanowires were identified by both X-ray diffraction and high resolution transmission electron microscopy (HRTEM) to be single-crystalline wurtzite ZnO unidirectioned along [0001]. The epitaxial relationship was determined to be $[11\text{-}20](0001)\text{ZnO} \parallel [0001](11\text{-}20)\text{Al}_2\text{O}_3$, which accounts for the vertical alignment of the wires. Results of the optical properties (photoluminescence and Raman) of the nanowire arrays will be presented, too.
- T-X.04** 12:00 **SIZE AND EMISSION WAVELENGTH CONTROL OF InP/InAs/InP QUANTUM WIRES**
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 In this work we study the influence of the growth temperature (T_s) of the InP layer covering InAs quantum wires (QWr) on their optical properties. Our results show that we can tune the emission wavelength of the QWr between 1.30 – 1.55 μm at room temperature by using an appropriate T_s for the cap layer growth. This parameter could affect the QWr size by influencing the P/As exchange process at the InAs/InP interface. In this way, the higher the T_s of the cap layer, the smaller in height the QWr, leading to a blue shift of their emission wavelength. For its verification, we have performed in situ stress measurements of phosphorous incorporation at InAs(001) surface due to P/As exchange for $330\text{ }^\circ\text{C} < T_s < 515\text{ }^\circ\text{C}$. The results show that accumulated stress increases when InAs surface is exposed to P₂ flux, corresponding to the growth of InP at the expense of In from the InAs surface and incoming P₂ flux. The InP thickness increases with T_s , getting values higher than 2 monolayers at $T_s = 515\text{ }^\circ\text{C}$. This process explains the QWr size change when the InP cap layers are grown at different temperatures.
- T-X.05** 12:15 **ELECTRICAL STUDY OF MOS STRUCTURES WITH Ge NANOCRYSTALS IN SiO₂ AS FLOATING GATE FOR NON VOLATILE MEMORIES**
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 In the last decade, several works have been focused on semiconductor nanoparticles embedded in SiO₂ matrix for future low power memory devices. The use of a floating gate composed of isolated Si dots reduces the problems of charge losses encountered in conventional flash memories. In order to improve data retention of NVM it seems even more interesting to use Ge rather than Si because of its smaller band gap. In spite of the fact that non volatile memories with implanted Ge have been demonstrated, it is important to evaluate alternative fabrication methods such as LPCVD or MBE deposition on SiO₂.
 In this work we present a method to realize nc-Ge in a SiO₂ matrix by MBE deposition of amorphous Ge and Si layers combined with RTA and oxidation steps. A 1 nm-thick a-Ge layer was deposited on a 5 nm-thick SiO₂ thermal oxide on p-Si. This was followed by the deposition of a 4.5 nm a-Si capping layer. A dry oxidation at 800°C for 90 min was then used to transform the a-Ge into a GeO₂ layer. The spectral ellipsometry analysis confirms that the final stack consist of a pure GeO₂ layer sandwiched between two SiO₂ layers. In order to transform the GeO₂ layer into nc-Ge in SiO₂, the sample was annealed under N₂ at 950°C. The control of the formation of the Ge dots and their electrical isolation from the substrate has been optimised by the annealing time under N₂. For that purpose many MOS capacitors with different annealing times (10s, 30s, and 50s) have been characterized using C-V and I-V measurements. In addition, the electrical measurements allow the study of electron trapping in Ge dots. Those experiments have shown storage effects only for samples annealed for 30s. Finally, we have optimized the process for the fabrication of nc-Ge – NVMs with our a-Si/a-Ge/SiO₂/Si stack.
- T-X.06** 12:30 **THE EFFECTS OF OXIDATIVE ENVIRONMENTS ON SYNTHESIS OF CuO NANOWIRES ON Cu SUBSTRATE**
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 CuO nanowires (or nanobelts) are synthesized by thermal oxidation. Copper substrate was oxidized at the temperature range of 300 – 800 $^\circ\text{C}$ under different oxidative environment, such as oxygen, air ... with or without H₂O vapor. The nanowires were characterized by scanning electron microscope, X-ray diffraction and transmission electron microscope. The condition of forming nanowires is identified. The relation of the size of nanowires and forming condition is analyzed. The crystal orientation of nanowires is recognized. A possible mechanism of forming nanowires was proposed based on the analysis on the experimental results.

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