SYMPOSIUM T

T: Self-Organized Processes in Semiconductor Heteroepitaxy

December 1 - 5, 2003

Chairs

Rachel S. Goldman
Dept. of Materials Science & Engineering
University of Michigan
2300 Hayward St.
Ann Arbor, MI 48109-2136
734-647-6821

Richard Noetzel
COBRA Inter-University Research Institute
Eindhoven University of Technology
P.O. Box 513
Eindhoven, 5600 MB NETHERLANDS
31-40-247-2047

Andrew G. Norman
National Renewable Energy Lab
MS 3215
1617 Cole Blvd.
Golden, CO 80401
303-384-6483

Gerald B. Stringfellow
College of Engineering
University of Utah
Rm. 214
1495 E. 100 South
Salt Lake City, UT 84112-1109
801-581-8387

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*Invited paper
SESSION T1: Morphological Evolution: Patternning and Islanding

Chairs: Vivek Shenoy and Xiaojun Weng
Monday Morning, December 1, 2003
Room 209 (Hyne)

8:30 A.M. T1.1
Atomic-scale pathways of the pyramid-to-dome transition during Ge growth on Si(001): I-Experimental determination.
Giovanni Costantini1, Carlos Musero2, Georgios Kazanas3, Armando Rastelli1, Hans von Koenig4, Ulrich Denker5, Oliver Schmidt1 and Klaus Kern1.
Instiut fuer Festkoerperforschung, Stuttgart, Germany; 1Dipartimento di Fisica, INFMI, Politecnico di Milano, Milano, Italy.

The atomic processes driving the pyramid-to-dome transition in the Ge/Si(001) system are identified by in-situ scanning tunneling microscopy. The transition is observed using two different experimental conditions: (1) by depositing more than 7 ML of Ge at 560°C or (2) by annealing 6 ML of Ge at the growth temperature of 560°C for more than 600 s. The two methods show qualitatively similar results, indicating that the material redistribution from the wetting layer and among the islands is at the origin of the transition. The precise pathway of the transition is determined from atomic-resolution images and can be described as a selective overgrowth of pyramid islands. A cap composed by (105) facets is formed on the top of pyramids to excess a critical volume, during the growth of the cap, the bunching of the step edges evolves into (153.25) facets whilst the covered edges of the pyramids develop into (113) facets. Thus, the transformation takes place from the top and gradually covers the whole island leaving only a small (105) rim at its base. This technique of detailed chemical imaging is used to determine the island composition at the various stages of the transition. The chemical composition appears to be highly non-uniform with a Si/Ge proportion that depends on the size of the islands. Contrarily to what is commonly believed during the transition, the dome-like parts of the islands show a higher Ge composition than the pyramid-like ones. The experimental results clearly demonstrate the decisive influence of kinetics on the transition and are strongly supported by ab-initio calculations of the strain-dependent diffusivity of Ge adatoms on the reconstructed (105) facets of the islands [1]. [1] see F. Montantelli et al, "Atomic-scale pathways of the pyramid-to-dome transition during Ge growth on Si(001): II-Theory and simulations" (next abstract).

8:45 A.M. T1.2
Atomic-scale pathways of the pyramid-to-dome transition during Ge growth on Si(001): II-Theory and simulations.
Francesco Montantelli, Dmitri B Migan, Paolo Raineri and Leo Miglio.
INFMI, Materials Science Department, University of Milano, Bicocca, Milano, Italy.

We investigate the pyramid-to-dome transition occurring during Ge growth on Si(001) by combining semiempirical and ab initio techniques. By modeling the atomic interactions with Tersoff potentials, we compute the surface lattice-parameter variations which occur in a typical (105) Ge pyramid on Si(001). In small pyramids, by moving from base to top, one finds a continuous increase of the average surface lattice parameter which at the very top tends to reach the pure Ge value. When pyramids reach the typical size in which the pyramid-to-dome transition is experimentally observed [1], on the other hand, the expansion of the lattice parameter is observed only in the region closer to the island top. We explore the effect of such variations in the lattice parameter on the system kinetics by computing ab-initio the diffusion barriers for a Ge adatom on Ge(105) for different values of the surface lattice parameter. The barrier turns out to be lattice-parameter dependent: adatom diffusion is faster at the pyramid top. A simple atomic model is presented, suggesting that the above mentioned height-dependent diffusion coefficient could be the main cause of the instability driving the pyramid-to-dome transition.

9:00 A.M. T1.3
Size Dependent Shapes of 2D domains on Surfaces.

The need for new nano-scale fabrication techniques has driven renewed interest in self-organized pattern formation on surfaces. In general, the key ingredients are well understood: the energy cost associated with long-range dipolar fields (electrostatic, magnetic, or elastic) favors the breakup of large domains into smaller ones. But the energy cost due to increased domain boundary length counteracts this trend. The result is the spontaneous formation of extended 2D patterns, where the detailed nature and length scale of the pattern depends on the details of system. Unfortunately, quantifying the interactions in such pattern forming systems is quite difficult, because the thermodynamic parameters that enter into the theory (long range interdefect energy and domain wall energy) are often not known, even experimentally, and for reasons other than equilibrium may be difficult. In this work we describe a simple theory for the size dependent shapes of isolated 2D domains of one phase embedded in a second phase. In the absence of interactions, the 2D domain shape depends only on the boundary energy and is given by the Wulff construction. The Wulff shape is always convex, and does not depend on size. However, inclusion of long range interactions changes the situation in important ways: the shape depends strongly on size, with concave shapes appearing for large sizes, irrespective of symmetry. We apply this theory to the size dependent shape of Si (100) 2D domains near the 7x7-1x1 phase transition. We calculate 7x7 domains can be embedded in a 1x1 background. The 7x7 and 1x1 phases have different surface stresses, leading to long range elastic interactions. Key thermodynamic parameters such as the magnitude of the stress difference between the phases, as well as the boundary energy, have been previously determined empirically. For isolated details of an observed shape transition from convex to concave shape with increasing domain size, studied in situ with Low Energy Electron Microscopy, we obtain a clear and quantitative understanding of the domain dynamics, in close agreement with the theoretical results. Thus, the study of size dependent isolated phases provides a new avenue, both theoretically and experimentally, for studying the tradeoff between boundary energies and long range interaction energies in 2D pattern forming systems.

9:15 A.M. T1.4

The morphological evolution of crystalline surfaces and overlayer films in heterteropatic systems is strongly coupled to the details of surface structure, surface energy and surface stress. In particular, knowledge of the structure and energetics of the wetting layer on Ge/Si (100) heterteropaticity is fundamental to accurate quantitative modeling of growth and evolution of threedimensional nanostructures in this system. We present results of first-principles calculations of the properties of Ge (100) surfaces relevant to Ge on Si (100) heterteropaticity. The (c2x2) reconstruction and higher order “dimer vacancy line” reconstructions of the Ge (100) surface are discussed, and the strain dependence of the structure and energetics of these surfaces is examined in detail. Results are compared to available experimental data, and to previous theoretical studies.

9:30 A.M. T1.5

We demonstrate that the 2x2 reconstruction observed for the Ge-covered Si(001) surface is determined by the competition between the formation energy of isolated vacancy lines and the metal-dimer repulsion. We found that the formation energy of vacancy lines is strongly dependent on strain and can become negative, while their interaction is purely repulsive, with a quadratic dependence of the density of vacancy lines and a very weak strain dependence. These results imply that previous experiments that were based on a competition between a long-range attraction and short-range repulsion between the vacancy lines could be revisited. Our results and interpretation are of enexperimental and may provide a robust explanation of the physical origin of the 2x2 reconstruction.

9:45 A.M. T1.6
Energetics of Germanium Island Formation by Atomistic Simulation. Richard Joseph Wagner and Erdogan Gulser, Chemical Engineering, University of Michigan, Ann Arbor, Michigan.

During heteropaticity of Ge on Si(001), beyond a critical thickness the Ge self assemblies into small islands, or quantum dots, with widths of around 30 nm. We studied the energetics of this island formation by atomistic simulation. The islands are modeled as sphere-based pyramids with recombined step [105] energy. We determine how island energy depends on island size, interisland spacing, and wetting layer thickness. From this information we can predict island size distributions as functions of anneal temperature and surface coverage.

10:00 A.M. T1.7
Atomic modelling of Ge/Si/Si[001]. Quantum Dots: The small size (in nm in dimension) of quantum dots (QDs) leads to quantum confinement of the electrons, resulting in electronic and optical properties which show promise for use in a wide range of devices. These properties of the QDs are controlled by their size, shape and composition. The recent literature on Ge-Si QD formation discusses alloying in the QDs as a source of strain relief. Si diffuses into the QD from the substrate to form a GeSi alloy and therefore lowers the lattice mismatch between the QD and the substrate. There is considerable evidence that the composition of this alloy is non-uniform throughout the QD. We present a method that predicts the non-uniform alloying profile by combining atomistic relaxations with a Monte Carlo process. The Tersoff potential is used to describe the interaction between the atoms. The degree of the alloying profile on the QD size is explored and the results of the simulation are compared to results from experimental measurements and from phenomenological predictions in the literature. We also show how this algorithm can be extended to study the formation of QDs and the change in the QD shape as the increasing Si content and size. This approach makes it possible for the first time to model the evolution of the QD and to obtain a quantitative insight into the energetics of the process while taking into account the size, shape and composition. The roles of the surface energy, the mixing energy and the strain energy are analyzed and all three are found to play important, separate roles in this process. The possible application of this simulation technique as a modelling tool for nano-engineering applications is discussed.

10:45 AM T1.8
Three-dimensional Simulations of the Early Stages of SiGe Quantum Dot Growth: Vasek Stucky and Ashok Ramasubramaniam, Division of Engineering, Brown University, Providence, Rhode Island.

The initial stages of quantum dot growth remain the least understood part of the self-assembly process in SiGe/Si. In this work, we present the results of three-dimensional modeling of heteroepitaxial thin film growth. The underlying physics of interactions of crystallographic surface steps is used to develop a continuum model. The inputs to this model are obtained from atomistic simulations. Our results show that quantum dots grow without any barrier to nucleation in agreement with recent experiments. Evolution of these dots towards low-energy orientations, analogous to faceted pyramids, is also demonstrated. Calculations of remelting of these structures provide insight into coarsening and shape-transitions in these systems.

11:00 AM T1.9
The Morphology of Misfitting Islands: Volmer-Webber Growth. Oleg Chikinev 1, Michael J. Mikkelsen 2 and Peter W. Voorhees 3.


The misfit strain that accompanies heteroepitaxy can drive the formation of islands on surfaces. The shape of misfitting islands in systems in which the substrate is completely wet by the film has been widely studied. In contrast, the equilibrium shape of an island where there is a non-zero contact angle between the film and substrate has received little attention. We have determined the equilibrium morphology of misfitting islands on a surface as a function of the contact angle. The presence of a nonzero contact angle induces a dependence of the island width on its volume that is absent in the case where the film wets the substrate. We also find equilibrium island morphologies that are strongly nonconvex and have multiple bumps. The stability of these equilibrium shapes and the dependence of island shape on both contact angle and volume will be presented.

11:15 AM T1.10
Elastic Fields of Surface Quantum Dots: Glenn E. Eick 1, Alexei Romov 2, 3, 4, Fjoln Jonsdottir 1, 3, 4 and James S. Speck 2.

1Department of Mechanical and Environmental Engineering, University of California, Santa Barbara, California; 2Materials Department, University of California, Santa Barbara, California; 3Department of Mechanical and Industrial Engineering, University of Iceland, Reykjavik, Iceland; 4A. F. Ioffe Physics-Technical Institute, St. Petersburg, Russian Federation.

In this work, we present models based on isotropic elasticity theory for evaluating the stress fields in the vicinity of a coherent surface island. The models are based on three different approaches for solving the elastic boundary value problem of a small, misfitting domain bonded at the surface of a semi-infinite space. The first model treats the quantum dot as a point source of dilatation, and does not take into account the details of the dot shape into account. The second approach integrates the point source over a prescribed volume, applying a rudimentary assessment of the effect of dot shape. Finally, the finite element method is used to study simple quantum dot shapes such as spherical caps and cylinders. These three methods are used to assess the effect of lattice mismatch, dot volume, and dot/surface contact area on the induced stress field. We conclude by discussing some preliminary results on the effect of nano- and microhelical wetting layer between the dot and the substrate, and issues pertaining to the interaction between two surface-based quantum dots.

11:30 AM T1.11
Self-Assembly of Three-Dimensional Metal Islands in Heteroepitaxy: nonstrained vs. strained islands. Feng Liu, Materials Science & Eng., University of Utah, Salt Lake City, Utah.

The epitaxial growth of three-dimensional (3D) islands is of both scientific interest and technological importance. The surprising size uniformity of 3D islands achieved in the growth of both elemental and compound semiconductor thin films has shown great promise for their use in quantum dots. A good understanding of the origin of size uniformity for 3D semiconductor islands has also been obtained in terms of strain induced self-assembly and self-organisation theory. However, in contrast to semiconductors, the size uniformity of 3D metal islands is less common and little theory has been reported for self-assembly of 3D metal islands. Here, I present a theoretical model for self-assembly of 3D metal islands. We will focus on the case of Volmer-Webber growth of 3D metal islands on insulating substrates, where there is a large difference of surface energy as well as a surface stress between metal and insulator. We show that a large surface stress discontinuity along island edge introduces an elastic doppler island edge-edge interaction. The existence of such island edge effect makes the island shape dependent of island size. Furthermore, it induces a stable island size against coarsening, leading to self-assembled islands of uniform size. The dependence of the stable island size on total film coverage is shown to be different for nonstrained vs. strained islands, in the regime of strong island-substrate interaction. This work is supported by DOE. [1] Feng Liu, Phys. Rev. Lett. 89, 266105 (2002).

11:45 AM T1.12
Kinetics-driven Nanoscale Patterning on Metal Surfaces. L. G. Zhou and Hauke Husting, Department of Mechanical, Aerospace and Nuclear Engineering, Rensselaer Polytechnic Institute, Troy, New York.

Nanoscale features develop on surfaces as a result of either kinetic or thermodynamics or both. Recently, we have proposed two kinetic barriers: facet-facet and step-facet barriers. Combining an ab initio calculation, classical Embedded Atom Method (EAM) calculations, and Monte Carlo simulations, we demonstrate the nanoscale patterning due to the two new kinetic barriers. For copper, our ab initio results show that the facet-facet barrier is substantially larger than that on a flat surface, in agreement with the EAM predictions. Further, the ab initio results show that island addition is effective in reducing this barrier. The ab initio calculations of selected barriers of step-facet configurations confirm that the EAM estimations. Finally our Monte Carlo calculations show that the facet-facet barrier leads to the formation of nano facets, and the step-facet barrier the nano islands.

SESSON T2: SiGe Nanostructures
Chair: James Hannon and Gilberto Medeiros-Ribeiro
Monday Afternoon, December 1, 2003
Room 209 (Hynes)

1:30 PM T2.1
Directed Assembly, Strain Engineering, and Materials Integration on Silicon. Max G. Loglily, Dept. of MS&E, Univ of Wisconsin-Madison, Madison, Wisconsin.

Future generations of micro- and optoelectronic devices will require approaches beyond the conventional in terms of materials fabrication and integration at the nanoscale. From the point of view of technology, great advantage can be gained if it could "all be done on silicon". This is also fortunate from a scientific viewpoint, as Si is the model semiconductor for fundamental studies of surfaces, growth, and electrical properties. Ongoing efforts at Wisconsin to form nanoscale structures on Si and to investigate their properties include: 1) Directed strain driven self-assembly of nanoparticles during semiconductor heteroepitaxy. We describe a simple process of directed assembly of Ge QDs on Si that also allows us to develop a general and quantitative understanding of the mechanism of directed assembly on nano-patterned substrates. 2) Ge QDs that grow on the thin Si template of silicon-on-insulator (SOI) can act as a nanoressor that distorts the Si layer and causes the oxide underneath to flow. We present an understanding of this process and speculate on the implications for electrical properties of locally strained Si. 3) Growth of heteroepitaxial films on SOI rather than Si also brings with it unique defect generation mechanisms. The use of low-energy electron microscopy (LEEM) as a unique tool for investigating dislocation
behavior at the Si/SiO\textsubscript{2} interface is described. We discuss the possibility of extracting quantitatively energetic parameters for dissipation of phonon self-consistent calculations of thin SiO\textsubscript{2} films, and use Kramers-Kronig decomposition of the reflectance to extract the energy loss of phonons. We have constructed a model for the sliding of thin SiO\textsubscript{2} films along the Si/SiO\textsubscript{2} interface, and used this model to explain the observed behavior of the films.}

2:45 PM T2.5 Growth and ordering of Ge quantum dots on natural and nanostructured Si surfaces: a real time study using Scanning Tunneling Microscopy. Matteo Carbonaro, Gianluca Sanna, and Corrado Baraldi, University of Rome Tor Vergata, Rome, Italy; Physics, University of Rome Tor Vergate, Rome, Italy.

Quantum dots grown on semiconductors surfaces are actually the researchers interest for possible applications in the forthcoming nano-technology era. New approaches to grow ordered patterns of homogeneous nanostructures include growth on meso structures, natural patterning by surface instabilities, nano lithography or Scanning Tunneling Microscopy (STM) or Atomic Force Microscopy (AFM). We report on the nucleation and growth of Ge quantum dots on nano-patterned Si surfaces followed in real time by STM imaging. Nano patterning has been realised using two different approaches: on Si(100) by STM lithography and on Si(111) by step bunching effect. Different issues regarding the hetero-epitaxial growth on these substrates have been discussed: the nanoengineering of the substrate, the wetting layer (WL) growth, the transition up to 3D islands formation and finally the arrangement of QDs. We have observed that on Si(100), the Ge islands nucleate near the holes and on Si(111) step bunching can guide the growth of aligned rows of islands. Finally, a comparison with samples patterned by FIB will be addressed.

3:30 PM T2.6 3D composition profiles of GeSi(001)domes. Gilberto Modena-Ribeiro, Francisco, Ambrosio, and Renato Ferreira, University of Brasilia, Brazil; Department of Physics, UFMG, Belo Horizonte, MG, Brazil; 2Hewlett-Packard Laboratories, Palo Alto, California.

Several independent studies with electron microscopy and x-ray techniques have targeted the issue of Si diffusion into Ge islands grown on Si(100), which is a significant factor in determining the shape and size distribution of an island ensemble. All support the existence of a distinct SiGe wetting layer, with composition slightly higher in Si than in the Si substrate. The 3D composition profiles across the entire dome have been determined using Grazing Incidence Angle X-ray Scattering (GIAXS) measurements on an ensemble of Ge domes with an uniform size distribution. We determined the (average) three-dimensional composition of the domes from an analysis of the monochromatic scattering reciprocal space intensity maps near the Ge K absorption edge by first segmenting the domes into a stack of layers and then mapping the lateral concentration of Ge in each layer. Finally, we performed additional selective etching experiments and qualitatively confirmed our proposed structural model. This type of analysis could be extremely valuable when combined with real-time nanocrystal growth studies, both in providing increased understanding of the kinetic and energetic processes that determine the size, shape and composition of islands, and in monitoring and controlling island properties during growth. Finally, for the realistic modelling of quantum dots confining potentials, this work provides a solution for imitating lateral composition profiles with its nanostructured strain. This work was funded by FAPESP (contract 98/14755/4) and HP Brazil.


We show that quantum dots grown from a SiGe surface morphology structure exhibits a surprisingly strong degree of
preferred size selection. These structures, consisting of four SiGe quantum dots surrounding a central pit, are formed during growth of Si$_{0.75}$Ge$_{0.25}$ at 1000°C and 1.0 Torr by molecular beam epitaxy on Si (001) substrates. Growth under these kinetically limited conditions may provide a new route to self-organized nanostructures. Initial strain relaxation results in the formation of shallow pyramidal pits in the metastable SiGe layer. As growth is continued, the formation of quantum dots develops via cooperative nucleation of islands surrounding the edges of each pit. These structures evolve to a maximum lateral size that is constant over a wide range of film thickness and temperature when annealing is performed at the growth temperature. This size selection can be explained by the formation of a [011] faceted, continuous island wall surrounding each pit that creates a barrier against diffusion out of the pit. Finite element analysis of the elastic-energy distribution in and around a quantum dot will be shown in support of this hypothesis. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract No. DE-AC04-94AL85000.

4:00 PM T2.8 1D Growth Instabilities in Bound Island/Pit Configurations. N. N. Singh, Jennifer L. Greg, Robert Hull, Dunn M. Eley and Jerold A. Kevo. 1Materion Science and Engineering, University of Virginia, Charlottesville, Virginia; 2Sandia National Laboratories, Albuquerque, New Mexico.

We have observed two examples of 1D growth instabilities during kinetically limited self-assembly of strained SiGe/Si nanostructures. The first is the elongation of initially square islands bounding square pits, which eventually evolve to form a continuous wall surrounding the pit (the so called Quantum Fourier structure). The second is a growth instability of the pit itself, which can rapidly extend in a [100] direction to become a highly symmetric trench bounded on each side by parallel islands - a potential mechanism for self-assembly of high-aspect quantum wires. All these structures are bound by the (101) facets ubiquitously observed on compressed SiGe surfaces. Using finite element calculations and detailed considerations of the island/pit geometry, we show that diffusional constraints upon island diffusion paths, local energy minimization, and facet nucleation barriers can combine to promote strongly anisotropic growth in bound island/pit configurations. In essence, the presence of the pit breaks the local symmetry of strain and diffusion fields near the island. 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.

4:15 PM T2.9 The role of the surfactant-mediated crystallization of Ge-films on Si (111), Roland Kroeger, Thomas Schmidt, Jens Falta, Michael Horn-von Heegen, Peter Ryder and Andreas Janzen. 1Institute of Solid State Physics, University of Bremen, Bremen, Germany; 2University of Essen, Essen, Germany.

Ge films grown on Si (111) are of great interest for the realization of microelectronic devices. The use of a surfactant, in our case Sb, significantly improves the film smoothness and suppresses island formation. A microstructural analysis of these films was performed using transmission electron microscopy (TEM) in conjunction with X-ray diffraction techniques (XRD) for Ge films, which were grown at different deposition temperatures (in the range of 450°C to 530°C) by molecular beam epitaxy (MBE) with a layer thickness of about 5 to 10 nm. The films were studied using high resolution TEM (HRTEM) in plan view and cross section. Due to the 4% lattice mismatch of Ge with respect to Si, undesirable dislocations (MFDs) are formed at the interface to reduce the film stress. HRTEM images show that the average distance of the MFDs increases with increasing temperature, which means that the MFD density decreases, although the density of extended defects such as stacking faults in the Ge films significantly decreases. In addition, an increase of the Sb content can be observed by which it can be concluded that strain relaxation and ordering of MFDs are competing processes. A model was developed taking into account the strain energy as a function of the MFD density and the ordering. It explains the experimental results and sheds light on the role of ordering in the selforganized, surfactant-mediated growth of the Ge films.

4:30 PM T2.10 Ga Surfactant Effect During UHV-CVD of Si and Ge in Epitaxy on Si (001). Alain Portaute, Martin Kammel, Robert Hull and Frances M Ross. 1Materials Science and Engineering, University of Virginia, Charlottesville, Virginia; 2IBM T. J. Watson Research Center, Yorktown Heights, New York.

The use of surfactant elements during semiconductor epitaxial growth is an important self-organization technique allowing the modification of fundamental growth mechanisms such as surface diffusion or island nucleation. Surfactants have been successfully employed to change growth modes and to create nanostructures. For example, in the particular case of Ge on Si, surfactants have been shown to change the shape, size and density of self-organized Ge islands. While surfactant effects have been studied during molecular beam epitaxy of Ge on Si, such effects have not been studied in nearly as much detail during chemical vapor deposition (CVD). Using an ultra high vacuum (UHV) system composed of a modified 300VH Hitachi UHV-1000 transmission electron microscopy (TEM) attached to a UHV chamber allowing solid source deposition, the surfactant effect of Ga was investigated during UHV-CVD of Si and Ge on Si (001). After the deposition of a Ga layer on the substrate at room temperature, the samples were in-situ annealed in the TEM without breaking vacuum, where deposition of Si and Ge was monitored in real time. It was observed that a pre-deposited Ga layer significantly decreases the rate of Ge deposition. This can be explained by the ability of Ga to passive agglomeration bands on the Si substrate. For low deposition temperature (T = 550°C, P = 10\(^{-8}\) Torr), the growth of small Ge islands (20 nm in diameter) with low surface density is observed. For higher pressure and temperature (T = 600°C, P = 10\(^{-7}\) Torr), two periods of island nucleation are seen leading to a bimodal island distribution with smaller islands and higher surface density. Ga pre-deposition is also shown to decrease the wetting layer thickness and the critical island size at which dislocations nucleate, compared to islands grown on an unmodified Si surface. We will discuss how these results may be related to the effect of Ga on surface diffusion and surface structure and how surfactants may be used to control nanostructure fabrication during UHV-CVD.

SESSION T3: Poster Session: Semiconductor Nanostructure Chair: Daniel Friedman, Rachel Goldsmith and Philippe Guittet

Monday, December 1, 2003 8:00 PM Exhibition Hall D (Hynes)

T3.1 Real time, in situ PEEM Growth and Decay of Dy$_3$S$_2$ Nanowires on Si (001). Anderson Simela, Moya, Lenn Flittig, Matt C. F. Whittingham, Robert J. Nemeth, Physics, North Carolina State University, Raleigh, North Carolina.

Nanowires of Dy$_3$S$_2$ were formed on a Si(001) substrate through deposition of few monolayers of dysprosium and annealing at 730°C. In situ and real time imaging of the formation, growth and decay of the silicide nanowires was observed by photo electron emission microscopy (PEEM). Direct observations combined with ex situ AFM measurements were used to analyze the wire growth dynamics, their ordering, shape and size. We report on the growth and decay of the nanowires at different temperatures between 700°C and ~1000°C. At high temperatures, the Dy evaporates from the surface, and the wires eventually disappear. Upon annealing, we observe that the nanowires remain constant while the length decreases with time. At some point, they then sequentially break in sections, and we speculate that the breakage is related to dislocation formation.

Research supported by the NSF and the APOST through the NSF LDR program.

T3.2 Epitaxial Growth and Structural Evolution of Hexagonal Close-Packed Ni Nanostructures on The (100) Surface of MgO. Haiying Sun*, Wei Tins*, Mark Yedvich*, Chris Boothroyd*, Jinhua Yu*, Ate Lukaszew*, Roy Clarke* and Xiaoming Pan*†.

1Department of Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan; 2Institute of Materials Research and Engineering, Singapore, Singapore; 3Department of Physics, University of Toledo, Toledo, Ohio; 4Department of Physics, University of Michigan, Ann Arbor, Michigan.

Heteroepitaxial island strain and its various relaxation mechanisms are predominant factors in nucleation and growth on single crystal substrates. In some cases, nanostructures and metastable phases are formed which exhibit novel properties. In this paper we report the first observation of the formation and structural evolution of hexagonal close-packed (hcp) structure in the early stages of epitaxial growth of nickel on a [001] single crystal MgO substrate. The study was performed in an ultra-high vacuum transmission electron microscopy equipped with an electron beam energy distribution function analyzer in situ thin film growth. The hcp phase of nickel does not exist in nature and is thought to be stabilized by epitaxy. We observe the nano-sized hcp-nickel islands to subsequently transform into the normal face-centered cubic (fcc) structure with fcc-Ni (111)/MgO(001) when the lateral size of the islands exceeds a critical value of ~5 nm. The structural transition proceeds via a martensitic change in the stacking sequence of the close-packed planes, representing a novel way to
relieve microstrain. Equivalent in-plane orientations of the fcc Ni (110) islands were observed as a result of the fourfold degenerate characteristic of the (110) surface. This finding is consistent with the Ni nanostructures with unusually large crystallographic c/a ratio (~6% larger than ideal hcp) is very interesting for spintronic applications where controlled uniaxial anisotropies are desirable.

**T3.3**


In this study, the formation and evolution of nanoscale titanium disilicide islands in two structures were observed. Using a tunable free electron laser (FEL) and a Hg discharge lamp as light sources, we employed an ultra-Violet Photo Electron Emission Microscope (UV-PEEM) to achieve real-time observation of the evolution of these nanostructures at temperatures up to 1150°C. The islands are formed by first depositing an ultrathin Ti(2-10ML) layer on Si(001) at room temperature. We then observe the Ti/Si island formation during annealing at temperatures above 900°C. Further annealing at higher temperatures favors island growth. This growth, a result of island–island interactions via ripening and coalescence, was observed in real-time in the PEEM. Near 1150°C a notable fraction of events are observed near islands migrate attractively toward each other and subsequently coalesce. High temperature depositions of Ti are also studied. Once islands are formed from a room temperature deposition followed by a high temperature anneal, a second deposition is performed. During this high temperature deposition we observed the extinction of all islands in succession with the increased photon concentration on the surface due to the steady Ti flux. Furthermore, it is during this period of high temperature deposition that wire structures are formed on the surface. The observed wires are of uniform width and grow in the <111> direction, up to a few microns in length. Research supported by NSF and the AFOSR/MEL program.

**T3.4**

Non-aggregated nanodisperse particles of noble metals synthesized by pulse-laser deposition: ultramicroscopy structural and analytical characterization. Vladimir P. Ohashi, Christopher E. Althoff, James M. Fitzgerald, and James M. Toney, Materials Science and Engineering, University of Virginia, Charlottesville, Virginia.

Noble-metal nanoparticles with sizes ranging from 1 to 20 nm were produced by pulsed laser deposition (PLD). The experiments were performed using a typical PLD set-up, operating with a KrF excimer laser (λ = 248 nm, 25 ns FWHM) operating between 5–20 Hz. After reaching a base pressure of 5×10⁻⁷ Torr, Ag (99.995% at.) and Pd (99.9% at.) targets were ablated in an inert backfill gas of Ar at pressures of 100 and 200 mTorr and fluences ranging from 2.5 to 5 J/cm². Formation of nanostructures and molecular clusters is largely facilitated by collisions with the inert gas, and by the interaction of the plume with the leading edge of the laser induced plume. Noble-metal nanoparticles were collected on carbon grids and examined by high-resolution transmission electron microscopy (HRTEM), analytical electron microscopy utilizing parallel electron energy-loss (PEEL) and windowless energy-dispersive x-ray (EDX) microscopies. It was shown that PLD parameters (energy, pressure) affect deposition densities, particle size and morphologies (spherical, elongated, and irregular shapes influenced by melting, fracturing and fragmentation), and defect structures (multiple twinning and stacking faults).

Elemental composition of the nanoparticles [Ag and Pd (the latter with admixtures of Au and Fe)] were confirmed by EDX. A small number of large polycrystalline particles from 100 nm up to 140 μm in size, in some cases surrounded by an amorphous shell, were also observed. Some small particles with diameters ranging from 1 to 3 nm reveal sporadic structures. Due to the inherent energy of the PLD process, very little evidence of nanoparticle aggregation was observed. Interrelations between low-loss PEEL spectral features governed by interband transitions and many-electron effects and solid-state properties of the particles are considered.

**T3.5**

Band Structure of Epitaxial Metallic Islands: A Hartree-Fock Study at Semiempirical Level. Anna Maria Manzane, Istituto IMM, CNR, Bologna, Italy.

In recent years the formation of islands on surfaces, as observed in epitaxial growth, has been the object of intensive theoretical and experimental studies. There are two reasons for studying islands. First, by understanding these complex patterns, important information about surface kinetics can be extracted. The second perspective toward which some research is oriented is to obtain metal film characteristics long known to be produced by artificial structures, like arrays of regularly spaced monatomic steps on vicinal surfaces, generally Au(111), Ag(111) and Cu(111). Confinement effects are reported also for Ag epitaxial islands grown on Cu(111) but the dependence on the size of the islands is different in these systems. This divergence from the bulk behaviour is due to the formation of islands in the band structure of homogeneous metallic islands formed by Cu and Ag. The calculations, carried out at paramagnetic level, show an enhanced dependence of the density of states on the atomic location. The dependence of states in incomplete shells is very different in the two materials. In Au, top states have narrow peaks in the energy range of the bulk d electrons. On the contrary, the density of states of atoms with a large localization at the island basis retains the broad energy distribution of the bulk state.

**T3.6**


Nanoparticles of metals and semiconductors are attracting much attention, as they possess promise in photonic, electronic, magnetic and chemical applications. Reproduced chemical and nanomaterials are especially interesting and important as new functional materials. Nanoparticles are usually synthesized in solution by chemical, photochemical, radiolytic and hydrothermal reactions. In the present work we explored synthesis of nanoparticles by various chemical reactions and the morphology of the ultrathin nanospace of ultrathin TiO₂-gel films using low temperature H₂ and O₂ plasma as reductant and oxidant respectively. Catalytic activities of Pt monometallic and Pt-Ag bimetallic nanoparticles for hydrocarbon (toluene) and acrylate. Recently, we have developed a general, efficient and effective approach of incorporation of metal ions in metal-oxide ultrathin films by a template-free exchange process. Noble metal (Ag, Au, Pd, Pt) ion exchanged films were fabricated according to this approach. The films were then exposed to H₂ plasma, producing metal nanoparticles in thin films. Decreases in the extent of reaction, plasma power and the amount of metal ions result in decreases of size and size distribution of metal nanoparticles. Compared with chemical and photochemical reduced particles, H₂ plasma reduced particles retain a high degree of integrity. In addition, organic moieties in thin films can be simultaneously removed. The current method could be extended to preparation of semiconductor nanoparticles by chemical transformation from metal nanoparticles in thin films. As an example, we studied the redox transformation of silver and silver oxide in TiO₂-gel films by H₂ and O₂ plasma. Such chemical transformation in nanospace was used, for the first time, as a tool to tailor the composition, shape, size and size distribution of nanocatalysts. Catalytic activities of noble and metal oxide nanoparticles can result in monodisperse spherical metal and metal oxide nanoparticles in thin films. It is also possible to fabricate bimetallic and multimetallic nanoparticles by the current approach. Thus, Ag-core/Pd-shell bimetallic nanoparticles were fabricated in ultrathin TiO₂ film by first preparing Ag nanoparticle, followed by introduction of Pd⁺ ion and reduction with H₂ plasma. A mixture of individual Pt and Ag nanoparticles was obtained, however, by a reversed procedure. The Pt monometallic particles and Ag-core/Pd-shell bimetallic nanoparticles showed a catalytic activity for hydroxylation of methyl acrylate 233 and 367 times, respectively, as large as that of commercial Pt black. The outstanding catalytic activity was attributable by a large fraction of surface-exposed Pt atoms. References [1] J. He, J. Ichinohe, S. Fujikawa, T. Kunita, A. Nakao, Chem. Mater. 2002, 14, 3488. [2] J. He, J. Ichinohe, T. Kunita, A. Nakao, Langmuir 2002, 18, 11005. [3] J. He, J. Ichinohe, S. Fujikawa, T. Kunita, A. Nakao, Chem. Comm. 2002, 1910.

**T3.7**


The kinetics and morphology of Ge nanoparticles and nanowire CVD growth on Si substrates by Vapor Liquid Solid (VLS) epitaxy will be presented. While many groups have formed random clusters of Si nanoparticles at higher pressures with both VLS and with VLS less effort has been focused on the controlled CVD growth of epitaxial arrays of nanoparticles or nanowires directly on Si substrates. In our studies eutectic forming metallic nanodots such as Au are formed by UV vaporization on hydrocarbon terminated Si (100) and (111) substrates. Subsequent selective area growth is carried out using dimerine or disilane at pressures from 1 to 2.5 Torr, and temperatures from 400 to 600°C. At the lower pressures we observe the growth of Ge nanoparticles that nucleate at the Au eutectic and grow vertically and laterally.
undergoing coalescence as growth continues. RBS, ion channeling, and TEM are used to investigate the temperature dependent kinetics and orientation of the nanowire growth, and SEM elucidates the morphological evolution of the nanowires. At pressures above 1.04 T, we observe an abrupt change in the nature of the growth from a relatively slow nanowire growth to a much more rapid nanowire growth. The mechanism of this transition is not related to the dimensions of these 3-D structures, which were determined to be consistent with the structural dimensions of the GaAs nanowire growth. These CVD nanowires could form the basis for new in situ synthesis of 3-D Si device structures on Si substrates.

GaAs, AlGaAs and GaAs/AlGaAs heterostructure III-V group nanowires have been grown on GaAs (100) and (111) substrates by the method of Au-catalyzed vapor-liquid-solid (VLS) growth process. A nanocrystalline AlAsIn has been used to define the location and size of gold clusters, and thus to control the growth and diameter distribution of the nanowires. The morphology, size distribution, and structural characteristics of the nanowires are controlled by such parameters as the reaction temperature, growth rate, and deposition conditions. The T-shaped nanowires are single crystalline with a zinc-blende structure and diameters ranging from 10 to 60 nm. Most nanowires grown on (100) and (111) substrates have a (111) growth axis. Less than 5 percent of the nanowires grow in different directions, for example in the [110] direction that also often shows multiple branches. Branches, defects, and stacking faults, are frequently observed in the (111) oriented nanowires. However, no defects are observed in the (110) oriented nanowires. TEM also reveals that the GaAs nanowires are single crystalline with the InAs nanowires. The growth interface is sharp and atomically flat or more often curved. In this report we will also present photoluminescence (PL) data and the elemental distribution through the nanowires determined by EDS analysis.

T3.10 Preparation and Magnetoresistance Properties of Silver Telluride Nanowires by Electrodeposition, Xiu Dongsheng, Xu Yuxing, Chen Ruizhi and Guo Guolin. Department of Chemistry, Institute of Physical Chemistry, Beijing, China.

Silver telluride alloys present interesting thermoelectrical, electrical and magnetoresistance properties, which find widespread applications in the fields of thermoelectronics, optics, and sensors. Silver telluride is known to be a typical semiconductor with a narrow bandgap, high carrier mobility and low lattice thermal conductivity, whereas its high temperature phase gives rise to unexpected magnetoresistance effects. A high positive magnetoresistance effect has been observed in both Ag-rich [n-type] and Te-rich [p-type] silver telluride bulk samples or thin films. In this paper, we present a method for preparation of crystalline silver telluride nanowires by electrodeposition from dimethyl sulfoxide (DMSO) solutions containing 0.1 M NaNO3, 5.0 M AgNO3 and 3.5-7.0 M TeCl4. We found that silver telluride nanowires can be deposited without the need for a controlled composition from Ag-rich to Te-rich by adjusting the concentration of TeCl4 or the deposition potential. Interestingly, when the concentration of TeCl4 increased to 6.07 M, the deposited nanowires could be adjusted from monocrystalline AgTe to hexagonal Ag2Te. Finally, magnetoresistance properties of these electrodeposited nanowires of silver telluride have also been investigated.

T3.11 Synthesis, Characterization and Electron Field Emission Study of Tungsten Disulphide Nanotubes, Lifeng Dong1, Jun Jiao1, and Aitor Maiz2; 1Department of Physics, Portland State University, Portland, Oregon; 2School of Science, University of the Basque Country, Spain.

Due to the high aspect ratio and small diameter, carbon nanotubes have been investigated in the electron sources for flat panel displays and electron microscopes. Since tungsten disulphide (WS2) nanotubes have similar morphologies to carbon nanotubes and the existing electron field emission mechanism of nanotubes, the investigation of electron field emission properties of WS2 nanotubes will allow us to explore new candidates of tubular emitters and improve the understanding of the electron field emission mechanism of nanotubes. In this study, WS2 nanotubes were synthesized on the tungsten substrate by a chemical vapor deposition (CVD) method. First, WOX nanotubes were formed on these substrates. Second, sulfur powder was put into the upstream of the substrate and WS2 nanotubes were then synthesized in the flowing H2 gas at 700-1000 K. Using field emission high-resolution transmission electron microscopy (HRTEM) and field emission scanning electron microscopy (FESEM), we systematically studied the effects of growth temperature, the position of the tungsten wire, the tungsten wire diameter and internal structures of WS2 nanotubes. Furthermore, using a field emission probe system and field emission microscope (FEM), we investigated the field emission characteristics of WS2 nanotubes including turn-on field, threshold field and field enhancement factor. This research was financially supported by the National Science Foundation (DMR-0907575) and ECS-0217001 and the Donors of the American Chemical Society Petroleum Research Fund (PRF-38118-G5).


For the first time vertically grown GaN nanowire arrays were fabricated using vapor-liquid-solid (VLS) method. GaN/200 AIN double buffer layers pre-sputtered on the Si(111) wafer were used for the epitaxial and vertical growth of GaN nanowire arrays. Scanning electron microscopy (SEM) analysis show that GaN nanowires are micrometer in length and 30-80 nm in diameter. Transmission electron microscopy (TEM) analysis reveal that GaN nanowires are single crystalline and defect free. The photoluminescence (PL) spectrum on the GaN nanowire arrays strongly suggests the excitation energy per thiolate ligand is 3.04 eV and a broad emission peak at ~584 nm in comparison to the randomly oriented GaN nanowires grown on Si wafers without double buffer layers. The vertically grown GaN nanowire arrays show strong possibility for the application in laser diode.

T3.13 Self-Ordered Gallium Nitride (GaN) Film Growth Studies, M. Gokmen K. Sunakara, Hoongui Li, Sreeram Vaidyaram, Hui Chaudhureekar, Krishna Rajan and Jhann Chaudhury; 1Chemical Engineering, University of Louisville, Louisville, Kentucky; 2Materials Science and Engineering, Remsen Polytechnic Institute, Troy, Kentucky; 3Mechanical Engineering Department, Western State University, Kunitaro, US.

We have recently demonstrated a concept in which hexagonal Gallium Nitride crystals could self-assemble during nucleation and growth
from molten gallium to form self-orientated films. We obtained these results by direct nitridation of this molten gallium covered on fused silica glass substrates (~100 nm thick) and p-DB (polydispersible) substrates using atomic nitrogen in an ECR-MW plasma reactor. The samples were characterized extensively using X-ray diffraction, cross-sectional SEM and TEM. The results showed self-oriented regions as large as 1 mm or higher. These isolated SEM images revealed that the gallium buffer layer below the self-oriented regions. Cross-sectional TEM characterization of the regions indicated low-angle grain boundaries that formed in the nitridation process. The X-ray tomography using the Sanford synchrotron facility showed that the GaN film was in an epitaxial relationship with the underlying GaN substrate. The cross-sectional SEM images indicated the coexistence of layers of GaN and SiN in the GaN buffer layer. These results suggest that self-assembly of GaN/GaAs interfaces occurred along with epitaxial growth of the underlying GaN substrate.

High-quality Zn/Oxide nanomaterials and GaN nanomaterials were fabricated using a non-catalytic metal-organic vapor-phase epitaxy. ZnO nanorods with a mean diameter smaller than 10 nm were initially grown as a core material for the nanometer heterostructures. Overgrowth of GaN on ZnO nanorods yielded the so-called ZnO/GaN nanocomposite heterostructures. For the GaN growth, tris(dimethylglyoximato)trimethylgallium (TMGa) and N2 were used as reactants. Transmission electron microscopy images revealed the 5–10 nm thick GaN layers were epitaxially grown on the ZnO nanorods, and the GaN layers were almost defect-free single-crystalline. Microstructural analysis was performed by the synchrotron radiation x-ray diffraction (SR-XRD). SR-XRD peaks of the GaN/ZnO nanocomposite heterostructures exhibited a slight shoulder indexed as the (002) reflection, with a progressive increase in the (002) peak intensity as the GaN layer coverage and ZnO nanorods. Moreover, full width at half maximum (FWHM) values depend on the GaN layer thickness. Lattice distortion along the c-axis was due to biaxial in-plane compressive or tensile strain, depending on growth time of GaN layer.

Furthermore, GaN nanotubes were fabricated by removing the ZnO core material via thermal treatment. The ZnO/GaN coaxial nanomaterials and GaN nanotubes can be used as building blocks for nanoscale devices including high-mobility field-effect transistors and light-emitting devices.

T3.15 Critical Thickness for Composition Modulation in Low Temperature InGaNAs Layers. Maria Ujine González, Yolanda González, Luisa González, Miriam Herrera, David González and Rafael García, Fabricación y caracterización de nanomateriales, Instituto de Microelectrónica de Madrid (CNMNCSIC), Tres Cantos, Madrid, Spain; Departamento de Ciencia de los Materiales e I.M. y Q.I., Universidad de Cadiz, Puerto Real, Cadiz, Spain.

Low temperature growth processes have a great interest for the achievement of layers showing flat morphology without modulating composition features in InGaAs/GaAs heterostructures. An AlMBe epitaxy technique has been revealed as a good technique for obtaining stoichiometric In_{x}Ga_{1-x}As layers at temperatures as low as 250°C. Besides its practical interest, these layers show significant differences in comparison with layers grown at conventional temperatures. In this work, we present results on the relation between composition evolution of In_{x}Ga_{1-x}As layers and layer morphology. We have shown that the AlMBe epitaxy technique is a reliable method for growing high-quality In_{x}Ga_{1-x}As layers at temperatures as low as 250°C. We have determined that the crosshatch formation and plastic relaxation is completely inhibited for In_{x}Ga_{1-x}As layers at temperatures lower than 250°C.
The evolution of sputter ripples provides a means of testing theoretical models of surface evolution. This method can also potentially be used to measure diffusion constants and activation energies for surface transport processes. In this work, we use a variational model to study the non-linear and singular nature of the equations that govern the evolution of crystalline surfaces below the roughening temperature. Our modeling approach is applied to realistic systems of sputter ripples in different kinetic regimes. The inherent non-linearity of the problem along with mode-coupling effects allow for non-classical, inverse-linear decay of the ripple amplitude. We suggest the use of other metrics such as the integrated power spectral density or the peak intensity as possible alternatives.

Quantum dots of Si in Ag and Au in Si. Hyo-Won Seo, Irene A. Rouskova, Xuemei Wang, Quek Y. Chen and Wei-Kim Chu, Texas Center for Superconductivity and Dept. of Physics, University of Houston, Houston, Texas.

As the sizes of particles or dots shrink, the electron energy levels would be quantized, giving rise to novel physical properties. Indeed, the physics and chemistry of nano-particles have been intensively studied in the past decade, with most works having nano-particles dispersed on the surface of a substrate or in an amorphous or polycrystalline matrix. However, for both scientific and technological reasons, there is an incentive to have them embedded in single crystalline solids, as emphasized in this investigation. The approach is largely based on the phase separation of two immiscible elements in a simple binary system, though this principle can be readily extended to more complex pseudo-binary and quaternary systems that demonstrate a tendency toward phase separation. Specifically, we study the silver-silicon pair which is a simple example with distinctive immiscibility. This is done by introducing beyond the solid solubility of one type of atoms (solid solute) in a matrix (solid solvent) of another using high beam current ion implantation. We have formed 2-10 nm of nano-silicon dots in silicon or Si in Ag matrices by high dose ion implantation. However, during ion bombardments, the matrices became amorphous. As a remedy, we used solid phase epitaxy to convert the amorphous layer into the single crystalline state. This was achieved by first depositing aluminum on the amorphous Si layer followed by a proper annealing procedure. We’ve investigated the crystal structure, interface perfection, impurity distribution and their relationships. In this paper, we’ll present the electrical and optical measurement results conducted to seek correlations between the nanostructure and novel quantum phenomena in the quantum particle assemblies. This work was supported by the State of Texas in part through the Advanced Technology Program and in part through the Texas Center for Superconductivity at the University of Houston.

Nuclear In The Presence Of 3D Islands During Heteroeptaxy. Michael L. Falk, Mathieu Bovaille and Joanna Mirecki Mellungk, Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan.

Pits nucleate subsequent to the nucleation of 3D islands during the heteroepitaxial growth of InGaNAs on GaAs under some growth conditions. This process leads to surface patterning extending out to about 150 μm. In light of these observations we developed a theoretical model for the nucleation of a secondary feature, in this case a pit, on a surface upon which primary features, 3D islands, have already nucleated. This analysis focuses on the role of adatoms in the nucleation of pits. While experimental evidence indicates that adatom concentrations are almost uniform across the surface, small inhomogeneities in the adatom concentration have been observed to lead to localization of the nucleation of islands. Therefore even a small inhomogeneity in the adatom concentration has a significant effect on the resulting morphology. Using a nucleation model, we show that under a variety of conditions, pits nucleate homogeneously, particularly in the presence of 3D islands. However, the nucleation and growth of pits can be prevented by a high adatom concentration. Also, the inhomogeneity of the adatom concentration due to diffusion makes pit nucleation more likely close to the islands where the adatom concentration is lower. This theoretical framework identifies four experimental requirements that depend on the elastic energy due to the misfit and on the growth rate: complete suppression of pit nucleation, pit nucleation between neighboring islands, pit nucleation adjacent to isolated islands, pit nucleation even in the absence of islands. While the regime where pits can nucleate even in the absence of islands dominates thermodynamically, when kinetic limitations are taken into account pitting is often kinetically prevented except in the presence of 3D islands. Comparison to experimental observations indicates that the effect of strain inhomogeneities on adatom concentrations further localizes pit nucleation.

Intentional growth of short-period superlattices (SPSs) along the [0 0 1] growth direction causes natural SPSs perpendicular to growth direction, or lateral composition modulation (LCM), where the binary composite materials of SPSs have different lattice constants, and the period of the SPSs is less than 2-1 monolayers (MLs). The novelty of LCM is that this is the most promising and practical way to fabricate the array of quantum wires (QWires) through strain-relaxed self-organization phenomena. However, few works have been done on the optical properties of QWires grown using LCM. In this present work, we examine the optical properties of QWires grown using LCM are studied by photoluminescence (PL) measurements, as a function of growth temperature. The growth of QWires is confirmed by a TEM measurement. By analysis of the dependence of PL intensity and peak energy of the QWires on measurement temperature, the origin of the optical peak energy (LP) investigated. While the LP peak behaves like that of an ordered InGaP, the LP peak shows the insensitivity of LP peak energy to T. This is attributed to compensation of bandgap by competition of ordered InGaP QWires region (T - T, J. Appl. Phys. 87, 295-2900) and indicates that the LP peak is related to QWires. Strong dependence of the LP peak on the position of polarizer also supports it. Additionally, the PL intensity of the LP peak has a maximum value at T - T (10 K) but decreases with T > 50 K. The LP peak decreases monotonously as T increases. We introduce idea of compensation of thermal expansion coefficient to explain this phenomenon.

T3.26 Effects of Growth Sequence on Optical and Structural Properties of InAs/GaAs Quantum Dots Grown By Atomic Layer Molecular Beam Epitaxy. Ji-Sung Yoon, M V Murphy, J C Shin, J G Lim, Y J Park1, W J Choi, I K Ham, W J Cho1, J I Lee, H S Kim2 and C G Park2, School of Electronic Science and Engineering, Seoul National University, Seoul, South Korea; 1Cnr for Adv. Aerospace Mat, POESTECH, Pohang, 790-884, South Korea.

Three-dimensionally confined electron, hole, and exciton induced by semiconductor quantum dots (QDs) have attracted much attention due to introduction of new physical phenomena and, as a result, improvement of photonic and electronic devices such as low threshold current density, large characteristic temperature, and so on. Therefore, many researchers have focused on this topic and developed QD lasers. However, since QD lasers have a room temperature, for more practical application to QD lasers, more uniform formation of QDs and weaker wetting layer effects are required, because efficient gain volume of QDs for a specific spectrum will be increased by uniform QDs and the wetting layer is suspected as a source of non-radiative recombination. Although QDs are formed by atomic layer molecular beam epitaxy (ALMBE), they are expected to solve these problems, fewer articles are reported on this topic compared to those on strained-layer quantum wells (SKW) QDs. In this report, effects of growth sequence on optical and structural properties of InAs/GaAs QDs grown by ALMBE. Each InAs QD sample was grown on semi-insulating (001) GaAs wafers at 580 °C with 3 periods of each 1 ML-thick sequence. Total coverage of InAs is 3 monolayers (MLs), and As / ML ratio is = 10.5. Five growth sequences studied were InGAs/GaAs/GaAs/GaAs/GaAs. InGAs/GaAs/GaAs/GaAs/GaAs and InGAs/GaAs/GaAs/GaAs/GaAs and designated as #1, #2, respectively. Where, InGAs/GaAs/GaAs/GaAs/GaAs represents 1 ML-thick deposition of InAs/GaAs/GaAs/GaAs/GaAs of growth interruption, 2-3 long deposition of As4, 1 ML-thick growth of InAs, respectively. It is found that GaAs after InAs is more effective than non-GaAs after InAs in reducing density of conduction dots, and reducing dot width distribution of the QDs. Moreover, dot densities are approximately doubled by non-GaAs after GaAs reduces dot height distribution compared with non-GaAs after GaAs. Generally, GaAs after InAs plays a more critical role than GaAs after GaAs in formation of the QDs. As a result, GaAs after InAs enhances the QD peak energies of the InAs/GaAs/GaAs/GaAs/GaAs growth sequence among the samples increase as sample number increases (#1, 1, 1, and 1 shows the lowest PL linewidth (~ 300 meV), high PL peak separation between ground and 1st excited level (~ 500 meV). From the result, it is known that GaAs after InAs (111) is favorable growth sequence among the samples set. Dependence of PL peak linewidth of QDs on crystal temperature (TCP) is insensitive to the TCP (28 ~30 meV for TCP = 18 ~300 K) and in contradiction to that of QWs which shows strong fluctuation in TCP changes (50 ~75 meV for TCP = 18 ~300 K). It is attributed to lack of wetting layer effects in #1, and cross-sectional TEM images - no visible sign of wetting layers - support it.

T3.27 Lateral Ordering in InAs/GaAs Stacks Grown on InP/InGaP Template. J R R Bezeklen, H R Gutiérrez, M A Cotta and M M G Carvalho, LPDE/EEA, IFGW/UNICAMP, Campinas, S Paulo, Brazil.

Self-assembly of InAs/GaAs have been extensively investigated by the scientific community. Both theoretical and experimental works have shown that vertical ordering of quantum dots may lead - via their elastic strain fields - not only to a better size homogeneity but also to lateral arrangement. However, despite the lateral ordering tendency, an increase of the island size has been found in III-V dot superlattices. Moreover, the lateral ordering degree achieved in these systems has been rather limited. Alternative approaches such as patterned surfaces, vicinal substrates and misfit dislocations networks were proposed in order to solve this problem. In this work, we have obtained bidimensional arrays of InP quantum dots grown on slightly In-rich (0.6%) InGaP(100) GaAs layers by chemical beam epitaxy. The InP periodic array is aligned along both [110] and [110] directions. In this work, we use this two-dimensional matrix of InP islands as a template for the lateral ordering of InAs dots in InAs/GaAs bilayers. An uncapped layer of InAs dots was deposited on the top surface of all samples in order to study the lateral ordering by an atomic force microscopy (AFM). The Fourier transform (FFT) of the AFM images was used to quantify the dot lateral ordering degree. The correlation between the ordering of the first InAs dot layer and the InAs island size was investigated by cross-sectional transmission electron microscopy (XTEM) measurements. The results presented here show a path for obtaining highly ordered three-dimensional arrays of InAs dots, which could be widely used in new generation quantum devices.

T3.28 (In,Ga)As/GaAs nanostructure evolution at high growth temperature. Song Gi Cho, Young Won Kim, and Jong J. Salomo. Physics department, University of Arkansas, Fayetteville, Arkansas, USA.

Self-organization of (In,Ga)As/GaAs nanostructures have been widely investigated since these structures offer great potential for optoelectronic application. Despite the intense effort worldwide, however, there is still a significant need for control of both the shape and position of the nanostructures. The possibility of introducing a shape transition to control lateral ordering has been investigated for (In,Ga)As nanostructures with an In content of 0.3 grown at the high substrate temperature of 540°C degree C. In the work reported here, the shape and lateral ordering evolution of (In,Ga)As/GaAs nanostructures grown at 540°C degree C has been experimentally studied by a combined system of molecular beam epitaxy (MBE) and scanning tunneling microscopy (STM). In particular, lateral ordering through an island shape transition has been explored. Anisotropic two-dimensional (2D) InGaAs islands was observed at the initial stage of the growth mode. A transition from 2D to 3D, resulting in elongated islands, was then observed in the following stage. At first the 3D islands had an anisotropic ratio of about 6 but turn to an anisotropic ratio of 5 with further deposition. The development of the anisotropic ratio indicates that the higher nonuniform strain favors the formation of isotropic islands. The 3D islands are observed to grow larger with additional deposition while the density of islands is observed to remain constant. The mechanism of a shape transition to control lateral ordering will be discussed.


We propose a new nano-probe assisted technique which enables the formation of site-controlled InAs quantum dots (QDs). By using a specially designed atomic force microscopy (AFM) probe. named Nano-Jet Probe, we have fabricated two-dimensional (2D) arrays of ordered indium (In) nano-dots on a GaAs substrate. These In nano-dots can be directly converted to InAs QD arrays by subsequent irradiation of arsenic flux. The cantilever developed in this study is a piezoelectric type with a hollow pyramidal tip having a micro aperture of about 500 nm in diameter on the apex and an In-reservoir located at the stubs. The In is used for the formation as well as for sensing the force in AFM observations after the nano-dot formation. By applying a voltage pulse between the pyramidal tip and the sample in an ultrahigh vacuum (UHV) condition, In clusters are extracted from the reservoir through the aperture, resulting in the In nano-dot formation. By using this probe, we have reproducibly fabricated 2D In nano-dot arrays. The regularity of the In nano-dot
arrays was controlled in a sub-nm scale, since the position of each nano-dot was determined by an AFM scanning mechanism. These ordered In nano-dots can be directly converted to InAs QD arrays by subsequent irradiation of arsenic flux in the molecular beam epitaxy chamber, which is connected to the AFM chamber through a UHV tunnel. The developed technology will be applicable to the high-throughput site-controlled InAs QD formation with high uniformity, high density, and high selectivity. This work was supported by the New Energy and Industrial Technology Development Organization (NEDO) within the framework of the Femtosecond Technology Project.

T3.30
The Observation of Temperature-Dependent Photoluminescence of InAs/GaAs Quantum Dots with Different Coverage. Shih-Yen Lin, Ren-Bor Lin and Li-Mei Chen; Industrial Technology Research Institute, Hsinchu, Taiwan.

MBE prepared InAs quantum dots with 3.0, 2.2 and 1.5 ML InAs coverage denoted as A, B, and C grown on (100) GaAs substrate at 510°C. The AFM images show different dot density 3.80×10^5, 5.80×10^5 and 1.2×10^6 cm^-2 for the three samples. Lower dot density of 3.0 ML InAs QDs is attributed to the coalescence of different QDs with the appearance of large-size QDs. The temperature dependence of PL full width half maximum (FWHM), peak energies and PL intensities of the three samples are investigated. Pronounced decrease of FWHM and the increase of PL intensities with increasing temperature for samples A and B with higher dot density are observed. A model is proposed to explain the temperature-dependent InAs QD PL behavior. As the electrons in QDs would be thermalized such that repulsion of electrons to nearby dots would occur via the wetting layer. Hence, the optical recombination process would occur at the globally lowest conduction band minimum. Further, the separation of the wave functions of different dots would be relaxed, which would result in the decrease of FWHM and the increase of PL intensities of denser QDs with increasing temperature. As for sample C with lower dot density, the temperature dependence of PL is less pronounced with increasing temperature. No intensity increase is therefore observed for sample C, the FWHM would increase for T > 180 K and a rapid decrease of peak energies occurs for T > 150 K. Also, a smaller band filling effect with a thickness of 0.3 nm of Ge is also observed using alternating Si/Ge deposition in the step flow growth mode. The Si and Ge nanowires grow along preexisting step edges. Also a nanowire superlattice covering the entire surface was fabricated. The key factors governing the self-organized growth of the nanowires will be discussed.

T3.31
InNas and GaInNas self-assembled quantum dots and lasers grown by solid source molecular beam epitaxy. Zhengjie Sun, Soon Fatt Yoon, Kuek Chun Yew and Braxie Bo; School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore, Singapore.

Self-assembled Ga_0.6In_0.4N_{0.5}As_{0.5} quantum dots were grown on GaNas by solid source molecular beam epitaxy (SSMBE). Introduction of N was achieved by a RF Nitrogen plasma source. Formation of quantum dots by S growth mode is confirmed by observation of a standard 2D-3D RHEED pattern transition. Atomic force microscopy (AFM) and photoluminescence (PL) measurements of this growth demonstrate good correlation between the structure and optical properties of GaInNas quantum dots. High GaNas quantum dot density (10^8 cm^-2) was obtained for different In and N composition (0.35 < x < 0.01). The effect of surface coverage on dot density, dot size, and optical properties was studied in detail. Adjusting the bandgap confinement by incorporating a GaNas strain-reduction layer into the GaInNas dot layer was found to extend the emission wavelength by 180 nm. Multilayer structure is also found to increase the emission wavelength with the effect of electron state couple between dots in different layers. Room temperature pulsed operation is demonstrated for a Ga_0.6In_0.4N_{0.5}As_{0.5} quantum dot laser emitting at ~1.1 µm.

T3.32

In the field of semiconductor nanostructure, progress shows possibility of realizing the characteristics required for next generation electronic and optical devices. In the last several years, quantum dots (QDs) have been intensively studied for realization of advanced quantum devices such as silicon laser. In this study, we use a droplet growth process to fabricate InAs quantum dots. In this study, we investigate the growth of one-dimensional arrayed GaAs QDs on patterned substrate using Droplet Epitaxy. GaAs (100) substrates patterned using conventional photolithography were wet chemically etched in the direction used for the growth. After etching, the surface of mask stripes are 100 nm and 1.0μm, respectively. The GaAs QDs growth was carried out using a Riber-32P molecular beam epitaxy (MBE) system. The QDs structures were observed by a high-resolution scanning electron microscopy (HR-SEM), photoluminescence, and cathodoluminescence/nano-fluorescence scanning optical microscope (NSOM). To grow GaAs QDs on patterned substrate, AlGaAs buffer layer is used with variation of thickness, and formation of GaAs QDs depends on the dot density, dot size, and growth temperature. Addition of the one-dimensional array of GaAs QDs grown on a (100) facet on the top of mesa, in this study, we observed that the (110) facets prevent the formation of Ga droplets because the migration length of Ga atom on (110) is larger than that on (001) and that temperature to form Ga droplets need over 250°C. It is found that fabrication of one-dimensional arrayed QDs is possible by Droplet Epitaxy.

T3.33
Fabrication of two-dimensional Si/Ge nanowires and nanorings. Midori Kawanuma1,2, Bert Voigtlander2, Neelima Paul2 and Vasily Gritsan3; 1Materials Science, Kitami Institute of Technology, Kitami, Japan; 2IGIS, Forschungszentrum Juclich, Juelich, Germany; 3 IGIS, Forschungszentrum Juclich, Juelich, Germany.

It has been difficult to differentiate between the elements Si and Ge in thin films and especially in two-dimensional structures at surfaces by scanning tunneling microscopy (STM). Here we show that two-dimensional Si/Ge nanostructures with a thickness of a single atomic layer can be imaged with chemical sensitivity using STM. We used an atomic layer of Bi terminating the nanostructures to distinguish between Si and Ge. It turned out that the apparent height measured by the STM is ~0.3 nm higher for Si than for areas consisting of Si. This distinction between Si and Ge enabled us to fabricate and characterize two-dimensional Si/Ge nanostructures in a controlled way by self-organized growth. Si/Ge nanowires consisting of alternating Si and Ge rings having a width of ~0.3 nm were grown around a Si core on a Si(111) substrate by molecular beam epitaxy (MBE). The thickness of the Si and Ge rings is only one atomic layer (0.3 nm). Alternating Si/Ge nanowires with a width of 0.35 nm and a thickness of 0.13 nm also fabricated using alternating Si/Ge deposition in the step flow growth mode. The Si and Ge nanowires grow along preexisting step edges. Also a nanowire superlattice covering the entire surface was fabricated. The key factors governing the self-organized growth of the nanowires will be discussed.

T3.34
Preparation of Ge (100) Substrates for High Quality Epitaxial Growth of Group IV Materials and Quantum Dots. Mark Edward Nowakowski1,2, Jordana Bandura3, Lloyd Douglas Bell4 and Shoude Nikola4; 1Materials Science, University of Illinois, Urbana, Illinois; 2Jet Propulsion Laboratory, Pasadena, California.

We compare various wet chemical treatments, in preparing high-quality Ge (100) surfaces suitable for molecular beam epitaxy (MBE). Various surface treatments were employed to improve the substrate quality, both in terms of surface cleanliness and structure, and in terms of chemical properties. The chemical treatments to remove the oxide are performed in a nitrogen environment to prevent further formation of oxide prior to surface analysis. Following chemical cleaning, high-energy electron diffraction (HED) analysis is performed to observe the surface evolution as a function of temperature in a separate chamber, we analyze each sample, before and after chemical treatment as well as after the heating by x-ray photoelectron spectroscopy (XPS) to directly determine the oxide description following each chemical treatment. Atomic Force Microscopy (AFM) is also used for visual comparison of effectiveness and reproducibility of each chemical treatment. In the comparative study, effectiveness of each chemical treatment and the ability of the passivated surface will be discussed and the quality of epitaxial growth following each treatment will be presented.

T3.35
Controlled Fabrication by LPCVD of SiGe/SiO2 (LTO) Multilayers with tailored Luminescence Emission Spectrum. Annas Rodriguez1,2, Jesus Sisengrad1,2, Fernando Rodriguez2, Manuel Avella2, Pilar Martín2, Juan Jimenez2, Isabel Ortiz2 and Carmen Balesteros1,2; 1Tecnología Electrónica, E.T.S.I.Telecomunicación, U.P.M., Madrid, Spain; 2Facultad de Ingeniería, Universidad Complutense, E.T.S.I.T., Universidad de Valladolid, Valladolid, Spain; 3Facultad de Ingeniería, E.P.S., Universidad Carlos III, Leganes, Madrid, Spain.

Amorphous or polycrystalline SiGe/SiO2 multilayers with film thickness below 5 nm are of interest for the fabrication of optoelectronic devices which can be easily integrated with the
Si-based electronic circuits. SiGe offers some properties of technological interest, since it can be deposited by LPCVD at lower temperatures than Si. This also allows it to be compatible with that of a Low Temperature Oxide (LTO). In this work, an alternative to the Si/SiO₂ multilayer structures fabricated using magnetron sputtering is proposed. SiGe/SiO₂ multilayers are obtained in a single process at a constant temperature (in the 330 to 390 °C range) using a conventional hot wall LPCVD reactor equipped with a system for LTO deposition. Pure disilane (Si₂H₆) and germane (GeH₄) were used as precursor gases for SiGe deposition. The pressure was fixed at 0.66 mTorr, and the Si₁₋ₓGeₓ H₂ flow ratio was varied to obtain SiGe films with different Ge fractions. The SiO₂ layers were deposited using Si₂H₆ and O₂ at 185 mTorr, using N₂ as carrier gas. The Si₂H₆ to O₂ flow ratio was varied to obtain stoichiometric oxide films. In the selected conditions, the deposition rates of both kinds of films are low enough to accurately control the layer thickness using deposition times from 10 to 30 minutes. To investigate the possibilities of tailoring the characteristics of the low-temperature silicon (both using the peak wavelength and widening the spectrum), two kinds of samples have been fabricated.

First, multilayers consisting of 5 to 10 periods of SiGe/LTO with different compositions and thicknesses of the SiGe films. Second, structures consisting of alternated SiGe/LTO films with variable SiGe film composition through the stack. The structural features of the samples have been characterized by X-ray diffraction and cross-section TEM. The layer thicknesses were derived from the TEM observations. The diffractiongrams as well as the TEM analysis show that the deposited SiGe films are amorphous. FTIR spectroscopy was used to analyze the characteristics of the LTO. Crystalline SiGe/LTO structures were obtained by solid phase crystalization of the SiGe films, which also results in a densification of the LTO layers. The optical characterization of the samples was carried out by photoluminescence, cathodoluminescence and micro-Raman spectroscopy. The optical determination of the bandgap energy of the SiGe films was studied as a function of the composition, thickness, and the number of periods. These results are correlated to the structural data extracted from the Raman spectra, in particular the composition of the layers and the confinement effects associated with the reduced size of the structures.

**T3.38 Enhanced 2DEG-1D Carrier Coupling Efficiency in a V-groove Quantum Wire Field Effect Transistor.** Cheol-Koo Han¹,², Hoon Kim¹ and Munsoo Ohgra².

Adiabatic energy level connection between the electron reservoir (2-dimensional electron gas: 2DEG) and quantum wire (QWR) is one of the main interests in the carrier transport observation in a 1-D channel because the reflection of electron wave function at the 2D-1D interface suppresses the high-confinement properties. Although high-quality QWR, whose optical coherence length is as long as 2.5 microns, is easily available with our FME method, growth pinch off region between sidewall quantum well (QWV/2DEG reservoir) of the key lower quantum wire coupling efficiency between 2DEG-1D channel. We have been reporting on the carrier transport mechanism in a V-groove GaAs/AlGaAs quantum wire (QWR). By using high-quality V-groove QWR, field effect transistors (FET), with various QWR thickness and device parameters are fabricated and their transport properties were characterized. Conductance fluctuations, ranging from 0.2 to 3 micro-S, were observed from all the fabricated devices at cryogenic temperature. Although their step heights were extremely small compared to the unity of the universal one, drain bias dependent conductance and magnetoresistance measurements at 50 mK revealed that the observed steps are universal conductance fluctuations (G = 2e²/h, 77.5 micro-S). The main reason of such a small step height is low QW-1D carrier coupling efficiency. Although using thick QWR as a channel could increase step height, it is accompanied by small energy sublevel spacing in the QWR which prevents high temperature operation of QWRFET. Recently, we are trying to realize 2DEG-1D coupling efficiency enhanced structures by modified V-groove structure. By using a newly designed V-groove pattern, two-2DEGs surrounded by multi-faceted sidewalls are connected via very narrow regions like quantum point contacts (QPC) structure. Around 10 times of enhanced coupling efficiency comparing to the conventional V-groove structure is observed. Optical/carrier transport properties of the new structures will be presented in detail.

**T3.39 SelfAssembled microcavities incorporated into the Si(100) surface.** Nizhar Bagrati¹, Alexei Bourauel¹, Wolfgang Gehlhoff², Leonid Khodykin³ and Roman Khrushchev³. ¹Institute of Physics, Atomic-Physics and Astrophysics, A.F.Ioffe-Physico-Technical Institute RAS, St. Petersburg, Russian Federation; ²Institut fuer Festkoerperfysik, Technische Universitaet Berlin, Berlin.

We present the findings of self-assembled silicon microcavities that contain quantum wells and exhibit distributed feedback identified by the FIR transmission spectra. The photo and electroluminescence from these self-assembled microcavities is found to be extremely strong in the range of the Rabi splitting. Diphoton diffusion in silicon is known to be amenable to control by means of adjusting the fluxes of self-interstitials and vacancies emerging from the monocrystalline surface. The goal of the present work is to exhibit silicon microdefects induced by the excess fluxes of self-interstitials that form the microcavities incorporated into the self-assembled quantum well system on the Si(100) surface. The short-time boron diffusion was carried out from the gas phase into the Si(100) wafers. The wafers were previously oxidized in dry oxygen containing CO₂ vapor. Short-time impurity doping was done under fine surface injection of both self-interstitials and vacancies into windows which were cut in the oxide layer and preparing the test photoluminescence. Additional replenishment with dry oxygen into the gas phase during the diffusion process provides the generation of excess fluxes of intrinsic point defects from the working side. Using SiGe as a test sample under high-power excitation, the analysis of the structures obtained shows that the ultrashort boron
profiles consist of self-assembled silicon quantum wells (SQW) divided by heavily doped delta barriers. The SQW characteristics have been identified in the cyclotron resonance angular dependencies and CV diagrams brought about the detection of the bias voltage from the normal to the p-n junction plane. Space-independent fluxes of intrinsic defects that cause the formation of SQW appear to be transferred from the microelectrode into the sample, and may be revealed with the STM technique as the deformed potential fluctuations (DPF) near the Si-SiO2 interface and the surface of the ultrashallow diffusion profile. The DPF effect induced by microdefects of the self-interstitial type is demonstrated and is shown to be effective for the enhancement of secondary boron diffusion. The interplay between the dimensions of these microdefects and their distribution inside the ultrashallow diffusion profile is found to modify the fractal mechanism that causes the formation of the microcavities embedded into the SQW system. These silicon microcavities are revealed by the spectral dependencies of the transmission coefficient that exhibits a distributed feedback identified by the Rabi splitting.

T3.40
Spin-dependent single-hole transport in silicon one-dimensional nanowires. Nikolai Bagraev1, Alexei Bournaveas1, Wolfgang Gehlhoff2, Leonid Kluychnikin3, Anna Malynyenko3 and Ivan Shelykh1,1 Division of Plasma Physics, Atomic Physics and Astrophysics, A.F.Ioffe Physico-Technical Institute RAS, St.Petersburg, Russian Federation; 2Institut fuer Festkoerperphysik, Technische Universitaet Berlin, Berlin, Germany; 3Experimental Physics, St.Petersburg Polytechnical University, St.Peterburg, Russian Federation.

We present the findings of the transmission phase shift (TPS) in the 0.7(2eV/ħ) structure of the quantum staircase and in the Kondo-correlated state revealed by the quantum wire which is inserted within one of the arms of the Aharonov-Bohm (AB) ring prepared inside the ultrashallow silicon probing structure. The phase shift in the 0.7(2eV/ħ) structure caused by heavy holes is found to be changed by electrically-detected NMR of the 29Si nuclei thereby verifying the spin polarization in the quantum wire. The relative contribution of the spin-orbit splitting and spontaneous hole polarization to the mechanism of the spin polarization in quantum wires is also identified by varying the density of 2D hole gas.

T3.41
White light emission from nanostuctures embedded in ultrashallow silicon p-n junctions. Nikolai Bagraev1, Alexei Bournaveas1, Wolfgang Gehlhoff2, Leonid Kluychnikin3 and Anna Malynyenko3, St.Petersburg, Russian Federation; 2Institut fuer Festkoerperphysik, Technische Universitaet Berlin, Berlin, Germany.

We present the findings of high efficient white light emission at room temperature that is induced by the electron-hole injection into the self-assembled quantum well (SQW) series embedded in the ultrashallow p-n diffusion profile of boron in the n-type Si(100) surface. The electron-hole injection is carried out through the single quantum wire that crosses the SQW cascade structure. The electron-hole recombination between quantum sublevels that causes the red-green-blue emission is found to be enhanced by the incorporation of silicon microcavities into the ultrashallow p-n junctions. The TMs detection of the electro luminescence spectra that seems to result from spontaneous exciton-polaritons emission has been observed. 

T3.42
Room Temperature Resonant Tunneling and Coulomb Blockade in Nanocrystalline Si With Double SiO2 Barriers. Liangguo Wu, Kunji Chen, Min Dai, Wei Li, Linwei Yu and Xinfan Huang, National Lab of Solid State Microstructures and Dept. of Physics, Nanjing University, Nanjing, China.

Recently, nanocrystalline silicon (nc-Si) floating gate double-barrier structure on single crystal Si substrate (SiO2/nc-Si/SiO2/c-Si) has attracted great interests both for new physical phenomena (such as single electron tunneling, Coulomb blockade, etc) and for potential applications in future nanoelectronic devices. In such structure, the transfer of a single electron and the operation with a small number of stored electrons can be realized which is based on Coulomb blockade and quantum confinement principle in the three-dimensional confined nc-Si layer. In this paper, we used low temperature, about 40K, that is far beyond the usual temperature, about 77K, which can be achieved by using layer-by-layer deposition of Si and treatment of hydrogen plasma. The gate SiO2 layer (about 5 nm) was also made by plasma oxidation. The whole process were carried out continuously in the one PECVD chamber in order to avoid interfacial contamination. By using frequency-dependent capacitance spectroscopy, we studied the electronic properties in SiO2/nc-Si/SiO2/c-Si structure with different size of nc-Si dots. Distinct size and frequency-dependent capacitance peaks due to electron resonant tunneling into discrete energy levels of nc-Si and Coulomb blockade changing in nc-Si have been observed in large ensemble of nc-Si at room temperature for the first time. The results demonstrate that the Coulomb blockade for electron in nc-Si is larger than room thermal energy kT and size fluctuation effects on the quantum confinement in our SiO2/nc-Si/SiO2/c-Si structure. Quantum level and the experimental results of capacitance spectroscopy are consistent with the theoretical calculations.

T3.43
Imaging Si Quantum Dots as Charge Storage Nodes. Raffaele A. Pagliuca1, Salvatore Lombardo1, Giuseppe Nicotra1, Isidora Grupi2, Domenico Corso2, Giuseppe Ammendola2, Valentina Aneram2 and CosimoGennari2,1, Curta2, CNR-IMM, Catania, Italy; 2STMicroelectronics, Catania, Italy.

Charge storage nodes made of silicon quantum dots have been proposed over the last years as an important alternative to the conventional continuous-floating gate, for application in non-volatile memory devices. In the nanocrystal memory technology, indeed, fundamental parameters ruling the electronic transport, such as Coulomb Blockade and the energy quantization due to the carrier confinement are strong function of the size, shape and stress level of the dot. For this reason is important to study the local electrical characteristics of the nanoparticles, correlated to their structural morphology. In order to experimentally investigate their potential for this type of application, we have fabricated MOS structures consisting of Si quantum dots deposited by CVD of SiH4 over thin ultra-thin silicon oxide substrate. The Si clusters have been then covered with a 7 nm thick oxide layer deposited by CVD, thus resulting completely embedded in a stoichiometric silicon oxide matrix. A group of samples followed the standard CMOS process flow. The local electrical characteristics of the samples have been investigated by means of an atomic force microscopy tip. Electrostatic force measurements show a strong localization of the charge within the quantum dots, and the non-volatile character of the stored information. Measurements also show that no charge is stored in the oxide layers. Local characterization results agree with the informations obtained on the complete device structures, which have been electrically characterized by means of standard electrical measurements.

SESSION T4: Quantum Dots: Ordering and Patterning
Chair: Richard Noetzli and Catherine Piester
Tuesday morning, December 2, 2008
Room 209 (Hyx)

8:30 AM T4.1
On lateral organization of quantum dots on a prepatterned substrate. Catherine Piester, ISEN, IEMN - CNRS, Villeneuve d'Ascq, France.

The work reported here focuses on the role of nanopatterning in strained heteroepitaxy. This study makes use of an atomicistic description. Two types of “manufactured prepatternning” are considered. A perfectly periodic strain field, induced by the buried array of twist interface dislocations in a twist-bonded bilayer substrate (such Si/Si twist bonded samples are performed in CEN/G-Leti). Network periodicty is controlled by the disorientation angle between the substrate and the twist bonded layer. Within enough surface bonded layer (a few tens of nm) the strain field variation appears strong enough to locally organize surface quantum dots when a strained layer is grown ( Ge deposited on a Si/Si twist bonded sample ). The mechanism is somewhat similar to what happens for vertical alignment in quantum dots multilayers.

Noncovalent a quite regular array of nanomesa can be got using stress selective etching of the surface of twist bonded samples. First results of a study of strained growth on nanomesa, compared to strained growth on ideally flat substrates, is also reported. It is shown how and why the elastic relaxation at the edges of the mesa can delay or even prevent 2D-3D transition. However, related to the design parameters of these nanomesa, one will gets 2D quantum dots (whose shape is quite different from usual self-assembled quantum dots shapes) which are very well laterally organized and calibrated. The considered systems are Ge/Si 001, 2×1 reconstructed.

9:00 AM T4.2
Highly uniform (In,Ga)As quantum dot (QD) arrays on planar GaAs (100) substrates. A self-organized anisotropic strain engineering technique, which we call multi-junction epitaxy (MJE), is used to form the QDs. The resulting quantum well (QWR) structure is investigated using X-ray diffraction, photoluminescence, and scanning tunneling microscopy. The MJE process allows for the formation of highly uniform QD arrays with a precisely controlled dot size and shape. These arrays exhibit strong optical and electronic properties, making them suitable for various applications in nanotechnology and quantum computing.
Self-assembly of SiGe nanostructures on ultrathin patterned silicon-on-insulator substrates provides a unique opportunity for conducting and non-conducting elements. Ultrathin (10 nm) SOI is patterned using e-beam lithography, then etched to produce a silicon substrate laterally patterned into elements with linear micron and width 100 nm. When Ge/Si layers are etched by molecular beam epitaxy at 700 degrees Celsius, SiGe nanostructures nucleate at the edges of the patterned portions of the substrate. This process of substrate engineering allows the formations of the resulting SiGe nanostructures to be defined and manipulated. Electronic force microscopes in conjunction with tailored three-dimensional simulations allow measurement of the resulting connectivity of the SiGe nanostructures on insulator substrates, allowing for the same properties such as local work function and charge. [1] Emma Tevaranek, P. Rugheimer, O. M. Castelli, D. G. Keppel, S. T. Ulesey, D. Savage, M. G. Lagally, M. A. Eriksson, Appl. Phys. Lett. 80, 4626 (2002). [2] M. G. Lagally, P. Rugheimer, Jpn. J. Appl. Phys. 1, 4803 (2002) [3] Emma Tevaranek et al, to be submitted.

SESSION T5: III-V Self Organized Nanostructures
Chair: Subhash Mahajan and Alexander Rosliko
Tuesday, December 2, 2013
Room 209 (Hyne)

1:30 PM T5:1
Roles Of Interfacial Energy And Local Strains In Evolution Of Self-Assembled Microstructures, Subhash Mahajan, Department of Chemical and Material Engineering, Arizona State University, Tempe, Arizona

The self-assembly nanostructures provide an additional degree of freedom in tailoring electronic properties of heterostructures. Several factors affect their formation. In this talk, we will elaborate on the effects of interfacial energy and local strains, respectively, on the evolution of GeP nanostructures on silicon substrates and the occurrence of phase separation and atomic ordering in mixed III-V layers. In a heteroepitaxial system, two sources contribute to interfacial energy between an overgrowth and a substrate: (1) electronic, and (2) strain. To assess the role of electronic interfacial energy on the formation of islands, we investigated the GaP/GaS system because the room-temperature mismatch between the two materials is very small. We studied the evolution of GaP islands on the (001), (111), and (113) surfaces of Si by transmission electron microscopy and atomic force microscopy. The growth nucleated as faceted three-dimensional islands on the (001) and (111) Si surfaces because of the polar nature of the heterointerface that increases the electronic interfacial energy. A more two-dimensional-like growth mode was seen on the (110) and (113) surfaces. This was attributed to the absence of charge buildup at the GaP/Si interfaces for these orientations, thereby reducing the electronic interfacial energy. Generally, the atomic species constituting mixed III-V livers have different covalent tetrahedral radii. This process different bond tetrahedral radii are distributed at the heterointerface of the respective sublattices. These layers exhibited phase separation that was two-dimensional in nature and occurred on the surface during growth. In addition, phase separated microstructures underwent ordering due to surface stress processes occurring at the surface. We have determined the binary V terminated (001) surfaces. Results on phase separation and atomic ordering in mixed group III-nitrides will also be presented. The author would like to acknowledge the contributions of many of his colleagues to the above studies, and is grateful to AFSOR, DOE, NSF, and ONR for financial support.

2:00 PM T5:2
Stability of Self-Assembled InAs/InP nanostructures: kinetic and thermodynamic parameters, Humberto Rodriguez-Gutierrez, Rogerio Magalhaes-Paningo, J.R.R. Bertolato and Monica A. Cotta

InAs nanostructures in an InP matrix have received much attention in recent years. In this work we report the conditions that determine the shape transition from dots to wires for InAs (100) InP substrates by Chemical Beam Epitaxy. We have obtained intermediate states containing both wires and dots in the same sample. However the growth of such self-assembled nanostructures requires a complete understanding and control of the formation mechanisms. In this sense we have obtained a complete picture of the InAs nanostructures formation. InAs growth evolution was monitored by Reflection High Energy Electron Diffraction (RHEED).
samples were analyzed by Atomic Force Microscopy (AFM) and High Resolution Transmission Electron Microscopy (HRTEM). The influence of the growth rate, growth thickness, and InAs deposition on the wires formation was studied. Our results suggest that the wires are a metastable shape originated by the anisotropic diffusion over the InP buffer layer during the formation of the first InAs monolayer.

This kinetic process is consistent with an interfacial energy minimization model. The characteristic of this parameter can be performed using grainizing incidence x-ray scattering, an accurate method sensitive to both local lattice parameter variations and nanostructure lateral size. All measurements were done as a function of the scattering angle (radial) and the sample rotation (angular).

Angular scans (which are size sensitive) at different radial positions (strain sensitive) were correlated with Atomic Force Microscopy and Transmission Electron Microscopy nanostructural anisotropy. A remarkable nanostructure was observed for strained structures parallel and perpendicular to the wires. The higher strain relaxation was measured along the [110] direction, perpendicular to the wires. Correlating these results with HRTEM, AFM, and RHEED measurements, we have also obtained the height dependence of the strain for both crystalline directions.

Size and Critical Thickness Evolution During Growth of Stacked Layers of InAs/InP(001) Quantum Wires Studied by In Situ Stress Measurements. David Foster*, Marín Ujue González1, Lluis Barber2, Yolanda García, Teresa Ben2, Arturo Ponce2, Sergio I Melma* and Rafael García*, 1Instituto de Microelectronic \ de Madrid, \ Tres Cantos, Madrid, \ Spain; 2Departamento de Ciencia de los Materiales e I. M. y Q. l, Universidad de Castilla, \ Puerto Real, Castilla, Spain.

Incorporation of self-organized semiconductor nanostructures in devices requires a narrow size distribution, and a common strategy to improve it consists of growth of stacked layers. It is now established that, for thin enough spacer layers, stacking produces vertical correlation due to the strain field of the buried nanostructures; however, several aspects related to critical thickness or size evolution during stacking will remain open. In this paper we present in situ RHEED and stress measurements, and exists TEM characterization of stacked layers of InAs/InP(001) quantum wires (QW) separated by InP spacer layers of different thickness, 5 nm ≤ Δ[InP] ≤ 20 nm. We have observed the InAs critical thickness (h_{c}) at the QW formation, as observed by a 2D-3D RHEED pattern transition, decreases from the 1st QWR layer for stacks with Δ[InP] = 5 nm, remaining constant for Δ[InP] = 10 nm. Accordingly, for our samples where InAs deposition is interrupted just as h_{c}, the density and size of QWRs is expected to be smaller in the correlated layers (Δ[InP] = 5 nm), since less InAs should be involved. However, XTEM images show, besides vertical correlation effects, that the QWR period, width and height are basically independent of the thickness of the spacer layer and therefore independent of the amount of InAs deposited. On the other hand, results obtained from accumulated stress evolution in correlated layers show that, from the 3rd layer of the stack, QWR formation stops, and no net strain of InAs is observed. Moreover, the total amount of incorporated InAs exceeds that deposited probably due to enhanced As/P surface exchange during QWR formation caused by the strain field from the buried nanostructures. All these results imply that concepts like the critical thickness for 2D-3D growth mode transition should be revised in correlated QWR stacks of layers.

First stages of the two-to-three dimensional transition in the InAs/GaAs(001) heteroepitaxial growth. Fabrizio Arpino1,2,3, Pulina Patelli1,2, Sandra Nufis1,2, Ernesto Pluchino1,2, Massimo Panfili1,2, Anna Sparlin1,2, and Andrea Balzocchi1,2, 1Department of Physics, University of Rome “Tor Vergata”, Rome, Italy; 2National Institute for the Physics of the Matter, Rome, Italy. Atomic Force Microscopy and Scanning Tunneling Microscopy have been used to study subsequent stages of the heteroepitaxy of InAs on GaAs(001), from the initial formation of a welledefined range of strained-two-dimensional wetting layer up to the self-assembly of three-dimensional quantum dots (QDs). We provide evidence of structural features that play a crucial role in the two-to-three dimensional transition and affect their contribution to the final morphology of the self-assembled nanostructures. The features to be considered, close to the 2D-3D transition, are: large and small 2D-islands, and coalescence of 2D-islands of height ≤ 2 nm, 3D QD of height 3-4 nm. Although reported several times, a definite conclusion on the role of these features in QD nucleation is not yet achieved. 2D-features contribute only as step edge by supplying nucleation sites. Structural data show clearly separated distributions for the quasi-3D QD and the 3D-QD and the gap between them does not fill in at any InAs deposition. These observations are consistent with the existence of two equilibrium sizes for the 3D islands, one of which (quasi-3D QD) is stable only for a limited range of InAs thickness. No clear evidence exists that the nucleation of quasi-3D QD is the first step of the self-assembling QD. A model is suggested for the strained phase at the critical thickness consisting of an intermittent 2D-InAs and InAs "fluctuating" on top. Such "fluctuating" phase participate to the huge mass transport along the surface during the two-to-three dimensional transition that accounts for the total volume of dots.


In an effort to develop materials that are sensitive to mid and far infrared radiation, we examine InAs quantum dot/GaAs matrix multilayer structures grown by molecular beam epitaxy (MBE). We use a growth procedure that allows independent control of the quantum dot’s lateral and vertical dimensions. Manipulating the dots on a nanoscale level allows us to tailor their electrical and optical properties. The MBE growth temperature can be set to yield dots having the desired lateral dimension; however this leads to dots of insufficient vertical height. The vertical dimension is manipulated by growing the dots in a multilayer structure with very thin GaAs matrix layers. In this experiment we grew a layer of InAs quantum dots on top of GaAs, followed by a few seconds short growth of GaAs, and then repeated the growth of the InAs quantum dots by laterally, but does not bury, the InAs quantum dots. When the second layer of InAs dots is grown, they tend to self-organize directly on top of the exposed first layer of dots. This effectually results in a pseudo-single layer of dots of the desired height which is then completely buried in GaAs. We use transmission electron microscopy (TEM), atomic force microscopy (AFM), and x-ray diffraction spectroscopy to characterize these nanostructures. The major function of the dot’s height and the total number of dot layers within the structure is to develop structures that can be integrated into high operating temperature quantum dot infrared detectors (QDIPs) that have maximum sensitivity, robustness, and portability.

Grazing Incidence Small Angle X-ray Scattering Study of Semiconductor Quantum Structures. Chia-Hung Hu1,2,3,4, Yung-Wei Hsieh1, Chih-Min Huang1, Yi-Wei P. Shu2, J.-J. Chyi3 and K.S. Liou1, 1Research Division, National Synchrotron Radiation Research Center, Hsinchu, Taiwan; 2Electrical Engineering, National Central University, ChungLi, Taiwan.

The size, shape, strain distribution, compositional profile and spatial distribution are the critical factors determining the electronic level and thus the optoelectronic properties of semiconductor quantum dots. Following our recent study utilizing Grazing Incidence x-ray diffraction [1], which reveals the strain and composition distribution within the dots, Grazing Incidence Small Angle X-ray Scattering (GISAXS) [2] is also performed using synchrotron X-rays. As compared to the microscopic techniques, which only probe a limited area, GISAXS samples an ensemble of over 10^10 quantum dots and provides valuable information about the shape and spatial distribution of these nanosized islands. Specifically, GISAXS measurements have been carried out on InGaAs quantum dots grown on GaAs(001). We find that these dots are not only elongated along the [1 1 0] direction but also skewed, which strongly alter their energy levels. In addition, the dots are self-arranged following a chain-like pattern. References 1. C.-H. Hsu et al., to be published in Physica B. 2. C.-H. Hsu et al., Mat. Res. Soc. Symp. Proc. 612, D5.23 (2000).

Lateral and Vertical Distribution of Self-Assembled InGaAs Quantum Dots on GaAs Substrates. Alexander Roslo, S Y Leeman1, R P Mirin, K D Coleby, W Ye3, M Reitzon, X Weng2 and R S Goldman2, 1Optoelectronics Division, NIST, Boulder, Colorado; 2Mat. Sci. & Eng. U. Michigan, Ann Arbor, Michigan. Numerous devices are under development that utilize quantum dots both because of their unique photoluminescence and electronic properties. The fabrication of these devices will require that the density and size of the quantum dots be consistent across the surface of the wafer on which the devices are processed. Several studies have examined the wafer-to-wafer variation in quantum dot density as a function of growth conditions. To our knowledge, however, the lateral variation of dot density over the wafer surface has not been reported. We have used atomic force microscopy to examine the density and height distributions of self-assembled InGaAs dots across GaAs substrates. Quantum dots
grown in two different molecular beam epitaxy systems were studied. For dots grown at temperatures between 500 and 550 °C, the density was found to increase by 30% across a 2 µm-wide wafer. The average height was found to vary up to 16%. The densities of the top layer of stacked dots with 5 nm spacer layers have also been determined for 1-, 5-, and 10 layer stacks. Preliminary measurements indicate an increase in the lateral variation in dot density with increasing layers of dots. Comparisons with the distributions of quantum dots grown by OMVE will also be discussed.

4:00 PM T5.8
Optical properties of InGaAs QDs grown in a GaAs matrix by MOVCVD at 130nm thick. 
Maria Broan Tedeschi, Mikael De Dongh, Vittorianna Tasco, Massimo De Vittorio, Adriano Pasquato and Roberto Cingolani; Ingegneria dell’Innovazione, National Nanotechnology Laboratories (NNL-INFN), Lecce, Italy.

Self-assembled quantum dots (QDs) are of considerable interest both for their physical properties and their application in novel light emitters such as single photon sources, high efficiency light emitting diodes and lasers. Progresses in the growth of self-assembled In(Ga)As QDs on GaAs substrates have permitted to extend the emission wavelength around 1300nm, the low absorption window for optical fiber communications. The most effective approach to achieve 1300nm emission by both molecular beam epitaxy (MBE) and metal organic chemical vapor deposition (MOCVD) growth techniques, was to embed QDs into a barrier of InGaAs ternary compound. In this work we present, for the first time, the optical properties of InGaAs QDs, grown by MOCVD, embedded directly into a binary GaAs matrix. These QD nanostructures, having a low density (down to 10^12 cm^-2), emit efficiently at 1300 nm at room temperature. By increasing the excitation intensity, photoluminescence (PL) spectra show a clear band filling dynamics, which is characteristic of quantum dots with uniform size distribution. The ground state transition linewidth is 30 meV at low temperature and becomes as low as 24 meV at room temperature. PL integrated-intensity of the ground state is reduced by only a factor of 3.3 when the temperature is increased from 10 to 290K, showing the high quantum efficiency of our QDs. To our knowledge, this emission quenching with the temperature is the lowest value ever reported for QD structures emitting at 1300nm.

4:15 PM T5.9
Growth and overgrowth of InAs/GaAs(001) quantum dots studied at the atomic scale. Carlos Muratore, Giovanni Costantini, Armando Rastelli, Rudeane Schmiedig, Oliver Schmidt and Klaus Kern; Max-Planck-Institut fuer Festkoerperforschung, Stuttgart, Germany.

InAs/GaAs(001) quantum dots (QDs) are grown at high temperature and extremely low flux and analyzed by in-situ scanning tunneling microscopy. A bimodal distribution of dots is measured, composed of “small” and “large” islands. While the former show a broad distribution of sizes and shapes, the latter appear to be highly uniform and have a truncated pyramid shape with irregular octagonal base. (110) and (111) facets are identified and atomically resolved, showing a [1x1] and [2x2] surface reconstructions, respectively. The experimental findings are in excellent agreement with recent theoretical predictions of the equilibrium crystal shape of InAs quantum dots, demonstrating that the chosen deposition conditions are close to thermodynamic equilibration. The low-temperature overgrowth of these QDs is investigated during the initial stages (1.30 ML). Two regimes appear to dominate the etching, an initial partial dissolution of the QDs followed by a true overgrowth. This picture is confirmed by experiments done at different overgrowth rates. The observed dependence of the QD evolution on the GaAs flux demonstrates that the observed phenomena are kinetically driven and that the two regimes are governed by different atomic processes. An atomicistic description of the dot overgrowth is presented, and a simple quantitative model for the dot dissolution is developed that captures the essential experimental features.

4:30 PM T5.10
Electron Transport through Self-Assembled InP Quantum Dots embedded in AlGaInP and grown on (Al,Ga)InP/(GaIn)P, Superlattices. Roberto E. Martínez1,2, Venkatesh Narayanan1,2, Xuebing Zhang1,2 and Russell D. Dupuis1,3; 1Division of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts; 2Department of Physics, Harvard University, Cambridge, Massachusetts; 3Department of Electrical and Computer Engineering, University of Texas at Austin, Austin, Texas.

For optoelectronic applications, the binary to quaternary phosphides, [Al,Ga,In,P]4, have the widest direct band gap of III-V semiconductors with the advantage of GaAs lattice-matching and luminescence in the visible range. Although these characteristics are well understood, the local electronic properties of buried heterostructures—dots and nanowires—are not. To the end, ballistic-electron-emission microscopy (BEEM)1, a three-terminal scanning tunneling microscopy-based technique, has been implemented with success. We report resonant electron transport through buried, self-assembled InP quantum dots in two related systems: embedded in AlGaInP double barrier heterostructures and grown on (Al,Ga)InP/(GaIn)P a strongly-coupled superlattices. A comparison of on-the-dot and off-dot selected BEEM spectra in both systems reveal transport processes not observed when compared with the I-V conduband. Moreover, we conclude that although the quantum dots are much smaller in the quaternary system than in the ternary system their 2D mass may be resolved using BEEM. Furthermore, Monte Carlo simulations of transport are in agreement with experiment. 1V. Narayananmurti, M. Kozhevnikov, Phys. Rep. 349, 447 (2001).
inside such nanowire structures. Direct comparison between 3K-grown quantum dots and quantum dots formed inside nanowires will be made. This research is supported from the Swedish Research Council (VR) and the Swedish Foundation for Strategic Research (SSF). The presentation will be based on contributions from Werner Seifert and Magnus Borgström in MOVPE-growth, Sören Jeggeps, Jonas Ohlsson and his co-workers in CBE-growth, Reidar Wilkens-growth, al in TEM-imaging, Anders Mikkelsen et al. in STM-imaging, Chies Theander, Mikael Bjorck, Tomas Brebels, and Thomas Martensson in transport device studies, Valery Zmir, Jonas Persson, Lars Lundin, Nicole Papanicolaou in Skold in PL-studies and Marta-Erik Pistlo, Craig Pryor, Magnus Holm, Martin Persson and Hongki Xu in theory/modelling.


A single material superlattice or “twinning superlattice” can have significantly different properties from the bulk. The structure does not suffer from interface degradation due to mismatch or incoherent electron scattering from defects that occurs in a conventional superlattice. Theoretical investigations of the electronic band structure of such superlattices have revealed a red shift in the band gap. For example, the twinning superlattice of Si exhibits a band gap of 0.6 eV, while the band gap of the bulk is 1.1 eV. We have used a micro beam electron gun (MBEG) to form GaAs nanowires with an almost periodic twinning superlattice. As the wire diameter (d) ranges from 5 nm to 100 nm, the superlattice period decreases, e.g., at d=18 nm, a typical period would be ~8 unit cells along the [111] growth direction. The highest resolution (PL) spectra exhibit 3 peaks at 308 K: doublet (1072 nm, 1151 nm) and weak peak at 580 nm (bulk GaAs has a band gap PL at 580 nm). The doublet is identified with a redshift in the band gap; the origin of the peak at 580 nm is not currently understood, and it grows intense at 580 K. We observe an ~11 cm/s downshift and a broadening of the LO and TO phonon modes relative to bulk GaAs via Raman scattering that is identified with a thermal broadening and phonon confinement effects. Also results of SEM, HRTEM and optical absorption will be presented. We believe that this simple synthesis route, if properly understood, might be used to fabricate perfectly periodic nanowires: GaAs twinning superlattice, and other twinned superlattice nanowires as well.


Recent clever techniques for fabricating nanoscale materials, one-at-a-time, have simultaneously opened the door to new physics, chemistry, biology, and engineering. Nanosize materials simply do not behave as the bulk. Indeed, the rules that govern the behavior of these tiny structures are not known and must be uncovered. Going small is also a fantastic adventure and offers a new frontier in science and engineering. So many of our ideas have come from a better understanding of nature, that the trend is sure to continue as we examine and view nature on a nanoscale. In this talk, we will discuss our recent efforts to engineer shape, size, density, and position of nanostructures and of the interactions between them, and to develop a clear understanding of their optical and electrical behavior. While self-assembly is providing exciting quantum dot structures to explore, it is trying to understand the limits of this methodology. We encourage you to come together to take a desired path. Can we understand the formation of faceted nanostructures? Can we encourage or seed dot structures to form specific arrays? Is it possible to engineer greater homogeneity of dot shape and size? Can we design both the optical and electrical behavior of either individual or arrays of nanostructures? In this talk we will review our progress to answer these questions and discuss the possibilities and challenges ahead. For example, we will discuss the formation of individual faceted nanostructures as well as the formation of a vertically and laterally ordered structure forming three-dimensional quantum arrays. We will present results from the photoluminescence (PL) spectra of individual dots and discuss the role of such phenomena as photoluminescence. We will also discuss an investigation of the PL spectra from ordered arrays of QDs, both in a function of temperature and optical excitation intensity, which reveals both a lateral and vertical transfer of excitation. Moreover, we will present results that explore the tunneling law between quantum dots. As another example, we will discuss the importance of surfaces with high Miller indices, as a template to the formation of nanostructures as well as their potential role in determining the shape and increased size uniformity of the confined structures. Importantly, these observations lead to an even more basic question of why and how high index surfaces are stable. Indeed, we have found that in order to understand the origins of high index surfaces that bound nanostructures we have to study them directly. Yet in another example we will discuss the manipulation of surface reconstruction and a critical role that it can play in the selection of dot or wire nanostructures. Finally, we will discuss the many exciting opportunities that may be ahead although we expect and look forward to many surprises.


EE and Physics, Virginia Commonwealth University, Richmond, Virginia; 4North Carolina State University, NCSU, Raleigh, NC, University of Bristol, Bristol, United Kingdom. Quantum dots in conventional semiconductors have been explored for the many degrees of confinement resulting in unique device and material states which are thought to lead to low laser threshold current, among other applications. In the case of GaN, an additional advantage is that the layer or layers of quantum dots will decouple the active layer from the substrate. This has been achieved with a 5-layer structure to reduce number of extended and point defects, because they would nucleate on dislocated regions. In this vein, GaN dots have been grown on c-plane sapphire and [111] Si substrates by reactive molecular beam epitaxy. A method involving two-dimensional growth followed by a controlled annealing during which dots are formed was employed. Due to the dot nature and large dot density, relatively high luminescence efficiencies were obtained on both substrates. Single layer dots were used for AFM analysis whereas 30 layer dots were used for photoluminescence experiments. AIN barrier layers, some too thick for mechanical interaction, some thin enough for vertical coupling were used. Strong polarization effects lead to a sizedependent red shift, which depends on the thickness of the light layer. Optical processes in these quantum dots will be discussed in detail.

11:00 AM *T6.6* Diffuse X-Ray Scattering of InGaAs/GaAs Quantum Dots. Rolf Koehler, Michael Hanke, Daniil Grigoriev, Martin Schmidbauer, Peter Schaefer, Udo Polak, Roman Silles, Dieter Blumberg, Nikola Zakharchov, and Peter Werner. Institute of Physics, Humboldt-University, Berlin, Germany, 4Institute of Solid State Physics, Technical University Berlin, Berlin, Germany, 5Max-Planck-Institute of Microscopic Physics, Halle, Germany.

Strained self-organized InGaAs/GaAs (811) quantum dots (QDs) are presently subject of intense research efforts due to their promising
behavior and it does not vanish at zero magnetic field. We interpret this observation to involve an internal effective magnetic field induced by the surface charge in the quantum dot. Interestingly, the single InP dots with non-zero splitting typically have broader line widths. This fact suggests that the broadening can come from the interaction between the exciton and nuclear spins.

11:45 AM T6.9 Evidence of Aharonov-Bohm effect on neutral excitons in type-II quantum dots
Evandro Ribeiro1, Alexander G. Genov2, Wilson de Carvalho Jr.3, and Luis F. G. S. Filho3
1Department of Physics of Materials, University of São Paulo, São Paulo, Brazil, 2Department of Physics, University of São Paulo, São Paulo, Brazil, 3Department of Physics of Materials, University of São Paulo, São Paulo, Brazil.

By allowing a charged particle to create a confined magnetic field flux region, Aharonov and Bohm showed in 1959 that, surprisingly, there exist effects of the vector potential on the charged particles moving outside the magnetic field region. After following the circular path, the particlewavefunction acquires a phase change, proportional to the magnetic flux contained within the closed path. For these effects to exist, phase coherence is mandatory. All observable phenomena depend only upon the magnetic flux $\Phi$ through the enclosed region, and we are shown to be periodic with period $\Phi = h/e$. This oscillatory characteristic is the signature of the Aharonov-Bohm (AB) effect. It is commonly believed that the AB effect is a typical feature of the motion of a charged particle interacting with the electromagnetic vector potential.

Here we present a magnetophotoluminescence study of type-II InP/GaAs self-assembled quantum dots, unambiguously revealing the AB type oscillations for neutral excitons when the hole ground state changes its angular momentum from $m_s = 0$ to $m_s = -1$. Although forbidden, the transitions from the electron ground state to higher angular momentum states reflect a broken symmetry for this island system. This can be understood in terms of the alignment of quantum confinement revealed in both Atomic Force Microscopy experiments on uncapped islands as well as polarization dependent photoluminescence spectra. In addition to this, due to the fact one does not have a well confining potential, the spin of the electron and hole wavefunctions and into the islands can be anticipated. The wavefunction overlap can be inferred from the photoluminescence intensity, and revealed a complex behavior which could be understood by the successive adjustments of the wave functions in QDs to the non-uniform edges of the island, being more sensitive at higher magnetic fields. The hole ring parameters derived from a simple model are in excellent agreement with the structural parameters determined for this system.

SESSION T7: Joint Session with T7: Quantum Dots and Wires Devices
Chairs: Puliafiko Bhattacharya and Zhining Wang
Wednesday Afternoon, December 3, 2019
Room 298 (Hynes)

1:30 PM T7.1 Quantum Dot Lasers and Amplifiers
Udo W. Pohl and Dieter Bimberg, Institut fuer Festkuerperforschung, TU Berlin, Berlin, Germany.

Self-organized formation of quantum dots (QDs) upon heteroepitaxial growth of highly strained semiconductor layers has gained increasing importance for a novel generation of optoelectronic devices. The electronic and optical properties of such nanostructures are more similar to those of atoms than of solids [1]. A decade after the prediction that a laser using active QDs should be superior to classical lasers e.g. with respect to decreased threshold current, high temperature stability and high gain, the first QD laser was demonstrated by us in 1993. Since then we developed new concepts for stimulating emission and interband control to define the laser performance parameters in a definite way and to reduce losses. Today, we have actually achieved unique device performance for both, edge and surface emitting QD lasers grown using MOCVD and MBE. In GaN/InGaN QD edge emitters show an ultralow threshold for infinite length of 18A/cm² and 1.16 μm for threefold stacked dot layers, an optical output power exceeding 10 W, and internal loss below 1.5 cm⁻¹. We measured relaxation oscillations at 6 GHz, demonstrating the potential for cut-off frequencies above 10 GHz. For 1.3 μm emission, lasers with $L = 70$ A/cm² and 2.3 μm output power were realised. As to surface emitters, we presented the first GaN VCSEL based on QDs operating at 1.3 μm with 1.2 mW cw output power and more than 30% slope efficiency. The GaN lasers can now replace InP/GaInP lasers in the range up to 1.3 μm, and the potential exists to extend the range up to 1.55 μm. First results on MOCVD growth of lasers using organic group-III precursors as replacements for highly toxic hydrides are very promising. After demonstrating QDs with high density and excellent optical quality, we realized edge emitters with a transparency current below 30 A/cm², 91% internal quantum efficiency and 2.2 cm⁻¹ internal loss. Using alternative precursors, we demonstrated the first
electrical VCSELs grown using MOCVD, having similar diameters at 1.1 μm as the MBE-grown VCSELs presented above. Semiconductor Optical Amplifiers (SOAs) show gain recovery times up to 100 fs, much faster than QW-based ones, indicating the potential of QDs for a novel class of devices with large commercial importance in multi-turn biophotonic networks. Unusually long phase-relaxation times of excitons in QDs of more than 6000 ps make QDs presently the best candidates as backbone of optical computers. This work was performed in cooperation with N.N. Ledentsov, J. Lott, V. Ustinov, E. Sollie, C. Bibelb, P. Borri, J. Heum, U. Woggton, F. Hoeger and other scientists at D. Birnberg, M. Grundmann, N. N. Ledentsov, Quantum Dot Heterostructures, J. Wiley, Chichester 1999.

2.00 PM TET_2
1.5 micron InAs quantum dot lasers based on metamorphic InGaAs/GaAs heterostructures, Victor M. Ustinov, Alexei E. Zhukov, Alexei R. Koval’sh, Nikolai A. Mikhov, Sergey S. Mikhailov, Alexei P. Kudel’kin, Eleonora V. Mikhail, Elizaveta S. Semenova, Natalya V. Kudel’kin, Yuri G. Miroshnichenko, Michael V. Maximov, N. N. Ledentsov, Dieter Birnberg and Zhores I. Alferov.

Microcavity light emitting diodes (MCLEDs) operating at 1.3 μm are suitable as telecom sources by virtue of single mode beam profile, low divergence output for optical fibers coupling, and are directly compatible with the existing fiber infrastructure. As opposed to the more expensive and temperature sensitive InP technology, the Smirnov-Kristnov self-assembly technique allows the fabrication in the same epitaxial run of 1.3 μm emitting InGaAs/GaAs QDs and of high efficiency GaAs/AlAs distributed Bragg Reflectors (DBR) QDs. The growth techniques using molecular beam epitaxy (MBE) have already demonstrated high efficiency devices at the emission wavelength of 1.3 μm, such as room-temperature (RT) continuous-wave operation in-plane lasers. On the other hand, very few works are reported about 1.3 μm emission from metal-organic chemical vapour deposition (MOCVD) grown QDs. This problem, due to the increased density of confined QDs correlated to the increased strain and complicated surface environment, becomes more important when QDs are grown on a DBR structure. In this work we present the first electrically driven QD-MCLED operating at 1.3 μm and grown by MOCVD. The device shows an efficient and very narrow RT electrically-driven emission centered at 1.3 μm, obtained with a very low injection current. The MCLED structure consists of a bottom mirror, formed by 60 stacked GaAs/AlAs DBR, designed for a reflectivity of 33%, and a p-doped top mirror designed with a reflectivity of 82%. A single stacked InGaAs QD epitaxially grown on GaAs, is inserted in the centre of the GaAs one-wavelength-thick cavity. The morphological analysis of the DBR surface and of the free-standing QDs, grown on the bottom DBR, has been carried out by Atomic Force Microscope (AFM). The optical and electrical behavior of the device has been investigated by photoluminescence (PL) and electroluminescence (EL) measurements.

The RT PL emission of a reference sample, where the InGaAs QDs have been directly grown, shows a 1.3 μm emission line with a full width at half maximum (FWHM) of 24 meV and clear band filling dynamics. The PL intensity quenches by a factor of 2 as the temperature is increased from 10 K to 300 K. A detailed study of the bottom DBR surface morphology has led to the optimal conditions for InGaAs/GaAs QD growth over the mirror. They show, however, a larger FWHM of 31 meV (exactly centred at the reflection stop band), demonstrating a slightly lower size uniformity of the InGaAs islands, due to the higher surface roughness of the DBR structure. Both PL and EL measurements performed on the microcavity embedding the QDs inside two DBRs, show a very efficient RT emission at 1.3 μm with a FWHM of 6 meV and a Q factor of 150. The temperature quenching is less than a factor of 6.

3:15 PM TET_7
Self-assembled Nanostructures and Quantum Devices in InGaAs/GaAs and InAs/GaAs/AlAs/InP. Wang Zhangbo, Wu Ju and Zhao Feng, Key Lab of Semiconductor Microscale, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, China.

Self-assembled In (Ga)As/GaAs, InAlAs/InGaAs/GaAs, and InAs/InGaAs/GaAs quantum dots (QDs) and/or quantum wires (QWRs) of free defects have been successfully fabricated using SK growth mode and MBE in our lab. Through adjusting the strain distribution of strained layer by optimizing growth condition, properly choosing component of InxGa1-xAs QDs, and introducing a special seed layer etc., the size, shape, and density of QDs with emission wavelength ranging from 780 nm to 2 μm can be controlled. The room temperature CW lasing at 960 nm with maximum output power of 3.6 W and the lifetime of more than 4000 hrs for the multilayer InGaAs/InGaAs QDs active layer is realized. In addition, the multiple stacked self-assembled InAs dots have been made use of as the active region of a superluminescent diode, and above 200mW continuous wave output with the spectral bandwidth of 60nm is obtained at room temperature.

In order to reduce the irregularity arising out of atomic processes during MBE growth, it is required to understand the underlying mechanisms of the various growth morphologies in these dot- and wire-structures. In this work, the effect of the bottom mirror, the buffer layer, and the growth mode on the morphology of self-assembled InAs dots and wires has been also investigated in the InAs/InGaAs/InP system. It was found that these growth parameters had the direct influence on the final device transition, and the diagonal space alignment of dots.

The atomic processes underlying these growth morphologies will be discussed in detail.
Defect-aided Single Electron and Single Photon Detection in InP/InGaAs and GaAs/AlGaAs Based Quantum Wires and Quantum Point Contacts. P. Bandaru 1,2, Hideo Kosaka 1,2, Deepak Rao 2, Hans Robinson 2 and Eli Yablonovitch 2.

1Materials Science Program, UC, San Diego, La Jolla, California.
2Electrical Engineering, UCLA, Los Angeles, California.
3Fundamental research labs., NEC Corporation, Tsukuba, Japan.

Defects, such as point defects and impurities, play an increasingly important role in quantum structures and devices, such as self-assembled quantum emitters (QEs). The discussion will focus on how defect engineering in quantum wires and quantum dot arrays can be used for extremely sensitive (~10^-17 erg/Hz) single electron and single photon detection. We will report on our experiments in quantum wires and Quantum Point Contacts (QPCs) fabricated in InP/InGaAs and GaAs/AlGaAs heterostructures. Charge trapping by defects in quantum wires is manifested in the occurrence of Random Telegraph Signal (RTS) noise in the Conducting/Anti-Conducting regime of the RTS noise yieldled defect-specific information, such as the presence of a single striped donor atom in a quantum well. In another study, the binding of holes by DX-centers present in (Al,Ga)As was utilized for single photon detection [1, 2]. Potential applications in nano-electronics and quantum information processing will be discussed. I. H. Kosaka et al., Phys. Rev. B, 65, 2001 (R). 2002. 2. P. Bandaru et al., SPIE TECH, 2001. This work was sponsored by Defense Advanced Research Projects Agency and Army Research Office. MDA 972-817-1 and DAAD15 (01.172)

4:00 PM T7.7 Improving the Structural and Optical Properties of 1.3 µm InAs/GaAs Quantum Dots Using InAlAs Layers. Hai Yuan Liu 1, Ian Sellers 1, Mark Hopkins 1, Colin N. Harrison 1, David J. Movreboy 1 and Maurice S. Skolnick 1.

1Department of Electronic & Electrical Engineering, University of New South Wales, Technology, Sheffield, S.Yorkshire, United Kingdom; 2Department of Physics & Astronomy, University of Sheffield, Sheffield, South Yorkshire, United Kingdom.

Self-organized InAs/GaAs quantum dots (QDs) have gained much interest due to their unique atomically precise properties and potential device applications. In recent years, the continued interest is driven by the expansion of InAs/GaAs QD to an important telecommunication wavelength of 1.3 µm, and the development of 1.3 µm InAs/GaAs QD laser has progressed rapidly. However, its performance is still limited by gain saturation of the QD ground-state transition, and high temperature stability is compromised by carrier excitation into QD excited states and/or out of the dot. The growth approach of InAs islands directly deposited on InGaAs strained buffer layer (SB) has been widely used to increase the dot density and hence improve the gain of 1.3 µm QD laser. To extend the InAs QD wavelength to 1.3 µm, an InGaAs strain-reducing layer (SRL) has also been widely used to directly cover InAs QDs. However, the InGaAs SRL and SRL used in these techniques result in a reduced emission and, consequently, an increase in the temperature sensitivity of the laser devices. Furthermore, to improve the optical gain, it is not only necessary to increase the dot density but also to improve their radiative recombination efficiency, particularly at high temperatures. Here, a combination of InAlAs-GaAs strained buffer layer and InAlAs-InGaAs composite strain-reducing layer was presented to tailor increase the density and energy separation between the quantum-dot ground and first-excited states from 84 to 38 meV with adjusting the thickness of GaAs in InAlAs-InGaAs buffer layer. The experimental relationship between InAs QD density and matrix of InAlAs-GaAs SRL could be understood in term of the increasing additional material from wetting layer into dots and the decreasing regulate structure between both neighboring islands within substrate. We also investigate the effect of InAlAs layer surrounding InAs quantum dots on optical properties. With increasing (decreasing) InAlAs (InGaAs) thickness in the strain-reducing layer grown above the QDs, the integrated optical density increase (decrease) by 3 times of QD energy level transition increases dramatically and the emission wavelength decreases slightly from 1.36 to 1.31 µm. The enhancement of the photoluminescence efficiency is temperature dependent, being much greater above a certain radiation temperature and 450°C is achieved at room temperature. This improvement of the high temperature photoluminescence efficiency should lead to significant improvement in the characteristics of 1.31µm InGaAs/GaAs QD lasers.

4:15 PM T7.8 Growth and characterization of InAs quantum dots on GaAs (100) emitting at 1.31 µm. Vincent Cellier 1, Bassem Sisla 1, Cedric Guillot 1, Maxime Renou 1, Philippe Gilet 2 and Alain Millien 2.

1Laboratoire de Physique de l’Institut du Rayonnement, Villeurbanne, France; 2CEN/DRF-LEIT/DOPT, Grenoble, France.

The interest for quantum dots (QDs) remains strong in the domain of telecommunications or quantum cryptography for example. Even if recent achievements made possible to approach on GaAs substrate the 1.3 µm window of fiber telecommunication, reserved to InP, it remains very important to control the growth of QDs emitting at 1.3 µm on GaAs. In this work, we investigate the influence of various parameters on the growth of self-assembled InAs/GaAs QDs and study their optical properties, the ultimate goal being to integrate them in the active zone of vertical cavity surface emitting lasers (VCSELs). The growth was carried out by gas source molecular beam epitaxy (GSMBE) in the SubKnotera mode optimizing two significant parameters: samples are grown using a very low deposition rate of InAs increasing the average size of the dots and thus allowing higher wavelength emission. A high speed deposition rate of the GaAs passivation layer is chosen in order to rapidly freeze the structure of QDs to avoid any modifications. Structural and optical characteristics are carried out by means of atomic force microscopy (AFM), photoluminescence (PL), and PL excitation (PLE). The mean height, width, length and density of the dots measured from AFM images are 7nm, 40nm, 55nm, and 2x10^10m⁻², respectively. A good size homogeneity is also observed. The PL properties of QDs measured at 30K show an emission at 1.31µm, with a full width at half maximum around 20meV, which reveals a narrow QD size dispersion. The integrated PL intensity remains very strong at room temperature, as much as 10% of the measured at 8K, indicating an efficient spatial localization of the carriers in the InAs QDs. Four optical transitions are clearly observed in the PL spectrum at 8K under strong excitation density. In order to identify the origin of these optical transitions, PL as function of excitation density has been performed, showing only one optical transition at low excitation, in agreement with a unimodal size distribution. For high excitation density, three excited states are arising due to a state filling phenomenon. These excited levels are also studied by PLE at low temperature as this technique is expected to describe the absorption of the sample weighted by the different recombination paths. The relative importance of absorption and relaxation of the photo-carriers created in the QDs is discussed from the PLE spectra and complementary measurements. Due to a very good reproducibility of the growth, many samples exhibited very close characteristics this is promising for the fabrication of VCSEL devices containing QDs in their active layer.

4:30 PM T7.9 Abstract Withdrawn

SESSION T8: Spins in Semiconductor Nanostructures

Chair: Rachel Goldman and Pierre Petroff

Thursday, December 4, 2003

Room 209 (Hyves)

8:30 AM T8.1 Application-Diluted Magnetic Semiconductors and Quantum Dots to Spin Polarized Light Emitters. Pabul Bhattacharya, Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, Michigan.

I was invited by Prof. Rachel Goldman. Diluted magnetic semiconductors (DMS) have been studied over the past decade due to their potential application in spin-based devices. Their suitability as spin-injector layers in spin-polarized light sources is also being investigated. For electronic or optoelectronic spin injection devices, it is desirable to achieve such injection and device operation at high temperatures. In this context it is of interest to study the ferromagnetic properties of DMS alloys and of DMS quantum dots buried in a non-magnetic matrix. In this paper we will describe the molecular beam epitaxy (MBE) growth, structural characterization and ferromagnetic properties of GaMnAs alloys and (In,Mn)As self-organized quantum dots or diluted magnetic quantum dots (DMQD). The characteristics of spin-polarized quantum dot surface emitting LEDs, using DMS or DMQD layers as spin aligners will be described. The DMS and DMQD heterostructures, grown by MBE, were characterized by cross-sectional TEM and STEM measurements. The dot density is typically ~1 10^10 cm⁻², as observed from AFM measurements. The Curie temperature in the as-grown quantum dot samples increases steadily with Mn content and is ~150K for 55% Mn. The results are analyzed by a model considering a strong non-Kramers spin in Mn-content dependent QDs, as confirmed by the XTEM measurements. Polarized light emitters, wherein spin-polarized charge carriers recombine in quantum dots demonstrate a peak optical polarization efficiency of 18% and a spin injection efficiency of 30% at 5K. Work supported by ARO (MURI program) and ONR.

9:00 AM T8.2 Locating, Injecting And Confining Spins Into Self-Assembled
Quantum Dots.  Materials Dept., Univ. of California Santa Barbara, Santa Barbara, California.

The use of self assembled quantum dots (QDs) for single photon generation used in quantum cryptography or quantum computing, will eventually require a control over the QD position, and over the polarization of the emitted photons. We will present our progress towards localizing, injecting and confining spins into QDs. Locating the carrier has been realized by using a crystal growth method which allows for the positioning of a single QD. The method uses MBE growth of InAs/AlGaSb QDs on a pre-patterned substrate. We will show the importance of stress engineering using a substrate stressor layer for positioning of a single or group of QDs. Carrier confining in QDs is demonstrated using QDs in a p-i-n structure. In a layer over long times (>10e5c). Electrical or hole spin injection from a ferromagnetic GaNAs magnetic semiconductor layer into QDs is observed through analysis of the polarized electro luminescence of a QD spin LED. We will discuss the small injection efficiency (<1%) of polarized spins (for both electrical and optical). These results suggest that optical spin injection methods be favored for this type of applications.

9:30 AM T8.3
Effects of Quantum Dot Morphology in Optical and Quantum Computing Applications.  Harley T. Johnson and Ranjeoy Bose, Mechanical & Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois.

Self-assembled quantum dot arrays are of increasing interest for applications in optical, nanoelectronic, biological, and even quantum computing systems. Sophisticated growth methods and morphology simulation methods are made possible by self-assembled quantum dots with controlled size, shape, and to some extent even spatial ordering within lateral and vertical arrays. In this work, the effects of specific morphological details are discussed for two sequence applications in optoelectronic and quantum computing. First, self-assembled quantum dot arrays are shown to have particular morphological features that lead to the unexpected resonances that have been observed recently in NISOM phonomicroscopy excited in time experiments. Second, self-assembled quantum dot arrays are evaluated as potential quantum bits in quantum computing schemes. Both analyses are based on calculated electron and hole energies and wave functions for realistic quantum dot arrays. The phenomena underlying both applications are due to quantum states coupling multiple dots; these special states are sensitive to dot size, shape, and proximity.

9:45 AM T8.4
Ferromagnetic LaSrMnO Quantum Dots Prepared by Pulsed Laser Deposition.  Hans-Ulrich Habermeier1, Xiao-Jin Chen2 and Hui Zhang3, 1MPI-PK, Stuttgart, Germany; 2Kent State University, Kent, Ohio.

Pseudomorphically grown perovskite-type thin films can exhibit appreciable interfacial biaxial strain either compressive or tensile, depending on the lattice mismatch of substrate and film, respectively. In an epitaxial pseudomorphous film, biaxial strain and the film thickness can be used to generate quantum dots of functional ceramics similarly to the concept used in elemental semiconductors. Furthermore, the structural flexibility of the perovskite systems as described by their tolerance factor intrinsic physical properties such as resistivity and phase transitions to ordered states [e.g. Curie temperature in ferromagnetic colossal magnetoresistance (GMR)] can be tailored. In this study we explore these possibilities using La0.8Sr0.2MnO3 as a prototype functional ceramic. Stress causes a shift of the intrinsic alignment of the Mn-O-Mn building block and thus the properties of the material. The Curie temperature can be tailored to be lower or higher depending on the pressure coefficient of bandwidth and pressure-induced changes of the John-Teller distortion. In this contribution, the conditions will be fabricated LSMO quantum dots by pulsed laser deposition and film results of the perovskite will be given. LSMO films of thicknesses below 10 nm have been grown and the formation of LSMO quantum dots with dimensions 30 nm diameter and 4 nm height have been detected. It could be shown that these quantum dots are ferromagnetic with a Curie temperature well above room temperature, i.e. more than a doubling as compared to the intrinsic bulk values.

10:30 AM T8.5

The growth of III-V semiconductor heterostructures by MBE is an inherently non-equilibrium process that often leads to the formation of self-organized nanostructures. Sometimes the structures are desirable and intended, and sometimes they are detrimental to device performance. I will review our efforts to characterize and understand a variety of such structures using atomic-resolution, cross-sectional scanning tunneling microscopy (XSTM), including studies of infrared detectors and lasers, and "spintronic" devices. I will show how XSTM can be combined with theoretical calculations and device characterization to shed light on the interplay between nanostructure and function. Supported by ONR and DARPA - DSO.

11:00 AM T8.6
Mn Interstitial Diffusion in GaNAs.  Piotr Boguslawski1,2, Kevin W. Edmonds3, K. Y. Wong3, R. P. Campman3, N. R. S. Flerley3, B. L. Gallagher4, C. T. Foxon5, M. Sawicki1, T. Dietl6 and J. Bernholc7, 1Institute of Physics PAS, Warsaw, Poland; 2Department of Physics, North Carolina State University, Raleigh, NC; 3School of Physics and Astronomy, University of Nottingham, Nottingham, United Kingdom.

We present a combined theoretical and experimental study of the ferromagnetic GaNAs. Careful control of the growth and annealing conditions allows us to obtain samples with ferromagnetic transition temperature up to 150 K. We show that the remarkably large increases in hole densities and Curie temperature observed on low temperature annealing of as-grown samples are due to the out-diffusion of the high concentration of compensating interstitial Mn ions identified in the study of Yu et al. [Phys. Rev. B 65, 201310 (2002)] in situ monitored resistivity measurements during annealing were performed for film thicknesses ranging from 10 to 100 nm, and the data were unambiguously interpreted in out-diffusion of the compensating Mn towards the surface. Consistently, an increased concentration of surface Mn in annealed samples was observed by Auger spectroscopy. Annealing at temperatures between 160 °C and 200 °C allowed us to determine the temperature dependence of the diffusion coefficient, and the energy barrier governing the diffusion process is ΔG = 1.7±0.1 eV. Calculations were performed within the Local Spin Density Approximation. In the realistic case of p-type samples, MnI double donor occupies the tetrahedral interstitial site T:A, which is 5.5 eV lower than the energy of MnGa. The energy barrier for diffusion of Mn(1+4+) is low, 0.7 eV. This leads to the formation of nearest-neighbor donor-acceptor MnI(2+)+MnGa(-) pairs, driven by Coulomb attraction and a short, short-range antiferromagnetic coupling. The energy for dissociation of MnI-MnGa pairs is 1.2 eV. Complexes of nearest neighbor Mn:Ga:MnI:MnGa have similar properties. Electric fields induced by the high concentration of substitutional Mn ions are shown to lower the diffusion barriers to ~0.2 eV, in satisfactory agreement with experiment. Finally, the kick-out mechanism of diffusion (MnI+Ga-MnGa→MnI-MnGa) is not efficient, since the calculated barrier is about 3 eV. This work is supported by FENIKS project [EC: GIRD-CRT-2001L-08353), grant PHZ-KBN-944/P03/2001, and grants from US ONR and DoE.

11:15 AM T8.7
Cross Sectional Scanning Tunneling Microscopy Studies of Mn Segregation in GaNAs Films.  J. N. Glason1, M. E. Hjelmstad2, S. Fastighom2, S. Ghosh2, P. K. Bhattacharyya2 and R. S. Goldman1, 1Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan; 2Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, Michigan.

GaNAs is a promising candidate for spintronic applications particularly with conventional GaAs technologies. Theoretical studies have predicted that an increase in disorder of Mn atom positions will lead to a significant increase in the Curie Temperature [1]. At present, the nanometer-scale details of Mn segregation in GaNAs are not well understood. Therefore, we have investigated Mn segregation in GaNAs by low temperature molecular beam epitaxy using ultra high vacuum cross-sectional scanning tunneling microscopy (XSTM). The heterostructures consist of 10-period superlattices of alternating GaNAs 0.5, 2.5 and 5.0% Mn and AlGaAs layers sandwiched between thick p+ and n+ layers. XSTM images reveal nanometer-sized regions with higher apparent tip height, presumably related to a local increase in the density of states associated with the presence of Mn atoms in GaNAs. In the 0.5% Mn films, the nanometer-sized bright regions appear dispersed, with ~5nm separation. For the 2.5 and 5.0% Mn films, agglomeration of the nanometer-sized bright regions is observed with separations of ~5-10nm, and an increase in XSTM contrast is observed in the Mn clustering. The apparent Mn clustering is not affected by the presence of adjacent AlGaAs superlattices, indicating that local misfit stress does not act as a sink for Mn accumulation. The apparent Mn clustering is likely due to a low energy attractive potential between Mn atoms, and may be correlated with charge carrier screening, similar to earlier GaAs:Zn studies [2]. As the Mn composition increases, the free carrier concentration increases, and the screening length decreases. This work in turn leads to a lower segregation of Mn and an increase in Mn clustering. This work was supported in part by ONR.[1] M.Berciu et al., Phys. Rev. Lett. 87, 107203 (2002). [2] P. Ebert et al., Phys. Rev. Lett. 83, 757 (1999).
by Long-Range Force Fields. Yasuaki Gyo, Division of Engineering, Brown University, Providence, Rhode Island.

A binary monolayer adsorbed on a solid surface can separate into distinct phases that further self-organize into various two-dimensional patterns. The process minimizes the combined free energy of mixing, phase boundary, and elasticity. The elastic field is caused by the different surface stresses in the two phases. Consequently, we can find many possibilities of manipulating the phase patterns by engineering the elastic field. One can obtain diverse patterns by using substrates with various crystalline symmetries and mechanical properties or by using a layered substrate. Surface properties designed for the applications of those patterns can be obtained by choosing appropriate material structures and parameters for the monolayer and the top layer of the substrate. The subsequent layers of the substrate provide the required stiffness anisotropy, the effect of which is passed to the monolayer patterns through the elastic field. Depending on the thicknesses and the degrees of the stiffness anisotropy of the substrate layers, the low-energy stripes can have tunable equilibrium stripe size and orientation. We solve the elastic field in the anisotropic, heterogeneous, three-dimensional half-space by using the Eshelby-Streh-Lokshinik formalism and the Fourier transformation.

2:45 PM T9.4 Self-Assembling Phase Patterns in a Monolayer Adsorbed on a Cylindrical Surface. Wei Huang, University of Colorado, Boulder, and Zhang Tao, Princeton University, Princeton, New Jersey. 4Division of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts.

Two-phase monolayer of molecular dipoles adsorbed on a solid substrate can selfassemble into phase patterns, such as periodic stripes and dots. The phase boundary energy drives the phases to coexist, and the electronic energy drives the phases to refine. The phase domain evolution to minimize the combined free energy is similar. In the electrostatic interaction is mediated through the space. If the space is somehow shaped, the phase patterns will be affected. To illustrate this idea, we develop a model to evolve phase patterns in a monolayer adsorbed on a cylindrical surface. Nano- or microscale tubes and wires of various materials could provide such a cylindrical surface.

Both convex and concave surfaces are considered. Our simulation shows that patterns have a strongly directional bias. Under different situations, the strips or dots align either along or perpendicular to the cylinder axis. When the radius of the cylinder is comparable to, or smaller than, the size of the phases, different pattern structures are observed.

3:00 PM T9.5 Self-Organization of Quantum-Wire Superlattice in Strain-Compensated Multilayer Films. Feng Bai, Junlan Bai, and Jerry Tersoff, 1Materi\hspace{0.1em} Science & En\hspace{0.1em} g., Utah University of Utah, Salt Lake City, Utah; 2Thomas J. Watson Research Center, IBM, Yorktown Heights, New York.

We develop a simple model to investigate step flow growth of strained multilayer films, taking into account the strain-induced interlayer step-step interaction. Computer simulations show that such interaction may improve the ordering of step bunches successively in each layer in a multilayer film. We apply the model to simulate the growth of strain-compensated multilayer films consisting of alternating tensile and compressive layers, as a potential method for fabricating quantum-wire superlattices.

This work is supported by DOE.


GalnAsSb alloys are of interest for mid-infrared optoelectronic devices such as lasers, detectors, and thermophotovoltaics. Although these alloys exhibit a large miscibility gap, epilayers with excellent optical and structural properties can be grown by kinetically inhibiting phase separation. However, phase separation cannot be completely eliminated, and several different manifestations of lateral and vertical composition modulation are observed in lattice-matched GaAsSb epilayers grown on [001] GaSb substrates miscut 2° or 6° toward [1-11], [1-11], or [001]. Examinations of GaAsSb Cross sections by transmission electron microscopy (TEM) reveal not only a spinodal-like contrast, but also a self-organized and highly regular vertical superlattice (NSL). The NSL is observed at the onset of growth, is laterally continuous throughout the epilayer, maintains a constant periodicity through all the subsequent microns of deposition, and forms in epilayers grown over a wide range of substrate miscuts, alloy compositions, and deposition temperatures. The periodicity of the
vertical modulations is typically between 10 and 30 nm, and is dependent on deposition temperature and alloy composition. Furthermore, the amount of lateral period increases as the 
substrate surface roughness. Cross-section field-emission scanning electron microscopy and 
three-axis x-ray diffraction reciprocal space mapping are consistent with TEM observations. The tilted NSL is associated with surface 
undulations that are measured by atomic force microscopy. The 
Lateral period of the surface undulation is correlated with the period of the NSL as it intersects the growth surface, while the amplitude of the undulation increases as the angle of incidence, position and orientation between the GaAs- and InSb-rich GaAs/InSb layers in the superlattice. 
This NSL results from complex interactions between thermodynamic solubility limits associated with steps in the vicinal surface as well as inherent substrate surface roughness. GaAs-rich compositions preferentially incorporate at surface valleys, while InSb-rich compositions incorporate at surface peaks, and is illustrative of the compositional, structural and morphological perturbations imposed by the implications of the self-organized NSL, and associated band structure modifications on minority carrier lifetime, and thus on device performance will also be discussed.

4:00 PM T9.7
Role of Compositional Modulation of InGaP Buffer Layer on Lateral Order of InP Dots. J. R. R. Bertoluzza, H. R. Gutierrez, M. A. Cotini, J. Bettini and M. M. de Carvalho, IFGW/UNICAMP, Campinas, S. Paulo, Brazil.

In the last years, several approaches have been used to improve the size homogeneity and lateral ordering of self-assembled quantum dots. In this work, we investigate the spontaneous formation of a bidimensional array of self-organized InP dots grown on slightly In-rich InGaP buffer layers. Atomic force microscopy investigation shows that the InGaP buffer growth rate increases in order to obtain the nucleation of the bidimensional dot array. Both temperature and V/III ratio chosen for InGaP deposition play an important role. These results show that a period strain field forms within the InGaP layer via surface processes. InGaP layers may show both GaP-type or non-stoichiometric regions and compositional modulation phenomena. These bulk properties activated by surface processes during growth can create preferential sites for InP dot nucleation.

To identify which bulk phenomena give rise to lateral dot ordering, transmission electron microscopy (TEM) was performed using a JEM 3010 URP 300 K V TEM. TEM plus-view images from InGaP layers without InP dots on top show bright domains ordered into a bidimensional pattern. The period of the contrast modulation is compatible with the bidimensional array of InP dots (around 100 nm). Such patterns have been extensively credited to compositional modulation on InGaP films. Indeed, Energy Dispersive Spectroscopy measurements show that the different contrast in the plus-view images is associated to small (a few percent) variations in In content. On the other hand, cross-sectional TEM micrographs with g=(1/2,1/2,2) shows round hexagonal domains, preventing the lateral spatial dot ordering. This fact rules out any correlation between GaP phenomena and spatial dot distribution. Cross-section TEM images clearly show the dot alignment with the contrast modulation in the InGaP buffer layer. These results show that compositional modulations trigger a periodic strain field in the InGaP buffer layer, which induce the lateral ordering of InP dots nucleated on the top.

4:15 PM T9.8
InGaAs/AlAsSb self-organized quantum wires grown on (775)B InP substrates by molecular beam epitaxy. Yugi Misui, Manuyuki Imura, Yu Higuchi, Takahiro Kitado, Satoshi Shimomura and Satoshi Hayama; Physical Science, Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka, Japan.

Self-organized InGaAs/AlAsSb quantum wires (QWRs) were formed on (775)B InP substrates by molecular beam epitaxy (MBE) for the first time. The QWRs were investigated by atomic force microscopy (AFM) and phosphomiseoence (PL) measurements. Previously we reported self-organized In0.35Ga0.65As/In0.52Al0.48As QWRs grown on (775)B InP substrates which showed good one-dimensionality and emission wavelength in a range of 1.2 micrometer. On the other hand, In0.35Ga0.65As/Al0.58Sb0.44 heterostructures lattice matched to InP are interesting for 1.3 micrometer electronic devices because of their large conduction band offset (1.7 eV), which makes it 4 times larger than that of In0.53Ga0.47As/In0.52Al0.48As heterostructures. So we can expect much larger lateral confinement energy of electrons for (775)B In0.35Ga0.65Sb0.44As/Al0.58Sb0.44 quantum wires (QWRs). The obtained QWRs are 100 nm thick and grown at Ts = 510°C. According to AFM surface image of the cap InGaAs layers, clear surface corrugation with a vertical amplitude of 1.3 nm and lateral period was observed as 4 nm by atomic force microscopy. Hence, we can expect that InGaAs QWRs are self-organized in the InGaAs/AlAsSb quantum wire structure grown on (775)B InP substrates at Ts = 570°C. PL spectra from the (775)B InGaAs/AlAsSb QWRs were observed on an Ar laser (wavelength 488 nm) excitation at 12 K. The observed PL wavelength was in a range of 1.2 micrometer and full width at half maximum of the PL peak was about 70 meV for (775)B InGaAs/AlAsSb QWRs grown at Ts = 570°C. PL emission was not strong so because of its high B band alignment. Further improvements can be improved by introducing additional InAlAs barrier layers.

4:30 PM T9.9
Structural and Optical Properties of InAs/GaSb Nanowires. Donna W. Stokes, Jinuhan H. Li, Rebecca L. Forrester, Saisith L. Aummu, Julia C. Lenevi, Simon C. Moss, Brett Z. Nalboh, Brian R. Bennett, Edward H. Aifer and Lloyd J. Whittingham, Department of Chemistry, Texas A&M University, College Station, Texas; Naval Research Laboratory, Washington, District of Columbia; Department of Natural Sciences, University of Houston-Downtown, Houston, Texas.

The nanostructure of lateral composition modulation (LCM) in InAs/GaSb superlattices grown by molecular beam epitaxy (MBE) on GaSb (001) substrates has been studied by high-resolution x-ray diffraction (XRD) and infrared absorption. These samples are designed for mid-infrared (3-12 μm) detector applications; therefore, the effects of the LCM on the optical properties of the material were investigated. Three samples were analyzed in this study: two LCM samples, A and B, and one with no LCM, sample C. All three samples were grown with 140 periods of [InAs]y/[GaSb]z (y, z, and x are close monolayers thick) with InSb interfacial bonds. The samples grown with Asy and Sbx sources demonstrated LCM, while those grown with the Asy and Sbx sources demonstrated LCM. XRD radio and reciprocal space map (RSM) scans were taken to determine the average morphology of the LCM structures, including the vertical and lateral composition modulations. Lateral satellite peaks were observed for both LCM samples about the zero order superlattice peak as well as about higher order peaks. Up to three lateral satellite peaks were observed for sample B indicating highly regular modulations. The vertical wavelength measured for sample A, 154 Å, was twice the period intended by the growers, 80 Å. This is believed to be due to the unusual structure of the LCM observed in the cross-sectional scanning tunneling microscopy (XSTM) image of this sample. The lateral and composition modulation wavelengths for sample A were measured from XSTM and XRD were ~1200 Å and ~600 Å, respectively, where the pure lateral modulation refers only to the lateral thickness undulations. For sample B, the vertical wavelength was twice the period intended by the growers. The relationship between the lateral and composition modulation for sample B is not yet clear from the XRD; therefore, XSTM and/or a fitting of the XRD data will be performed. Optical absorption measurements at 77 and 300 K using a Bruker FTS-165 Fourier Transform Infrared Spectrometer (FTIR) were performed to determine the effects of the LCM on the optical response of the samples. Absorption spectra were compared with that of an InAs0.53Ga0.47Sb superlattice with no LCM, sample C. The three samples were grown with a cut-off wavelength of 4.5 μm.

In sample C, with no modulation, the cutoff wavelength was 8 μm and the transitions involving the heavy- and light-hole bands in the GaSb hole quantum well and the electron subbands of the InAs quantum well were easily identified. LCM did affect the optical response of the samples; identification of the hole and electron subband transitions was not clear and different cutoff wavelengths were observed for each sample. The nanostructure of the LCM does affect the optical response of the sample and this is important when employing these structures for mid infrared detector applications.

4:45 PM T9.10
In (Ga)As heteroepitaxial growth on GaAs (311). Shahram Seyedinmohammadi, Zhiming M. Wang, Vahid R. Yazdanspers and Gregory J. Salamo, Physics, University of Arkansas, Fayetteville, Arkansas.

It has been demonstrated that GaAs epitaxial growth on (311) results in a beautiful wire-like faceted surface. Our observation of the surface indicates that the facets are identified as (110) and (111). The wire-like surface indicates that the GaAs quantum wire growth. We report the use of the GaAs (311) wire-like surface as a template to grow (In,Ga)As quantum wires. The growth was performed by Molecular Beam Epitaxy (MBE) using Multiple Reflection High Energy Electron Diffraction (MRHEED) and Scanning Tunneling Microscopy (STM) characterized the surfaces. While GaAs (311) homoeptaxial growth always leads to a faceted ridge-like surface, it is important to note that In0.2Ga0.8As growth over this surface results in a smooth surface depending on growth and annealing temperature at the
substrate temperature of 540 °C, the In0.2Ga0.8As growth results in a stable smooth (331) surface. In the structure of In0.2Ga0.8As layer bounded by a lower correlated (In,Ga)As/GaAs interface, upper smooth GaAs/In,Ga)As interface, optical characterization demonstrates one-dimensional confinement. On the other hand, when the growth temperature is lower than 450 °C, the In0.2Ga0.8As turns to have wire-like corrugation. In addition, the smooth phase of the (In,Ga)As surface grown at 540 °C will transfer to the corrugated phase by annealing at a temperature lower than 450 °C, while the corrugated phase turns to the smooth phase by annealing at 540 °C. The transition between two phases is reversible, indicating that both phases are thermodynamic favored at different temperatures.

SESSION T1.0: Atomic Ordering
Chairs: Andrew Norman and Gerald Stringfellow
Friday Morning, December 5, 2003
Room 209 (Hyenas)

8:30 AM **T1.0.1**
Tuning the degree of order in semiconductor alloys: experimental and theoretical studies of the phenomenon of spontaneous ordering, Yong Zhang, NREL, Golden, Colorado.

Experimental and theoretical results will be presented for studies of spontaneous ordering in semiconductor alloys, using GaInP as a prototype system [1]. The effects of ordering can be divided into the following areas: (1) changes of the statistical properties (2) changes of microscopically averaged properties. For the first area, one deals with how ordering changes alloy fluctuations of the electronic properties (e.g., band edge energy, excitonic linewidth, band length, etc.) [2]. The second area may include the changes in the band structure and various optical properties which often are related to the ordering. In this conference we will present the results of an ongoing study of the effects of ternary alloy films grown by MBE and MBE at different temperatures exhibiting GaInPz ordering. Coexistence of A- and B-type ordering in some of the samples is directly evidenced from the x-ray data. Other interesting scattering phenomena, accompanying the statistically ordered structure, including peak splitting, shifting, intensity modulation, and streaking, were also observed. A structural model considering packing of different ordering variants and misfitting is proposed to give a qualitative explanation of these new observations.

9:45 AM **T1.0.4**
Effects of Surfactants N and Br on Ordering in GaInP, David C. Changman, 1, Alex Howard, 2, Loren Rieh, 1, Gerald B. Stringfellow, 2, Y. W Ok, 2 and T Y Seong, 2 1Materials Science, University of Utah, Salt Lake City, Utah; 2Materials Science, Kwangju Institute of Science and Technology, Kwangju, South Korea.

The formation of the CuPt structure ordered domain of OMVE growth of GaInP is well established to be due to the surface structure during growth. For this reason, the ordered surface structure formed and the degree of order have potential applications for the formation of Sb and Bi surfactant atoms on the surface that are isoelectronic with P. Since both are larger than P, they not to reduce the thermodynamic driving force for ordering. The opposite is expected for L' surfactants, which is smaller than P. Hence, the addition of N' also found to reduce the degree of order in the GaInP layers, as indicated by both photoluminescence peak energy and TEM/EDS observations. Surface photo absorption (SPA) indicates this is due to a reduction in the concentration of P dimers on the surface. Based on published information, we conclude that N does not dimerize on the surface. This results in less ordering as P is displaced by N on the surface. CuPt ordering in GaInP is also reduced by the surfactant Te, added during OMVE growth. In this case, the major changes is kinetic. An increase in step velocity leads to less rearrangement of In and Ga atoms at the growing step edge, similar to the effect observed by simply increasing the growth rate. The addition of halide atoms during growth has been observed to increase the lateral velocity for patterned GaAs. This suggests that Br may lead to a reduction in the degree of order by a mechanism similar to that observed for Te. Indeed, experimental observations of the photoluminescence peak energy support this phenomenon. The degree of order for GaInP layers lattice matched to GaAs is found to monotonically decrease with increasing Br in the vapor from the pyrolysis of CBr4. These results are summarized in TEO/EDS observations. The effect of Cl has also to studied; but Cl2 also exhibits a dramatic effect on solid composition (Ga/In ratio in the solid) that ambiguous conclusions about the effect of Cl are difficult.

10:30 AM **T1.0.5**
Growth Model for Atomic Ordering: The Quadruple-Period Ordering in GaAs/Alloy, Shenghai Zhang, National Renewable Energy Laboratory, Golden, Colorado.

It has long been understood that atomic ordering, widely observed in epitaxially grown semiconductor AB1_xC_x alloys, is driven by surface thermodynamics and/or by growth kinetics; but not by bulk thermodynamics. Atomic ordering and reconstruction at the growing surface, typically a (001) surface, naturally provides an atomic-scale compressive/tensile strain field below the surface. This creates a subsurface site preference for site-mismatched B and C atoms and hence ordering. Subsequent first-principles calculations for III-V alloys confirmed the large in-plane (2D) ordering energies but the ordering energies between layers (3D) are small. It is customary to invoke surface steps to enhance the correlation between layers and hence the 3D ordering. In several experiments we have correlated the degree of ordering with the density and orientation of surface steps. However, a microscopic model regarding step-induced 3D ordering based on first-principles theory is still lacking. Recently, a new quadruple-period (QP) ordering was observed in AB1_xC_x alloys by transmission electron diffraction (TED) and x-ray diffraction measurements. The QP ordered structure has several unique but unexplained physical features: (i) The growth of the quadruple-period ordered materials requires a high growth temperature (T > 600°C). At such temperatures, although the 2D surface pattern still holds, the surface transforms into a different reconstruction, as seen by reflection high-energy electron diffraction (RHEED). (ii) It breaks CuAs-like structure but with a periodic array of nanoscale boundaries
along the [110] direction. (iii) The ordering direction is perpendicular to the surface-parallel dimer direction. Hence, within the framework of surface 
dimerization-induced ordering, it is not clear why such an ordering would have taken place, unless it is associated with surface 
cation dimers. (iv) The quadrupole size of 1.6 nanometers represents 
probably the largest period in 3D atomic ordering in semiconductor 
alloys observed so far. By combining first-principles total energy 
calculations with experimental analyses, we are able to determine the 
atomic structure of the QP ordering and the ordering mechanism. A 
short-range correlation between a high-temperature 3As-stabilized 
(101) facet of Ag/Ag(100) surface structure with respect to the substrate. This leaves room 
for the development of new, ultrafast, and ultra-efficient, high- 
performance, full-spectrum detectors.

Effects of Substrate Orientation on the Spontaneous Ordering of GaAsSb Epilayers Grown By Molecular Beam Epitaxy.
Brian E. Norman1, Reiko Lukic-Zoric1, Andrew Norman1, Terry D. 
Golding2, and Chris C. Louit3,1, Dept. of Physics, University of North 
Texas, Denton, Texas; 2National Renewable Energy Laboratory, 
Golden, Colorado.

GaAs1-xSbx epilayers (0.10 < x < 0.71) grown by molecular beam 
epitaxy (MBE) on GaAs substrates with various surface orientations 
were investigated using Fourier transform infrared spectrometry (FTIR), 
atomic force microscopy (AFM) and transmission electron microscopy (TEM). Atomic ordering in these epilayers was observed 
with a decrease in the energy gap measured by FTIR absorption, 
and corroborated by superlattice reflections in electron diffraction. 
Contrary to previous investigations of ordering in III-V alloys, a 
larger energy gap reduction corresponding to CuPt1-B type ordering is 
observed in the GaAs1-xSbx grown on A-type GaAs substrate offsets, as 
observed in the more commonly observed B-type. This suggests 
that A-type steps may play an important role in the CuPt1-B ordering 
process in MBE grown GaAs1-xSbx layers.

11:15 AM T10.7

Non-native Pb(Se, Te) islands and their crystallographic 
structures. Peter Meeck1, Armando Acha1, Jens Foster2, James 
Morr3, Nigel D Browning1 and Patrick J. McCarran4, 1Physics, 
Portland State University, Portland, Oregon; 2Electrical and 
Computer Engineering, Portland State University, Portland, Oregon; 
Chemical Engineering and Materials Science, University of California 
and National Center for Electron Microscopy, Davis, California; 
3Electrical and Computer Engineering, University of Oklahoma, 
Norman, Oklahoma.

PbSe islands under in-plane tensile strain were grown on a 
(111) oriented PbSe/InP(100) substrate by molecular beam 
epitaxy. The morphology and crystallographic structure of these 
epilayers were analyzed by means of atomic force microscopy and 
transmission electron microscopy/diffraction. Strained small and 
medium sized random alloy Pb(Se,Te) islands with a halite 
structure form diameters of 5 nm to 10 nm and 
respective number densities of approximately 5 x 1013 
cm−2 and 1016 
cm−2 were observed. Regions with small and essentially unstrained 
atomically ordered islands of a number density of approximately 5 x 1013 
1016 
and a size on the order of 5 nm that consisted of 
atomically ordered Pb(Se,Te) compounds were also identified in 
the electron microscope. The crystallography of the atomically ordered 
epilayers is discussed and a hypothesis for their existence provided.

11:30 AM T10.8

Superlattice Ordering In Termary And Quaternary III/V-Compound Bulk Semiconductors And Quantum Wells.
Carsten H. Dohler1,2, Kramen3,4,5,6, Neumayer3,4,5,6, W. 
Proetz1, F. T. Tegude2 and P. Kersel1, Inst. Techn. Phys. I, University 
of Erlangen, Erlangen, Germany; 2Fakultät 
Halle, Technikum/Halle, Technikum, Universität Saarland, 
Darmstadt, Germany; 3Palo Alto Research Center, Palo Alto, 
California.

It has been known for many years that ternary III/V compounds 
semiconductors like InGaP or InGaAs, grown by metal organic vapor 
phase epitaxy at sufficiently low temperatures on (101) oriented or 
slightly mis-oriented substrates exhibit a CuPt1-B crystal 
structure which results from a superlattice formation due to 
nano-twinning interfaces in gallium-rich layers alternating along one of 
the two [111] directions. This spontaneous ordering leads to