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

Symposium Support
†Omicron NanoTechnology USA
†Veeco Instruments Inc. (MBE Operations)
†2003 Fall Exhibitor

Proceedings to be published in both book form and online
(see *ONLINE PUBLICATIONS* at www. mrs.org)
as Volume 794
of the Materials Research Society
Proceedings Series

* Invited paper

SESSION T1: Morphological Evolution: Patterning and Islanding
Chairs: Vivek Shenoy and Xiaojun Weng
Monday Morning, December 1, 2003
Room 209 (Hynes)

8:30 AM T1.1
Atomic-scale pathways of the pyramid-to-dome transition during Ge growth on Si(001): I-Experimental determination.
Giovanni Costantini[1], Carlos Manzano[1], Georgios Katsaros[1], Armando Rastelli[1], Hans von Kaenel[2], Ulrich Denker[1], Oliver Schmidt[1] and Klaus Kern[1]; [1]Max-Planck-Institut fuer Festkoerperforschung, Stuttgart, Germany; [2]Dipartimento di Fisica, INFM, 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 Ge at 560C or (2) by annealing 6 ML of Ge at the growth temperature of 560C 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 that excess a critical volume; during the growth of this cap, the bunching of its lower step edges evolves into (15 3 25) facets whilst the non-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. The technique of selective chemical etching is used in order 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 intermixing that depends on the shape and 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. Montalenti 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 AM T1.2
Atomic-scale pathways of the pyramid-to-dome transition during Ge growth on Si(001): II-Theory and simulations.
Francesco Montalenti, Dmitri B Migas, Paolo Raiteri and Leo Miglio; INFM, 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 one. When pyramids reach the typical size at 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 atomistic 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 AM T1.3
Size Dependent Shapes of 2D domains on Surfaces.
Gayle Echo Thayer, Rudolf M. Tromp and James B. Hannon; Nanoscale Analysis, IBM T.J. Watson Research Center, Yorktown Heights, New York.

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 interaction energy and domain wall energy) are often not well known experimentally, and/or because reaching thermodynamic 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 long range 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(111) 7x7 domains near the 7x7-1x1 phase transition, where isolated 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 experimentally. From the 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 energetics, in close agreement with the theoretical results. Thus, the study of size dependent isolated shapes 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 AM T1.4
First-Principles Calculations of Ge on Si(100) Wetting Layer Properties. Matthew J. Beck, Axel van de Walle, Mark Asta and Peter W. Voorhees; Materials Science and Engineering, Northwestern University, Evanston, Illinois.

The morphological evolution of crystalline surfaces and overlayer films in heteroepitaxial 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 in Ge on Si (100) heteroepitaxy is fundamental to accurate qualitative and quantitative modeling of growth and evolution of three dimensional nanostructures in this system. We present results of first-principles calculations of the properties of Ge (100) surfaces relevant to Ge on Si (100) heteroepitaxy. The $c(4x2)$ 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 AM T1.5
Self assembly of dimer vacancy lines on Si(001): a novel view on the 2xN reconstruction. Cristian Ciobanu, Dhananjay Tambe and Vivek Shenoy; Engineering, Brown University, Providence, Rhode Island.

We demonstrate that the 2xN reconstruction observed for the Ge-covered Si(001) surface is determined by the competition between the formation energy of isolated vacancy lines and their mutual elastic 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 explanations of the 2xN structure that are 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 in agreement with experimental data and provide a robust explanation of the physical origin of the 2xN reconstruction.

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

During heteroepitaxy of Ge on Si(001), beyond a critical thickness the Ge self-assembles into small islands, or quantum dots, with widths of around 30 nm. We study the energetics of this island formation by atomistic simulation. The islands are modeled as square-based pyramids with rebonded step {105} facets. We determine how the 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.

10:30 AM T1.7
Atomistic modelling of GeSi/Si(001) Quantum Dots.
Christian Lang, Duc Nguyen-Manh and David J. H. Cockayne; Department of Materials, University of Oxford, Oxford, Oxfordshire, United Kingdom.

Atomistic modelling of GeSi/Si(001) Quantum Dots The small size (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 GeSi 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 dependence 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 nucleation of QDs and the change of the shape with increasing surface coverage. 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 analysed 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. Vivek Shenoy and Ashwin 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 annealing 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 Chkliaev[2], Michael J Miksis[2] and Peter W Voorhees[1]; [1]Materials Science and Engineering, Northwestern University, Evanston, Illinois; [2]Applied Mathematics, Northwestern University, Evanston, Illinois.

The misfit strain that accompanies heteroepitaxy can drive the formation of islands on surfaces. The shape of misfitting islands in systems in which the film completely wets the substrate has been widely studied. In contrast, the equilibrium shape of an island where there is a nonzero 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 completely wets the substrate. We also find equilibrium island morphologies that are strongly nonconvex and have multiple humps. 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. Beltz[1], Alexei Romanov[4,2], Fjola Jonsdottir[3,1] and James S. Speck[2]; [1]Department of Mechanical and Environmental Engineering, University of California, Santa Barbara, Santa Barbara, California; [2]Materials Department, University of California, Santa Barbara, California; [3]Department of Mechanical and Industrial Engineering, University of Iceland, Reykjavik, Iceland; [4]A. F. Ioffe Physico-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 method treats the quantum dot as a point spot of dilatation, and does not take details of the dot shape into account. The second approach integrates the point spot over a prescribed volume, this providing 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 the 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 a several-monolayer 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 as 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-organization theory. However, In contrast to semiconductor, 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 [1]. We will focus on the case of Volmer-Weber growth of 3D metal islands on insulator substrates, where there is a large difference of surface energy as well as surface stress between metal and insulator. We show that a large surface stress discontinuity along island edge introduces an elastic dipolar 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-island interaction. This work is supported by DOE. [1] Feng Liu, Phys. Rev. Lett. 89, 246105 (2002).

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

Nanoscale features develop on surfaces as a result of either kinetics or thermodynamics or both. Recently, we have proposed two kinetic barriers: facet-facet and step-facet barriers. Combining ab initio calculations, 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 estimations. Further, the ab initio results show that indium 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 simulations show that the facet-facet barrier leads to the formation of nanofacets, and the step-facet barrier the nanowires.

SESSION T2: SiGe Nanostructures
Chairs: 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. Lagally, 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". That 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 faceted nanocrystals 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 nanopatterned substrates. 2) Ge QDs that grow on the thin Si template of silicon-on-insulator (SOI) can act as a nanostressor that distorts the Si layer and causes the oxide underneath to flow. We provide 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_2 interface is described. We discuss the possibility of extracting quantitatively energetic parameters for dislocation behavior. 4) Self-assembly of 3D Si islands during thermal decomposition of thin SOI. As time permits we will describe: 5) Investigation of the effect of added uniaxial stress on the diffusion, nucleation, and coarsening of nanostructures and films using MEMS techniques to stress a Si membrane, and 6) Growth of carbon nanotubes at specific spots on Si to make circuits, using a unique method to place catalyst in desired regions. Photoconductivity measurements suggest that these nanotubes are phototransistors. Supported by NSF, DARPA, ONR, DOE In conjunction with B. Yang, F. Liu, P. Rugheimer, D. Savage, E. Sutter, P. Sutter, M. Roberts, E. Rehder, T. Kuech, P. Zhang, C-H. Lee, A. Lal, T. Narkis, B. Larson, M. Eriksson, M. Marcus.

2:00 PM T2.2
Frustrated Alloying: The Growth of Ge on Ultra-Flat Si(001).
James B Hannon, Matt Copel, Mark Reuter and Ruud Tromp; IBM Research Division, Yorktown Heights, New York.

Using low-energy electron microscopy (LEEM), we have investigated the alloying of Ge at the Si(001) surface during growth at elevated temperature(750 to 900 C). We show that alloying occurs primarily via step flow during growth. That is, an advancing step buries some fraction of the Ge in the surface layer as it moves. However, on large terraces, where step flow does not occur, subsurface alloying is frustrated. As a result, complex and coordinated step structures spontaneously form that facilitate alloy formation in the near-surface region. These structures – linked chains of adatom and vacancy islands – migrate rapidly over the large terraces, at speeds approaching 1 um/sec, leaving alloyed regions in their wake.

2:15 PM T2.3
Real-time PEEM observation of the growth dynamics of Ge islands on vicinal and on-axis Si(001) surfaces.
Marcel Himmerlich[1,2], Wooschul Yang[1], Robert J. Nemanich[1] and Juergen A. Schaefer[2]; [1]Physics, NC State University, Raleigh, North Carolina; [2]Physics, Technical University Ilmenau, Ilmenau, Thuringia, Germany.

The growth dynamics of Ge islands on both on-axis Si(001) and off-axis (miscut 22° towards (111)) surfaces is studied using ultra-violet photoelectron emission microscopy (UV-PEEM). In situ Ge deposition and real-time monitoring of the growing islands allow us to study the evolution of the size, shape and density of the surface structures. The samples were prepared by Ge deposition of ∼20ML with a growth rate of about 0.3 - 0.5 ML/min at temperatures of 450°C - 550°C followed by annealing at temperatures up to 600°C. Photoelectrons were excited by UV-light with an energy of 4.9 - 5.0 eV using the tunable UV free electron laser (FEL) at Duke University. After the first 10 min of deposition (∼3ML) uniform emission was observed indicating the growth of a strained wetting layer. During further growth the transition from layer by layer to 3D-growth occurred by formation of round dots with a density of $\sim 5\text{x}10^9\text{cm}^{-2}$. During continuous deposition of Ge enlargement of the islands was observed, but no further island nucleation occurred. During annealing the average size of the islands increased while the island density decreased to $\sim 8\text{x}10^8\text{cm}^{-2}$, which indicates Ostwald ripening through diffusion of Ge on the surface. AFM measurements performed on the islands grown on the on-axis surface show dome structures while the islands on the off-axis substrates display flat tops with multiple steep facets on their sides. The plane facets on top probably have the (113)-orientation, which is one of the most stable configurations with a low surface free energy. Research supported by the NSF and the AFOSR through the MFEL program.

2:30 PM T2.4
Surface Roughening and Quantum Dot Self-Assembly in Ge/Si(100) Epitaxy. Peter Werner Sutter, Eli Sutter, Ian Carl Schick and Winfried Ernst; Department of Physics, Colorado School of Mines, Golden, Colorado.

The surface morphology evolution during semiconductor epitaxy has been subject of intense recent research. Lattice mismatch strain present in many heteroepitaxial systems drives a rich set of phenomena such as the self-assembly of nanostructures with potential applications in quantum devices. Faceted quantum dot islands are generated via strain-induced self-assembly during Ge growth on Si(100). These nanostructures have long been believed to form via random nucleation on a planar 'wetting layer'. Recent observations of SiGe alloy growth on Si(100), however, demonstrated a strong tendency toward alternative kinetic routes to islanding [1,2]. Roughness generated at the initial growth stages, for instance, may mediate the continuous formation of faceted islands [1,2]. We have developed the capability of obtaining large-area ($>1\mu m^2$ field of view), atom-resolved scanning tunneling microscopy scans, and thus achieved an unprecedented combination of statistics and detail at all length scales relevant to epitaxial growth. Using this unique capability, we were able to identify the dominant, yet previously unknown, mechanisms leading to initial roughening and, ultimately, quantum dot formation during Ge/Si(100) heteroepitaxy [3]. At low Ge coverage, the interaction of steps with surface defects progressively generates a template of highly periodic, correlated roughness on the Ge 'wetting layer'. We discuss the detailed processes driving the formation of this correlated roughness, its role in the initial self-assembly of quantum dot islands, and its potential for the spontaneous generation of ordered arrays of Ge quantum dots. [1] P. Sutter and M.G. Lagally, Phys. Rev. Lett. 84, 4637 (2000). [2] P. Sutter, P. Zahl, and E. Sutter, Appl. Phys. Lett. 82, 3454 (2003). [3] P. Sutter et al., Phys. Rev. Lett., submitted.

2:45 PM T2.5
Growth and ordering of Ge quantum dots on natural and nanostructured Si surfaces: a real time study by Scanning Tunneling Microscopy. anna sgarlata[1], Pierre David Szkutnik[1], Adalberto Balzarotti[1] and Nunzio Motta[2]; [1]Physics, University of Rome Tor Vergata, Rome, Italy; [2]Physics, University of Rome Tre, Rome, Italy.

Quantum dots grown on semiconductors surfaces are actually the researchers interest for possible applications in the forecoming nanotechnology era. New approaches to grow ordered patterns of homogeneous nanostructures include growth on mesa structures, natural patterning by surface instabilities, nano lithography techniques as Electron Beam Lithography (EBL), implantation of Ga+ ions (Focused Ion Beam), and in situ substrate patterning by Scanning Tunneling Microscopy (STM) or Atomic Force Microscopy (AFM). We report on the nucleation and growth of Ge islands on nanopatterned Si substrates followed in real time by STM imaging. Nanopatterning has been realized using two different approaches: on Si(001) by STM lithography and on Si (111) by step bunching effect. Different issues regarding the heteroepitaxial growth on these substrates have been discussed: the nanostructuring 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(001), 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 Ge:Si(001)domes.
Gilberto Medeiros-Ribeiro[1,3], Stefan Kycia[1], Angelo Malachias[2], Rogerio Magalhaes-Paniago[2,1], Ted Kamins[3] and R. Stanley Williams[3]; [1]LNLS, Campinas, SP, Brazil; [2]Departamento de Fisica, UFMG, Belo Horizonte, MG, Brazil; [3]Hewlett-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 vertical composition variation, with most of the Si concentrated at the base of the island. Different growth conditions produce distinct lateral profiles. Hence, the assessment of lateral composition profiles is important to both identify the dominant growth mechanisms and model the confining potential of quantum dots. We report 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 anomalous 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 dot confining potentials, this work presents a solution for imputing lateral composition profiles with its associated strain. This work was funded by FAPESP (contract 98/14757-4) and HP Brazil.

3:45 PM T2.7
Size Selection of Surface Morphologies Produced Under Kinetically Limited Growth Conditions in the Si/SiGe Epitaxial System. Jennifer L. Gray[1], Nitin Singh[1], Robert Hull[1], Dana M. Elzey[1] and Jerrold A. Floro[2]; [1]Materials Science and Engineering, University of Virginia, Charlottesville, Virginia; [2]Sandia National Laboratories, Albuquerque, New Mexico.

We show that quantum fortress or quantum dot molecule surface morphology structures exhibit 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 Si0.7Ge0.3 films at 550°C and 0.9 Å/s by molecular beam epitaxy on Si (001) substrates. Growth under these kinetically limited conditions may provide a new route to self-organized nano-structures. Initial strain relaxation results in the formation of shallow pyramidal pits in the metastable wetting layer. As growth is continued, the formation of quantum fortresses 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 even when annealing is performed at the growth temperature. This size selection can be explained by the formation of a {501} faceted, continuous island wall surrounding each pit that creates a barrier to adatom diffusion out of the pit. Finite element analysis of the elastic energy distribution in and around a quantum fortress 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.
Nitin Singh[1], Jennifer L Gray[1], Robert Hull[1], Dana M Elzey[1] and Jerrold A Floro[2]; [1]Materials Science and Engineering, University of Virginia, Charlottesville, Virginia; [2]Sandia National Laboratories, Albequerque, 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 coalesce to form a continuous wall surrounding the pit (the so called Quantum Fortress structure). The second is a growth instability of the pit itself, which can rapidly extend in a [100] direction to become a highly asymmetric 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 {501} facets ubiquitously observed on compressed SiGe surfaces. Using finite element calculations and detailed considerations of the island/pit geometries, we will show how morphological constraints upon adatom 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 suported 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 ordering in the surfactant mediated growth of Ge-films on Si (111).
Roland Kroeger[1], Thomas Schmidt[1], Jens Falta[1], Michael Horn-von Hoegen[2], Peter Ryder[1] and Andreas Janzen[2]; [1]Institute of Solid State Physics, University of Bremen, Bremen, Germany; [2]University 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 630°) 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 misfit 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 ordering can be observed, from which it may 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 self-organized, 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 Portavoce[1], Martin Kammler[1], Robert Hull[1] and Frances M Ross[2]; [1]Materials Science and Engineering, University of Virginia, Charlottesville, Virginia; [2]IBM T. J. Watson Research Center, Yorktown Heights, New York.

The use of surfactant elements during semiconductor epitaxial growth is an important self-organisation 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 epitaxy 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 300kV Hitachi UHV-9000 transmission electron microscope (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 loaded 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 passivate dangling bonds on the Si surface. For low pressure and 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
Chairs: Daniel Friedman, Rachel Goldman and Philippe Guyot-Sionnest
Monday Evening, December 1, 2003
8:00 PM
Exhibition Hall D (Hynes)

T3.1
Real time, in situ PEEM Growth and Decay of $DySi_2$ Nanowires on Si(001).
Anderson Sunda-Meya, Lena Fitting, Matt C Zeman, Woochul C Yang and Robert J Nemanich; Physics, North Carolina State University, Raleigh, North Carolina.

Nanowires of $DySi_2$ were formed on a Si(001) substrate through deposition of few monolayers of dysprosium and annealing at 700° 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 and ~1000° C. At high temperatures, the Dy evaporates from the surface, and the wires eventually disappear. Upon annealing, we observe that the nanowires width remains constant while the length decreases with time. At some point, they then sequentially break in sections, and we speculate that the breaks correspond to misfit dislocations.
ResearchsupportedbytheNSFandtheAFOSRthroughtheMFELprogram.

T3.2
Epitaxial Growth And Structural Evolution Of Hexagonal Close-Packed Ni Nanostructures On The (100) Surface Of MgO.
Haiping Sun[1,2], Wei Tian[1], Mark Yeadon[2], Chris Boothroyd[2], Jinhua Yu[2], Ale Lukaszew[3], Roy Clarke[4] and Xiaoqing Pan[1,2]; [1]Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan; [2]Insitute of Materials Research and Engineering, Singapore, Singapore; [3]Department of Physics and Astronomy, University of Toledo, Toledo, Ohio; [4]Department of Physics, University of Michigan, Ann Arbor, Michigan.

Heteroepitaxial misfit 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 a hexagonal close-packed (hcp) structure in the early stages of the epitaxial growth of nickel on a (001) single crystal MgO substrate. The study was performed in an ultra-high vacuum transmission electron microscope equipped with an electron beam evaporator for 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 (110)//MgO(001) when the lateral size of the islands exceeds a critical value of ~5nm. The structural transition proceeds via a Martensitic change in the stacking sequence of the close-packed planes, representing a novel way to

relieve misfit strain. Equivalent in-plane orientations of the fcc-Ni (110) islands were observed as a result of the four-fold degenerate characteristics of the (001) surface of MgO. The formation of hcp-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
The formation and evolution of nanostructures for Ti on Si(001). Matthew C. Zeman, Woochul Yang and Robert J Nemanich; Physics, North Carolina State University, Raleigh, North Carolina.

In this study the formation and evolution of nanoscale Titanium disilicide island and wire structures are 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 prepared by first depositing an ultra thin Ti (2-10ML) layer on Si(001) at room temperature. We then observe the TiSi2 island formation during annealing at temperatures above 900°C. Further annealing at higher temperatures fosters 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 were nearby 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 existing islands grow larger in size. This is attributed to the increased adatom 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 <110> direction up to a few microns in length. Research supported by NSF and the AFOSR-MFEL program.

T3.4
Non-aggregated nanodisperse particles of noble metals synthesized by pulse-laser deposition: ultramicroscopy structural and analytical characterization. Vladimir P Oleshko, Christopher E Allmond, James M Fitz-Gerald and James M Howe; 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 5-20Hz. After reaching a base pressure of 5x10-6 Torr, Ag (99.99% at.) and Pd (99.95% at.) targets were ablated in an inert backfill gas of Ar at pressures of 100 and 200 mTorr and fluences ranging from 2.5-4 J/cm2. Formation of nanoparticles and molecular clusters is largely facilitated by collisions both inter-plume and with the inert gas on the leading edge of the laser induced plume. Metal nanoparticles were collected on carbon grids and examined by high-resolution transmission electron microscopy and field-emission analytical electron microscopy utilizing parallel electron energy-loss (PEEL) and windowless energy-dispersive x-ray (EDX) nanospectroscopies. 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 compositions of the nanoparticles (Ag and Pd (the latter with admixtures of Ag, 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 aperiodic structures. Due to the inherent energetics 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 Mazzone, 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 shapes. First, by understanding these complex patterns, important information about surface kinetics can be extracted. The second perspective arises from quantum confinement. Quantum well states are known to be produced by artificial structures, like arrays of regularly spaced monoatomic 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 step width is different in the two cases. This divergence suggests a central difference between vicinal surfaces and islands which should be continuously and systematically investigated. The assessment of this point has motivated this work. Hartree-Fock calculations at semiempirical level have been used to describe the band structure of homoepitaxial metallic islands formed by Cu and Ag. The calculations, carried out at paramagnetic level, show an enhanced dependence of of the density of states on the atomic location. The density of states of atoms located in incomplete planes at the island top posses narrow peaks in the energy range of the bulk d electrons. On the contrary, the density of states of atoms with a large coordination at the island basis retains the broad energy distribution of the bulk state.

T3.6
Facile Fabrication of Nanoparticles in the Nanospace of Ultrathin TiO_2-Gel Films: Composition, Morphology and Catalytic Activity. Junhui He and Toyoki Kunitake; Frontier Research System, The Institute of Physical and Chemical Research (RIKEN), Wako, Saitama, Japan.

Nanoparticles of metals and semiconductors are attracting much attention, as they posess promises in photonic, electronic, magnetic and chemical applications. Thin films consisting of such nanoparticles 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 of various compositions and morphologies in the nanospace of ultrathin TiO_2-gel films using low temperature H_2 and O_2 plasmas as reductant and oxidant respectively. Catalytic activities of Pd monometallic and Pd-Ag bimetallic nanoparticles were tested for hydrogenation of methyl acrylate. Recently, we have developed a general, efficient approach of incorporation of metal ions in metal-oxide ultrathin films by a template/ion exchange process.[1] Noble metal (Ag, Au, Pd, Pt) ion exchanged films were fabricated according to this approach. The films were then exposed to H_2 plasma, producing metal nanoparticles in thin films.[2] 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 photoinduced reductions, H_2 plasma is a clean and versatile reductant. In addition, organic moieties in thin films can be simultaneously removed. The current approach 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 TiO_2-gel films by H_2 and O_2 plasmas.[3] Such chemical transformation in nanospace was used, for the first time, as a tool to tailor the composition, shape, size and size distribution of nanoparticles. Repeated chemical transformation of metal and metal oxide 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 nanoparticle was fabricated in ultrathin TiO_2 film by first preparing Ag nanoparticle, followed by introduction of Pd^{2+} ion and reduction with H_2 plasma. A mixture of individual Pd and Ag nanoparticles was obtained, however, by a reversed procedure. The Pd monometallic and Ag-core/Pd-shell bimetallic nanoparticles showed a catalytic activity for hydrogenation of methyl acrylate 233 and 367 times, respectively, as large as that of commercial Pd black. The outstanding catalytic activity was explicable by a large fraction of surface-exposed Pd atoms. References [1] J. He, I. Ichinose, S. Fujikawa, T. Kunitake, A. Nakao, *Chem.Mater.* **2002**, *14*, 3493. [2] J. He, I. Ichinose, T. Kunitake, A. Nakao, *Langmuir* **2002**, *18*, 10005. [3]J. He, I. Ichinose, S. Fujikawa, T. Kunitake, A. Nakao, *Chem.Comm.* **2002**, 1910.

T3.7
Nanopillar and Nanowire Growth by Vapor-Liquid-Solid (VLS) Epitaxy. S. T. Picraux[1], J W Dailey[1], J Taraci[1], T Michael[1], J C Thorp[1] and J Drucker[2]; [1]Dept. of Chemical and Materials Engineering, Arizona State University, Tempe, Arizona; [2]Dept. of Physics and Astronomy, Arizona State University, Tempe, Arizona.

The kinetics and morphology of Ge nanopillar 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 nanowires at higher pressures by VLS, less effort has been directed at the controlled CVD growth of epitaxial arrays of nanopillars or nanowires directly onto Si substrates. In our studies eutectic forming metallic nanodots such as Au are formed by UHV evaporation on hydrogen terminated Si (100) and (111) substrates. Subsequent selective area growth is carried out using digermane or disilane at pressures from 1 x 10-2 to 1 x 10-5 T and temperatures from 400 to 600 C. At the lower pressures we observe the growth of Ge nanopillars that nucleate at the AuSi 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 Ge nanopillar growth, and SEM elucidates the morphological evolution of the nanopillars. At pressures above 10-4 T we observe an abrupt change in the nature of the growth from a relatively slow nanopillar growth to a much more rapid nanowire growth. The nanowires are distinguished by long narrow axial growth structures with much slower lateral growth. The transition from nanopillar to nanowire growth is interpreted in terms of a nucleation-limited process. Implications for controlled heteroepitaxial growth of multilayered wires are discussed. Due to the small lateral dimensions (10 to 50 nm) of these 3-D structures lateral strain relief is expected to occur after relatively short wire lengths and large lattice mismatches accommodated without defects, in contrast to large area heteroepitaxy. These CVD nanoscale structures could form the basis for new in situ synthesis of 3-D Si device structures on Si substrates.

T3.8

GaAs and AlGaAs Nanowires Grown on GaAs Substrates by MBE. Jinqiang Liu[1], Karen L Kavanagh[1], Zhanghua Wu[2], Xiangyang Mei[2] and Harry E Ruda[2]; [1]Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada; [2]Energenius Centre for Advanced Nanotechnology, University of Toronto, Toronto, Ontario, Canada.

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 nanochannel alumina template 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 microstructure of the nanowires have been studied by using field-emission scanning electron microscopy (SEM), high-resolution transmission electron microscopy (TEM) and energy dispersive x-ray spectroscopy (EDS) analysis. The studies show that the 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 instance in <110> direction that also often show multiple branches. Planar defects, such as twins and stacking faults, are frequently observed in <111>-oriented nanowires. However, no defects are observed in <110>-oriented nanowires. High-resolution TEM also reveals that the Au/GaAs 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.

T3.9

Generally Applicable Self-masking Technique for Nanotip Arrays Fabrication. Kuei-Hsien Chen[1,2], Chih-Hsun Hsu[3], Chia-Fu Chen[3], Li-Chyong Chen[2] and Jeff Tsai[1]; [1]Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei, Taiwan; [2]Center for Condensed Matter Sciences, National Taiwan University, Taipei, Taiwan; [3]Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu, Taiwan.

Silicon nanotips with tip diameter and height measuring 1 nm and 1 micron, respectively, and density up to 100 billions per centermeter square, were fabricated monolithically from silicon wafers by electron cyclotron resonance plasma etching technique at a temperature of 200 degree C. High-resolution transmission electron microscope and Auger electron spectroscopy analyses concluded that the nanotips are composed of monolithic silicon and nanometer-size SiC cap at the top. Not only to a Si-substrate, this technique can also be applied to other materials such as GaN, GaP, Al, etc. This can be attributed to the formation of SiC nano-masks and simultaneous isotropic etching in the process. This process combined with photolithography can also generate patterned nanotip arrays, using silicon nitride or other etch-resistant material as a hard mask. The advantages of this technique lie in the relative process simplicity, general applicability in a number of semiconductors and metals, and compatibility with conventional semiconductor processes. Therefore, it is a promising process to fabricate large area field electron sources for vacuum electronic components in industrial applications. Field emission current densities of 3.0 mA/cm2 at an applied field of ~1.0 V/micron was obtained from these silicon nanotips. In the measurement, a 0.35 V/micron turn-on field to draw a 10 microamp/cm2 current density was demonstrated, which is much lower than other reported materials. The excellent field emission property demonstrated by these nanotips, which were fabricated by a process integrable to the existing silicon device technology at low temperatures, is a step forward in achieving low-power field emission displays and vacuum electronic devices.

T3.10

Preparation and Magnetoresistance Properties of Silver Telluride Nanowires by Electrodeposition. Xu Dongsheng, Yu Yuxiang, Chen Ruizhi and Guo Guolin; Department of Chemistry, Institute of Physical Chemistry, Beijing, China.

Silver telluride alloys present interesting thermoelectrical, electrical and magnetoresistive properties, which find wide applications in the fields of thermoelectronics, magnetics and sensors. Silver telluride is known as a typical example of mixed ionic-electronic conductivity in solid. The low temperature phase of monoclinic silver telluride is a semiconductor with narrow band-gap, high carriers mobility and low lattice thermal conductivity, whereas its high-temperature phase gives rise to superionic conductivity. Perfectly stoichiometric Ag2Te has negligible magnetoresistance, but large 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 present, we describe a method for preparation of crystalline silver telluride nanowires by electrodeposition from dimethyl sulfoxide (DMSO) solutions containing 0.1M NaNO3, 5.0 mM AgNO3 and 3.5-7.0 mM TeCl4. We found that silver telluride nanowires can be electrodeposited with 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 6.0-7.0 mM, the deposited nanowires could be adjusted from monoclinic Ag2Te to hexagonal Ag7Te4. Finally, magnetoresistive properties of those electrodeposited nanowires of silver telluride have also been investigated.

T3.11

Synthesis, Characterization and Electron Field Emission Study of Tungsten Disulfide Nanotubes. Lifeng Dong[1], Jun Jiao[1] and Aitor Maiz[2]; [1]Department of Physics, Portland State University, Portland, Oregon; [2]Catlin Gabel School, Portland, Oregon.

Due to the high aspect ratio and small diameter, carbon nanotubes have been investigated as the electron sources for flat panel displays and electron microscopes. Since tungsten disulfide (WS2) nanotubes have similar morphology and internal structures to carbon 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 nanowires were formed on these substrates. Second, sulfur powder was put into the upstream of the substrates, the WS2 nanotubes were then synthesized at the flowing H2 gas at 700øC -1000øC. Using field emission high-resolution transmission electron microscope (HRTEM) and field emission scanning electron microscope (FESEM), we systematically studied the effects of growth temperature on the morphologies, 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. Acknowledgements. This research was financially supported by the National Science Foundation (DMR-0097575 and ECS-0217061) and the Donors of the American Chemical Society Petroleum Research Fund (PRF-38108-G5).

T3.12

Fabrication of the First Vertically Grown GaN Nanowire Array Using GaN/AlN Double Buffer Layer. Yun-Mo Sung, Dae-Hee Kim and Jung-Chul Lee; Materials Sci. & Eng., Daejin University, Pochun-koon, South Korea.

For the first time vertically grown GaN nanowire arrays were fabricated using vapor-liquid-solid (VLS) method. GaN(200)/AlN 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) analyses show that GaN nanowires are micrometer in length and 30-80 nm in diameter. Transmission electron microscopy (TEM) analyses reveal that GaN nanowires are single crystalline and defect free. The photoluminescence (PL) spectra on the GaN nanowire arrays show a strong emission peak at ~389 nm and a weak and broad emission peak at ~594 nm in comparison to the rondomly 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-oriented Gallium Nitride (GaN) Film Growth Studies. Mahendra K Sunkara[1], Hongwei Li[1], Sreeram Vaddiraju[1], Hari Chandrasekaran[1], Krishna Rajan[2] and Jharna Chaudhuri[3]; [1]Chemical Engineering, University of Louisville, Louisville, Kentucky; [2]Materials Science& Engineering, Rensselaer Polytechnic Institute, Troy, Kentucky; [3]Mechanical Engineering Department, Wichita State University, Wichita, Kansas.

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-oriented films. We obtained these results by direct nitridation of thin molten gallium covered on fused silica quartz (amorphous) and p-BN (polycrystalline) 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. The cross-sectional SEM showed the presence of molten gallium buffer layer below the self-oriented regions. Cross-sectional TEM characterization of the regions indicated low angle grain boundaries between the neighboring crystals with no contrast from dislocations. However, the results indicated the presence of a high density of stacking faults perpendicular to [0001] direction. XRD scans showed predominant reflections of (0002) and (0004) planes indicating good orientation. The direct nitridation of molten gallium covered Sapphire substrates resulted in larger regions of self-assembled gallium nitride layers. The X-ray tomography using the Stanford synchrotron facility showed that the GaN film was in epitaxial relationship with the underlying Sapphire substrate. The cross-sectional SEM images indicated the occasional presence of gallium layer between GaN and Sapphire. These results suggest that self-assembly of GaN crystals over molten gallium occurred along with occasional epitaxy with underlying substrate. In some regions, arrays of hetero-epitaxially grown GaN pillars on the Sapphire substrate were also observed. Preliminary results using hydrogen or ammonia addition to nitrogen in ECR-MW plasma for direct nitridation of molten gallium film resulted in single crystal GaN tubes with regular and star-shaped hexagonal morphologies. Certain experiments involving hydrogen/ammonia dilution in nitrogen plasma showed bulk nucleation and growth of GaN nanowires.

T3.14

Heteroepitaxal Growth and Structural Characterizations of Ultrafine GaN/ZnO Coaxial Nanorod Heterostructures.
SungJin An[1], Gyu-Chul Yi[1] and Miyoung Kim[2]; [1]Material Sciences and Engineering, POSTECH, Pohang, South Korea; [2]Samsung Advanced Institute of Technology, Suwon, South Korea.

High quality ZnO/GaN coaxial nanorod heterostructures and GaN nanotubes were fabricated using 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 nanorod heterostructures. Over-growth of GaN on ZnO nanorods yielded the coaxial ZnO/GaN nanorod heterostructures. For the GaN growth, trimethyl-Ga (TMGa) and NH3 were employed as reactants. Transmission electron microscopy images revealed that 5-10 nm thick GaN layers were epitaxially grown on the ZnO nanorod stems with an atomically abrupt interface. 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 coaxial nanorod heterostructures exhibited a slight increase at 34.5o to 34.7o presumably depending on the time of GaN layer coated ZnO nanorods. Moreover full width at half maximum (FWHM) values depends on the GaN layer thickness. Lattice distortion along the c-axis was due to biaxial in-plane expansive or compressive 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 nanorod heterostructures and GaN nanotubes may 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 InGaAs Layers.
Maria Ujue Gonzalez[1], Yolanda Gonzalez[1], Luisa Gonzalez[1], Miriam Herrera[2], David Gonzalez[2] and Rafael Garcia[2]; [1]Fabricacion y caracterizacion de nanoestructuras, Instituto de Microelectronica de Madrid (CNM-CSIC), Tres Cantos, Madrid, Spain; [2]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 modulation composition features in lattice-mismatched heteroepitaxial systems as InGaAs/GaAs. Atomic layer molecular beam epitaxy (ALMBE) technique has been revealed as a good technique for obtaining stoichiometric $In_{0.20}Ga_{0.80}$ As layers at temperatures as low as 200°C. Besides its practical interest, these layers show significant differences in structural aspects compared with layers grown at conventional temperatures. In this work we present results on the relaxation behaviour and morphology evolution of $In_{0.20}Ga_{0.80}$ As /GaAs layers grown by ALMBE at substrate temperatures 190°C ⟨ T_s⟨ 270°C. We have determined that crosshatch formation and plastic relaxation is completely inhibited for T_s ⟨ 200°C by means of *insitu* characterization techniques: laser light scattering and accumulated stress measurements. However, at T_s ⟨ 200°C a new type of morphology with a different size scale as compared with the well-known crosshatch pattern appears, as observed by atomic force microscopy (AFM). This morphology, aligned along [110] direction and with a periodicity of 50 nm, starts developing for thickness 120 nm ⟨ h ⟨ 200 nm. Furthermore, cross section transmission electron microscopy (XTEM) characterization of these layers shows that composition modulation appears in bulk in layers with thickness h ⟩ 170 nm. This coincidence of the critical thickness for the onset of development of both morphology and composition modulation points out that both processes are intrinsically related. In order to get plastic relaxation in these low T_s $In_{0.20}Ga_{0.80}$ As/GaAs samples, a post growth thermal treatment at 500°C was carried out. *Insitu* stress measurements and X-ray diffraction results show that layers with composition modulation features present an asymmetric relaxation behaviour and that the relaxation degree achieved is lower than the obtained in layers grown at conventional temperatures. Moreover, the degree of relaxation obtained with the thermal annealing depends critically on the growth temperature of the layer, as have been measured for samples grown at temperatures of 200°C⟨T_s ⟨270°C.

T3.16

Observation of an optical near-field energy transfer between closely spaced ZnO/ZnMgO multiple-quantum-well nanorods for nanophotonic devices.
Takashi Yatsui[1], Jungshik Lim[2], Tadashi Kawazoe[1], Kiyoshi Kobayashi[1], Motoichi Ohtsu[2,1], Wonil Park[3] and Gyu-Chul Yi[3]; [1]ERATO, JST, Machida, Japan; [2]Tokyo Institute of Technology, Yokohama; [3]Postech, Kyungbuk, South Korea.

For future optical transmission systems, we have proposed nanometer-scale photonic devices. These devices consist of nanometer-scale dots, and an optical near-field is used as the signal carrier. ZnO nanocrystallites is a promising material for realizing these devices at room-temperature, due to its large exciton binding energy. To confirm the promising optical properties of ZnO nanocrystallites, we measured the photoluminescence (PL) spectra using an optical near-field microscope. In this measurement, we found anti-correlation features in PL spectra between closely spaced ZnO/ZnMgO multiple-quantum-well (MQW) nanorods, which we attributed to optical near-field energy transfer from one nanorod to the other. We used the MQW nanorods which consist of ten periods of 3-nm ZnO/6-nm ZnMgO as samples. These were grown on the ends of ZnO nanorods with a 40-nm mean diameter. In the near-field PL spectra at 15 K, several sharp peaks were observed. The number of the sharp peaks and their energy values (E1: 3.420 eV, E2: 3.426 eV, E3: 3.436 eV) in each spectrum showed strong position dependence. To investigate their origins, we measured spatial distribution of PL intensity for individual ZnO/ZnMgO MQW nanorods with a spatial resolution of 50 nm. The outstanding feature was the anti-correlation in the PL intensity of E1 (I1) and I2; I1 was suppressed while I2 was enhanced in one nanorod, and I1 was enhanced while I2 were suppressed in a closely adjacent nanorod. Furthermore, since the degree of the anti-correlation was larger for more closely spaced pair of nanorods, such an anti-correlation feature is due to energy transfer phenomena induced by optical near field between two resonant energy levels in a ZnO/ZnMgO MQW and its adjacent ZnO/ZnMgO MQW. This phenomenon can be used to realize nanophotonic devices, such as the switching mechanism confirmed by the authors in CuCl quantum cubes.

T3.17

Controlled Growth of Zinc Oxide Nanostructures.
Jae-Hwan Park, Heon-Jin Choi, Jig-Sang Gam and Jae-Gwan Park; Div. of Materials, Korea Institute of Science and Technology, Seoul, Seoul, South Korea.

Nanostructures including zero-dimensional (0D) (quantum dots), one-dimensional (1D) (nanowires), and two-dimensional (2D) (nanobelts or sheets) have received special interests due to their potentials as building blocks for fabricating electronic, optoelectronic, electromechanic, and sensor devices on a nano-meter scale. To exploit this potential, it would be desirable to prepare nanostructures in a controlled manner microscopically and/or macroscopically. In this study, we examined the controlled growth of various 1D and 2D nanostructures of ZnO including nanowires, comblike structures, rods, and sheets by the carbothermal reduction process. We found that the evolution of various ZnO nanostructures can be controlled by controlling the processing temperature and atmosphere. Especially, by controlling processing conditions, ultrawide single crystalline nanosheets were fabricated, which have thickness of c.a. 50 nm and width of up to 50um. The width-to-thickness ratio of the sheet reaches up to a thousand. We will demonstrate the microscopical evidence that the 2D nanostructures are seeded by the nanowires and dendritic structures. The processing parameters dominating the dimensionality of nanostructures will be discussed together with the growth mechanism. Our methods of controlled growth of ZnO nanostructures could be useful for fabricating nanodevices in optoelectronics and sensors.

T3.18

Novel Zinc Oxide Nanostructures. Jingyu Lao[1], Zhifeng Ren[1], Debasish banerjee[1], Jianyu Huang[1], Sung-Ho Jo[1], J.G. Wen[1], Dezhi Wang[1], B Kimball[2], Diane Steeve[2] and Mike Sennet[2]; [1]physics, Boston College, Chestnut Hill, Massachusetts; [2]The US Army Natick Soldier Systems Center, Natick, Massachusetts.

A variety of ZnO nanostructures including hierarachical nanostructures with 6-, 4-, and 2-fold symmetry, nanobridges, nanonails, nanowalls, both aligned and random nanowires, and large quantity production have been created by vapor transport and condensation technique. The detailed analysis of these novel nanostructures will be presented. On the other hand, interesting physical properties, such as photoluminescence and field emissions of these zinc oxide nanostructures are also discussed.

T3.19

Misfit stress analysis by a TEM curvature method : application to the GaInAs/(001)InP epitaxial system. Andre M Rocher[1], Martiane Cabie[1], Anne Ponchet[1], Lise Durand[1] and Nicolas Bertru[2]; [1]CEMES, CNRS, Toulouse, France; [2]INSA, Rennes, France.

The stress induced by a lattice mismatch between an epilayer and its substrate is responsible for bending the sample. This stress and the curvature are related together through Stoney's formula which also involves the thicknesses of both the epitaxial layer and the substrate. This stress is classically determined by measuring the curvature of thick samples. In this work, this method has been transposed to TEM analysis, as described by Rocher et al (1). The investigated samples are GaInAs 30 nm layers grown by MBE on (100) InP substrate. The In concentration has been chosen equal to 43 and 71% in order to obtain respectively tensile and compressive biaxial stresses in the epilayer. Samples have been prepared for TEM plane view observation. When the substrate is thinned from 300μm to 0.3μm the curvature radius induced by the misfit stress decreases from about 100m to less than 100μm. Positive and negative curvatures have been observed in good agreement with the tensile or compressive character of epitaxial stress. The variation of the curvature radius with the substrate thickness agrees well with the Stoney formula. However, its experimental value is always larger than predicted. As a consequence, the measured misfit stress is about 20% lower than the theoretical one calculated for an ideal pseudomorphic layer. The possible origins of this difference are discussed in terms of chemical heterogeneity of the epitxial layer and the geometry of the specimen. Numerical calculation based on Finite Element Method has been performed to justify the use of the Stoney formula for the thin samples studied by TEM. (1) Rocher A, Cabie M, Ponchet A, Carrere H, Proceedings of the Microscopy of Semiconducting Materials Conference, Cambridge, UK, April 2003.

T3.20

Abstract Withdrawn

T3.21

Current-Induced Pattern Formation on Vicinal Surfaces. Tong Zhao and John D Weeks; Institute for Physical Sciences and Technology, University of Maryland, College Park, Maryland.

Vicinal surfaces can exhibit a number of different morphological instabilities that are important in crystal growth and nano-scale device fabrication. Particularly interesting step bunching and step wandering patterns arise from electromigration on semiconductor surfaces; these patterns are observed depend on both the current direction and the temperature. We develop a novel two-region diffusion model that captures the interplay between surface reconstruction and driven diffusion of adatoms induced by the electric field. The results from analyzing the linear stability of this theoretical model can be directly applied to understand various bunching and wandering regimes on Si(111) and Si(001) under direct current heating. The transition between different regimes with the temperature and the current direction is also obtained. Moreover, to account for the long time behavior of such surfaces, we combine our model with a geometric representation of the interface to derive a nonlinear evolution equation for a step in the presence of anisotropic diffusion arising from the electric field. The nonlinear evolution of the step yields intriguing pattern formation, where a sinusoidal wave first appears as the linear instability, then the peak of the wave gradually turns to align with the electric field. We find good agreement of the above theories with existing experiments. We believe this model can be applied more generally to many other far-from-equilibrium problems on vicinal surfaces.

T3.22

Dynamics of the Morphological Evolution of Sputter Ripples. Ashwin Ramasubramaniam and Vivek Shenoy; Division of Engineering, Brown University, Providence, Rhode Island.

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 does not allow for simplistic predictions of exponential or 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.

T3.23

Quantum dots of Si in Ag and Ag in Si. Hye-Won Seo, Irene A Rusakova, Xuemei Wang, Quark Y Chen and Wei-Kan 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 start with the silver-silicon pair, which is a simple eutectic system 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 silver-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.

T3.24

Pit Nucleation In The Presence Of 3D Islands During Heteroepitaxy. Michael L. Falk, Mathieu Bouville and Joanna Mirecki Millunchick; Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan.

Pits nucleate subsequent to the nucleation of 3D islands during the heteroepitaxial growth of InGaAs on GaAs under some growth conditions. This process leads to surface patterning extending out to about 150 nm. In light of these observations we propose 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 can have 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 regimes 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 a 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.

T3.25
Optical Properties of Quantum-Wires Grown Using Lateral Composition Modulation Induced By $(InP)_1/(GaP)_1$ Short-Period Superlattices. Jin Dong Song[1], Jong Min Kim[2] and Yong Tak Lee[2]; [1]Nano-device Res. Ctr., KIST, Seoul, 136-791, South Korea; [2]Dept. of Info. & Comm., K-JIST, Gwangju, 506-303, South Korea.

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 two binary composite materials of SPSs have different lattice constants, and the period of the SPSs is less than 1 - 2 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 strained-related self-organization phenomena. However, few works have been done on the optical properties of QWIREs grown using LCM. In this presentation, the optical properties QWIRE grown using LCM are studied by photoluminescence (PL) measurement as a function cryostat temperature. 3 stacked arrays of QWIREs were formed by sequential growth of ~180 Å-thick LCM layers (lateral period : ~90 Å) induced by $(InP)_1/(GaP)_1$ SPSs, and 200 Å-thick InGaP spacers at the growth temperature of 490 °C. The formation of QWIRE is confirmed by a TEM measurement. By the analysis of the dependence of PL intensity and peak energy of the QWIRE on measurement temperature (T), the origin of higher energy peak (H) and lower energy peak (L) are investigated. While the H peak behaves like that of an ordered InGaP, the L peak shows the insensitivity of PL peak energy to T. This is attributed to compensation of bandgap by competition of strain in QWIRE region (S. -T. Chou, J. Appl. Phys. 87, 285 (2000)) and indicates the L peak is related to QWIRE. Strong dependence of the L peak on the position of polarizer also supports it. Additionally, the PL peak intensity of the L peak has the maximum value not at the lowest T (10 K) but at 50 K, while the H peak decrease 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 Qunatum Dots Grown By Atomic Layer Molecular Beam Epitaxy. Jin Dong Song[1], Y M Park[1], J C Shin[1], J G Lim[1], Y J Park[1], W J Choi[1], I K Han[1], W J Cho[1], J I Lee[1], H S Kim[2] and C G Park[2]; [1]Nano-device Res. Ctr., KIST, Seoul, 136-791, South Korea; [2]Ctr. for Adv. Aerospace Mat., POESTECH, Pohang, 790-784, South Korea.

Three-dimensionally confined electron, hole, and exciton induced by semiconductor quantum dots (QD) have attracted much attention due to introduction of new physical phenomena and, as a result, improvement of performance in optoelectronic devices such as low threshold current density, large characteristic temperature, and so on. Therefore, many researchers have focused on this topic and developed QD laser diodes (LD) that can be operated at room temperature. For more practical application to QD LDs, however, more uniform formation of QDs and weaker wetting layer effects are required, because effective gain volume of QDs for a specific spectrum will be increased by uniform QDs and the wetting layer is suspected to be a source of non-zero-dimensional phenomena in QDs. Although QDs formed by atomic layer molecular beam epitaxy (ALMBE) are expected to solve these problems, fewer articles are reported on this topic compared to those on Stranski-Krastanov (S-K) 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 a semi-insulating (001) GaAs wafers at 480 °C with 3 periods of each 1 ML-thick sequence. Total coverage of InAs is 3 monolayers (MLs), and As $_4$/III ratio is $< \sim 10$. Five growth sequences studied were In/GI/As/GI, In/GI/As, In/As/GI, In/As, and InAs/GI/As/GI and designated as #1 - #5, respectively. Where, In, GI, As and InAs represent 1 ML-coverage deposition of In, 5 s of growth interruption, 2 s-long deposition of As_4, 1 ML-thick growth of InAs, respectively. It is found that GI after In is more effective than non-GI after In in reducing density of coalescence dots, and reducing dot width distribution of the QDs. Meanwhile, dot densities are approximately doubled by non-GI after In. GI after As reduces dot height distribution compared with non-GI after As. Generally, GI after In plays a more critical role than GI after As does in formation of the QDs. 300 K-photoluminescence (PL) peak energies of the samples increase as sample number increases (#1 - #5), and #1 shows the lowest PL linewidth (~ 30 meV), high PL peak separation between ground and 1st excited level (~ 80 meV). From the result, it is known that In/GI/As/GI (#1) is favorable growth sequence among the sample sets. Dependence of PL peak linewidth of #1 on cryostat temperature (Tcr) are insensitive to the Tcr (28 ~ 30 meV for Tcr = 18 ~ 300 K) and in contradiction to that of #5 which shows strong fluctuation as Tcr changes (55 ~ 75 meV for Tcr = 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. Bortoleto, H R Gutierrez, M A Cotta and M M G de Carvalho; LPD/DFA, IFGW/UNICAMP, Campinas, So 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 a better 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. On the other hand, we have obtained bidimensional arrays of InP quantum dots grown on slightly In-rich (0.6% mismatched) InGaP/(001)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 a atomic force microscopy (AFM). Fast 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 InP template was investigated by cross-section 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. Seong Oh Cho, Zhiming Wang and Gregory J. Salamo; Physics department, University of Arkansas, Fayetteville, Arkansas.

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 about 0.3 grown at the high substrate temperature of 540 degree C. In the work reported here, the shape and lateral ordering evolution of (In,Ga)As/GaAs nanostructures grown at 540 degree C has been systematically 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) (In,Ga)As 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 2 with further deposition. The decrease in the anisotropic ratio indicates that the higher accumulated 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 for the use of a shape transition to control lateral ordering will be discussed.

T3.29
Site-Control Technology for InAs Quantum Dot Formation by Direct Deposition of Indium Nano-Dots With a Nano-Jet Probe. Shunsuke Ohkouchi, Yusui Nakamura, Hitoshi Nakamura and Kiyoshi Asakawa; The Femtosecond Technology Research Association (FESTA), Tsukuba, Ibaraki, Japan.

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-microscope (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 tank within the stylus. This probe is used for nano-dot fabrication 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 ultra-high vacuum (UHV) condition, In clusters are extracted from the reservoir tank 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 sample A, B and C are grown on (100) GaAs substrate at 510°C. The AFM images show different dot density $3.8\text{x}10^{10}$, $5.8\text{x}10^{10}$ and $1.7\text{x}10^{10}$ cm^{-3} for the three samples. Lower dot density of 3.0 ML InAs QDs is attributed to the coalescence of different dots 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. With increasing temperature, the electrons in the InAs QDs would be thermalized such that repopulation of electrons to nearby dots would occur via the wetting layer. Hence, the optical recombination process would tend to occur at the globally lowest conduction band edge and the separation of electrons and holes at 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, due to the longer distance between each dot, the repopulation process 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 observed is the quick band filling phenomena with increasing pumping laser power for sample C, which is attributed to the less energy states available resulted from its lower dot density.

T3.31
InNAs and GaInNAs self-assembled quantum dots and lasers grown by solid source molecular beam epitaxy. Zhongzhe Sun, Soon Fatt Yoon, Kuok Chuin Yew and Baoxue Bo; School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore, Singapore.

Self-assembled $Ga_{1-x}In_xN_yAs_{1-y}$ quantum dots were grown on GaAs by solid source molecular beam epitaxy (SSMBE). Introduction of N was achieved by a RF Nitrogen plasma source. Formation of quantum dots by S-K growth mode is confirmed by observation of standard 2D-3D RHEED pattern transition. Atomic force microscopy (AFM) and photoluminescence measurements were used to characterize the structure and optical properties of GaInNAs quantum dots. High GaInNAs quantum dot density ($10^{10}\sim10^{11}cm^{-2}$) was obtained for different In and N composition ($0.3\leq x \leq 1$, $y \leq 0.01$). The effect of surface coverage on dot density, dot size, and optical property 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 180nm. 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 $Ga_{0.5}In_{0.5}N_{0.01}As_{0.99}$ quantum dot laser emitting at $\sim1.1\mu m$.

T3.32
One-Dimensional Arrayed GaAs Quantum Dots Grown On Patterned GaAs Substrate Using Droplet Epitaxy. Kyoung-Kook Kim, Takahro Tateno, Tadashi Mitsui, Takashi Sekiguchi and Nobuyuki Koguchi; Nanomaterials Laboratory, National Institute for Materials Science, Tsukuba, Ibaraki, Japan.

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 quantum cellular automata (QCA) due to their appealing electronic and optical properties. Furthermore, to realize the QCA, it is require to control position, size, and distance of the QDs. In the case of growing QDs on a planar substrate, however, the QDs are randomly grown on flat surface with size fluctuations. In this study, we investigate the growth of one-dimensional arrayed GaAs QDs on pattered substrate using Droplet Epitaxy. GaAs (001) substrates patterned using conventional photolithography were wet chemical etched in the solution. The direction and periodicity of mask stripes are [100] and 1.0um, respectively. The GaAs QDs growth was carried out with a Riber-32P molecular beam epitaxy (MBE) system. The QDs properties were observed with a high-resolution scanning electron microscopy (HRSEM), photoluminescence, and cathodeluminescence/near-filed 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 thickness of buffer layer. In addition, HRSEM images show clearly the one-dimensional array of GaAs QDs grown on a (001) facet on the top of mesa. In this study, it is 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 Kawamura[1,2], Bert Voigtlaender[2], Neelima Paul[2] and Vasily Cherepanov[2]; [1]Materials Science, Kitami Institute of Technology, Kitami, Japan; [2]ISG3, Forschungszentrum Juelich, Juelich, Germany; [3]ISG3, Forschungszentrum Juelich, Juelich, Germany; [4]ISG3, Forschungszentrum Juelich, 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 microscope (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 use 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 $\sim$0.09 nm higher at areas consisting of Ge than on 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 nanoring structures consisting of alternating Si and Ge rings having a width of $\sim$5 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 3.5 nm and a thickness of 0.3 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 nanostructures will be discussed.

T3.34
Preparation of Ge (100) Substrates for High Quality Epitaxial Growth of Group IV Materials and Quantum Dots. Mark Edward Nowakowski[1,2], Jordana Bandaru[2], Lloyd Douglas Bell[2] and Shouleh Nikzad[2]; [1]Materials Science, University of Illinois, Urbana, Illinois; [2]Jet 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 are explored such as UV-ozone treatment followed by exposure to chemical solutions such as HF, or HCl. Chemical treatments to remove the oxide are performed in a nitrogen environment to prevent further formation of surface oxide prior to surface analysis. Following chemical treatments, in situ Reflection high-energy electron diffraction (RHEED) 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 desorption following each chemical treatment. Atomic Force Microscopy (AFM) is also used for visual comparison of effectiveness and aggressiveness of each chemical treatment. Results of this comparative study, effectiveness of each chemical treatment and the stability 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/SiO$_2$ (LTO) Multilayers with Tailorable Luminescence Emission Spectra. Andres Rodriguez[1], Jesus Sangrador[1], Tomas Rodriguez[1], Manuel Avella[2], Pilar Martin[2], Juan Jimenez[2], Isabel Ortiz[3] and Carmen Ballesteros[3]; [1]Tecnologia Electronica, E.T.S.I. Telecomunicacion, U.P.M., Madrid, Spain; [2]Fisica de la Materia Condensada, E.T.S.I.I., Universidad de Valladolid, Valladolid, Spain; [3]Fisica, E.P.S., Universidad Carlos III, Leganes, Madrid, Spain.

Amorphous or polycrystalline SiGe/SiO$_2$ 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 temperature than pure Si, thus allowing the deposition process to be compatible with that of a Low Temperature Oxide (LTO). In this work, an alternative to the Si/SiO_2 multilayer structures fabricated using magnetron sputtering is proposed. $SiGe/SiO_2$ 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 (Si_2H_6) and germane (GeH_4) were used as precursor gases for SiGe deposition. The pressure was 300 mTorr and no carrier gas was used. The Si_2H_6 to GeH_4 flow ratio was varied to obtain SiGe films with different Ge fractions. The SiO_2 layers were deposited using Si_2H_6 and O_2 at 185 mTorr, using N_2 as carrier gas. The Si_2H_6 to O_2 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 luminescence emission (both tuning 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 thickness 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 diffractometry and cross-section TEM. The layer thickness were derived from the TEM observations. The diffractograms as well as the TEM analysis show that the as-deposited SiGe films are amorphous. FTIR spectroscopy was used to analyze the characteristics of the LTO. Crystalline SiGe/LTO structures were obtained by annealing the samples for solid phase crystallization 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 evolution of the luminescence bands 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.

T3.36

Self Organized Compound Semiconductor Nanocrystallite Distributions in SiO2 on Silicon Synthesized by Ion Beam Implantation. Helmut Karl, Ingo Grosshans and Bernd Stritzker; Institut fuer Physik, Universitaet Augsburg, Augsburg, Germany.

The temporal and spatial evolution of the Cd and Se concentration distribution during the formation of buried CdSe nanocrystals in thermally grown 500 and 300 nm thick SiO2 on Si(100) was investigated. Depending on the Cd-Se dose ratio of the overlapping concentration distributions different diffusion and reaction behavior was observed after an ex-situ rapid thermal annealing process in Ar at atmospheric pressure at 973, 1073 and 1273 K. The annealing times were increased in steps from 30 seconds up to 32 minutes. The evolution of the concentration distributions was quantitatively analyzed by Rutherford Backscattering Spectrometry (RBS) and dynamic Secondary Ion Mass Spectrometry (SIMS). It was found, that CdSe formation, also confirmed by X-ray diffraction and cross-sectional TEM images, takes place immediately during the first 30 sec of the annealing procedure. For longer annealing times Cd and Se material diffuses congruently to greater depths with CdSe precipitation, completely different to the diffusion behavior of the single elements in the same matrix and thermal treatment. Once CdSe material has reached the SiO2-Si interface accumulation of CdSe in form of nanocrystallites takes place. In the case of a surplus of Cd over Se and long annealing times self-organized, nearly periodic concentration variations of Cd and Se over the SiO2 thickness can be observed. TEM cross-sectional images show that these concentration pattern are correlated to layers of CdSe nanocrystallites. Photoluminescence measurements of partially sputtered areas of the thin SiO2 film containing nanoparticles allow to study their depth resolved optical properties. Technical applications in the field of optoelectronics on Silicon on the basis of the herein described findings will be discussed.

T3.37

Experimental Separation of Rashba and Dresselhaus Spin-Spittings in Semiconductor Quantum Wells.
Sergey D. Ganichev[1,2], Vasily V. Bel'kov[2], Leonid E. Golub[2], Eugenius L. Ivchenko[2], Petra Schneider[1], Stephan Giglberger[1], Jonathan Eroms[1], Jo De Boeck[3], Gustaaf Borghs[3], Werner Wegscheider[1], Dieter Weiss[1] and Wilhelm Prettl[1]; [1]Physics, University of Regensburg, Regensburg, Germany; [2]A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russian Federation; [3]IMEC, Leuven, Belgium.

The relative strengths of Rashba and Dresselhaus terms describing the spin-orbit coupling in semiconductor quantum well (QW) structures are extracted from photocurrent measurements on *n*-type InAs QWs containing a two-dimensional electron gas (2DEG). This novel technique makes use of the angular distribution of the spin-galvanic effect [1] or circular photogalvanic effect [2] at certain directions of spin orientation in the plane of a QW. The ratio of the relevant Rashba and Dresselhaus coefficients can be deduced directly from experiment and does not relay on theoretically obtained quantities. Thus our experiments open a new way to determine the different contributions to spin-orbit coupling. The method can also be used for other material systems like GaAs quantum wells. [1] S.D. Ganichev, E.L. Ivchenko, V.V. Bel'kov, S.A. Tarasenko, M. Sollinger, D. Weiss, W. Wegscheider, and W. Prettl, *Nature* (London) **417**, 153 (2002). [2] S.D. Ganichev, E.L. Ivchenko, S.N. Danilov, J. Eroms, W. Wegscheider, D. Weiss, and W. Prettl, Phys. Rev. Lett. **86**, 4358 (2001).

T3.38

Enhanced 2DEG-1D Carrier Coupling Efficiency in a V-groove Quantum Wire Field Effect Transistor.
Cheol-Koo Hahn[1,2], Hoon Kim[1] and Mutsuo Ogura[2]; [1]Nano scale quantum devices research center, Korea Electronics Tech. Inst., Pyung-Taek, South Korea; [2]Photonics Research Institute, National Institute of Advanced Industrial Science and Technology, Tsukuba.

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 2DEG-1D interface screens the observation of pure transport properties. Although a high-quality QWR, whose optical coherent length is as long as 2.5 microns, is easily available with our FME method, growth pinch off region between sidewall quantum well (SQW: 2DEG reservoir) and QWR extremely lowers the carrier 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 deiveces at cryogenic temperature. Although their step heights were extremely small comparing to the unity of the universal one, drain bias dependent conductance and magneto-resistance measurements at 50 mK revealed that the observed steps are universal conductance fluctuation (G0 =2e2/h, 77.5 micro-S). The main reason of small step height is low SQW-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 region like quantum point contact (QPC) structure were realized. Around 10 times of enhanced coupling efficiency comparing the conventional V-groove sturucture is observed. Optical/carrier transport properties of the new structures will be presented in detail.

T3.39

Self-assembled microcavities incorporated into the Si(100) surface. Nikolai Bagraev[1], Alexei Bouravleuv[1], Wolfgang Gehlhoff[2], Leonid Klyachkin[1] and Anna Malyarenko[1]; [1]Division of Plasma Physics, Atomic Physics and Astrophysics, A.F.Ioffe Physico-Technical Institute RAS, St.Petersburg, Russian Federation; [2]Institut fuer Festkoerperphysik, 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-organized microcavities is found to be enhanced in the range of the Rabi splitting. Dopant 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 CCl4 vapors. Short-time impurity doping was done under fine surface injection of both self-interstitials and vacancies into windows which were cut in the oxide after preparing a mask and performing the subsequent photolithography. 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 SIMS and four-point probe technique under layer-by-layer etching, the analysis of the structures obtained shows that the ultra-shallow boron

profiles consist of self-assembled silicon quantum wells (SQW) divided by heavily doped del'ta barriers. The SQW characteristics have been identified by the cyclotron resonance angular dependencies and CV diagrams brought about the deflection of the bias voltage from the normal to the p+n junction plane. Space-independent excess fluxes of intrinsic defects that cause the formation of SQW appear to be transformed also into macrodefects which can be revealed using the STM technique as the deformed potential fluctuations (DPF) near the Si-SiO2 interface and the surface of the ultra-shallow diffusion profile. The DPF effect induced by microdefects of the self-interstitials type is demonstrated to be brought about by the previous oxidation and to be enhanced by subsequent boron diffusion. The interplay between the dimensions of these microdefects and their distribution inside the ultra-shallow diffusion profile is found to be evidence of 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 rings. Nikolai Bagraev[1], Alexei Bouravleuv[1], Wolfgang Gehlhoff[2], Leonid Klyachkin[1], Anna Malyarenko[1] and Ivan Shelykh[3]; [1]Division of Plasma Physics, Atomic Physics and Astrophysics, A.F.Ioffe Physico-Technical Institute RAS, St.Petersburg, Russian Federation; [2]Institut fuer Festkoerperphysik, Technische Universitaet Berlin, Berlin; [3]Experimental Physics, St.Petersburg Polytechnical University, St.Petersburg, Russian Federation.

We present the findings of the transmission phase shift (TPS) in the 0.7(2e2/h) 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 self-assembled silicon quantum well of the p-type. The phase shift in the 0.7(2e2/h) structure caused by heavy holes is found to be changed by electrically-detected NMR of the 29Si nuclei thereby verifying the spin polarisation in the quantum wire. The relative contribution of the spin-orbit splitting and spontaneous hole polarisation to the mechanism of the spin polarisation in quantum wires is also identified by varying the density of 2D hole gas.

T3.41
White light emission from nanostructures embedded in ultra-shallow silicon p-n junctions. Nikolai Bagraev[1], Alexei Bouravleuv[1], Wolfgang Gehlhoff[2], Leonid Klyachkin[1] and Anna Malyarenko[1]; [1]Division of Plasma Physics, Atomic Physics and Astrophysics, A.F.Ioffe Physico-Technical Institute RAS, St.Petersburg, Russian Federation; [2]Institut 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 ultra-shallow p+ diffusion profile of boron on the n-type Si(100) surface. The electron-hole injection is carried out through the single quantum wire that acrosses 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 ultra-shallow p-n junctions. The THz modulation of the electroluminescence spectra that seems to result from spontaneous exciton-polariton emission has been observed.

T3.42
Room Temperature Resonant Tunneling and Coulomb Blockade in Nanocrystalline Si With Double SiO2 Barriers. Liangcai 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-dimensionally confined nc-Si. In this paper, we used low temperature plasma oxidation technique to make an ultra-thin (about 2 nm) SiO2 tunneling layer on p-type Si (100) substrate in a plasma enhanced chemical vapor deposition (PECVD) system. The nc-Si layer with different average size of about 7 nm and 3 nm was prepared 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 processes 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 this 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 charging 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 kBT and size fluctuation effects on the quantum confinement in our SiO2/nc-Si/SiO2/c-Si structure. Quantitatively, the experimental results of capacitance spectroscopy are consistent with the theoretical calculations. These are the physical basis and basic unit of nc-Si floating gate FET, which could be applied for future nanoelectronic devices such as nanomemory and single electron transistor.

T3.43
Imaging Si Quantum Dots as Charge Storage Nodes.
Rosaria A. Puglisi[1], Salvatore Lombardo[1], Giuseppe Nicotra[1], Isodiana Crupi[1], Domenico Corso[1], Giuseppe Ammendola[2], Valentina Ancarani[2] and Cosimo Gerardi[2]; [1]Catania, CNR-IMM, Catania, Italy; [2]STMicroelectronics, 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 dots. 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 silane over an 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 then 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 whithin 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
Chairs: Richard Noetzel and Catherine Priester
Tuesday Morning, December 2, 2003
Room 209 (Hynes)

8:30 AM *T4.1
On lateral organization of quantum dots on a prepatterned substrate. Catherine Priester, 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 atomistic description. Two types of "manufactured prepatterning" are considered : - A perfectly periodical 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 CENG-Leti). Network periodicity is controlled by the disorientation angle between the substrate and the surface bonded layer. For a thin enough surface bonded layer (a few tens of nm) the strain field variations appear to be strong enough to laterally 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. - Nanomesa : 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 still gets 3D 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, 2x1 reconstructed.

9:00 AM T4.2
The Effects of Embedded Strained Structures on the Island Formation of the Stranski-Krastanow Systems.

Cheng-hsin Chiu and Hangyao Wang; Materials Science, National University of Singapore, Singapore, Singapore.

The quantum-dot super lattice is a promising method for fabricating a three-dimensional array of nano-structures in the Stranski-Krastanow systems with a uniform dot size and regular dot positions. This topic has been widely studied from both the experimental and the theoretical points of view, and it is now well known that the embedded strained structures in the system can significantly affect the positions of the islands as the islands grow on the top film surface. Most of the theoretical studies, however, were based on the assumption that the embedded structure was a two-dimensional flat disk. Contrary to the earlier works, we studied the case where the embedded structure was an array of three-dimensional facet islands. We evaluated the energy of the system, consisting of the surface energy and the strain energy. In particular, the strain energy was determined by employing a first-order boundary perturbation method to solve the elasticity problem of the quantum-dot super lattice system. According to the energy analysis, we examined the effects of the geometry of the embedded structures on the formation of islands on the film surface. Of particular interest are the critical film thickness for the Stranski-Krastanow transition, the critical size for island formation, and the stability of the islands against coarsening. The implications of the results on controlling the growth of uniform and regular quantum-dot super lattice are discussed.

9:15 AM *T4.3
Interlayer correlations and shape transitions in self-assembled PbSe quantum dot superlattices. Gunther Springholz, R. T. Lechner, A. Raab, T. Schuelli, L. Abtin, V. Holy and G. Bauer; Institut fuer Halbleiterphysik, Johannes Kepler Universiy, Linz, Austria.

Self-assembled quantum dot superlattices are of great interest due to the formation of interlayer dot correlations caused by the elastic interactions between the dots during growth. This can result in an efficient lateral dot ordering and allows an additional tuning of the dot sizes and shapes as well as of the lateral dot separations. In the present work, these phenomena as well as the dot shape transitions occurring during overgrowth are studied for the case of narrow band gap self-organized PbSe/PbEuTe quantum dot superlattices, which are of interest for mid-infrared opto-electronic device applications. It is shown that due to the existing high elastic anisotropy different types of ordered structures can be obtained as a function of the PbEuTe spacer thicknesses as well as the PbSe dot sizes. The underlying mechanisms of the ordering processes are clarified by strain calculations using finite element methods as well as by growth simulations. As a result, a complete phase diagram of the ordered phases is developed that explains the experimental observations for a wide range of growth conditions and layer thicknesses. It is also shown that during dot overgrowth marked shape transitions occur due to intermixing effects with the matrix material. These shape transitions strongly depend on the chemical composition of the spacer material and can be completely suppressed by the use of PbEuTe ternaries as diffusion barrier, which is important for practical device applications.

9:45 AM T4.4
Three-dimensional Ordering of Self-assembled Ge Islands. Zhenyang Zhong, Gang Chen, Julian Stangl, Thomas Fromherz, Friedrich Schaffler and Guenther Bauer; Semiconductor Physics, University of Linz, Linz, Austria.

For any conceivable application of self-assembled Ge islands a control of their lateral positions is essential. We report on the mask-free growth of Ge islands on prepatterned Si substrates with areas of (500 x 500 μm, and periods ranging from 200 nm to 400 nm, fabricated by e-beam lithograhy and reactive ion etching. To eliminate damage induced by plasma etching first a Si buffer layer is deposited followed by Ge, using solid source MBE and substrate temperatures of up to 700 C. Dome-shaped islands nucleate in the periodic pits, AFM data reveal their unparalleled size and shape homogeneity over the entire pre-patterned area. In the photoluminescence data of Si capped island layers the no-phonon and TO phonon replicas are well separated. The perfect lateral long-range ordering is subsequently used to stack layers of Ge islands, separated by Si spacer layers. The strain fields of the buried islands induce a vertical stacking. By an appropriate reduction of the Ge coverage in the 2nd and the following island layers, a homogeneous size and shape of the islands was preserved throughout the whole layer sequence. By this combination of prepatterning and self-organized growth a real 3D island "crystal" in the Si matrix is created. This is demonstrated by cross-sectional TEM and x-ray diffraction. From reciprocal space maps, taken with high resolution at the ESRF synchrotron radiation source, we determined the long range island correlations, the Ge profile within the islands and their strain status.

10:30 AM T4.5
Highly uniform (In,Ga)As quantum dot arrays formed by self-organized anisotropic strain engineering. Takaaki Mano, Richard Noetzel and Joachim H Wolter; eiTT/COBRA Inter-University Research Institute, Eindhoven University of Technology, Eindhoven, Netherlands.

We have created highly uniform one-dimensional single (In,Ga)As quantum dot (QD) arrays on planar GaAs (100) substrates by self-organized anisotropic strain engineering of an (In,Ga)As/GaAs quantum wire (QWR) superlattice (SL) template in molecular beam epitaxy (MBE). The distinct stages of QWR SL template formation, i.e., elongated island formation at elevated temperature, thin GaAs capping, annealing, and stacking, which govern the uniformity of the QD arrays, are directly imaged by atomic force microscopy (AFM). The AFM observations of the template formation process clearly reveal the transformation of the elongated QD arrays into very smooth QWRs during annealing due to anisotropic adatom surface migration and In desorption which is supported from X-ray diffraction measurements. From the AFM images it is, moreover, evident that excess strain accumulation causes the residual fluctuations of the QWRs, i.e., width variations, bends and branches, which are associated with the presence of multiple QD arrays in addition to single ones. By reducing the strain accumulation for decreasing amount of (In,Ga)As deposition and increasing GaAs separation layer thickness in each SL period, a dramatic improvement of the uniformity is achieved which is directly reflected in narrow asymmetric X-ray diffraction peaks and photoluminescence (PL) linewidth of the QWR SL template. The one-dimensional single (In,Ga)As QD arrays formed on top of the template due to local strain recognition are now perfectly straight over more than 1 micrometer and extended to over 10 micrometer length. These uniform QD arrays embedded in a GaAs matrix show efficient PL emission up to room temperature without significant increase of the linewidth (68 meV at 4.2 K, 72 meV at RT) as is expected for QDs with strong carrier confinement.

10:45 AM T4.6
Heteroepitaxy on ultrathin SOI substrates.
Winfried Josef Ernst, Ian Carl Schick, Peter Sutter and Eli Sutter; Department of Physics, Colorado School of Mines, Golden, Colorado.

In conventional lattice-mismatched heteroepitaxy, the thickness of the growing layer is much smaller than that of the substrate. Lattice mismatch strain is then largely concentrated in the film, and the substrate plays a minor role in strain accommodation and relaxation. However, substrate thickness should be regarded as a variable in heteroepitaxy. An ultrathin subtrate, for instance, can accept a substantial fraction of the total lattice mismatch strain, and should participate actively in strain relaxation. Such a configuration may provide new opportunities for nanostructure formation and for modifying electronic materials at the nanoscale. As substrates in the form of ultrathin membranes are not sufficiently robust for applications, we have explored heteroepitaxial growth of Ge and SiGe alloys on silicon-on-insulator (SOI) composite substrates, in which an ultrathin ($<$ 10 nm) crystalline Si template is bonded to a thick Si wafer via a layer of amorphous SiO2. At typical growth temperatures, the Si/SiO2 interface is essentially rigid and prevents the transfer of biaxial strain from a planar adlayer into the thin Si template. Local strain due to a nanoscale stressor, however, is readily transferred and leads to dramatic morphological changes [1,2]. We have investigated the heteroepitaxial growth of Ge on ultrathin SOI films by transmission electron microscopy, scanning tunneling microscopy, and atomic force microscopy. We discuss the mechanisms of local strain transfer from faceted Ge islands into ultrathin SOI, focusing on the response of the Si/SiO2 interface to local strain. We highlight strain relaxation mechanisms and their dependence on the thickness of the Si template, and identify novel pathways toward tailoring the morphology and band structure of a semiconductor with nanometer resolution. [1] P. Sutter, E. Sutter, P. Rugheimer, and M. G. Lagally, Surf. Sci. 532 (2003), p.789 [2] E. Sutter, P. Sutter, P. Rugheimer, and M. G. Lagally, Surf. Sci. 532 (2003), p.785

11:00 AM T4.7
Systematic studies of SiGe/Si islands nucleated via separate in situ, or ex situ, Ga^+ focused ion beam-guided growth techniques. Thomas E Vandervelde[1], Surajit Atha[3], Timothy L Pernell[2], Robert Hull[3] and John C Bean[2]; [1]Physics Department, University of Virginia, Charlottesville, Virginia; [2]Electrical and Computer Engineering, University of Virginia, Charlottesville, Virginia; [3]Materials Science and Engineering, University of Virginia, Charlottesville, Virginia.

In this study we use 25 keV in situ, and 30 keV ex situ, Ga^+ focused ion beams (FIB) to locally modify the substrate, before deposition, to determine the affect on nucleation of MBE-grown SiGe/Si islands. FIB processing may alter island formation in at least four ways: the surfactant effect of Ga, doping effects of subsurface Ga^+, crystalline

damage, surface roughening. To explore these possibilities, we milled square regions of increasing Ga^+ dose, and used AFM to monitor islanding in and around these regions. For in-situ experiments, doses ranged from $\sim$4X10^{13} to 3X10^{17} ions/cm^2. Doses as low as $\sim10^{14}$ ions/cm^2 began to affect island topology. For doses from $\sim10^{15}$ ions/cm^2 to $\sim$8X10^{16} ions/cm^2, implanted areas were surrounded by denuded zones that grew from $\sim$0.5 to 6 μm. Immediately inside the adjacent implanted area, island concentration (size and density) appeared to peak. At doses above $\sim$6X10^{16} ions/cm^2, Ga^+ produced noticeable surface depressions, which were often surrounded by enhanced island densities (rather than a denuded zone). For ex-situ FIB patterning, samples had to withstand both pre-growth cleaning and growth of a thin buffer layer. For these reasons, high doses of $\sim$3X10^{17} ions/cm^2 were used which produce significant sample milling. After growth, islands tended to accumulate immediately outside FIB patterned regions (and were depleted farther out). This compared well with high-dose in-situ experiments. These results suggest two phenomena: 1) Adatoms are attracted towards lightly Ga implanted regions. This explains the denuded zones and island build-up of the low-dose in-situ experiments; 2) Adatom movement is inhibited by the downward steps entering more heavily milled regions. The competition between these effects explains high-dose experiments: Atom movement appears to be minimal across steps, but immediately outside milled regions, low dose Ga ion beam tails may attract adatoms from areas farther from the milled area.

11:15 AM T4.8
Nanoparticles size tuning and self-organization with ion beam assisted Ge/Si heteroepitaxy.
Anatoly Vasilievich Dvurechenskii[1], Zhanna Viktorovna Smagina[1], Vladimir Anatolievich Zinovyev[1], Rainer Groetzschel[2], Sergei Aleksandrovich Tyes[1] and Anton Konstantinovich Gutakovskii[1]; [1]Siberian Branch of Russian Academy of Science, Institute of Semiconductor Physics, Novosibirsk, Novosibirsk region, Russian Federation; [2]Research Center Rossendorf, Institute of Ion beam and Material Research, Dresden, Germany.

Self-assembled Ge islands on Si have been intensity investigated as the basis of future electronic and optical devices. At present, it is commonly accepted that the energy gain caused by the strain relaxation in island apexes is the key factor in the transition from a two-dimensional (2D) to three-dimensional (3D) island growth. The 3D islands are formed due to the morphological instability of strained films in systems with a large (more then 2%) lattice mismatch between a film and substrate, among which Ge/Si (4%) and InAs/GaAs (7%) are most familiar. The conventional manner to control island formation (size, shape, density) is changing of growth conditions by the alteration of substrate temperature and molecular flux. However, to establish a method to achieve sufficiently uniform island sizes with regular spatial dustribution still remains a critical issue. This should be solved since a well defined size with little dispersion is generally required for any practical applications. We offer new facility to tune island dimensions, their surface densities and self-organization by the use of low ion beam irradiation in semiconductor heteroepitaxy [1-3]. The energy exceeds the source thermal energy in the molecular beam, but less than the energy of defects generation in the bulk of growing layer. The experiments were carried out in an ultrahigh-vacuum chamber of molecular beam epitaxy (MBE). Three types of Ge/Si heterostructures were investigated: conventional MBE of Ge on Si, substrate temperature was 300 - 500 C; MBE with single pulsed Ge+ ion action (0,5 s, 100 - 200 eV) for each completed Ge monolayer at layer-by-layer growth mode; MBE under continuous irradiation by Ge+ ion beam. The island sizes and array density were studied ex situ with scanning tunneling microscopy. Ge/Si structures with embedded Ge islands were analysed by Rutherford backscattering/channeling technique and transmission electron microscopy. We have found that low-energy ion irradiation during Ge/Si heteroepitaxy stimulates the nucleation of 3D Ge islands. As result reduction of the average island sizes, and increase in their density is revealed. A pulsed ion beam action during heteroepitaxy provides the narrower size distribution of 3D island in comparison with conventional MBE and epitaxy with continuous ion beam. Defect-free Ge nanoclusters embedded in Si can be grown at epitaxy with pulsed ion-beam actions. This is important for potential applications in technology of nanostructures. 1. A.V.Dvurechenskii, V.A.Zinoviev, Z.V.Smagina, V.A. Kudryavtsev, JETF Letters, 72, 296 (2000). 2. A.V.Dvurechenskii, V.A.Zinoviev, Z.V.Smagina, JETF Letters, 74, 267 (2001). 3. A.V. Dvurechenskii, V.A. Zinovyev, V.A. Kudryavtsev, J.V. Smagina, P.L. Novikov, and S.A. Teys. Phys. Low-Dim. Struct., 1/2, 303 (2002).

11:30 AM T4.9
Guided Self-Assembly and Electronic Properties of SiGe Nanostructures on Ultra-thin Patterned Silicon-on-Insulator.
Emma Rosamond Tevaarwerk[1], M. M. Roberts[2], D. G. Keppel[1], Peter Himpsel[1], P. Rugheimer[2], D. Savage[2], M.G. Lagally[2] and M. A. Eriksson[1]; [1]Dept of Physics, University of Wisconsin-Madison, Madison, Wisconsin; [2]Dept of Materials Science, University of Wisconsin-Madison, Madison, Wisconsin.

Self-assembly of SiGe nanostructures on ultra-thin patterned silicon-on-insulator substrates produces a unique organization of conducting and non-conducting elements. Ultra-thin (10 nm) SOI is patterned using e-beam lithography, then etched to produce a silicon substrate laterally patterned into elements with length 1 micron and width 100 nm. When Ge is deposited by molecular beam epitaxy at 700 degrees Celsius, SiGe nanostructures nucleate at the edges of the patterned portions of the substrate [1, 2]. This process of substrate engineering allows the surroundings of the resulting SiGe nanostructures to be defined and manipulated. Electric force microscopies in conjuction with tailored three-dimensional simulations allow measurement of the resulting connectivity of the SiGe nanostructures on insulator [1, 3], along with other electrical properties such as local workfunction and charge. [1] Emma Tevaarwerk, P. Rugheimer, O. M. Castellini, D. G. Keppel, S. T. Utley, 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, 4863 (2002). [3] Emma Tevaarwerk et al, to be submitted.

SESSION T5: III-V Self Organized Nanostructures
Chairs: Subhash Mahajan and Alexana Roshko
Tuesday Afternoon, December 2, 2003
Room 209 (Hynes)

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-assembled microstructures 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 GaP islands 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/Si system because the room-temperature mismatch between the two materials is very small. We studied the evolution of GaP islands on the (001), (111), (110) 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 layers have different covalent tetrahedral radii. This produces different bond lengths within tetrahedral units, leading to local strains in layers. We studied the influence of these strains on microstructures of mixed III-V layers using transmission electron microscopy. Results indicated that atomic species in layers having different tetrahedral radii were not distributed at random on their 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 sub-surface stresses produced by the occurrence of surface reconstruction on group 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 AFOSR, 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[1], Rogerio Magalhaes-Paniago[2], J.R.R. Bortoleto[1] and Monica A. Cotta[1]; [1]LPD/DFA, Intituto de Fisica Gleb Wataghin, UNICAMP, Campinas, SP, Brazil; [2]Departamento de Fisica, Instituto de Ciencias Exatas, UFMG, Belo Horizonte, MG, Brazil.

InAs nanostructures in an InP matrix have received much attention in the last years. In this work we report the conditions that determine the InAs shape transition -from wires to dots - for films grown on (100) InP substrates by Chemical Beam Epitaxy. We have obtained intermediary states containing both wires and dots in the same sample. However, the grown 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). The

samples were analyzed by Atomic Force Microscopy (AFM) and High Resolution Transmission Electron Microscopy (HRTEM). The influence of the temperature, growth rate and the InAs thickness 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 kinetically controlled process occurs in a well-defined range of growth conditions, which determine the distribution, homogeneity and shape of the resulting nanostructure. Another significant factors that determine the shape, size and facet formation in these nanocrystals is the strain distribution. The characterization of this parameter can be performed using grazing 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 measurements. A remarkable anisotropy was observed for strain distributions 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.

2:15 PM T5.3
Size and Critical Thickness Evolution During Growth of Stacked Layers of InAs/InP(001) Quantum Wires Studied by In Situ Stress Measurements. David Fuster[1], Maria Ujue Gonzalez[1], Luisa Gonzalez[1], Yolanda Gonzalez[1], Teresa Ben[2], Arturo Ponce[2], Sergio I Molina[2] and Rafael Garcia[2]; [1]Instituto de Microelectronica de Madrid, Tres Cantos, Madrid, Spain; [2]Departamento de Ciencia de los Materiales e I.M. y Q.I., Universidad de Cadiz, Puerto Real, Cadiz, 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 still remain open. In this paper we present *insitu* RHEED and stress measurements, and *exsitu* TEM characterization of stacked layers of InAs/InP (001) quantum wires (QWR) separated by InP spacer layers of different thickness, 5 nm $\leq$d(InP) $\leq$ 20 nm. We have observed that the InAs critical thickness (h_c) for QWR formation, as observed by a 2D-3D RHEED pattern transition, decreases from the 1st QWR layer for stacks with d(InP) = 5 nm, remaining constant for d(InP) = 20 nm. Accordingly, for our samples where InAs deposition is interrupted just at h_c the density and size of QWR is expected to be smaller in the correlated layers (d(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 2nd layer of the stack, QWR formation starts at the onset of InAs deposition. Moreover the 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 existence of a critical thickness for 2D-3D growth mode transition should be revised in correlated QWR stacks of layers.

2:30 PM T5.4
First stages of the two-to-three dimensional transition in the InAs/GaAs(001) heteroepitaxial growth. Fabrizio Arciprete[1,2], Fulvia Patella[1,2], Sandra Nufris[1,2], Ernesto Placidi[1,2], Massimo Fanfoni[1,2], Anna Sgarlata[1,2] and Adalberto Balzarotti[1,2]; [1]Department of Physics, University of Rome "Tor Vergata", Rome, Italy; [2]National 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 the pseudomorphic strained two-dimensional wetting layer up to the self-assembling 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 discuss their contribution to the final morphology of the self-assembled nanoparticles. The features to be considered, close to the 2D-3D transition, are: large and small 2D-islands one-monolayer high, small quasi-3D islands of height $\leq$2 nm, 3D QD of height 3-4 nm. Although reported several times, 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. Statistical 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 intermixed $In_xGa_{(1-x)}As$ and InAs "floating" on top. Such "floating" phase participate to the large mass-transport along the surface during the two-to-three-dimensional transition that accounts for the total volume of dots.

2:45 PM T5.5
Microanalysis of Self-assembled InAs Quantum Dot Structures Grown for Infrared Detector Applications.
Wendy L. Sarney, John W. Little, Stefan Svensson, Kimberley Olver and Stephen Kennerly; U.S. Army Research Laboratory, Adelphi, Maryland.

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 followed by the growth of another layer of InAs dots. The GaAs laterally surrounds, 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 effectively 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 as a function of the dot's height and the total number of dot layers within the structure. The goal is to develop structures that can be integrated into high operating temperature quantum dot infrared detectors (QDIPs) that have maximum sensitivity, robustness, and portability.

3:30 PM T5.6
Grazing Incidence Small Angle X-ray Scattering Study of Semiconductor Quantum Dots. Chia-Hung Hsu[1], Hsin-Yi Lee[1], Yung-Wei Hsieh[1], Chih-Mon Huang[1], Yuri P. Stetsko[1], N.T. Yeh[2], J.-I. Chyi[2] and K.S. Liang[1]; [1]Research Division, National Synchrotron Radiation Research Center, Hsinchu, Taiwan; [2]Electrical Engineering, National Central Univeristy, Chung-Li, Taiwan.

The size, shape, strain distribution, compositional profile and spatial distribution are the critical factors determining the electronic level and thus the opto-electronic properties of semiconductor quantum dots. Following our recent study on quantum dots using 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 10^8 quantum dots and provides valuable information about the shape and spatial distribution of these nano-sized 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 may 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).

3:45 PM T5.7
Lateral and Height Distributions of Self-Assembled InGaAs Quantum Dots on GaAs Substrates. Alexana Roshko[1], S Y Lehman[1], R P Mirin[1], K D Cobry[1], W Ye[2], M Reason[2], X Weng[2] and R S Goldman[2]; [1]Optoelectronics Division, NIST, Boulder, Colorado; [2]Mat. Sci. & Eng., U. Michigan, Ann Arbor, Michigan.

Numerous devices are under development that utilize quantum dots because of their unique optical or electronic properties. The majority 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 530ø C, the density was found to vary up to 25 % across the central 2 x 2 cm^2 region of a two inch 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 OMVPE will also be discussed.

4:00 PM T5.8
Optical properties of InGaAs QDs grown in a GaAs matrix by MOCVD emitting at 1300nm at room temperature.
Maria Teresa Todaro, Milena De Giorgi, Vittorianna Tasco, Massimo De Vittorio, Adriana Passaseo and Roberto Cingolani; Ingegneria dell'Innovazione, National Nanotechnology Laboratories (NNL-INFM), 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 $10^9 cm^{-2}$), emit efficiently at 1300nm 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 Manzano, Giovanni Costantini, Armando Rastelli, Rudeesun Songmuang, 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 (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 equilibrium. The low-temperature GaAs overgrowth of these QDs is investigated during the initial stages (1-30 ML). Two regimes appear to dominate the capping, an initial partial dissolution of the QDs followed by a true overgrowth. The generality of 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 atomistic 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 $(AlInP)_{11}/(GaInP)_{10}$ Superlattices. Roberto E. Martinez[1], Venkatesh Narayanamurti[1,2], Xuebing Zhang[3] and Russell D. Dupuis[3]; [1]Division of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts; [2]Department of Physics, Harvard University, Cambridge, Massachusetts; [3]Department of Electrical and Computer Engineering, University of Texas at Austin, Austin, Texas.

For optoelectronic applications, the binary to quaternary phosphides, $(Al_xGa_{1-x})_yIn_{1-y}P$, have the second 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 superlattices–are not. To this 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 $(AlInP)_{11}/(GaInP)_{10}$ strongly-coupled superlattices. A comparison of 'on-the-dot' and 'off-the-dot' second derivative BEEM spectra in both systems reveals the major channel of transport can be associated with the L conduction band. Moreover, we conclude that although the quantum dots are much smaller in the quaternary system than in the ternary system, resonance can still be resolved using BEEM. Furthermore, Monte Carlo simulations of transport are in agreement with experiment. [1]V. Narayanamurti, M. Kozhevnikov, Phys. Rep. **349**, 447 (2001)

4:45 PM T5.11
Electrical Transport in InAs/InP Wire-Dot Assemblies. Klaus O Vicaro[1], Humberto R Gutierrez[1], Jose Roberto R Bortoleto[1], Flavio Plentz[2], Peter A Schulz[1] and Monica Alonso Cotta[1]; [1]IFGW - DFA, UNICAMP, Campinas, SP, Brazil; [2]ICEx - DF, UFMG, Belo Horizonte, MG, Brazil.

In this work we explore the electrical properties of InAs/InP semiconductor nanostructures, mainly wires and dots. Kelvin-Probe microscopy (KP), conductive atomic force microscopy (C-AFM) as well as electron-beam litographically-processed devices were used in order to access the parallel conductance of the grown nanostructures. C-AFM in a controlled atmosphere provided current imaging measurements as well as I-V spectroscopy. The InAs/InP nanostructures were grown by Chemical Beam Epitaxy in the Stranski-Krastanov mode. All samples were n-type, non-intentionally doped. KP measurements on InAs films - few monolayers thick - grown on InP have shown that the position of the Fermi level is affected by the presence of the InAs film either on the top surface or under a thin InP layer. The evaluated Fermi level position is also influenced by the type of grown nanostructure (dots or wires). This result suggests a suppression of the depletion region, probably due to accumulation of carriers in the InAs structures. C-AFM measurements have indeed shown larger currents on the nanostructures than the wetting layer. I-V spectroscopy measurements show that the general electrical characteristic is that of a Schottky contact, due to oxidation by exposition to air. However, I-V curves show quite different threshold bias values when wetting layer, wires or dots are measured. Such values correlate well with the expected band gap energy for these nanostructures. On the other hand, e-beam lithography was used to fabricate a 400nm wide gap in between two metallic contacts on top of a 2-micron wide mesa with the InAs nanostructures. I-V curves from this ensemble of nanostructures present a large peak in conductance at approximately 0.15V, observable even at room temperature. These results are interpreted in terms of the carrier transport processes in the wire-dot-wire assembly in the sample.

SESSION T6: Joint Session with N8 and Z6: Quantum Dots and Wires: Structure, Spectroscopy, and Transport
Chairs: Hedi Mattoussi and Andrew Norman
Wednesday Morning, December 3, 2003
Room 302 (Hynes)

8:30 AM *T6.1
Nanowire Semiconductor Materials for Low-dimensional Physics and Applications. Lars Samuelson, Solid State Physics, Lund University, Lund, Sweden.

Self-assembly of quantum structures into zero-dimensional (quantum dot) and one-dimensional (nanowire) structures is becoming a very hot item in materials science as well as for what it may offer for basic physics and for nanoelectronic/photonic applications. In this talk I will first discuss the formation of quantum dots via the Stranski-Krastanow (SK) self-assembling growth mode which has allowed the study of highly ideal quantum dot structures for basic investigations of the physics of few-particle configurations and exciton phenomena in single quantum dots, as well as for their use in different quantum optics applications. By assembly of SK quantum dots for electrical addressing, it has been possible to fabricate tunneling devices in which electrons tunnel via the zero-dimensional states of the quantum dot as the active element or for electrons tunneling via double-dot artificial molecule structures. Very recently this more traditional approach to optical and electrical applications of quantum dots has been rivaled by the alternative approach to form quantum dots arranged inside one-dimensional nanowires. I will present optical properties of quantum dots inside nanowires as well as resonant tunneling via single quantum dots placed in-between tunnel barriers

inside such nanowire structures. Direct comparison between SK-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 Borgstrom in MOVPE-growth, Soren Jeppesen, Jonas Ohlsson and Ann Persson in CBE-growth, Reine Wallenberg et al. in TEM-imaging, Anders Mikkelsen et al. in STM.imaging, Claes Thelander, Mikael Bjork, Tomas Bryllert and Thomas Martensson in transport device studies, Valery Zwiller, Jonas Persson, Lars Landin, Nicolay Panev and Niklas Skold in PL-studies and Mats-Erik Pistol, Craig Pryor, Magnus Holm, Martin Persson and Hongqi Xu in theory/modelling.

9:00 AM T6.2
Observation of Quasi-Periodic Twinning Superlattice in GaAs Nanowires. K W Adu[1], U J Kim[1], B K Pradhan[4], D Tham[3], D Yates[3], J E Fischer[3], U D Venkateswaran[5] and P C Eklund[1,2]; [1]Physics, Pennsylvania State University, University Park, Pennsylvania; [2]Materials Science & Engineering, The Pennsylvania State University, University Park, Pennsylvania; [3]Material Science and Engineering and LRSM, University of Pennsylvania, Philadelphia, Pennsylvania; [4]Commertial Technology, Columbia Chemical Company, Marietta, Georgia; [5]Physics, Oakland University, Oakland, Michigan.

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 occur in a conventional superlattice. Theoretical investigations of the electronic band structure of such periodically twinned materials reveal a red shift in the band gap. For example, the twinning superlattice of Si exhibits a bandgap of 0.6eV, while the bandgap for the bulk is 1.1eV. We have used a simple thermal batch process to grow GaAs nanowires with an almost periodic twinning superlattice. As the wire diameter (d) ranges from 5nm to 100nm, the superlattice period decreases, e.g., at d=10nm diameter, a typical period would be ~5 unit cells along the (111) growth direction. The photoluminescence (PL) spectrum exhibits 3 peaks at 300 K: a doublet (1072nm, 915nm) and weak peak at 580nm (bulk GaAs has bandgap PL at at 850nm). The doublet is identified with a redshift in the bandgap; the origin of the peak at 580 nm is not currently understood, and it becomes intense at T=30K. We observe an ~ 11cm-1 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 nanowire: GaAs twinning superlattice, and other twinned superlattice nanowires as well.

9:15 AM T6.3
Optical Studies of Charged Single Self-Assembled Quantum Dots. Morgan E. Ware[1], Allan Bracker[1], Daniel Gammon[1] and David Gershoni[2]; [1]Naval Research Laboratory, Washington, District of Columbia; [2]Physics Department, Technion-Israel Institute of Technology, Haifa, Israel.

Semiconductor quantum dots have been viewed in recent years as attractive components for implementing quantum computation schemes [1]. In particular, the unpaired spin of an electronically charged semiconductor quantum dot is especially exciting, not only because of its relatively long spin dephasing time, but also because a single spin in a single dot can be controlled and measured optically [2]. Knowledge of the discrete energy spectrum of these dots is vital for any future progress in this field. We have grown InAs/GaAs self-assembled quantum dot samples by molecular beam epitaxy using an indium flush technique [3]. Submicron aluminum apertures created by electron beam lithography have been used as a shadow mask such that single quantum dots can be selectively excited and measured. In addition, we have employed this shadow mask as the metal contact of a Schottky diode structure, providing us the capability to control the charge state of the isolated quantum dot. By varying the bias across the diode and at the same time measuring the photoluminescence from the dot, we precisely control and identify the charge states of the dot [4,5]. By analyzing the magnetic field dependence of the photoluminescence we can fully characterize the degeneracy of these charge states [6] and their polarization selection rules. The basic understanding of this system will be discussed as it provides the groundwork for further studies of more complex systems. [1] D. Loss, D. P. DiVincenzo, Phys. Rev. A 57, 120 (1998). [2] D. Gammon et al., Phys. Rev. Lett., 86, 5176 (2001). [3] Z. R. Wasilewski, S. Fafard, and J. P. McCaffrey, J. Cryst. Growth 201/202, 1131 (1999). [4] R.J. Warburton, et al., Nature, 405, 926, (2000) [5] D.V. Regelman, E.Dekel, D.Gershoni, et al., Phys. Rev. B 64, 165301, (2001) [6] J.G. Tischler, A. S. Bracker, D. Gammon, Phys. Rev. B 66, 081310(R) (2002).

9:30 AM *T6.4
Engineering Quantum Structures and their Behavior.
Gregory J. Salamo, Physics, Univ of Arkansas, Fayetteville, Arkansas.

Recent clever techniques for fabricating nanosize materials, one-atomic-layer-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 smaller is a fantastic adventure opening 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 equally exciting to try to use the rules we uncover to encourage dot formation 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 fabrication of a vertically and laterally ordered QD stacks forming three-dimensional QD arrays. We will present results from the photoluminescence (PL) spectra from individual dots and discuss the role of such phenomena as the phonon bath. We will also discuss an investigation of the PL spectra from ordered arrays of QDs, both as a function of temperature and optical excitation intensity, which reveal 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 when and why high index surfaces are stable. Indeed, we have found that in order to understand the origin 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.

10:30 AM *T6.5
Growth, Structure, And Optical Properties Of III-Nitride Quantum Dots. Hadis Morkoc[1], Arup Neogi[2] and Martin Kuball[3]; [1]EE and Physics, Virginia Commonwealth University, Richmond, Virginia; [2]North Texas University, Denton, Texas; [3]University of Bristol, Bristol, United Kingdom.

Quantum dots in conventional semiconductors have been explored for their many degrees of confinement resulting in unique density of 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 layers to be studied from the substrate or buffer layer and, thus 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 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 photolumiscence experiments. AlN barrier layers, some too thick for mechanical interaction, some thin enough for vertical coupling were used. Strong polarization effects lead to a sizeable red shift, which depends on the size of the dots. 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[1], Michael Hanke[1], Daniil Grigoriev[1], Martin Schmidbauer[1], Peter Schaefer[1], Udo Pohl[2], Roman Sellin[2], Dieter Bimberg[2], Nikolai Zakharov[3] and Peter Werner[3]; [1]Institute of Physics, Humboldt-University Berlin, Berlin, Germany; [2]Insitute of Solid State Physics, Technical University Berlin, Berlin, Germany; [3]Max-Planck-Institute of Microstructure Physics, Halle, Germany.

Strained self-organised InGaAs/GaAs(001) quantum dots (QDs) are presently subject of intense research efforts due to their promising

potential for optoelectronic device applications. We will report about structural investigations on five-fold stacks of $In_{0.6}Ga_{0.4}As$ QDs within a GaAs matrix grown by means of metalorganic chemical vapor deposition. The GaAs spacer thickness between the subsequent QD layers amounts to 20 nm, a thickness at which vertical QD correlation is believed to vanish, however, cross-sectional transmission electron micrographs (TEM) reveal a pronounced vertical correlation, whereas no lateral ordering could be observed in plan-view images. Applying highly strain sensitive high resolution x-ray diffraction in vicinity of different reciprocal lattice points we provide a non-destructive access to the detailed QD shape and local strain status within the QDs and the surrounding matrix material. Since the expected diffuse signal will be extremely weak all measurements were carried out at synchrotron beamlines. Scattering simulations are based on a dynamical treatment within the framework of Distorted Wave Born Approximation. The strain field which enters the simulation procedure has been calculated by finite element method. Grazing incidence diffraction (GID) near the (200) and (020) reciprocal lattice points did not show any significant difference between the [100] and [010] directions. A similar shape isotropy was found with respect to [110] and [$1\bar{1}0$], proving an at least four-fold lateral QD symmetry. Moreover, scattering simulations regarding various dot shapes clearly indicate prismatic QDs with a flat top rather than pyramides. The mean lateral QD distance significantly influences the diffuse scattered intensity in GID geometry. Thus, we could deduce a value of approximately 80 nm, which corresponds well to the QD density of about 2E10 cm^{-2} estimated from plan-view TEM.

11:15 AM T6.7
THz Manipulation of Excitonic Levels in Single InAs Quantum Dots. Frederik F. Schrey, Thomas Mueller, Gottfried Strasser and Karl Unterrainer; FKE, Vienna Univ. of Technology, Vienna, Austria.

The energy spacing of electronic states in self-assembled quantum dots (QDs) coupled with efficient electron capture capabilities into these discrete states predestine dots to be used as MIR photodetectors, emitters and turns them into candidates for q-bit operations. In contrast to subband transitions in two-dimensional structures the density of states is sharply peaked at the transition energy, which reduces the phase space for scattering. Therefore we expect longer relaxation and dephasing rates in QDs compared to quantum wells. A strong requirement for q-bit applications is the knowledge about a possible radiative coupling between the electronic levels. In our experiments we superimpose a pulsed NIR excitation laser field with a low intensity cw THz field on a single quantum dot. The dot is separated from other dots by etching a micropillar structure into the GaAs matrix. Furthermore the pillar structure allows a more efficient coupling to the THz radiation. The exciton recombination is recorded with a micro luminescence (PL) setup for NIR excitation as well as for combined NIR/THz excitation. First results show an electron transfer from the lower excitonic levels into higher levels, which changes the count rates for the emission lines. The efficiency of this process seems to depend on the NIR pump intensity and is object of further studies. Furthermore ultrabroadband MIR time-domain spectroscopy allows us to study the dynamical properties within the electronic dot levels. In a first approach we study the electron capture respectively injection into the electronic levels of dot ensembles. Combined with the micro-PL system we want to investigate the dynamics of electrons in single dots. We hope to gain knowledge of the relaxation and dephasing processes and to achieve coherent excitations within the electronic dot levels, which would allow very fast control of QD based devices.

11:30 AM T6.8
Near-Field Magneto-Potoluminescence of Single Self-Organized Quantum Dots. Alexander Mintairov[1], James Merz[1], Alexei Vlasov[1] and Alexander Govorov[2]; [1]University of Notre Dame, Notre Dame, Indiana; [2]Physics and Astronomy, Ohio University, Athens, Ohio.

We present measurements of Zeeman splitting and diamagnetic shifts of single self-organized InAs/AlAs, InAs/GaAs and InP/GaInP quantum dots using low temperature (10K) near-field scanning optical microscopy with spatial resolution <200 nm, operating at magnetic field strengths up to 10 T. The measurements allow us distinguish dots of different sizes, atomic content and homogeneity and attribute their specific structural properties, with their magneto-optical properties. For InAs/GaAs and InAs/GaAs QDs we found an increase of the diamagnetic coefficient from 0.4 to 15 meV/T2 with increasing emission energy. This corresponds to an increase of the QD size from 5 to 10 nm. This observation is quite unexpected and implies lower In content for larger dots, compensating the usual quantum confinement effects. We estimated the difference in In composition between small and large dots to be quite large, approximately 40%. For InP/GaInP QDs we observed an anomalous behavior of the Zeeman splitting dependence on the initial value of magnetic field. When the magnetic field is swept from 10 to 0T, the spin splitting shows oscillatory behavior and it does not vanish at zero magnetic field. We interpret this observation to involve an internal effective magnetic field induced by polarized nuclear spins via the hyperfine interaction. Interestingly, the single InP dots with non-zero splitting typically have broad 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. Evaldo Ribeiro[1], Alexander O Govorov[2], Wilson de Carvalho Jr.[1] and Gilberto Medeiros-Ribeiro[1]; [1]LNLS, Campinas, SP, Brazil; [2]Department of Physics and Astronomy, Clippinger Research Labs, Ohio University, Athens, Ohio.

By allowing a charged particle to circulate 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 particle wavefunction acquires a phase that is 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 Φ through the excluded region, and are shown to be periodic with period $\Phi_0 = hc/e$. 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 $l_h = 0$ to $l_h = 1$, 2, and 3. Although forbidden, the transitions from the electron ground state to higher angular momenta hole states reflect a broken symmetry for this island system. This can be understood in terms of the anisotropy of the islands revealed in both Atomic Force Microscopy experiments on uncapped islands as well as polarization dependent photoluminescence spectra. In addition to that, due to the fact one does not have a hard wall confining potential, a spillage of the electron and hole wavefunctions out 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 function lobes 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 Z7: Quantum Dots and Wires: Devices
Chairs: Pallab Bhattacharya and Zhiming Wang
Wednesday Afternoon, December 3, 2003
Room 208 (Hynes)

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

Self-organized formation of quantum dots (QDs) upon heteroepitaxial growth of highly strained semiconductor layers has gained enormous importance for a novel generation of opto-electronic 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 strain engineering and interface control to define QD size and density 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. InGaAs/GaAs QD edge emitters show an ultralow threshold for infinite length of 18A/cm^2 at 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 J_{th} = 70 A/cm^2 and 3 W cw output power were realized. As to surface emitters, we presented the first GaAs VCSEL based on QDs operating at 1.3 μm with 1.2 mW cw output power and more than 50% slope efficiency. Thus GaAs-lasers can now replace InP-based ones at least 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 V-precursors as replacements for highly toxic hydrides are very promising. After demonstrating QDs with a high density and excellent optical quality, we realized edge emitters with a transparency current below 30 A/cm^2, 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 data at 1.1 μm as the MBE-grown VCSELs presented above. Semiconductor Optical Amplifiers based on QDs show gain recovery times as short as 100 fs, much faster than QW-based ones, indicating the potential of QDs for a novel class of devices with large commercial importance for multi-tera bit metropolitan area networks. Unusually long phase relaxation times of excitons in QDs of more than 600 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, R. Sellin, C. Ribbat. P. Borri, J. Hvam, U. Woggon, F. Hopfer and others. (1) D.Bimberg, M.Grundmann, N.N.Ledentsov: Quantum Dot Heterostructures, J. Wiley, Chichester 1999.

2:00 PM T7.2
1.5 micron InAs quantum dot lasers based on metamorphic InGaAs/GaAs heterostructures. Victor M. Ustinov[1], Alexei E. Zhukov[1], Alexei R. Kovsh[1], Nikolai A. Maleev[1], Sergei S. Mikhrin[1], Alexei P. Vasil'ev[1], Ekaterina V. Nikitina[1], Elizaveta S. Semenova[1], Natalya V. Kryzhanovskaya[1], Yurii G. Musikhin[1], Yurii M. Shernyakov[1], Mikhail V. Maximov[1], Nikolai N. Ledentsov[1,2], Dieter Bimberg[2] and Zhores I. Alferov[1]; [1]Ioffe Institute, St. Petersburg, Russian Federation; [2]Institut fur Festkorperphysik, Technische Universitat Berlin, Berlin, Germany.

1.5 micron range emission has been realized using the InAs quantum dots embedded into the metamorphic InGaAs layer containing 20% of InAs grown by MBE on a GaAs substrate. This significant decrease in the matrix band-gap is presumably the reason for the increase in the quantum dot luminescence wavelength. Growth regimes were optimized to reduce significantly the density of dislocations propagating into the active layer from the lattice mismatched interface. 2 mm long InGaAs/InGaAlAs lasers with 10 planes of quantum dots in the active region showed threshold current density about 1.4 kA/cm2 with the external differential efficiency as high as 38%. Lasing wavelength depends on the optical loss being in the 1.44-1.49 micron range at room temperature. On the increasing the temperature the wavelength reaches 1.515 micron at 85C while the threshold current characteristic temperature of 55-60K was estimated. High internal quantum efficiency (?>60%) and low internal losses (?=3-4 cm-1) were realized. Maximum room temperature output power in pulsed regime as high as 5.5 W for 100 micron wide stripe was demonstrated. Using the same concept 1.3 micron InGaAs/InGaAlAs quantum well lasers were fabricated. The active region contained quantum wells with high (~40%) indium content which was possible due to intermediate InGaAs strain relaxation layer. 1 mm stripe lasers showed room temperature threshold current densities about 3.3 kA/cm2 (?=1.29 micron) and 400 A/cm2 at 85K. Thus, the use of metamorphic InGaAs layers on GaAs substrate is very promising approach for increasing the emission wavelength of GaAs based lasers. However, quantum dot lasers demonstrated superior performance as compared to that of quantum well lasers even the latter having much shorter emission wavelength. This is probably due to the three-dimensional quantum confinement of recombination region in quantum dot structures which drastically reduces carrier spreading and the probability of non-radiative recombination on dislocations.

2:15 PM T7.3
Nanoengineered Quantum Dot Active Medium for Thermally-Stable Laser Diodes. Vadim Tokranov, Michael Yakimov, Alex Katsnelson, Matthew Lamberti and Serge Oktyabrsky; School of NanoSciences and NanoEngineering, University at Albany - SUNY, Albany, New York.

With a goal of development of an efficient active layer for laser diodes operating at elevated temperatures, we have studied the influence of an overgrowth procedure on the properties of multiple-layer self-assembled InAs quantum dot (QDs) using photoluminescence, transmission electron microscopy (TEM), and electroluminescence. Optical properties of QDs were optimized by shape engineering through the adjustment of a GaAs overlayer thickness prior to a heating step, which has introduced truncation of pyramid-shaped QDs. TEM micrographs of these QD structures has confirmed that the employed growth procedure results in a truncated (flat top) pyramidal shape of QDs. We have also compared QD and multilayer QD structures with and without a few-monolayer-thick AlAs capping layer. The optical properties of InAs QDs capped by AlAs were found to have a strong dependence on truncation height. Both single-layer and in particular multilayer QDs with AlAs capping have demonstrated up to 15 meV larger energy separation between the ground state and the first excited state as compared to QDs without AlAs capping. Triple-layer truncated QD structure with AlAs capping showed 94 meV separation between ground state and first excited state. We believe that AlAs capping in combination with truncation procedure result in significant suppression of carrier transport between QDs within the layer as well as between QD layers. A record high characteristic temperature for lasing threshold, T_o = 380 K up to 55 °C, and maximum ground state lasing temperature of 219 °C were measured for 1.22 μm edge-emitting laser with this triple-layer truncated QD gain medium.

2:30 PM T7.4
First electrically injected QD-MCLED emitting at 1.3 μm, grown by metal organic chemical vapour deposition.
Vittorianna Tasco, Adriana Passaseo, Maria Teresa Todaro, Milena De Giorgi, Massimo De Vittorio, Iolena Tarantini and Roberto Cingolani; NNL-National Nanotechnology Laboratories, INFM, Lecce, Italy.

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 fibres coupling, and vertical emission suitable. As opposed to the more expensive and temperature sensitive InP technology, the Stranski-Krastanov self-assembling 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 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 coalesced 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 electroluminescence emission centred at 1.3 μm, obtained under a very low injection current. The MCLED structure consists of a bottom mirror, formed by n-doped GaAs/AlAs DBR, designed for a reflectivity of 93 %, and a p-doped top mirror designed with a reflectivity of 82%. A single layer of In0.5Ga0.5As QDs, directly 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 behaviour 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 on a GaAs layer, shows 1.3 μm emission with a full width at half maximum (FWHM) of 24 meV and clear band filling dynamics. The PL intensity quenches by a factor of 3 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, indeed, a larger FWHM of 31 meV (exactly centred at the reflectance 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 micro-cavity 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 *T7.5
Self-Assembled Nanostructures and Quantum Devices In InGaAs/GaAs and InAs/InGaAlAs/InP. Wang Zhanguo, Wu Ju and Zhao Fengai; Key Lab of Semiconductor Materials Science, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, China.

Self-assembled In (Ga) As/GaAs, InAlAs/AlGaAs/GaAs, and InAs/InAl (Ga) As/InP 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 about 700 nm to 2 micrometer can be controlled. The room temperature CW lasing at 960nm with maximum output power of 3.62 W and the lifetime of more than 4000hrs for the multiplayer InGaAs/InAs/GaAs 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 buffer composition, the buffer thickness, and the growth mode on the morphology of self-assembled InAs dots and wires has been also investigated in the InAs/InGaAlAs/InP system. It was found that these growth parameters had the direct influence on the dot-wire transition, and the diagonal space alignment of wires. The atomic processes underlying these growth morphologies will be discussed in detail.

3:45 PM T7.6
Defect-aided Single Electron and Single Photon Detection in InP/InGaAs and GaAs/AlGaAs Based Quantum Wires and Quantum Point Contacts. Prabhakar Bandaru[1,2], Hideo Kosaka[3,2], Deepak Rao[2], Hans Robinson[2] and Eli Yablonovitch[2]; [1]Materials Science Program, UC, San Diego, La Jolla, California; [2]Electrical Engineering department, UCLA, Los Angeles, California; [3]Fundamental research labs., NEC Corporation, Tsukuba, Japan.

Defects, such as point defects and impurities, play an increasingly important role in nanostructures and devices such as single electron transistors(SETs). The talk will focus on how defect engineering in quantum wires and quantum dots can be used for extremely sensitive ($\sim 10^{-5}$e/$sqrt$Hz) electron and 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 Conductance(G)-Voltage(V) spectra. Careful analysis of the RTS noise yielded defect-specific information, such as the presence of a single stray 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. 1. H. Kosaka et al., Phys. Rev. B, 65, 201307 (R), 2002. 2. P. Bandaru et al., SPINTECH I, 2001. This work was sponsored by Defense Advanced Research Projects Agency and Army Research Office Nos. MDA972-99-1-0017 and DAAD19-00-1-0172.

4:00 PM T7.7
Improving the Structural and Optical Properties of 1.3 μm InAs/GaAs Quantum Dots Using InAlAs Layers.
Hui Yun Liu[1], Ian Sellers[2], Mark Hopkinson[1], Colin N. Harrison[1], David J. Mowbray[2] and Maurice S. Skolnick[2]; [1]Department of Electronic & Electrical Engineering, EPSRC National Centre for III-V Technologies, Sheffield, S-Yorkshire, United Kingdom; [2]Department of Physics & Astronomy, University of Sheffield, Sheffield, South Yorkshire, United Kingdom.

Self-organized InAs/GaAs quantum dots (QDs) have gained much interesting due to their unique atomic-like properties and potential device applications. In recent years, the continuing interesting is driven by the extension of emission wavelength of InAs/GaAs QDs to an important telecommunication wavelength of 1.3 μm, and the development of 1.3 μm InAs/GaAs QD laser has progressed rapidly. However, their 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 dots. The growth approach of InAs islands directly deposited on InGaAs strained buffer layer (SBL) 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 SBL and SRL used in these techniques result in a reduced energy barrier and, consequently, an increase of 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 dot density and energy barrier of 1.3 μm InAs/GaAs quantum dots. This growth technique exhibits an increment of InAs quantum-dot density from 160 to 280 μm-2 and an improvement of energy separation between the quantum-dot ground and first-excited states from 84 to 93 meV with adjusting the thickness of GaAs in InAlAs-GaAs buffer layer. The experimental relationship between InAs QD density and matrix of InAlAs-GaAs SBL could be understood in term of the increasing additional material from wetting layer into dots and the decreasing repulsive strain field between 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 photoluminescence intensity of the QD ground-state 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 200 K. A maximum enhancement of 450 is achieved at room temperature. This improvement of the high temperature photoluminescence efficiency should lead to a significant improvement in the characteristics of 1.3-μm InAs/GaAs QD lasers.

4:15 PM T7.8
Growth and characterization of InAs quantum dots on GaAs (100) emitting at 1.31μm. Vincent Celibert[1,2], Bassem Salem[1], Gerard Guillot[1], Catherine Bru-Chevallier[1], Laurent Grenouillet[2], Philippe Gilet[2] and Alain Million[2]; [1]Laboratoire de Physique de la Matiere, Villeurbanne, France; [2]CEA-DRT-LETI/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 the1.55μm window of telecommunications, reserved up to now to InP, it remains very important to control the growth of QDs emitting at 1.3μm 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 Stranski-Krastanov mode by optimizing two significant parameters: samples are grown using a very low deposit rate of InAs increasing the average size of the dots and thus allowing higher wavelength emission. A high speed deposit rate of the GaAs encapsulation layer is chosen in order to rapidly freeze the structure of QDs to avoid any modifications. Structural and optical characterizations 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$\hat{1}$0cm-2, respectively. A good size homogeneity is also observed. The PL properties of QDs measured at 300K 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 that 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 filing 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
Chairs: Rachel Goldman and Pierre Petroff
Thursday Morning, December 4, 2003
Room 209 (Hynes)

8:30 AM *T8.1
Application of Diluted Magnetic Semiconductors and Quantum Dots to Spin Polarized Light Emitters.
Pallab 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-polarised 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 epitaxial (MBE) growth, structural characterization and ferromagnetic properties of GaMnAs alloys and (In,Mn)As self-organized quantum dots or dilute 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 STM measurements. The dot density is typically $\sim$ 109 cm-2, as obtained from AFM measurements. The Curie temperature in the as-grown quantum dot samples increases steadily with Mn content and is $\sim$ 150K for 5% Mn. The results are analyzed by a model considering a strong non-uniformity in Mn-content amongst dots, 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 36% 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. Pierre Petroff, 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 state of the emitted photons. We will present our progress towards locating, 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/ GaAs QDs on a pre-patterned substrate. We show the importance of stress engineering using a subsurface stressor layer for positioning of a single or group of QDs. Carrier confining in QDs is demonstrated using QDs pairs in a p-i-n structure to extend over long times (>10sec.). Electrical or hole spin injection from a ferromagnetic GaMnAs magnetic semiconductor layer into QDs is observed through analysis of the polarized electroluminescence of a QD spin LED. We will discuss the small injection efficiency (<3%)of polarized spins (for both electrons and holes) in the QDs. The results suggest that optical spin injection methods should 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 Ranojoy 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 make it possible to design and grow 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 separate applications in optoelectronics 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 NSOM photoluminescence excitation 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. Hanns-Ulrich Habermeier[1], Xiao-Jia Chen[2] and Hui Zhang[1]; [1]MPI-FKF, Stuttgart, Germany; [2]Kent 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 appropriate lattice misfit/ film thickness combination this strain can be used to generate quantum dots of functional ceramics similarily to the concept used in elemental semiconductors. Furthermore, due to 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. Curietemperature in ferromagnetic colosssal magnetoresistance materials] can be tailored. In a case study we explore these possibilities using La0.9Sr0.1MnO3 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 Jahn-Teller distortion. In this contribution, the conditions will be explored to fabricate LSMO quantum dots by pulsed laser depostion and first results of their properties 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 4nm height have been detected. It could be shown that these quantum dots are ferromagnetic with a Cuiretemperature well above roomtemperature, i.e. more than a doubling as compared to the intrinsic bulk values.

10:30 AM *T8.5
Cross-Sectional STM Studies of III-V Semiconductor Nanostructures. Lloyd Whitman, Naval Research Laboratory, Washington, District of Columbia.

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 (X-STM), including studies of infrared detectors and lasers, and "spintronic" devices. I will show how X-STM 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 GaMnAs. Piotr Boguslawski[1,2], Kevin W. Edmonds[3], K. Y. Wang[3], R. P. Campion[3], N. R.S. Farley[3], B. L. Gallagher[3], C. T. Foxon[3], M. Sawicki[1], T. Dietl[1] and J. Bernholc[2]; [1]Institute of Physisc PAS, Warsaw, Poland; [2]Department of Physics, North Carolina State University, Raleigh, North Carolina; [3]School of Physics and Astronomy, University of Nottingham, Nottingham, United Kingdom.

We present a combined theoretical and experimental study of the ferromagnetic semiconductor GaMnAs. Careful control of the growth and annealing conditions allows us to obtain samples with ferromagnetic transition temperatures up to 159 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:I ions identified in the study of Yu et al. (Phys. Rev. B 65, 201303 (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 as out-diffusion of the compensating Mn:I 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 as 0.7±0.1 eV. Calculations were performed within the Local Spin Density Approximation. In the realistic case of p-type samples, Mn:I double donor occupies the tetrahedral interstitial site T:As , which is 0.35 eV lower in energy than T:Ga. The energy barrier for diffusion of Mn:I(2+) is low, 0.8 eV. This leads to the formation of nearest-neighbor donor-acceptor Mn:I(2+)-Mn:Ga(-) pairs, driven by Coulomb attraction and a strong, short-range antiferromagnetic coupling. The energy for dissociation of Mn:I-Mn:Ga pairs is 1.2 eV. Complexes of nearest neighbor Mn:Ga-Mn:I-Mn:Ga have similar properties. Electric fields induced by the high concentration of substitutional Mn acceptors are shown to lower the diffusion barriers to 0.9±0.1 eV, in satisfactory agreement with experiment. Finally, the kick-out mechanism of diffusion (Mn:I+Ga:Ga → Mn:Ga+Ga:I) is not efficient, since the calculated barrier is about 3 eV. This work is supported by FENIKS project (EC: G5RD-CT-2001-00535), grant PBZ-KBN-044/P03/2001, and grants from US ONR and DoE.

11:15 AM T8.7
Cross Sectional Scanning Tunneling Microscopy Studies of Mn Segregation in GaMnAs Films. J. N. Gleason[1], M. E. Hjelmstad[1], S. Fathpour[2], S. Ghosh[2], P. K. Bhattacharya[2] and R. S. Goldman[1]; [1]Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan; [2]Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, Michigan.

GaMnAs is a promising candidate for spintronic applications compatible 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 GaMnAs are not well understood. Therefore, we have investigated Mn segregation in GaMnAs grown 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 GaMnAs 0.5, 2.5 and 5.0% Mn and AlGaAs layers, sandwiched between thick p+ GaAs layers. Constant current 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 GaMnAs. In the 0.5% Mn films, the nanometer-sized bright regions appear relatively dispersed, with ~5nm separation. For the 2.5 and 5% Mn films, agglomeration of the nanometer-sized bright regions is observed with separations of ~5-10nm, and apparently increases with increasing Mn composition. The apparent Mn clustering does not appear to be affected by the presence of adjacent AlGaAs superlattices, indicating that any local misfit stress does not act as a sink for Mn accumulation. The apparent Mn clustering is likely due to a long-range attractive potential between Mn atoms, and may be associated 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 would in turn lead to a lower self-repulsion of Mn atoms, and an increase in Mn clustering. This work was supported in part by ONR.
[1] M.Berciu et al., Phys. Rev. Lett. 87, 107203 (2001). [2] P. Ebert et al., Phys. Rev. Lett. 83, 757 (1999).

11:30 AM *T8.8
Effects Of Clustering And Dimensionality On The Magnetic Properties Of Diluted Magnetic Semiconductors.
Ravindra N. Bhatt[1], Mona Berciu[2] and Malcom Kennett[3]; [1]Department of Electrical Engineering, Princeton University, Princeton, New Jersey; [2]Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada; [3]Cavendish Laboratory, Cambridge, United Kingdom.

The magnetic properties of diluted magnetic semiconductors (DMS) such as (Ga,Mn)As films, as well as bulk grown crystals for similar materials, have been found to be extremely sensitive to growth conditions, both in terms of the ferromagnetic transition temperature, and details of the magnetization curves. Using an impurity band model for carriers in Mn-doped DMS applicable in the low carrier density regime, we discuss the effects of clustering on the magnetic properties of DMS, using both numerical mean field and Monte Carlo simulations. In addition, we study the effects of dimensionality on the transition temperature and other magnetic behavior, and compare our results with experimental data. * Research supported by the Princeton Center for Complex Materials, under NSF DMR-0213706

SESSION T9: Composition Modulation
Chairs: Brian Spencer and Donna Stokes
Thursday Afternoon, December 4, 2003
Room 209 (Hynes)

1:30 PM *T9.1
Self-Organized Patterns of Compositional Modulation during Strained Alloy Growth. Brian J Spencer and Mihaela Blanariu; University at Buffalo, Buffalo, New York.

Strained solid films are unstable to the formation of surface ripples due to the driving force of strain relaxation. In alloy films, the development of the instability can be modified by the interaction of compositional stress and differences in the surface mobilities of the alloy components. A stability analysis of an isotropic continuum model for strained alloy growth indicates that under certain conditions it may be possible for the mobility difference of surface atoms to stabilize a sustained compositional modulation at the growth front. The steady-state compositional modulation would then be inherited by the bulk as growth proceeds to create a compositionally modulated alloy. Here we summarize recent theoretical efforts which address whether such sustained compositional modulation is possible, and, if so, the resulting patterns of compositional modulation.

2:00 PM *T9.2
Instabilities, Elasticity And Wetting Effect In Single- And Multi-Layer Heteroepitaxial Growth. Rashmi C. Desai and Zhi-Feng Huang; Department of Physics, Univ of Toronto, TORONTO, Ontario, Canada.

During the heteroepitaxial growth of semiconductor films, elasticity plays a crucial role in the initial system instabilities and in their later development to the formation of nanoscale structures. For strained alloy films, the elastic effect comes from the film-substrate misfit strain, compositional stress, and the composition dependence of elastic moduli. Their coupling with the kinetic factors such as the deposition rate determines both the morphological and compositional instabilities during the thin film growth, which can result in the self-organized formation of surface morphological and compositional patterns. For multilayer films composed of various material layers, the coupling of strain fields in different layers as well as the nonequilibrium nature of the growing film are essential in the understanding of the surface and interface morphological instability, and hence that of the growth mechanisms of nanostructures in the overall film (e.g., quantum wires).We will present our theoretical results for stress-driven instabilities in both single- and multi-layer semiconductor films, based on the continuous nonequilibrium models and the elastic analysis. First, we shall discuss the stability properties for single- layer alloy films including the stability diagrams and the behavior of kinetic critical thickness. For the growing multilayer films, we shall present a general method which directly calculates the elastic state of the multilayer system; we apply the results to the tensile/compressive and strain/spacer periodic multilayers. The wetting effect, which arises from the change of material properties across interlayer interfaces is incorporated. It exhibits a significant influence of stabilization on film morphology, including the short-period multilayers. Our results are consistent with the experimental observations in InGaAs and SiGe single-layer alloy films and in AlAs/InAs/InP(001) and Ge/Si(001) multilayer systems. We also give predictions of stability properties for strain-balanced multilayers.

2:30 PM T9.3
Manipulating the Nanoscale Self-Organized Surface Patterns by Long-Range Force Fields. Yanfei Gao, 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. A more powerful and flexible way is to use a layered substrate. Surface properties designed for the applications of those patterns can be obtained by choosing appropriate materials and structures 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 lowest energy stripes can have tunable equilibrium size and orientation. We solve the elastic field in the anisotropic, heterogeneous, three-dimensional half-space by using the Eshelby-Stroh-Lekhnitskii formalism and the Fourier transformation.

2:45 PM T9.4
Self-Assembling Phase Patterns in a Monolayer Adsorbed on a Cylindrical Surface. Wei Hong[1,2] and Zhigang Suo[1,2]; [1]Mechanical and Aerospace Engineering Department, Princeton University, Princeton, New Jersey; [2]Division of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts.

Two-phase monolayer of molecular dipoles adsorbed on a solid substrate can self-assemble into phase patterns, such as periodic stripes and dots. The phase boundary energy drives the phases to coarsen, and the electrostatic energy drives the phases to refine. The phase pattern evolves to minimize the combined free energy. 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 micro-scale 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 strong 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 liu[1], Lugang Bai[1] and Jerry Tersoff[2]; [1]Materials Science & Eng., University of Utah, Salt Lake City, Utah; [2]Thomas J. Waston 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 superlattice. This work is supported by DOE.

3:30 PM *T9.6
Self-Organized Vertical Composition Modulation in GaInAsSb Grown on Vicinal Substrates. Christine A Wang[1] and Christopher J Vineis[2]; [1]Electro-Optical Materials and Devices, MIT Lincoln Laboratory, Lexington, Massachusetts; [2]AmberWave Systems Corporation, Salem, New Hampshire.

GaInAsSb 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 GaInAsSb epilayers grown on (001) GaSb substrates miscut 2 or 6° toward (-1-11)A, (1-11)B, or (101). Examinations of GaInAsSb cross-sections by transmission electron microscopy (TEM) reveal not only a spinodal-like contrast, but also a self-organized and highly regular vertical natural superlattice (NSL). The NSL is observed at the onset of growth; is laterally continuous throughout the epilayer; maintains a consistent periodicity throughout several 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 modulation is typically between 10 and 30 nm, and is dependent on deposition temperature and alloy composition. Furthermore, the natural superlattice can be tilted as much as 4° in addition to the miscut angle of the (001) substrate surface plane. Cross-section field-emission scanning electron microscopy and triple-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 is related to the degree of compositional difference between the GaAs- and InSb-rich GaInAsSb layers in the superlattice. This NSL results from complex interactions between thermodynamic solubility limitations and elastic strain associated with steps of the vicinal substrate 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 coupling of compositional and morphological perturbations. 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. Bortoleto[1], H R Gutierrez[1], M A Cotta[1], J Bettini[1,2] and M M G de Carvalho[1]; [1]LPD/DFA, IFGW/UNICAMP, Campinas, So Paulo, Brazil; [2]LME, LNLS, Campinas, So 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 coherent InGaP layers. Atomic force microscopy investigation shows that the InGaP layer growth conditions are crucial 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 suggest that a periodic strain field forms within the InGaP layer via surface processes. InGaP layers may show both CuPt-type atomically ordered 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 gives rise to lateral dot ordering, transmission electron microscopy (TEM) was performed using a JEM 3010 URP 300 kV TEM. TEM plan-view images from InGaP layers wihout InP dots on top shows bright domains organized 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 plan-view images is associated to small (a few percent) variations in In content. On the other hand, cross-sectional TEM micrographs with g={1/2,1/2,1/2} shows random, weak CuPt domains for samples with and without spatial dot ordering. This fact rules out any correlation between CuPt phenomena and spatial dot distribution. Cross section TEM images clearly show the dot alignment with the contrast modulation in the InGaP buffer layer. Our results show that compositional modulation 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. Yuji Masui, Masayuki Imura, Yu Higuchi, Takahiro Kitada, Satoshi Shimomura and Satoshi Hiyamizu; Physical Science, Graduate School of Engineering Science, Osaka University, Toyonaka,Osaka, Japan.

Self-organized InGaAs/AlAsSb quantum wires (QWRs) were formed on (775)B-oriented InP substrates by molecular beam epitaxy (MBE) for the first time.The QWRs were investigated by atomic force microscope (AFM) and photoluminescence (PL) measurements. Previously we reported self-organized In0.53Ga0.47As/In0.52Al0.48As QWRs grown on (775)B InP substrates which showed good one-dimentionality and emission wavelength in a range of 1.2 micrometer. On the other hand, In0.53Ga0.47As/AlAs0.56Sb0.44 heterostructures lattice matched to InP are interesting for 1.3 micrometer-range optoelectoronic devices because of their large conduction band offset (1.7 eV), which was 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 In0.53Ga0.47As/AlAs0.56Sb0.44 QWRs than (775)B In0.53Ga0.47As/In0.52Al0.48As QWRs. A single In0.53Ga0.48As/AlAs0.56Sb0.44 quantum well (QW) structure was grown on (775)B InP substrates. A single QW and cap layer were nominally 4-nm-thick In0.53Ga0.48As grown at substrate temperature Ts = 530, 550, 570, and 590C. The barrier layers were 10-nm thick and grown at Ts = 510C. According to AFM surface image of the cap InGaAs layers, clear surface corrugation with a vertical amplitude of 1.6 nm and lateral period of 57 nm was observed at Ts = 570C. Hence, we can expect that InGaAs QWRs are self-organized in the InGaAs/AlAsSb QW structure grown on (775)B InP substrates at Ts = 570C. PL spectra from the (775)B InGaAs/AlAsSb QWRs were observed with 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 QWRs grown at Ts = 570C. PL emission was not so strong because of its type II band alignment, which can be improved by introducing additional InAlAs barrier layers.

4:30 PM T9.9

Structural and Optical Properties of InAs/GaSb Nanostructures. Donna W Stokes[1], Jianhua H Li[1], Rebecca L Forrest[3], Santosha L Ammu[1], Julia C Lenzi[1], Simon C Moss[1], Brett Z Nosho[2], Brian R Bennett[2], Edward H Aifer[2] and Lloyd J Whitman[2]; [1]Department of Physics, University of Houston, Houston, Texas; [2]Naval Research Laboratory, Washington, District of Columbia; [3]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 affects 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 $(InAs)_{13}/(GaSb)_{13}$, (each layer is 13 monolayers thick) with InSb interfacial bonds. The samples grown with As_4 and Sb_4 sources demonstrated LCM, while those grown with the As_2 and Sb_4 sources showed no modulations. XRD radial and reciprocal space map (RSM) scans were taken to determine the average morphology of the LCM structures, including the vertical and lateral modulation wavelengths. 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, 155 Á, was twice the period intended by the growers, 80 Á. 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 measured from XSTM and XRD were ~1200 Á and ~600 Á, respectively, where the pure lateral modulation refers only to the lateral thickness undulations. For sample B, the vertical wavelength was also 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 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 $(InAs)_{13}/(GaSb)_{13}$ superlattice with no LCM, sample C. All three samples were designed with a cutoff wavelength of 8 μm. In the sample 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 electron 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(331). Shahram Seydmohamadi, Zhiming M Wang, Vahid R Yazdanpanah and Gregory J Salamo; Physics, University of Arkansas, Fayetteville, Arkansas.

It has been demonstrated that GaAs epitaxial growth on (331) 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 potential to act as a template for uniform quantum wire growth. In this work, we report the use of the GaAs(331) wire-like surface as a template to grow (In,Ga)As quantum wires. The growth was performed by Molecular Beam Epitaxy (MBE) while in-situ Reflection High Energy Electron Diffraction (RHEED) and Scanning Tunneling Microscopy (STM) characterized the surfaces. While GaAs(331) homoepitaxial growth always leads to a faceted ridge-like surface, it is important to note that In0.2Ga0.8As growth over this surface can lead to either quantum wires or a smooth surface depending on growth or 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 corrugated (In,Ga)As/GaAs interface and 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 into 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 T10: Atomic Ordering
Chairs: Andrew Norman and Gerald Stringfellow
Friday Morning, December 5, 2003
Room 209 (Hynes)

8:30 AM *T10.1
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 and (2) changes of macroscopically 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, bond length, etc.)[2,3]. The second area may include the changes in the band structure and various optical properties which often are related to the ordering induced symmetry change (e.g., band gap, effective mass, band offset, optical anisotropy, etc.)[4-7]. 1. A. Mascarenhas and Y. Zhang, The physics of tunable disorder in semiconductor alloys, in Spontaneous Ordering in Semiconductor Alloys, edited by A. Mascarenhas (Kluwer Academic/Plenum Publishers, New York, 2002), p. 283. 2. Y. Zhang, A. Mascarenhas, S. Smith, et al., Phys. Rev. B 61, 9910 (2000). 3. Y. Zhang, A. Mascarenhas, and L. W. Wang, Phys. Rev. B 6412, 125207 (2001). 4. B. Fluegel, Y. Zhang, H. M. Cheong, et al., Phys. Rev. B 55, 13647 (1997). 5. P. Ernst, Y. Zhang, F. Driessen, et al., J. Appl. Phys. 81, 2814 (1997). 6. Y. Zhang, A. Mascarenhas, and L. W. Wang, Phys. Rev. B 63, R201312 (2001). 7. Y. Zhang, A. Mascarenhas, and L. W. Wang, Appl. Phys. Lett. 80, 3111 (2002).

9:00 AM *T10.2
X-ray Scattering Study of CuPt-type Atomic Ordering in $Ga_{0.5}In_{0.5}P$ Alloy Films. Jianhua Li[1], Simon C. Moss[1], Yong Zhang[2] and Angelo Mascarenhas[2]; [1]Physics Department, University of Houston, Houston, Texas; [2]National Renewable Energy Laboratory, Golden, Colorado.

CuPt-type atomic ordering in III-V semiconductor ternary alloy films is a phenomenon known for more than a decade. However, a quantitative characterization of the ordered structures from atomic level to mesoscopic level has not been available until our recent x-ray scattering work. Here, we present a new synchrotron x-ray scattering study of $Ga_{0.5}In_{0.5}P$ alloy films grown by MOCVD and MBE at different temperatures exhibiting CuPt-type atomic 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 atomically ordered structure, including peak splitting, shifting, intensity modulation, and streaking, were also observed. A structural model considering packing of different ordering variants and antiphasing is proposed to give a quantitative explanation of these experimental observations.

9:30 AM T10.3
Self-Organized Modulation and Ordering Structures in Heteroepitaxial GaInP Layers. Jiechao Jiang[1] and Andreas Karl Schaper[2]; [1]Mechanical Engineering Dept., Louisiana State University, Baton Rouge, Louisiana; [2]Materials Science Center, Philipps University, Marburg, Germany.

During heteroepitaxial growth of compound semiconductor alloys, depending on the amount of lattice mismatch and on the growth conditions, internal strains build up leading to characteristic strain relief patterns throughout the layers and at the layer surfaces. Among those processes, one-dimensional nano-structuring may serve as an elegant route to achieving particular device performances of quantum wire arrays. Using mainly electron microscope techniques, we have studied the structural evolution during alternating fractional monolayer by monolayer growth in the metal organic vapor phase epitaxy of GaInP on (001) GaAs with and without miscut. The variations in the spontaneous CuPtB ordering observed in dependence on the growth conditions are described in accordance with the dimer-induced subsurface stress model of intra-plane ordering and surface reconstruction. Whilst exceptionally high degrees of ordering are achieved applying the alternating growth regime, the atomic ordering mechanism influences even the formation of lateral strain and composition modulation. Making use of the opposite mismatch of GaP and InP on GaAs, the accumulation of strain can be forced beyond a value where it is no longer capable of homogeneous elastic accomodation. Under the conditions of islanding, roughening and step bunching of the growing surface, partial strain relaxation produces lateral modulation patterns along the [100] and [010] directions with a wavelength in the order of 50-100 nm. The columnar high-ordering domains thus formed intersect the antiphase domain morphology in quite a regular manner; the lateral size of the domains is rather uniform. In case of no substrate misorientation, faceting of the growth front creates complementary CuPtB type ordering superdomains containing the elementary columnar modulation domains. The results of these structural studies contribute to a closer understanding of the fundamentals of ordering phenomena in semiconductor heteroepitaxy.

9:45 AM T10.4
Effects of Surfactants N and Br on Ordering in GaInP. David C Chapman[1], Alex Howard[1], Loren Rieth[1], Gerald B Stringfellow[1], Y W Ok[2] and T Y Seong[2]; [1]Materials Science, University of Utah, Salt Lake City, Utah; [2]Materials Science, Kwangju Institute of Science and Technology, Kwangju, South Korea.

The formation of the CuPt ordered structure during the OMVPE growth of GaInP is well-established to be due to the surface structure during growth. For this reason, the ordered structure formed and the degree of order have both been found to be dependent on the presence of Sb and Bi surfactant atoms on the surface that are isoelectronic with P. Since both are larger than P, they act to reduce the thermodynamic driving force for ordering. The opposite is expected for N, which is smaller than P. Nevertheless, the addition of N is also found to reduce the degree of order in the GaInP layers, as indicated by both photoluminescence peak energy and TEM/TED observations. Surface photo absorption (SPA) indicates that 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 OMVPE growth. In this case, the mechanism 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 growth 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 substantiated by TEM/TED observations. The effect of Cl was also studied, but Cl has such a dramatic effect on solid composition (Ga/In ratio in the solid) that unambiguous conclusions about the effect of Cl are difficult.

10:30 AM *T10.5
Growth Model for Atomic Ordering: The Quadruple-Period Ordering in GaAsSb Alloys. Shengbai Zhang, National Renewable Energy Laboratory, Golden, Colorado.

It has long been understood that atomic ordering, widely observed in epitaxially grown semiconductor AB_xC_{1-x} alloys, is driven by surface thermodynamics and/or by growth kinetics, but not by bulk thermodynamics. Atomic dimerization 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 size-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, as several experiments have correlated the degree of ordering with the density and orientation of surface steps. However, a microscopic model regarding step-induced 3D stacking based on first-principles theory is still lacking. Recently, a new quadruple-period (QP) ordering was observed in $GaAs_{1-x}Sb_x$ 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 2x4 surface pattern still holds, the surface transforms into a different reconstruction, as seen by reflection high-energy electron diffraction (RHEED). (ii) It has a CuAu-like structure but with a periodic array of antiphase boundaries

along the [110] direction. (iii) The ordering direction is perpendicular to the surface anion 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 quadruple-period of 1.6 nanometer represents probably the longest 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 close relationship between a high-temperature Sb-stabilized (001)-δ_2(2x4) surface reconstruction and the QP ordering is established. It was proposed that an interplay between the already-grown substrate and the reconstructed surface at the growth front could be a general missing link between 2D and 3D ordering in the III-V alloys. In other words, although the surface reconstruction has been established by the growth conditions, there are still remaining degree of freedoms regarding translation and flip/flop of the surface structure with respect to the substrate. This leaves room for the development, via surface energetics, of the final 3D patterns seen by the experiments. Work was in collaboration with I. Batyrev, A. Norman, and S.-H. Wei

11:00 AM T10.6
Effects of Substrate Orientation on the Spontaneous Ordering of GaAsSb Epilayers Grown By Molecular Beam Epitaxy.
Brian P Gorman[1], Reiko Lukic-Zrnic[1], Andrew Norman[2], Terry D Golding[1] and Chris L Littler[1]; [1]Dept. of Physics, University of North Texas, Denton, Texas; [2]National Renewable Energy Laboratory, Golden, Colorado.

GaAs1-xSbx epilayers (0.19 $<$ x $<$ 0.71) grown by molecular beam epitaxy (MBE) on GaAs substrates with various surface orientations were investigated using Fourier transform infrared spectroscopy (FTIR), atomic force microscopy (AFM) and transmission electron microscopy (TEM). Atomic ordering in these epilayers was observed from 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 CuPt-B type ordering is observed in the GaAs1-xSbx grown on A-type GaAs substrate offcuts, as opposed to the more commonly observed B-type. This suggests that A-type steps may play an important role in the CuPt-B ordering process in MBE grown GaAs1-xSbx layers.

11:15 AM T10.7
Nanometer sized Pb(Se,Te) islands and their crystallographic structures. Peter Moeck[1], Armando Acha[1], Jeahuck Lee[2], James Morris[2], Nigel D Browning[3] and Patrick J McCann[4]; [1]Physics, Portland State University, Portland, Oregon; [2]Electrical and Computer Engineering, Portland State University, Portland, Oregon; [3]Chemical Engineering and Materials Science, University of California and National Center for Electron Microscopy, Davis, California; [4]Electrical and Computer Engineering, University of Oklahoma, Norman, Oklahoma.

PbSe islands under in-plane tensile strain were grown on a (111)-oriented PbTe/BaF_2 pseudo-substrate by molecular beam epitaxy. The morphology and crystallographic structure of these islands 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 the halite structure having diameters on the order of 5 nm to 10 nm and respective number densities of approximately 5 x 10^{11} cm^{-2} and 10^{10} cm^{-2} were observed. Regions with small and essentially unstrained atomically ordered islands of a number density of approximately 5 x 10^{11} cm^{-2} 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 islands is discussed and a hypothesis for their existence provided.

11:30 AM *T10.8
Superlattice Ordering In Ternary And Quaternary III/V-Compound Bulk Semiconductors And Quantum Wells.
Gottfried H. Dohler[1], S. Kramer[1], J. Spieler[1], S. Neumann[2], W. Prost[2], F. J. Tegude[2] and P. Kiesel[3]; [1]Inst. Techn. Phys. I, University of Erlangen, Erlangen, Germany; [2]Fachbereich Halbleitertechnik/Halbleitertechnologie, Universitat Duisburg, Duisburg, Germany; [3]Palo Alto Research Center, Palo Alto, California.

It has been known for many years that ternary III/V compound semiconductors like InGaP or InGaAs, grown by metal organic vapor phase epitaxy at sufficiently low temperatures on [001]-oriented (or slightly mis-oriented) substrates exhibit a $CuPt_B$-like crystal structure which results from a superlattice formation due to mono-atomic indium- and gallium-rich layers alternating along one of the two $[111]_B$ crystal directions. This spontaneous ordering leads to a reduction of the crystal symmetry and significant changes of the electronic structure and, as a consequence, of the optical properties. In particular, a strong polarization anisotropy regarding the [110]- and [1-10]-direction for vertical incidence of light, resulting from the ordering-induced splitting of the Γ_8-valence band edge, has been observed and used for prototype opto-electronic devices. In this paper we report on ordering phenomena in ternary InGaAs and quaternary InGaAsP, lattice matched to InP. These materials are particularly appealing for opto-electronic device applications, as they cover the interesting wavelengths of 1.3 and 1.55 μm for optical fiber communication. The quaternary system InGaAsP is also of significant fundamental interest as it implies the possibility of ordering on both the group-III- and the group-V-sub-lattices. In particular, the question arises whether ordering favors bonds of relatively similar length (i.e. InP- and GaAs-bonds) or rather bonds of maximum difference in length (i.e. InAs- and GaP-bonds). Interestingly our experiments are strongly supporting the latter option, evidenced by the observation of the largest ordering-induced valence band splitting ever reported. This finding is consistent with the predictions of the "stepgrowth-model" for the superlattice formation. In addition we will report on our most recent elecroabsorption studies in ordered quantum wells which have provided unambiguous evidence for the theoretically expected piezoelectric fields of the order of 100 kV/cm.