Friday Morning, November 7, 2003

Semiconductors
Room 321/322 - Session SC+NS-FrM

Low Dimensional Structures and Amorphous Silicon
Moderator: A.C. Gossard, University of California, Santa Barbara

8:20am **SC+NS-FrM1 Self-Organized Template Formation for Quantum Dot Ordering**, ***R. Noetzel***, Eindhoven University of Technology, The Netherlands **INVITED**

The realization of semiconductor quantum dot arrays and networks in well-defined lateral arrangements is essential for the development of future quantum functional devices. We have successfully created these kinds of networks by self-organized anisotropic strain engineering of (In,Ga)As/GaAs templates for the ordering of InAs quantum dots by local strain recognition: On GaAs (100) substrates, during molecular beam epitaxy of a strained (In,Ga)As/GaAs superlattice, elongated (In,Ga)As quantum dots develop into very uniform and long quantum wire arrays with a well-defined lateral periodicity. Quantum wire formation relies on the anisotropic adatom surface migration and In desorption during annealing of the layers of elongated quantum dots after capping with a thin GaAs layer. The accumulation and improvement of the uniformity of the generated anisotropic strain field in superlattice growth provides a well-defined template for the ordering of InAs quantum dots grown on top in one-dimensional arrays. On high-index GaAs (311)B substrates, strain induced growth instability of (In,Ga)As layers occurs to from a matrix of closely packed cells. The related strain distribution constitutes a uniform template for the full control of InAs quantum dot nucleation in a two-dimensionally connected network. Excellent structural perfection and optical properties are established for these ordered InAs quantum dot arrays by atomic force microscopy, high-resolution X-ray diffraction, and photoluminescence spectroscopy. Temperature dependent photoluminescence measurements reveal efficient carrier transfer from the templates, which themselves are distinct one- and zero-dimensional quantum nanostructure arrays, to the quantum dots and within the quantum dot arrays. Hence, self-organized anisotropic strain engineering provides a unique route for the realization of well-defined and functional quantum dot arrays and networks of high quality.

9:00am **SC+NS-FrM3 Self-Assembly of Nanostructures in GaAs/InAs and GaAs/GaSb Multilayer Structures**, ***C.A. Pearson***, *C. Dorin, J. Mirecki Millunchick, Y. Chen, B.G. Orr,* University of Michigan, Flint

Reproducibly obtaining regular arrays of phase-separated material is a promising way to acquire low dimensional structures such as quantum dots or wires. Short period superlattice (SPS) structures, where each layer is approximately one or two monolayers thick, can spontaneously phase separate under certain growth conditions resulting in compositional modulations. The appearance of lateral composition modulation is correlated to roughening of the surface front. To further elucidate this progression, in situ scanning tunneling microscopy (STM) was used to examine SPS structures at integral and fractional periods, where one period consists of 2 monolayers (ML) of GaAs followed by 2 ML of InAs or GaSb. For both integral and fractional periods, the surfaces are quite distinct. The as-grown InAs surface is decorated with anisotropic islands that exhibit a (2x4) reconstruction upon a terrace with a (nx3) reconstruction. The GaAs terminated surfaces are characterized by flat mesa structures surrounded by deep trenches. With increasing number of periods, both surfaces evolved towards greater long scale roughness. Furthermore, the islands (InAs terminated) or trenches (GaAs terminated) become larger and show a preferential lateral arrangement with a characteristic separation in the [110] direction of ~20 nm, which corresponds to the modulation wavelength observed using other techniques. Similar results are also observed in the GaAs/GaSb structure where islanding of GaAs is observed in a GaSb matrix. These results are consistent with continuum perturbation models that predict the coupling of morphological and compositional instabilities under the appropriate circumstances.

9:20am **SC+NS-FrM4 Tuning of the Electronic Properties of Self-assembled InAs/InP(001) Quantum Dots by Rapid Thermal Annealing and Low-energy Ion Implantation**, ***C. Dion***, École Polytechnique de Montréal, Canada*; C. Nì Allen, S. Raymond, P.J. Poole,* National Research Council, Canada*; F. Schiettekatte,* Université de Montréal, Canada*; R.A. Masut, P. Desjardins,* École Polytechnique de Montréal, Canada

We have investigated the effect of post-growth rapid thermal annealing on the low temperature photoluminescence (PL) spectra of self-assembled InAs/InP(001) quantum dots (QD) grown by chemical beam epitaxy (CBE) and metal-organic vapor phase epitaxy (MOVPE). Annealing temperatures T@sub a@ and times t@sub a@ ranged from 650 to 800 °C and 30 to 210 s, respectively. As-grown samples are characterized by a broad emission peak centered near 800-900 meV arising from the e1-hh1 transition of an ensemble of QDs and a narrow peak near 1100 meV from radiative recombination in the wetting layer. Detailed analysis of the QD PL emission reveals that it is composed of up to 9 peaks corresponding to families of dots emitting at different energies. A blueshift of the QD transitions, resulting from intermixing, is observed upon annealing. It increases with T@sub a@ and t@sub a@; blueshifts of up to 90-100 meV are obtained for annealing time of 210s at 800 °C. While the PL emission energies of the various QD families shift at different rates upon annealing, their width remains constant. This behavior is consistent with inhomogeneous broadening dominated by monolayer height fluctuations in InAs/InP(001) dots. In order to obtain larger blueshifts, we studied the effect of introducing point defects into thick InP cap layers, either by growing InP at low temperature or by implanting P at energies sufficiently low to insure that the InAs QDs are not damaged. Such point defects, located far from the QDs, dramatically increase diffusion rates; shifts of up to 250 meV have been obtained following annealing at 765 °C for 90 s.

9:40am **SC+NS-FrM5 Anisotropic Stress Relaxation and Ordering of InAs/GaAs Quantum Dot Superlattices**, ***W. Ye***, *M. Reason, X. Weng, R.S. Goldman,* The University of Michigan

Recently, self-assembled quantum dot (QD) superlattices (SLs) have shown significant promise for a wide range of electronic and optoelectronic device applications. In general, self-assembled QD formation is driven by the elastic relaxation of stress via island nucleation. The vertical stacking of QDs is often explained by the preferred nucleation of islands at strain energy minima directly above buried dots. However, the mechanisms of lateral ordering of QD arrays are the subject of continued debate. For example, anisotropic lateral alignment of QDs has been observed in a number of materials systems. A significant remaining question concerns the relative effects of buffer layer patterning and anisotropic stress relaxation on this lateral QD alignment. Therefore, we have examined the patterning effects of buffer layers, as well as the stress relaxation process during the growth of stacked QDs. Our QD SLs consisted of 2.6 ML InAs and 5 nm GaAs grown by molecular beam epitaxy at 500°C. Prior to QD deposition, GaAs buffer layers were grown at 580°C and/or 500°C. During QD growth, reflection high energy electron diffraction (RHEED) reveals a streaky to spotty pattern transformation, typical of the Stranski-Krastanov (S-K) growth mode transition. However, simultaneous wafer curvature measurements using multi-beam optical stress sensor (MOSS) reveal that stress relaxation occurs after the S-K growth mode transition is complete. Ex-situ atomic force microscopy measurements indicate a preferential alignment of QDs along the [-110] direction. This anisotropic alignment is enhanced as the number of SL periods increases and may be due to pre-patterning by the 500°C buffer layer. We will discuss the relative roles of buffer layer patterning and anisotropic stress relaxation on QD ordering. This work was supported in part by DOE (Photovoltaics Beyond the Horizon Program), ARO (MURI Program), and NSF (Nanoscale Exploratory Research Program).

10:00am **SC+NS-FrM6 Ge Island Nucleation on Large-Miscut Si(001) Surfaces**, ***K. Ohmori***, *Y.L. Foo, S. Hong, J.G. Wen, J.E. Greene, I. Petrov,* University of Illinois at Urbana-Champaign

We study self-organized growth of Ge nanostructures on Si surfaces with large off-[001]-axis miscut as a function of the tilt angle @theta@ and in-plane azimuth angle @phi@ with respect to the [100] direction. The off-axis surfaces were fabricated using focused ion beam (FIB) to precisely pattern a variety of structures such as trenches, concave cones, and square-pyramids on Si(001) surfaces. During the FIB processing, the Si(001) substrates were covered with 200-nm-thick protective SiO@sub 2@ films. A 50-nm-thick Si buffer layer was grown at 800°C by ultrahigh vacuum gas-source molecular beam epitaxy using Si@sub 2@H@sub 6@ precursor prior to Ge deposition at 600°C using Ge@sub 2@H@sub 6@. The nominal thickness of the Ge layer is about 7 ML. Diverse Stranski-Krastanov growth modes (Ge domes, elongated islands, and nanowires) were observed as a function of @theta@ and @phi@, which we attribute to differences in anisotropic-strain relief mechanism. While on a vicinal (001) surface (@theta@ = 0.3°), dome-shaped Ge islands with a density of 30.9 µm@super -2@ are formed, the island density increases by 30% on a surface with @theta@ = 5° for all @phi@-values . In the range of @theta@ = 10 to 20°, elongated island shapes emerge in directions near @phi@ = 45 n° (n = 1, 3, 5, 7), while at @phi@ = 90 n° (n = 0, 1, 2, 3) island nucleation is

suppressed. With @theta@ @>=@ 25°, Ge nanowires with a length of about 2 µm are formed on planes with @phi@ = 45 n° ± 15° (n = 1, 3, 5, 7).

10:20am **SC+NS-FrM7 Bond-Centered Hydrogen in Amorphous Silicon: New Infrared Studies***, **J.-F.T. Wang**,* Vanderbilt University*; G. Lüpke,* The College of William and Mary*; L.C. Feldman, N.H. Tolk,* Vanderbilt University

Recent infrared absorption spectroscopy measurements taken at 77 K on initially hydrogen free amorphous silicon following hydrogen implantation at low temperature, exhibit an absorption line associated with the bond-centered (BC) hydrogen local vibration stretching mode at 1993 cm-1. This line, newly observed in amorphous silicon, appears at the same wavelength seen in crystal silicon following hydrogen implantation at LN temperatures.@footnote 1,2@ These results indicate that the bond-center (BC) hydrogen defect structure can form in amorphous silicon as well. The experimental data give insight into recent molecular dynamic simulations involving hydrogen's role in the amorphous-to-nanocrystalline phase transition in amorphous silicon.@footnote 3@ In both the crystalline and amorphous case, the 1993 cm-1 line disappears when the samples are annealed to room temperature. However only in the crystalline silicon case does the migrating hydrogen reappear in other IR-active defect sites.@footnote 1,2@ @FootnoteText@ @footnote 1@M. Budde, G. Lüpke, C. Parks Cheney, N. H. Tolk, and L. C. Feldman, Phys. Rev. Lett. 85, 1452 (2000). @footnote 2@B. Holm, K. Bone Nielsen, and B. Bech Nielsen, Phys. Rev. Lett. 66, 2360 (1991). @footnote 3@Saravanapriyan Sriraman, Sumit Agarwal, Eray S. Aydil & Dimitrios Maroudas, Nature (London) 418, 62 (2002).

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