Semiconductors
Room 304C - Session SC-TuA

Semiconductor Heteroepitaxy and Nanostructures

Moderator: R.S. Goldman, University of Michigan

1:20pm **SC-TuA1 Lattice Mismatched Heteroepitaxy: Evolution and Revolution***, **E.A. Fitzgerald**,* Massachusetts Institute of Technology **INVITED**

The scientific understanding of lattice-mismatched epitaxy has lead to a third era in the applications of epitaxy. Epitaxy was applied in applications benefiting from lattice-matched materials, and has migrated to applications with mild lattice-mismatch, such as the SiGe HBT and the InGaAs pHEMT. Today, we are able to create relaxed lattice constants that have significant lattice-mismatch with respect to bulk substrate, and in turn use those lattice constants to create extremely high levels of strain in new and conventional materials. In this talk, we will review the general principles of strain-relaxed epitaxy and show how new SiGe templates on Si have extended the electron and hole mobility in SiGe materials to unforeseen enhancements. Such enhancements promise to increase the current drive in MOSFET transistors at a time when smaller transistors are losing their driving efficacy as scaling continues. We show that strained SiGe nanochannels are most likely shaping the vertical wavefunction of carriers, leading to the very high enhancements in mobility despite very high vertical fields. New structures that not only add strain but are further engineered for robust processing will be presented.

2:00pm **SC-TuA3 Strain Relaxation of MBE-grown Step-Graded Metamorphic InAsP Buffers on InP Substrates***, **M.K. Hudait**, Y. Lin, S.A. Ringel,* The Ohio State University

Step-graded metamorphic InAsP buffers grown on InP substrates to increase the substrate lattice constant are of interest to support a range of high-speed electronic and infrared optoelectronic devices. Recent work by our group has shown that grading the composition of the anion sublattice using InAsP buffers as opposed to the group-III cation sublattice using InAlAs buffers is advantageous for MBE growth for such applications since decoupling the growth rate from the composition control results in superior morphological and thermophotovoltaic device properties. Here, we discuss the strain relaxation properties of step-graded InAs@sub y@P@sub 1-y@ (y=0.32-0.4) buffers, representing a total misfit of ~1.1-1.2% with respect to InP. For this study, InAsP buffers were grown on both (100) and 2° off-cut (100) InP substrates under identical MBE growth conditions with an average grading rate of 20% As/µm. The relaxation of each layer within each buffer was measured along [1-10] and [110] directions using TAXRD to evaluate asymmetric relaxation and tilt relative to the initial substrate orientation. For both substrate types, the strain relaxation was found to be symmetric and greater than 90% for the top InAs@sub 0.4@P@sub 0.6@ layer. This indicates that @alpha@ ([1-10] direction) and @beta@ ([110] direction) slip systems have similar activation energies for dislocation nucleation. Moreover, a small epilayer tilt of ~20-190 arcsec was observed for both substrate orientations, which indicates that tilt generated by @alpha@ and @beta@ dislocations will be in proportion to the substrate offcut resolved in [110] and [1-10] directions, respectively. The relation between these observations and properties of group-V and group-III core dislocations will be made to optimize the growth of these buffers. Correlations with the strain relaxation properties, surface morphology and cross-sectional interface properties will also be made as a function of substrate misorientation.

2:20pm **SC-TuA4 Molecular Beam Epitaxy of High-quality Ge on Si by Self-directed "Touchdown" of Nanoscale Seed Pads Through a Thin SiO2 Layer***, Q. Li, D. Leonhardt, Y.B. Jiang, H. Xu, S.R.J. Brueck, S. Hersee, **S.M. Han**,* University of New Mexico

Growing a lattice-mismatched, dislocation-free epitaxial film on Si has been a challenge for many years. Herein, we exploit nanoheteroepitaxy to grow high-quality Ge epilayer on Si. A 1.2-nm-thick chemical SiO@sub 2@ film is produced on Si in a H@sub 2@O@sub 2@ and H@sub 2@SO@sub 4@ solution. When the chemically oxidized Si substrate is exposed to Ge molecular beam, relatively uniform-size nanoscale seed pads form in the oxide layer and "touch down" on the underlying Si substrate. Although the "touchdown" location is random, the seed pad growth is self-limiting to 7 nm in size. Upon continued exposure, Ge selectively grows on the seed pads rather than on SiO@sub 2@, and the seeds coalesce to form an epitaxial lateral overgrowth (ELO) layer. The Ge ELO layer is characterized by high-resolution, cross-sectional transmission electron microscopy (XTEM), Raman spectroscopy, and etch-pit density (EPD). The XTEM images reveal that the Ge ELO layer is free of dislocation network and that the epilayer is fully relaxed at 2 nm from the heterojunction. The Raman shift of Ge optical phonon mode exactly matches that of relaxed bulk Ge, further supporting that the ELO layer is fully relaxed. The XTEM images, however, show that stacking faults exist near the Ge-SiO@sub 2@ interface. A small fraction (~4x10@super -3@%) of these stacking faults propagate to the epilayer surface and form etch pits, when immersed in a solution containing HF, HNO@sub 3@, glacial acetic acid, and I@sub 2@. The resulting EPD is consistently less than 2x10@super 6@ cm@super -2@. The reduction of strain density near the Ge-Si heterojunction, leading to high quality Ge ELO layer, is mainly attributed to a high density (~10@super 11@ cm@super -2@) of nanoscale Ge seed pads interspaced by 2- to 12-nm-wide SiO@sub 2@ patches. This "touchdown" technique may potentially enable growing other highly lattice-mismatched epilayers on Si, such as GaN and SiC.

2:40pm **SC-TuA5 Tuning of the Emission Wavelength of Self-assembled InAs/InP (001) Quantum Dots using Grown-in Defects and Ion Implantation***, **C. Dion**, N. Shtinkov,* École Polytechnique de Montréal, Canada*; S. Raymond,* Conseil National de Recherche du Canada, Canada*; M. Chicoine, F. Schiettekatte,* Université de Montréal, Canada*; P.J. Poole,* Conseil National de Recherche du Canada, Canada*; R.A. Masut, P. Desjardins,* École Polytechnique de Montréal, Canada

We have investigated the effect of post-growth rapid thermal annealing (RTA), grown-in defects, and ion implantation 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) in order to develop a detailed understanding of the key diffusion mechanisms involved in such defect-mediated intermixing techniques. In untreated samples, blueshifts of up to 90 meV in the PL spectra are observed after RTA at 800 °C for 210s with no broadening of the emission peak. We attribute this thermally induced shift to the diffusion of group V atoms between the QD and the surrounding material. In order to promote interdiffusion and to obtain larger blueshifts, we have studied the effect of introducing point defects into an InP capping layer, far from the QD region, either by growing InP at low temperature or by implanting P atoms at doses ranging from 10@super11@ to 10@super 14@ ion/cm@super 2@. The introduction of grown-in defects results in a marked increased in PL shifts, which can reach up to 250 meV following RTA at 765 °C for 90 s, revealing that the excess of points defects in that layer promote interdiffusion in the QD region. Even more dramatic effects are measured in ion implanted sample for which significant blueshifts of 300 meV can be observed following anneals at temperatures as low as 400 °C. In order to quantify these effects, we carried out tight-binding calculations of the transition energies in thin diffused quantum wells. Experimental results for the emission of the wetting layer and our simulations indicate that ion implantation leads to an important reduction of the activation energy for As/P interdiffusion to values as small as 0.4 ± 0.2 eV.

3:00pm **SC-TuA6 Gated Si/SiGe Quantum Dots with Low Charge Noise***, **L.J. Klein**, S. Goswami, K.A. Slinker, K.L.M. Lewis, S.N. Coppersmith, D.W. van der Weide, M.A. Eriksson,* University of Wisconsin, Madison*; J.O. Chu, J.A. Ott, P.M. Mooney,* IBM, TJ Watson Research Center

The stability and noise affecting single electron charging in quantum dots fabricated in a Si/SiGe heterostructure are investigated. Electron beam lithography and subsequent reactive ion etching are used to define the quantum dot. The dot potential and electron density are modified by laterally defined side gates in the plane of the dot. Low temperature measurements (0.2 K) show Coulomb blockade with a single electron charging energy of 4 meV. The long term stability of the Coulomb blockade oscillations is determined in part by the number and stability of electrons captured in trap states in the vicinity of the quantum dot. Motion of this trapped charge modifies the dot potential and is detected as discrete shifts in the Coulomb blockade peak positions. Thermally annealing the sample (400C in Ar) after reactive ion etching reduces the charge noise from such trap states, allowing the acquisition of stable Coulomb diamond data over several hours. Tunnel-coupled double quantum dots have been fabricated and measured using similar techniques. The potential application of such Si/SiGe quantum dots for spin based quantum computation is discussed.

3:20pm **SC-TuA7 Blue Photoluminescence of Si Nano-crystallites Embedded in Silicon Oxide*, G.-J. Kim*,** *J.H. Kim, K.A. Jeon, S.Y. Lee,* Yonsei University, Korea

Synthesis and luminescent characteristics of Si nano-crystallites are reported depending on deposition condition. Si nanocrystalline thin films on p-type (100) silicon substrate have been prepared by a pulsed laser deposition (PLD) technique using a Nd:YAG laser. The Si nano-crystallites with the average size of 2 nm are observed in the SiO@sub 2@ matrix. Strong blue photoluminescence has been observed at room temperature. The optical and structural properties of thin films have been investigated as a function of laser energy density, ambient gas pressure, annealing, and oxidation process. These results indicate that the blue photoluminescence of Si nano-crystallites is related to the quantum size effect of Si nanocrystallites.

3:40pm **SC-TuA8 Silicon Nanocrystal Formation in an Oxide Matrix: Chemical and Strain Effects*, D. Yu*,** *G.S. Hwang,* The University of Texas at Austin

Nanocrystalline Si (nc-Si) embedded in an oxide matrix has received great attention due to its promising applications for advanced electronic and optical devices. The unique electrical and optical properties of oxide-embedded nc-Si appear to be strongly influenced by the crystallite size, shape, density, and oxide composition. It is therefore necessary to develop a detailed understanding of the nc-Si growth. We have developed a multiscale computational model for nc-Si synthesis in an oxide matrix by phase separation of silicon suboxide. This multiscale approach combines i) first principles quantum mechanics calculations of fundamental processes and ii) kinetic Monte Carlo simulations of long-time scale phase separation. Using the computational approach, we have identified formation mechanism of Si clusters in silicon suboxide. In this talk, first we will present fundamental processes involved in the phase separation including: i) Si interstitial behavior in an oxide and ii) O diffusion energetics which depends on strain and chemical environment. Based on these results, we will discuss the relative contribution of strain and suboxide penalty to the phase separation. Finally, we will present the process of Si particle formation, together with a comparison to experimental observations.

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