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Session GG: Quantum Effect Materials: Quantum Dots II

Session Chairman: C.M. Sotomayor Torres, Nanoelectronics Research Centre, Department of Electronics and Electrical Engineering, University of Glasgow, Glasgow, G128QQ, UK. Co-Chairman: TBA

1:30PM, GG1+

"Structural Transition in Strained Epitaxial Island Growth:" YONG CHEN, Jack Washburn, Materials & Molecular Research, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720

The structures of lattice-mismatched Ge and InGaAs islands grown on Si and GaAs substrates, respectively, have been studied with transmission electron microscopy (TEM) and atomic force microscopy (AFM). Based on experimental observations, theoretical models are proposed to explain the processes of nucleation and growth of the strained islands, and dislocation formation mechanisms in these islands. The stress field in lattice-mismatched islands with different morphologies are calculated analytically by continuum elastic theory, the strain energies can then be calculated and compared with surface energies. From thermodynamic calculations, it has been shown that there is a nucleation energy barrier for island nucleation, which decreases vs island size. When island size exceeds a critical value, an island can nucleate thermally with a low energy barrier. The critical island size for nucleation decreases with increasing lattice-mismatch, therefore may merge to form flat complete layers. After islands nucleate, the total free energy decreases vs island size, which causes growth and coarsening of islands. However, it is also shown that the stress concentration near island edges, which increases with island size, may kinetically prevent adatoms on the substrate from reaching the island edge. When island reaches a certain size, then it can only grow slowly via adatoms deposited directly on the island surface. Quantitative calculation indicates that this effect may lead to a homogeneous distribution of island sizes and spacing. When island size increases further, our experiments show that Frank partial dislocations are formed by a growth error at the island edge, resulting in a stacking faults that extends during further growth of the island. This nucleation of a misfit dislocation locally reduces the stress concentration at the island edge permitting resumption of rapid growth. Shockley partial dislocation then nucleates later from the surface at the edge of the stacking fault, and glides in removing the stacking fault and reacting with the Frank partial to form a perfect 90deg. dislocation. An atomic model is proposed to explain the formation of the Frank partial, and the critical island size for dislocation nucleation is calculated.

1:50PM, GG2

"Self-Limiting Growth Kinetics of 3D Coherent Islands: A Route to Monosized Quantum Dot Arrays:" KEMING CHEN, D.E. Jesson, S.J. Pennycook, T. Thundat, R.J. Warmack, Solid State Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6031

The self assembled growth of three-dimensional (3D) coherent islands is an area of great topical interest for their potential applications to quantum dot devices. In this paper, we present experimental and theoretical results that reveal an important new phenomenon, the self-limiting growth behavior of coherent, faceted islands. This new mechanism could provide a new rout to the fabrication of monosized quantum dot arrays.

To reveal the growth kinetics, we investigate 3D island growth by post-deposition annealing of a metastable two-dimensional (2D) $Ge_{0.5}Si_{0.5}$ strained film. This approach emulates equilibrium surface conditions, at least locally, as close as possible. We show that large strained and faceted 3D islands kinetically resist further growth during the annealing, even though it is thermodynamically favorable to form larger islands. We establish that an activation barrier exists to the completion of strained facets when the island is sufficiently large. This is primarily associated with the highly stressed region near the base of the 3D island. The barrier height increases with the island size. This resistance to further growth therefore results in a self-limiting growth regime. The self-limiting effect provides a natural explanation for many interesting features observed in the growth of coherent islands, including surprising island size uniformity and high number densities. Although a self-limiting could also exist to the growth of a non-faceted coherent island due to its local stress field, we emphasize that the nucleation kinetics of an island facet would induce much more severe self-limiting effect on the island growth. One important consequence of the faceting growth would allow us to fabricate small and uniform islands even for low misfit systems.

More generally, our results provide new and important insights into the kinetics of stress-driven 2D/3D transitions which may be applicable to other strained epitaxial systems. Based on this understanding of the self-limiting growth of coherent islands, we are able to control the growth kinetics of 2D/3D transition to attain a uniform size distribution. Since the individual islands are responsible for the self-limiting behavior, the islands sizes and island number densities can be sensitively "tuned" by the misfit strain and/or thickness of pre-annealing strained films, as well as the annealing conditions. This demonstrates that post-deposition annealing of strained films may provide a better way of fabricate monosized quantum dot arrays for various device applications.

2:10PM, GG3

"Quantum Rings Fabrication and Optical Properties: C. GUASCH, J.A. Mejia Galeana, M.C. Holland, C.M. Sotomayor Torres, Nanoelectronics Research Centre, Department of Electronics and Electrical Engineering, University of Glasgow, Glasgow, G12 8QQ, UK

The first reason to fabricate new quantum features like quantum rings is to use near-field scanning of microscopy [1] to investigate single nanostructure. The spatial resolution afforded by this new technique should visualization of the oscillator strength and excitonic wavefunction inside a ring by measuring the emission into distribution along its diameter. Quantum rings could become the first block of built-in optical quantum interface system. Coupled rings and connections to other elements of the same nanometer scale could produce interferences and be useful in all optical devices.

The fabrication of GaAs-AlGaAs quantum rings using electron beam lithography and dry etch described. Quantum rings of outer diameter varying from 400 to 200 nm and of wall thickness varying from electron microscopy shows good geometrical shapes of these rings despite the challenge of etching a deep hole free standing structures like rings.

Low temperature photoluminescence (PL), photoluminescence excitation (PLE) and Raman scattering been used to characterize rings of different sizes. The PL spectrum for rings of 25 nm wall thickness is found blue shifted with respect to the as-grown multiple quantum well heterostructure. The integrated emission rings is about the same as the as-grown material after correction of the filling ratio. PLE and Raman scattering allow to separate quantum confinement from other contributions. Results from all sets of rings will be presented. Best suited rings for near-field scanning optical microscopy are available.

2:30PM, GG4 On page 72(?) of the Technical Program of the Electronic Materials Conf., 1996

"Strain-Field Effects on Bank Gap and Bank Alignment in Pseudomorphic Zero-and One-Dimensional Structures:" MIN YANG, J.C. Sturm, Department of Electrical Engineering, Princeton University, Princeton, NJ 08540; Jean Prevost, Department of Civil Engineering and Operations Research, Princeton University, Princeton, NJ 08540

Recently there has been an increasing interest in zero-dimensional (0-D) and one-dimensional (1-D) pseudomorphically strained structures. The strain distributions in these structures are very different from those in two-dimensional (2-D) biaxially-strained layers. The effect of the strain on the bands of the 0-D and 1-D structures is not well understood. In this paper, we investigate strain fields for several 0-D and 1-D Si $_{1-x}$Ge$_x$/Si structures using both analytic methods and finite element simulation. The calculation of band alignments and band gaps follows the theories of Van de Walle [1] and Pollak [2]. The strain distribution obtained only relies on the shape of the structure but not on the size. For ideal structures with high symmetry such as pseudomorphically strained Si $_{1-x}$Ge$_x$ cylinders and spheres inside a Si matrix, the conduction band (CB) minimum is in the Si matrix near the interface, while valence band (VB) maximum is in the Si $_{1-x}$Ge$_x$ inclusion, i.e. the CB minimum and the VB maximum are at different points in real space.

Experimental results have been obtained for Si $_{1-x}$Ge$_x$ wires and dots grown on the bottom of V-grooves etched by KOH in a Si substrate [3,4]. We have calculated the band structure of these triangular cross-sectional wires and have found that again the CB minimum lies in the Si near the bottom of the V-groove and the VB maximum is in the Si $_{1-x}$Ge$_x$ wire at the corner on the top interface. These results can be used to explain the photoluminescence spectra of these structures, which are quite different from those in 2-D quantum wells.

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1. C.G. Van de Walle, Phys. Rev. **B39**, 1871 (1989).
2. F.H. Pollak, and M. Cardona, Phys. Rev. **172**, 816 (1968).
3. A. Hartmann, L. Vescan, C. Dieker, and H. Luth, J. Appl. Phys. **77**, 1959 (1995).
4. N. Usami, T. Mine, S. Fukatsu, and Y. Shiraki, Appl. Phys. Lett. **64**, 1126 (1994).

2:50PM, GG5

"Optical Properties of Arrays of Quantum Dots with Internal Disorder:" E.V. TSIPER, A.L. Efros, Department of Physics, University of Utah, Salt Lake City, UT 84112

The theory of PL and PLE spectra of large arrays of isolated self-organized quantum dots is developed to interpret the recent photoluminescence data [1]. It is assumed that all dots contribute independently to optical processes and that emission of light occurs from the ground state of each dot only. The theory explains the large observed shift between the PL and PLE peaks. It is shown that the shift is equal to the average distance between the ground and first excited states of the dots. It is also shown that PL and PLE data give statistical correlation between positions of the ground and excited energy levels in the presence of disorder. The lineshape of the spectra is calculated for the case of alloy disorder. The influence of the rough boundary of quantum dot is also discussed. The calculated PL and PLE lineshapes are in good agreement with the experimental data [1]. We also predict an unusual sensitivity of the lineshape to the magnetic field. This happens because the dots that accidentally have small disorder-induced splitting of the excited level are strongly affected by a relatively weak magnetic field.* Financed by QUEST of UCSB subagreement KK3017.

[1} S. Fafard, D. Leonard, J.L. Merz, and P.M. Petroff, Appl. Phys. Lett., **65**, 1388, 1994.
