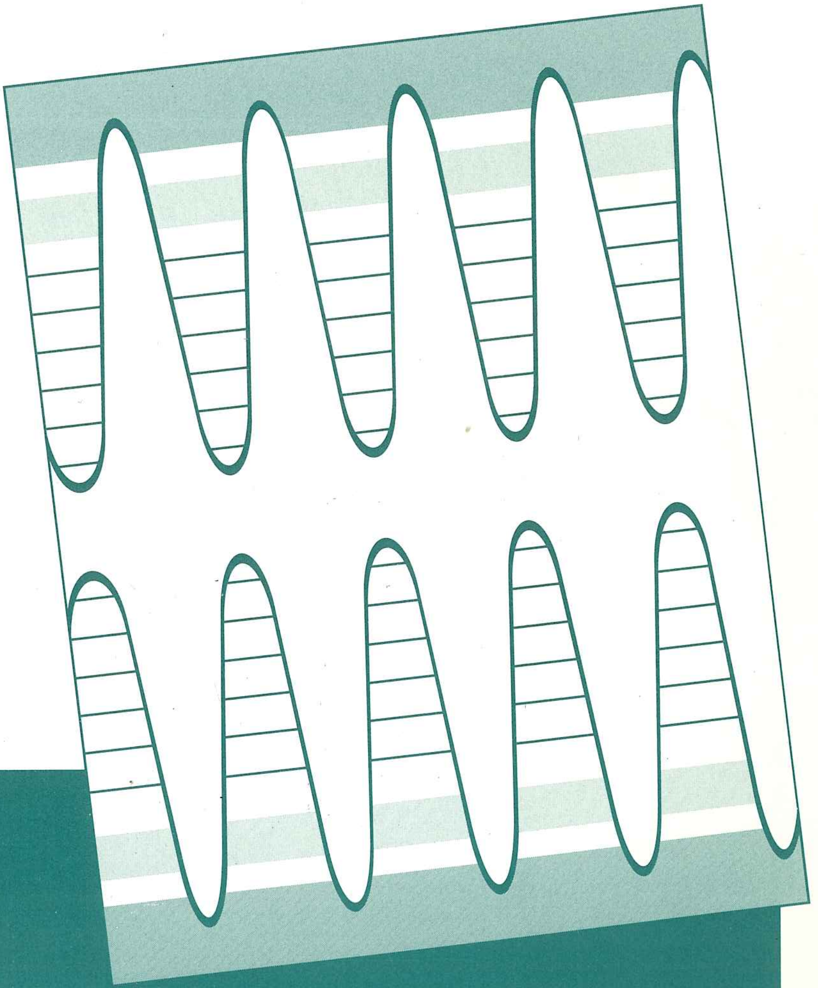
J. C. Sturm

43rd

2001
ELECTRONIC MATERIALS CONFERENCE



Featuring...
Special Electronic Materials Exhibit

University of Notre Dame

Notre Dame, Indiana

June 27-29, 2001

TMS

Technical Program with Abstracts

grown by low pressure metalorganic vapour-phase epitaxy (MOVPE) on (100) GaAs substrate tilted towards the (111)B plane by 15°. Power-dependent photoluminescence (PL), and optical gain measurements have been carried out and the consequences of our findings are directly compared to the emission characteristics of our InP/GaInP QD injection lasers. At low excitation densities we observe strong PL due to the QD ground state at 1.69-1.71 eV (90K) with a FWHM of 30 meV due to nonuniformities in size and shape. At higher excitation densities up to 4 QD-related PL transitions appear. They are almost equally spaced with an energetical distance of approximately 45 meV. At 90 K our lasers with a cavity length of 1.5 mm emit at 1.75 eV which is identified as lasing due to the first excited state of the QDs. Well above threshold multimode lasing is found and explained in terms of spectral hole burning due to a narrow homogeneous linewidth and the absence of coupling between different dots. Towards higher temperatures the emission blueshifts by about 20 meV to the next higher excited state of the QDs. Optical gain measurements clarify this behaviour. In contrast lasers with a 3 fold stack of QDs and a comparable cavity length show ground state emission up to room temperature due to a larger filling factor and thus reduced gain saturation. The temperature dependence of the threshold current density is analyzed in detail. At low temperatures an almost constant threshold (approx. 250 A/cm^2) validates the expected behaviour for QD lasers. Towards 300K a thermally activated increase is found and a T0 of 40K to 60 K at RT is determined. The rise in threshold current density is accompanied by a dramatic decrease of the quantum efficiency. Our observations will be described in terms of carrier leakage and nonradiative recombination. Finally the performance of the QD lasers is compared to QW lasers emitting at similar wavelengths and concepts for further improvement are discussed.

Session Q: Materials Integration: Wafer Bonding and Alternate Substrates

Thursday AM	Room: 136
June 28, 2001	Location: University of Notre Dame

Session Chairs: Pete Moran, University of Wisconsin, Chem. Eng. Dept., Madison, WI 53706 USA; Karl Hobart, Naval Research Laboratory, Washington, DC 20375 USA

8:20 AM (Student)

Q1, Dislocation Dynamics of SiGe Film Relaxation on Silicon on Insulator Substrates: *Eric M. Rehder*[1]; T. S. Kuan[2]; T. F. Kuech[1]; [1]University of Wisconsin, Matls. Sci. Prog., 1415 Engineering Dr., Madison, WI 53706 USA; [2]University at Albany, State University of New York, Albany, NY 12222 USA

The incorporation of relaxed SiGe films with Si substrates allows new opportunities and applications within the range of Si electronics. Relaxed Ge is closely lattice matched to GaAs. Also, Si layers deposited on relaxed SiGe films are under a tensile strain, which results in a conduction band offset. This brings devices based on electron confinement and tunneling to Si substrates. Relaxed SiGe requires strain-relieving dislocations, which are accompanied by threading dislocations terminating at the surface of the film. The threading dislocations degrade electronic and optical device operation. Silicon on insulator(SOI) substrates have been found to be effective in reducing the threading dislocation density (TDD) in SiGe films. The SOI top Si layer thickness is expected to play a significant role in the dislocation dynamics during film relaxation, which is the focus of our present study. Samples have been grown with a 1μm $Si_{0.82}Ge_{0.18}$ film on a SOI substrate where the SOI top Si layer has a thickness ranging from 50nm to 10μm. For comparison, a reference film was deposited on a bulk Si substrate. All the films develop similar crosshatch. X-ray reciprocal space maps of the film and substrate (004) peaks determine the films on the two substrates to have comparable mosaic spread and strain. The crosshatch and X-ray data indicates that the relaxed films have a similar density of interfacial misfit dislocations. Also observed on the thinnest SOI substrates, the SOI top Si layer is under a tensile strain with a peak shift of 155 arc seconds. TEM analysis observed a low film TDD on the thin SOI substrates, which increases with Si layer thickness approaching bulk Si behavior for the thickest SOI substrates. Threading dislocations are also observed terminating at the buried oxide. On bulk Si, as a gliding dislocation approaches a misfit dislocation, the misfit dislocation is pushed into the substrate in order to allow the approaching dislocation to pass. These loops in the substrate lead to dislocation repulsion and form pile-ups. We present a modification of this mechanism accounting for the affect of the SOI buried oxide. The buried oxide provides an image force assisting the intersection by pulling dislocations into the substrate toward the softer oxide material. Upon entering the relaxed Si of the substrate these dislocation loops strain the Si due to constraint from the oxide and base wafer. Upon reaching the oxide interface the dislocation loops annihilate at the amorphous oxide leaving the observed buried threading segments. The annihilation and reduction in pile-ups on the SOI substrate allows relaxation to occur with fewer pinned dislocations and a lower film TDD.

8:40 AM (Student)

Q2, Modeling of In-Plane Expansion and Buckling of SiGe Islands on BPSG: *Haizhou Yin*[1]; James C. Sturm[1]; Zhigang Suo[1]; Rui Huang[1]; Karl D. Hobart[2]; [1]Princeton University, Ctr. for Photonics & Optoelect., POEM, J301, Princeton, NJ 08544 USA; [2]Naval Research Lab, Washington, DC 20357 USA

There has been increasing interest in compliant substrates for integration of heterogeneous epitaxial materials. In this talk, borophosphorosilicate glass (BPSG) on silicon is used as a compliant substrate to allow the relaxation of strained SiGe layers[1]. The talk will focus on the relaxation process and its modeling. For the first time, we show quantitative 2-D modeling of the relaxation process and of the buckling process, along with good correlation with experiments. The SiGe layers are first grown in a strained state on a (100) silicon wafer by CVD, and then bonded to the BPSG wafer. After the silicon substrate under the SiGe is removed by hydrogen implantation and cleavage, the SiGe is patterned into islands. The samples are then annealed at 800°C to allow the SiGe to relax. The relaxation takes place by two competing mechanisms: a desired in-plane expansion and an undesired out-of-plane bending (namely, buckling). The in-plane expansion of the SiGe islands is observed by X-ray diffraction from their (400) peak, while the buckling is measured by AFM. The characteristic time of in-plane expansion is linearly proportional to the island area. And the buckling rate is independent of the island size. Islands will buckle if the in-plane expansion alone is not fast enough to relax the strain. We study the buckling dependence of the island size and it clearly shows islands smaller than 40μm have negligible buckling. An analytical 2-D model for the in-plane expansion of the islands has been developed. It is in good agreement with our experimental data of small islands, but it underestimates the relaxation rate for larger islands. The underestimation stems from the fact that the analytical 2-D model for in-plane expansion ignores the relaxation contribution of the buckling. Surface roughness of the center of the 200μm SiGe islands is measured as a function of anneal time at 800°C to study the buckling rate. In-plane expansion in this case can be neglected because the center of large islands relaxes solely by buckling. A theory for buckling of thin film islands on viscous compliant substrate has recently been developed[2]. It is shown that the buckling amplitude grows exponentially over time. Our data agrees well with such predictions. The BPSG viscosity at 800°C can be independently extracted both from in-plane expansion and buckling modeling and the viscosities extracted are in close agreement. This is sound evidence that the models for 2-D in-plane expansion and buckling are valid in our case. This work is supported by DARPA(N66001-00-1-8957) and ARO (DAA655-98-1-0270). Reference: [1]K. Hobart, et. al. Journal of Electronic Materials, 29, 897 (2000); [2]N. Sridhar, D. J. Srolovitz and Z. Suo, to be published.

9:00 AM (Student)

Q3, High Quality Heteroepitaxial InGaAs Layers Grown on Strain Relaxed Seed Membranes Using the 'Paramorphic' Approach: *Mouloud Boudaa*[1]; Jean-Louis Leclercq[1]; Marie-Paule Besland[1]; Philippe Regreny[1]; Olivier Marty[2]; Guy R. Hollinger[1]; [1]Ecole Centrale de Lyon, LEOM, Ecully, Cedex 69621 France; [2]Université Lyon, 1 Lenac, Villeurbanne, Cedex 69621 France

The most common method for preparing relaxed mismatched layers is metamorphic heteroepitaxial growth, where strain is plastically and par-