Tuesday Morning, October 3, 2000

Semiconductors
Room 306 - Session SC+EL+SS-TuM

Compound Semiconductors
Moderator: J.W. Rogers, Pacific Northwest National Laboratory

8:20am **SC+EL+SS-TuM1 Reconstructions and Steady-state Surface Structures on InAs(001)-(2x4): Implications for Atomistic Modeling of Growth**, ***W. Barvosa-Carter***, *F. Grosse,* HRL Laboratories and University of California, Los Angeles*; M. Gyure,* HRL Laboratories*; J.H.G. Owen, C. Ratsch,* HRL Laboratories and University of California, Los Angeles*; R.S. Ross, J.J. Zinck,* HRL Laboratories

Heterostructures involving InAs, GaSb, and AlSb are increasingly finding applications in high-frequency, infrared, and 'spin-tronic' devices. Interface structure in these devices can be critical in determining device performance. The robustness of any model that seeks to relate process parameters and in-situ sensor signals to the surface chemistry or roughness of the growing film ultimately depends on our understanding of the relevant surface reconstructions and epitaxial growth mechanisms. Using MBE, RHEED, and atomic-resolution STM, we have studied the reconstructions and 'steady-state' surface structures present on MBE-grown InAs homoepitaxial surfaces in the (2x4) growth regime. On InAs we find two reconstructions that are relevant for growth: the familiar @beta@2(2x4) (as on GaAs) and the less familiar @alpha@2(2x4). We find excellent agreement between detailed atomic-resolution STM and first-principles simulated images of these structures. Upon quenching, we find that "steady-state" InAs surfaces exhibit small islands and adatom-like structures residing on a disordered mixture of the @beta@2 and @alpha@2 reconstructions, and that the proportions of these structures vary as a function of As pressure and temperature. Hence, the growth surface structure for InAs is remarkably different than for GaAs, where only the @beta@2 reconstruction is present with relatively few defects under device growth conditions. These results are in excellent qualitative agreement with an ab initio-based Monte Carlo model that is being developed in parallel with the experimental effort to describe reconstructions and growth on this surface.

8:40am **SC+EL+SS-TuM2 Oscillations of Local Density of States at the Epitaxially Grown InAs(111)A Surfaces Characterized by Low-temperature Scanning Tunneling Microscopy**, ***K. Kanisawa***, *M.J. Butcher, H. Yamaguchi, Y. Hirayama,* NTT Basic Research Laboratories, Japan

The characterization of semiconductor surface electrons is very important for understanding microscopic electron behavior. Though the local density of states (LDOS) has been studied at metal surfaces by using low-temperature scanning tunneling microscopy (LT-STM), the only studies that have been reported for semiconductors are on cleaved (110) surfaces. A LT-STM study of an epitaxial semiconductor surface makes it possible to compare the electron behavior directly with nanometer-scale morphology. We have performed a LT-STM study of the epitaxially grown InAs(111)A surface on the GaAs(111)A substrate in layer-by-layer growth mode at 5 K. Topographic and dI/dV images were obtained simultaneously by using a lock-in technique. In the dI/dV images, LDOS oscillation patterns were clearly imaged at surface defect sites, which were identified in the corresponding STM images. At an isolated defect, clear LDOS Friedel oscillations made of concentric circles were observed. From the dependence of the oscillation period, the effective mass was calculated to be 0.043m@sub 0@, which is consistent with that of InAs with a relatively high electron concentration. In the case of steps with a height difference of integral monolayers, the oscillation patterns showed dark bands along the steps. In contrast the Frank partial dislocations, with height differences of fractional monolayers, showed bright bands. This implies that there are large differences between the electron scattering phases at the steps and at the dislocations. During the InAs growth, triangular regions are formed on the surface by three {111} stacking fault planes. Such boundaries showed symmetric and regular patterns inside. Our detailed analysis suggests that these patterns are related to zero-dimensional electron systems confined within the InAs nanostructures.

9:00am **SC+EL+SS-TuM3 Something Old, Something New, Something Borrowed, Something BLUE - Fifty Years of III-V Compound Semiconductors!**, ***R.D. Dupuis***[1], University of Texas, Austin **INVITED**

III-V compound semiconductors, first identified in 1950, have become critically important for the commercial development of advanced semiconductor devices and systems. In the past fifty-some years, many workers from all over the world have contributed to this outstanding success. The epitaxial growth of III-V films began in 1960 with the early work of Holonyak who used iodine transport in a closed tube to produce epitaxial layers of GaAs/GaAs, GaAs/Ge, and various GaAsP alloys. Open-tube VPE and LPE for III-Vs were developed soon after this work. In 1967, Manasevit, et al., demonstrated the metalorganic chemical vapor deposition (MOCVD) epitaxial growth process and in 1970 Cho, et al. reported the first molecular beam epitaxy (MBE) growth of GaAs. Thus, twenty years after the first identification of III-Vs as semiconductors, all of the epitaxial growth processes we use today had been developed. It has taken 30 more years of technological and scientific advances to arrive at the understanding of these materials that we take for granted today. In fact, much of the new advanced communications systems that will be employed in the next 10 years depend fundamentally upon III-V epitaxial growth. In this talk, I will briefly review some aspects of the history of the development of these material systems and growth processes and I will discuss some of the recent results as well as speculate on the future development of III-V compound semiconductor materials.

9:40am **SC+EL+SS-TuM5 Strain-Induced Anisotropy of Gallium Phosphide Islands on Gallium Arsenide**, ***C.H. Li***, University of California, Los Angeles*; L. Li,* University of Wisconsin, Milwaukee*; Q. Fu, M.J. Begarney, R.F. Hicks,* University of California, Los Angeles

We have undertaken a study to produce ordered nanostructures on compound semiconductor surfaces by the heteroepitaxial growth of highly strained island structures. Phosphorous-rich (2x4) islands are produced by decomposing phosphine on gallium arsenide (001)-(4x2) surfaces in ultrahigh vacuum. These islands exhibit anisotropy of approximately 10 to 1 with the (2x4) domains dramatically elongated along the [110] direction. The island width increases with the phosphorous coverage from 24 @Ao@ at 0.1 ML to 48 @Ao@) at 0.75 ML. This is attributed to strain induced by the lattice mismatch of phosphorous dimers on gallium arsenide. The implication of this finding to the epitaxial growth of GaP/GaAs heterostructure will be discussed at the meeting.

10:00am **SC+EL+SS-TuM6 Relative Reactivity of Arsenic and Gallium Dimers and Backbonds during the Adsorption of Molecular Oxygen on GaAs(100)(6x6)**, ***P. Kruse***, *J.G. McLean, A.C. Kummel,* University of California, San Diego

The semiconductor industry has a strong interest in understanding and employing the reactions of oxygen with III-V materials for fabrication of GaAs CMOS devices. We have monitored the initial stages of the chemisorption of molecular oxygen on the GaAs(100)(6x6) reconstructed surface by means of room temperature scanning tunneling microscopy. This surface is terminated by both gallium dimers and arsenic dimers, allowing for a direct comparison of their reactivity. Neither the As nor Ga dimer bonds react with thermal molecular oxygen. Likewise, the Ga-As back bonds of the Ga dimers do not exhibit any reactivity. Instead, the chemisorption proceeds with 100% chemical selectivity via the reaction of molecular oxygen with the As-Ga back bonds of the As dimers. The interaction between the highly electronegative oxygen atoms and the surface is initiated through the high electron density at the arsenic atoms. One oxygen atom displaces the attacked arsenic atom while the other oxygen atom bonds to two neighboring gallium atoms, resulting in the thermodynamically most stable reaction products: metallic arsenic clusters and gallium oxide.

10:20am **SC+EL+SS-TuM7 Role of Ligand Termination in Atomic-Layer-Controlled Growth**, ***R.M. Osgood***, *N. Camillone III, Y. Luo, M. Han,* Columbia University **INVITED**

We describe employment of a series of in situ UHV diagnostics to study the surface chemistry of ligand capping in limiting reactions for atomic-layer-defined growth of semiconductor thin films. In the study, molecular precursors were on surfaces held at temperatures from 180-300K in a UHV chamber. The terminating groups, formed by the dosing, were identified and their chemistry investigated using thermal desorption spectroscopy, NEXAFS, Auger, spectroscopy, and LEED. Using CdS growth on ZnSe(100) as the model system, we have found that CH@sub 3@ and H terminal groups

[1] **Featured Speaker - Science and Technology in the 21st Century**

deposited by reactions with Cd(CH@sub 3@)@sub 2@ and H@sub 2@ S, respectively, effectively limit growth precisely on all except the first monolayer. A study of intermixing in the first layer shows clearly the role of surface temperature in controlling the reaction chemistry and coverage of terminating species. The implications with regard to atomic-layer-controlled growth of other systems will also be discussed.

11:00am **SC+EL+SS-TuM9 Two-step MOCVD Growth of Piezoelectric ZnO Thin Film on SiO@sub 2@/Si Substrates**, ***S. Muthukumar***, *N.W. Emanetoglu, G. Patounakis, C.R. Gorla, S. Liang, Y. Lu,* Rutgers University

ZnO is a wide bandgap semiconductor with a direct bandgap of 3.3eV. Piezoelectric ZnO has high electro-mechanical coupling coefficient. Thin film piezoelectric ZnO deposited on semiconductor substrates is used for surface and bulk acoustic wave (SAW & BAW) devices, which offer advantages such as low power consumption, circuit miniaturization and cost reduction by integration with main stream MMIC technology. Furthermore, temperature compensation may be achieved in the ZnO/SiO2/Si system as ZnO and Si have positive temperature coefficient of delay (TCD), while SiO2 has negative TCD. Temperature compensated SAW devices are attractive for both communication and sensor technologies. In the present work, ZnO thin films were grown on SiO2/Si substrates by MOCVD. The structural properties of the films were investigated using XRD, SEM, and scanning probe microscopy. The films grown at 300°C were dense and had a smooth surface morphology, but poor crystallinity. In contrast, the films grown at 500°C were predominantly c-oriented, but had a rough surface. A two-step growth process was developed to obtain films with both good crystallinity and smooth surface. A high temperature (450-500°C) buffer layer was initially deposited, to provide a highly crystalline template for the subsequent low temperature (300-330°C) growth. Annealing was done on the thin films in N2 and O2 ambient for different durations to improve film resistivity, essential for fabricating low-loss SAW devices. The SAW velocity, coupling coefficient and TCD of the ZnO/SiO2/Si system were investigated through modeling and computer simulation based on Adler's transfer matrix method and Green's function analysis. The test devices with the proper ZnO and SiO2 thickness exhibited multiple temperature compensated frequency points in the 1.42 GHz to 2.15 GHz range. These results show that temperature compensated ZnO/SiO2/Si system is promising for fabricating low-loss SAW devices.

11:20am **SC+EL+SS-TuM10 Spontaneous Island Formation Caused by Reconstruction Changes During III-Sb Homoepitaxy@footnote 1@**, ***A.S. Bracker***, *B.Z. Nosho, B.R. Bennett, J.C. Culbertson, B.V. Shanabrook, L.J. Whitman,* Naval Research Laboratory

Most III-V semiconductor surfaces exhibit reconstructions with compositions that differ from the bulk material. These nonunity III:V stoichiometries constitute an inherent source of interfacial roughness during molecular beam epitaxy when the reconstruction changes during growth. This issue is especially important for the AlSb and GaSb(001) surfaces, because several reconstructions exist over the range of substrate temperatures and beam fluxes typically used for growth. For AlSb, the relevant reconstructions include @alpha@(4x3), @beta@(4x3), @gamma@(4x3), and c(4x4), in order of increasing Sb:Al coverage.@footnote 2@ We have used scanning tunneling microscopy (STM) and reflection high-energy electron diffraction (RHEED) to characterize how the initial stages of homoepitaxy depend on the surface reconstruction and growth conditions. When the growth conditions cause a transition between reconstructions, islands spontaneously form on the surface. In addition to roughening an otherwise flat surface, these islands change the island size distribution during subsequent growth. Unfortunately, the RHEED patterns for the three (4x3) surfaces all have a similar streaky (1x3) symmetry during growth, making it difficult to optimize growth conditions based on this diagnostic alone. However, because of its sensitivity to surface roughness, RHEED intensity oscillations may be used to monitor the reconstruction-mediated roughening. We will discuss the realistic growth situations where this type of roughening should be important. @FootnoteText@ @footnote 1@This work was supported by ONR and DARPA. @footnote 2@Barvosa-Carter et al., Phys. Rev. Lett. 84, 4649 (2000).

11:40am **SC+EL+SS-TuM11 Photon-activated Electron-Transfer-Reaction Surface Modification of GaAs(001)**, ***N. Camillone III***, *K.A. Khan,* Columbia University*; J.A. Yarmoff,* University of California, Riverside and Lawrence Berkeley National Laboratory*; R.M. Osgood, Jr.,* Columbia University

UHV methods for adjusting the reconstruction and composition of the top layer of atoms on a semiconductor surface are expected to have important implications for precise control of growth surfaces and surface reactions. In this talk we will describe a transformation of the surface reconstruction resulting from a photoinduced electron transfer reaction occurring thereupon. We have carried out preliminary studies which demonstrate that variation in photon exposure and thermal treatment allows the surface reconstruction to be controllably adjusted from the Ga-rich c(8x2) to the (4x6), (3x1) and As-rich c(2x8) terminations. The modification of the reconstruction is the result of a modification of the surface stoichiometry due to the extraction of surface Ga atoms as a result of reaction with bromine. The bromine is produced at the surface by photoinitiated dissociative electron attachment to methyl bromide molecules physisorbed in a single monolayer at ~ 90 K. Subsequent to the photoinduced surface reaction, the gallium is removed by annealing to desorb a gallium bromide product. A comparison of the results obtained with low energy electron diffraction, temperature programmed desorption and energy-resolved photofragment angular distribution measurements shows that the most As-rich surface obtained by our technique is identical in structure to that of a control surface prepared using the standard iodine thermal reaction method. In principle, the use of this photon-activated reaction, and others like it, could allow for precise patterning of the surface structure based on control of photon or electron exposure, molecular coverage, thermal treatment and lateral patterning of the incident photon or electron beam.

Author Index

Bold page numbers indicate presenter

— B —
Barvosa-Carter, W.: SC+EL+SS-TuM1, **1**
Begarney, M.J.: SC+EL+SS-TuM5, 1
Bennett, B.R.: SC+EL+SS-TuM10, 2
Bracker, A.S.: SC+EL+SS-TuM10, **2**
Butcher, M.J.: SC+EL+SS-TuM2, 1
— C —
Camillone III, N.: SC+EL+SS-TuM11, **2**; SC+EL+SS-TuM7, 1
Culbertson, J.C.: SC+EL+SS-TuM10, 2
— D —
Dupuis, R.D.: SC+EL+SS-TuM3, **1**
— E —
Emanetoglu, N.W.: SC+EL+SS-TuM9, 2
— F —
Fu, Q.: SC+EL+SS-TuM5, 1
— G —
Gorla, C.R.: SC+EL+SS-TuM9, 2
Grosse, F.: SC+EL+SS-TuM1, 1
Gyure, M.: SC+EL+SS-TuM1, 1
— H —
Han, M.: SC+EL+SS-TuM7, 1
Hicks, R.F.: SC+EL+SS-TuM5, 1
Hirayama, Y.: SC+EL+SS-TuM2, 1
— K —
Kanisawa, K.: SC+EL+SS-TuM2, **1**
Khan, K.A.: SC+EL+SS-TuM11, 2
Kruse, P.: SC+EL+SS-TuM6, **1**
Kummel, A.C.: SC+EL+SS-TuM6, 1
— L —
Li, C.H.: SC+EL+SS-TuM5, **1**
Li, L.: SC+EL+SS-TuM5, 1
Liang, S.: SC+EL+SS-TuM9, 2
Lu, Y.: SC+EL+SS-TuM9, 2
Luo, Y.: SC+EL+SS-TuM7, 1
— M —
McLean, J.G.: SC+EL+SS-TuM6, 1
Muthukumar, S.: SC+EL+SS-TuM9, **2**
— N —
Nosho, B.Z.: SC+EL+SS-TuM10, 2
— O —
Osgood, Jr., R.M.: SC+EL+SS-TuM11, 2
Osgood, R.M.: SC+EL+SS-TuM7, **1**
Owen, J.H.G.: SC+EL+SS-TuM1, 1
— P —
Patounakis, G.: SC+EL+SS-TuM9, 2
— R —
Ratsch, C.: SC+EL+SS-TuM1, 1
Ross, R.S.: SC+EL+SS-TuM1, 1
— S —
Shanabrook, B.V.: SC+EL+SS-TuM10, 2
— W —
Whitman, L.J.: SC+EL+SS-TuM10, 2
— Y —
Yamaguchi, H.: SC+EL+SS-TuM2, 1
Yarmoff, J.A.: SC+EL+SS-TuM11, 2
— Z —
Zinck, J.J.: SC+EL+SS-TuM1, 1