Thursday Morning, November 5, 1998

Selected Energy Epitaxy Topical Conference
Room 327 - Session SE-ThM

In Situ Characterization and Real-Time Diagnostics of Surface Growth Processes

Moderator: R.D. Tromp, IBM T.J. Watson Research Center

8:20am **SE-ThM1 Low Energy Electron Microscopy of SEED Growth of GaN Layers**, *A. Pavlovska, **E. Bauer**, I.S.T. Tsong, V.M. Torres, R.B. Doak,* Arizona State University **INVITED**

The early stages of growth of GaN layers on GaN(0001), 6H-SiC(0001) and on Si(111) surfaces are studied in a low enery electron microscope equipped with a NH@sub 3@ seeded He supersonic jet source, a RF discharge nitrogen source and a thermal NH@sub 3@ beam source. This allows a comparison of the influence of the different substrates and deposition modes on the growth and structure of the layers. Results will be reported on the effects of relative arrival rate of Ga and N containing species, of the substrate temperature and surface condition.

9:00am **SE-ThM3 Observation and Nucleation Control of Ge Growth on Si Surfaces using Scanning Reflection Electron Microscopy**, ***M. Ichikawa,*** Joint Research Center for Atom Technology, Japan **INVITED**

Scanning reflection electron microscopy (SREM) is one of the useful techniques for studying surface phenomena and also for modifying surfaces through the use of a focused beam. We have developed high-resolution SREMs (2 nm beam diameter) combined with other surface analysis techniques, such as STM, scanning Auger electron microscopy and X-ray photoelectron spectroscopy (XPS), and applied these to study and control surface reaction phenomena. In this study, we mainly show that focused electron beam (EB)-stimulated reactions in ultra-thin SiO@sub 2@ films on Si substrates, are useful for controlling Ge growth on Si surfaces. Ultra-thin Si oxide films less than 1 nm thickness are formed by heating clean Si substrates in oxygen gas at about 700 °C. The thermal oxidation occurs layer-by-layer. The interface between the oxide film and Si substrate becomes atomically abrupt. The oxide film is mainly composed of silicon dioxide (SiO@sub 2@), which is confirmed by XPS. When the samples are annealed at about 750 °C after focused EB irradiation on the SiO@sub 2@ films at room temperature, Si clean surfaces (open windows) are exposed in the oxide films on the substrates due to the EB-stimulated oxygen desorption and selective thermal decomposition of SiO@sub 2@ at the EB irradiated areas. The typical size of these open windows is about 10 nm. After the deposition of Ge on the sample with Si open windows and subsequent annealing, Ge island growth occurs only in the window areas by Ge diffusion from the surrounding areas during the thermal decomposition of SiO@sub 2@ where Ge reacts with SiO@sub 2@ producing volatile SiO and GeO gases. Ge islands with 10-20 nm size can be formed at given areas on the Ge wetting layer by this method. Other Si nanostructures can be also formed by the selective thermal reactions on the patterned ultra-thin SiO@sub 2@. This work is supported by NEDO.

9:40am **SE-ThM5 Wurtzite GaN Surface Structure Studied by Scanning Tunneling Microscopy and Total Energy Calculations**, ***A.R. Smith**, R.M. Feenstra, D.W. Greve, M.-S. Shin, M. Skowronski,* Carnegie Mellon University*; J. Neugebauer,* Fritz-Haber-Institut der MPG, Germany*; J.E. Northrup,* Xerox Palo Alto Research Center **INVITED**

Using scanning tunneling microscopy (STM) and electron diffraction, two new families of reconstructions have been identified on wurtzite GaN surfaces. First-principles theoretical calculations have yielded a number of novel structural models - many consisting of metallic Ga surface layers - for these reconstructions. The two families of reconstructions are those associated with the inequivalent (0001) and (000-1) surfaces, denoted as Ga-face and N-face respectively. Films are grown using molecular beam epitaxy with an RF plasma source to activate the N@sub 2@ molecules. The N-face results from nucleating the growth directly on sapphire, while the Ga face is prepared through homoepitaxial growth on an MOCVD-grown GaN/sapphire template. For either polarity, smooth growth occurs under Ga-rich growth conditions whereas N-rich growth leads to surface roughening. On the N-face, the least Ga-rich structure is the 1x1, composed of a single Ga monolayer (or adlayer) bonded to the ideal, N-terminated bilayer. Higher-order reconstructions on this face, 3x3, 6x6, and c(6x12), occur with increasing Ga coverage. On the Ga-face, the most Ga-rich structure is the pseudo-1x1, consisting of a double layer of Ga atoms in a fluid-like discommensurate structure on the surface. Removal of Ga atoms from the pseudo-1x1 results in the 6x4, 5x5, and 2x2, in order of decreasing Ga coverage. The 6x4 and 5x5 appear to be composed primarily of Ga adatoms. The 2x2, on the other hand, is formed through nitridation of the annealed surface or by growth under nearly N-rich conditions and therefore is consistent with a N adatom 2x2. @FootnoteText@ This work is supported by the Office of Naval Research under contract N00014-96-1-0214.

10:20am **SE-ThM7 Low-Energy Electron Microscopy of (0001) Surfaces of GaN Films@footnote 1,2@**, ***M.G. Lagally,*** University of Wisconsin, Madison **INVITED**

The ability to observe growth in real space and in real time at growth temperatures and manipulate growth conditions dynamically is essential to determine fundamental mechanisms of epitaxial growth, especially in complex systems. Only low-energy electron microscopy (LEEM) provides this capability. We have begun a program of LEEM investigations of the surfaces of GaN films prepared in several ways as a springboard to subsequent in-situ exploration of homoepitaxial growth. Surfaces of films grown by metal-organic vapor phase epitaxy (MOVPE), by halide vapor phase epitaxy (HVPE), and by lateral epitaxial overgrowth (LEO) using MOVPE are compared. Although a number of surface reconstructions have been observed, clean stoichiometric GaN(0001) surfaces are unreconstructed, and hence conventional dark-field imaging cannot provide information on terrace sizes and step heights, although steps themselves can be viewed with step-contrast imaging. We demonstrate that through use of multiple scattering we can view terraces and step heights and determine terrace size distributions. We compare surface morphologies of the above films. We have also demonstrated (so far only on SiGe/Si) that LEEM has potential for imaging 3D features. We have identified 3D epitaxial islands and have followed in real time their shape and size evolution during embedding by matrix material. We will describe initial LEEM measurements of Ga deposition on the above GaN surfaces as a start to homoepitaxial growth. Although none of this work as yet reflects selected-energy epitaxy, it will help to establish the baseline for understanding growth mechanisms that might be modified by selecting the energies of the depositing species. @FootnoteText@ @footnote 1@Research supported by ONR. @footnote 2@Work done in conjunction with J. Maxson, L. Zhang, T. Kuech, and P. Sutter.

11:00am **SE-ThM9 Defect-Driven Nucleation Kinetics of GaN Growth on Sapphire(0001)**, ***A.R. Woll**, J.D. Brock, R.L. Headrick, S. Kycia,* Cornell University

Real-time, x-ray scattering techniques using the Cornell High Energy Synchrotron Source have been used to study the kinetics of GaN nucleation and growth on sapphire (0001) by RF plasma-assisted MOMBE. The initial growth rate of GaN, measured by gallium fluorescence, is observed to be highly nonlinear. The time to form the first bilayer was the same for substrates from the same wafer, but increased from 10 to 30 seconds on substrates with decreasing surface defect density, as indicated by x-ray measurements of surface quality. This suggests that the initial nucleation of GaN is defect-driven, perhaps occurring at steps on the surface. This work is supported by NSF Grant Nos DMR--9632275 (MSC) and DMR--9311772 (CHESS).

11:20am **SE-ThM10 Site-Selective Reaction of Br@sub 2@ with the Second Layer Ga Atoms on the As-rich GaAs(001)-2x4 Surface**, *Y. Liu, A.J. Komrowski, **A.C. Kummel**,* University of California, San Diego **INVITED**

The top layer of the GaAs(001)-2x4 surface consists of rows of As-As dimers while the second layer has exposed Ga atoms between the arsenic rows. Using scanning tunneling microscopy (STM), we have observed that in the initial adsorption stage monoenergetic Br@sub 2@ molecules (0.89 eV) react exclusively with the second layer Ga atoms exposed in trenches or at defects on the As-rich GaAs(001)-2x4 surface. This gallium-selective chemisorption indicates that bromine molecules preferentially react with exposed atoms which have the least filled dangling bonds regardless of their layer. Both abstractive and dissociative chemisorption of Br@sub 2@ molecules are observed to be surface-site selective. The abstractive chemisorption of Br@sub 2@ molecules formed isolated gallium monobromides at As atomic vacancies, As-As dimer vacancies, and in trenches. However, the dissociative adsorption of Br@sub 2@ molecules forms paired gallium monobromdies at As-As dimer vacancies and in trenches. Dissociative adsorption of a Br@sub 2@ molecules in a trench is orientation-specific and results in two GaBr species on the opposites sides of the trench.

Author Index

Bold page numbers indicate presenter