Electronic Materials and Processing Division
Room 316 - Session EM2-WeA

Application of Scanning Probes to Electronic Materials

Moderator: A. Smith, Ohio University

2:00pm **EM2-WeA1 Oscillating Contrasts Surrounding Charged Defects and Dopant Atoms in (110) Surfaces of III-V Semiconductor at Room-Temperature***, **Ph. Ebert**, C. Domke, M. Heinrich, K. Urban,* Forschungszentrum Jülich, Germany

Positively and negatively charged defects and dopant atoms in n-doped GaAs(110) surfaces give rise, at room temperature, in occupied-state scanning tunneling microscope images to a bright elevation, which is surrounded by a dark depression ring. This oscillating contrast is not observed in empty-state images. A similar effect is found on n-doped GaP(110) surfaces. In order to explain the origin of this contrast behavior we simulated the spatial variation of the tunnel current as a function of the tunneling voltage, the polarity of the charge, and the doping of the material. The calculation of the tunnel current takes into account the tip-induced band bending, the local potential change induced by the screening of the charge, and the extension of the Tersoff-Hamann model for larger voltages. The results suggest that the oscillation in room-temperature STM images can be explained as the image of the local potential change (screened Coulomb potential) induced by the presence of the charge on (110) surfaces of III-V semiconductors. It is found that the oscillating contrast behavior occurs only if competing contributions to the tunnel current from the valence and conduction bands exist. The simulation also reproduces qualitatively all presently known contrast features of charged defects and dopant atoms on III-V and II-VI compound semiconductor cleavage surfaces in STM images.

2:20pm **EM2-WeA2 Two-Dimensional Carrier Profiling of III-V Structures using Scanning Spreading Resistance Microscopy***, P. De Wolf, T. Hantschel,* IMEC, Belgium*; M. Geva, C.L. Reynolds,* Bell Laboratories, Lucent Technologies*; **W. Vandervorst**,* IMEC, Belgium*; F. Bylsma,* Bell Laboratories, Lucent Technologies

Scanning Spreading Resistance Microscopy (SSRM) is a powerful tool originally developed for measuring two-dimensional (2D) carrier distributions in Si device structures with nm-spatial resolution.@footnote 1@ It is in essence based on an Atomic Force Microscope equipped with a conductive tip that is biased relative to the sample. From the current flowing through the tip one deduces the local spreading resistance value. The spreading resistance value is determined primarily by the resistivity of the material in the small semi-hemispherical volume at the surface region where the tip contacts it. The resistivity is closely related to the local carrier concentration (and mobility) in this surface region. The spatial resolution thus mainly depends on the tip radius and pressure. Since SSRM measures resistance, a material property that depends upon carrier concentration, rather than detecting the carriers directly, it is capable of producing images of both high spatial resolution and wide dynamic range of carrier concentration. We have demonstrated spatial resolution values as small as 20 nm, and dynamic ranges of 10@super 15@-10@super 20@ atoms/Cm@super -3@ in analyses of Si devices.@footnote 1@ Whereas its application has been explored in detail on Si structures,@footnote 1@ we report here for the first time on the application of SSRM for the analysis of III-V semiconductor structures, and in particular MOCVD-grown InP-based structures. We found that the application of SSRM to InP-based structures is much simpler than to Si. A minimal surface preparation is required in the cross sectioning process, much lower tip forces are needed, and metal tips instead of diamond tips can be used. When imaging complex multilayer epi-structures (containing p, n, and semi-insulating layers), close agreement between the SSRM profile and SIMS profiles can be obtained. More importantly is the capability of SSRM to image and determine 2D structures in actual devices, such as mesas and trenches common in semiconductor laser devices. SSRM also proved very valuable in characterizing with high spatial resolution 2D dopant and implant distributions. In this presentation we will present SSRM analysis of lateral Zn-diffusion into a semi-insulation layer in a mesa-like InP structure. @FootnoteText@ @footnote 1@P. De Wolf, T. Clarysse, W. Vandervorst, L. Hellemans, Ph. Niedermann, and W. Hänni, J. Vac. Sci. Technol. B16, 355 (1998).

2:40pm **EM2-WeA3 The Structure of InAs/AlSb/InAs Surfaces and Interfaces Grown by MBE***, **B.Z. Nosho**, W.H. Weinberg,* University of California, Santa Barbara*; B.V. Shanabrook, B.R. Bennett, W. Barvosa-Carter, L.J. Whitman,* Naval Research Laboratory

We have used in-situ plan-view scanning tunneling microscopy to study the surfaces and interfaces within an InAs/AlSb/InAs resonant tunneling diode-like structure grown by molecular beam epitaxy. The nanometer and atomic-scale morphologies of the surfaces have been characterized following a number of different growth procedures. When InAs(001)-(2x4) is exposed to Sb@sub 2@ a bilayer surface is produced, with one monolayer-deep (3 Å) vacancy islands covering approximately 25% of the surface. Both layers exhibit a (1x3)-like reconstruction characteristic of an InSb-like surface terminated with >1 ML Sb, indicating that there is a significant amount of Sb on the surface. When 5 ML of AlSb is deposited on an Sb-terminated InAs surface, the number of layers observed on each terrace increases to three. Growth of an additional 22 ML of InAs onto the AlSb layer, followed by a 30 s interrupt under Sb@sub 2@, further increases the number of surface layers observed. The rms roughness is found to increase at each subsequent interface; however, on all the surfaces the roughness is @<=@2 Å. The surface roughness is attributed to a combination of factors, including reconstruction-related stoichiometry differences and kinetically-limited diffusion during growth. To begin to elucidate these various factors and help distinguish between kinetic and thermodynamic effects, we have examined the initial stages of Sb@sub 2@ deposition on InAs(001)-(2x4) under various growth conditions. Possible methods to reduce the roughness of the interfaces will be discussed.

3:00pm **EM2-WeA4 In-Situ STM of MBE Growth Quality for GaAs(001) and InP(001)****, **G. Lengel**, F.G. Johnson, W.T. Beard, R.J. Phaneuf,* Laboratory for Physical Sciences*; E.D. Williams,* University of Maryland

As heterostructure-based devices continue to shrink in size, the roughness of the interface between two materials plays a larger role in determining the performance of the final product. Characterization of the lateral length scales of the roughness as well as the root-mean-square roughness is important for understanding the impact of interface quality on device performance, To address this problem, In-Situ Scanning Tunneling Microscopy (STM) has been used to study the geometry of freshly prepared MBE samples. The evolution of roughness as a function of the initial condition of the surface before growth, the thickness of the buffer layer, as well as the role of the growth temperature on both GaAs and InP will be presented. The relative quality of these surfaces has been quantified by calculation of the height- height correlation function from the measured images. The physical significance of the measured parameters, and their usefulness as criteria for judging growth quality will be discussed. @FootnoteText@ *This work has been supported by the Laboratory for Physical Sciences.

3:20pm **EM2-WeA5 Structural and Morphological Studies of GaN Heteroepitaxy on SiC(0001)***, **V. Ramachandran**, A.R. Smith, R.M. Feenstra, D.W. Greve,* Carnegie Mellon University

Heteroepitaxial growth of GaN on SiC has been studied using scanning tunneling microscopy (STM), atomic force microscopy (AFM) and high resolution x-ray diffraction. Growth was performed by molecular beam epitaxy (MBE) on hydrogen etched SiC(0001) substrates that show a @sr@3x@sr@3 R-30° reconstruction. Significant differences are seen in the growth morphology in different growth temperature regimes, both at low and high film thicknesses. At a coverage of a few monolayers, STM observation of GaN grown at temperatures around 550°C shows layer-by-layer growth. Terraces show sub-Å corrugation corresponding to the formation of misfit dislocations at the heterointerface, indicating that the film has relaxed. Films grown at around 650°C with a similar thickness show columnar, flat-topped islands of uneven heights with deep crevices between them. This difference in morphology may be understood in terms of the different strain relaxation mechanisms in the two temperature regimes. At higher temperature, films prefer to relieve strain by forming 3-D islands, which can be distorted to relieve strain. Alternatively, at lower temperature, the films remain pseudomorphic and grow in a layer-by-layer manner both before and after the formation of misfit dislocations. AFM measurements also show remarkable morphological differences between thicker (200 nm) films grown in the two temperature regimes mentioned above. Films grown at 550°C show a large number of spiral growth fronts while films grown at 650°C show a stepped layer-by-layer structure. Based on the growth model outlined above, it is apparent that in the low temperature 2-D growth mode, misfit dislocations at the interface are associated with screw dislocations which extend upto the surface and act as a source for the spiral growth. In 3-D growth, misfit dislocations can form at the edges of islands without the need for as many screw dislocations. X-ray rocking curve measurements on GaN films 200-400 nm thick show decreasing FWHM with increasing growth temperature. This would agree with the above model, where, as the growth temperature rises, the film requires fewer screw dislocations in order to create the necessary number of misfit dislocations at the interface.

3:40pm **EM2-WeA6 Impact of Deposition Method on the Microstructural and Electrical Properties of Thin Film Silica Aerogels*, C. Caragianis-Broadbridge*,** *L. Carmona, M. Farag, M. Guillorn, F. Stellabotte,* Trinity College

Aerogels are nanoporous materials with unique optical, thermal and electrical properties. Silica thin film aerogels demonstrate great potential as low dielectric constant insulators for interlevel dielectric applications. The focus of this research is the fabrication of thin film silica aerogels through a sol-gel process in conjunction with low-temperature supercritical extraction of CO@sub 2@. The microstructural and electrical properties of the aerogel were studied as a function of deposition method, using non-contact atomic force microscopy (nc-AFM), scanning and transmission electron microscopy (SEM and TEM) and capacitance-voltage (C-V) instrumentation. Alcogels, aerogel precursors, were prepared by hydrolysis and condensation of metal alkoxide, tetraethyothrosilicate, and were catalyzed by both acids and bases, according to a standard reaction. Before gelation, the solution was deposited on two substrates (bare Si and SiO@sub 2@ coated Si) by two techniques (dipping and spin coating). After supercritical extraction of the CO@sub 2@, the resulting aerogels were characterized using AFM, SEM and TEM to obtain film uniformity, thickness and pore size. C-V data were acquired from metal insulator semiconductor (MIS) capacitors fabricated using the aerogel-coated wafers. This study reveals a correlation between deposition technique and uniformity of the aerogel. Thin films deposited by the spinning technique yield consistently smaller pore sizes, ranging between 150 and 440nm while producing a more uniform film thickness. C-V characterization of the aerogel MIS devices (for both substrates) indicates a high quality dielectric with minimal mobile, fixed and interface state charge. These measurements also reveal that these aerogel MIS capacitors possess a substantially lower dielectric constant (1.5-3.5 vs. 3.9) when compared with standard control SiO2 MOS devices.

4:00pm **EM2-WeA7 UHV STM Nanofabrication and the Giant Deuterium Isotope Effect: Applications to CMOS Technology*, J.W. Lyding*,** *M.C. Hersam, G.C. Abeln, E.T. Foley, J. Lee, Z. Chen, D.S. Thompson, J.S. Moore, S.-T. Hwang, H. Choi, K. Hess,* University of Illinois, Urbana-Champaign **INVITED**

The use of the UHV STM to selectively desorb hydrogen with atomic scale precision from Si(100)-2x1:H surfaces@footnote 1@ has opened new opportunities for creating nanoelectronic device structures. The chemical contrast between H-passivated and clean Si has enabled the development of nanoscale selective chemical schemes including oxidation,@footnote 1@ nitridation,@footnote 2@ and molecular functionalization.@footnote 3@ Using a high temperature STM these schemes are also being extended to include nanoscale metallization by UHV chemical vapor deposition. A key aspect of this work is the establishment of an electronic interface between nanoelectronic device structures and macroscopic contacts to enable testing. We will report on several schemes that are being developed for this purpose. In a parallel set of experiments it was found that the desorption of deuterium from Si(100)-2x1:D surfaces is much more difficult than hydrogen desorption.@footnote 4@ Using this as a basis, we discovered that deuterium treatment can dramatically prolong the lifetime of CMOS transistors by factors of 10 to 50.@footnote 5@ Recent low temperature STM desorption experiments@footnote 6@ have shed additional light on the CMOS degradation problem and the giant isotope effect. @FootnoteText@ @footnote 1@J.W. Lyding, T.-C. Shen, J.S. Hubacek, J.R. Tucker, and G.C. Abeln, Appl. Phys. Lett. 64, 2010 (1994). @footnote 2@J.W. Lyding, T.-C. Shen, G.C. Abeln, C. Wang, E.T. Foley, and J.R. Tucker, Mat. Res. Soc. Symp. Proc. 380, 187 (1995). @footnote 3@G. C. Abeln, S. Y. Lee, J. W. Lyding, D. S. Thompson, and J. S. Moore, Appl. Phys. Lett. 70, 2747 (1997). @footnote 4@Ph. Avouris, R.E. Walkup, A.R. Rossi, T.-C. Shen, G.C. Abeln, J.R. Tucker, and J.W. Lyding, Chem. Phys. Lett. 257, 148 (1996). @footnote 5@J.W. Lyding, K. Hess, and I.C. Kizilyalli, Appl. Phys. Lett. 68, 2526 (1996). @footnote 6@E. T. Foley, A. F. Kam, J. W. Lyding, and Ph. Avouris, Phys. Rev. Lett. 80, 1336 (1998).

4:40pm **EM2-WeA9 Scanning Probe Microscopy Imaging of IC Cross Sections*, K.-J. Chao*,** *R.J. Plano, J.R. Kingsley, X. Lu, I. Ward,* Charles Evans & Associates

Various Scanning Probe Microscopy (SPM) techniques have been applied to investigate the cross sections of modern integrated circuit (IC) devices. The IC devices were prepared by polishing using common Scanning Electron Microscope (SEM) sample preparation methods. Some of the samples were further etched to delineate the various oxides. Atomic force microscope (AFM) was used to simultaneously acquire both topography and phase images of these surfaces. The topography images reveal height information about the sample while the phase images are sensitive to material differences and show edges clearly. Different metal layers and device structures are clearly resolved. To verify the results, these samples were coated with a thin layer of metal and then imaged with an SEM. AFM and SEM results show a close agreement, with the AFM topography image having additional height information and the phase image showing sharper detail than the SEM images. Also, the doping regions of IC devices were investigated by the scanning capacitance microscope (SCM) and low voltage SEM. A detail comparison will be presented.

5:00pm **EM2-WeA10 Silicon Nitride Islands as Oxidation Masks for the Formation of Silicon Nano-Pillars*, J.S. Ha*,** *K.-H. Park, W.S. Yun, E.-H. Lee,* ETRI, Republic of Korea

We have used nanometer-scale silicon nitride islands as oxidation masks for the formation of silicon nano-pillars. For the growth of silicon nitride islands on Si(111)-7x7 surface, two different methods were used; N @sub 2@ exposure at temperatures between 700 and 800 ° C and 100 eV N @sub 2@ @super +@ ion exposure at room temperature followed by subsequent post-annealing at 980 ° C. Scanning tunneling microscope (STM) images taken from the two differently prepared surfaces showed a submonolayer coverage of nanometer-sized silicon nitride islands. On these surfaces, O @sub 2@ was exposed at high temperatures where silicon etching was dominant over oxide formation. It was found that N @sub 2@ @super +@ ion induced silicon nitride islands work as successful oxidation masks to form silicon nano-pillars as high as several nanometers via selective oxygen etching of silicon. On the other hand, oxygen exposure to the silicon surface covered with N @sub 2@ - induced silicon nitride islands resulted in the increase of lateral size and density of pillars, compared to the initially formed islands. Such difference can be explained in terms of the segregation of extra nitrogen species which had migrated into subsurface region when N @sub 2@ had been exposed at high temperatures. Optimum conditions for the formation of silicon nano-pillars could be obtained by controlling the nitridation temperature, annealing time, and oxidation temperature. In this paper, we will propose a successful way to form silicon nano-structures using silicon nitride islands and also discuss underlying mechanisms of the island growth.

Author Index

Bold page numbers indicate presenter