Electronic Materials and Processing Division
Room 316 - Session EM-FrM

Fabrication and Characterization of Semiconductor Device Layers

Moderator: A. Bensaoula, University of Houston

8:20am **EM-FrM1 Optical, Structural, and Morphological Properties of Epitaxial Al@sub x@Ga@sub (1-x)@N(0001) Films Grown by Gas-Source Molecular Beam Epitaxy**, ***J.E. Van Nostrand***, Air Force Research Laboratory; *R.L. Hengehold,* Air Force Institute of Technology; *K.D. Leedy, M.L. Seaford, D.H. Tomich, C.E. Stutz, Q.-H. Xie,* Air Force Research Laboratory

Al@sub x@Ga@sub (1-x)@N/GaN(0001) is a material system of great interest due to its potential for optoelectronic and high temperature electronic applications. However, published studies on the growth and characterization of Al@sub x@Ga@sub (1-x)@N films are limited, and the structural and optical properties of Al@sub x@Ga@sub (1-x)@N films are not well understood. We present optical, microstructural, and morphological results for 0.5 µm thick Al@sub x@Ga@sub (1-x)@N thin solid films on 2.0 µm thick GaN on Al@sub 2@O@sub 3@(0001) grown by gas source molecular beam epitaxy. Films are deposited at 800°C with a 0.5 µm hr@super -1@ growth rate, and ammonia is used for the nitrogen source. High-resolution X-ray diffraction results show deformation of the unit cell in the Al containing layers for x<0.15 due to tensile biaxial strain. Measurement of the evolution of surface morphology as a function of Al mole fraction using atomic force microscopy shows a large increase in surface roughness with increasing Al mole fraction for x<0.15, followed by an order of magnitude decrease in roughness for relaxed films. Microstructural properties such as dislocation type and density as a function of Al mole fraction are systematically evaluated using cross-sectional transmission electron microscopy. Finally, low temperature (6K) cathodoluminescence is used to evaluate the location of the donor-bound exiton in the Al@sub x@Ga@sub (1-x)@N bandgap as a function of Al mole fraction. An approximately linear dependence on x is observed, suggesting the Al@sub x@Ga@sub (1-x)@N bandgap also exhibits a linear dependence on x.

8:40am **EM-FrM2 Investigation of High Temperature Characteristics of Metal-Insulator-Semiconductor Diode Structures Fabricated Using BN Layers Grown on GaN and SiC**, ***D. Starikov***, *N. Badi, I. Berichev, N. Medelci, A. Tempez, V. Zomorrodian, A. Bensaoula,* University of Houston

Dielectric materials commonly used for fabrication of silicon-based semiconductor devices did not prove their viability when applied on wide band gap materials for high temperature applications, such as GaN and SiC. Boron nitride layers grown by physical vapor deposition have several advantages over conventional dielectrics due to their high thermal and chemical stability, mechanical and radiation strength, and excellent surface morphology. In this work we will describe the basic technological processes for fabrication of Metal-Insulator-Semiconductor (MIS) structures on GaN and SiC using insulating BN layers. I-V curves measured in a temperature range up to 700 °C will be presented for MIS-structures based on GaN grown on sapphire, epitaxial 3-C SiC films grown on silicon, and 6H-SiC single crystal wafers. These data will be compared with results obtained from MIS-structures fabricated using similar technology on silicon wafers. The potential barrier height for all structures will be calculated using C-V and I-V measurements at different temperatures. Preliminary results show that GaN-based MIS structures rectify up to 600 °C, while those based on silicon lose their rectification characteristics only at 250 °C. The dependence of the potential barrier height on the thickness of the dielectric (BN) layer and its stability under high temperature vacuum annealing will be discussed and presented. This work was supported by funds from a NASA cooperative agreement #NCC8-127 to SVEC, a Texas Advanced Research Program Grant # 1-1-27764, and a Texas Advanced Technology Program Grant # 1-1-32061

9:00am **EM-FrM3 Chemical Beam Epitaxy of GaAsN on GaAs (100)**, ***J.W. Rogers, Jr.***, *C.L. Aardahl, H.K. Yun, T.P. Pearsall,* University of Washington

Chemical beam epitaxy (CBE) has been used to deposit GaAsN on GaAs (100) at a growth pressure of order 5e-5 mbar and a substrate temperature of order 500C. Triethyl gallium, arsenic dimers, and an electron cyclotron resonance (ECR) nitrogen plasma were used as the Ga, As, and N sources, respectively. Secondary-ion mass spectrometry (SIMS) showed a maximum nitrogen content of 15% in the films grown in this study. Thermodynamic arguments predict that GaAs and GaN are immiscible due to the large discrepancy in atomic radii between As and N which leads to a positive heat of mixing for GaN and GaAs alloys. X-ray diffraction measurements show that higher nitrogen content does indeed result in phase segregation to a mixture of zinc-blende GaAs, zinc-blende GaN, and wurzite GaN depending on the growth conditions. However, unstrained alloys were deposited with a nitrogen content of up to 3%. Transmission electron micrographs and selected area diffraction patterns are used to discuss the orientation of segregated phases and ordering in the films. The effect of these morphological features on the band gap bowing parameter of the GaAsN system is discussed.

9:20am **EM-FrM4 InP Photocathode Surface Preparation by Atomic Hydrogen Cleaning**, ***K.A. Elamrawi***, *M.A. Hafez, H. Elsayed-Ali,* Old Dominion University

III-V semiconductors are efficient photocathodes. They provide a high quantum efficiency (QE), defined as the number of emitted electrons per incident photon. The QE is strongly reduced if the surface is contaminated with oxides and carbon compounds. For InP, the cleaning temperature is about 530 °C. At this temperature, incongruent evaporation occurs, and phosphorous evaporates preferentially leaving indium droplets on the surface. This heat cleaning process produces a surface that cannot be activated to Negative Electron Affinity (NEA). We use a low temperature cleaning process at 360 °C under atomic hydrogen irradiation. This process produces a phosphorous stabilized surface free of contaminants that can be activated to NEA. RHEED patterns acquired before the atomic hydrogen cleaning process show a halo indicating a thick oxide layer on the surface. However, the patterns acquired after cleaning show clear (2x4) reconstruction features. QE more than 6.5% is obtained after atomic hydrogen cleaning for InP photocathodes activated with cesium and oxygen. InP photocathodes revived by heating with atomic hydrogen irradiation produce higher QE than photocathodes revived by heating only.

9:40am **EM-FrM5 Deposition and Electroluminescent Properties of Sputter Deposited Zn(x)Mg(1-x)S:Mn**, *M.R. Davidson,* ***K.E. Waldrip***, *J.S. Lewis, D. Moorehead, B. Speck,* University of Florida, Gainesville, U.S.; *P.H. Holloway,* University of Florida, Gainesville; *S.S. Sun,* Planar Systems, Inc.

Alternating current thin film electroluminescent devices (ACTFELD) have been prepared using a ZnxMg(1-x)S:Mn phosphor. The phosphor films were deposited by RF magnetron sputter deposition. The composition of the films was varied by adjusting the substrate temperature causing the relative sticking coefficient of the ZnS and MnS to vary. It was found that the Mg gives a green shift of the peak emission of up to 17 nm. This shift is due to the increased crystal field on the Mn due to the smaller Mg ion substituting on a Zn site. The effects of the Mg on the crystal structure and emission have been characterized using XRD, TEM, and UV-Visible band-edge absorption spectroscopy. The effects of post-deposition anneal and fluxes on the ZnMgS:Mn ACTFELDs will be discussed.

10:00am **EM-FrM6 Small Area XPS Analysis of Silicon Wafers Employing Cu Line Technology**, ***E. Principe***, *R. Brigham, T.J. Schuerlein,* Charles Evans & Associates

Shrinking device sizes are requiring semiconductor manufacturers to change the materials they use in their processes. The semiconductor industry is becoming aware that the future generations of devices will no longer be able to utilize aluminum as a conductor. As a fundamentally new technology, the development of copper metallization using Damascene processes have undergone a great deal of investigation. It is understood that the chemical and physical states of the copper and surrounding silicon can alter device performance, and therefore these states must be controlled. X-Ray Photoelectron Spectroscopy (XPS, also know as Electron Spectroscopy for Chemical Analysis, ESCA) can provide information that is difficult, if not impossible, to obtain by other methods. XPS will be shown to provide chemical state identification of copper, as well as measure the copper oxide thickness. Residual copper concentrations on the silicon surface at various process steps will be reported.

10:20am **EM-FrM7 Epitaxial Ferroelectric Ba@sub (1-x)@Sr@sub x@TiO@sub 3@ Thin Films for Tunable Microwave Devices**, ***C.L. Chen***, University of Houston, U. S. A.; *F.F. Feng,* University of Houston; *Z.H. Zhang,* University of Houston, U. S. A.; *A. Brazdeikis,* University of Houston; *F.A. Miranda,* Lewis Research Center; *Y. Liou,* University of Houston; *W.K. Chu,* University of Houston, U. S. A.; *C.W. Chu,* University of Houston

Perovskite Ba@sub (1-x)@Sr@sub x@TiO@sub 3@ thin films have been synthesized on (001) LaAlO@sub 3@ substrates by pulsed laser ablation. Extensive X-ray diffraction, rocking curve, and pole-figure studies suggest that the films are (001) oriented and exhibit good in-plane relationship of SBTO//LAO. RBS studies indicate that the epitaxial films have excellent crystalline quality with an ion beam minimum yield of only 2.6 %. Atomic force microscopy studies indicate that the as-epitaxial films are atomic smooth under the selected growth conditions. The dielectric property measurements by the interdigital technique at frequency up to 1.0 GHz show room temperature values of the relative dielectric constant and loss tangent of 1000 and 0.007 with no bias, and 500 and 0.001 with 35 V bias, respectively. The obtained data suggest that the as-grown BSTO films can be used for development of room temperature high frequency tunable elements and DRAM applications.

10:40am **EM-FrM8 Reaction Pathways/Energetics for Chemical Attack of Amorphous Si-O-F and C-F-(H,OH) Low-k Dielectric Thin Films by Water Molecules***, **H. Yang**, G. Lucovsky,* North Carolina State University

Amorphous films of Si-O-F and C-F-(H,OH) are being considered for low-k inter-metal dielectrics in advanced CMOS devices. The relative stabilities of these different types of dielectrics with respect to chemical attack by water molecules are discussed. FTIR studies have provided the basis for a pseudobinary alloy model for Si-O-F with F-atoms incorporated solely in Si-F bonds. Network bonding statistics have been used to calculate the probability for F-atoms being i) isolated[1] on Si-atoms separated by one or more O-Si-O groups, ii) paired[1] on Si-atoms connected through at most one O-atom, and iii) more strongly clustered. Ab intio calculations are used to study reaction pathways for attack of Si-F bonds by water. For isolated Si-F bonds, the energy of attachment, E@sub a@, of a water molecule through one H-bond is Si-OH + HF, is exothermic by ~0.1 eV, whereas the reaction between a pair of Si-F bonds and a water molecule, HOH + 2Si-F --> 2HF + Si-O-Si, is exothermic by 0.7 eV. Based on the alloy model statistics, the ab initio calculations predict good stability against attack by water extending to ~10 at.% F, corresponding to a dielectric constant of 3.2 to 3.4. The situation is quantitatively different for the C-F materials. Reaction pathways for attack of C-F bonds by water have also been studied by the same ab initio approach. The attachment energies of water for isolated, and near-neighbor C-F bonds are each significantly lower, ~0.1 eV, and reaction pathways are endothermic: e.g., HOH + 2C-F --> 2HF + C-O-C is endothermic by 1.6 eV. This suggests that initial attack of C-F low-k materials by water must be through other bonding groups such as C-H or C-OH. Ab initio calculations are being extended to C-F-(H,OH) materials to study reaction pathways and reaction energetics. Supported by ONR, NSF and INTEL Corporation.

11:00am **EM-FrM9 Carbon Incorporation in SiGeC Alloys Grown by UHV/CVD***, **A.C. Mocuta**, D.W. Greve,* Carnegie Mellon University

We report on growth and carbon incorporation in Si@sub1-x-y@Ge@sub x@C@sub y@ alloys with up to 2% carbon concentration grown by Ultrahigh Vacuum Chemical Vapor Deposition using silane, germane and methylsilane as Si, Ge and C precursors. Alloy growths have been performed at temperatures ranging from 550 °C to 650 °C. Carbon incorporation has been studied for alloys with Ge content of about 5%, 10% and 20%. The Si@sub1-x-y@Ge@sub x@C@sub y@ layers grown on Si(100) substrates have been analyzed by High Resolution X-ray Diffraction (HRXRD) and Secondary Ion Mass Spectrometry (SIMS). For low methylsilane flow and growth temperature of less than 600 °C carbon is incorporated on substitutional positions in levels of up to 0.3%. With increasing methylsilane flow carbon begins to occupy interstitial positions as well but also, the germanium fraction in the layer begins to increase. For carbon concentrations of 1% or higher the crystal quality of the alloy is degraded. Thermal stability and critical thickness for layers with about 10% Ge and low carbon levels (0.2%) has also been studied. Addition of small amounts of carbon to SiGe layers greatly improves the thermal stability of the layer. Upon annealing for 1 hour at 900 °C no significant strain relaxation occurs in Si@sub1-x-y@Ge@sub x@C@sub y@ single layers or multiple quantum well structures while in similar SiGe structures with comparable strain and thickness strain relaxation is observed.

11:20am **EM-FrM10 XPS Study of the Role of Ti and TiN Caps on the Cobalt / SiO@sub 2@ Interface***, **T. Conard**,* IMEC, MAPFCA, Belgium*; E. Kondoh, W. Vandervorst,* IMEC, Belgium

Continuous downscaling of devices features and increases in operation frequency of ICs requires a low electric resistance of interconnects to transistors. Due to its low resistivity, high thermal stability and small lattice mismatch with Si, the integration of CoSi@sub 2@ into ultra large scale ICs is becoming the main stream. The role of metal caps layer (Ti, TiN) on the Si/Co interface chemistry has already been described but its effect on insulation dielectric such as SiO2 has not yet been widely studied. In this study, a 20 nm Co film was grown on a 150 nm LPCVD SiO@sub 2@ and Ti or TiN top layers were deposited on the Co layer without breaking the vacuum. The samples were annealed for 90 sec at 850 C in N@sub 2@ ambient and the specimens were analyzed by X-ray Photoelectron Spectroscopy (XPS) in depth profile mode using Ar@super +@ sputtering. Significantly different depth profiles were obtained depending on the nature of the cap layer. The multilayer with a top TiN layer presents a profile corresponding to sharp interfaces with only a limited diffusion of Ti inside the Co layer and no differences in chemistry of the interfaces due to the annealing procedure. The Co depth profile has a very symmetric shape. On the contrary, the presence of a Ti cap layer induces very strong modification of the interface reactions. First, an important diffusion of the Ti is observed through the Co layer is observed and an accumulation of Ti occurs at the Co/SiO@sub 2@ interface. At the interface, Ti is observed in an oxidized form and reduces the SiO@sub 2@ top layer. The effect of the annealing temperature will also be presented.

Author Index

Bold page numbers indicate presenter