Electronic Materials and Processing Division
Room: 210 - Session EM+SS-FrM

Surfaces and Materials for Next Generation Electronics
Moderator: E.X. Zhang, Vanderbilt University, L. Porter, Carnegie Mellon University

8:20am **EM+SS-FrM1 Growth of 3C-SiC Epitaxial Layers on 4H-SiC Step-Free Mesas**, ***R.L. Myers-Ward***, *E.A. Imhoff, J.D. Caldwell, L.O. Nyakiti, V.D. Wheeler, K.D. Hobart, C.R. Eddy, Jr., D.K. Gaskill*, Naval Research Laboratory (NRL)

To avoid defects such as polytype inclusions or dislocations, the epitaxial growth of 3C-SiC requires a lattice-matched, perfect substrate. One solution to this problem is to use step-free mesas of 4H-SiC as 3C-SiC lattice templates [1]. In this work, we describe the formation of large area step-free mesas and the subsequent nucleation and growth of 3C-SiC layers. A powerful array of tools were utilized to characterize the properties of these layers including Nomarski microscopy, secondary electron microscopy (SEM), atomic force microscopy and X-Ray diffractometry. Micro-photoluminescence (µ-PL) was employed to investigate the presence of electronic defects and identification of polytype, enabling us to obtain information about the structural and electronic properties on a micron-sized length scale.

On-axis 4H-SiC substrates were initially patterned and reactive ion etched to produce hexagonal and square shaped mesas with varying widths ranging from 40 to 400 µm (400% greater area than previous reports), and heights from 2 to 5 µm. Homoepitaxial layers were grown on the mesas in an Aixtron VP508 horizontal hot-wall chemical vapor deposition reactor using the standard chemistry of silane and propane in order to grow out the steps on the mesas. The homoepitaxial layers were terminated at the mesa step edge and further growth is prohibited. The films were grown at 2µm/hr and the pressure and temperature were 100 mbar and 1580°C, respectively. The yields of 200 µm width 4H-SiC step-free mesas was ~95%. Heteroepitaxial 3C-SiC was grown 2 µm thick on the homoepitaxy (4H-SiC) by means of reducing the growth temperature to 1450°C, while maintaining 100mbar.

Under Nomarski evaluation, ~ 18% of the 200 µm wide 3C-SiC mesas appeared to be step-free. Micro-PL maps were used to confirm the presence of 3C-SiC, where uniform 3C-SiC was detected across the entire mesas. X-ray rocking curves also indicated 3C-SiC, with the FWHM of the SiC (111) being ~21", indicating good quality material.

Yield maps for the 200 and 400 µm mesas will be presented. In addition, real color PL imaging will be used to determine the types of defects within the mesas which displayed lower PL intensity regions of 3C-SiC. Lastly, initial results of Schottky rectifiers performance made on the layers will given.

References

[1] J. A. Powell, *et al*., Appl. Phys. Lett. **77**, 1449 (2009).

8:40am **EM+SS-FrM2 Growth of Epitaxial Rare Earth Nanostructures in III-V Semiconductors**, ***B.D. Schultz***, *J.K. Kawasaki, C.J. Palmstrøm*, University of California, Santa Barbara

Highly ordered embedded nanostructures of rare-earth monopnictides can be formed within III-V semiconductor heterostructures providing a new degree of control over the structural and transport properties of the heterostructures. Materials such as ErAs and ErSb are thermodynamically stable with GaAs and GaSb respectively, and in both cases a common group-V sublattice is maintained throughout the heterostructures. In both the arsenides and antimonides, co-deposition at concentrations above a few atomic percent results in the formation of nanoparticles and nanorods. The shape of the nanostructures is strongly dependent of the growth surface including reconstructions, stoichiometry, temperature, and crystallographic orientation. Codeposition of Er with GaAs can produce nanoparticles or ordered nanorods oriented along either the [111] or [211] directions depending on aforementioned conditions[1]. While codeposition of Er with GaSb produces either particles or nanorods oriented primarily along the [100] direction. STM of the GaAs(311)A and B surfaces during the initial stages of nucleation show that following the deposition of a fractional monolayer of ErAs, embedded growth of ErAs particles are observed on the B surface, while the A surface shows primarily surface cluster formation. MBE growth of GaAs on (311)A and B orientations produces relatively flat surfaces with uniquely different (8×1) reconstructions. Codeposition of Er with GaAs results in significant roughening of the surface during growth due to anisotropic diffusion of Ga and Er along the <233> and <011> directions and the general tendency of GaAs not to wet ErAs(100) surfaces. The [211] orientation of the ErAs nanorods on the surface is found to result from preferential growth along the (1 -1 -1) plane on Ga-polar A surfaces. While the angle between the (1 -1 -1) and surface normal remains less than or equal to 90º, the [211] orientated growth is supported. The {111} surface of the rocksalt ErAs is typically a high-energy surface; however, the Ga-rich (1 -1 -1) plane provides a flux mediated epitaxial growth surface for the ErAs analogous to a vapor-liquid-solid type of growth. *In-situ* RHEED, LEED and STM surface studies will be presented along with a detailed growth model to explain differences in the growth process and in nanorod formation for different substrates and substrate orientations.

Supported by AFOSR FA9550-10-1-0119 and ARO W911NF-07-1-0547.
[1] T.E. Buehl, C.J. Palmstrøm, and A.C. Gossard, J. Vac. Sci. Technol. B **29**, 03C108-1, 2011.

9:00am **EM+SS-FrM3 Bulk Topological Insulators and Superconductors: Discovery and the Frontier**, ***M.Z. Hasan***, Princeton University **INVITED**

While most known phases of matter are characterized by broken symmetries, the discovery of quantum Hall effects (1980s) revealed that there exists an organizational principle based on topology rather than broken symmetry. In the past few years, theory and experiments have suggested that new types of topological states of matter exist in certain insulators without any applied magnetic field. These topological insulators are characterized by a full band gap in their bulk and gap-less conducting edge or surface states protected by time-reversal symmetry. Unlike the quantum Hall systems, the topological insulators can be doped into superconductors and magnets revealing the interplay between topological order and broken symmetry order. In this talk, I will briefly review the basic theory and highlight the experimental developments in topological insulators. I will then conclude by drawing connections b etween the emergent novel physics and their potential applications.

10:20am **EM+SS-FrM7 Inter-band GaN/InGaN/GaN Tunnel Diodes**, ***S. Krishnamoorthy***, *D.N. Nath, S. Bajaj, S. Rajan*, Ohio State University

The III-Nitride material system has demonstrated its potential for a broad range of optoelectronic and electronic applications. However there are no reports of efficient III-Nitride tunnel junctions due to the large band gaps in this material system. In this work, we show that with unique properties such as the polarization, tunneling can be enhanced using band bending over smaller distances in nitride heterostructures, leading to record reverse and forward tunneling current density for the III-nitride material system.

We have designed and demonstrated GaN/InGaN/GaN tunnel junction with a record high current density of 118 A/cm^2 at a reverse bias of 1 V by utilizing a 6.4 nm thin $In_{0.33}Ga_{0.67}N$ barrier material. N-polar p-GaN/$In_{0.33}Ga_{0.67}N$/n-GaN heterostructure designed for tunneling close to zero bias was grown by plasma assisted molecular beam epitaxy by choosing the critical thickness of InGaN barrier appropriately. The tunnel junction sample shows five orders of magnitude higher current at a reverse bias of 1 V as compared to a standard p+/n+ GaN sample indicating efficient tunneling across the InGaN barrier. The tunneling turn-on close to zero bias, and maximum current density of 9.1 kA/cm^2 achieved in this work demonstrates the potential of polarization-engineered tunnel junctions.

Two distinct regimes of transport are identified based on the temperature dependent I-V measurements. At lower reverse bias, defect assisted tunneling with strong temperature dependence is found to dominate. In this regime, a plot of ln (J/E) vs $E^{1/2}$ shows a linear behavior suggesting a Frenkel- Poole emission mechanism due to the high field in the InGaN quantum well. A direct band to band tunneling regime resulting in weak temperature dependence that arises from band gap variation with temperature is observed from a reverse bias of 1 V. A decrease in current density is observed with increase in temperature in the range of 77- 150 K and this can be attributed to the presence of band tail states which has been observed previously in In face InGaN.

We discuss the design of these quantum well tunnel junctions. Athough higher indium compositions yield higher band to band tunneling probability, calculations using a simplified Kane model reveal that the wider depletion region in n GaN due to higher band offset considerably reduces the net tunneling probability. Calculations also reveal the need for very high doping in the n GaN layer so as to minimize the depletion region thickness in order to achieve very high current densities in such polarization charge assisted tunnel junctions. These calculations can guide future tunnel junctions with better performance characteristics.

10:40am **EM+SS-FrM8 Probing Surface-Induced Fluctuations in Organic Materials using an Atomic Force Microscope**, ***N.C. Hoepker***, *S. Lekkala, R.F. Loring, J.A. Marohn*, Cornell University

The development of organic electronics calls for new tools to study organic thin films. By measuring the frequency noise experienced by a cantilever near a surface, we are able to microscopically probe organic materials. In previous work, we used an Atomic Force Microscope to measure frequency noise due to dielectric fluctuations as a function of cantilever height and voltage over a thin film of polyvinyl acetate. In parallel, we have developed a zero-free parameter linear-response theory of thermally induced dielectric fluctuations that successfully describes our observations.[1]

Having understood dielectric fluctuations, we are now investigating fluctuations induced by carrier motion in polymeric semiconductors. Charge transport in these devices is not well understood. Previous work indicates that the ratio of diffusion constant to mobility in these materials violates what is predicted by the Einstein relation. In addition, there is an ongoing controversy on the charge density and electric field dependence of mobility. While the correlated-disorder model correctly predicts the electric field dependence of mobility, models that predict a density dependence of mobility rely on uncorrelated site-to-site energies.

A resolution of these controversies calls for new tools to study carrier motion in organic semiconductors. By measuring the frequency fluctuations experienced by a cantilever near a surface, we are able to microscopically probe carrier motion in organic materials. Comparing our observations over a poly(3-hexylthiophene) transistor to a calculation based on free diffusion, we find that while theory overestimates the observed fluctuations, it predicts the correct spectral shape and distance dependence of the fluctuations. Even at high gate bias, the observed cantilever frequency fluctuations differ from what we expect based on free diffusion and on the measured carrier mobility. This discrepancy indicates a breakdown of the Einstein relation. Further we present a number of different charge hopping models. We find that the predicted cantilever frequency noise is very sensitive to the details of the model, indicating that frequency noise spectra are a vital tool for selecting appropriate charge transport models.

[1] Nikolas Hoepker, Swapna Lekkala, Roger F. Loring, John A. Marohn (manuscript in preparation). *Quantifying Dielectric Fluctuations over Polymer Films Using an Atomic Force Microscope.*

11:00am **EM+SS-FrM9 2011 AVS Albert Nerken Award Lecture - Electron Spectroscopy of Reconstructed Surfaces: From Silicon to Graphene**, ***J.E. Rowe****, North Carolina State University **INVITED**

Surface reconstruction of silicon (and other materials) refers to the process by which atoms at the surface of a crystal assume a different structure than that of the bulk and has been extensively discussed and reported at a number of AVS meeting from the early 1960's until present time. In the 1970's a number of electron spectroscopy methods were applied to study this effect and many atomic models were proposed. Early 1970's experiments using electron energy loss spectroscopy and photoemission spectroscopy are described which along with modern theory methods led to the now accepted dimer model (later confirmed by STM) for the Si(100)2x1 and most other reconstructed (100) semiconductor surfaces. Additional core-level synchrotron spectra are described along with very recent studies which include adsorbate-induced surface reconstruction and the role of interface reconstruction of SiC(0001) used for the growth of graphene and studied by STM and STS. Spectroscopy has continued to play an important role even during the past 25 years after the discovery of atomic--scale imaging by STM of the Si(111)7x7 reconstruction. Both early and more recent studies of reconstruction by the author are reviewed.

11:40am **EM+SS-FrM11 Molecular Motion Confined to Self-Assembled Quantum Corrals**, ***E. Yitamben***, *R.A. Rosenberg, N.P. Guisinger*, Argonne National Laboratory

Engineering molecular superstructures on metals opens great possibilities for the control and exploration of complex nanosystems for technological applications. Of particular interest is the use of chiral molecules, such as alanine, to build self-assembled nanoscale structures for the trapping of the two-dimensional free electron gas of a metal. In the present work, molecules of D- or L-alanine were deposited on Cu(111). Scanning tunneling microscopy and spectroscopy revealed the formation of a uniform network of hexagonal pores of average diameter ~1.2 nm. Each pore acts as a quantum corral by confining the two-dimensional electron gas of the Cu(111) surface state. Furthermore, excess alanine molecules were trapped at the inner perimeter of the hexagonal pore, and were observed as rotating or immobile spatial states. This study demonstrates the engineering of one of the smallest quantum confined structure, and the dynamics of molecular motion within these potential wells.

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***** Albert Nerken Award Winner

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