Wednesday Afternoon, November 11, 2009

Electronic Materials and Processing
Room: B1 - Session EM-WeA

Contacts, Interfaces, and Defects in Semiconductors
Moderator: K.L. Kavanagh, Simon Fraser University, Canada

2:00pm **EM-WeA1 Contact Resistance and Material Mixing at the Metal/Organic Interface**, ***Y.B. Kim***, *D. Jeon*, Seoul National University, South Korea

The properties of interface formed by depositing metal on an organic substrate is very different from those of an organic film deposited on a metal substrate, which is because metal atoms can easily penetrate into the loose organic substrate. The degree of mixing at the interface of metal-on-organic depends on the growth condition such as temperatrue and deposition rate. We have compared the morphology and the contact resistance of a Au electrode deposited on a pentacene film at room and liquid nitrogen temperature. The samples were prepared by thermally depositing two Au electrodes on a pentacene thin film. The resistance between the two Au electrodes was measured for different channel lengths between them so that the Au/pentacene contact resistance could be estimated by extrapolating the resistance curve to zero channel length. Figure 1 shows resistance vs channel length measured between two Au electrodes deposited at room and liquid nitrogen temperatures. For both samples, the resistance decreases with decreasing channel length. Between the two Au electrodes deposited at room and liquid nitrogen temperature, the latter yields smaller resistance and thus the smaller contact resistance when extrapolated. Atomic force microscopy revealed a much higher degree of interface mixing for Au deposited at room temperature. Interface mixing or alloying is a common method to make an Ohmic contact for the case of metal electrodes on Si. Our experiment implies that the same strategy may not be applicable to the case of metal electrodes on the organic substrates. The structural deformation of pentacene molecules seem to create traps rather than creating conductive channels. We performed Fourier transform infrared spectrascopy to check the amount of deterioration of pentacene molecules due to the Au deposition. For both liquid nitrogen temperature and room temperature deposition, the infrared peak intensity of pentacene decreased due to the Au deposition, but the peak intensity for the latter case decreased more. We will also discuss X-ray photoemission spectroscopy measurements.

2:20pm **EM-WeA2 Schottky Metal-GaN and AlGaN-GaN Interface Issues Critical to HEMTs**, ***P. Shah***, *I. Batyrev*, *M. Derenge*, *K. Jones*, US Army Research Laboratory

GaN devices promise advantages over other compound semiconductors including higher power amplification, increased linearity, and less temperature dependent degradation. But today current collapse, slow switching transients, and poor gain profiles are present and may be related to interface trap densities. To shed some light, we analyzed the interfaces found in GaN HEMTs and correlated results with amplifier performance characteristics and first principle atomic and electronic structure simulations.

MOCVD grown GaN Schottky diodes were mesa isolation etched, and KOH etched to remove Ga residue and surface defects. Then Ti/Al/Ti/Au Ohmic and Ni/Au Schottky contacts were deposited and annealed.

These blocked 340V in the off-state. KOH reduced surface roughness and improved the on-state performance (150mA at 3.5V in good devices). The undoped GaN layer had a free carrier concentration of $5x10^{16}$ cm^{-3} from CV measurements. The reverse bias exhibits a soft breakdown due to an initial depletion followed by a slower field spreading. For three devices, the forward (2V) and reverse leakage (-1 V) currents were (A) 45mA, $3.4x10^{-10}$A, (B) 17mA, $2.0x10^{-9}$A, and (C) 4 mA, $3.6x10^{-8}$A. Comparing the ideality factors for the three devices over a voltage range of 0 to 0.5 V, device (A) exhibited no bumps between 0.1 and 0.4 V (n = 1.04 at 0.2 V) and a smooth transition into the series resistance region, device (B) exhibited a bump at 0.4V with a peak n= 4.3. Device (C) exhibited a bump at 0.1V with a peak n=2.08.

These ideality factor bumps were seen with GaAs Schottky diodes and linked to interface trap densities. Our conductance measurements gave corresponding trap densities 0.3 eV from the band edge of (C) $1.02x10^{12}$, and (B) $7.9x10^{11}$ cm^{-2} eV^{-1}, and for (A) much less. Also, the interface trap time constants are (C) 97 ns and (B) 81.9 ns and for (A) much longer.

Our first-principle simulation model of a planar bonded metal-semiconductor interface included an inhomogeneity at the interface and semiconductor interface defect interactions with H atoms and OH radicals during KOH etching. We assume that N antisite defects are common defects in GaN causing point defect pinning. After KOH etching these defects are passivated by two hydrogen atoms forming complexes H-N(Ga)-H and OH-N(Ga)-OH. The complexes do not have dangling bonds and do not participate in hybridization with extended states of a metal. Formation of the complexes could improve the interface state associated electrical properties of the Schottky diode, smooth the GaN (0001) surface and remove oxides residues.

Vendor provided GaN HEMTs were similarly analyzed and will be discussed.

2:40pm **EM-WeA3 The Use of Simulations to Address Current Problems in Schottky Barrier Contacts**, ***S.E. Mohney***, *K. Sarpatwari*, *O.O. Awadelkarim*, *N.S. Dellas*, Pennsylvania State University **INVITED**

A combination of simulations and experiments often provides a powerful approach to address scientific and engineering problems. In this presentation, we describe two examples of research on contacts to semiconductors in which we use simulations to develop methods to analyze data collected from Schottky barrier contacts. In the first example, we present an approach to accurately extract the Schottky barrier height from an axial contact to a semiconductor nanowire. Modification of the method usually used to analyze current-voltage (I-V) data from microscale planar Schottky diodes is necessary because of the influence of the semiconductor nanowire surface adjacent to the Schottky barrier contact. Band-bending at this surface influences the shape of the depletion region at the metal/semiconductor interface and must be controlled. We accomplish this control with a wrap-around gate. By analyzing I-V data generated using a commercial device simulator, we identify a method to treat the data to accurately extract the Schottky barrier height. Using the same approach that worked well for the simulated data, we next analyze Schottky barrier contacts to silicon nanowires that we nanofabricated with wrap-around gates. In another investigation, we examine approaches to extract the Richardson constant from planar Schottky barrier contacts that contain nanoscale inhomogeneities. Using Tung's model for inhomogeneous Schottky barrier contacts, we generate simulated I-V data for contacts with inhomogeneities of different sizes, densities, and departures from the homogeneous background barrier height. Then we compare various published approaches for extracting the Richardson constant, identifying their strengths and weaknesses. This section of the presentation concludes with the recommendation of a new approach for treating experimental data, and the approach is demonstrated for Schottky barrier contacts to wide band gap semiconductors.

4:00pm **EM-WeA7 2009 AVS John A. Thornton Memorial Award and Lecture - Nanofabrication Chemistry: The Impact of Solid Interfaces**, ***F.A. Houle****, Fremont, California **INVITED**

The presence of an interface can impose distinct local conditions that can have an important influence on the outcome of a chemical reaction at a nanoscale level. Loosely, two broad types of phenomena can be identified. In one, the interface can serve as an impermeable structure that imposes concentration gradients on materials in contact with it, leading to measurably different chemistry than would occur in its absence. In the other, the interface can serve as a means of accelerating transport, building in significant blur to the contacted regions. Semiconductor fabrication processes are influenced by one or both, directly controlling how well methods developed for the microscale can be adapted to the nanoscale. Examples drawn from etching, deposition, photolithography and nanoimprint lithography will be discussed, illustrating some general principles that may potentially be used to advantage in materials nanoprocess design.

4:40pm **EM-WeA9 A Novel Route Towards Electrical Connection and Probing of Nano-scaled Devices on Semiconductor Surfaces**, ***J. Koeble***, *M. Maier*, Omicron NanoTechnology GmbH, Germany, *D. Jie*, *N. Chandrasekhar*, Institute of Materials Research and Engineering (IMRE), Singapore, *C. Joachim*, CEMES-CNRS, France

A major challenge in Nanotechnology is the incorporation of single nano-devices into larger integrated circuits. Although work on individual (and non-integrated) nano-structures such as molecules is intense, the question of their electrical connection with more than two probes (such as conventional SPM experiments) remains an open question. Established nano-lithography techniques such as EBL and FIB seem to not satisfy requirements for ultra clean and defined contact structures at the atomic scale. Traditional

***** John A. Thornton Memorial Award Winner

instrumentation for analysis is fundamentally limited: How to cover the dimensional range of an integrated circuit (mm) down to the atomic scale of a single molecule device and at the same time to have an adequate integrated navigation system? To meet these requirements, we have established and being advancing a new approach integrating SPM technology with high resolution electron microscopy: (1) Bridging dimensions by combined SEM (down to below 3nm resolution) and STM operation at the atomic scale; (2) Rapid SEM navigation of four local STM probes; (3) Individual probe fine positioning by high resolution STM imaging; (4) STM based probe approach for "soft-landing" of sharp and fragile probes and controlled electrical contact for transport measurements. To open a route for fundamental evaluation of the potential of single molecule devices, this instrumental technology is employed to establish electrical connection for local transport measurements. As a model system, we have chosen Au nano-islands on MoS_2. These islands represent contact pads, each electrically connected by an individual STM probe. As good band gap (approx. 1.3eV transverse gap) semiconductor, MoS_2 has the potential to sufficiently decouple those nano-structures electrically at low voltage. Those Au triangular nano-islands have a lateral size of typically 10-30nm and form an "atomically" ultra clean and defined metal-semiconductor interface. We present measurements that prove (1) SEM based navigation and STM based electrical contacting with a tip radius in the 10nm range: (2) reproducible Schottky like IV properties for the individual STM tip/Au nano-island/substrate contact; (3) surface conductance measurements with variable inter-island distance down to 17nm; (4) comparison with surface conductance measurements of the bare MoS2 substrate. We also show that the individual STM probe can be employed under SEM to manipulate those Au nano-islands [1] with high precision in order to generate arbitrary multi probe planar contact configurations.

[1]: J.S. Yang, D. Jie, N. Chandrasekar and C. Joachim J. Vac. Sci. Tech. B, 25, 1694 (2007).

5:00pm **EM-WeA10 Dynamic Imaging and Analysis of the Charge Trapping at the Metal-Organic Interface**, ***C. Kim***, *D. Jeon*, Seoul National University, South Korea

Understanding of metal/organic interfaces is one of the key issues for the design of high performence organic devices. We have studied the interface properties of the Al/pentacene/Au sandwich samples by performing electrostatic force microscopy (EFM) and measuring *I-V* curves at various temperatures. The Al/pentacene/Au sandwich sample showed a typical rectifying *I-V* curve as expected from the energy diagram. Interestingly, the current increased with time when a constant forward bias was applied. In order to understand the reason, we performed EFM of the cross section of Al/pentacene/Au to measure the time variation of the charge density across the interface. The result suggested that there was a charge accumulation at the Al/Pentacene interface and that the reason for the current increase with time was the lowered potential barrier caused by the trapped charges. From the temperature-dependent *I-V* measurement, we could estimate the amount of barrier lowering. When the measurement was performed in UHV environment, the current increase was not observed, which suggested that water molecules diffused into pentacene in the ambient condition played a role of trap sites.

5:20pm **EM-WeA11 Au-$Al_{0.27}Ga_{0.73}N$ Shottky Barrier Formation and Charge Carrier Mobility Estimation**, ***S. McHale***, Air Force Institute of Technology, *Ya. Losovyj*, Nebraska Center for Materials and Nanoscience, University of Nebraska-Lincoln and J. Bennett Johnston Sr. Center for Advanced Microstructures and Devi, *D. Wooten, J. McClory, J. Petrosky*, Air Force Institute of Technology

Au-AlGaN Shottky barrier formation is observed using Au evaporation on an $Al_{0.27}Ga_{0.73}N$ strained Wurtzite structure, thin film that is deposited on GaN. Low Energy Electron Diffraction was performed to verify the integrity of the Au deposition. Energy dependent, synchrotron generated photoemission spectroscopy ranging from 15 to26 eV under UHV conditions clearly determines a Fermi edge shift of up to 0.5 eV. Charge carrier mobility is inferred using valence band mobility edge data.

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