

Tuesday Morning, October 19, 2010

Electronic Materials and Processing Room: Dona Ana - Session EM-TuM

Contacts and Transport

Moderator: L. Porter, Carnegie Mellon University

8:00am **EM-TuM1 Resistivity Increase due to Electron Surface Scattering in Nanoscale Metal Films**, *J.S. Chawla, D. Gall*, Rensselaer Polytechnic Institute

8:20am **EM-TuM2 Extracting Inelastic and Elastic Hot Electron Attenuation Lengths from nm-Thick Metal Films using BEEM**, *J.J. Garramone, J.R. Abel, I.L. Stimitsky, V.P. LaBella*, University at Albany

Measuring the scattering of electrons in nm-thick structures of metals such as Cu and Ag is both technologically and fundamentally significant. For example, sidewall and grain boundary scattering in nanoscale Cu-metal interconnects dramatically increases the resistance, which is detrimental to device performance. A highly accurate method for studying hot electron transport on the nanometer length scale is ballistic electron emission microscopy (BEEM). BEEM is a three terminal scanning tunneling microscopy (STM) based technique, where electrons tunnel from a STM tip into the grounded metal base of a Schottky diode [1]. The BEEM current is a measurement of the electrons that traverse the metal film and are collected in the semiconductor. Results from BEEM measurements of the hot electron attenuation length of the metal films will be presented. A Fermi liquid based model is utilized to extract the inelastic and elastic contributions to the scattering. The metal films are deposited on H-terminated Si(001) under ultra-high vacuum (UHV). The BEEM measurements are taken at 77K under UHV. Recently we fabricated a contact to the metal layer on the silicon utilizing standard lithography prior to deposition of the metal in UHV [2]. This allowed these BEEM measurements to be performed *in situ*. The process utilized to fabricate this contact will be presented along with the *in situ* BEEM results.

References:

- [1] L. D. Bell and W. J. Kaiser, Phys. Rev. Lett. 61 2368 (1988)
- [2] J. J. Garramone, et al., J. Vac. Sci. Technol. A (in press) (2010)

8:40am **EM-TuM3 Influence of Spontaneous Polarization and Intrinsic Gap States in Schottky Contacts to ZnO**, *M.W. Allen*, University of Canterbury, New Zealand, *S.M. Durbin*, University at Buffalo
INVITED

Zinc oxide is an interesting test case for evaluating theoretical Schottky contact formation models as it is significantly more ionic than most semiconductors. This results in weaker Fermi level pinning, which in turn allows the barrier height of Schottky contacts to vary with metal properties. Equally important is the fact that contacts can be prepared on laterally homogeneous, bulk-grown, single crystals with minimal surface processing as there is no requirement, as with most semiconductors, to remove native surface oxide layers with potentially damaging etching treatments. As a result, we have been able to fabricate very low ideality factor, laterally homogeneous Schottky contacts to 'intrinsic' ZnO surfaces for a wide variety of metals using a novel eclipse pulsed laser deposition technique. Using these contacts, we have evaluated the two leading contemporary Schottky contact formation models – Tung's 'chemical bond polarization model' and Mönch's 'metal induced gap states and electronegativity model'. The lack of broad agreement with either of these models suggests the involvement of additional mechanisms, perhaps involving the large spontaneous polarization of ZnO and ionic surface charge screening effects, with important consequences for other oxide semiconductors.

9:20am **EM-TuM5 Dynamics of the Charge Transfer through the Individual Molecules in Alkanethiolate Self-Assembled Monolayers**, *P. Kao*, Pennsylvania State University, *S. Neppel, P. Feulner*, Technische Universität München, Germany, *D.L. Allara*, Pennsylvania State University, *M. Zharnikov*, Universität Heidelberg, Germany

Emergence of molecular and organic electronics as frontier fields of modern science and technology require reliable experimental data regarding the charge transport (CT) in individual molecules and their functional units. Whereas static conductance of molecules arranged in self-assembled monolayer (SAM) fashion on a suitable substrate has been extensively studied, little is known about the CT dynamics in these systems. By the example of alkanethiolate films on Au(111), we show that the latter phenomena can be successfully addressed by resonant Auger spectroscopy, using the core hole clock method. The charge transfer pathway was

unambiguously defined by resonant excitation of the nitrile tailgroup attached to the alkyl backbone. The length of this backbone was varied to monitor the respective dependence of the CT time. It was found that, similar to the static conductance, this dependence can be coarsely described by an exponential function with an attenuation factor of 0.93 per a methylene unit. As a result, the CT time is quite long even for a relatively short alkyl chain; in particular, it is ca. 100 fs for the chain consisting of only four methylene units. In contrast, the CT time associated with the thiolate headgroup anchor was found to be quite short, viz. 2.3 fs (upper limit), which suggests an efficient interfacial electronic coupling between the aliphatic backbone of the molecules and substrate over the thiolate-gold linkage.

9:40am **EM-TuM6 Electronic Properties and Assembly of Zinc Metalloporphyrin Islands on Au(111) Surfaces**, *A.E. Schuckman, K.M. Webb, L.M. Perez*, Texas A&M University, *M. Jurow*, Hunter College of the City University of New York, *L.H. Yu*, National Institute of Standards and Technology, *C.M. Drain*, Hunter College of the City University of New York, *J.G. Kushmerick*, National Institute of Standards and Technology, *J.D. Batteas*, Texas A&M University

Porphyrins are stable, highly conjugated compounds and the choice of metal ion and substituents bound to the macrocycle as well as other effects such as chemical surrounding and cluster size modulate the electronic and photonic properties of the molecule. Porphyrins and their derivatives are relatively non-toxic, and due to their very rich photo- and electro-chemistry as well as their small HOMO-LUMO gaps, this makes them outstanding candidates for use in molecularly-enhanced electronic applications.

For this study, the transport properties of self-assembled zinc coordinated tri-pyridyl porphyrin thiol islands inserted into a dodecanethiol matrix on Au(111) were investigated using scanning tunneling microscopy (STM) and cross-wire inelastic tunneling spectroscopy (IETS). The zinc porphyrin thiol islands observed by STM exhibited reversible bias-induced switching at high surface coverage due to the formation of Coulomb islands of ca. 10 nm diameter driven by porphyrin aggregation. Low temperature measurements (~ 4 K) from crossed-wire junctions verified the appearance of a Coulomb staircase and blockade which was not observed for single molecules of this compound or for the analogous free base. Scanning probe lithography via nanografting has been implemented to fabricate nanoscale patterns of the zinc porphyrin thiols on Au surfaces and ultimately ~ 10 nm islands which is the optimal size for the observed switching effect.

10:40am **EM-TuM9 Deposition of Nickel Nanostructures by Electroless Deposition on Micron-Scale Patterned SAMs**, *Z. Shi, A.V. Walker*, University of Texas at Dallas

We have investigated the reaction pathways involved in the electroless deposition of nickel on -COOH, -OH, and -CH₃ terminated functionalized alkanethiolate self-assembled monolayers (SAMs) adsorbed on gold, using time-of-flight secondary ion mass spectrometry (TOF SIMS), scanning electron microscopy (SEM) and x-ray photoelectron spectroscopy (XPS). This work has important applications in molecular/organic electronics as well as other technologies.

We observe that the nickel electroless deposition rate increases as the plating bath pH increases. For -COOH, terminated SAMs, this effect is very pronounced, with the largest deposition rates observed at above pH = 9. This is most likely due to the -COOH terminated groups deprotonating to form forming carboxylate ions, COO⁻. These carboxylate ions can easily complex with Ni²⁺ ions in solution, forming Ni-carboxylate complexes which serve as the nucleation sites for Ni deposition. Furthermore on -COOH terminated SAMs the nickel overlayer forms almost immediately, while on -CH₃ and -OH terminated SAMs the nickel overlayer forms after 15-20 minutes deposition. The nucleation of the Ni overlayer is slightly faster on the hydrophobic -CH₃ terminated SAM than on the hydrophilic -OH terminated SAM.

By exploiting the different nickel deposition rates on -COOH, -OH, and -CH₃ terminated SAMs we demonstrate that a variety of nanostructures can be produced, including nanowires and rings, using micron-scale patterned SAM surfaces.

11:00am **EM-TuM10 Rapid DNA Sequencing via Transverse Electronic Transport**, *M. Zwolak*, Los Alamos National Laboratory, *M. Di Ventra*, University of California at San Diego

A rapid and low-cost DNA sequencing method would revolutionize medicine: a person could have their full genome sequenced so that treatments could be tailored to their specific conditions; doctors could know in advance a patient's likelihood to develop a given ailment; cures to major diseases could be developed faster. These goals of "personalized medicine" is hampered today by the high cost and slow speed of DNA sequencing

methods. I discuss a sequencing protocol we suggest that uses the measurement of transverse electronic currents during the translocation of single-stranded DNA through nanopores. I present support for our conclusions using molecular dynamics simulations coupled to quantum mechanical calculations of electrical current in experimentally realizable systems. Several recent experiments also support our theoretical predictions. In addition to their possible impact in medicine and biology, the above methods offer ideal test beds to study open scientific issues in the relatively unexplored area at the interface between solids, liquids, and biomolecules at the nanometer length scale [1].

[1] M. Zwolak, M. Di Ventra, "Physical Approaches to DNA Sequencing and Detection", *Rev. Mod. Phys.* 80, 141 (2008).

11:20am **EM-TuM11 Using Scanned-Probe Microscopy to Study Surface-Induced Fluctuations as a Tool for Microscopically Probing Organic Materials**, *N. Hoepker*, Cornell University

11:40am **EM-TuM12 High Precision Local Electrical Probing: Potential and Limitations for the Analysis of Nanocontacts and Nanointerconnects**, *A. Bettac, J. Koebler, B. Guenther, M. Maier, A. Feltz*, Omicron NanoTechnology GmbH, Germany, *D. Jie, N. Chandrasekhar*, Institute of Materials Research & Engineering, Singapore, *C. Joachim*, CEMES-CNRS, France

The variety of approaches for individual nanoscale devices is tremendous. In contrast however, comprehensive concepts towards electrically integrated and therefore functional devices are rare. The individual (metallic) contact interface represents one of the main challenges and high precision local electrical probing has the potential to increase efficiency in evaluating different approaches. To meet the involved requirements, we have established and being advancing an approach integrating SPM technology with high resolution electron microscopy: (1) Rapid and simultaneous SEM navigation of four local STM probes; (2) Localization of nanostructures by high resolution SEM; (3) Individual probe fine positioning by atomic scale STM imaging; (4) STM based probe approach for "soft-landing" of sharp and fragile probes and controlled electrical contact for transport measurements; (5) approaches towards sharp and clean STM tips; (6) suitable low noise signal re-routing for transport measurements; and (7) chemical or magnetic analysis by complementary analysis techniques.

We will report on recent technical enhancements and illustrate achievements and limitations along specific applications. As a model system, we have chosen Au islands on MoS₂ [1]. These islands represent contact pads, each electrically connected by an individual STM probe. As good band gap (approx. 1.3eV transverse gap) semiconductor, MoS₂ has the potential to sufficiently decouple nanostructures electrically at low voltage. Those Au triangular islands have a lateral size of typically 10-30nm and form an "atomically" clean and defined metal-semiconductor interface. We will present measurements on (1) probe navigation and electrical contacting with contact distances in the 10nm regime. (2) reproducible Schottky like IV properties for the individual STM tip/Au island/substrate contact; (3) surface conductance measurements with variable inter-island distance down to 17nm; and (4) we also show that the individual STM probe can be employed under SEM to manipulate those Au islands [2] with high precision in order to generate arbitrary multi probe planar contact configurations.

Furthermore, we will present a newly developed probing system. The complete stage including probes is cooled down to LHe temperatures, while each probe is capable of atomic resolution STM. A major challenge is the integration of an high performance UHV Gemini SEM into the thermally shielded probe stage compartment, while maintaining the sample temperature below 10K during SEM operation.

[1] MSM Saifullah et al., *Nanotechnology*, 13, 659 (2002)

[2] J.S. Yang et al., *J. Vac. Sci. Tech. B*, 25, 1694 (2007)

Authors Index

Bold page numbers indicate the presenter

— A —

Abel, J.R.: EM-TuM2, 1
Allara, D.L.: EM-TuM5, 1
Allen, M.W.: EM-TuM3, 1

— B —

Batteas, J.D.: EM-TuM6, 1
Bettac, A.: EM-TuM12, 2

— C —

Chandarsekhar, N.: EM-TuM12, 2
Chawla, J.S.: EM-TuM1, 1

— D —

Di Ventra, M.: EM-TuM10, 1
Drain, C.M.: EM-TuM6, 1
Durbin, S.M.: EM-TuM3, 1

— F —

Feltz, A.: EM-TuM12, 2
Feulner, P.: EM-TuM5, 1

— G —

Gall, D.: EM-TuM1, 1
Garramone, J.J.: EM-TuM2, 1
Guenther, B.: EM-TuM12, 2

— H —

Hoepker, N.: EM-TuM11, 2

— J —

Jie, D.: EM-TuM12, 2
Joachim, C.: EM-TuM12, 2
Jurov, M.: EM-TuM6, 1

— K —

Kao, P.: EM-TuM5, 1
Koeble, J.: EM-TuM12, 2
Kushmerick, J.G.: EM-TuM6, 1

— L —

LaBella, V.P.: EM-TuM2, 1

— M —

Maier, M.: EM-TuM12, 2

— N —

Neppl, S.: EM-TuM5, 1

— P —

Perez, L.M.: EM-TuM6, 1

— S —

Schuckman, A.E.: EM-TuM6, 1
Shi, Z.: EM-TuM9, 1
Sitnitsky, I.L.: EM-TuM2, 1

— W —

Walker, A.V.: EM-TuM9, 1
Webb, K.M.: EM-TuM6, 1

— Y —

Yu, L.H.: EM-TuM6, 1

— Z —

Zharnikov, M.: EM-TuM5, 1
Zwolak, M.: EM-TuM10, 1