Nanometer-Scale Science and Technology
Room 210 - Session NS-WeM

Nanometer Scale Imaging

Moderator: R. Bennewitz, McGill University

8:20am **NS-WeM1 Atomic Scale Analysis of Dielectric Surfaces and Nanostructures***, **M. Reichling**,* Universitaet Osnabrueck, Germany **INVITED**

Nanostructures involving dielectric materials play an increasingly important role in numerous fields of science and technology. Prominent examples are ultra-precision machined optical surfaces, high-k dielectrics and diamond in microelectronics, catalytic surfaces and insulating substrates for sensor applications and molecular electronics. Dynamic scanning force microscopy (SFM) operated in the so-called non-contact mode is the method of choice for an atomic scale characterisation of such structures. The method of dynamic SFM is introduced as the only analysis tool capable of atomic resolution imaging of insulating surfaces and nanostructures. The state of the art in highest resolution dynamic SFM on insulators and challenges for future developments are illustrated for examples from different fields of application. While a detailed interpretation and quantitative understanding of atomic contrast formation is demonstrated for fluoride surfaces, the formation and dynamics of surface defects is discussed for oxide surfaces.

9:00am **NS-WeM3 Bioelectromechanical Imaging by Scanning Probe Microscopy: Galvani's Experiment on the Nanoscale***, **S.V. Kalinin**,* Oak Ridge National Laboratory*; B.J. Rodriguez,* North Carolina State University*; S. Jesse, A.P. Baddorf,* Oak Ridge National Laboratory*; A. Gruverman,* North Carolina State University

Coupling between electrical and mechanical behavior is a universal feature of biological systems. However, macroscopic studies are inherently limited by the complex structure of these materials. Here, we demonstrate a scanning probe microscopy (SPM) based approach for electromechanical imaging and spectroscopy of biological systems based on Piezoresponse Force Microscopy (PFM). Electromechanical imaging of tooth dentin and enamel has been performed using PFM with sub-10 nm resolution. Characteristic piezoelectric domain sizes and local protein fiber ordering in dentin have been determined. The shape of a single collagen fibril in enamel is visualized in real space and local electromechanical hysteresis loops are measured. We have also shown that the electromechanical response vector is related to the local molecular orientation and provides an approach for molecular orientation imaging in biological systems. This technique is further used to address several biological systems, including cartilage, antler, bone, and butterfly wing. This approach repeats Galvani's experiment on the nanoscale - 230 years later and with a million times higher resolution. The future opportunities of electromechanical SPM for characterization of complex biological systems are discussed. Research performed as a Eugene P. Wigner Fellow (SVK) at ORNL, managed by UT-Battelle, LLC under DOE contract DCE-AC05-00OR22725. AG acknowledges financial support of the National Science Foundation (Grant No. DMR02-35632).

9:20am **NS-WeM4 Bridge Enhanced Nanoscale Impedance Microscopy***, **L.S.C. Pingree**, M.C. Hersam,* Northwestern University

Bridge Enhanced Nanoscale Impedance Microscopy (BE-NIM) advances the ability to measure the impedance of individual nanoscale conductive pathways in a variety of materials. Similar to Nanoscale Impedance Microscopy (NIM),@footnote 1@ this technique concurrently monitors the magnitude and phase response of the current through a conductive AFM tip in response to an AC bias. By varying the frequency of the driving potential, the resistance and reactance of nanometer scale conductive pathways can be quantitatively determined. Previously, we have demonstrated the extreme accuracy of NIM on a variety of control systems, such as a set of gold nanowires connected to known impedances, resulting in concurrent current and phase images. In addition, we have performed NIM on 8 µm x 8 µm Organic Light-Emitting Diode (OLED) pixels, which exhibit enhanced negative capacitance.@footnote 2@ However, the effects of long-range electrostatic interactions impose a detection limit on NIM of ~1 pF. These interactions, or fringe capacitance, act as a capacitor in parallel with the sample/tip junction. BE-NIM minimizes the contribution of this capacitance by employing a LRC bridge that improves the detection limit to ~50 aF. This improved sensitivity has been demonstrated on metal-oxide-semiconductor capacitors ranging in size from 5 fF to 50 aF. The application of BE-NIM to other materials systems, such as carbon nanotube/polymer composites and sub-micron OLEDs, will also be discussed. @FootnoteText@ @footnote 1@ L. S. C. Pingree, et al., IEEE T. Nanotechnol., 4, 255 (2005).@footnote 2@ L. S. C. Pingree, et al., Appl. Phys. Lett., 86, 073509 (2005).

9:40am **NS-WeM5 Development of a Tunable Microwave Frequency Alternating Current Scanning Tunneling Microscope to Profile Dopant Density in Semiconductors***, **A.M. Moore**,* The Pennsylvania State University*; B.A. Mantooth,* GeoCenters*; P.S. Weiss,* The Pennsylvania State University

We have built a scanning tunneling microscope (STM) capable of profiling dopants in semiconductor devices and test structures at sub-nanometer resolution. The alternating current signals, and thereby the dopant density and type, are obtained through a heterodyned signal. Two frequencies are applied to the STM tip and the nonlinearity of the tunnel junction mixes the frequencies, generating new signals including at the difference of the frequencies applied; this in combination with the DC bias yields information on the dopant density and type. This ultrahigh resolution (<1 nm) profiling tool enhances what is obtained through current metrology tools and will support semiconductor processing as the size scale of devices continues to decrease.

10:20am **NS-WeM7 Single-Electron Charging in InAs Quantum Dot Observed by NC-AFM***, **P. Grutter**,* McGill University, Canada **INVITED**

In this paper, we present the first successful observation of single electron charging events in an individual InAs QD by spectroscopic measurement with a 4.5K vacuum non-contact AFM (NC-AFM). The main features of the experimental results agree with a simple theory based on the semiclassical theory of the Coulomb blockade effect.@footnote 1@ The sample structure consists of a two dimensional electron gas (2DEG) layer used as a back electrode. The uncapped InAs QD were grown on top of a InP spacer layer serving as a tunneling barrier. The resonant frequency shift and the dissipated energy of an oscillating AFM cantilever were measured as a function of the tip-back electrode voltage, and the resulting spectra show distinct jumps when the tip was positioned above a QD. The observed jumps in the frequency shift, with corresponding peaks in dissipation, are attributed to a single-electron tunneling between the dot and the back electrode governed by the Coulomb blockade effect, and are consistent with a model based on the free energy of the system. The observed phenomenon may be regarded as the force version of the Coulomb blockade effect. The peaks in dissipation are essentially due to a single electron back action effect on a micromechanical transducer. This NC-AFM based technique has several advantages: It does not need any leads to be attached to individual QD and is also much less invasive for the mesurement of quantum states in the QD because only weak, controllable coupling between the tip and the QD is required. @FootnoteText@ @footnote 1@ Stomp et al., Phys. Rev. Lett. 94, 056802 (2005).

11:00am **NS-WeM9 Development and Characterisation of Reference Materials for Nanotechnology: High Lateral Resolution Auger Electron Spectroscopy on Semiconductor Heterostructures***, J. Westermann, **U. Roll**,* Omicron NanoTechnology GmbH, Germany*; M. Senoner, W. Unger,* Federal Institute for Materials Research and Testing, BAM, Germany

Today, a broad variety of different techniques and instruments is used to characterise nanoscale materials. However, a comparison between results taken with different instruments is often difficult or impossible. To overcome this gap, the Federal Institute for Materials Research and Testing (BAM), the Physikalisch-Technische Bundesanstalt, ION-TOF GmbH and Omicron Nanotechnology GmbH have entered into a project to develop reference samples with nanoscale structures. We report on the characterisation of the first prototype of a semiconductor heterostructure with alternating AlGaAs and GaAs layers. The cross section of the epitaxially grown multilayer stack shows a variety of strips in the thickness range between 700nm and well below 10nm. The strip pattern includes strip gratings, isolated narrow strips and wide strips with step transitions. SEM and Auger measurements with highest lateral resolution (sub 10 nm) reveal the distribution of the various elements on the sample surface, and prove the quality of the sample preparation. We discuss the suitability of the sample to become a widely accepted, certified reference standard for lateral resolution in surface chemical analysis.

11:20am **NS-WeM10 STM and AFM Imaging with In-Situ Tip-Characterization***, **C.J. Chen**, O. Pietzsch, D. Haude, R. Wiesendanger,* Hamburg University, Germany

The biggest unknown factor in STM and non-contact atomic-force microscopy (NC-AFM) experiments is tip electronic states. Experimental observations show that the STM and AFM images vary dramatically with change of tip structure, either intentionally, or spontaneously. Conceptually, tunneling is symmetric to tip and sample, and the STM and AFM images should be determined by a convolution of tip electronic states and sample electronic states. From the beginning of STM, various attempts to characterize the tip have been proposed and tried, most notably using FIM. However, the correlation between the FIM image of the tip and the tip electronic states relevant to STM and AFM imaging is still not clearly identified. For spin-polarized STM, the azimuthal dependence of spin polarization of tip electronic states often determines the images. Currently, there is no well-defined method to determine the azimuth of spin polarization. We present a new method for determining the tip electronic states and the azimuthal dependence of spin polarization of the tip by imaging the tip with well-understood samples. For general tip states, Si(111)7X7 is an ideal standard sample, because the dangling-bond states on the adatoms are well separated in space and the mean energy levels cover more than 1 eV across the Fermi level. For spin-polarized tips, the Fe monolayers on W(001) system provides a perfect standard sample, because of its well-known properties of providing different ferromagnetic orientations.@footnote 1,2@ Using tips characterized by standard samples to image unknown samples, image interpretation is becoming much more certain. Furthermore, through tip reconditioning and tip characterization, tip properties can be optimized to achieve maximum contrast. @FootnoteText@@footnote 1@M Bode, O Pietzsch, A Kubetzka, S Heinze and R Wiesendanger, PRL 86, 2142 (2001).@footnote 2@A Kubetzka, M Bode, O Pietzsch and R Wiesendanger, PRL 88, 057201 (2002).

11:40am **NS-WeM11 Towards the Fabrication of Ultra High Throughput Optical Fiber Probes***, **B.C. Gibson**, S.T. Huntington,* University of Melbourne, Australia*; J. Canning, K. Lyytikainen,* University of Sydney, Australia*; J.D. Love,* Australian National University, Australia

Scanning near field optical microscopy (SNOM) has become an important characterization tool across all major disciplines of science. The ability to "cheat" the resolution limit in optical microscopy has enabled characterization of structures on a nanometer scale. At the heart of the technique is a metal coated scanning probe, which features a sub-wavelength aperture as a source or collector of light that explores the near-field of the sample surface. The key problem with this type of SNOM probe is the excessive loss that occurs, which effectively limits the sensitivity of the microscope. The high loss arises from attenuation through the sub-wavelength aperture, which is unavoidable. In addition, the high loss stems from an interaction with the metal coating at the tapered region of the tip. Preliminary theoretical models of tapered air-silica structured fibers suggest that this interaction with the metal may be reduced with the use of these fibers, along with a new type of fiber called a Fractal Fiber (special class of air-silica fiber), instead of using standard single-mode optical fibers. Tapering of these fibers has been performed using a custom-built CO@sub 2@ laser-based fiber pulling system to produce a prototype ultra high throughput optical probe. Initial optical throughput measurements have shown improved power levels to that of conventional SNOM probes. This suggests that the fiber design and fabrication is critical to the successful advancement of SNOM probes.

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