SYMPOSIUM O
Scanning- Probe and Other Novel Microscopies of Local Phenomena in Nanostructured Materials

November 29 - December 3, 2004

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* Invited paper

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Lock-and-Key Effect in the Surface Diffusion of Large, Organic Molecules


We have investigated the effect of biaxial strain on local electrical/electronic properties in thin films of La$_{0.7}$Ca$_{0.3}$MnO$_3$. The local electrical properties were investigated primarily in the ferromagnetic (FM) metallic phase of the system, as a function of temperature using scanning tunneling spectroscopy (STS). We found that the diffusion coefficient of the complex organic molecule named the Viloet Lander (VL, C10H8N104) on a Cu(110) surface can be changed by two orders of magnitude by purposefully manipulating the VL molecules on the terraces and steps of the substrate to result in a change in the local potential. This is because the potential distribution across the sample is reflected in the ratio E$_T$/E$_S$, which shows a monotonic increase with temperature. Thus even a small imbalance (biaxial strain) can induce significant changes in the electrical properties of the system. It is rather interesting and important to quantify such strain effects and optimize its role in potential device applications.

10:00 AM *01.4 The Frontiers of Scanning Tunneling Probes in Condensed Matter Physics. E. Ward Plummer',2 and A. V. Balatsky 3;

1Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee; 2Condensed Matter Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee; 3Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

This presentation will describe the state-of-the-art and our vision of the future in the development and utilization of scanning tunneling probes for the elucidation of phenomena in the world of contemporary condensed matter physics. The new results will be presented, and how they will aid the field in quantum technologies and material science.

6:30 AM *00.11 Scanning Tunneling Spectroscopy in the Study of Semiconductor Surfaces: New Perspectives and Challenges. S. Bhattacharya; Physics Department, University of New Mexico, Albuquerque, NM

This presentation will introduce the reader to some unique applications of scanning tunneling microscopy (STM) and spectroscopy (STS) in the study of surfaces of various materials. This will include the study of adsorbed atomic species, the study of electronic states at surfaces and the study of local structure at surfaces.

9:00 AM *01.3 Atom Selective Imaging and Mechanical Atom Manipulation Based on Noncontact-AFM Method. Sergio Morita 1,2, Noraki Oyabu, Yoshiaki Sugimoto, Oscar Custance, Masayuki Abe 1 and Ryujin Nishihara 1; 1Department of Electronic Engineering, Osaka University, Suita, Osaka, Japan; 2Handai FRC, Suita, Osaka, Japan.

instruments, and more importantly how do we make them available to the materials community. There is a need for national centers for the Advancement of Scanning Probe Technology.


A quantitative study of the long-range interactions between bromine islands on Cu(111) mediated by the surface state at elevated temperatures is presented. Randomly distributed bromine adatoms are immobile at 250 K, but when annealed to 600 K the adatoms become mobile and aggregate to form islands. The interaction potential between these islands has been determined by evaluating the distance distribution between the bromine islands from a series of scanning tunneling microscopy images taken at 4 K. By only taking two-body interactions into consideration, we demonstrate that the interaction potential is oscillatory in nature with potential energy minima observed at 12, 26 and 41 Å. This corresponds to a period of about half the Fermi wavelength of Cu(111). Unlike previous quantitative studies of long-range interactions between single metal adatoms on Cu(111) at temperatures up to 21 K, (1, 2) we do not observe long-range interactions up to 70 Å due to the shorter coherence length of the Cu surface state at elevated temperatures. Our findings indicate the pair potential only exists up to about 40 Å, which is in good agreement with the coherence length of 34 Å of the Cu(111) surface state at 600 K. For this study we present conclusive evidence that the perturbations due to the surface state are important and relevant in mediating interactions between adsorbates at catalytically relevant temperatures. (1) Pepp, J., Moretto, F., Meyer, G., Rieder, K. H., Hyldgaard, P. Phys. Rev. Lett. 2000, 85, 2901. (2) Knorr, N.; Brune, H.; Eppe, M.; Hirstein, A.; Schneider, M. A. K.; Kern, K. Phys. Rev. B 2002, 65, 115420. (3) Fujita, D.; Amemiyi, K.; Yakabe, T.; Nojoh, H.; Sato, T.; Iwatsuki, M. Phys. Rev. Lett. 1997, 78, 3504.

10:45 AM Q1.6 Pairwise Movement of Iodine on Si(100) at Room Temperature: Direct Observation with Scanning Tunneling Microscopy. Ji Xiu1, A. W. Signor1, Ashish Agrawal1, Koji S. Nakayama1, B. R. Trentham2 and John H. Weaver1,2. 1Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois; 2Physics, University of Illinois at Urbana-Champaign, Urbana, Illinois.

Halogen molecules dissociatively chemisorb on Si(100)-(2x1) and the subsequent mobility of atomic and paired ad-species increases from CI to Br to I. For CI, which has the highest barrier for diffusion, scanning tunneling microscopy reveals both single and paired adatoms at 295 K. For Br, the barrier is smaller and single adatoms interrogate the surface until they form pairs, which are then immobile, or are trapped at CI-type defects. For the barrier to diffuse the pairs still act as traps, and pairwise motion is possible and can be quantified at room temperature. Studies over long times reveal pairwise diffusion that is ultimately quenched by the increasing density of CI-type defects (dislocations), and the diffusion of I pairs is thermally activated, the events are random, and they can be frozen-out at 80 K. The diffusivities along and across the dimer row are 0.61 and 0.24 Å²/sec at T = 295 K. Their respective energy barriers are estimated to 0.79 and 0.81 eV, assuming an attempt frequency of 10¹³ sec⁻¹. The effective barrier for pairwise motion is the sum of the isolated atom barrier and the energy needed to dissociate a pair, i.e., the π bond energy for Si(100).

11:00 AM Q1.7 Temperature dependence of molecular diffusion in alkanethiol self-assembled monolayers: studies with scanning tunneling microscopy. The effect of melting transition and molecular desorption. Ung Hwan Pi¹, Huy Young Yu¹, Chan Woo Park¹, Sung-Yool Choi¹, Jun Ho Kim³, Yong-Kwan Kim³ and Jeong Sook Nam¹. 1Dept. of chemical engineering, UNIST; 2 dept. of electrical engineering; 3 dept. of physics, Korea University, Seoul, South Korea.

We have studied the surface diffusion of the molecules in alkanethiol self-assembled monolayer (SAM) by using scanning tunneling microscopy (STM) with a variation of surface temperature. From the successive STM images obtained at several temperatures, we could visualize the motion of the molecules and molecular desorption of alkanethiol SAM. The melting temperature estimated from the STM images was dependent upon the chain length of the alkanethiol, that is, the longer chain alkanethiol SAM has the higher melting transition temperature. Below melting transition temperature, the molecules diffuse only through narrow channels, i.e., the boundaries of the well ordered lattice domains, resulting in a slow structural change of the surface. Above melting transition temperature, the molecular diffusion shows different behaviors depending upon the chain length of the alkanethiol. For a relatively short octanethiol SAM, the enhancement of molecular diffusion after melting transition is dominant. For dodecanethiol that has a longer chain, however, the diffusion is dramatically enhanced after melting transition, rendering an abrupt structural change of the surface. The measurement of the molecular coverage shows that the desorption temperature is quite near the temperature of melting transition in case of dodecanethiol SAM. The dramatic enhancement of the molecular diffusion observed in dodecanethiol is induced by the molecular desorption. The empty sites formed during the desorption process give much room for the molecular diffusion.

11:15 AM Q1.8 Using ultra-small amplitude AFM for linearized measurements of nanomechanical phenomena. Peter M. Hoffmann, Shivprasad Patil, George Matei and Atay Taslakli, Physics, Wayne State University, Detroit, Michigan.

Dynamic Atomic Force Microscopy (AFM) is typically performed at amplitudes that are quite large compared to the measured interaction range. This complicates the data interpretation as measurements become highly non-linear. In the last few years we have successfully employed a new dynamic AFM technique in which deliberately ultra-small amplitudes are used (as low as 0.15 Angstrom). This way we have been able to linearize measurements of nanomechanical phenomena, including single atom bonding, atomic-scale dissipation and molecular ordering in adsorbate layers, including water. We will introduce the technique, its theory, and recent results in vacuum and liquids.

11:30 AM Q1.9 Atomically Resolved Imaging of Epitaxial CaF₂ on Si(111) using Non-contact Atomic Force Microscope. Yoshitake Sano1,2, Masayuki Abe3, and Seizo Morita1,3. 1Hokkaido Frontier Research Center, Osaka University, Suita, Osaka, Japan; 2Electron Engineering, Osaka University, Suita, Osaka, Japan; 3Department of Chemical and Biological Engineering, Incheon University, Incheon, South Korea.

Non-contact Atomic force microscope (NC-AFM) enables high resolution imaging of surfaces regardless of sample's electric conductivity. It has been accepted the truth that UHV-NC-AFM had already succeeded in the true atomic resolution imaging for various surfaces of metals, semiconductors and insulators. But the imaging mechanism of the atomic contrast is not yet fully understood. NC-AFM involves many kinds of tip-sample interactions, each with different interaction-range, both short- and long-range interactions between them affect the measured forces but only short-range forces give the atomic images. In view of the sensitivity, not only the adatoms but also the rest-atoms on Si(111)-7x7 and Ge(111)-c(2x8) reconstructed surfaces had been imaged with atomic resolution. In CaF₂/Si(111) surface of cleaved crystal, combined theoretical and experimental investigations have shown the contribution of several inner atomic features.

Atomically Resolved Imaging of Epitaxial CaF₂ on Si(111) using Non-contact Atomic Force Microscope. Yoshitake Sano1,2, Masayuki Abe3, and Seizo Morita1,3. 1Hokkaido Frontier Research Center, Osaka University, Suita, Osaka, Japan; 2Electron Engineering, Osaka University, Suita, Osaka, Japan; 3Department of Chemical and Biological Engineering, Incheon University, Incheon, South Korea.

We have studied the surface diffusion of the molecules in alkanethiol self-assembled monolayer (SAM) by using scanning tunneling microscopy (STM) with a variation of surface temperature. From the successive STM images obtained at several temperatures, we could visualize the motion of the molecules and molecular desorption of alkanethiol SAM. The melting temperature estimated from the STM images was dependent upon the chain length of the alkanethiol, that is, the longer chain alkanethiol SAM has the higher melting transition temperature. Below melting transition temperature, the molecules diffuse only through narrow channels, i.e., the boundaries of the well ordered lattice domains, resulting in a slow structural change of the surface. Above melting transition temperature, the molecular diffusion shows different behaviors depending upon the chain length of the alkanethiol. For a relatively short octanethiol SAM, the enhancement of molecular diffusion after melting transition is dominant. For dodecanethiol that has a longer chain, however, the diffusion is dramatically enhanced after melting transition, rendering an abrupt structural change of the surface. The measurement of the molecular coverage shows that the desorption temperature is quite near the temperature of melting transition in case of dodecanethiol SAM. The dramatic enhancement of the molecular diffusion observed in dodecanethiol is induced by the molecular desorption. The empty sites formed during the desorption process give much room for the molecular diffusion.

11:45 AM Q1.10

Wednesday Afternoon, November 29, 2004
Commonwealth (Sheraton)

1:30 PM Q1.21
Fabrication and Characterization of an Inductance Gate in a Superconducting Flux Flow Transistor Using AFM Lithography

Chair: Bryan D. Huey
Monday Afternoon, November 29, 2004
Commonwealth (Sheraton)

1:45 PM Q1.22
Dispersive Kinetics in Atomic Force Microscope Assisted Oxidation of Zirconium Nitride

Jeffrey R. Corners, Natalia Farina, Guanghui Zhang, Rex D. Ramsier, Edward A. Evans and John A. Dagata; Physics, Chemistry, and Chemical Engineering, The University of Akron, Akron, Ohio; Precision Engineering Division, National Institute of Standards and Technology, Gaithersburg, Maryland.

We report on our local oxidation kinetics of zirconium and zirconium nitride thin-film samples, using Atomic Force Microscopy (AFM) assisted lithography. The addition of various proportions of nitrogen to the sputtering gas during thin-film deposition modifies the crystal structure and electrical properties of the substrates, which we determine through thin-film electrical measurements, X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), and four-probe measurements. By employing a dispersive kinetics model, we investigate the effects of the altered material properties and a range of applied voltages on ionic diffusion during oxide growth. We model predicts the existence of power-of-time dependent rate constants, where the exponent (gamma-1) is related to the diffusion coefficient. We have determined that gamma increases from 1.3 to 2.4 for films deposited with nitrogen flowrates from 0.0 to 5.5 sccm. While the local oxidation kinetics of systems such as silicon are highly sub-diffusive, with gamma ranging from 0.12 to 0.15, the features developed tend to be a few tens of nanometers high, the zirconium nitride system displays controlled oxide growth to heights of several hundred nanometers. J. A. Dagata, F. Perez-Murano, G. Adam, R. D. Ramsier, and H. Yokoyama, Thin Solid Films 76, 2710 (2000). N. Farkas, J. C. Tokash, G. Zhang, E. A. Evans, R. D. Ramsier, and J. A. Dagata, J. Vac. Sci. Technol. A, in press (2004). N. Farkas, Zhang, K. M. Donnelly, E. A. Evans, R. D. Ramsier, and J. A. Dagata, Thin Solid Films 447/448, 468 (2004). A. Plonka, Prog. Reaction Kinetics 16, 157-333 (1991).

2:00 PM Q1.23
Electrical AFM Based Xerography for Nanofabrication in Liquids

Nicola Naujoks and Andreas Stenmer; Nanotechnology Group, Swiss Federal Institute of Technology Zurich, Zurich, Switzerland.

The ability to precisely position molecules at predefined locations onto solid substrates is key to the fabrication of molecular sensors and chemistry platforms where they serve as docking sites or scaffolds for further modification steps. Local surface charges have proven useful to guide the deposition of a variety of materials. We will present sub-µm structures fabricated by a guided assembly process, combining the advantages of a lithography-based top-down approach with the bottom-up self-assembly route. In this universal and highly selective process, various kinds of particles and molecules, ranging from SiO2 beads, over gold nanoparticles, to biomolecules, are directed to specific regions on solid substrates using electrostatic interactions. In our lithography-like method, water droplets act as vehicles to transport the desired molecules or nanoparticles to charge patterns written into the substrate by a conductive AFM tip. The water droplets are emulsified into an insulating perfluoroalkane liquid to prevent discharging and screening of the surface charges due to the electric double layer present in any liquid. The electrostatic field generated by the surface charges causes a net force of Coulomb and/or dipolar nature on the disperse phase of the emulsion. 330 nm SiO2 beads are attracted charged particles on Teflon and repelled by positive ones, implicating Coulomb interaction, whereas on PMMA deposition is observed for both polarities, possibly due to the electrostatic field being weakened by a positive background charging of PMMA against the oil. The phenomenological rule of Coehn predicts such behaviour for the dielectric constants involved. Above example shows how the choice of substrate material influences the balance of dipolar and Coulomb forces experienced by the droplets. In addition to properties of the substrate material a number of parameters related to the development conditions have been studied to have crucial influence on the deposition results such as surface charge amount and pattern preparation, especially the use of surfactants, and development duration, to name just a few. In our contribution, we will discuss how to adjust parameters for optimal feature resolution and process selectivity for different deposited materials. With regard to the fabrication of microarrays we will further show that biotin-modified immunoglobulin G, attached to positively charged gold nanoparticles patterned on PMMA and air-dried, is capable of selectively binding fluorescently labelled Avidin from aqueous solution. Proving site-specific reactions, these results suggest applications in the field of biosensors and patterned cellular arrays.


2:15 PM Q1.24
Patternning of Nanoscale Metallic Structures Using Automated Scanned Probe Lithography

James Battas and Jayne Gano; Surface and Microanalysis Science Division, NIST, Gaithersburg, Maryland.

The ability to precisely construct nanoscale metallic structures has a wide range of applications from the fabrication and testing of molecular electronic devices to the construction of plasmonic waveguides. Wiring molecules to an electronic device, by patterning each nanoscale metallic structures using a tip conducting each end to a metal conductor is a key requirement for construction of nanostructured materials. Challenges exist however for the construction of multidimensional contacts and their controlled organization on surfaces. For device applications it is desirable to reproducibly pattern metal structures on self-assembled monolayers (SAMs) to function as nanoscale connections, with tunable gaps ranging from 1 nm to 100 nm. Herein we report a lithographic method for patterning nanosized metallic structures using AFM-based nanofabrication and electron-beam lithography on carboxylic acid.
Nanocrystal (NC) memory devices are currently under investigation as a possible solution to the scaling limitations of Flash memory devices used today. One of the key challenges in this new technology, an array of Si nanocrystals embedded in a thin tunnel oxide to act as a storage node that replaces the more conventional floating gate structure. Therefore, it is important to understand the charging/discharging characteristics and charging retention behavior of individual NCs with respect to dot size and tunnel oxide properties. To this end, we have conducted charging experiments of individual Si and Ge NCs on thermal SiO\(_2\) and high-K dielectrics (HfO\(_2\) and Al\(_2\)O\(_3\)) on Si using electrostatic force microscopy (EFM) in ultrahigh vacuum (UHV). Nanocrystals were grown via a ULSI friendly CVD process where the dot density (368-1212/cm\(^2\)) and size (5-50 nm) could be carefully controlled. Quantitative charge imaging was accomplished by both the shift in cantilever resonance frequency (constant charge state) and shift in cantilever resonant frequency (constant amplitude mode) after individual NCs were charged in contact mode with electrons or holes. Although constant frequency mode is not traditionally used in vacuum because of the slow response time for imaging (amplitude relaxation time cantilever Q factor \(1/f_{relax}\)), the high cantilever Q-factor in vacuum can provide enhanced amplitude sensitivity to charging related forces. As such, low levels of stored charge as well as fluctuations due to leakage through the oxide barrier can be measured. By changing the tip bias with respect to dot potential for different lift heights before and after the charging step, one can separate the effects of tip-substrate capacitance (\(V_{satur} + V_{tip}\)) from dipole-charge forces between the tip and charged nanoparticle (\(Q_{stored} = V_{satur} + V_{tip}\)). Specifically, we measure the charging requirements and storage characteristics for a range of Si and Ge nanocrystal sizes by writing individual dots using a biased tip to induce tunnelling through the oxide barrier, followed by spectroscopic EFM.

Simultaneous analysis of these images and the near-field spectra show that the spatial resolution of these experiments is 300 nm. The larger images, and their observed elongated shapes, are due to the overlapping of different dots. Using those near-field images we observed a strong lateral inhomogeneity in GaAsN eplayers on the length scale of 1000 nm. For the GaAsN NW images the individual clusters consist of bright stripes having 400-600 nm in width along one of the (110) directions. The minimum width of the stripes is 300 nm. The length of the stripes is greater than 2000 nm. Plan-view transmission electron microscopy micrographs showed the presence of composition modulation along the [110] direction having a wavevector of 100 nm. The orientation and the lateral dimensions of the composition modulation stripes observed in TEM agree well with NSOM images. However as the NSOM data are related to the emission of individual clusters, the stripe character of the images can be related to the distribution of photo-generated carriers along the quantum-wire-like channels created by As and Sb phase separation. The very large spatial extent of the images, exceeding a few micrometers, suggests a long lifetime of photogenerated carriers, which can be attributed to II-VI band alignment in GaAsSb. [1] M. Mintairov et al., Phys. Rev. Lett. 87, 244701 (2001).

We have observed and manipulated hydrogen atoms beneath the surface of a Pd\(_{111}\) crystal using low-temperature scanning tunneling microscopy (STM). We demonstrate that the subsurface region of Pd can be populated with hydrogen atoms from the bulk by applying voltage pulses from a STM. We present topographic and local electronic data characterizing subsurface hydrogen in these stable sites. We discuss our ability to selectively populate subsurface sites with hydrogen and present a full STM characterization of this state. We explain this phenomenon with an inelastic excitation mechanism, whereby hydrogen atoms in the bulk are excited by tunneling electrons and are promoted to more stable sites in the subsurface region. We also induced the motion of surface hydrogen atoms at \(300\) K using the STM tip. The motion has been ascribed to inelastic tunneling of electrons, inelastic electron tunneling spectroscopy (IETS) corroborates this assignment, and the surface hydrogen atom can change for motion has been detected.

**SESSION O3: Near and Far-Field Spectroscopy of Quantum Structures**

**Chair:** Lukas Novotny

**Monday Afternoon, November 29, 2004**

**Commonwealth (Sheraton)**

**3:30 PM O3.1**

**Near-field optical scanning microscopy of phase separation effects in diluted nitride alloys.** Alexander Mintairov1, James Merz1, Kai Sun1, Thomas Kasel1, Victor Ustinov2 and Gregory Peake1, 1University of Notre Dame, Notre Dame, Indiana; 2Tofe

**Physico-Technical Institute, St. Petersburg, Russian Federation; Sandis National Laboratory, Albuquerque, New Mexico.**

Dilute nitride alloys (GaAsN, InGaAsN and GaAsSbN) have recently attracted considerable attention as promising materials for laser diodes in the 1.3-1.5 micrometers range as well as for more efficient solar cells. These applications exploit unique properties such as a giant bowing parameter (\(b > 2\) eV), which arises from the large electronegativity and the small size of the nitrogen. The resulting large energy scale for statistical composition fluctuation leads to the creation of intrinsic quantum dots (QDs) with widths between 20 and 300 nm, which have been observed in near-field photoluminescence (NPL) [1]. Here we present images of the QD emission in GaAsN eplayers and a GaAsSbN quantum well (QW) using low-temperature near-field scanning optical microscopy (NSOM). Two different solutions of Au nanostars were used to partially fill a Au mesh, for a thioglycolic acid (thickness 0.1-0.3 micrometers) and a 6 nm GaAsSbN QW grown on (001) semi-insulating GaAs substrates by solid source molecular beam epitaxy and by metal-organic vapor phase epitaxy, respectively. NPL spectra were taken in collection illumination mode in UHV. Nanocrystals were grown via a ULSI

**Spectroscopic EFM Measurements of Nanoparticle Charge Storage.** Michael Gordon, Sebastien Decossas and Thierry Baron, LTM - CNRS, Grenoble, France.

Nanocrystal (NC) memory devices are currently under investigation as a possible solution to the scaling limitations of Flash memory devices used today. One of the key challenges in this new technology, an array of Si nanocrystals embedded in a thin tunnel oxide to act as a storage node that replaces the more conventional floating gate structure. Therefore, it is important to understand the charging/discharging characteristics and charging retention behavior of individual NCs with respect to dot size and tunnel oxide properties. To this end, we have conducted charging experiments of individual Si and Ge NCs on thermal SiO\(_2\) and high-K dielectrics (HfO\(_2\) and Al\(_2\)O\(_3\)) on Si using electrostatic force microscopy (EFM) in ultrahigh vacuum (UHV). Nanocrystals were grown via a ULSI friendly CVD process where the dot density (368-1212/cm\(^2\)) and size (5-50 nm) could be carefully controlled. Quantitative charge imaging was accomplished by both the shift in cantilever resonance frequency (constant charge state) and shift in cantilever resonant frequency (constant amplitude mode) after individual NCs were charged in contact mode with electrons or holes. Although constant frequency mode is not traditionally used in vacuum because of the slow response time for imaging (amplitude relaxation time cantilever Q factor \(1/f_{relax}\)), the high cantilever Q-factor in vacuum can provide enhanced amplitude sensitivity to charging related forces. As such, low levels of stored charge as well as fluctuations due to leakage through the oxide barrier can be measured. By changing the tip bias with respect to dot potential for different lift heights before and after the charging step, one can separate the effects of tip-substrate capacitance (\(V_{satur} + V_{tip}\)) from dipole-charge forces between the tip and charged nanoparticle (\(Q_{stored} = V_{satur} + V_{tip}\)). Specifically, we measure the charging requirements and storage characteristics for a range of Si and Ge nanocrystal sizes by writing individual dots using a biased tip to induce tunnelling through the oxide barrier, followed by spectroscopic EFM.

Simultaneous analysis of these images and the near-field spectra show that the spatial resolution of these experiments is 300 nm. The larger images, and their observed elongated shapes, are due to the overlapping of different dots. Using those near-field images we observed a strong lateral inhomogeneity in GaAsN eplayers on the length scale of 1000 nm. For the GaAsN NW images the individual clusters consist of bright stripes having 400-600 nm in width along one of the (110) directions. The minimum width of the stripes is 300 nm. The length of the stripes is greater than 2000 nm. Plan-view transmission electron microscopy micrographs showed the presence of composition modulation along the [110] direction having a wavevector of 100 nm. The orientation and the lateral dimensions of the composition modulation stripes observed in TEM agree well with NSOM images. However as the NSOM data are related to the emission of individual clusters, the stripe character of the images can be related to the distribution of photo-generated carriers along the quantum-wire-like channels created by As and Sb phase separation. The very large spatial extent of the images, exceeding a few micrometers, suggests a long lifetime of photogenerated carriers, which can be attributed to II-VI band alignment in GaAsSb. [1] M. Mintairov et al., Phys. Rev. Lett. 87, 244701 (2001).

**3:45 PM O3.2**

**Low-Temperature Spectroscopy of Single CdSe Nanorods: Fine Structure and Polarization Properties.** Nicolas Le Thomas1, Erik Herz1, Oliver Schoeps1, Mikhail Artemyev1, Wolfgang Langbein1 and Ulrike K. Woggon1, 1Physics, University Dortmund, Dortmund, Germany; 2Institute for Physico-Chemical Problems, Farbwerke Bayer AG, Leverkusen, Germany.

Colloidal CdSe nanorods (NR) are nanomaterials that emit highly polarized light and can be used, e.g., as active optical material in laser devices or photonic structures. For these nanocrystals, the exact knowledge of wave function symmetries, energies and optical transition dipole moments is a crucial problem for future applications in quantum optics, laser devices or as polarization sensitive marker or detector. Fine structure splitting as a result of exchange interaction in quantum confined CdSe nanorods and the consequences for the optical spectra are currently less addressed in literature, mainly because room temperature single rod spectra exhibit a large homogeneous broadening which prevents the observation of line shape details. In this work we present low-temperature, polarization-sensitive photoluminescence spectroscopy of single CdSe(ZnS) core-shell nanorods. As experimental method we combine low-temperature confocal microscopy with differential interference contrast microscopy using a high-numerical aperture (NA=0.85) microscope optics built-in into a He cryostat allowing us to temperature variation from 5K to 300 K. We investigate CdSe nanorods of radius \(R=50\) nm and length \(L=250\) nm dispersed in a polymer film emitting at 610 nm with an inhomogeneous line broadening of 80 meV. The linear degree of polarization (LDP) is recorded simultaneously during the temperature scans of the single nanorods. In such case with simultaneous measurement of Faraday and Kerr signal using a unpolarized light beam with an uncoated low-energy peak. This fine structure in the single rod emission...
spectra we assign to exchange splitting of a 1D-exciton confined in a cylindrical CdSe nanorod. Using an effective-mass model, the observed degree of polarization is consistent with the temperature-dependent photoluminescence dynamics can be explained based on the revealed ground state exciton symmetry. We find a radial-dependent change in the symmetry of the 1D-exciton ground state which transforms from a dark state for large radius to a critical nanorod radius of 3.15 nm into optically allowed states for radii R<Recrit. The calculated 1D-exciton ground state symmetries are supported by the measured degree of linear polarization and the temperature-dependence of the photoluminescence dynamics. The observed high degree of linear polarization (LD>0.95) and the obtained size/shape dependent PL decay times emphasize the important role of exchange interaction for the understanding of the optical properties of CdSe nanorods.

4:00 PM O3.3
Evidence of Multie exciton Emission from Single CdSe/ZnS Colloidal Nanocrystals; Brent Fisher, Jean-Michel Caruge and Moniuni Buu-Hoi; Chemistry, M.I.T., Cambridge, Massachusetts

We report the results of measurements that uncover multie exciton photoluminescence from single CdSe/ZnS colloidal nanocrystals. Time-correlated single-photon counting measurements in a Hanbury-Brown-Twiss detection scheme reveal a suppression of photon antibunching from a single quantum dot, due to cascaded photon emission out of multie exciton states. Finally, single QD emission spectra during the first nanosecond after pulsed excitation using a picosecond-gated CCD system reveal trionic excitonic spectral signatures as compared to the spectrum at longer delay times. Although observation of multie exciton and charged exciton emission is now commonplace for single-exciton-exciton fabrication quantum dots, observation of multie exciton emission from single CdSe nanocrystals was thought to be unlikely because of efficient Auger recombination pathways. Our measurements show that detection of photons from higher excited states of single nanocrystals is, in fact, feasible. This opens up avenues of spectroscopy for the study of single nanocrystals, without the blurring effects of an ensemble.

4:15 PM O3.4
Evaluation of the Fine Structures of Isolated ZnO Nanorod Single-Quantum-Well Structures using Near-Field Ultraviolet Photoluminescence Spectroscopy; Takashi Yatsu1, Junghshik Lim1, Tadashki Kawazoe2, Motoichi Ohtsu1,2,3, Sung Jin An3 and Moungi Bawendi; Chemistry, M.L.T., Cambridge, Massachusetts

A nanometer-scale ZnO dot is a promising material for realizing nanometer-scale electronic devices at its large exciton binding energy. Furthermore, recent demonstration of semiconductor nanorod quantum-well structure enables us to fabricate nanometer-scale electronic and photonic devices on single nanorods. Recently, ZnO/ZnMg nanorod multiple-quantum-well structures (MQWs) were fabricated and the quantum confinement effect of the MQWs were fabricated and the quantum confinement effect of the MQWs were successfully observed. In addition, further improvement in the fabrication of nanorod heterostructures has resulted in the observation of significant PL intensity, even from nanorod single-quantum-well structures (SQWs). To confirm the promising optical properties of individual ZnO/ZnMgO SQWs for realizing nanometer-scale photonic devices, we measured the PL spectra using a low temperature (<2 K) near-field optical microscope. In the near-field measurements, we found fine structures of PL spectra from isolated ZnO SQWs. ZnO/ZnMgO SQWs were fabricated on the ends of ZnO nanorods with a diameter of 20 nm using catalyst-free metalorganic vapor phase epitaxy. The Mg concentration in the ZnMgO layers used in this study was determined to be 0.2. The ZnO well layer thickness L investigated in this study were 2.5, 3.8, and 5.0 nm, while the thickness of the ZnMgO bottom and top barrier layers L investigated in this study were 5.0 and 18 nm, respectively. After the growth of ZnO/ZnMgO nanorod SQWs on sapphire (0001) substrate, they were dispersed on the substrate to be isolated. A 325-nm light source was used to excite the ZnO/ZnMgO nanorod SQWs. We used a UV fiber probe with an aperture diameter of 30 nm. In the near-field spectra obtained at the ZnO nanorod, the single emission peak was observed at 3.365 eV, which correspond to the neutral-donor bound exciton (DOX). However, at the well layer, the emission from the neutral-donor bound exciton was not observed. A well-separated component to the decay. Single photon correlation measurements in a Hanbury-Brown-Twiss detection scheme reveal a suppression of photon antibunching from a single quantum dot, due to cascaded photon emission out of multie exciton states. Finally, single QD emission spectra during the first nanosecond after pulsed excitation using a picosecond-gated CCD system reveal trionic excitonic spectral signatures as compared to the spectrum at longer delay times. Although observation of multie exciton and charged exciton emission is now commonplace for single-exciton-exciton fabrication quantum dots, observation of multie exciton emission from single CdSe nanocrystals was thought to be unlikely because of efficient Auger recombination pathways. Our measurements show that detection of photons from higher excited states of single nanocrystals is, in fact, feasible. This opens up avenues of spectroscopy for the study of single nanocrystals, without the blurring effects of an ensemble.

4:30 PM O3.5
Simultaneous near-field Raman and fluorescence spectroscopy of single-walled carbon nanotubes; Achim Hartschuh1, Alfred Meixner1, Neil Anderson2 and Lukas Novotny2; 1Physical Chemistry, University of Siegen, Siegen, Germany; 2The Institute of Optics, University of Rochester, Rochester, New York

Raman spectroscopy is a powerful tool used extensively for the structural analysis of single-walled carbon nanotubes (SWNT). We present tip-enhanced Raman spectroscopy of SWNT based on the local field enhancement effect at a laser illuminated metal tip and demonstrate Raman imaging with sub 20 nm resolution. The high-resolution capability of the presented method is used to study localized phonon modes and variations in the Raman spectra caused by structural defects which would be hidden in farfield measurements. The technique opens up new insights into the structural properties of SWNT on the nanoscale [1]. Recently, SWNT were found to fluoresce at distinct energies that are determined by their structural parameters [2,3]. Using local field enhancement, near-field fluorescence and Raman images of the same individual tube can be acquired. Fluorescence images on the nanoscale show the spatial extension of the emitting excited state and allow to distinguish between excitonic and localized trap states. Moreover, this technique offers the possibility to quantify and directly compare the enhancement factors for Raman and fluorescence signals achieved under the same experimental conditions. [1] A. Hartschuh et al., Phys. Rev. Lett. 90, 095503 (2003). [2] S.M. Bucolo et. al., Science 298, 1361 (2002). [3] A. Hartschuh et. al, Science 301, 1354 (2003).
was defined on both topside and backside of the SOI wafer and then silicon was removed by DRIE. Without additional process, silicon oxide formation was achieved through oxidation of the oxide at the end of the DRIE process. The prior etching process of holes in the buried oxide layer was useful to remove the silicon inside oxide NSOM tip. Furthermore, this procedure made simplifying the fabrication process and lowering the cost. The upward apertured tip in this work was proper for approaching the NSOM probe to the sample without collision.


An original instrument intended to integrate the advantages of scanning probe, near and far field optical microscopy is presented. Recent breakthrough in near field microscopy, specifically the realization of subwavelength resolution based on light field concentration under the specially prepared probe tip [1-3] have challenged the development of the unit providing coupling atomic force microscope with high resolution optical means. The device named Apertureless Head (AH) can work as a standard atomic force scanning microscope. Principal optical scheme of the unit is presented at fig.1. Being equipped with high numerical aperture objective, AH allows illumination and observation of the sample in the proximity of the probe and under the cantilever as well. The working distance of objective is large enough to accommodate the cantilever holder with piezo driver in the space between the frontal meniscus and the sample. Laser beam monitoring the cantilever deflections and oscillations is equipped with suitable optics allowing its work through the objective. Light signal caused by the laser induced excitation of the sample surface under the probe tip is collected in the backward direction by the same objective for further analysis. Phase plates based polarization handling system provides radial polarization of annular excitation laser beam. Such an arrangement generates a focal electric field with a predominant E0 component suitable for better light field concentration and excitation of the surface enhanced Raman scattering [4,5]. Beam splitter allows optical observation of the sample during the scanning, providing possibility of exact positioning of scanning microscope probe to the object under investigation disregarding non transparency of the probe (see fig.2.). The cantilever is seen not sharply at the bottom of photographs as a blurred triangle. Pieces of dust are seen under the probe as if the cantilever being transparent due to the inclined rays collected by the objective. Apertureless head is supposed to be a powerful tool for high resolution analysis in different fields of investigations such as Material sciences (optical and optoelectronic, magnetic, semi- and superconducting materials), Polymers and Biological sciences (structural biology, molecular and cell biology, microbiology, etc.). The presented device was specially designed to be incorporated into Ntegra Scanning Probe Laboratory, the powerful analytical instrumentation in the nanotechnology field produced by NT-MDT Company, Russia.


Apertureless head is supposed to be a powerful tool for high resolution analysis in different fields of investigations such as Material sciences (optical and optoelectronic, magnetic, semi- and superconducting materials), Polymers and Biological sciences (structural biology, molecular and cell biology, microbiology, etc.). The presented device was specially designed to be incorporated into Ntegra Scanning Probe Laboratory, the powerful analytical instrumentation in the nanotechnology field produced by NT-MDT Company, Russia. In this work, we investigate using nanoscale ridge apertures as nanoscale antenna to concentrate light at visible wavelengths into a nanoscale domain. The optical transmission characteristics of ridge apertures in the vicinity of these species after each surface chemical and plasma treatments in conducting regions show distinct conductive and non-conductive regions. It is known to be formed in ITO films as an ohmic behavior; whereas the local I-V from the nonconducting regions show unusual one. It implies the presence of a resistive oxide layer with the breakdown voltage of about 7 V. It is known to be formed in stable oxides of In2O3 and SnO in the surfaces.(ref, Hehran Lin et al., JAP, 89, 3976) We confirmed also the formation of In2O3 and SnO by XPS. Consequently, the stable oxides prevent the formation of an ohmic contact between the ITO surfaces and the conducting AFM tip. In 02 inducing oxide treatment, nonconducting regions are increased due to the formation of the stable oxides. Finally, KFM (Kelvin Force microscopy) was used to reveal the regions of the increase of the work function by the stable oxides with high spatial resolution. These nanoscale ridge apertures in the transmission-collection mode. Field concentration of these apertures is also demonstrated in a nano-lithography experiment.
Rudy Schif, Electrical Engineering, University of South Florida, Tampa, Florida.

Scanning probe microscopy based electrical characterization methods with nanometer resolution become increasingly important as the downsizing of device dimensions in integrated circuits reaches the sub-100 nm regime. While various powerful characterization methods have become standard tools for wafer-scale monitoring in semiconductor manufacturing, they are typically limited in their spatial resolution. We have investigated corona charge deposition combined with KPFM (KPFM) for non-contact, high lateral resolution electrical characterization of semiconductors. The number of semiconductor parameters that can be obtained, such as surface barrier height, surface doping density, oxide thickness or oxide charge density, reveals the versatility of this characterization method. However, currently available commercial devices based on corona charge characterization employ the traditional macroscopic vibrating Kelvin probe suitable for wafer-scale in-line monitoring. In order to examine the feasibility deposition method for nanometer scale device characterization we have determined the surface potential distribution of nanometer sized oxide patterns with different thicknesses on Si wafers using KPFM.

O4.09 A Scanning Tunneling Microscopy Study: Si/SiO2 Interface Roughness Induced by Chemical Etching. Jung Yul1,2, Layan Liu1 and Joseph W. Lyding1; 1Electrical Engineering, University of South Carolina, Columbia, South Carolina; 2Beckman Institute, University of Illinois, Urbana, Illinois.

The Si/SiO2 interface roughness has received tremendous interest due to its relation to channel mobility degradation and dielectric reliability. We have used ultra-high vacuum scanning tunneling microscopy (STM) to directly examine the Si/SiO2 interface and study the roughening effect caused by chemical etching. Three Si(100)/SiO2 samples studied were cut from 8-inch wafers that had gone through different surface treatments before 1nm gate oxide growth at 1000°C. The rms-roughness extracted quantitatively from the STM topography was found to be doubled from 0.111nm to 0.232nm by the normal SC-1 treatment, and further increased to 0.285nm for additional etching steps, which is consistent with the conclusion inferred from other experiments. It was also found that there were no regular situations on the Si(100)/SiO2 interface, even on the samples without SC-1 treatment. An industry standard shallow trench isolation process flow was examined to find out the process steps that affect the Si/SiO2 interface roughness. Process improvements were proposed to produce a smooth interface with emphasis on the pre-oxidation surface preparation and oxidation, which could be easily incorporated into the current shallow trench isolation process flow.

O4.10 Charging Effects in Silicon Nanocrystals in SiO2 Layers Observed by Scanning Capacitance Microscopy. Eunjoo Lee1, S. H. Jin1, Y. Khang2, J. M. Kim3, Y. S. Kim3 and Chi Jung Kang1; 1Department of Electrical Engineering, University of South Carolina, Columbia, South Carolina; 2Samsung Advanced Institute of Technology, Suwon, South Korea; 3Physics, Myongji University, Yongin, Kyonggido, South Korea.

Scanning capacitance microscopy (SCM) is used for characterizing the charging effects of silicon nanocrystals. The nanocrystal samples produced by aerosol technique have the size of about 2-10 nm. Trapping phenomena of electrons and holes are observed and analyzed through the SCM images and capacitance spectroscopy. These localized properties of each nanocrystal are compared with C-V characterization of the conventional MOS capacitor structure. We also present the detrapping process of trapped charge in nanocrystal with changing temperatures and stress conditions.


Silicon-on-insulator (SOI) is fast becoming the material of choice for high performance devices. Evaluation of materials quality before the creation of devices is important to SOI manufacturers, and measurement of low-concentrations (less than 5 x 10^{15} carriers per cubic centimeter) of free carriers in ultra-thin silicon-on-insulator can be difficult [1]. Voltage-modulated EFM has been previously shown to be sensitive to small concentrations of free carriers [2]. Here we present a method for measuring small carrier concentrations on minimally processed SOI wafers. Ultra-thin SOI is patterned using e-beam lithography into nanostructures of varying surface area, volume, and perimeter. Using voltage-modulated EFM, we are able to measure free carrier concentration in SOI nanostructures. Our measurements show that some of these nanostructures have free charge (< 5 x 10^{14} carriers per cubic centimeter), and are not fully depleted as would be predicted by simple calculations of depletion widths. [1] S. Henaux, F. Mondon, F. Gusella, I. Kling, and G. Reymond, Doping Measurements in Thin Silicon-on-Insulator Films, J. of Electrochemical Society, 146 (7) 2737-2743 (1999). [2] Emma Tevaarwerk, P. Rugheimmer, O.M. Castellini, D.G. Keppel, D. E. Savage, M.G. Lagally, and M.A. Eriksson, Electrically Isolated SiGe QDs, Appl. Phys. Lett. 80, 4626 (2002).


Both photons and electrons incident on a glass surface can promote charge carriers into trap states with energies that lie within the effective band gap of an amorphous solid such as a silicate glass. The surface conductivity is then enhanced when carriers from these states hop to other trap states or are emitted into extended states. It is possible to use scanning probe microscopy to detect the change in the surface conductivity of glasses associated with the thermally-excited emission of carriers from traps. A 40 mW 325 nm He/Cd laser was used to irradiate the fracture surface of a commercial boronasilicate glass display (Corning Code 1737) maintained in ultra-high vacuum at a temperature of 500°C. After this irradiation process, continued heating of the glass releases carriers from traps and results in a surface conductivity much greater than the bulk ionic conductivity. The conductivity can be determined directly by contacting the surface with an etched Si tip of a scanning probe microscope and measuring the current flowing between the tip and deposited surface electrodes; the conductivity has an activation energy of 0.18 eV. With the proper annealing and irradiation conditions, the conductivity is sufficiently large to allow imaging of the surface in the scanning tunneling microscope mode. A larger and much lower-doped surface conductivity can be achieved by irradiation with 600 eV electrons; morphological changes suggest that a restructuring of the glass surface occurs during electron irradiation.


Scanning capacitance microscopy (SCM) is a scanning probe microscopy technique that gives spatially resolved information on the distribution of N and P-type carriers employed in a complex semiconductor structure. Quantitative measurement of the carrier concentration is also possible in favorable cases, provided suitable calibration standards are used. We will compare the application of SCM with conventional scanning electron microscopy (SEM) for the reverse engineering of advanced semiconductor devices, such as a CMOS image sensors and bipolar transistors. The SEM provides higher spatial resolution and better delineation of the dielectrics and metals, while the SCM provides greater detail on the structure of the semiconductor device. Our results suggest that a complete understanding of the device under study requires the application of both SCM and SEM.


Recently, we have proposed and developed Scanning Nonlinear Dielectric Microscopy (SNDM) for observing the polarization distribution on ferroelectric materials [1]. Now, its resolution in measuring the polarization distribution is sub-nanometer order [2]. In conventional SNDM technique, however, it is operated in the contact-mode to measure the dielectric constants and properties of materials where the point end of the tip directly contacts the surface of the specimen. Therefore, the point end of tip is easily damaged and the resolution of SNDM becomes degraded. In this paper, we newly developed SNDM technique of non-contact mode (nc-SNDM) to avoid a degradation of tip and specimen and to realize a simultaneous observation of the highly resolved topography and the ferroelectric polarization. In this newly invented technique, we applied technique of higher order nonlinear microscopes to detect and keep the quite short distance between the point end of a SNDM tip and specimen [3]. The magnitude of the nonlinear dielectric signal markedly varies (decreases) with the quite small variation (increase) of the gap between the tip and specimen. As the higher order nonlinear dielectric constant (3333; fourth rank tensor) is much

more sensitive against the gap variation than the lowest order nonlinear dielectric constant (ε333: third rank tensor) and is complementary sensitive to the polarization distribution and topography simultaneously using nc-SNDM. Theoretically, the sensitivity of nc-SNDM is quite high as much as scanning tunneling microscopy. Experimental evaluation of the height sensitivity of nc-SNDM and the domain images of the non-contact mode were also reported. [3] Y. Cho, A. Kirihara and T. Sueki: Rev. Sci. Instrum. Vol.67 (1996) 2297.


O4.15 Evolution of Isolated Ferroelectric Domains in Nanometer Scale, Hyunjun Shin1, Bongki Lee2, Changhyun Kim1 and Seung-Hyun Kim3, 1School of Advanced Materials Engineering, Kookmin University, Seoul, South Korea; 2Inatek Inc, Seoul, South Korea.

Study of domain structure and its evolution is important in understanding the microscopic behavior of ferroelectric materials for various applications. In this work, we prepared sol-gel PZT (52/48) thin films with about 30, 40 and 50nm in thickness and fabricated ferroelectric grains with various lateral sizes from 100 to 500nm by controlling annealing temperature and time. In order to observe the evolution of domains, piezo-response force microscopy, based on the detection of the converse piezoelectric effect of the ferroelectric thin film under electric field, has been employed. As a result, we can observe that ferroelectric domains are formed in pyrochlore matrix containing single domains with one preferred direction (Polarization is upward direction parallel to the surface normal). Further, they are developed into domain structures with preferred orientation as grain size increases. Switching of single ferroelectric with sub-100nm in diameter was achieved and piezoelectric hysteresis loops were also recorded. Critical aspect ratio of the internal size (i.e. diameter) to the thickness for the single ferroelectric domain is investigated.

O4.16 Direct Observation of Polar Nanostructures in PLZT Ceramics for Electrooptic Applications, A. L. Kholkin1, V. V. Shvartsman2 and A. Sternberg2, 1Ceramics and Glass Engineering, University of Aveiro, Aveiro, Portugal; 2Institute of Solid State Physics, University of Latvia, Riga, Latvia.

The wide range of unique properties of lead lanthanum zirconate titanate (PLZT) ferroelectric materials makes them suitable for electronic applications including electromechanical actuators, multilayer capacitors, electrooptic modulators, and pyroelectric sensors. The compositions with high concentration of La are especially important because they exhibit low remnant polarization ("slim" hysteresis loops) combined with high dielectric permittivity. These compositions belong to so called ferroelectric relaxors, where the macroscopic ferroelectric order does not develop in the absence of sufficient external electric field and the high dielectric and electromechanical properties are due to formation of nanosized polar regions (polar nanoclusters) with a short-range order. Even though these compositions were intensively investigated in the past, little attention has been paid to the studies of domain structures and its evolution under the variation of external conditions. The common optical methods have limited resolution and are appropriate only for the observation of "normal" domains having the sizes of the order of micron. Recently, the Piezoresponse Force Microscopy (PFM) has been successfully applied for the investigation of ferroelectric materials at the nanoscale. The advantages of the PFM are extremely high spatial resolution (down to few nanometers) and high sensitivity to local polarization, which make this method well suitable to study PLZT ceramics. We report here our results of the investigation of local piezoelectric properties of transparent electrooptic ceramics Pb1-xLa2x(Zr1-xTiO3)3 (x0.075, x0.35) prepared by hot pressing. Piezoelectric contrast has been clearly observed in this material indicating spatial distribution of polarization with the typical domain size of the order of ~0.1nm. Irregular domain patterns of the labyrinth type could be linked to the formation of a glassy state where the random electric and stress fields are responsible for the formation of the long range ferroelectric order. The evolution of the polar structures under the variation of temperature, dc and ac external electric fields of various frequencies was also investigated. Time relaxation of the ferroelectric state induced by poling was studied in this work by allowing that allowed to quantify the dynamics of ferroelectric-relaxor phase transition. The nature of the observed phenomena is discussed based on the current understanding of the relaxor state in ferroelectrics and possible effect of PFM instrumentation
Performance of Si transistor is strongly affected by mechanical stress in the device area. Minimization of the device tends to cause the stresses. In particular, the strain of shallow-trench isolation (STI) and Si-on-insulator (SOI) structures often results in stress in the transistor area. Stress in Si can be monitored by Raman spectroscopy but to meet the device shrinkage requirement, the spatial resolution should be well beyond the diffraction limit of light. Though optical spectroscopy beyond diffraction limit had made remarkable progress in the last decade, the subwavelength-resolution Raman microscopy of solids is still a challenge. We have developed a method that enables us to obtain Raman spectra with a spatial resolution much better than the wavelength. The method is based on the fact that the light is partly depolarized when it is scattered on a small metal particle (except for highly symmetric shapes). We use forbidden polarization configuration for the 1st order Raman band of Si at 520 cm

-1 under a conventional microscope to suppress the intensity of this band. Then an Ag particle of 50 to 100 nm size is introduced into the illuminated area, giving rise to the intensity of this band. This signal is associated with the light elastically scattered and depolarized by the Ag particle and then inelastically scattered in small area of Si just around the particle. Another point is utilization of the near-UV light of 364 nm for the excitation. Penetration depth of the light to Si is only 12 nm making the excitation area highly localized, and yet the Raman cross-section very large owing to the resonance with the direct electron transitions in Si. We have actually realized this scheme with the quartz AFM probe with an Ag particle on top. The probe was immersed into a small droplets of glycerol with refraction index equal to that of quartz minimizing scattering by the probe itself. We applied this method to various Si device structures and demonstrated stress measurements with 100 nm spatial resolution; e.g., observation of compression extending to 1 micron around an STI structure and gradual increase of strain from the edge to the interior part of the strained Si on Si/Ge island.

The field enhancement at a laser-irradiated metal tip defines a strongly confined photon source. We use this localized source for absorption spectroscopy with single molecule sensitivity by making use of the localized SH generation at the metal tip. Because of thermal and zero-point fluctuations the tip interacts with the sample even in absence of external irradiation. These fluctuations give rise to the Wannas attraction and to friction forces if tip and sample are in relative motion. We show that this electromagnetic friction depends sensitively on the dielectric properties of the sample material and that it can be used for nanoscale subsurface imaging in metals.

We demonstrate that (apertureless) scattering-from-a-tip near-field optical microscopy (s-SNOM) allows optical imaging at 10 nm spatial resolution [1]. In our s-SNOM the tip apex of an atomic force microscope (AFM) is illuminated either by a HeNe laser at 633 nm or a CO2 laser at about 10.6 micrometer wavelength. The light scattered from the tip in near-field interaction with the sample surface is detected interferometrically and allows material specific imaging at a spatial resolution independent of the wavelength or to visualize the optical eigenfield patterns of plasmon-resonant nanoparticles [2]. Probing a SiC sample with our s-SNOM at mid-infrared wavelengths we observe that the optical near-field interaction between tip and a flat surface can be strongly enhanced due to near-field excitation of lattice vibrations specifically by phonon-polaritons. Near-field spectroscopy in the range 9.2 - 11.2 micrometer yields a resonant light-matter near-field interaction of unprecedented dynamic range and spectral sharpness [3]. This phonon-enhanced near-field interaction is not only sensitive to the local chemical composition but also to the local structural properties of a surface and thus allows besides chemical microscopy also mapping of crystal quality at nanoscale resolution. Altogether we envisage applications in optical near-field microscopy and imaging of physical, chemical and biological nanomaterials. A more general view of surface phonon polaritons in nanostructures suggests phonon photonics, an infrared nanotechnology for manipulating, guiding and controlling infrared light in nanoscale devices [1] R. Hillebrand and F. Keilmann, Appl. Phys. Lett. 80, 25 (2002); [2] R. Hillebrand et al., Appl. Phys. Lett. 83, 368 (2003); [3] R. Hillebrand, T. Taubner, and F. Keilmann, Nature 418, 159 (2002).

In the last years a wide range of optical applications came up for noble metal nanoparticles in biology, medicine, chemistry and physics. Luminescence spectra of gold nanoparticle aggregates were recorded and compared with their light scattering spectra. A substantial enhancement of the luminescence by surface plasmon resonance was found. The luminescence enhancement of the aggregates was red-shifted with respect to the bulk and had maxima close to those of the respective plasmon resonances. Enhancement factors reached up to three orders of magnitude. The resonance behaviour of the closely packed almost two dimensional aggregates can be well described by the plasmon resonance of ellipsoids in the quasistatic approximation. Most of the aggregates with strong luminescent enhancement also showed a considerable SERS-activity. Copper nanoparticles agglomerates show a similar behaviour with a pronounced red-shift of the emission maximum and a substantial enhancement of the luminescence yield with respect to the bulk material.

The optical field variation in the proximity of surfaces depend on their structure and composition. Space and time coherence of the scattered field leads to constructive and destructive interference resulting in considerable local field variations. A detailed examination shows that there are several phenomena taking place side by side which depend on the distance between surface and image plane. We explain the observed phenomena in terms of coherent diffuse scattering, specular reflection, diffraction and self-imaging. We have calculated the local optical field variations in the proximity of microgratings using asymmetric illumination in order to compare them with experimental images recorded with a scanned optical fibre in external illumination mode. We compare the lateral resolution or reproduction of the regular grating structure for the two main orientations of the grating with respect of the incident beam and as a function of angle of incidence. Two different zones can be distinguished: one zone where the grating structure is well reproduced and a second zone where diffraction fringes from the finite size of the grating dominate the image. The appearance of the two zones can be explained in terms of isotropic diffuse scattering and displacement of the diffracted image with increasing distance from the surface. The image contrast is reversed as the image height is changed revealing the interferometric nature of the image. The zone which reproduces well the grating structure is not free of diffraction fringes which are visible particularly well on the grating groove edges. The differences of the two zones correspond to the zones outside and inside of the scattering cone defined by the angle and direction of incidence. We will discuss the results of the numerical simulation and compare them with experimental images.

A new far-field optical microscopy approach capable of reaching near-field-resolution is developed using the in-plane image magnification by surface plasmon polaritons. This approach is based on the optical properties of a metal-dielectric interface that may provide extremely large values of the effective refractive index n_{eff}.
Dopant profile engineering for sub-45 nm devices has become an increasingly difficult task as simple one-dimensional profiles/simulations are no longer sufficient to describe the actual material interactions. As such, true two-dimensional dopant profiling with high concentration sensitivity and quantification accuracy has become essential in technology development. Scanning spreading resistance microscopy (SSRM) has emerged as one of the sole tools suitable for this purpose as it combines sub-nm spatial resolution with extreme concentration sensitivity over 5-6 orders of magnitude and quantification accuracy. This progress has been achieved through the successful development of dedicated solid diamond tips, pulsed force measurement procedures and a thorough understanding of the tip-semiconductor contact. Despite their apparent bluntness, as they are made with the moulding technique, these diamond tips proof to provide a very high spatial resolution. Dedicated test structures have been developed to probe the electrical tip radius which is as small as 0.5 nm although the mechanical radius is much larger. Finite element simulations confirm that this small electrical tip is indeed only related to a very localized plasma transformation in Si limiting the effective electrical tip radius to a region much smaller than the mechanical radius. The latter is one of the main reasons why SSRM outperforms other concepts such as Scanning capacitance microscopy with an order of magnitude in resistance sensitivity. Due to the high spatial resolution the sampling volume is very limited and a direct conversion from resistance to resistivity can be obtained using a calibration curve. The reproducibility of this quantification procedure is shown to be better than 10-20% across the entire dopant range of interest. Finally it needs to be stressed that SSRM is the sole technique with sufficient dopant sensitivity to probe the very small variations induced by for instance the very important halo-implants and thus also able to study their diffusion and activation in devices. This superior resolution needs to be stressed that SSRM is the sole technique with sufficient dopant sensitivity to probe the very small variations induced by for instance the very important halo-implants and thus also able to study their diffusion and activation in devices. This superior resolution enables detailed analysis of lateral diffusion, halo-implants and SPER-junctions in very small devices with a demonstrated sensitivity to junction position differences of 1-2 nm to various process variations in line and wafer to wafer. For applications towards failure analysis, analysis of any transistor becomes possible through the sample preparation scheme based on contacting all the dopant layers with a small AC excitation in the 10kHz to 2MHz frequency range. In the presence of disorder, the 2DEG will break up into two-dimensional clusters. In the 2DEG, the 2D carrier density and the local sheet resistance are measured by the SSRM probe. The SSRM at low temperatures (300 mK), the 2DEG is expected to show rich local states and the local resistivity of the 2DEG. We use the plot of normalized potential across the width (or channel) a function of annealing time. Furthermore, we investigated the influence of surface state on p/n+ potential contrast dependent upon the existence of thermal oxide, which suggests surface state density causes a Fermi level to be pinned. The SSRM images are reproducible and semi-quantitative when the surface states were passivated properly. I. H. Park, J. Jung, D.-K. Min, S. Kim, S. Hong, and H. Shin, "Scanning Resitive Microscopy: Imaging Ferroelectric Domains", Appl. Phys. Lett., 84, 1734-1736 (2004)

SESSION 06: SPM of Semiconductor Materials
Chair: Arthur Baddorf
Tuesday Afternoon, November 30, 2004
Commonwealth (Sheraton)

1:30 PM *06.1
Sub-Nanometer Resolution Dopant Profiling in Si and Ge-Based Nanoscale Devices, Wilfried Vandervorst, Pierre Eyben, David Alvarez and Marc Fouchier; IMEC, Leuven, Belgium.

Silicon-on-insulator (SOI) wafers can be fabricated using the Separation by Implantation of Oxygen (SIMOX) process. Oxygen ions are implanted into the silicon substrate which is then annealed to form a uniform buried silicon dioxide layer with low defect density. SIMOX wafers are typically used in the fabrication of high-performance and low power CMOS and MEMS devices. Insulating silicon dioxide strongly changes when irradiated with an electron beam in a scanning electron microscope. Irradiation of semiconducting silicon under identical conditions results in negligible charging at 293K. Kelvin Probe Microscopy has been used to characterize the magnitude and spatial distribution of residual potential in electron irradiated SIMOX. The SIMOX specimens investigated have a 355nm thick buried oxide layer capped with a 720nm thick silicon layer. The specimens were implanted with a stationary continuous normal incident electron beam for a range of electron beam energies and doses. Focussed electron beam irradiation induces trapped charge within the insulating buried oxide layer which produces high electric fields. The charging processes are dynamic, localized, and dependent on pre-existing and irradiation induced defect concentrations. The reproducible characteristic potentials associated with the charge trapped in the buried oxide layer have been measured using Kelvin Probe Microscopy in controlled ambient conditions. Potentials of typically several hundred millivolts were measured; however, the measured values are limited to charging potentials that are less than 60 nm for 515 nm illumination wavelength. Applications of this technique to bioimaging and sub-100 nm lithography will be discussed.

2:00 PM 06.2
Radiation Induced Subsurface Charging in the Buried Oxide Layer in SIMOX, Marion Spirig-Kalceff, School of Physics, University of New South Wales, Sydney, New South Wales, Australia.
as sharp and bright lines penetrating this dark region. The filaments also have an extreme aspect ratio, being often several microns long, but with widths down to the minimum length scale in the physics of the 2DEG. This is much smaller than our expected resolution, which should be limited by the 100 nm depth of the 2DEG below the surface. Equally puzzling is the spatial structure of the filaments. They show no well defined periodicity, but have a strong orientational selectivity, following preferential directions along crystallographic axes of the host GaAs crystal. The data suggest that interactions between the tip and the 2DEG greatly enhance the resolution of the probe. We present ideas for how this occurs and conjectures for the origin of these astonishing features.

SESSION 07: SPM Characterization of Ferroelectrics and High-k Materials
Chair: Lucas M. Eng
Tuesday Afternoon, November 30, 2004
Commonwealth (Sheraton)

3:15 PM **07.1**
Progress in Nanoscale Studies of Ferroelectrics.
Aleks Gruverman 2, Brian J. Rodriguez 3, Angus I. Kingon 2 and Robert J. Nemanich 1
1Physics, North Carolina State University, Raleigh, North Carolina; 2Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina.

Scanning probe microscopy (SPM) has revolutionized ferroelectric research in the last decade. It provides a unique opportunity to measure local ferroelectric properties, to tailor and engineer these properties and to fabricate ferroelectric devices. In this paper, recent advances in understanding the physical properties of ferroelectric materials at the nanoscale made possible by the use of SPM techniques will be reviewed. This information has been used as a basis to study the basic mechanisms of polarization reversal as well as the mechanisms of ferroelectric fatigue and imprint in thin films and capacitors. Investigation of the scaling effect on variability of switching parameters has been used to predict the required level of performance reliability. Progress in tailoring electrical, mechanical and optical properties of ferroelectrics with a viewpoint of developing novel nanofabrication approaches and nanoelectronic devices will be discussed. Support provided by the National Science Foundation (Grant No. DMR-0355352).

3:45 PM **07.2**
Domain Growth Scenario and its Implication to High Density Storage Device, Seung-Hun Hong 1, Yumssok Kim 2, Seung-Hyen Kim 3, Hong Sik Park 1, Hyungsoo Ko 1, Dong-Ki Min 1, Juwan Jung 2, Chul Min Park 1, Kyoungho Baeck 1, Sungdong Kim 1, Eunskim Kim 1, Yong-Su Kim 1, Kwangsoo No 2 and Noyeol Park 1
1Storage Lab, Samsung Advanced Institute of Technology, Suwon, Kyonggi, South Korea; 2Department of Materials Science and Engineering, University of California, Berkeley, California; 3Department of Materials Science and Engineering, University of Wisconsin, Madison, Wisconsin; 4INOSTEK, Ansan, South Korea.

We present the ferroelectric material issues for high density probe storage with a focus on domain growth scenario and its implication to the device performance, i.e. ultimate recording density and read/write speed. Grain boundary based coupled domain wall motion makes the analysis difficult, so a qualitative trend will be briefly discussed based on the assumption that composition variation is of minor importance to bit size. The domain scenario where forward domain growth is limiting step for switching is studied on both top and bottom electrode and bare ferroelectric thin films by piezoelectric force microscopy. As evidenced by ring structure and domain image evolution as a function of pulse voltage, the scenario is believed to be applicable to our system. This implies that as the bit size and film thickness scale down, the switching speed increases which enhances the competitiveness of ferroelectric thin film as a candidate material for high density probe storage.

4:00 PM **07.3**
Absolute Measurement of Three-dimensional Polarization Direction using Scanning Nonlinear Dielectric Microscopy, Yasuo Cho 1, Tomoyuki Sugimura 1 and Hiroshi Odagawa 1
1RIKEN, Tohoku Univ., Sendai, Japan.

Recently, ferroelectric materials have attracted a lot of attention in various fields such as FRAM and ultra-high density data storage [1]. Measurement of the ferroelectric polarization distribution is very important subject of research. We have developed a Scanning Nonlinear Dielectric Microscopy (SNDM) which can observe the polarization distribution with sub-nanometer resolution [2]. SNDM can measure the polarization component perpendicular to the surface by applying electric field in the perpendicular direction. Moreover, we have succeeded in observing the polarization component parallel to the surface by applying electric field in the parallel direction [3]. In this study, we developed new method for measuring the absolute value of three-dimensional polarization direction using SNDM. At first, we developed a new system that makes more exact measurement for an azimuth angle (φ) of polarization component parallel to the surface without an error caused by a residual normal component of electric field. This was achieved by adding a normal component field canceling system to the conventional 3-D type SNDM [3]. Second, we developed new experimental procedure determining the elevation angle (θ2θ4) of the polarization using the modified normal polarization component measurement. Thus, combining these two methods, we can determine the absolute three-dimensional polarization direction. Using this new system, the polarization distribution of periodically poled LiNbO3 (PPLN) in three-dimension was observed and it was successfully demonstrated that the three-dimensional polarization direction was determined precisely. Moreover, we also report nanoscale three-dimensional polarization measurements for several materials obtained by using this new developed 3-D type SNDM. [1] Y. Cho, K. Fujimura, Y. Hirayama, Y. Watanabe, A. Otsubo, K. Totsu, K. Kitamura, Appl. Phys. Lett, Vol.81(2002) 4401. [2] H. Odagawa and Y. Cho, Surf. Sci. Vol.463(2000) L621. [3] H. Odagawa and Y. Cho, Appl. Phys. Lett, Vol.80(2002) 2159.

4:15 PM **07.4**
Nanoscale Piezoelectric Imaging and Modeling of a Single Antiparallel Ferroelectric Domain Wall, David Scrymgeour and Venkata Gopalakrishna
Materials Research Institute, Penn State University, University Park, Pennsylvania.

Surprising asymmetry in the local electromechanical response across a single antiparallel ferroelectric domain wall made possible by the use of SNDM techniques will be reviewed. This data has been used to study the basic mechanisms of polarization reversal as well as the mechanisms of ferroelectric fatigue and imprint in thin films and capacitors. Investigation of the scaling effect on variability of switching parameters has been used to predict the required level of performance reliability. Progress in tailoring electrical, mechanical and optical properties of ferroelectrics with a viewpoint of developing novel nanofabrication approaches and nanoelectronic devices will be discussed. Support provided by the National Science Foundation (Grant No. DMR-0355352).

4:30 PM **07.5**
Effect of Nanostructuring on the Piezoelectric Responses of 0.67 Pb(Mg1/3Nb2/3)O3-0.33 PbTiO3 Ferroelectric Films Engineered for MEMS Applications, Jun Ouyang 1, Dong Min Kim 2, Zhengguan Ma 2, V. Nagarajan 2,4, J. Melngailis 2, C.-B. Eom 2,3,4, A. L. Royburd 2 and R. Ramesh 2,3,4
1Materials Research Science and Engineering Center, Department of Materials Science and Engineering, University of Maryland, College Park, Maryland; 2Dept. of Materials Science and Engineering, University of California, Berkeley, California; 3Department of Materials Science and Engineering, University of Wisconsin, Madison, Wisconsin; 4Institute for Electronic Materials, IFF, Forschungszentrum, Julich, D-42425, Germany.

There are increasing interests in fabricating piezoelectric film-based microelectro-mechanical systems (MEMS), which include the integration of piezoelectric components to silicon and nanostructuring them to devices with semi-micron size. Here we report a systematic study of piezoelectric response on the longitudinal piezoelectric constants (d33) of rhombohedral 0.67Pb(Mg1/3Nb2/3)O3-0.33PbTiO3 ferroelectric films, which in single crystal form is known for its giant piezoelectric response. These films were engineered on different substrates by choosing different film thickness and film orientations and nanostructured by a focused ion beam process. It was found that as high as 1200pm/V can be realized for (001) oriented films grown on Si, which is the highest ever reported for piezo-active components integrated to Si substrates. This work is supported by the NSF under contract No. DMR-02-10512 and NSF-MRSEC under contract No. DMR-00-80008.

4:45 PM **07.6**
Local Electromechanical Properties of Ferroelectric Materials for Piezoelectric Applications, A. L. Kohlkin, V. V. Shvartsman and Igor K. Baskin
Dept. of Ceramics and Glass Engineering and CICECO, University of Aveiro, Aveiro, Portugal.

Ferroelectric materials are being intensively investigated due to their high dielectric, ferroelectric and piezoelectric properties useful for...
As critical dimensions shrink below a micrometer, new tools are required to investigate material properties on commensurate scales. In response, atomic force microscopy (AFM) techniques are being used for two-dimensional mapping. In this talk, we will describe new methods for quantitative mechanical property imaging. A cornerstone of our approach is a frequency-tracking circuit to locate the contact-resonance frequencies at each image position. The circuit is based on a digital signal processing architecture that enables rapid data acquisition (typically < 20 minutes for a 256 x 256 image). With a range of operation from approximately 1 to 3000 kHz, the circuit can accommodate a wide variety of different cantilever vibration modes. We will present imaging results obtained with both flexural and torsional modes on several nanostructured materials. By combining information from flexural and torsional images, it may be possible to simultaneously determine both Young's modulus and Poisson's ratio for an isotropic material. Issues related to quantitative image interpretation will also be discussed, such as calibration methods, cantilever selection, tip wear, and choice of contact-mechanics model. Each of these elements plays a significant role in attaining the goal of truly quantitative nanomechanical imaging.

8:30 AM *08.1 Atomic Force Microscopy at Ultrasonic Frequencies, State-of-the-Art and Prospect. Ute Rabe, Applied Research, Fraunhofer Institute for Nondestructive Testing, IZFP, Saarbruecken, Saarland, Germany.

The combination of ultrasound with atomic force microscopy (AFM) opens the high lateral resolution of scanning probe techniques to ultrasound. Acoustic microscopic force microscopy (AFM) and ultrasonic friction force microscopy are techniques that use the vibration modes of AFM cantilevers. The resonance frequencies of commercial cantilevers of a few 100 micrometers length are predominantly in the ultrasonic frequency range between 20 and 200 MHz. In the AFM-mode the cantilever is vibrating in one of its flexural or torsional resonances at frequencies between several MHz and several 10 MHz. Polycrystalline ceramics which appear mechanically isotropic on a macroscopic scale are therefore anisotropic on the length scale which is probed by AFM and the elastic constant which is measured by the tip is the indentation modulus. When ferroelectric ceramics are imaged, the acoustic image reveals a substructure within the grains indicating variations in contact stiffness. In ferroelectrics an important contribution to the contact stiffness results from the electrical polarization of the individual domains. Shear stiffness and friction phenomena can be investigated in ultrasonic friction force microscopy by evaluating the torsional resonances of AFM cantilevers. At lower ultrasonic frequencies the sensor tip remains in elastic contact with the sample surface, and the cantilever behaves like a linear oscillator with viscous damping and a certain set of resonance frequencies. If the surface vibration is increased above the critical amplitude, the maximum of the resonance curves does not increase any more and the curves develop a plateau at their highest amplitude. Numerical simulations of a nonlinear oscillator driven by a dry friction element produced curve shapes as in the experiment. This led us to the conclusion that the plateau in the resonance curves indicate the onset of stick-slip in the relative tip-sample oscillation.
microscopy revealed that the thin films were nanocrystalline with an average grain diameter ranging from 16 to 27 nm. Thus, grain-boundary microstructure percolation effects are likely to be responsible for the observed reduction in $M$.

9:45 AM OS.5
Van der Waals and electrostatic force imaging with higher harmonic noncontact scanning force microscopy.
Scott Russell Crittenden1, Arvind Raman2 and Ron Reifenberger3;
1 Sensors and Electron Devices Directorate, U.S. Army Research Laboratory, Adelphi, Maryland; 2Physics, Purdue University, West Lafayette, Indiana; 3Mechanical Engineering, Purdue University, West Lafayette, Indiana.

Conventionally, the cantilevers used in scanning force microscopy (SFM) are treated as simple harmonic oscillators driven sinusoidally at their resonance frequency. Interesting nonlinear behavior lies beyond this approximation when the cantilever is treated as a continuous beam oscillating in a non-quadratic potential well. Any real SFM cantilever can be expected to oscillate at higher harmonics of the driving frequency as well as at a set of frequencies corresponding to higher order bending modes. Recently, attempts to understand these nonlinear effects have provided a better understanding of what information SFM measurements can give about the tip-sample interaction. There are now a number of papers treating both linearized approximations and the full nonlinear system. Higher harmonic signals depend on the details of the force between the cantilever tip and the sample and therefore on such physical properties as the Hamaker constant, Young’s Modulus, electrostatic charge, and the work function difference between the tip and sample. The literature on higher harmonic spectroscopy has focused on the tapping mode or on the contact mode where the sample is vibrated acoustically. In both modes the tip operates in the repulsive regime of tip-sample interaction potential. Because the repulsive interaction, which is nearly independent of local structural effects, has attempted to measure the local elastic properties of the sample using nonlinear effects with the customary nanoscale resolution of SFM. As yet unexplored regime lies in the noncontact mode origin of nonlinear contact oscillations. Here, the tip-sample forces are dominated by local electrostatic and van der Waals forces; therefore, higher harmonic signals are expected to depend on these parameters. Because the tip never touches the sample surface, any contact mechanical issues such as tip and sample deformation, etc., do not arise, leading to a simpler system of study. This offers the possibility of characterizing the local van der Waals forces and electrostatic change which are far superior and more specific indicators of local chemical composition than local elasticity. We will present noncontact higher harmonic amplitude and phase images of, and dynamic force curves (DFC) over, thin biological bilipid membranes deposited on mica. We also show noncontact images and DFCs at a harmonic near the second bending mode of the cantilever and compare these results to those for harmonics far from any bending mode. Finally, higher harmonic imaging under careful control of experimental parameters allows for the determination of electrostatic screening where van der Waals force differences as the most plausible explanation of the image contrast observed in higher harmonic noncontact images. This work was supported by an Army Research Office MURI grant under contract DAAD19-09-1-0988.

10:30 AM OS.6
Probing Nanoscale Tip-Surface Interactions using Dynamic Spectroscopies, Kathryn J. Wahl;
U.S. Naval Research Laboratory, Washington, District of Columbia.

In order to investigate adhesion, mechanical, and tribological processes at the nanometer scale, we need to better understand how model asperity contacts respond to surface forces and dissipate energy. Perhaps the most significant complication in the measurement and interpretation of nanoscale tip-sample interactions is the fact that the contact sizes are below the optical limit (1 micron). Macroscopic measurements often rely on optical observations of the contact, and many of the relevant contact mechanics models are formulated around direct measurement of the contact area or radius as a function of externally controlled parameters such as force and displacement. Consequently, for studies at the nanoscale to go beyond simple measurements of force and displacement requires approaches that enable indirect measurement of the contact area. Small, oscillatory force or displacement perturbations of the tip or sample can be used to determine the interaction or contact stiffness, and thus provide a measure of the contact size. In this talk, I will review various approaches to making quantitative, dynamic measurements using scanned probe microscopes. I will give examples of how dynamic force and displacement methods can be used to develop quantitative adhesion spectroscopies, mechanics imaging modes, and hybrid contact mechanics experiments.

11:00 AM OS.7
Near-Field Acoustic Holography Novel High Resolution Sub Surface Imaging for Geologic and Biological Structures.
Gyandesh Behlauher1 and Vinayak P. Dravid; Material Science and Engineering, Northwestern University, Evanston, Illinois.

As materials, structures and phenomena continue to shrink, and the micro/nanofabrication paradigm move from planar to 3-D/stacked platforms, there is an acute need to image and analyze surface/sub-surface features and phenomena at ultra-high resolution and environmental/contamination considerations. Keeping view of these technological challenges and to overcome these, we have developed a turn-key Near-Field Acoustic Holography (NFAH) system. This unique system will address emerging issues in imaging and analysis of diverse embedded nano and microscale structures, and engineered systems. In NFAH, one high frequency acoustic wave is launched from below the specimen, and another one on the scanning cantilever of the scanning probe microscopy (SPM) system at a slightly different at the driving frequency. The resultant beat frequency which forms a pseudo-standing wave on the surface specimen, acts as a reference lattice. Any perturbation to phase and amplitude of the specimen acoustic wave is then measured with SPM tip as an antenna, and converted in quantitative pectoral map. Thus, internal features, e.g., voids, cracks, phases, which perturb the acoustic wave, can be seen in such images. This technique will fill a critical void in characterization and investigation of the static and dynamic mechanics of nanoscale systems, ranging from engineering systems to biologically active structures, in-vitro. In the presentation, we will report efficacy of NFAH approach, starting with a model surface microstructure of buried Au nanoparticles/prisms underambient pressure/microstructure and internal features of carbon nanotubes, among others. It will be argued that ramping the acoustic frequency to 100 MHz would enable the extraction of subsurface defects (voids, deformation) with spatial resolution < 5 nm.

11:15 AM OS.8
Photoinduced reversible hardening of the Young’s modulus in ZnO nanobelt. Minhui Zeng1, Chaoshun Jiang2, Shouxin Li3, Lei Liu4 and Scott X. Mao1; 1Department of Mechanical Engineering, University of Pittsburgh, Pittsburgh, Pennsylvania; 2Shenyang National Laboratory for Materials Science, Institute of Metal Research, Chinese Academy of Sciences, Shenyang, China.

We report photoinduced reversible hardening of the Young’s modulus in ZnO nanobelt. The effective Young’s modulus of ZnO nanobelts under over band gap illumination is at least twice as large as that under darkness or below band gap illumination, which is derived by two methods. One is from the unloading part of the load-displacement curve in the nanoindentation depth of 10nm to 80nm using cube corner diamond indenter. The other is from loading part of AFM force-displacement curve below the penetration depth of 5nm using cantilever typed diamond probe. For comparison, similar work is done on (0001) bulk ZnO. We find little difference in the effective Youngs modulus of ZnO bulk with and without illumination. The physical mechanism for the observed phenomenon is discussed in terms of the electronic strain induced by the photogeneration of free carriers in ZnO. This finding sheds light on realizing nanoscale optical tunable surface acoustic wave (SAW) devices.

11:30 AM OS.9
Fabrication and Mechanical Properties of Suspended One Dimensional Nanostructures: Carbon Nanotubes, Polypyrrole Nanotubes, and Helical Polyacetylene Nanofibers.
Sang-Wook Lee1, DongSu Lee1, Bio Kim1, Eleanor E. B. Campbell2 and Youn Park1; 1School of Physics, Seoul National University, Seoul, South Korea; 2School of Physics and Engineering Physics, Gothenburg University and Chalmers University of Technology, Gothenburg, Sweden.

Suspended structures of one dimensional nano materials were fabricated using an acid free method. Poly (methyl methacrylate) that has the same height as Au anchors was fabricated in order to prevent the materials from falling down. The mechanical properties of suspended carbon nanotubes (CNTs), polypyrrole (PPy) nanotubes, and helical polyacetylene (PA) nanofibers were studied by the force-distance measurement with atomic force microscope tip manipulation. Elastic modulus of suspended CNT, PPy nanotube, and helical PA nanofiber were estimated at 0.3 TPa, 3 GPa, and 0.6 GPa respectively.

11:45 AM OS.10
Variation in Atomic-Scale Friction with Substrate Surface Order and Partial Fluorination for Alkanephosphonic Acid
Self-Assembled Monolayers on Alumina, Matthew J. Brukman 1, Robert W. Carpick 2 and Timothy D. Dunbar 1. 1Engineering Physics, University of Wisconsin - Madison, Madison, Wisconsin; 2Corporate Research Materials Lab, 3M Company, St. Paul, Minnesota.

Self-assembled monolayers (SAMs) are of considerable interest for applications from the nanoscale to the macroscopic scale, such as lubrication, corrosion protection, and water repellency. While much attention has been paid to SAMs on gold and silicon, less work has been performed for SAMs that form dense layers on other surfaces such as metal oxide-semiconductors. In this work, we compared the nano-scale friction and adhesion of two phosphonic acid self-assembled monolayers (SAMs): C(8)F(8)H(11) versus the H(18) samples deposited on a series of Al(2)(O)3 surfaces: C- and R-plane single crystal sapphire, and an amorphous alumina layer. The molecules form densely packed hydrophilic layers with strong substrate adhesion. Atomic force microscopy was then used to characterize the nano-scale dependences of adhesion and friction on SAM composition and substrate surface order. We observe consistently greater friction in the F8H11 versus the H18 samples for each substrate. The R-plane sapphire substrate also leads to reduced friction.

In addition, partial fluorination generally reduces the wettability of the monolayer by both water and hexadecane. This indicates that substrate-imposed variations in packing density, ordering, and wettability have measurable nanotribological effects.

SESSION 09: Electrical SPM and SPM-Based Transport Measurements
Chair: Wilfried Vander Vorst
Wednesday Afternoon, November 1, 2004
Commonwealth (Sheraton)

1:30 PM 09.1
Semiconductor Dopant Profiles and Dielectric Characterization with Scanning Capacitance Microscopy. Joseph J. Kopanski, Semiconductor Electronics Division, National Institute of Standards and Technology, Gaithersburg, Maryland.

Scanning capacitance microscopy (SCM) has been commonly used to image dopant gradients in silicon and other semiconductors. As a mobile, high-resolution (10 nm) metal-oxide-semiconductor (MOS) probe, SCM also is a non-destructive, contactless tool with which to examine local electronic structures and determine variations in semiconductor substrate properties. Virtually any MOS qualification measurement that can be made with fabricated metal electrodes can also be made with SCM. Two particular applications being pursued are characterization of high-k dielectric films on silicon for next generation integrated circuits and characterization of native and deposited insulators on wide bandgap semiconductors. Local differential capacitance (dc/IV) versus tip bias (Vtip) measurements can be made with SCM using an ac voltage to generate the differential capacitance signal. These measurements differ from conventional C-V measurements due to the 3-D nature of the SCM tip and the method used to generate the differential capacitance signal. Theoretical predictions of SCM measurements can be made of SCM differential capacitance versus dc bias voltage (dc/IV) for metal-oxide-semiconductor (MOS) capacitors with various levels of fixed and interface traps. The goal of this work is to determine if the quantitative information on defect distributions measured using SCM and if variations in interface trap density can be observed under defects or device structures. The response of the SCM MOS capacitance measurement to a local electric field stress and optical pumping from the AFM laser will also be discussed.

2:00 PM 09.2
In situ Resistance Measurement of Epitaxial Silicided Nanowires. H. Okano 1, Y. Hosono 1, Shoji Hasegawa 2 and Peter Bennett 1, 1Physics Department, Arizona State University, Tempe, Arizona; 2Physics Department, University of Tokyo-Hongo, Tokyo, Japan.

We have measured the resistance of self-assembled epitaxial silicide nanowires (NWs) using a multi-tip UHV-STM instrument. NWs were grown by deposition of 1 monolayer cobalt onto a Si(110) substrate at 750 C, producing NWs with a single orientation and average dimensions: 50nm wide by 4 microns long. Resistance is measured in situ by placing two independent STM tips at variable separations along a single NW using an integral SEM to guide the placement. Leakage conduction through the substrate is less than 1/100 ohms, while the NW resistance increases linearly with tip separation, with a nominal value of 500 ohms. Measured resistivity for NWs is approximately 100 micro-ohm-cm, similar to the value for extended epitaxial films. This NW resistance is further reduced by interface scattering, even though the NW boundaries are atomically perfect.

2:15 PM 09.3

To date, models of charge injection, trapping, and transport have mainly been tested by measuring and modeling the current-voltage characteristics of devices as a function of voltage and temperature. Since organic conductors are often unavoidably disordered, one worries that bulk characterization techniques are poorly suited for testing microscopic theories. We have used electric force microscopy to image the local electrochemical potential and capacitance in films of the high-mobility conjugated polymer polyfluorene and polythiophene (P3HT) on gold, a molecularly doped polymer system used in thick-film charge injection and transport in LEDs, and in pentacene, a candidate material for organic field effect transistors. In order to get a clearer picture of charge injection in the TPQ-P3HT model system, we have imaged electrochemical potential drops in a working device. We observe a gradual change in the shape of the potential drop and capacitance as the source-drain voltage is increased. This data qualitatively verifies a microscopic picture of hole conduction in which charge transport transitions from ohmic to space charge limited transport. Internal electric field and charge density at the metal-organic interface are inferred from the measured electrochemical potential and the current. We find that the charge density at the TPD-P3HT interface increases with electric field much faster than is predicted by the commonly assumed diffusion-limited thermionic emission theories. In 20-100 nm thick TPD-P3HT films created under a wide variety of conditions (varied substrates, host polymer, degree of dipole doping, film thickness, TPQ concentration, and temperature) we observe a 0.8-20 nm-Vpp variation in electrochemical potential exhibiting a 100-200 nm correlation length. These observations cannot easily be explained using the accepted understanding of charge injection and transport in hopping materials. Even in this model system, it seems that charge injection may be a far more complicated process than has been assumed. We have used electric force microscopy to show that charge traps are spatially inhomogeneous in polycrystalline pentacene devices. These experiments follow changes in local capacitance and contact potential as traps fill in a working device and correlate charge behavior with the structure.

2:30 PM 09.4
Electric Force Microscopy Study on Photo-Induced Charging of Pentacene Monolayer in Dry Nitrogen. Liwei Chen 1, Oksana Chernyak 2, Alex Shalke 2, Alejandro Schrott 2 and Louis E. Brus 2.

With the recent progress in organic electronic devices such as OLED and OTFT, there is an ever increasing demand in the understanding of these electronic materials and their interfaces with metals and dielectrics. We recently reported an interfacial dipole between pentacene monolayer and silicon dioxide and pentacene-related in-gap states at the interface in UHV. Here we investigate the pentacene/Si02 interface in dry nitrogen and under photo-excitation at 532nm. Pentacene monolayer is thermally deposited in UHV of 5x10^-9 torr onto silicon wafer with a 2nm thick thermal oxide and then put in dry nitrogen box with short exposure to the air. EFM measurements found that first the electric field gradient on pentacene is dependent on the doping of the Si wafer and second, it is also dependent on the sample history in ambient and in dry nitrogen. Third, when the pentacene is illuminated with a 532nm (2.3 eV) CW laser from a glancing angle, the field gradient increases monotonically, indicating the accumulation of positive charges regardless of the substrate doping and sample history. Time trajectories of individual islands charging and then decay after the laser is turned off were collected. The pentacene islands in regions with these small particles are smaller in size compared to samples in dark or weak illumination, and less charged than under weak illumination. We propose a Coulombic explosion mechanism for this phenomenon.

3:15 PM 09.5
Exploring Carbon Nanotubes with Scanned Probe Microscopy. Pan Ma, Eric Y. J. Wang, Ping Zhu, Marko Balcar, Jeffrey Kong Park, Yuval Yaish, Ethan Minot, Vera Sazonova and Sami Rosenblatt; Laboratory of Atomic and Solid-State Physics, Cornell University, Ithaca, New York.

Carbon nanotubes are an exciting new class of materials with...
remarkable electronic and electromechanical properties. These nanometer diameter cylinders offer an unprecedented opportunity to explore novel solid state phenomena in a one-dimensional system. We show that the nanotube occupy one-dimensional subbands that result from the quantization of the electron motion around the circumference of the tube. The tubes can be metals or semiconductors, depending on the detailed structure of the tube. While much is known about nanotubes, many important questions remain about the effects of strain, disorder, and electric and magnetic fields on their properties. This talk will review experiments by our group that use scanned probe measurements to probe the electronic and electromechanical properties of nanotubes. In one set of experiments, an AFM is used to look inside carbon nanotube devices. A metalized AFM tip is used to make local, moveable, electrical contact to a nanotube. Using this technique in conjunction with electrical measurements, we determine the resistance of nanotube/metal contacts and also probe intrinsic scattering lengths in both metallic and semiconducting nanotubes. The measurements demonstrate that transport mean free paths can be several microns, as determined by electron-electron interactions. We use the AFM to explore suspended carbon nanotube devices. The tip can be used to apply tension to the tube and explore how mechanical strain affects the bandgap. These measurements also show that the suspended section of the tube is nearly free of the disorder and threshold voltage shifts characteristic of tubes on oxide surfaces. Finally we use a low-temperature AFM to explore single-electron charging phenomena in nanotube quantum dots. The addition of individual electrons to the dot produces a detectable force on the cantilever, as well as shifting its resonant frequency and producing additional dissipation. All of these can be used to image single electron states of nanotubes, even in tubes without external electrical contacts.

3:45 PM 09.8

Scanning Conductance Microscopy (SCM), Scanning Gate Microscopy (SGM), and Scanning Impedance Microscopy (SIM) are very powerful approaches for measuring the local electrical properties of nanoscale structures. SCM can be used to determine whether nanotubes, nanowires, and even DNA are insulating or conducting. SGM has been used to image Schottky barriers that develop within carbon nanotube circuits and to quantify the local Fermi energy at gate-resistant defects along the nanotube length. Here we present two new advances for these microscopies. First, we develop a model for the electrostatic (capacitive) interaction between tip and sample/substrate that makes SCM a more powerful quantitative technique. We show that experimental data from samples of conducting carbon nanotubes and (insulating) polyethylene-oxide (PEO) nanofibers are in excellent agreement with the model predictions. As an important new application we use this approach to measure the dielectric constant of PEO nanofibers. We also present recent results from a new scanning gate microscopy (SGM) approach to measure the frequency range of SGM. This technique is used to image changes in the gate properties of CNFETs in the frequency range 40Hz-10MHz induced by a voltage-based AFM tip that acts as a local gate. We show that our data consistent with a parallel RC model for the CNFET circuit. In the low frequency range (f=40Hz-100KHz), the resistance of the SWNT dominates the total impedance of the circuit, while the capacitive effect of the electrical contacts dominates in the intermediate-high frequency range (f=100KHz-10MHz).

4:30 PM 09.9
Two-dimensional Carrier Profiling on Operating Si-MOSFET by Scanning Capacitance Force Microscopy. Kenjuro Kimura1, Kei Kobayashi2, Hirofumi Yasuda1,4, Koji Ueda2 and Kazumi Matsushige1,2.

Investigations of two-dimensional (2D) carrier profiles on nanometer scale are essential for the developments of novel devices to make its fabrication process more optimized. We have recently developed a novel scanning probe technique, scanning capacitance force microscopy (SCFM), which is capable of measuring 2D density profile on a semiconducting sample. Its principle is based on the detection of the local electric force proportional to the differential capacitance, which is obtained by measuring the third harmonic components (3f) in the mechanical oscillation of an AFM cantilever induced by the electric field between the AFM tip and the sample. The magnitude and the polarity of its component correspond to the carrier concentration and species such as p-type or n-type [1, 2]. Although, SCFM has been a powerful tool for the visualization of local dopant...
profiles on cross-sectional Si-MOSFETs in the state of nOFF, it has not been applied yet to analyze dynamical changes of the carrier profiles near the channel area in the state of nON. In this study, we prepared a special Si-MOSFET sample (p-type) for the cross-sectional analysis, and measure the 2D carrier profiles in the nON state by both SCFM and SCM. We first cut Si-MOSFET device to have its cross-sectional profile in the n-area under the gate, and then etched it few microns to remove contaminant and possible mobile charge. Next, we put tungsten wires on the top side by utilizing Ion beam assist deposition in order to connect the external bias controller to each electrode. Source, drain and gate. In the SCFM measurement, we applied an ac bias voltage (36 kHz) between the tip and the sample, and detected the third harmonic component (108 kHz) of the cantilever mechanical oscillation induced by the electrostatic force in vacuum. We found that SCFM contrast in the vicinity of the channel area was changed depending on the gate bias voltage. The contrast change appeared to reflect some changes of the carrier profile related to the inversion layer on the depleted region under the gate. Another possibility is that it is affected by mobile or fixed charge inside the native oxide layer on the sample surface. For the discussion of carrier density more quantitatively from the SCFM or SCM data, several issues such as accidental charge injection to the sample from the tip, leak current between the electrodes through the surface, and the optimization of the measurement condition have to be taken into consideration. [1] K. Kobayashi, H. Yamada, and K. Matsushita Appl. Phys. Lett. 81, 2929 (2002). [2] K. Kimura, K. Kobayashi, H. Yamada, and K. Matsushita Appl. Surf. Sci. 210, 93 (2003).

4:45 PM 09.10
Measurement of Variations in Electron Transport across Organic/Metal and Metal/Semiconductor Junctions on the Molecular Length Scale using a Scanning Probe.
Regina Ragan1, Sehen Kim1, Douglas A.A. Ohberg1 and R. Stanley Williams1, 1Quantum Science Research, Hewlett Packard, Palo Alto, California 94304, 2Advanced Institute of Science and Technology, Daejon, South Korea.

As electronic devices size scales down toward the nanometer length scales, the effects of atomic interfaces and atomic ordering on electron transport must be well characterized. We use scanning tunneling microscopy (STM) to image the molecular arrangement of octanethiol and benzethiol self-assembled monolayers on Pt(111) and of Pt(111) and of Pt(111) and of Pt(111) and of Pt(111) and of Pt(111) and of Pt(111) and of Pt/Re disilicide nanowires/Si junction for both the cases. We measure variations in electron transport for these materials systems with molecular resolution using the scanning probe as the top electrode. On Pt(111), we compare the packing of octanethiol to that of benzethiol and compare both of these to the well studied system of alkanethiols on Au(111). Both octanethiol and benzethiol form ordered monolayers on Pt(111) yet have different packing arrangements. Using constant current tunneling spectroscopy combined with STS we image the variations in electron transport as a function of position. Across grain boundaries, a higher current is measured than across ordered domains. In the case of RE disilicide nanowires on Si(100), the IV spectra is consistent with electron transport through a depletion layer at the surface. Hexagonal Re disilicide nanowires self-assemble during epitaxial growth as one-dimensional metallic nanostuctures on Si(001) substrates due to an anisotropic lattice mismatch with Si[110]. Previously we have shown that Re disilicide nanowires exhibit high aspect ratios, having lengths exceeding 1 micron and widths less than 5 nm can be grown on vicinal Si(001) substrates in a miscut of 2.5 degrees toward the [110] azimuth. The Re disilicide metallic nanostuctures can be used as building blocks for chemical self-assembly of organic molecules to build nanostuctures from the bottom up. Molecular/Re/Er disilicide/p-type Si nanometer scale junctions could have current switching and rectifying behavior and in large arrays have applications as highly dense logic devices utilizing a defect tolerant crossbar architecture. Since decades of research have been devoted to CMOS technology, the combination of organic materials with inorganic nanostuctures on the silicon platform holds promise to yield innovative devices while allowing for integration with silicon.

O10.1
STM Image Simulation: Effect of the Number of Tunneling States and the Isosurface Value. Juan Radilla1, Yolanda Trinidad-Reyes2, Nikola Butina1 and Marcelo Galvan1, 1Quimica Aplicada, Fisicoquimica, Universidad Autonoma Metropolitana-Iztapalapa, Mexico, D. F., Mexico; 2Quimica, Area Electroquimica, Laboratorio de Nanotecnologia e Ingenieria Molecular, Universidad Autonoma Metropolitana Iztapalapa, Mexico, D. F., Mexico.

In this work Scanning Tunneling Microscopy (STM) images were simulated for the organic molecule 3,4,9,10-Perylene-tetracarboxylic dihydride (PTCDA) to study the effect of both the number of tunneling states and the isosurface value. Local Density Approximation to the Density Functional Theory (DFT-LDA) calculations were performed to achieve the simulated images under the Tersoff and Hamann approximation. The number of tunneling states has a strong effect on the STM appearance, convergence for a certain number of tunneling states. Intermediate contour values for the integrated Local Density Of States (LDOS) produce good resolution and matching in relation to the experimental images. This work was supported in part by Instituto Meso American de Petroleo (IMP) through the project FIES-08-100-1.0. 2115-31786 "Mecanismos de Deposicion de Compostos Orgánicos Pesados en Flújo de Petroleo en Ductos", and the Consejo Nacional de Ciencia y Tecnología (CONACYT) through a Juan Radilla scholarship.

O10.2
Atomically Resolved STM Images of CVD Grown Carbon Nanotubes. Daniel (Ching-Shih) Chang2, Philip (Zifeng) Lei1, Lifeng Dong2 and Jun Jiao2, 1Materials and Mechanical Engineering, Washington State University, Vancouver, Washington; 2Physics, Portland State University, Portland, Oregon.

We have obtained atomically resolved STM images of CVD-grown single-wall carbon nanotubes (CNT) under the air ambient and room temperature. The crystal structure of carbon nanotube surface has been studied intensively since its chirality determines the electronic properties of nanotubes. However most studies focused on the CNTs grown by arc discharge or laser ablation. In this work Scanning Tunneling Microscopy (STM) images were captured at both ultra high vacuum and room temperature. In this research, we studied the chirality and diameter of the single-wall CNTs synthesized by CVD and CVD growth methods are highly promising for scale-up of defect-free nanotube materials, and enable well-aligned CNT growth with better control that is not possible with arc-discharge or laser ablation techniques. The preliminary studies on STM images of CNTs are either in the range of 1.2nm or 0.8 nm. The chiral angle is about 0 degree for all nanotubes. We will also discuss the two key factors for reaching capability of atomic resolution at the air ambient and room temperature: the absolute vibration free environment and the sharp probe tips.

O10.3
Surface Potential Reversibility on Self-Assembled Monolayer : Fermi Memory. Saito Nagahiro1,2, Lee Sun-hyang3 and Takai Osamu3,1, 1Department of Molecular Design and Engineering, Nagoya University, Nagoya, Japan; 2Department of Materials, Physics and Energy Engineering, Nagoya University, Nagoya, Japan; 3EcoTopia Science Institute, Nagoya University, Nagoya, Japan.

Scanning probe microscopy (SPM) has been widely used in order to observe microstructures and functional groups in a SAM. Moreover, scanning probe lithography (SPL) have been focused in the field of microstructural fabrication on self-assembled monolayers. The nanochemical conversion is based on electrochemistry in a minute water column formed between the sample and the tip of a SPM, which work as working and counter electrodes, respectively. In order to achieve a reversible chemical nanopatterning by SPM, we need to control both oxidation and reduction reactions. Simultaneously, the chemical conversion of functional group leads to shift of surface potential in nano-scale regions. Surface potential, that is, Fermi level was acquired by Kelvin probe force microscopy (KPFM). Here, we demonstrate that nanochemical conversion of amino-terminated groups in a SAM can be fabricated based on electrochemical polaron dianhydride (PTCDA) to study the effect of both the number of tunneling states and the isosurface value. Local Density Approximation to the Density Functional Theory (DFT-LDA) calculations were performed to achieve the simulated images under the Tersoff and Hamann approximation. The number of tunneling states has a strong effect on the STM appearance, convergence for a certain number of tunneling states. Intermediate contour values for the integrated Local Density Of States (LDOS) produce good resolution and matching in relation to the experimental images. This work was supported in part by Instituto Meso American de Petroleo (IMP) through the project FIES-08-100-1.0. 2115-31786 "Mecanismos de Deposicion de Compostos Orgánicos Pesados en Flújo de Petroleo en Ductos", and the Consejo Nacional de Ciencia y Tecnología (CONACYT) through a Juan Radilla scholarship.

O10.4

We propose a novel memory device concept, which we call the Fermi Memory, based on chemical conversion of functional groups in a SAM. The Fermi Memory is a novel device, which can be used for memory and information processing. The Fermi Memory can be fabricated based on electrochemical polaron dianhydride (PTCDA) to study the effect of both the number of tunneling states and the isosurface value. Local Density Approximation to the Density Functional Theory (DFT-LDA) calculations were performed to achieve the simulated images under the Tersoff and Hamann approximation. The number of tunneling states has a strong effect on the STM appearance, convergence for a certain number of tunneling states. Intermediate contour values for the integrated Local Density Of States (LDOS) produce good resolution and matching in relation to the experimental images. This work was supported in part by Instituto Meso American de Petroleo (IMP) through the project FIES-08-100-1.0. 2115-31786 "Mecanismos de Deposicion de Compostos Orgánicos Pesados en Flújo de Petroleo en Ductos", and the Consejo Nacional de Ciencia y Tecnología (CONACYT) through a Juan Radilla scholarship.
O10.4 Low temperature Ultra High Vacuum STM for local imaging and spectroscopies on Single Molecular Molecule. Messina Giovanni Paolo 1,2, Dante Gatteschi 3, Stefano Prato 3, Daniela Orani 2 and Paolo Sigalotti 2; 1INSTM, Sesto Fiorentino, Italy; 2Area Science Park, APEResearch, Trieste, Italy.

We are building a low temperature STM microscope designed to work with magnetic molecular adsorbates. The STM microscope relies on a pendulum mechanism to ensure high vertical stability. The STM Head allows both x-y coarse translation and high stability. The use of a custom fields up to 5T perpendicular to the surface plane. Scanning spatially inhomogeneous charge traps distribution will be shown. In experiments on pentacene thin film devices. It is obtained by the experiments provides a valuable input for advanced 3D-CMP model verification.

O10.5 Electrical AFM Measurements for Evaluation of Nitride Erosion in Shallow Trench Isolation Chemical Mechanical Planarization. Yordan Stefanov, Tino Ruhnau, Ruma Komaragiri and Udo Schwalle; Institute for Semiconductor Technology, Darmstadt Technical University, Darmstadt, Germany.

This article proposes a new application of tunneling current Atomic Force Microscopy (AFM) for evaluation of nitride erosion in Shallow Trench Isolation (STI) Chemical Mechanical Planarization (CMP). Excessive nitride erosion after the polishing step results in exposed and damaged active area surfaces, thus deteriorating yield and critically decreasing yield. Standard measurement techniques such as ellipsometry, profilometry, Scanning Electron Microscopy (SEM) and Scanning Tunneling Microscopy (STM) do not provide a simple, non-destructive and efficient means for detecting full nitride erosion on device level. Even pure topographical AFM is not applicable because of the gradual post-CMP transitions between nitride, silicon and silicon dioxide. However, with the help of simultaneous topographical and electrical AFM, positive identification of ‘open’ silicon surfaces on the nanometer scale can be achieved by detecting enhanced sub-picoampere tunneling currents in those areas and directly correlating them to surface topography. The experimental results from test wafers prepared at our CMOS processing facility demonstrate clearly the capabilities of this approach. Its advantages over the above-mentioned standard measurement techniques are discussed. The new measurement technique comprises a useful method for automated process control and the comprehensive experimental database obtained by the experiments provides a valuable input for advanced 3D-CMP model verification.

O10.6 Imaging Charge Traps in Pentacene Devices by High Sensitivity Electric Force Microscopy. Eric Muller 1,2,3, and John Marohn 1,2,3; 1Physics Department, Cornell University, Ithaca, New York; 2Department of Chemistry and Chemical Biology, Cornell University, Ithaca, New York.

We are investigating the electronic properties at the semiconductor-dielectric interface in pentacene thin film devices. It is believed that the conduction takes place within the first few nanometers of the organic and is adversely affected by the presence of charge traps. To date, information about charge traps has usually been inferred from analysis of bulk current-voltage measurements - few microscopic studies have been reported. By using a custom variable temperature electric force microscope in high vacuum we can probe the local charge and voltage distribution helping to understand the physics occurring at the interface. Experimental evidence of a charge trap layer in pentacene is shown here. We will present a critical microscopic investigation of the transport properties of these single-wall nanotubes.

O10.7 Transport Properties in Carbon Nanotubes Probed by SPM. Lucelle C. Travers 1,2, Sarbajit Bunejose 1, Stanislav S. Wong 1,2, James Reut-Robey 1,3, David Adamson 2, and Marek Zgod 1; 1Department of Chemistry and Biochemistry, University of Maryland-College Park, College Park, Maryland; 2Department of Chemistry, State University of New York at Stony Brook, Stony Brook, New York; 3Surface and Microanalysis Science Division, NIST Gaithersburg, Maryland; 4GMA Industries, Inc., Annapolis, Maryland.

The structural and electronic properties of several types of single-wall carbon nanotubes have been studied using scanned probe methods. Samples include pristine HiPco tubes, ozonized tubes, and tubes functionalized with CdTe quantum dots, and are deposited on HOPG and Au(111) surfaces. Scanning tunneling spectroscopy (STS) experiments and conductive probe atomic force microscopy allow transport I-V measurements on and along individual tubes and bundles of each type. Here, we discuss the results of these experiments, comparing and contrasting the effects of oxygenation and attached CdTe quantum dots on the transport properties of these single-wall nanotubes.

O10.8 Microscopic view of charge in semiconducting organic materials. William Richard Silvers, Tse Nga Ng and John A. Martin, Chemistry and Chemical Biology, Cornell University, Ithaca, New York.

We use high-sensitivity electric force microscopy to investigate charge transport and homogeneity in thin-films of conducting organic materials. We will present a critical microscopic investigation of the charge injection process in a disordered organic semiconductor, a triarylanilime (TPD) dispersed in poly(styrene) (PS). This study reveals a local observation of microscopic space-charge limited conduction (SCLC), an effect of great importance in many fields, such as OPV-PV. We will also discuss the observation of a local variation in the potential of uniform OPV-PV films and the likely causes for this surprising effect.

O10.9 Simultaneous Measurement of Conductive Property and AFM Force Curves. Takashi Mori 1,2, Rika Mizuno 1, Kazuhiro Yoneda 1, Hideki Haruta 1, Takashi Oka 1, Tetsuo Nozaki 1, and Murat Oktem 1; 1 Institute of Biomolecule Metabolism, Tsukuba, Ibaraki, Japan; 2 Med. Ins. of Bioreg., Kyushu Univ., Fukuoka, 812-8582, Japan.

Extending our knowledge on an electrical property of DNA molecules is fundamental to developing its application, such as a nano wire in future molecular electronics, even though it was clarified that DNA itself is not a conductor [1]. We are also concerned with the electrical properties of DNA nanostructures and we succeeded in the synthesis of the DNA nanostructures, such as L-shaped, Y-shaped, and hexagon [2]. Generally speaking, the measurements of the electrical property of soft materials are influenced by geometrical arrangement, mechanical deformation of these surfaces and are observed as forces and current-voltage characteristics of the sample by means of point contact method at the same time as force curve measurements. In this work, at the beginning, we applied it for a study of the conductive property of a DNA thin film. The DNA molecules adsorbed densely on a gold substrate and formed the film. DNA behaved as an insulator also in our experiment. Two types of breakdown of insulation were observed successfully. One is caused by an electric field and another is done by a mechanical deformation. The result shows that the control of the loading force is essential to the measurement of the electrical property of the materials. The extension of this method to the study of the electrical property of a single molecule will be discussed. The work was supported by New Energy and Industrial Technology Development Organization (NEDO). [1] C. Gómez-Navarro, F. De Giron, J.P. de Pablo, J. Colombo, J. Gómez-Herrero and A. Baró, PNAS, 99 8484-8487 (2002) [2] R. Mizuno, H. Haruta, T. Mori, T. Okada, K. Nakashii, T. Asakawa and K. Hayashi, Transactions of The Materials Research Society of Japan, 20(3) 439-441 (2004).

O10.10 Scanning Potentiometric Imaging of Hydride Blister and Inclusion in Irradiated and Non Irradiated Depleted Uranium Samples. Marilyn E. Hawley, Materials Science & Technology Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

Scanning potentiometric imaging is sensitive to local variations in electrical properties that can be directly correlated with structure. Uranium, like other metals, is susceptible to the corrosive effects of hydrogen gas, which can readily diffuse into the material because of its small size. In the case of uranium, hydrogen attack results in the formation of blisters that eventually cover the surface. Initially these blisters appear as local circular features, often including an inclusion in the center. The uranium hydride formed as a result of this process has significantly different electrical properties than the base metal that is dramatically revealed in the potentiometric images. In this work, samples were irradiated with positively charged fluoride ions through a grid in order to determine if the irradiation-induced damage and stress would act as initiation sites for the blisters. However, the distribution of blisters was uncorrelated. In contrast the local electrical properties were affected by the irradiation and the blisters appear in the potentiometric images in sharp contrast to the uranium background.
of the CMR supporting the nanotubes acts as a charge-sensitive plate for electrons signature of derivative C-V curves (i.e. dC/dV), KFM, the local surface barrier potential and TUNA, the local I-V curves. We use EFM as a tool to locally inject charges into capacitance and the tunneling current through a barrier. This study investigated by charge injection and Electric Force Microscopy (EFM) developed in order to probe single nanostructure or nanodevices by chemical vapour epitaxy (CVD) have been used. A low temperature oxidization process has been performed to oxidize the Si around the nanotubes in a similar way as the recent work performed on experiments. We use EFM as a tool to locally inject charges into single MWCNTs in a similar way as the recent work performed on silicon nanocrystals[1], and to detect the amount stored charges, with a sensitivity of 10 electrons, and a lateral resolution 50 nm[2]. We found that upon local injection from the biased EFM tip, charges delocalize over the whole nanotube length (i.e. 1-10 microns), which is consistent with a capacitive charging of the entire MWCNT-substrate capacitance. A drastic change for bigger nanotubes (i.e. with diameter greater than 25-30 nm), stored charges are left floating on the oxide layer, and exhibit retention times greater than ten hours under nitrogen atmosphere. However, for smaller nanotubes, abrupt discharging takes place within few seconds, in which stored charges are emitted to the EFM tip. Abrupt discharges occur either when scanning the nanotube apex, or at additional “defect” points along the nanotube. In addition, it is observed that the substrate supporting the nanotubes acts as a charge-sensitive plate for electrons emitted from the MWCNTs at low electric fields. This allows to measure to perform by EFM a spatial mapping of MWCNT field emissions patterns. EFM experiments on single MWCNTs can thus be directly correlated with the MWCNT structural (apex diameter or length) properties. See e.g. T. Melin et al, Appl. Phys. Lett. 81 5054 (2002). [2] T. Melin et al., Phys. Rev. B 69, 035321 (2004); J. Phys. Chem. C, 112, 16601 (2008); Y. Saito, K. Hamaguchi et al., Nature, 389 665-1 (1997). [3] See e.g. A. Buldum and J. P. Lu, Phys. Rev. Lett., 91 236801 (2003).
using several different AFM cantilevers on a sample with known elastic properties. Using the Hertz model for the contact mechanics, the value of $F$ was determined from the measurable deformation profiles (the reduction of the measurable height of the particles due to softening of particles at elevated temperature) of two target particles as a function of temperature. It is found that both the larger and smaller particles have similar deformation temperature dependence. Smaller particles tend to deform faster than the larger ones which is attributed to its smaller mass and heat transfer. Larger particles may require longer time to completely coalescence at the same temperature. Further work associated with the film formation process and mechanical property development are also discussed. Fundamental understanding of the film formation mechanism helps materials selection in practical application of semicrystalline polyolefin dispersion.

O10.17 Damping of Atomic Force Microscopy Cantilevers. Alan Schiottin1, Daifai Yaloh1 and Fredy Zippman2; 1Corporate Strategic Research, ExxonMobil Research and Engineering Co., Annandale, New Jersey; 2Department of Physics, Yeshiva University, New York, New York.

When the cantilever of an atomic force microscope (AFM) is immersed in fluid, its vibrational spectrum changes. More specifically, the position of the resonance and the quality factor change depending on fluid properties [1]. Both from a fundamental standpoint, to improve reconstruction algorithms of AFM, and to understand fluid-solid interaction at the nanoscale it is desirable to define rules which explain the impact of fluid properties on the cantilever’s frequency spectrum. In this work we present a new theoretical model for reconstruction algorithm to explain cantilever behavior. The algorithm is based on the continuum model of the cantilever [2] improved by the addition of fluid drag and a new internal friction term. Good agreement is found between theory and experiment. 1. J.W.M. Chon, P. Mulvaney and J.E. Sader, J. Appl. Phys. 87(8), 2000,030.278 2. L.D. Landau, E.M. Lifshitz, Theory of Elasticity (Theoretical Physics, Vol 7) Butterworth-Heinemann; 3rd edition (1986)

O10.18 Nanotomography: SPM goes 3D. Robert Megerle, Physikalische Chemie II, Universität Bayreuth, Bayreuth, Germany.

Nanotomography [1] is a novel procedure for high-resolution volume imaging with scanning probe microscopy (SPM). The method is similar to an excavation on the nanometer scale. More specifically, the position of the resonance and the quality factor change depending on fluid properties [1]. Both from a fundamental standpoint, to improve reconstruction algorithms of AFM, and to understand fluid-solid interaction at the nanoscale it is desirable to define rules which explain the impact of fluid properties on the cantilever’s frequency spectrum. In this work we present a new theoretical model for reconstruction algorithm to explain cantilever behavior. The algorithm is based on the continuum model of the cantilever [2] improved by the addition of fluid drag and a new internal friction term. Good agreement is found between theory and experiment. 1. J.W.M. Chon, P. Mulvaney and J.E. Sader, J. Appl. Phys. 87(8), 2000,030.278 2. L.D. Landau, E.M. Lifshitz, Theory of Elasticity (Theoretical Physics, Vol 7) Butterworth-Heinemann; 3rd edition (1986)

O10.19 In Situ Monitoring Film Formation of Polyolefin Dispersions Using Atomic Force Microscopy (AFM) Hot Stage. Jing Li, Wenbin Liang and Steve Chum; Analytical Sciences Lab, The Dow Chemical Company, Freeport, Texas.

Film formation from polymer latex has been the subject of great interest in recent years [1,2]. Despite the new advances, formation of void-free film from discrete particles, especially semicrystalline polyolefin particles, and the mechanisms involved in deformation of small polymeric particles are still the subjects of active research. In particular, particle size of the polymer dispersions has been found to affect film formation and temperature. The results of these experiments are consistent with the previous work by others [1]. We have been working on such a device based on a proposal by B. Kane (Nature 393, 133 (1998), in which buried P atoms placed 20 nm apart act as quantum bits (qubits) entangled through exchange.
SESSION 011: Novel Concepts in SPM
Thursday Morning, December 2, 2004
Commonwealth (Sheraton)

8:30 AM  **011.1**
**Novel Dynamic Scanning Probe Microscope and its Application to Local Electrical Measurement in an Ion Sensitive Field Effect Transistor.** Teranobu Akiyama, Kaspar Suter, Nicolas P. de Rooij and Uwe Stauffer, Univ. of Neuchatel, Inst. of Microtechnology, Neuchatel, Switzerland.

We present a unique, self-actuating and self-sensing scanning probe, which is based on a quartz tuning fork and a microfabricated cantilever. The probing tip can be electrically connected to an external source or measure unit. The sensitivity of the drain-source current of an ion sensitive field effect transistor (ISFET) was investigated as a function of the probe position in order to assess the potential of this method e.g. for pH measurement. A plain implementation of the probe has been recently introduced [Akiyama, et al., Rev. Sci. Instrum. 74, 112 (2003)]: a U-shaped microfabricated cantilever, exhibiting a sharp tip is assembled to a commercial quartz tuning fork, as used for wrist watches. The two legs of the cantilever are attached in a symmetrical way to the two prongs of the tuning fork. When exciting the tuning fork in its first resonance mode, the ends of the two prongs are moving in-plane and out of phase, meaning that they approach and withdraw from each other. This motion forces the U-shaped cantilever to start oscillating at the same frequency but in an out-of-plane motion. In a more advanced implementation, two additional, long and soft beams are added for electrical contact to the tip [Suter, et al., J. Vac. Sci. Technol. A 21, 606, 227 (2003)]. One end of each of these beams is connected to the U-shaped cantilever and the other end, which is shaped to form a bonding-pad, is fixed on the base of the tuning fork. The tuning fork is used as an oscillatory force sensor similar to a quartz microbalance. Its frequency and amplitude governs that of the tip vibration, while the cantilever determines the spring constant of the whole probe. During dynamic scanning probe microscopy, the resonance frequency of the tuning fork, which is below the eigenfrequency of the cantilever, is tracked by a phase locked loop and kept at a set point by adjusting the sample height-position with a feedback loop. The drain-source current in an ISFET is modulated by the specific adsorption of chemical species above the channel of the FET. For a new probe with the contact beams could be used to evaluate the sensitivity of an ISFET to local variations in adsorption. Since ISFETs are also light sensitive, the self-detecting property of the probe was instrumental for this experiment. We modified a small AC-potential tip to the tuning fork, scanning it above the channel area of an ISFET, which was driven at a constant current. By doing so, this current was perturbed. These small current variations were registered simultaneously with the topography image of the channel area. The most effective location turned out to be the interface to the source region. It is conceivable that such probes could also be used for interrogating signals in other integrated circuits, e.g. in a probe-station, where a highly accurate positioning of the probe-tips is required.

8:45 AM  **011.2**
**Ballistic Electron Emission Luminescence Spectroscopy of an InAs Quantum Dot Heterostructure.** Wei Yi, Ian Appelbaum, Kasey J. Russell, Venkatesh Narayananurthy, Mishe P. Hanson and Arthur C. Gossard, 1 Gordon McKay Laboratory of Applied Science, Harvard University, Cambridge, Massachusetts; 2 Department of Physics, University of California, Santa Barbara, California.

We present ballistic electron emission luminescence (BEEL) spectroscopy measurements of three-terminal hot-electron heterostructure devices embedding optically active InAs quantum dots. As a three-terminal variation of scanning tunneling microscopy (STM), BEEL is a novel probe of carrier transport and spontaneous emission of direct-gap semiconductor heterostructures. To realize both hot-electron injection and efficient radiative recombination, a BEEL device combines a Schottky metal-semiconductor interface with a buried light-emitting p-n heterostructure. By applying an emitter voltage higher than the Schottky barrier height, ballistic electrons are injected through the thin metal base layer into the n-type surface layer of the semiconductor collector. Provided that an external collector voltage bias is applied, currents due to optically stimulated ballistic emissions can be observed as well as energy conservation. Ballistically injected electrons can recombine radiatively with holes in a buried optically-active layer and emit inter-band luminescence. The principle of BEEL has been previously demonstrated in a GaAs quantum well heterostructure. In the present work, the GaAs quantum well layer is replaced by a layer of InAs self-assembled quantum dots as the optically active region. Complementary BEEL measurements are performed in configurations of both double-stripe tunnel-junction transistors and STM tip injection. Due to much higher injected current, the planar transistors allow us to detect the wavelength information of the emitted photons, which resolves both quantum dot luminescence peak near 1.34 eV and bulk GaAs luminescence peak at 1.48 eV. This picture is reinforced by the observation of a quantum-confined Stark-shift for the 1.34 eV peak. The wavelength spectroscopy from the solid-state transistor devices facilitates interpretation of collector voltage dependence of the BEEL spectra from STM devices. Furthermore, by freeing up the detector leakage current at low temperatures, consistent collector-current spectra are acquired with both STM and planar transistors. Our results pave the way to a simultaneous imaging of the surface topography, local electron transport, and luminescence of semiconductor heterostructures.

9:00 AM  **011.3**
**Single-Molecule Inelastic Electron Tunneling Spectroscopy.** Hyojune Lee1 and Wilson Ho2,1, 1 Department of Physics & Astronomy, University of California - Irvine, Irvine, Irvine, California; 2Department of Chemistry, University of California - Irvine, Irvine, California.

The spatial resolution and versatility of the scanning tunneling microscope (STM) allow us to study single atoms, molecules, and nanostructures in a well-characterized local environment free of uncertainties surrounding the nature of the system under study. The ability to probe individual atoms and molecules has made it possible to reveal properties which would otherwise be masked in the study of an ensemble of atoms and molecules. Combining the imaging, manipulation, and spectroscopic characterization capabilities of the STM, we have probed the electronic and vibrational properties of individual molecules and nanostructures. Spatially-resolved spectroscopy with the STM enables spatially-modulated excitations. The single-molecule studies provide insights into physics and chemistry at the atomic level.

9:30 AM  **011.4**
**Applying Nuclear Magnetic Resonance Force Microscopy to Spintronics and Quantum Computing Systems.** Sean R. Garner2, Seppe Kuehn2 and John A. Marchen2, 1 Cornell University, Ithaca, New York; 2Department of Physics, Cornell University, Ithaca, New York.

Magnetic resonance force microscopy (MRFM) is a technique which uses cantilevers to detect magnetization in a sample from a resonance-localized volume of spins. If single-nucleus sensitivity can be achieved, possible applications would include atomic-scale imaging in three dimensions, or readout of a spin quantum computer. In pursuit of this goal, we previously introduced a force-gradient-based type of MRFM which we demonstrated at unprecedented sensitivity. Here we will report our recent progress in further improving the sensitivity of nuclear MRFM and our application of the technique to Gd nuclei in GaAs. We will also discuss ongoing efforts to apply MRFM to organic self-assembled monolayer systems, which are being investigated as a framework for spin quantum computing.

9:45 AM  **011.5**
**Developing Low and Room Temperature Nanoprobe Spectroscopy to Address Individual Single Molecular Magnets.** Massima Giovanni Paolo1,2, Lorenzo Lencel1, Stefano Prato2, Daniela Orani2, Paolo Sigalotti3 and Dante Gatteschi1, 1 Istituto di Scienze dello Stato (IEA), Pisa, Italy; 2AIP Research, Trieste, Italy; 3IPCF-CNR, Pisa, Italy.

We are developing two Scanning Tunneling Microscopes specifically aimed at addressing Single Molecular Magnets. The first instrument is a Low Temperature UHV STM designed to perform STS spectroscopy on magnetic molecules both self assembled and drop casted on metal surfaces. The major instrumental challenge is the ability to detect low currents at low temperature. The second instrument is a Room Temperature High Vacuum STM able to detect Radio Frequency (RF) components of the tunneling current. The instrument is aimed to verify previous results in ESR-STM and extend them to Magnetic Molecules. In comparisons with earlier experiments this Microscope has the capability to monitor magnetic field, to vary the insitu magnetic field and present a superior RF recovery circuit. First
A number of multiple modulation approaches to scanning probe microscopy (SPM) have been developed recently. Utilizing multiple modulations allows frequency and time domain to be explored and accessing higher frequency dynamics of the sample. The movement of the cantilever below the tip is illustrated by the resonance function of the tip-surface system. In order to deduce the cantilever effect, we use tungsten probes that have a stiffness of 0.2 N/m. In our experiments, we achieve an enhanced tip-surface coupling and are able to clearly resolve the metallic grating structures. Terahertz images show that lines of 10 microns width can be clearly resolved. Despite an image contrast of less than 1%, a THz image of 0.9 microns can be recorded in less than 20 minutes. Experiments of organic layers of cresol resin showed that the minimum volume, which can be detected is about 10-18 m3. The spatial resolution is found to depend mostly on the tip radius of the metallic probe and the height at which the probe scans over the sample surface. Experiments with tips of 100 nm radius revealed spatial resolutions down to 150 nm. Such resolutions would allow to measure the terahertz response of isolated nanostructures and to investigate the electron dynamics within an individual quantum dot. References: [1] H.-T. Chen, R. Kersting, and G. C. Cho, "Terahertz imaging with nanometer resolution," Appl. Phys. Lett. 83, 3009 (2003). [2] H.-T. Chen, S. Kraatz, R. Kersting, and G. C. Cho, "Identification of a resonant imaging process in near-field microscopy," submitted to Phys. Rev. Lett. (2004).
developed a novel technique based on a scanning near-field microwave probe. The technique is non-contact, requires no sample preparation, and can be used on porous and non-conducting dielectrics. The probe has a few-micron sampling spot-size, so the measurement could be performed over a test region in the scribe line on a device wafer. For dielectric films with k<7 and thickness down to 300 nm the probe provides precision and accuracy better than 1% and 5%, respectively. We will present quantitative dielectric constant measurements on a variety of SOD and CVD low-k films and show excellent correlation with mercury probe measurements. The design of our probe is based on a balanced microwave transmission line tapered down to a one-micron tip aperture. Unlike the apertureless STM- or AFM-based schemes that have been previously employed, our "apertureless" approach allows for truly quantitative measurements on a few-micron length scale where the result is insensitive to the material property outside this probing volume. The balanced line geometry virtually eliminates stray fields and reduces the amount of power radiated from the tip by a few orders of magnitude compared to the unbalanced configuration. A microwave photo-induced degradation. Photo bleaching of the majority of PbS QDs occurred in 30 sec. An analysis of the blinking statistics will be presented as well.

SESSION O12: SPM of Low-Dimensional Systems
Chair: Alexei Gruverman
Thursday, December 2, 2004
Commonwealth (Sheraton)

1:30 PM ♦O12.1
Theory of Scanning Probe Microscopy of Carbon Nanostructures, Vincent Meunier, Computational Chemical Sciences Group, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Experimental techniques related to SPM imaging and spectroscopy of low-dimensional systems have significantly progressed in recent years. At the same time, new simulation methods and computational techniques have allowed the development of a theoretical basis to the interpretation and understanding of the measurements. In this contribution, we concisely review state-of-the-art modeling methods for scanning probe microscopy and spectroscopy. In particular, we focus on the computational model of the formalism will be illustrated for the case of carbon nanotubes, for which numerous high-resolution images and spectra are available. Research sponsored by the Mathematical, Information and Computational Sciences Division, Office of Advanced Scientific Computing Research of the U.S. Department of Energy. Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract DE-AC05-00OR22725.

2:00 PM ♦O12.2
Fluorescence from Individual PbS Quantum Dots, Jeffrey Peterson and Todd D. Krauss; Dept of Chemistry, University of Rochester, Rochester, New York.

Due to their extremely large electron, hole, and exciton Bohr radii, lead salt (PbS, PbSe, PbTe) quantum dots (QDs) can achieve levels of quantum confinement that are not accessible to more commonly studied III-V and II-VI QDs. Thus, the strong confinement regime can be attained for relatively large particles, which may mitigate deleterious surface effects and imparts to the particles novel optical and electronic properties. For example, compared to colloidal II-VI QD core particles, lead salt QDs have significantly larger fluorescence quantum yields and fluorescence lifetimes two orders of magnitude longer. In addition to being fundamentally important materials, lead salt QDs are optically active in the near-infrared (NIR) region, making these potentially useful materials for both telecommunication and biological-labeling applications. We will present investigations of single PbS QD fluorescence using far-field, epifluorescence microscopy and atomic force microscopy with a controllable size; well-defined exciton absorbance peaks could be tuned between 765 nm and 1800 nm. Of particular note is the ability to synthesize very small QDs, which allows for the detection of fluorescence with high sensitivity silicon detectors. Size distributions were determined from optical spectra and exhibited standard deviations of ±10%. Colloidal PbS QDs were synthesized with a poly(methylmethacrylate)-toluene (g/mL) on crystalline quartz substrates. At extreme dilutions near the single dot level, we observe fluorescence intermittency, or "blinking," a hallmark of single fluorophores. As expected for single fluorophores, a narrowing of the fluorescence spectra relative to the ensemble was also observed. We found that the fluorescence maximum irreversibly blue shifts with longer integration times and higher excitation intensities, indicative of a photo-induced degradation. Photobleaching of the majority of PbS QDs occurred in 30 sec. An analysis of the blinking statistics will be discussed.

2:15 PM O12.3
Local Transport Imaging in a SnO2 Nanobelt Sensor in a "Real World" Environment, Andrei Kolmakov1, Y. Lilach1, M. Moskovits1, J. Shair2, Arthur P. Baddorf3 and B. Kalinin1
1Department of Chemistry and Biochemistry, The University of California, Santa Barbara, California; 2Department of Physics and Astronomy, The University of Tennessee, Knoxville, Tennessee; 3Condensed Matter Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Electronic transport in a SnO2 quasi 1D nanodevice structure in a field effect transistor configuration is studied with a combination of macroscopic transport measurements and Scanning Probe Microscopy (SPM). The geometric structure of the nanobelt is determined from atomic force microscopy images that provide the height of the nanowire and scanning electron microscopy images that yield the cross-section. To address local transport behavior in the nanobelt, ac and dc potential distributions in an operating sensor device were measured using scanning impedance microscopy and Scanning Surface Potential Microscopy (SSPM) correspondingly. SSPM images exhibit dc conductive and drops at the contacts and at the nanobelt ends. The primary electroactive elements in the nanowire circuit. The dc transport measurements are strongly affected by the field-induced surface charge on the nanowire and gate oxide, low mobilities of which results in relaxation times of order minutes.

Under the conditions when charging effects are minimal, the potential distribution along the nanowires under positive and negative biases is strongly asymmetric, indicative of the presence of rectifying elements in the circuit. SPM is used to measure the current-voltage characteristic of individual electroactive elements in nanowires circuit. Combined with macroscopic sensing characteristics, this provides an opportunity for a spatially-resolved understanding of sensing and memory mechanisms in these devices. Research was sponsored by the U.S. Department of Energy, under contract DE-AC05-00OR22725 with UT-Battelle, LLC and by the National Science Foundation grant DMR-0072988. Research performed as an Eugene P. Wigner Fellow (SVK). Research at USCB was supported via AFOSR DURINT grant F49620-01-1-0459.

SESSION O13: Future SPM Challenges and Opportunities
PANEL DISCUSSION
Thursday, December 2, 2004
Commonwealth (Sheraton)
3:00 PM - 5:00 PM
Chair: Ward Plummer

The spectacular progress of scanning probe microscopies in the last two decades have brought about new opportunities in condensed matter physics, chemistry, biology and materials science. The examples are as diverse as imaging and quantification of single molecules, to manipulation of condensed matter systems, correlated electron behavior and quantum phenomena, surface reactivity and reaction mechanisms, electrical, optical, electromechanical, magnetic and elastic properties. This incredible progress is in large part due to the development of advanced microscopes capable of measurements under conditions ranging from ambient to liquid to ultra high vacuum, temperatures from milliKelvin to hundreds degree, high magnetic fields. Recently developed SPMs are capable of spatial resolutions down to tens of picometers. The development of advanced SPM instrumentation is a complex task requiring strong multidisciplinary expertise both in technical aspects of microscopy and instrumentation and chemistry, physics or biology. The purpose of this panel session is to provide a forum for a discussion of the current needs for advanced SPM instrumentation development in US and the equally important aspect of transferring new developments to the scientific community. The discussion will be initiated by several leaders in the field that will present their perspective on the development of advanced SPM techniques and approaches for disseminating new instruments and techniques to the community. In the second part, the representatives
from various federal agencies will discuss their agendas and potential role of SPM development. The invited speakers include:

E. Ward Plummer (University of Tennessee and ORNL)
Lukas Novotny (University of Rochester)
Katryn Wahl (Naval Research Lab)
Dawn Bonnell (University of Pennsylvania)
Clayton Teague (National Nanotechnology Coordination Office)
Jim Murday (Office of Naval Research, DOD)
Tof Carmin and Jim Horowitz (DOE, Basic Energy Sciences)
G. N. Tissema (National Science Foundation)

SESSION O14: Poster Session
Chair: Lucas M. Eng
Thursday Evening, December 2, 2004
8:00 PM
Exhibition Hall D (Hynes)

O14.1
We have proposed and developed a purely electrical technique for imaging the state of ferroelectric polarization and local crystal anisotropy of dielectric materials called "scanning nonlinear dielectric microscopy" (SNDM) [1]. To date, the spatial resolution of SNDM has been improved down to 0.5 nm, exceeding piezoelectric scanning force microscopy in its limit [2]. SNDM does not require any detection technique but use an electrical technique; SNDM measure a slight variation of capacitance in the top of a probe tip under applying an electric field. Therefore we expect that SNDM can be applied to an inactive insulator, in which it is difficult to use another scanning probe microscopy because of the weak interaction between sample and probe tip. In this paper, we will describe a newly developed ultra-high vacuum type scanning nonlinear dielectric microscope and measurement results of ferroelectric materials. In this experiment, ultra-high vacuum chambers are used to remove an undesired influence of an absorbed layer on the sample surface, and the samples are prepared by ion beam cleaning or by cleaning in the ultra-high vacuum atmosphere. One of the experiments is a observation of a cleaving (012) surface in LiTaO3 crystal. We can clearly observe a striped pattern in the period about 0.3 nm corresponding to the sub-lattice period. From this image we confirm that the SNDM can be applied to an inactive insulator, in which it is difficult to use another scanning probe microscopy due to the week interaction between sample and probe tip. In the next step [1] Y. Cho, A. Kirihara and T. Saeke, Rev. Sci. Instrum, Vol.6 (1996) 2297. [2] H. Odagawa and Y. Cho, Surf. Science, Vol. 463 (2000) L621.

O14.2
Raman and Rayleigh Analyses and Smart Imaging of Nanoporphyrins and Nanoporphyrinized Materials: Alternating Techniques to SEM, TEM and AFM. Philippe L. Colomban, LADIR UMR7075 UPMC, CNRS, Thiais, France.
Technological advances have significantly increased the performance of Raman instruments over the past decade. On-site measurements are now relatively easy, and controlled mapping of materials and devices allows consecutive spectra to be recorded stepwise with a lateral spatial resolution close to 0.1 nm. 100x100 point maps can be recorded in a reasonable timescale with high sensitivity Raman instruments. The Raman spectral parameters in these maps can be recorded in a reasonable timescale with high sensitivity Raman instruments. The Raman spectra of these materials are used to understand and even predict some properties. In addition, in some cases (for example a colored phase dispersed in a transparent matrix), the elastic Rayleigh scattering, which is orders of magnitude higher than the inelastic Raman scattering is used for quasi-instantaneous images of a material's skin, which is important, for example in corrosion studies, for observing surface composition or roughness change. Rayleigh imaging can offer very similar information as AFM for 2nd phase carbon containing magnetic materials. The technique provides conductivity, diffusivity, reaction, sintering, mechanical strength properties and has been reported for nanostructured materials, all of which result from the interfacial characteristics. Raman scattering is a unique tool for the characterization of such materials, providing information on the chemical bond arrangement and short-range order in amorphous, nanocrystalline or nanosized phases. This paper gives an overview of the information extracted from Raman spectra in nanomaterials chosen among colored nanoporphyrins (pigments, carbon-containing materials), electrolites films (ZrO2, CeO2), electrode films (Lu-doped InO4) and Bi2. The possibility of in situ analysis of working solid-state devices (under mechanical stress or electrochemical cycling) will be discussed. Spectroscopy Europe 15/6 8-15 (2005); http://www.spectroscopyeurope.com/

O14.3
Integrated photonics is an emerging field where insight at the quantum scale can be extracted from nanometer scale light. The possibility of using such technology in a broad variety of emerging applications is exciting. A unique property of ballistic electron emission luminescence (BEEL) microscopy is that it is able to sense the surface density of photo-generated freecarriers and such measurements may be used to determine the electrical origin of a device. The ability to focus and excite at high fluence without heating the sample makes BEEL a particularly powerful tool for studying photo-generated excitons. BEEL microscopy employs a scanning tunneling probe to locally inject hot electrons into a light-emitting Schottky-barrier heterostructure. To image the buried luminescent layer, emitted photons must be detected by a photo-sensitive device. Unfortunately, the low injection current and poor photon extraction efficiency in the BEEL collector results in a weak signal only detectable in the far-field using single-photon detectors. To solve this problem, we have integrated a photon detector directly into the BEEL heterostructure, just below a luminescent quantum well. Results from solid-state metal-base hot electron transistors fabricated with this design indicate more than 10% of the photons emitted by the quantum well escapes the detector region. In microscopy mode, typical tunneling currents of 1-10 nA result in a collector current of 10-100 pA; this is expected to give 1-10 pA BEEL photocurrent, well within the detection range of high-gain amplifiers.

O14.4
Surface Exciton Energies Determined by Velocity Resolved Atomic Desorption. Alan G. Joly1, Kenneth M. Beck2, Wayne P. Hess2, Peter V. Susko1, Paolo E. Trevisanutto1 and Alexander L. Shluger1.

Probing the electronic structure of surface excitons is important for our understanding of the mechanisms of surface processes including photo-catalysis, local characterisation of nano-structures and application of NSOM and STM excitations. While the bulk exciton energies are generally well known, the surface excitons are very elusive species due to low detection sensitivity of conventional techniques. Recent advances in the REMPI technique have provided an extremely sensitive tool for detecting of photo-induced desorption of atoms. We have developed a new method, which uses velocities of photo-desorbed surface species to determine the energies of the surface excitons. The energies of photons are finely tuned so that the induced thermal-expulsion of surface atoms, which is a signature of the surface-exciton relaxation. The method has been applied to determ the surface-exciton energies on alkali-halide and MgO surfaces. The energy shifts between the surface and bulk excitons range from about 3 eV for LiF to 0.2 eV in KI. They show a remarkable correlation with the inter-atomic distance for the whole range of materials studied. [4] Our ab initio embedded cluster calculations demonstrate that the excitation energy shift is determined by several factors including the change in the potential and kinetic energies as well as different electronic structures of the excited states, and cannot be explained on the basis of purely electrostatic considerations. The surface-exciton detection scheme developed for the desorption experiments is sensitive to as little as 105 atoms/cm2 and can be extended to probe optical properties of topological defects at surfaces of other dissimilar materials. An important feature of this technique is that the excitation and desorption can be induced locally using NSOM or STM which provides a tool for the surface sculpturing. [1] W. P. Hess, A. G. Joly, P. V. Susko, A. L. Shluger, J. Chem. Phys., 115(20), 9463, (2001) [2] A. G. Joly, K. M. Beck, M. Henyk, W. P. Hess, P. V. Susko, A. L. Shluger, Surf. Sci., 544, L683, (2005) [3] K. M. Beck, N. F. Dupuis, P. Perozzo, W. P. Hess, P. V. Susko, A. L. Shluger, J. Chem. Phys., 121(24), (2004) [4] W. P. Hess, A. G. Joly, K. M. Beck, P. V. Susko, A. L. Shluger, Surf. Sci., (in press).

O14.5
Designing Resonance Modes of AFM Cantilevers and its Application for Probing of Electric Properties and Operation with Ultrasmall Oscillation Amplitude. Kenji Kimura1, Takahiro Furukawa1, Kei Kobayashi2, Hirofumi Yamada1,2 and Kazumi Matsushige1,2.

1Electronic Science Engineering, Kyoto Univ., Kyoto-shi, Japan; 2Information and Innovation Center, Kyoto University, Kyoto-shi, Japan. 3Core Research for Evolutional Science and Technology, Japan Science and Technology, Kyoto-shi.
In dynamic force microscopy (DFM), distance between the tip and the sample is regulated by maintaining its resonance frequency shift or its oscillation amplitude damping. Owing to a high Q-factor of a microfabricated cantilever, weak interaction forces can be easily detected thus atomic or molecular resolution images have been obtained. Moreover, various techniques for probing local electronic properties have been developed, such as Kelvin-probe force microscopy (KFM) and scanning capacitance force microscopy (SCFM) [1, 2], which has been derived from DFM. Sensitive and lateral resolution for those techniques can be improved by tuning the modulation frequency with a laser on an external harmonic oscillator (modulation frequency: fm) so that the probing frequency (fm for KFM and 3fm for SCFM) matches one of the mechanical resonance frequencies of the cantilever. In general, the first resonance frequency (f1) is utilized for regulating the sample distance in DFM. Thus the lowest available resonance frequency is the second resonance frequency (f2) unless a two-pass (lift) mode is employed. However, since f2 is 0.3 times higher than f1 for rectangular cantilevers, it often becomes higher than the bandwidth of the deflection sensing system utilized in DFM, which is typically less than 1 MHz. Furthermore, effective spring constants at those higher resonance frequencies become quite large and thus not ideal for detecting weak interaction forces. In other words, there is a fixed relationship between the resonance frequency and the effective spring constant for all resonance modes. In order to overcome such limitations, we have newly designed a novel cantilever structure whose resonance frequency and spring constant at the second resonance mode could be adjusted independently without above-mentioned restrictions. We fabricated one or multiple resonators inside or outside of the main cantilever beam using a focused ion beam milling instrument. We tailored the resonance frequencies and the effective spring constants as optimized by the finite element method calculation and successfully utilized the novel cantilever for KFM and SCFM. Furthermore, another cantilever design permitting higher resonance frequency of the main beam was introduced. We fabricated a resonator whose vibration amplitude is much larger than that of a tip on the main cantilever beam. The design helps DFM operation at a very small amplitude without sacrificing signal-to-noise ratio of the deflection signal detected on the resonator.

We report on a study of individual CdS nanoribbon field effect transistors fabricated on SiO$_2$/p-Si substrates by thermal chemical vapor deposition. The photocurrent from the aligned nanoribbons was measured using a conductive scanning probe tip and lock-in amplifier. The morphology of the sample was studied using scanning electron microscopy and atomic force microscopy. Both apertureless high-resolution NSOM and SECM were used for analysis. Near-field fluorescence image of the single ZnO nanowire will be presented. Spectroscopic information from the nanowires will also be presented.

O14.8 Study of Vertically Aligned Carbon Nanotubes by Atomic Force Microscopy and Transmission Electron Microscopy. Oksana Vasilievna Kharissova, Ubaldo Ortiz, Eduardo Perez Tijerina and Jesus Rangel Cardenas; 1FCFM, UANL, Monterrey, Mexico; 2FIME, UANL, Monterrey, Mexico.

Since their discovery, carbon nanotubes, both single-walled and multiwalled, have been a focus of materials research. Fundamental research and application hinges on high quality tube materials and controlled routes to their organization and assembly. The development of a highly efficient one-step technique was carried out to obtain long and aligned carbon nanotubes with or without Fe filling. The synthesis, characterization, and modification of individual molecules, one-dimensional (1D) crystals, have been investigated in several laboratories. The aligned carbon nanotubes (CNTs) were synthesized by microwave (MW) irradiation heating from a ferrocene. In this research, Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) are used for the study of growth of aligned carbon nanotubes by microwave heating. As a contribution of this method, the aligned multi-layer carbon nanotubes were obtained. CNTs have been the subject of intense research because of their potential to revolutionize the nanoscale electron devices. This carbon nanostructure promises to become important in fuel cells and in nanoscale engineering of other systems in which electrical, mechanical, and chemical interactions are integrated to produce nanoscale effects. The morphology of the carbon nanostructure has been studied by Scanning Electron Microscopy, Atomic Force Microscopy, and Transmission Electron Microscopy. Measurements of distinct angles, distances, and spaces between waves were made.


Samples of platinum nanoparticles exhibiting moderate polydispersion were studied by transmission electron microscopy (TEM) and atomic force microscopy (AFM), coupled with x-ray diffraction (XRD) and extended x-ray absorption fine structure (EXAFS). While TEM and AFM provided a size distribution for each sample (diameter analysis), and EXAFS (using a homogeneous spherical model) were used to determine a mean particle size. Since XRD is weighted by the square of the volume and EXAFS by less than the volume, XRD is expected to generally yield a larger mean value than EXAFS. TEM and AFM are expected to yield the highest precision. The focus of this study is TEM and AFM (non-contact and contact) imaging of nanoparticle dispersions and the potential impact of specimen preparation on the size distributions measured by these imaging techniques. The TEM and AFM data collected revealed distributions that were compared with the results of XRD and EXAFS experiments. In this way, the relative merits of XRD and EXAFS for providing estimates of particle size were evaluated while the potential impact of sample preparation on TEM and AFM data collection was determined.

O14.10 Photoresponse of a Single CdS Nanoribbon Device. An Jiu, Chen Jian, Xue Kun, Li Quan and Xu Jianbin; 1Department of Electronic Engineering and Material Science and Technology Research Center, The Chinese University of Hong Kong, Shatin, NT, Hong Kong SAR, China; 2Department of Physics and Material Science and Technology Research Center, The Chinese University of Hong Kong, Shatin, NT, Hong Kong SAR, China.

We report on a study of individual CdS nanoribbon field effect transistors (FET) fabricated on SiO$_2$/p-Si substrates. The CdS nanoribbon devices have exhibited n-channel normal-on FET characteristics. The field effect mobility is around 50 cm$^2$/V s, the threshold voltage -27 V, and the on/off current ratio of 0.1 respectively. The photoresponse properties of CdS nanoribbons have been studied. The magnitude of photocurrent is found to increase linearly with the low light intensity, and saturate with the high light intensity.
intensity. The on-off ratio is as high as 105. Also it is observed that the photocurrent depends on the light polarization, which is attributed to the crystal orientation of CdS, not to the quantum confinement effect widely found in carbon nanotubes and some nanowires. From the photocurrent of CdS versus light wavelength, it is shown that the CdS nanoribbons have a significant photoresponse below 520 nm, with a fast photoreponse and decent stability. Scanning probe microscopy has been employed to study the contact potentials between n-Cds nanoribbons with different metals. The surface potential (SP) difference at CdS/Au and CdS/Al interfaces have been correlated with the potential signal of scanning Kelvin probe microscopy. It is found that the Au/CdS contact forms a larger barrier height than that of the CdS/Al, which is consistent with the characteristics. Under illumination, it is found that the surface potential signal increases with the light intensity, it can be ascribed to the surface photo voltage effect.

O14.11 Structure, Growth Behavior and Electric Transport Property of ZnSe Nanowires. Ning Yang, W. Y. Cai, S. K. Chan, Y. F. Chan and I. K. Sou; Physics Department, The Hong Kong University of Science & Technology, Hong Kong, Hong Kong.

Single crystalline ZnSe nanowires with uniform diameters (about 10nm) have been grown based on Au-catalyzed vapor-liquid-solid reaction by molecular beam epitaxy [1]. As determined by electron diffraction and high-resolution transmission electron microscopy (HRTEM), these nanowires grew epitaxially on GaP or GaAs substrates. We have observed that the diameters of the pre-formed nanowires to be dried, fixed, coated, and laboriously prepared for stability. Scanning probe microscopy has been employed to study the earlier growth stage, the nano catalysts in the form of Au-Ga alloy. The contact properties between n-CdS nanoribbons with different metals cannot be obtained via other imaging techniques. Here we describe the growth behavior and electrical transport properties of individual ZnSe nanowires. Using atomic force microscopy, the inherent complexities of virus particles in real time. Furthermore, during the preparation of the samples, the sample integrity may be compromised and their use in imaging of dynamic processes can be very limited. Atomic force microscopy not only allows for investigation of real-time imaging of virus particles but also give information on the topological and mechanistic-elastic features of the particles in three-dimensions which cannot be obtained by other imaging techniques. Here we describe the use of atomic force microscopy for imaging and characterization of the vaccinia virus particles in their native and non-native states. Vaccinia virus, a close relative to the smallpox virus, is one of the largest and complex viruses. The virus particles are made of a symmetric icosahedral or helical capsid. The virus has thiol group and biotin at either end which is used to measure the absorption of the samples. The inherent complexities of virus particles but also give information on the topological and mechanistic-elastic features of the samples. The virus particles are sampled and measured by force microscopy and atomic force microscopy. The virus particles are sampled and measured by force microscopy and atomic force microscopy.

O14.12 Abstract Withdrawn

O14.13 TRANSFERRED TO O2.5

Atomic Force Microscopy Imaging of Viruses. Azam Ghafour, Demir Akin, Amit Gupta and Rashid Bashir; Biomedical Engineering, Purdue University, West Lafayette, Indiana.

Imaging of virus particles are customarily done by scanning or transmission electron microscopy; however, these methods require the samples to be dried, fixed, coated, and laboriously prepared for imaging. These methods are incompatible with processing and analysis of virus particles in real time. Furthermore, during the preparation of the samples, the sample integrity may be compromised and their use in imaging dynamic changes can be very limited. Atomic force microscopy not only allows for investigation of real-time imaging of virus particles but also give information on the topological and mechanistic-elastic features of the particles in three-dimensions which cannot be obtained by other imaging techniques. Here we describe the use of atomic force microscopy for imaging and characterization of the vaccinia virus particles in their native and non-native states. Vaccinia virus, a close relative to the smallpox virus, is one of the largest and complex viruses. The virus particles are made of a symmetric icosahedral or helical capsid. The virus has thiol group and biotin at either end which is used to measure the absorption of the samples. The inherent complexities of virus particles but also give information on the topological and mechanistic-elastic features of the samples. The virus particles are sampled and measured by force microscopy and atomic force microscopy. The virus particles are sampled and measured by force microscopy and atomic force microscopy.


We report variable photon energy photoelectron emission microscopy (PEEM) observation of polarity contrast and measurement of the photo-threshold from polarity-patterned epitaxial GaN films and ferroelectric LiNbO3 (LNO) single crystals and PbZrTiO3 (PZT) thin films. The PEEM is an imaging technique that employs a femtosecond tunable optical laser to generate the photo-electrons from the sample. To find out the effect of junction resistance between biomolecule such as DNA and inorganic substrate for studying the transport property, we used local probe microscopy with different linker molecules. Gold dots deposited on the silicon substrate and lambda phage DNA that has thiol group and biotin at either end were prepared for the experiment. Electrical property according to the linker molecule and substrate combination is characterized. We also present the electrical properties of DNA imaged and analyzed by electrostatic force microscopy.

O14.15 Evanescent Wave Microscopy for Proteomics. Mesut Eraslan2, Bennett Goldberg1,2, M. K. Hong1, Xiuha Wang1 and Shyamsunder Erramilli1, 1Physics Department & Center for Photonics, Boston University, Boston, Massachusetts; 2Department of Electrical & Computer Engineering, Boston University, Boston, Massachusetts.

Infrared spectroscopy is a sensitive method for detection of proteins. Most biomolecules have characteristic normal modes of vibration that are infrared-active. The presence of protein molecules in solution can be inferred by measuring this intrinsic infrared absorption, with the amide I absorption band near 1660 cm\(^{-1}\) having the largest cross-section. Because IR absorption does not involve the use of perturbative stains or labels, its application to the newly emerging field of proteomics is promising. Several factors limit the use of IR absorption from the amide I band, such as the high absorption of infrared radiation due to liquid water, and the large wavelengths of CD spectroscopy increase with the light intensity, it can be ascribed to the surface photo voltage effect.

O14.16 Transport properties of DNA with respect to the linker molecules by Scanning Probe Microscopy. Jeong min Son1, Nam ju Lee1, Yong Sang Kim1, Ji Chung Kang2 and D. Jeong2; 1Physics, Meiji University, Yonin, Kawasaki, Japan; 2Materials Science and Engineering, Seoul National University, Seoul, South Korea; 3Electric Engineering, Myongji University, Yongin, South Korea.

To find out the effect of junction resistance between biomolecule such as DNA and inorganic substrate for studying the transport property, we used local probe microscopy with different linker molecules. Gold dots deposited on the silicon substrate and lambda phage DNA that has thiol group and biotin at either end were prepared for the experiment. Electrical property according to the linker molecule and substrate combination is characterized. We also present the local electrical properties of DNA imaged and analyzed by electrostatic force microscopy.
6.2 eV at the positive domain, while for PZT, the threshold of the negative domain was less than 4.3 eV. The PEEM polarity contrast is discussed in terms of the internal screening from free carriers and defects and the external screening due to absorbed ions.

O14.18 Abstract Withdrawn

SESSION O15: Dynamic Phenomena in Soft Condensed Matter

Chair: Sergei Kalinin
Friday Morning, December 3, 2004
Commonwealth (Sheraton)

8:30 AM *O15.1
Charge Transport in Alkanethiols and OPEs Probed by STM. James Battles, Carlos Gonzalez and Yamil Simon-Manso; NIST, Gaithersburg, Maryland.

A significant challenge exists in understanding and predicting electron transport in metal-molecule-metal junctions important in molecular based electronic and optical systems. As the electrical behavior of molecules depends on their chemistry and organization at metal contacts, we have carried out a series of STM experiments on alkanethiols with varying molecular orientations, as well as molecular wires of unsubstituted & fluoro-substituted oligo-phenylene-ethynylene (OPE) compounds. The adsorption of alkanethiols on Au results in domains of several architectures, ranging from molecules in closed packed structures covalently linked through the formation of a thiolate Au surface bond with the molecular axis nearly perpendicular to the surface, to lower density phases with the molecular axis parallel to the surface. As alkanethiols are frequently employed as test cases for conductance in metal-molecule-metal junctions, one may envision that a distribution of orientations may exist in many such studies. Here we have employed STM to investigate the transport properties of several phases of dodecanethiol on Au. For domains with the molecules chemisorbed to the surface with the molecular axis oriented relatively perpendicular to the surface, significant asymmetry is observed in the I-V spectra between the positive and negative bias regions of the I-V curve which can be associated with the differences in the metal-molecule-metal contact configuration. For physisorbed molecular domains with the molecules laying flat on the surface, a near symmetric tunnel junctions are formed resulting in nearly symmetric I-V curves. STM investigations of unsubstituted and fluorinated alkoxy-phenylene-ethynylene (OPE) compounds find that within the addition of the F group to the molecule results in an increased rectifying behavior as compared to the unsubstituted system. In conjunction with the STM measurements of the OPEs, conductance of the molecule-metal junctions based on Density Functional Theory calculations of modified quasi-molecular Green functions in a capacitor-like electric field have also been employed to compare the effects of orientation on the transport properties, with excellent agreement between theory and experiment.

9:00 AM O15.2
Scanning Probe Recognition Microscopy Investigation of Elastic Properties of Tissue Scaffolding, Q. Chen1, Y. Fan1, V. M. Ayres1, L. Udpa1, M.S. Schindler1 and A.F. Rice2; 1Michigan State University, East Lansing, Michigan; 2Veeco Metrology Group, Santa Barbara, California.

Scanning probe recognition microscopy is a new scanning probe capability under development within our group to reliably return to and directly interact with a specific nanoscale feature of interest, without the use of a zoom box with its thermal drift and local origin difficulty. A scanning probe recognition approach is possible through combining SPM piezoelectric implementation with on-line image processing and dynamically adaptive learning algorithms. Segmentation plus a recognized pattern is implemented within a scan plan and used to guide the tip in a recognition-driven return to a specific site. The specific application focus of our group is on the development of Scanning probe recognition microscopy for nanobiological investigations and we will present our results within this context. In previous work, we have successfully recognized and classified tubular versus biological objects from experimental AFM images using a method based on normalized central moments. We have also extended this work to include recognition schemes appropriate for more subtle differences between biological objects of similar globular shape by adding the Continuous Wavelet Transform (CWT) with a differential Gaussian mother wavelet. Normalized central moments are translation, rotation and scale invariant, and the 2-D continuous wavelet transform allows multi-scale analysis of images. Thus, these two methods together can be applied to analyze biological objects of any scale. In the present work, scanning probe recognition microscopy is used in a direct investigation of the surface and elastic properties along individual tubules within a tissue scaffold matrix. Elastic properties are indicated as important in the transport and cell mechanics of extension/contraction and adhesion. I. Qian Chen, Virginia Ayres, and Lalita Udpa, Biological Investigation Using Scanning Probe Recognition Microscopy, Proceedings of the 3rd IEEE Conference on Nonlinear Optics (IEEE-NAO 2003), Vol. 2, pp. 863-865 (2003) 2: B. Godsy, Q. Chen, L. Udpa, Y. Fan, R. Sammon, B. Bhoorwan, F. M. Salam, D. H. Wang, and V. M. Ayres, Scanning Probe Microscopy with Landmark Referenced Control For Direct Biological Investigations, J. Nanosci. Nanotech., Vol. 3, No. 4, PP 347-350 (2003).

09:30 AM O15.4

Quantum and size effects in nanomaterials may lead to significant enhancements of their thermoelectric energy conversion efficiency. Hence, techniques able to perform fast and reliable local measurements of electrical conductivity, Seebeck coefficient, and thermal conductivity are of high interest. However, exploring the characteristic of thermoelectric transport properties in nanoscale samples is a challenging task, due to difficulties such as contact resistance and the measurement of the local temperature and heat flow to the sample. This work reports a new technique for measurement of thermoelectric properties of nanomaterials by combining SPM and thermoelectric measurements of electrical conductivity, Seebeck coefficient, and thermal conductivity in a metal−insulator−metal junction. The method was tested on bulk and nanomaterial B2Te3 films deposited on glass substrates.

09:45 AM O15.5
Effects of Surface Functionality and Humidity on the Adhesion Force and Chemical Contrast Measured with AFM. Tinh Nguyen, Xiaohong Gu, Lijing Chen, Michael Pasolakis, Kim Bohnett, Juseong Hwang and Jon Martin; NIST, Gaithersburg, Maryland.

Mapping chemical heterogeneity of surfaces at the nanoscale spatial resolution is the subject of great interest in materials science and technologies. We have demonstrated previously that by using a combination of hydrophilic AFM probes and manipulating the relative humidity (RH) of the tip-sample environment in an AFM, hydrophilic/hydrophobic regions in model self-assembled monolayer...
(SAM) and polymer samples can be readily imaged. This study investigated the effects of environmental relative humidity and surface functionality on the tip-sample adhesion force and chemical contrast of gradient SAMs. Samples of chemically-homogeneous SAMs having CH₃, OH, NH₂ or COOH surface terminated groups prepared by thiol chemistry and hydrophilic/hydrophobic gradient SAMs fabricated by silanization followed by UV/Ozone treatment were employed. CH₃, COOH, and OH terminated AFM tips were used as the probes. The chemical specificity of both the samples and AFM tips were characterized by a variety of spectroscopic techniques. A humidity generator connected to a specially-designed humidity chamber fitted to an AFM is employed to provide highly controlled tip-sample RH between 0 and 95%. For all tip-sample combinations, the AFM image contrast between the hydrophilic and hydrophobic regions is poor (non-distinguishable) when the tip-sample RH is below 50%. With the hydrophilic tips, the chemical image contrast increases markedly with RH > 50%. At high RH levels, even chemical domains that have small difference in the polar surface energy component can be still detected. Further, except for the hydrophobic tip where RH has little effect, other tip-sample adhesion forces show a maximum between 50 and 70% RH. Mechanism for the enhanced chemical contrast and tip-sample adhesion force in elevated humidities will be discussed.

**10:30 AM Q15.5**

**Kinetic Studies of Molecular Motion via Nanoshear: Issues of Surface, Bulk and Perturbation.** Greg Haugstad, Ronald Schmidt, Craig Dystra and Wayne Gladfelter; University of Minnesota, Minneapolis, Minnesota.

The temperature and rate dependence of shear response on polymers, under constant-velocity sliding or small-amplitude harmonic drive, has been examined by several groups within the past several years using AFM methods. The "local" aspect of these measurements has regarded mainly the vertical rather than lateral dimension, interrogating near-surface response and contrasting with bulk response from conventional, macroscale methods. Interpretations often have assumed that the probe is sensing intrinsic "surface" dynamics; results then have been compared with conventional bulk characterization to conclude that the surface differs, or does not differ, from the bulk. In view of conflicting findings as briefly reviewed here, it is clear that determining the extent to which surface or bulk response is probed must be a focus of any AFM-based investigation. Moreover, the degree to which this response is altered by the tip interaction must be examined. We present several findings from the authors and other groups that have examined this "perturbation" question, wherein the effects of load as well as tribological heating and memory were systematically characterized. Our findings demonstrate that both sliding friction and small-amplitude harmonic shear modulation on polystyrene are inherently perturbative, mobilizing conformers in the former and penetrating to considerable depth in the latter. Based on these and other observations we suggest that AFM studies should not claim to measure intrinsic surface mobility on polymers without careful analyses of perturbation and depth penetration. This should include the presentation of images of the affected region following measurement procedures. We conclude that whereas AFM is a uniquely powerful probe to study the fundamentals of tribology, it is a problematic tool to study intrinsic surface dynamics.

**10:45 AM Q15.7**

**Micro-TA - An Analytical Tool in Materials Science.**


The new analytical technique micro-thermal analysis (m-TA) will be introduced and evaluated. It combines the visualization power of atomic force microscopy (AFM) and its ability to image topography, phase shifts, friction, stiffness, and adhesion with the characterization capabilities of thermal analysis (thermal conductivity, micro-differential thermal analysis and micro-thermo mechanical analysis) resulting in a characterization of surfaces with respect to their thermal and thermo-mechanical properties. The scanning mode may be used for the inspection of surfaces with respect to their thermal properties using a scanner with an active thermal sensor (heater, height and thermal sensor) as probe (tip), simultaneously acquiring topography, thermal conductivity and thermal diffusivity images. A second mode gives the option to perform a local thermo-mechanical analysis of discrete areas of a few square microns (L-TMA and L-CA), and detects at the same time during heating in contact mode changes of the sensor position and the heat flow to the sample in a very short time. Any thermodynamic phase transition, connected with a change in mechanical properties (softening, expansion, melting) and thermal properties (heat of fusion, change of heat capacity) will thus be detected by both methods. Therefore, such experiments surpass mere topographical mapping (commonly used in AFM imaging) because heat flow differences can be correlated to differences in chemical or physical structure. Applications for the analysis of many different types of materials including hard inorganic coatings and bulk materials, microelectronic circuits, organic coatings and bulk materials as well as of soft materials are presented and critically discussed. An application of the technique as a tool for high-throughput analysis seems possible. Moreover, the use of the instrument for controlled surface treatment and patterning is demonstrated with different samples. This may be used for data storage as well as for the creation of super smooth polymeric surfaces. Also attempts to determine thermal conductivities on surfaces on a quantitative matter will be presented and discussed.