Tuesday Afternoon, November 1, 2011

Nanometer-scale Science and Technology Division
Room: 203 - Session NS+AS-TuA

Frontiers in Nanoscale Imaging and Characterization

Moderator: E.I. Altman, Yale University

2:00pm **NS+AS-TuA1 Proximity, Phonon in Nanometer Size Superconducting Nb Islands : A STM Study**, ***S. Jeon***, Seoul National University, Republic of Korea, *H. Suh*, Samsung Advanced Institute of Technology, Republic of Korea, *Y. Oh, S. Kim, Y. Kuk*, Seoul National University, Republic of Korea, *M. Machida*, Japan Atomic Energy Agency, Japan

Despite successful macroscopic picture on a conventional superconductor niobium(Nb), not much were reported on nanometer scale objects. One may have to consider quantum mechanical size effect, fluctuation, and quantum phase slip in a nanometer scale superconducting object. In this study, quantum size effect of superconducting niobium(Nb) nano-islands grown on a tungsten(W) surface was investigated with scanning tunneling microscopy(STM) and scanning tunneling spectroscopy(STS). Various size (30nm ~ 200nm) of niobium islands were formed on a W(110) surface after making several layers of wetting layer. STS measurement at 4.2K showed that the Nb island have a BCS-like superconducting gap of about 2meV around the Fermi level. The critical temperature is much lower than that of the bulk value. In addition, We found spatial dispersion of DOS (density of states) outside of the superconducting gap. Spatially-resolved scanning tunneling spectroscopy(SR-STS) data taken inside and outside of the niobium islands reveal unique dispersion. That can be understood by quantum size effect based on Bogoliubov - de Gennes equation.

2:20pm **NS+AS-TuA2 Spin Excitation Spectroscopy**, ***D. Eigler***, IBM Almaden Research Center **INVITED**

The energies and relaxation times of spin excitations are traditionally measured using the classic spin resonance techniques, Nuclear Magnetic Resonance (NMR) or Electron Spin Resonance (ESR). The measurement of spatial variations of spin relaxation times is of profound practical importance as they are often used as the primary contrast mechanism in magnetic resonance imaging. It has been an outstanding challenge to extend the spatial resolution of these spectroscopies to the atomic scale. We have developed a new kind of spin spectroscopy, *Spin Excitation Spectroscopy*, that achieves this goal. Through a combination of inelastic tunneling spectroscopy and pump-probe techniques, we have extended the capability of the scanning tunneling microscope to interrogate both the energetics and dynamics of spin systems on the atomic scale. We anticipate that this will have application in a broad range of studies concerned with nanometer-scale magnetic systems, how they may be understood, and how they may be engineered to have a desired functionality.

Work done in collaboration with Cyrus Hirjibehedin, Andreas Heinrich, Christopher Lutz, Jay Gupta, Markus Ternes, Alexander Otte, Sebastian Loth and Bruce Melior

3:00pm **NS+AS-TuA4 Atom-Specific Interaction Quantification and Identification by Combined Scanning Tunneling and Atomic Force Microscopy**, ***M.Z. Baykara***, *H. Mönig*, Yale University, *T.C. Schwendemann*, Southern Connecticut State University, *M. Todorovic, R. Perez*, Universidad Autónoma de Madrid, Spain, *E.I. Altman, U.D. Schwarz*, Yale University

On surfaces, forces extending into the vacuum direct the behavior of many scientifically and technologically important phenomena such as corrosion, adhesion, thin film growth, nanotribology, and surface catalysis. To advance our knowledge of the fundamentals governing these subjects, it would be desirable to simultaneously determine a surface's structure, map electron densities, quantify force interactions, and identify chemical species. For example, in the case of a catalytically active surface, this would allow study of the role and effectiveness of surface defects such as vacancies, steps, kinks, impurities, and domain boundaries as active sites.

In this talk, we will show with the example of an oxygen/copper(100) surface phase that much of this information can be derived from combining the new method of three-dimensional atomic force microscopy (3D-AFM) [1,2], a variant of noncontact atomic force microscopy, with simultaneous scanning tunneling microscopy. The surface oxide layer of Cu(100) features domain boundaries and a distinct structure of the Cu and O sublattices that is ideally suited for such model investigations. By combining experimental results with theoretical simulations, we will show how 3D data sets enable the site-specific quantification of force interactions and tunneling currents, how different chemical species can be imaged using different tips, different tunneling conditions, and different interaction mechanisms, and how structure-induced stress fields and their influence on the local chemical activity and topographical deformation can be studied.

[1] B. J. Albers et al., Nature Nanotechnology **4**, 307 (2009).

[2] M. Z. Baykara et al., Advanced Materials **22**, 2838 (2010).

4:00pm **NS+AS-TuA7 The Role of Surface States in Inelastic Electron Tunneling Into Metal Surfaces**, ***P. Maksymovych***, *M.H. Pan, Q. Li*, Oak Ridge National Laboratory

A small fraction of electrons tunneling across a vacuum junction will undergo inelastic scattering, exciting surface phonons, molecular vibrations, magnons and plasmons in the contact leads. Although the study of surface phonons is a most straightforward inelastic electron tunneling spectroscopy (IETS) experiment, relatively few systematic studies have been done to date. One of the most surprising observations was that of atomic resolution in the IETS of Au(111) [1], and an equally intriguing variation phonon energy from 20 meV to 9 meV depending on the vertical stacking across the $22\times\sqrt{3}$ reconstructed surface.

To investigate the origin of these effects on Au(111), we have carried out systematic IETS measurements using a home-built scanning tunneling microscope operating in the temperature range from 20K to 77 K. Particular emphasis was put on understanding of the role of the surface state in the electron-phonon coupling, judged from the intensity of the IETS signal and the energy of the observed vibrational modes.

We have found that largely independent of the measurement temperature, IETS spectra feature a broad peak centered around 18 meV, representing a weighted average of the phonon density of states within the Brillouin zone. Lower lying surface phonon bands (with energies from 7 to 9 meV) were resolved, but the majority of spectra are dominated by the peak at 18 meV. corresponding to the bulk phonon modes at the zone boundary. Although the spectrum remained largely unchanged across the surface, in contrast to earlier observations, the IETS intensity markedly dropped at the step edges. Furthermore, the IETS intensity exhibited long-range oscillations, the wavelength of which coincided with the Friedel oscillations of the surface state in the vicinity of the defects. Combined, the observations attest to the important role of the surface state in electron-phonon coupling [2], likely emphasizing the critical enhancement in the lifetime of hot electrons that tunnel into surface states relative to bulk states. We will also discuss the important role of tip effects in the IETS measurement. Tip-sensitivity may produce significant variations in the IETS spectrum across the herringbone reconstruction because of selectivity toward a particular phonon mode due to the convolution of the tip-surface interactions and heterogeneity of the surface state across the surface.

Research was conducted at the Center for Nanophase Materials Sciences and sponsored by the Division of Scientific User Facilities, U.S. Department of Energy.

[1] H. Gawronski, M. Mehlhorn, K. Morgenstern, Science 319 (2008) 930-933.

[2] Q. Li, P. Maksymovych, M. Pan et al, to be submitted (2011)

4:20pm **NS+AS-TuA8 2011 AVS Medard Welch Award Lecture - Inelastic Electron Tunneling Spectroscopy and Imaging of Single Molecules**, ***W. Ho****, University of California, Irvine **INVITED**

The transformation of matter invariably involves energy transfer and redistribution. By probing matter and its coupling to external perturbations at the atomic scale with the scanning tunneling microscope (STM), it is possible to gain a broad range of new knowledge that would be difficult to achieve by other techniques. Through high precision measurements of inelastic phenomena inside single molecules with the STM, chemical and physical properties of molecules are obtained by probing their response to electrons, photons, and an external magnetic field. The STM is used to measure the electronic and vibronic states, vibrational and spin excitations, and optical transitions in single molecules. New features emerge when measurements are carried out at increasingly extreme conditions of vacuum, temperature, magnetic field, and pulse duration of light while maintaining the atomic-scale spatial resolution. The inelastic processes can result in nuclear motions such as molecular rotation, diffusion, conformational change, bond dissociation, and bond formation. By studying a wide range of systems from atomic hydrogen to large molecules such as metal porphyrins

***** Medard W. Welch Award Winner

and phthalocyanines on metal and thin oxide surfaces, the new knowledge obtained by the STM can be applied to the understanding and advancement of numerous technologies such as chemical catalysis, information storage, nanophotonics, alternative energies, and environmental remediation. Underlying these longer range applications is the immediate gain in the fundamental scientific understanding of matter that can be derived from these studies.

5:00pm **NS+AS-TuA10 Two-Color Ultrafast-Laser-Assisted STM**, *A. Dolocan, D. Acharya, P. Zahl, P. Sutter,* ***N. Camillone***, Brookhaven National Laboratory

Substrate–adsorbate charge transfer and carrier-mediated substrate–adsorbate energy transfer are central to photoinduced surface chemistry. To investigate fundamental links between surface electron dynamics and heterogeneous photocatalysis we are developing an ultrafast-laser-excited scanning tunneling microscopy approach to probing surface electron dynamics with simultaneous subnanometer spatial and subpicosecond temporal resolution. Historically, thermal effects associated with laser power variations have presented a major hurdle to progress. In particular, thermal load modulations due to optical interference have been a barrier to observing dynamics at timescales on the order of the temporal width of the laser pulses. In this talk we present results from a new two-color method that completely eliminates this interference. We will show results for two cases: (1) where the tip is retracted from the surface far enough to prohibit tunneling, and (2) where the tip is within tunneling range of the surface. A delay-modulation technique isolates the two-color photo-emission from concurrent one-color two-photon photoemission and the conventional tunneling current, and also enables subpicosecond time-resolved detection of the photoexcited surface electrons. Advantages of the two-color approach are highlighted by comparison with the one-color case where optical interference causes current modulations that are orders of magnitude larger than the desired signal. The two-color approach represents an important step toward the ultimate goal of simultaneous subnanometer and subpicosecond measurement of surface electron dynamics.

5:20pm **NS+AS-TuA11 High Precision local electrical Probing: A New Low Temperature 4-Tip STM with Gemini UHV-SEM Navigation**, *B. Guenther,* ***A. Bettac****, M. Maier, M. Oertel,* Omicron NanoTechnology, Germany*, F. Matthes, C.M. Schneider,* Forschungszentrum Juelich, Germany, *A. Feltz*, Omicron NanoTechnology, Germany

A major challenge in the development of novel devices in nano- and molecular electronics is their interconnection with larger scale electrical circuits required to control and characterize their functional properties. Local electrical probing by multiple probes with STM precision can significantly improve efficiency in analyzing individual nano-electronic devices without the need of a full electrical integration. Among a very few commercial approaches, the Omicron *UHV NANOPROBE* has been established as a suitable instrument for local electrical probing in UHV on nano-structures down to structure sizes in the 10 nm range. The mayor technical requirements for such sophisticated instrumentation are:

· Rapid and simultaneous SEM navigation of four local STM probes on small structures

· Localization of nanostructures by high resolution SEM (UHV Gemini)

· Individual probe fine positioning by atomic scale STM imaging

· STM based probe approach for "soft-landing" of sharp and fragile probes and controlled electrical contact for transport measurements

· Preparation techniques towards sharp and clean and STM tips

· Suitable low noise signal re-routing for transport measurements with third party electronics

Although the *UHV NANOPROBE* has been successfully used for various applications, today´s scientific requirements motivated the development of the next generation probing system. We will present the newly developed *LT NANOPROBE* which takes experimental capabilities one step further and opens up new research opportunities in nano-electronics, spintronics, and molecular electronics. Besides SEM/STM probe fine navigation and imaging, the excellent STM performance level of the LT NANOPROBE expands applications to tunneling spectroscopy and even the creation or modification of nano-structures by an ultimately precise STM probe. The R&D project has been driven by the following major milestones:

· Operation at temperatures of T<5 K for STM imaging and STM based probing

· SEM navigation at base temperature T<5 K

· Simultaneous operation of STM and SEM at base temperature

· Thermal equilibrium of sample and probes for (i) extremely low thermal drift and electrode positioning accuracy in time and (ii) defined temperature of the local electrical contact and

· Performance and stability level of each individual STM Probe suitable for STM spectroscopy and atom manipulation

First evaluation measurements with the system installed at the Forschungszentrum Jülich will be presented: STM on Au(111) with pm stability, STS revealing the superconducting gap of a Nb tip with approx. 3meV gap size, and transport measurements on nanowires at T<5K.

5:40pm **NS+AS-TuA12 Spin-Polarized VLEED: Experimental Access to the Spin-Dependent Surface Barrier**, ***K. Wulff****, A.B. Schmidt,* Westfälische Wilhelms-Universität Münster, Germany*, J. Braun,* Ludwig-Maximilians-Universität München, Germany*, M. Donath*, Westfälische Wilhelms-Universität Münster, Germany

The spin-dependent reflectivity of very-low-energy electrons from ferromagnetic surfaces has recently been utilized in a new type of electron spin detector [1,2]. The underlying effect is a result of electron scattering from a spin-dependent substrate potential as well as from a spin-dependent surface-potential barrier.

We present the first spin-polarized very-low-energy electron-diffraction (SPVLEED) measurements on a ferromagnetic system. Our data on Co/Cu(001) reveal a significant spin dependence of the reflected intensities that varies strongly with electron energy, polar and azimuth angle of incidence.

In these intensity vs. energy spectra *I(V)*, additionally, fine structures appear [3], which are caused by the surface-potential barrier. Their particular intensities and energy positions are very sensitive to the shape of the surface-potential barrier. On the vacuum side far from the surface, the barrier resembles the well-known Coulomb potential, while, on the crystal side, it converges to the inner potential. In theoretical calculations, the transition region is usually described by a parameterized phenomenological model. Our experiment provides access to exactly this transition region.

We could determine the spin-dependent shape of the surface-potential barrier of Co/Cu(001) from the dispersion of the fine structure as a function of polar and azimuth angle.

[1] T. Okuda *et al.*, Rev. Sci. Instrum. **79** (2008) 123117 ; [2] A. Winkelmann *et al.*, Rev. Sci. Instrum. **79** (2008) 083303 ; [3] R.O. Jones, P.J. Jennings, Surf. Sci. Reports **9**, 165 (1988)

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