## Nanometer-scale Science and Technology
## Room 213D - Session NS-WeA

### Nanotribology and Nanomechanics

**Moderator:** R.W. Carpick, University of Wisconsin-Madison

2:40pm **NS-WeA3 Qcm-Stm Study of the Nanotribology of Metal-Organic Interfaces***, **S.M. Lee**, M. Abdelmaksoud, J. Krim,* North Carolina State University

Energy transfer plays an important role in many surface processes such as surface diffusion, vibrational relaxation and sliding friction in adsorbed molecules.[1] The Quartz Crystal Microbalance has in recent years been employed to reveal much fundamental information on energy dissipation mechanisms associated with the sliding of atomically thin films along surfaces. While in quantitative agreement with theory and computer simulation, the QCM data have not been cross-referenced to scanning probe measurements of sliding friction and diffusive behavior of atoms along surfaces. We have thus combined a Scannning Tunneling Microscope and QCM to allow direct imaging of films adsorbed on the QCM electrode under both stationary and oscillating conditions.[2] In this study, the nano-scale frictional behavior of copper and nickel surfaces covered by various organic adsorbates (ethylene, iodobenzene, and etc.) was studied by means of STM-QCM. During the STM tip indentation, the changes in resonance frequency and amplitude of the quartz crystal were monitored simultaneously , to explore energy storage or loss mechanisms, as well as tribochemical effects, associated with tip-substrate interactions. The dependence of the frequency and the amplitude changes of each interface will be reported and interpreted in terms of the adsorbate-substrate chemical and physical interactions. Work supported by DOE, AFOSR and NSF. Reference: [1] J. Krim, Surf. Sci. 500, 741 (2002) [2] B. Borovsky, B. L. Mason, and J. Krim, J. Appl. Phys. 88, 4017 (2000).

3:00pm **NS-WeA4 Measurement of the Mechanical Adhesion between a Single-Walled Carbon Nanotube and a Silicon Dioxide Substrate***, **J. Whittaker**,* Brigham Young University*; E. Minot,* Cornell University*; D. Tanenbaum,* Pomona College*; P. McEuen,* Cornell University*; R.C. Davis,* Brigham Young University

Nanotubes were grown over a lithographically defined set of trenches, 60 nm deep and 300 nm wide on a pitch of 500 nm. After finding a nanotube that crossed three or more trenches, we used an atomic force microscope (AFM) to measure the amount of force required to make a single-walled carbon nanotube slip along the silicon dioxide trench tops. This measurement was made by pushing down on the tube with the AFM probe until slip was observed in the force-distance curve. The amount of slack in the slipped tube was also measured by looking at neighboring trenches, giving a force per unit length result.

3:20pm **NS-WeA5 Structural, Electronic and Frictional Properties of Gold Nanoclusters in Decane under Constrained Geometries***, **S.H. Kim**, F. Ogletree,* Lawrence Berkeley National Laboratory, University of California, Berkeley*; S. Hwang, Y.-S. Shon,* Western Kentucky University*; M. Salmeron,* Lawrence Berkeley National Laboratory, University of California, Berkeley

We investigated the behavior of gold nanoclusters suspended in decane (C@sub 10@H@sub 22@) when confined in narrow gaps of a few nanometers. The gaps are made by two parallel and atomically smooth mica surfaces in the Surface Force Apparatus (SFA). The diameter of the nanoclusters ranges from 1.8 to 3.2 nm. They are capped with alkanethiolate ligands of different lengths (C@sub 6@S or C@sub 15@S) to prevent metallic contact. Layering transitions of at least 3 layers are observed, indicating that the nanoclusters form ordered layers in the confined geometry. The mechanical and tribological properties (compressibility, shear resistance), and the dielectric properties of these clusters show remarkable variations with size, ligand length and confining pressure.

3:40pm **NS-WeA6 Nanoporous Au: Surface Characterization and Mechanical Properties***, **J. Biener**, A.M. Hodge, K.J.J. Wu, L.L. Hsiung,* Lawrence Livermore National Laboratory

Nanoporous Au prepared by electrochemically-driven dealloying of Ag-Au alloys has attracted considerable interest due to potential sensor and actuator applications. These materials exhibit an open sponge-like structure of interconnecting ligaments with an unimodal pore size distribution on the nanometer length scale. Due to a high surface-area to volume ratio, the properties of nanoporous materials should be influenced strongly by their surface properties. However, little is known about the surface chemistry of these materials. Here we will present our recent results regarding surface characterization and nanomechanical properties of nanoporous Au with a nominal relative density of ~30%. Time-of flight secondary ion mass spectroscopy (TOF-SIMS) was employed to obtain high-resolution, mass-resolved images of as-prepared Au foam surfaces. Our studies reveal the presence of adsorbed species such as chloride and nitrate from the dealloying process. It is well known from single crystal experiments that these species strongly interact with the Au surface, e.g. chlorine lifts the herringbone reconstruction on Au(111). This example demonstrates the necessity of surface science studies to better understand the properties of these nanoscale materials. The mechanical properties such as modulus and hardness of nanoporous gold were studied by nanoindentation combined with scanning electron microscope (SEM) characterization. This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

4:00pm **NS-WeA7 Nanotribological Properties of Ultrananocrystalline Diamond***, **D.S. Grierson**, A.V. Sumant,* University of Wisconsin-Madison*; J.E. Gerbi,* Argonne National Laboratory*; J.P. Birrell,* Argonne National Laboratory, U.S.*; J.A. Carlisle, O.H. Auciello,* Argonne National Laboratory*; R.W. Carpick,* University of Wisconsin-Madison

The development of micro- and nano-scale devices with moving parts continues to progress rapidly, but the issue of tribological failure remains critical. The high surface-to-volume ratio at small scales requires that nano-scale adhesion and friction be characterized and reduced. Silicon, the main material currently used in micro- and nanodevices, suffers from poor tribological properties. Ultrananocrystalline diamond (UNCD) is a thin film material that may be far superior tribologically. We present the first measurements of nano-scale adhesion and friction of the tribologically relevant underside of UNCD. This surface is far less adhesive than a silicon reference sample. Furthermore, UNCD can be processed to render it chemically identical to single crystal diamond, minimizing the work of adhesion to the van der Waals limit and strongly reducing friction as well. Our methodology is not only applicable to diamond-based devices but could very well be extended to any thin film material.

4:20pm **NS-WeA8 Gas Phase Lubrication of MEMS***, **S.A. Smallwood**,* Universal Technology Corporation*; K.C. Eapen,* University of Dayton Research Institute*; J.S. Zabinski,* Air Force Research Laboratory (AFRL/MLBT)

A number of different MEMS systems have been designed, fabricated and a few have been marketed. Most commercial MEMS designs are void of parts that simultaneously move and undergo contact due to the problems of stiction, friction and wear. Candidate solutions to tribological problems include monolayers and self-lubricating hard materials. The problem with thin film lubricants is that the coating is fairly quickly worn away. Even though hard coatings such as diamond like carbon (DLC) are expected to have a longer life, improvements in durability are still required. A combination of bound and mobile phase lubricants has been used to extend life through flow of the mobile phase. This provides a protective bound coating and a fluid mobile constituent that offers replenishment. Another replenishment scheme is gas phase lubrication, which offers a way to continuously provide a protective coating by constantly replenishing the contact region. Gas phase lubrication results for MEMS are discussed in this talk. Accelerated screening tests have been performed in vacuum with a pin on disk tribometer tester using a range of Hertzian mean normal stress from 180 to 390 MPa. The tribometer includes a 0.25 inch dia. silicon nitride ball against a polysilicon sample. Protective gases were leaked into the vacuum system during friction tests. These gases include low boiling organic compounds with different functional groups. Surface tribochemistry in the wear track and wear debris were examined using x-ray photoelectron spectroscopy (XPS), microRaman spectroscopy, IR spectroscopy and scanning electron microscopy (SEM). In addition, performance tests were run on operational electrostatic MEMS motors. Surface chemical analyses on screening tests and operational devices are used to provide information on friction and wear mechanisms.

4:40pm **NS-WeA9 Novel Tribological Properties of Quasicrystals in Ultra-High Vacuum***, **J.Y. Park**, D.F. Ogletree, M. Salmeron,* Lawrence Berkeley National Laboratory*; C.J. Jenks, P.A. Thiel,* Ames Laboratory, Iowa State University

The structural and tribological properties of the interface between decagonal Al-Ni-Co quasicrystals and conductive TiN-coated cantilevers have been investigated. This was accomplished using a combined atomic force and scanning tunneling microscopy apparatus in ultrahigh vacuum. Atomically resolved STM images of the 2-fold Al-Ni-Co surface were obtained showing a clear periodicity along 10-fold direction, and a quasi-periodicity (following Fibonacci sequences) along the 2-fold direction. To decrease the high adhesion between the atomically clean quasicrystal surface and the metallic AFM tip (with has high adhesion force as large as 1000 nN), the tip or the surface were passivated by hydrocarbon molecules (ethylene and alkylthiol), which made possible the formation of stable contacts. This allowed us to observe an elastic to plastic transition occurring at a threshold load. With alkylthiol passivated tips the friction properties of the highly anisotropic 2-fold surface could be studied. We found a strong dependence of the friction force on the scanning direction, with low friction occurring along the aperiodic direction and high friction in the periodic direction. This result will be discussed in light of friction models of the interface based on existence or not of commensurability between the two contacting surfaces.

5:00pm **NS-WeA10 Quartz Crystal Microbalance Studies of the Friction of Rotating vs. Rigid C60***, **T. Coffey**,* Appalachian State University*; J. Krim,* North Carolina State University

Since C@sub 60@ was first discovered, it has intrigued tribologists. Due to its weak van der Waals interaction with most materials, its round shape, and its rapid rotation within its lattice position, many had hopes that C@sub 60@ would make an excellent lubricant, and drew analogies to nano-scale ball bearings. Although most experiments have shown that C@sub 60@ is a comparatively poor lubricant, the question of how the rotation of C@sub 60@ affects friction is still an interesting one. We have designed a Quartz Crystal Microbalance (QCM) experiment in ultra-high vacuum to determine how the rotation of C@sub 60@affects slip time (friction). In this experiment, we compare the slippage of methanol at room temperature on one monolayer of stationary C@sub 60@ or slowly rotating (~1 Hz) C@sub 60@ and two layers of quickly rotating (~10@super 9@ Hz) C@sub 60@. We found that the stationary monolayer of C@sub 60@ had longer slip times, or lower friction, than the quickly rotating C@sub 60@, defying the ball-bearing analogy.

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