

Thursday Afternoon, October 5, 2000

Surface Science

Room 209 - Session SS2+NS-ThA

Tribology and Adhesion

Moderator: J. Krim, North Carolina State University

2:00pm **SS2+NS-ThA1 Friction at High Speeds**@footnote 1@, **J.E. Hammerberg**, T.C. Germann, B.L. Holian, P.S. Lomdahl, Los Alamos National Laboratory

INVITED

The mechanisms of dissipation at dry sliding metal-metal interfaces are complex, nonlinear, and involve a range of length and time scales. Depending upon the magnitude of the relative sliding velocity and the material pressure, phenomena described by phonons, dislocation generation and dynamics, microstructure formation, and mechanical mixing of materials are important. We discuss the variety of these phenomena as seen in extensive very large-scale molecular dynamics simulations for copper and Lennard-Jones systems in two and three dimensions. These simulations suggest universal behavior at large sliding speeds and we discuss some of the theoretical descriptions of these phenomena and recent high speed experimental results. @FootnoteText@ @footnote 1@Work performed under auspices of U.S. DOE at LANL under contract W-7405-Eng-36.

2:40pm **SS2+NS-ThA3 Energy Dissipation Thresholds During Interfacial Shear**, **N.D. Shinn**, R.W. Cernosek, S.J. Martin, Sandia National Laboratories
By measuring the power spectra of clean and surface-modified quartz crystal microbalance resonators in contact with nanometer thick fluid layers, we can detect and quantify energetic thresholds for interfacial slip and other dissipation mechanisms at interfaces under dynamic shear. Understanding fundamental dissipation mechanisms is a necessary prerequisite to mitigating friction via interfacial lubricants or surface coatings. Using an amplified network analyzer, we vary the QCM peak-to-peak potentials, and hence the shear acceleration, over a wide range (0.002-30V) and detect any resultant changes in resonant frequency or resonance damping. This approach allows us to access shear forces otherwise unavailable using traditional QCM oscillator circuits [1] or standard network analyzer systems and therefore to probe stronger interfacial adhesive forces. Initial experiments for water adsorption on polycrystalline Au(111) electrode surfaces with and without a hydrophobic (methyl-terminated) alkanethiol self-assembled monolayer reveal no new dissipation thresholds. This suggests that interfacial slip is not occurring because the nanometer-scale surface roughness is sufficient to entrain the water layer or the energetic barrier for lateral motion remains insurmountable. Experiments are in progress to distinguish interfacial slip thresholds from mechanical entrapment effects by preparing atomically flat microcrystalline domains, contrasting polar and non-polar fluids, and modifying the electrode surfaces with other functionalized monolayers. Research supported by DOE-BES Materials Sciences. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000. @FootnoteText@ @footnote 1@J. Krim and A. Widom, Phys. Rev. B38, 12184 (1988).

3:00pm **SS2+NS-ThA4 Chemical and Mechanical Contributions to the Friction In Self-Assembled Monolayers on Au Surfaces**, **H.I. Kim**, J.E. Houston, Sandia National Laboratories

By studying various combinations of chemically distinct end groups on alkanethiol molecules self-assembled on Au probe/substrate surfaces, and by varying the odd-even length of the chains, we are able to delineate the contributions of chemical and mechanical effects to interfacial friction. Because it is stable and quantitative throughout the entire range of the interfacial interactions (including the attractive load regime), we use the interfacial force microscope (IFM) to measure the friction force as a function of applied load. For even-length molecular chains, the friction forces progressively increase in the order CH₃-CH₃, CH₃-COOH, COOH-COOH, while the interfacial adhesive force remains virtually identical. In contrast, for odd chain lengths, friction on and adhesion are low for both CH₃-CH₃ and CH₃-COOH combinations, but much higher for COOH-COOH. By systematically correlating the interfacial adhesion and friction, we conclude that energy dissipation giving rise to sliding friction has distinct chemical and mechanical components. The making and breaking of hydrogen bonds, due to either intra- or inter-film interactions, gives rise to the "chemical" dissipation while simply disturbing the structure of the film under interfacial sliding invokes the "mechanical" component. This work was

supported by the US Department of Energy under Contract DE-AC04-94AL85000. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed-Martin Company, for the US Department of Energy.

3:20pm **SS2+NS-ThA5 Atomic and Molecular Level Insight into Discreet Frictional Events**, **S.S. Perry**, T.R. Lee, S.H. Lee, K.I. Kim, R. Colorado, P. Cao, Y.S. Shon, M. Graupe, University of Houston

INVITED

Technological advances in a number of industries has driven the need to understand interfacial friction on an atomic and molecular level. This level of understanding requires the careful design of model interfaces and experimental approaches sensitive to atomic and molecular scale events. This has been achieved in our studies by combining two recently developed techniques that operate at the subnanometer scale: control of the interfacial composition through molecular self-assembly or chemical modification under controlled UHV conditions and tribological measurements performed with the atomic force microscope. With this approach, we are able to control or measure the specific chemical composition and structure of interfaces and to correlate changes in composition and structure to the frictional properties of a single asperity contact. Examples will be drawn from both molecularly-thin organic film systems and composite coating systems to illustrate the origins of interfacial friction in terms of the composition and structure of the interface.

4:00pm **SS2+NS-ThA7 Molecular Tribology of Highly Ordered Monolayers**, D. Gourdon, University of California, Santa Barbara; C. Duschl, Swiss Federal Institute of Technology; **N.A. Burnham**, Worcester Polytechnic Institute

In order to investigate friction at a fundamental level, atomic force microscopy (AFM) in the wearless regime was performed on a model system - a highly ordered thiolipid monolayer on mica. In the monolayer, condensed domains with long-range orientational order were present. These domains revealed strong friction anisotropies as well as non-negligible asymmetries in the quasistatic friction loops. The directionality of these two effects appeared to correlate well with the tilt direction of the molecules (more specifically of their terminal alkyl chains) in the monolayer. The friction was measured as a function of applied load. The measurements versus load revealed two or three different frictional regimes (depending on the load range), that correlated well with a systematic stepwise behavior of the height of the domain as measured simultaneously. These discrete effects were attributed to molecular gauche defects created under the stress applied by the tip. Other studies include the friction as a function of sliding velocity, chemical preparation of the tip, alternative molecules, and nature of the substrate. Our work suggests that friction on this system is primarily a mechanical phenomenon.

4:20pm **SS2+NS-ThA8 The Effect of C60 on Interfacial Friction and Wetting of Toluene**, **T.S. Coffey**, M. Abdelmaksoud, J. Krim, North Carolina State University

Experimental investigations of friction, lubrication, and adhesion at nanometer length scales have traditionally been performed using atomic force microscopy (AFM), surface forces apparatus (SFA), or quartz crystal microbalance (QCM) techniques. While collectively these techniques yielded useful information, their results have never been cross-referenced. In order to achieve a cross referencing, we investigated the sliding friction of C60 using AFM, QCM, and macroscopic contact angle measurements. (Recent studies@footnote 1@ suggest that a larger contact angle implies a more slippery interface.) C60 has been previously studied by S.E. Campbell et al. with SFA,@footnote 2@ whereby it was reported that C60 at a toluene/mica interface resulted in a full-slip boundary condition, and C60 was recommended as a possible lubricant. Our contact angle measurements reveal that the contact angle of C60/toluene solutions on mica is greater than the contact angle of toluene alone and therefore support Campbell's result. Using QCM, we have also studied the system toluene/Ag(111) with and without C60 deposited on the silver. These studies indicate that toluene on the C60/silver surface is less slippery than the toluene on the silver alone, and that the contact angle for toluene on C60/silver surface is less than the contact angle for the toluene on the silver. This indicates that C60 is not a good lubricant for a silver surface. We believe that this seeming contradiction with Campbell's result is due to the manner in which the C60 is bound to the mica surface vs. the silver surface. We complete our cross referencing of C60/toluene solutions on these substrates by employing AFM. @footnote 3@ @FootnoteText@ @footnote 1@ J.L. Barrat and L. Bocquet, Physical Review Letters, vol. 82, p. 4671 (1999). @footnote 2@ S.E. Campbell, G. Luengo, V.I. Srdanov, F.

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Wudl, and J.I. Israelachvili, *Nature*, vol. 382, p. 520 (1996). @footnote 3@
This work is supported by NSF, AFOSR, and a GAANN fellowship.

4:40pm **SS2+NS-ThA9 Mechanical Behaviour of Confined Films: An In-situ Study of Silane Monolayers by Second Harmonic Generation (SHG), M.T. Strobel, J. Blümmel, W. Eck, M. Buck, M. Grunze**, University of Heidelberg, Germany

Understanding the tribological properties of ultrathin organic films is of vital interest for their application in micro electro-mechanical systems (MEMS). To elucidate structural aspects of layers confined between two solids SHG was applied to trace force-induced changes of the polar and azimuthal orientation of molecular entities. As a model system monolayers of a silane bearing an SHG-active moiety were adsorbed on a glass-substrate. Mechanical loading and shearing of the film was achieved by a lens pressing against or rolling over the substrate. Mapping the contact area reveals pronounced, site dependent changes of both the tilt angle and the azimuthal alignment of the SHG active moiety upon loading. Whereas the azimuthal alignment persists after unloading and can be controlled by the rolling direction of the lens, the tilt angle is largely reversible for a loading unloading cycle. A quantitative evaluation of the data shows that the degree of the alignment is significantly larger than expected from simple models of contact mechanics.

5:00pm **SS2+NS-ThA10 New Aspects of Friction Force Microscopy in Ultra-high Vacuum, R. Bennewitz, E. Gnecco, T. Gyalog, O. Pfeiffer, Ch. Loppacher, M. Guggisberg, E. Meyer**, University of Basel, Switzerland

Recent experimental results of Friction Force Microscopy in ultra-high vacuum on well defined surfaces give new insight into the atomic processes of friction. On Cu(111), atomic stick-slip behaviour was found for the first time on a metal surface. Lateral stiffness of the contact and its I(V)-characteristic indicate that a copper neck between tip and sample is dragged over the surface.@footnote 1@ The velocity dependence of atomic stick-slip processes was studied on Cu(111) and on NaCl(100) revealing a logarithmic increase of the friction with increasing scan velocity.@footnote 2@ This dependence can be explained by introducing the effects of thermal activation into the Tomlinson model for atomic friction. A new experimental approach to study dissipation processes on atomic scale is the measurement of the damping of vertical and horizontal tip oscillations in the non-contact mode, where power losses of the order of 100 meV per tip oscillation can be detected. @FootnoteText@ @footnote 1@ R. Bennewitz et al., *Phys. Rev. B* 60 (1999) R11301 @footnote 2@ E. Gnecco et al., *Phys. Rev. Lett.* 84 (2000) 1172.

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