

O 9: Nanotribology

Time: Monday 10:30–13:00

Location: H42

O 9.1 Mon 10:30 H42

The Interdependence of Timescale and Temperature on Nanoparticle Friction — ●MICHAEL FELDMANN, DIRK DIETZEL, and ANDRÉ SCHIRMEISEN — Institut für Angewandte Physik, JLU Giessen, Germany

In the endeavor to understand friction for a broad range of contact area sizes, friction measurement employing nanoparticle manipulation has emerged as a valuable experimental technique [1]. While the friction of nanoscopic point-like contacts have already been widely examined, investigations of more extended contacts as realized by sliding nanoparticles have recently been intensified. Here we present a study of nanoparticle friction measurements conducted with an atomic force microscope (AFM) in UHV, examining the dependence of friction on temperature and velocity [2]. A strongly non-monotonic relation between friction and temperature/velocity is observed, which cannot be explained in terms of classical models of nanoscale friction. We therefore introduce a model based on the Prandtl-Tomlinson concept, including a characteristic time evolution of the contact energy barrier. The corresponding simulations are in very good agreement with the experimental findings including the non-monotonic temperature/velocity dependence.

[1] Dietzel, D., Herding, C., Feldmann, M., Phys. Rev. B 82, 35401 (2010)

[2] Feldmann, M., Dietzel, D., Schirmeisen, A., *to be published*

O 9.2 Mon 10:45 H42

Superlubric sliding of metallic nanoparticles: The influence of contact area and orientation — ●D. DIETZEL¹, M. FELDMANN¹, H. FUCHS², U. D. SCHWARZ³, and A. SCHIRMEISEN¹ — ¹Institute of Applied Physics, University of Giessen — ²Institute of Physics, University of Muenster — ³Yale University, New Haven, USA

Superlubricity, or also termed structural lubricity, is a fundamental concept where ultra-low friction between atomically flat surfaces can originate from the lattice mismatch at the interface. But while the basic principle is intriguingly simple, unambiguous experimental identification of structural lubricity is often problematic and can best be achieved by analyzing characteristic features unique to structural lubricity. Two of the most significant features are the distinct contact area dependence of friction and the dependence on relative orientation between nanoparticle and substrate: Theory predicts a decrease of shear stress with contact area and the existence of distinct orientations of pseudo-commensurability with sharp peaks in friction. To measure the interfacial friction we have manipulated metallic nanoparticles of different size on atomically flat surfaces by contact mode atomic force microscopy techniques. Our results confirm the sublinear scaling of friction with contact area. Moreover, we could identify different scaling for amorphous and crystalline particles in good agreement with theoretical predictions. In case of the crystalline Gold particles, we could also observe abrupt friction changes due to nanoparticle rotation. By measuring the relative orientation between particle and substrate such friction changes can be related to orientations of pseudo-commensurability.

O 9.3 Mon 11:00 H42

Unraveling and eliminating dissipation mechanisms in contacts of polymer-bearing surfaces — ●SISSI DE BEER and MARTIN H. MÜSER — Jülich Supercomputing Centre, Institute for Advanced Simulation, FZ Jülich, Jülich, Germany

Polymer brushes are well known to lubricate high-pressure contacts, because they can sustain a high normal load while maintaining low friction at the interface. Depending on the contact-geometry, direction of motion and brush characteristics, different dissipation mechanisms dominate the friction forces. For example, in a parallel plate geometry the interdigitation of the opposing polymers determines the lubricity, while for spherical star polymers in relative motion, viscoelastic deformation governs the energy dissipation. We discuss the relative importance of the dissipation channels for real contacts and show via molecular dynamics simulations that, by using an asymmetric contact of a hydrophobic and hydrophilic polymer-bearing surface, the important dissipation-mechanisms - interdigitation and capillary break-up - can be eliminated. This can reduce friction by a few orders of magnitude compared to a symmetric contact. Our proposed system therefore

holds great potential for applications in industry.

O 9.4 Mon 11:15 H42

Correlating contact area and friction of laser-textured surfaces — ●NIKOLAY PRODANOV^{1,2} and MARTIN H. MÜSER^{1,2} —

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Laser surface texturing (LST) is a technique for producing surfaces with a sinusoidal topography. We conduct numerical contact mechanics simulations, which are based on experimentally determined height profiles, to investigate how the kinetic friction of such surfaces is related to the real contact area.

The Green's function molecular dynamics method is used in the calculations. Surface topographies of a flat steel substrate and a bearing ball are used. The periodicity of the grooves is 9 and 18 microns. Parallel and perpendicular relative orientations of the grooves are considered. To ascertain the effect of the roughness on different length scales, we use Gaussian or Fourier smoothing of the original topographies. The dependencies of the relative contact area and of the contact pressure distribution on load, relative orientation and smoothing are obtained. The contact area is very sensitive to the spatial resolution of the topographies. The ratio of the value of real contact area at the two orientations is insensitive to smoothing. The experimental differences for the kinetic friction are similar in magnitude to those for the relative contact area. The contact pressure distribution is not sensitive to changes in the normal forces and orientations of the surfaces. Changing the resolution considerably affects the distribution.

O 9.5 Mon 11:30 H42

Friction and atomic-scale wear of graphitic lubricants on SiC(0001) in dry sliding — ●FELIX WÄHLISCH¹, JUDITH HOTH¹, CHRISTIAN HELD¹, THOMAS SEYLLER², and ROLAND BENNEWITZ¹ —

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Sliding friction experiments on graphene grown on SiC(0001) have been performed using a combination of a microtribometer with an atomic force microscope (AFM) allowing for the investigation of atomic-scale wear. The graphene layer delaminates within ten sliding cycles starting from substrate step edges. After run in, friction is dominated by the interaction between a changing configuration of asperities at the probe sphere and a graphitic interface layer terminating the SiC substrate. Friction varies unpredictably due to changes in the contact configuration. However, the linear relation between friction and contact area can be confirmed and a shear strength as low as a few MPa is found for the contact between ruby and the graphitic layer on SiC, which remains intact under continuous sliding.

O 9.6 Mon 11:45 H42

Electrochemical control of friction in an ionic liquid —

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Ionic liquids are potential novel lubricants due to some unique properties which can be changed systematically by variation of the ion structures. Ionic liquids form ordered layers of anions and cations at solid interfaces which can be probed by atomic force microscopy and controlled by varying the electrode potential. Friction force microscopy with colloidal probes and sharp tips has been performed under electrochemical control to reveal the influence of the ordered layers of the ionic liquid [Py1,4][FAP] on the tribological behaviour of gold [1]. It is found that friction forces decrease for negative potentials which is attributed to a lubricating effect of the cation. The control of friction

in ionic liquids by electrochemical potentials is based on confined ionic liquid layers rather than on a modification of the underlying surface itself as observed for aqueous electrolytes.

[1] J. Sweeney, et al., Phys. Rev. Lett. 2012, 109, 155502

O 9.7 Mon 12:00 H42

Molecular friction at electrodes — NIKOLAY PODGAYNYY, SABINE WEZISLA, SHAHID IQBAL, and •HELMUT BALTRUSCHAT — Inst. f. Physikal. Chemie, 53117 Bonn, Roemerstr.164

Friction under ambient conditions often involves wet surfaces, and thus electrochemical interfaces. Yet measurements of friction at an atomic scale under electrochemical conditions are scarce.[1] We will present friction measurements performed on Au(111) single crystal electrodes and the effect of adsorbates on atomic stick-slip resolution. At the small normal load of 15 nN transition to atomic stick-slip resolution is observed, when sulfate is adsorbed on the surface. The reason for that transition could be a penetration of the tip in to the double layer. At the pzc on clean gold stick-slip behaviour does not show any transition or penetration effects. The adhesion on the force-distance curve disappear with a copper adsorption. However, with a monolayer of Cu on Au(111) a transition to stick-slip behavior is present, but without atomic resolution. Multiple slip was also observed. We will further report on the influence of the molecule orientation of pyridine adsorbed to Au(111). Molecular stick slip was also observed; the corrugation correlates with the molecule separation as determined by STM. [2]. [1]*M. Nielinger, H. Baltruschat, Physical Chemistry Chemical Physics 2007, 9, 3965.; F. Hausen, M. Nielinger, S. Ernst, H. Baltruschat, Electrochimica Acta 2008, 53, 6058. [2]*W. B. Cai, L. J. Wan, H. Noda, Y. Hibino, K. Ataka, M. Osawa, Langmuir 1998, 14, 6992.

O 9.8 Mon 12:15 H42

Chemical effects on the frictional characteristics of Pt(111) and a Pt-based metallic glass — •ARNAUD CARON¹, DMITRI V. LOUZGUINE-LUZGIN², and ROLAND BENNEWITZ¹ — ¹INM - Leibniz-Institute for New Materials, Saarbrücken, Germany — ²WPI-Advanced Institute of Materials Research, Tohoku University, Sendai, Japan

Nanometer-scale friction measurements on a Pt(111) surface and a Pt-based metallic glass surface have been performed in ultra high vacuum and at room temperature by using oxidized silicon and diamond coated silicon AFM-tips as counter bodies. Neither the load dependence of friction nor its velocity dependence are affected by the structural difference between the Pt(111) and the Pt-based metallic glass surfaces. However, we find that the friction forces greatly depend on the chemistry of the counter body, i.e. SiO₂ or diamond. For the SiO₂/Pt(111) and SiO₂/Pt-based MG friction couples we measure a friction coefficient COF = 0.05. In these cases the friction is determined by the adhesive contact between the involved surfaces that gives rise to intermittent sliding. For the diamond/Pt(111) and diamond/Pt-based metallic glass friction couples we measure COF = 0.002. There the relative motion between tip and sample surface did not exhibit any stick slip. The results are discussed on the basis of Pt-silicides formation and solid solution alloying between tip and sample surfaces.

O 9.9 Mon 12:30 H42

The effect of tip force field symmetry on atomic manipulation — •MATTHIAS EMMRICH, MAXIMILIAN SCHNEIDERBAUER and FRANZ J. GIESSIBL — Institute of Experimental and Applied Physics, Universität Regensburg, 93040 Regensburg, Germany

In the last years, significant progress has been made in understanding the manipulation of adatoms on atomically flat surfaces by scanning probe microscopy. Pushing, pulling and sliding atomic manipulation modes have been identified [L. Bartels et al., PRL 1997]. Moreover, the forces that act during manipulation have been measured [M. Ternes et al., Science 2008]. In the first demonstration of atomic manipulation by Eigler and Schweizer [M. Ternes et al., Science 2008], van-der-Waals forces have been identified to allow the lateral manipulation of Xe on Ni (110). Van-der-Waals forces only depend on distance, but in later experiments involving metallic adatoms, metallic bonding was expected to contribute. Recently, a strong angular dependence of these short-range bonding forces has been measured [J. Welker and F.J. Giessibl, Science 2012].

In this study we investigate the influence of the symmetry of the tip's force field on the lateral manipulation of a CO molecule over a Cu(111) surface. The symmetry of the tip is determined using the COFI (carbon oxide front atom identification) method recently introduced by Welker and Giessibl. Lateral forces are extracted from line scans over the CO molecule at different heights. These forces were evaluated not only for different tip symmetries, but also as a function of the direction of manipulation.

O 9.10 Mon 12:45 H42

Measuring the directionality of a chemical bond with lateral force microscopy — •DANIEL MEUER¹, ALFRED J. WEYMOUTH¹, PINGO MUTOMBO², MARTIN ONDRÁČEK², THORSTEN WUTSCHER¹, PAVEL JELINEK², and FRANZ J. GIESSIBL¹ — ¹University of Regensburg, Regensburg, 93053, Germany — ²Institute of Physics of Czech Academy of Science, Prague, CZ-162 53, Czech Republic

Lateral forces control friction [1] and diffusion processes of adsorbates on a surface [2]. Lateral forces can be extracted from 3D normal force measurements [3]. In this contribution we show a direct lateral force measurement by dynamic lateral force microscopy (LFM). In the past LFM has made great advances with smaller oscillations, presenting atomic-scale observations on Si(111)-7x7 [4] and graphite [5]. We resolve lateral bond stiffnesses in a sample that is expected to show a strong azimuthal dependence of lateral stiffnesses: the hydrogenated Si(100) surface. The "rocking horse"-type Si dimers change their orientations by 90° over a single atomic step, correspondingly, the experiment shows clearly a significant difference between the two directions. Furthermore the DFT-based calculations indicate that the tip oscillation induces a significant out-of-plane motion of the Si dimer.

[1] F.J. Giessibl et al, Proc. Nat. Acad. Sci. 99, 12006 (2002).

[2] T. Sonleitner, et al, Phys. Rev. Lett. 107, 186103 (2011).

[3] M. Ternes, et al, Science 319, 1066 (2008)

[4] S. Kawai et al, Phys. Rev. B 79, 195412 (2009).

[5] S. Kawai et al, Phys. Rev. B 81, 085420 (2010).