ATOMIC-SCALE STUDIES OF FRICTION AND NANO-INDENTATION

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The development of Scanning Force Microscopy has provided us with tools to study friction and wear on the nanometer scale. The atomic granularity of matter shows up in the lateral force which is necessary to slide a small contact over a flat surface. Also, mechanical damage of a sample surface can be monitored with monolayer resolution [1]. The laws which determine the dependence of friction on normal load or velocity [2,3] differ from the ones we have learned to describe macroscopic friction. For small scales, a regime of ultra-low friction has been suggested and experimentally realized [4].

The characteristic atomic stick-slip instability in friction force measurements is caused by the jump of the contacting tip from one atomic position to the next. The occurrence of such stick-slip behavior is one-to-one related to energy loss in the sliding process, since the high velocity during the slip movement causes significant dissipation. Thermal fluctuations in the combined system of tip, surface, and force sensor play an important role for the development of the stick-slip behavior.

We measured the friction force for atomic stick-slip friction of a nanometer-sized tip sliding on a KBr (100) surface in ultra-high vacuum. Our friction force microscope allows us to detect force fluctuations up to 3 MHz, well above the mechanical resonance of the force sensor. We could track thermal fluctuations and found that the duration of the slip event shows a broad distribution even for slips over neighboring atomic positions.

The indentation of surfaces by sharp tips is a standard method used to determine hardness and elastic modulus of materials. Scaling these experiments to small lengths can probe the initial stages of permanent deformation. At this scale the dominate mechanism by which the material is restructured may shift from the formation or movement of dislocations to the displacement and diffusion of single atoms.

Atomic scale plastic deformation at crystal surfaces has been achieved and characterized by use of non-contact force microscopy in ultra-high vacuum. A sharp silicon tip, first implemented as a nano-indenter, was used to image the atomic structure of displaced material on Cu (100) and KBr (100) surfaces.

Under nano-Newton loading conditions the debris reorganizes in crystalline terraces with the same orientation as the underlying crystal. The absence of discontinuities in the applied force-penetration curves suggests that the terrace formation is a result of surface diffusion rather than dislocations induced in the crystal.

References:

[1] E. Gnecco et al., Phys. Rev. Lett. 88 (2002) 215501
[2] E. Gnecco et al., Phys. Rev. Lett. 84(6) (2000) 1172-1175
[3] E. Riedo et al., Phys. Rev. Lett. 91(8) (2003) 084502
[4] A. Socoliuc et al., Phys. Rev. Lett. 92 (2004) 134301

Figures:

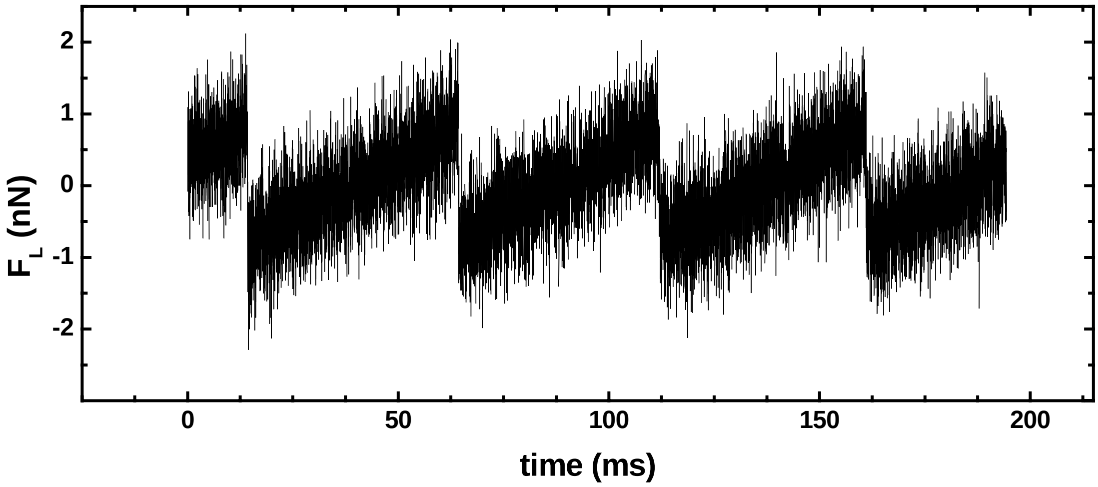

Fig. 1: Atomic stick-slip measurements with high temporal resolution.

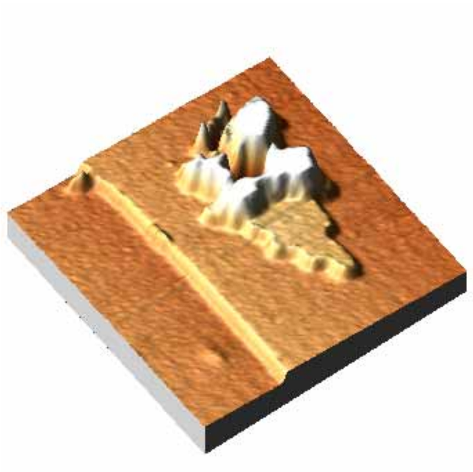

Fig. 2: Debris structure after nano-indentaion of a KBr surface (240 nm x 240 nm)

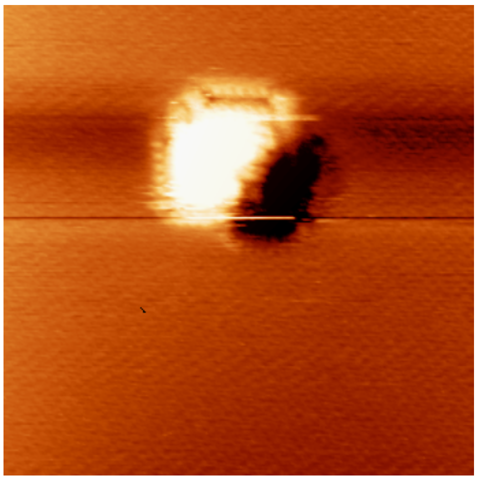

Fig 3: Atomic resolution image of the site of nano-indentation in KBr
(30 nm x 30 nm)