Development of a combined optical lever atomic force microscope with a quartz crystal microbalance

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1. Introduction

A probe-tip-quartz-crystal-resonator technique enables us to observe the energy dissipation rate at a small contact area.[1] In 2003, Berg and Johnnsmann studied the tribology of micron-sized Au-Au contacts based on the ring-down technique. They found that the frictional force remains small below the velocity of 0.4 m/s and explained that a local slip-to-stick transition occurs at the oscillation amplitude of about 0.5 nm. [2]

2. Experimental

To study the energy dissipation due to sliding motion in nano-meter scale, we have developed a combined optical lever atomic force microscope (AFM) with a quartz crystal microbalance (QCM). Figure 1 shows a sketch of the experimental setup. A resonator with substrate was mounted on a piezo-scanner base and was set facing an AFM cantilever as a force sensor. In the present experiments, a Si_3N_4 optical cantilever with a spring constant of 0.05 N/m (OMCL-RC800PSA-, Olympus Corporation) was used, and typical radius of the tip was 15 nm. The normal load acting on a Si_3N_4 tip was controlled by driving the piezo-scanner base.

The restoring force and the energy dissipation due to contact are detected by changes in the resonance frequency f_R and the Q-factor of the resonator $\Delta(1/Q)$,

$$\kappa = \omega_R^2 M_C \frac{\Delta f_R}{f_R},$$
$$\Delta E = 2\pi E \Delta\left(\frac{1}{Q}\right),$$

where, M_c is the mass of the oscillating area and κ is the *effective* spring constant, ΔE is the energy dissipated per cycle and E is the energy stored in the system. The average frictional force was observed as the dissipated energy par unit distance.

$$F_{\mathrm{ave}} = \frac{\Delta E}{4A} = \frac{\pi E}{2A}\left(\frac{1}{Q}\right),$$

Where, A is the oscillation amplitude of the resonator.

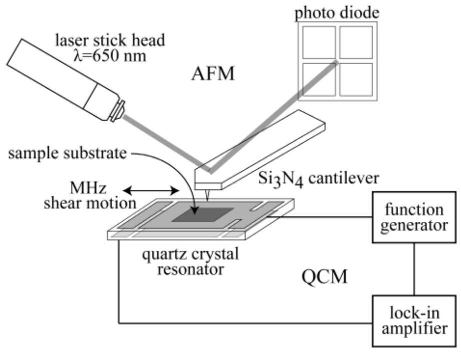

Figure 1. Schematic diagram of the experimental setup.

3. Results and Discussion

We prepared mica as the substrate. The sliding direction was parallel to the [110] direction. Figure 2 shows the average frictional force as a function of sliding distance for a normal load of 5 nN. The force increased with increasing sliding distance up to 0.7 nm, and became almost constant. We found that the force shows a transition around the lattice constant of the substrate.

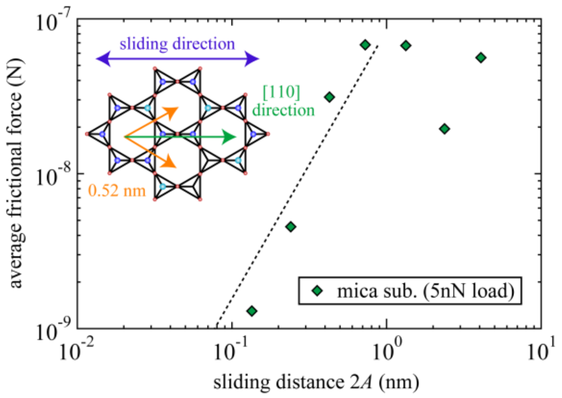

Figure2. Oscillation amplitude dependence of average frictional force for the mica substrate at the normal load of 5nN.

4. References

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