Dissipative interaction via capacitive coupling through mica nanosheets examined by non-contact atomic force microscopy

M.M. Hasan and M. Tomitori
School of Materials Science, Japan Advanced Institute of Science and Technology (JAIST),
1-1 Asahidai, Nomi-shi, Ishikawa 923-1219, Japan
E-mail: s1820425@jaist.ac.jp

In the last three decades, surface nanoscale properties have been intensely investigated by use of atomic force microscopy (AFM). In particular, non-contact atomic force microscopy (nc-AFM) has exhibited remarkable performance in high-resolution surface imaging of various exotic materials in vacuum, air, and water with no or less damage to their surfaces[1]. Therein, the shift (Δf) of cantilever resonant frequency (f) induced by the interaction between a tip and the sample, deviated from f_0 at free, is measured and used as a feedback signal to control the tip–sample distance; the topography along with various static and dynamic properties of the surfaces can be depicted. The interaction forces are categorized into conservative and nonconservative forces. The nonconservative forces cause energy dissipation, which is neither fully understood nor utilized, but still attracts much interest as a fascinating measurable physical quantity.

In the present work, we examine the distance and bias dependence of dissipative interaction using nc-AFM for artificially synthesized phlogopite ($KMg_3AlSi_3O_{10}F_2$, a mica family), exfoliated into nanosheets (a thickness of 5–10 nm) and affixed on an iridium (Ir) coated silicon (Si) substrate. Figure 1a shows an nc-AFM topographic image, taken in a chamber filled with pure Ar gas at 1 atm, with a Au-coated Si cantilever (f_0=306.7 kHz, A= 27 nm, Olympus) overcoated with Ir using DC magnetron sputtering by ~12 nm to improve the electric conductivity of the tip. Figure 1b shows the force–distance curves acquired on the mica nanosheet and the substrate, which were numerically converted from the Δf–distance curves[2]; when the tip approached the sample, first, attractive forces were found with decreasing tip-sample distance, followed by strong repulsive forces in the measured distance range. The hydrophilic mica nanosheet as well as Ir-coated Si substrate were probably covered with a thin water layer during the sample preparation in our lab environment. Thus, the attractive forces possibly corresponded to the interaction between the tip and the water layer covering sample surface. The simultaneously obtained dissipation curves (Fig. 1c) show sharp increase at the distance of ~15 nm both on the mica nanosheet and the substrate; the larger dissipation was found on the mica nanosheet. Depend on the thickness of the mica nanosheet, dissipation may vary from a thin to a thick layer. The tip–sample system can be regarded as a capacitor under a bias voltage inducing the electrostatic force, where the interactions of short-range chemical forces and long-range van der Waals forces are also acting; furthermore, displacement current passes during the tip oscillation of nc-AFM operation[3,4]. The mica nanosheet as dielectric probably increased the capacitance, which might increase the displacement current, resulted in larger Joule heating. We will discuss the bias dependence of the dissipation as well.

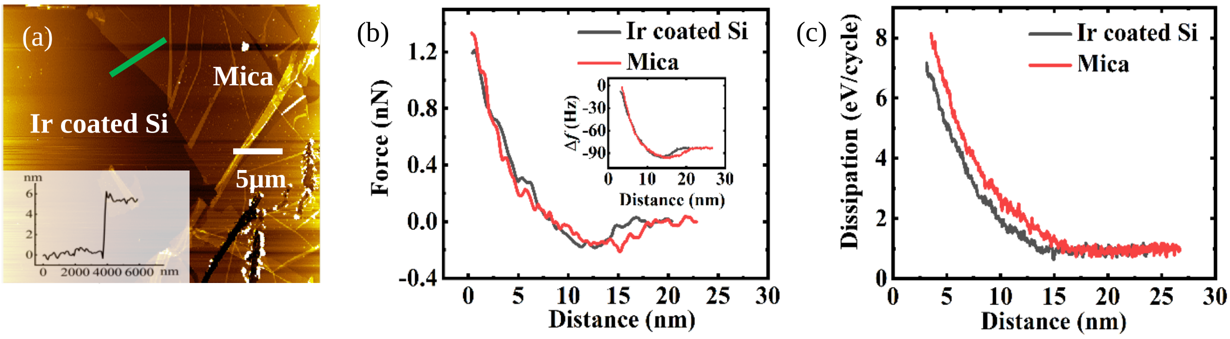

Figure 1: (a) nc-AFM topographic image of a 5-nm thin mica nanosheet affixed on the Ir-coated Si substrate at a bias voltage of 0 V. (b) force–distance curves and (c) simultaneously measured dissipation–distance curves on the mica nanosheet (in red) and the substrate (in black). The origins of horizontal axes were shifted by the thickness of mica (i.e., 5 nm) so that the scale numerically shows the tip height from their surfaces.

References:

[1] R. García and R. Pérez, Surf. Sci. Rep. **47**, 197 (2002).
[2] J. E. Sadar and S. P. Jarvis, Appl. Phys. Lett. **84**, 1801 (2004).
[3] W. Denk and D. Pohl, Appl. Phys. Lett. **59**, 2171 (1991).
[4] T. Arai, D. Kura, R. Inamura, and M. Tomitori, Jpn. J. Appl. Phys. **57**, 08NB04 (2018).