Observation of mechanical energy dissipation between a conductive tip and a thin dielectric film on a metal-coated Si-substrate by frequency modulated atomic force microscopy

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To characterize the atomic-scale force interaction between a tip and a sample with atom-resolved images, frequency modulated atomic force microscopy (FM-AFM) is highly appreciated. Characterization of two-dimensional (2D) nanosheets using FM-AFM has been utilized for the last three decades. Besides imaging, surface nanoscale properties (resistance, capacitance, tunneling current, force, dissipation, etc.) have also been investigated for not only understanding of such phenomenon but also the realization of valuable applications. Recently, the mechanical energy dissipation concerning capacitive coupling between a tip and a sample has attracted much attention due to its complexity at the nanoscale and a shorter distance where electron tunneling can appear[1]. In the present work, we measure and discuss the change in dissipation energy via capacitive coupling including an equivalent circuit model on a dielectric sample and metal-coated silicon (Si) substrate by using FM-AFM.

The energy dissipation took place through an oscillating cantilever of an FM-AFM at its resonance frequency (f), which had a high spring constant (k). The resonance frequency shift (Δf) and the energy dissipation were measured separately through the conservative and dissipative forces by keeping a 90° phase between the oscillation signal and the excitation signal[2] using a phase-locked loop (PLL). The distance and bias voltage dependences of dissipation were measured for a thin dielectric film on a metallic substrate. We used phlogopite mica (10 layers) ($KMg_3AlSi_3O_{10}F_2$) as the dielectric thin film affixed on an iridium (Ir) coated Si substrate, and a PtSi conductive tip on a cantilever (f = 297 kHz, k = 41 Nm^{-1}, A = 26 nm, Nanosensors). We used direct current magnetron sputtering for ~15 nm Ir coating on a Si substrate. Figures 1(a) and (b) show the topography and dissipation images taken in an Ar gas chamber to control the humidity. From Δf−distance curves measured at some places labeled in the image, we numerically calculated the force−distance curves[3] (Figs. 1(c) and (d)). We also measured the dissipation–distance curves in Figs. 1 (e) and (f). Long-range attractive electrostatic and van der Waals forces were dominant for both cases at –1.0 V. Also, using the measured contact potential voltages (CPDs) on the bared Ir and mica surfaces, we compensated the electrostatic force at –0.22 V and –1.40 V, respectively. Higher dissipation was observed on the mica at the applied and compensated voltages. Using a capacitive coupling model, it is reasonable that the mica insertion acted as a dielectric in the tip–sample system, leading to an increase in the capacitance. The increase generated more Jule heat through the displacement current. The details will be discussed with the model.

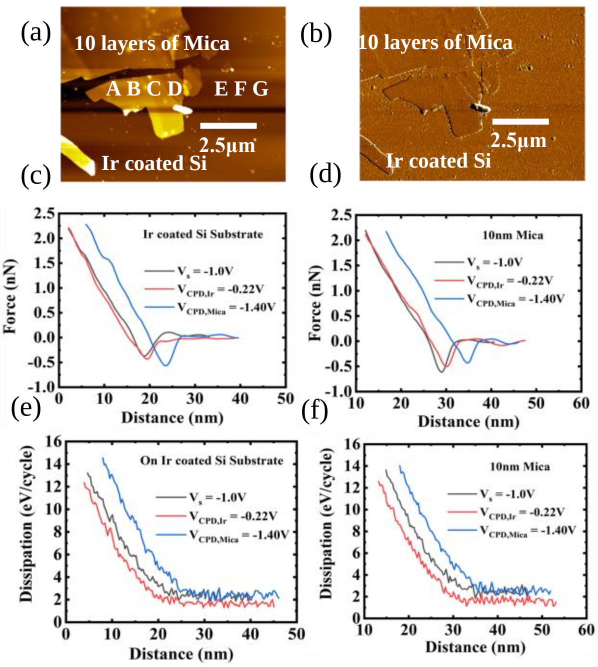

Fig. 1 (a) and (b) topography and dissipation images, respectively, for a 10 nm mica nanosheet at –1.0 V. (c) and (d) converted force−distance curves measured at the points marked in (a). (e) and (f) simultaneously measured dissipation curve.

References:

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