Bias voltage noncontact atomic force spectroscopy with measuring current

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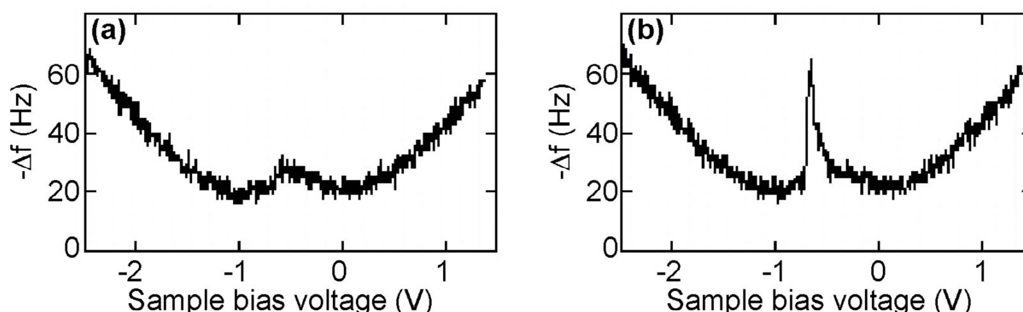
Recently, we have experimentally demonstrated the enhancement of chemical bond between a tip and a sample by energy-level tuning with changing tip-sample bias voltage using noncontact atomic force microscopy (nc-AFM) [1]. The energy levels of surface electronic states of tip and sample can be electrostatically shifted with bias voltage, resulting in quantum-mechanical resonance between these levels at atomically close separation as the their energies are matched. By taking Δf versus bias voltage curves while holding the tip-sample separation, the interaction between tip and sample that changes with bias voltage can be evaluated, termed bias voltage noncontact atomic force spectroscopy (nc-AFS). When the tip is brought closer to the sample, a parabolic Δf-bias voltage feature due to electrostatic interaction deviates prominently with some peaks in Δf-bias voltage curves, attributed to quantum mechanical interactions at close separation. Since the interaction at close separation with overlapping of wave functions of tip and sample is not straightforward, detailed analysis is required to clarify the features of interaction. In general, tunneling current spectroscopy is of help for us to understand them. Here we report the simultaneous measurements of the Δf-bias voltage curves with current passing between tip and sample: the tunneling current between tip and sample also originates from overlapping of wave functions with the same energy of the electronic surface states of tip and sample.

We simultaneously measured the Δf and current versus bias curves by nc-AFS based on UHV nc-AFM with a piezoresistive cantilever having a [001]-oriented Si tip; the sample was a n-type Si(111)7x7 surface. By bringing the tip closer to the sample, the parabolic feature in the Δf-bias curves deviated around the bottom, in Fig. 1. Figure 1(a) shows a blunt peak due to attractive interaction around –0.47 V, which is a contact potential difference between tip and sample: this indicates the formation of metallic bonding between the electronic states of tip and sample through a decreasing tunneling barrier [1]; the detected current was so less of the order of pA, because we measured the averaged tunneling current with the oscillating tip, while the current slightly increases with bias voltage. For the case with a sharp peak in the Δf, in Fig. 1(b), a sharp current peak appeared at the same voltage as the Δf peak. A strong overlapping between wave functions of surface states of tip and sample, leading to a strong chemical bonding, possibly opens a channel for electron passing between tip and sample.



[1] T. Arai, M. Tomitori, Phys. Rev. Lett. **93,** 256101 (2004)