Relationship between force and current on resonance state between a Si tip and Si(111)7x7

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Since the advent of non-contact atomic force microscopy (nc-AFM), we are able to simultaneously measure the force and the current between a tip and a sample on an atomic scale. The quantum mechanical properties become prominent at atomically close separations; chemical covalent bonding or metallic bonding is formed at less than 1 nm, the tunneling barrier between them collapses, and at closer distances quantized conductance comes up through atomically confined channels. To reveal the quantum mechanical effects between the tip and the sample, the relationship between the force and the current between them has attracted much interest. Through the matrix element of interaction potential between the electronic states of the tip and the sample, it has been discussed that the force and the current are convoluted linearly or quadratically [1, 2]. The measurements of the change in force and current with respect to the tip-sample separation were experimentally and theoretically reported; the relationship between the force and current changes from quadratically to linearly with decreasing separation less than 1 nm [3]. In these analyses it is assumed that metallic electronic state or one electronic state governs the force and the current. In general, it is demanded to take the integral over more electronic states to evaluate the force, in particular, for the case of semiconductors or molecules on a surfaces. Furthermore, the bias voltage applied between the tip and the sample should be included; we reported the force and the current exhibited prominent peaks with sweeping bias voltage between a Si tip and a Si(111)7x7, and attributed them to formation of the quantum resonance state between a electronic state of the top atom of Si tip and the Si adatom of the sample; bias-voltage non-contact atomic force spectroscopy (nc-AFS) [4]. Here we report the relationship on the resonance state between the force and the current between a Si tip and a Si(111)7x7 by measuring the changes in the force and the current with decreasing tip-sample separation.

Experiments were conducted using a home-made UHV-AFM/AFS with a B-doped Si piezoresistive cantilever with a Si tip, and a sample was Si(111)7x7 terminated with/without atomic hydrogen. After cleaning the tip and the sample by heating in UHV, we took nc-AFM images simultaneously with current while taking spectroscopic curves of frequency shift and current versus bias voltage or tip-sample separation. By analyzing the curves, we extracted the relationship between the force and the time-averaged current on the resonance state (Fig. 1). The current changes with respect to the force from quadratically to linearly with decreasing separation; this change is similar to the metal case. This implies that the resonance state is evaluated based on one electron approximation. The details and discussion will be presented.

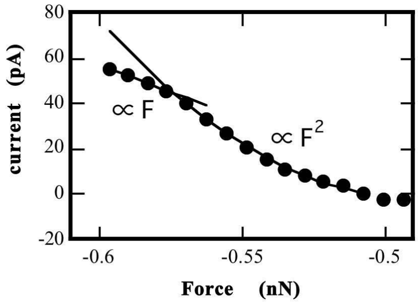

Figure 1. Time-averaged current vs. force between Si tip and Si(111) at V_s= -0.5 V. The force was de-convoluted from Δf.

References

[1] C. J. Chen, "*Introduction to Scanning Tunneling Microscopy*" (Oxford Univ. Press, 1993).
[2] W. A. Hofer, A. J. Fisher, PRL **91**, 036803 (2003).
[3] P. Jelinek, et al., J. Phys. Condensed Matter **24**, 084001 (2012).
[4] T. Arai, M. Tomitori, PRL **93**, 256101 (2004), PR B **73**, 073307 (2006).