Local Spectroscopy and Atomic Imaging of Tunneling Current, Forces, and Dissipation on Graphite

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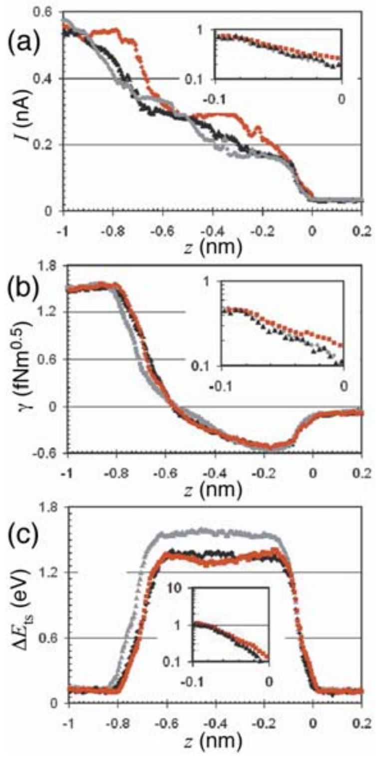
The capability of scanning tunneling microscopy (STM) and atomic force microscopy (AFM) to resolve single atoms in real space makes them powerful tools for surface science and nanoscience. Theory predicts that the tuuneling currents in STM and the attractive forces measured in AFM are directly related [1,2]. Atomic images obtained in an attractive AFM mode should therefore be redundant because they should be similar to STM. In this study, we investigate the experimental relationships between tunneling currents and conservative as well as dissipative forces for graphite (0001) surface probed with a W-tip by performing local spectroscopy at high-symmetry lattice sites [3]. We use a low-temperature STM-AFM operating at 4.9 K in ultrahigh vacuum. The microscope uses a qPlus sensor for simultaneous STM-AFM operation. All data are recorded at oscillation amplitude A = 250 pm. Figures (a) ~ (c) show local spectra of currents I, normalized frequency shifts γ, and dissipations ΔE_{ts} taken at the α-, β-, and *hollow*-lattice sites, which are indicated by black, red, and grey curves in each figure, respectively. All three signals initially increase roughly exponentially, as shown in the log-scale insets. The z dependence of I and γ is roughly the same as predicted in Hofer-Fisher theory for graphite. However, the constant-height experiments prove that attractive forces and currents are not directly related and STM and AFM do provide different information. ΔE_{ts} initially also increases exponentially, reaches a plateau for -170 > z > -600 pm, decays to zero, and remains zero for z < -800 pm because the cantilever remains in contact for the whole oscillation cycle. This points to a damping mechanism as described by Prandtl [4] and Tomlinson [5], where the energy loss is caused by a plucking action of the atoms on each other, and is qualitatively consistent with a theoretical prediction [6,7]. By measuring damping spectra as a function of oscillation amplitude, we could examine the origin of the energy dissipation in AFM thoroughly.



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