

Dissipative Interactions between Tip and Sample Measured Using Ultra-small Oscillation Amplitudes

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We investigated Cu(100) surface using a UHV-AFM/STM which employs a high resolution fibre interferometer [1]. The lever is oscillated with ultra-small amplitudes ($< 0.25 \text{ \AA}$) at a frequency well below its resonance while it is scanned across the surface with tunnelling current feedback and the changes in the oscillation amplitude is recorded using a lock-in amplifier. The oscillation amplitude data directly reveals the quantitative force gradient information without use of complicated mathematical tools. Furthermore the phase difference between the oscillations of the lever and the excitation, which is a measure of the energy dissipation due dominantly to the tip-sample interaction, is recorded as well.

We obtained dissipation images of Cu(100) surface along with STM topography and force gradient images using tungsten cantilevers. Force-distance spectroscopy experiments were also carried out simultaneously measuring tunnel current, oscillation amplitude, deflection of the lever and phase. A common observation with our previous works on Si surfaces was the onset of change in phase to occur once the tip enters the short- range potential region. In fact, the separation dependence of the phase curve was similar to that of the force curve. In a previous work we proposed a simple mechanism that explains the energy dissipation in the tip-surface region [2]. An atom or defect in the vicinity of the tip, which can assume two energy states undergoes a transition between the two states induced by the interaction. The transition rate will be an exponential function of the energy gap that can be expressed in terms of the tip-sample interaction force. The maximum energy loss per cycle was found to be around 0.1 eV for the W tip on Cu(100). We reported in [2] that the maximum energy loss was about 0.05 eV for Pt-Ir/Cu(100) and more then 0.1 eV for W/Si(100) [3]. Due to the different electronic properties resulting in different STM imaging conditions the extent of contribution of forces to the overall interaction varies from semiconductor to metal surfaces. On Si surfaces the onset of tunnel current is well before the start of considerable short-range force interaction. In contrast, under usual STM operating separations there is already a strong force interaction between the tip and the sample in case of Cu(100). We imaged atomic features in phase scans as well as the force gradient scans of the Cu surface. An atomic scale contrast in phase images suggests an energy loss on every atomic site. Within the aforementioned mechanism of a bistable atom that successfully accounts for the observed dissipation, the tip is able to preserve its integrity and this results in the stability of the AFM images despite the presence of significant dissipation.

We will also investigate dissipative interactions on Si(111) using a new AFM which implements frequency shift measurement at resonance in addition to the low-amplitude off-resonance method. In particular, the frequency dependence of the dissipative interactions will be explored.

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