Simultaneous imaging of current and local dipole moments of Si (111)-(7×7) surface by noncontact scanning nonlinear dielectric microscopy

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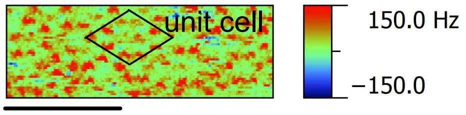
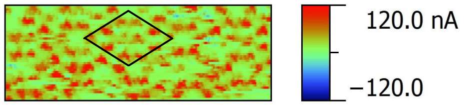
Non-contact scanning nonlinear dielectric microscopy (NC-SNDM) has been used for imaging local dipole moments of material surfaces. The images are acquired through the measurement of the first order tip-sample capacitance variation for a sinusoidal applied voltag ($\partial C/\partial V$) using a GHz-range LC oscillator. NC-SNDM has achieved the imaging of atomic dipole moments of the Si (111)-(7×7) surface [1]. On the other hand, the influence of considerable amount of a tunneling current on the NC-SNDM measurement has not been clearly understood yet. The applied ac voltage induces a rectified current as well as ac tunneling current because of nonlinear voltage current characteristics. In order to understand the influence of the tunneling current, we performed simultaneous measurement of $\partial C/\partial V$ and rectified tunneling current images. Our experiment was performed in UHV and the sample was p-type Si (111) prepared by a standard flashing procedure. A sinusoidal voltage of 3.5 Vpp at frequency of 30 kHz was applied between the Pt-Ir tip and the sample. The rectified tunneling current was measured using a preamplifier with bandwidth of 500 Hz. The constant height mode was utilized for the elimination of crosstalk caused by z-feedback. As shown in Fig.1(a), the $\partial C/\partial V$ image of Si(111)-(7×7) surface clearly resolves the atomic dipole moments pointing outward normal to the surface (red colored). The outward dipoles have been considered to originate in the adatoms of the Si(111)-(7×7) surface, each of which has a positive charged nucleus and three covalent bonds below it [1]. The atomic resolution was not artificially obtained because of using the constant height mode. $\partial C/\partial V$ signal was about 100 Hz above each of the adatoms. Figure 1(b) shows current image simultaneously acquired with the $\partial C/\partial V$ image. It is noted that a usual STM cannot acquire the rectified current image, since the rectified current can have zero-crossing points. The current image shows the atomic resolution and seems to have a strong correlation with the dipole moment image. The amplitude was several nano amperes to 100 nA on the adatoms depending on the tip condition. This implies that the tip apex is located closer to the surface in the NC-SNDM measurement than in the typical STM measurement. To check a crosstalk in the LC oscillator circuit, we measured the frequency shift induced by a test ac current with a dc offset. The tip-current induced frequency shift was estimated at most 20 Hz, which is negligible for observed $\partial C/\partial V$ signal in the measurement, as shown in Fig. 2. We therefore conclude that the atomic contrast of the $\partial C/\partial V$ image is attributed to a capacitive component of tip-sample interaction at the tunneling regime.



(a) $\partial C/\partial V$ image



(b) rectified current image

Figure 1. NC-SNDM image

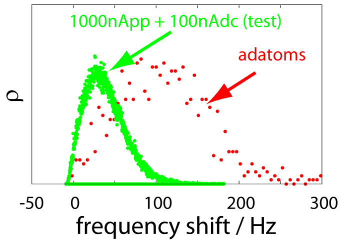


Figure 2. Comparison of histgram of frequency shift induced by test current and $\partial C/\partial V$ signal on adatoms

References: [1] Y. Cho and R. Hirose, Phys. Rev. Lett., **99**, 186101 (2007).