Observation of dipole moments on hydrogen-adsorbed Si(111)-7×7 surface by non-contact scanning nonlinear dielectric microscopy

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Non-contact scanning nonlinear dielectric microscopy (NC-SNDM) enables us to simultaneously observe local dipole moments and topography by detecting the nonlinear dielectric constants. This microscopy has revealed atomic dipole moments on Si(111)-7×7 surface in Ref [1]. The chemical interaction of hydrogen with Si surface has been interested in the discipline of surface science and thus there have been many studies by STM and so on [2]. However, in the STM studies, information on the dipole moment of hydrogen-adsorbed Si adatom has not been able to obtain. Therefore, by using NC-SNDM, we examine dipole moments of Si(111)-7×7 surface on which atomic hydrogen is adsorbed.

The sample used in this study was a p-type Si(111). We used a probe made up of a 1.7GHz LC oscillator and a Pt-Ir tip. Atomic hydrogen created by dissociating molecular hydrogen using W filament (1000℃) was adsorbed on the sample surface. The amount of exposure was 480L.

Figure 1 shows STM image with a sample bias voltage of 2.5V and a tunneling current of 100 pA. Some of the adatoms in the figure appear darker. This was caused by decrease of the local density of states of the hydrogen-adsorbed adatom. The ratio of the darker atoms to Si adatoms was about 20%. This ratio was estimated by tallying the number of hydrogen-adsorbed Si adatoms. Figure 2 shows simultaneously observed topography (Fig. 2(a)) and dipole moment image (Fig. 2(b)) with a sinusoidal voltage of 1.5Vpp at frequency of 30kHz applied between the tip and sample. Although almost all adatoms are clearly visualized in the topography, the dipole moment image shows a different result. In Fig. 2(b) the upward and downward dipole moment is shown with red color and blue one, respectively, and green one indicates weaker dipole moment. The adatoms on cleaned Si(111)-7×7 surface have upward dipole moments [1]. However, comparing these images, we found weak dipole moments in Fig. 2(b) (shown by white circle), and at the same position we can see bright atoms in Fig. 2(a). The ratio of the weak dipole moments to Si adatoms was 22%. This value was nearly equal to the adsorbed ratio estimated from the STM image and therefore we conclude the dipole moments become weaker on the hydrogen-adsorbed adatoms. On the cleaned Si(111)-7×7 surface, Si adatoms have positive nuclei and the covalent bonds below the adatoms have negative electrons. Thus Si adatoms have upward dipole moment. Moreover, Si adatoms have dangling-bonds and thus charge distribution of Si adatoms is asymmetry. On the other hand, when atomic hydrogen adsorbs on a Si adatom, the charge distribution in the neighborhood of the Si adatom has nearly central symmetry and, therefore, dipole moment of the hydrogen-adsorbed adatom becomes weaker.

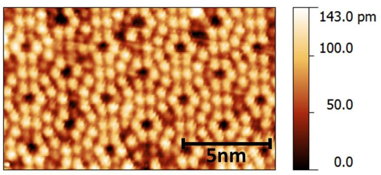
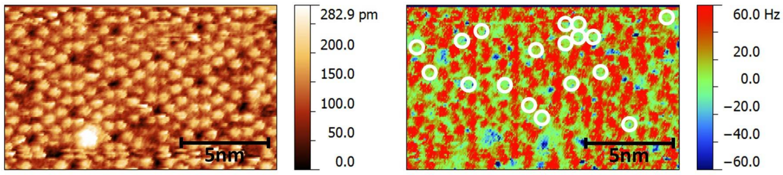


Figure. 1 STM image



(a) Topography (b) Dipole moment image

Figure. 2 NC-SNDM image

[1] Y. Cho and R. Hirose, Phys. Rev. Lett., 99, 186101 (2007).
[2] H. Tokumoto et al., J. Vac. Sci.Technol., A 8, 255 (1990).