研 究 速 報

Mapping of Lateral Vibration Amplitude of the Tip at a Sub-Atomic Level in Contact Mode Atomic Force Microscopy

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1. Introduction

Atomic force microscopy (AFM) traces the surface of a sample with a sharp tip. In contact AFM, the contact force causes bending or twist of the cantilever to accommodate topographic changes of a sample. Optical technique employing the laser beam and quadrant photo detector is the most common scheme to detect deflections of the cantilever.

By this technique, the vibrations of the cantilever corresponding to the each mode of the bending and twisting (lateral) directions can be obtained. In the torsional signal of the cantilever, the saw tooth signal caused by stick slip of the cantilever is usually seen as shown Fig. 1 during scan. It was conformed that the torsional resonance vibration of the cantilever superimposed on the saw tooth signal by spectrum analysis (Fig. 2) and calculations.

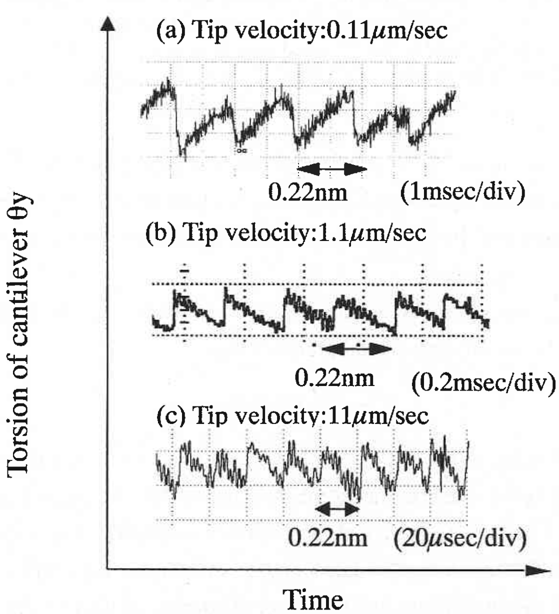

Fig. 1 Torsional signal of the cantilever

Fig. 3 shows the comparison of torsional signal when observing mica and graphite. It shows that the vibration amplitude at torsional resonance frequency when observing mica is smaller than that of graphite. These small waves seemed to include surface property information. Therefore, we mapped the amplitude variation of the torsional resonance frequency as scanning in contact mode AFM.

In order to measure the amplitude of the torsional resonance frequency, we composed the lateral amplitude method with employing lock-in voltmeter and absolute amplifier.

In this research, we would like to explain about method of amplitude mapping of the torsional vibration of the cantilever, and discuss about these contrast mechanism.

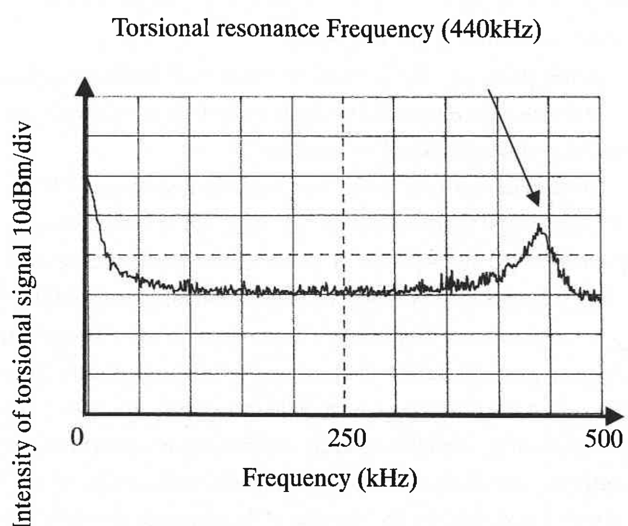

Fig. 2 Spectrum of the torsional signal
Tip velocity: 1.1μm/s

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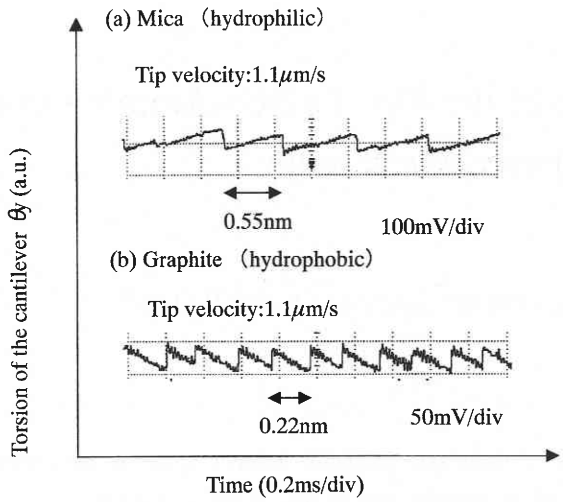


Fig. 3 The comparison of torsional signals from FFM

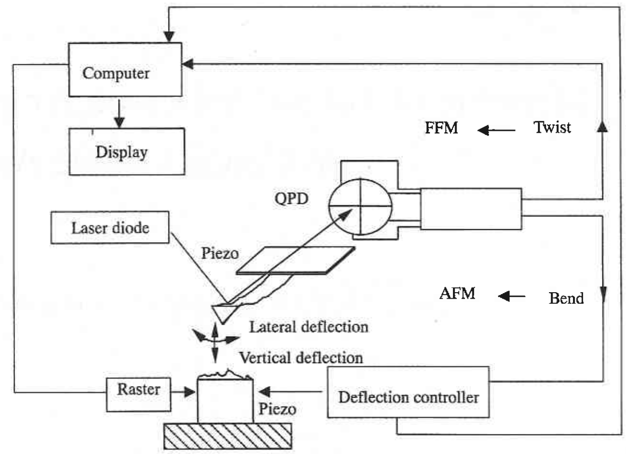


Fig. 4 The basic principles of contact mode AFM and FFM

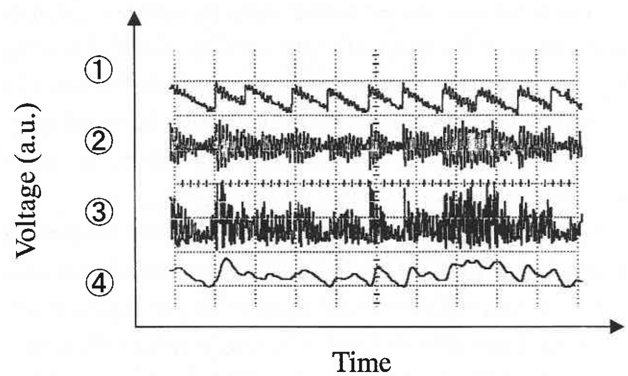


Fig. 5 The actual signal processing with absolute amplifier
scan speed: 1.1μm/s, specimen: HOPG
① Torsional signal, ② band pass filter signal (440 kHz),
③ absolute amplifier signal, ④ Low pass filter signal (20 kHz)

2. Experiments

Fig. 4 shows the basic principles of contact mode atomic force microscopy (AFM) and friction force microscopy (FFM). The AFM uses a cantilever with a sharp tip on one-end, which scans the surface of a sample. 2D topographical image can be obtained by observing the deflection of the cantilever, which follows the surface profile like a record player. FFM image can be obtained by mapping the torsional bending of the cantilever when scanning to vertically or parallel to the cantilever axis. The torsional signal (C-D) from quadrant photo detector (QPD) is used for amplitude mapping. The lateral (torsional) vibration resonance frequency, which depends on the cantilever dimensions was observed as 440kHz (0.8μm × 20μm × 200μm) and 250kHz (0.8μm × 40μm × 200μm) in torsional signal.

In this study, two kinds of lateral vibration amplitude mapping experiment were operated. One is the using lock-in voltmeter and another is the using absolute amplifier.

In the using lock-in voltmeter type, torsional signal from FFM and reference signal are put in lock-in voltmeter, and each signal is compared to output the amplitude of the resonance frequency. The value of the calculated signal is put in computer and mapped on display.

In using absolute amplifier, torsional signal from FFM is put in the band pass filter to extract the resonance frequency at first. Then this signal is put in absolute amplifier to rectify absolutely. The envelopes of the rectified signal are measured by low pass filter, and mapped on the display. The absolute amplifier method may be more suitable for recognizing the variation of the amplitude of oscillation.

Fig. 5 shows the actual signal processing with absolute amplifier while observing highly oriented poly graphite (HOPG). ① is torsional signal, ② is band pass filter signal (440kHz), ③ is absolute amplifier signal, ④ is low pass filter signal. The damping vibration of the resonance corresponding to stick slip can be seen on ②, ③, and ④.

It seems that these variations of the amplitude cause the contrast on the lateral vibration amplitude image.

3. Results

The Fig. 6 shows HOPG image using lock-in voltmeter. The contrast can be seen in the lateral vibration image. The step height is 2nm, the resonance frequency of the cantilever is 250kHz. Fig. 7 shows HOPG image using absolute amplifier when observing HOPG. The step height is 20nm, the resonance frequency of the cantilever is 440kHz. The contrast can be seen in the lateral vibration image also.

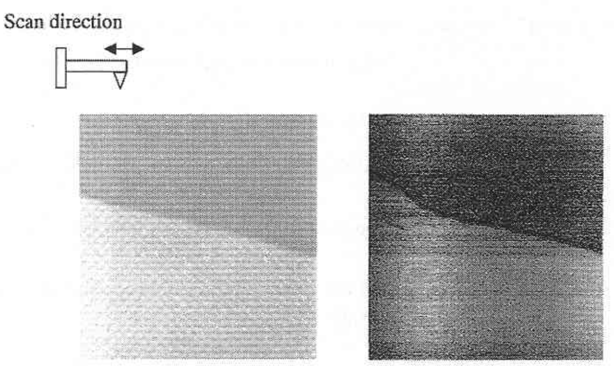
The probable causes of contrast in HOPG amplitude images are in the differences of crystalline orientation, surface properties or some effect of the step.

Fig. 8 shows the crystalline orientation images of each contrast section of Fig. 7 with Friction Force Microscopy (FFM). These images are obtained to ascertain whether the crystalline orientation is different in each contrast section. The right-above figure is the result of Fast Fourier Transforming (FFT). The direction of the hexagonal spot observed in FFT image represents the graphite crystalline orientation. Although the difference of the spot brightness can be observed, the orientation difference may not be observed in these images. Therefore, another hypothesis may be needed for the contrast image.

Fig. 9 shows the contrast change observed after re-approaching of the tip against HOPG. These images were taken by absolute amplifier method. (a) is an image taken before reapproach, (b) is after reapproach. Although both images are almost the same area, a contrast change can be observed. The difference of interaction of tip-surface, the contact point tip-surface, change of the attitude between the tip-surface, may cause the contrast part vice versa.

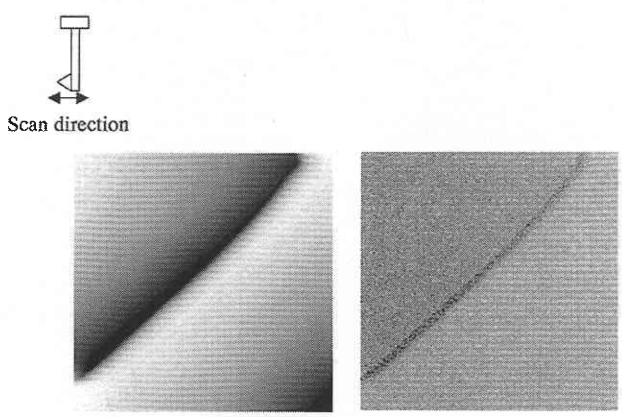
Fig. 10 shows the image of SiO_2 protrusions on Si substrate with lock-in voltmeter. (a) is topography, (b) is lateral vibration image. The step height is 60 nm. Scan size is 1.1μm × 1.1μm. The contrast can be observed the white section in hydrophobic Si and the black part in hydrophilic SiO_2 in this image. The probable causes of contrast in Si-SiO_2 are the differences of the surface property, difference of the crystal pitch or some effect of the step.

Au corrugation image shown in Fig. 11 is taken for an example of decreasing the effect of the sharp step. In this image, the dark part can be seen at the edge of the Au mound. The adhesion force



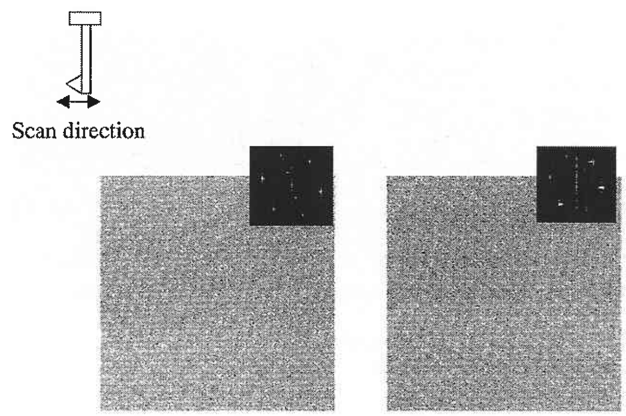
(a) Topography (Step height: 2nm, 1.1 μm × 1.1 μm)　(b) Lateral vibration image (1.9 μm × 1.9 μm)

Fig. 6　HOPG image using lock in voltmeter
resonance frequency of the cantilever: 250 kHz



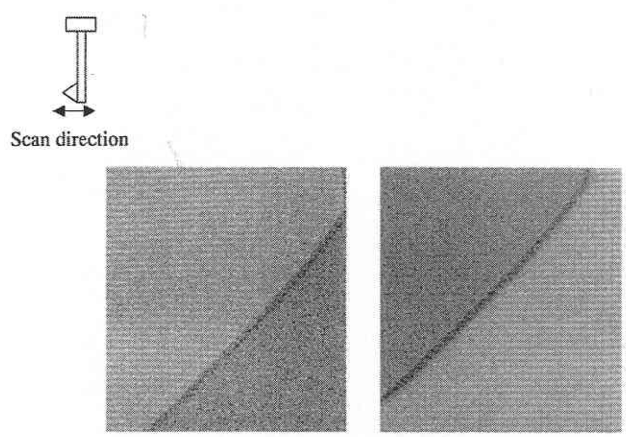
(a) Topography　(b) Lateral vibration image

Fig. 7　HOPG image using absolute amplifier
scan size: 1μm × 1μm, scan speed: 5.6μm/s, step height: 20 nm resonance frequency: 440 kHz, low pass filter: 1 kHz



(a) Dark part　(b) Bright part

Fig. 8　The crystalline orientation image of each contrast section with Friction Force Microscopy (FFM)
scan size: 5 nm × 5 nm, scan speed: 277 nm/s The right-above figure is the result after Fast Fourier transform.



(a) Before reapproaching　(b) After reapproaching

Fig. 9　The Contrast changing after reapproaching
scan size: 1μm × 1μm, scan speed: 5.54μm/s

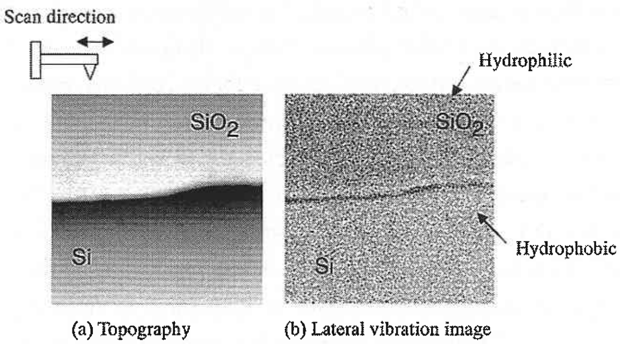


Fig. 10 The image of SiO_2 protrusions on Si substrate when using lock in voltmeter
scan size: 1.1μm × 1.1μm, step height: 60 nm
resonance frequency of the cantilever: 250 kHz

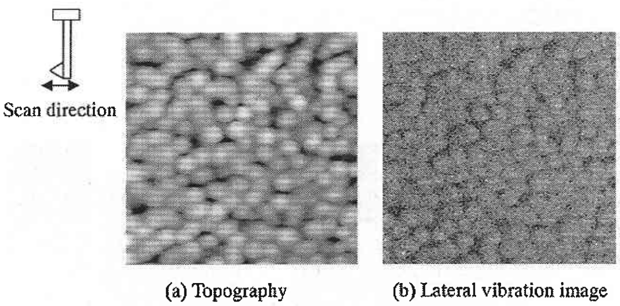


Fig. 11 Corrugation image of Au on Si base
scan size: 300 nm × 300 nm, scan speed: 332 nm/s, low pass filter: 140 Hz

increasing at the edge of Au mound or mechanical binding of the tip may be the provable causes for this contrast image.

Quantitative evaluation of the amplitude image is difficult at this point. However, the experiment demonstrates the possibility of detecting the differences in the tip-surface interaction not visible in the topographic image.

4. Discussion

The lateral vibration amplitude mapping of the cantilever resonance frequency was demonstrated with using lock-in voltmeter and absolute amplifier. The contrast image taken by these methods was provably including some effect of the step, not surface properties only. However, the contrast may give information of the tip-surface interaction not visible in the topographic image.

The passive vibration generated by scanning force is not reproducible entirely. Therefore, the active vibration control of the cantilever[1, 2] will be needed to detect the surface property.

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References

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