Rapid reconstruction of frequency shift vs. distance curves by multiple lock-in detection

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High-resolution three-dimensional dynamic force microscopy (3D-DFS) becomes an important tool to study tip-sample interaction forces. Measurements have been demonstrated mainly at low temperature where the thermal drift is negligibly small[1,2]. By incorporating an atom-tracked tip-positioning for excluding thermal drifts, 3D-DFS measurements recently become possible even at room temperature (RT)[3]. However, in both cases, a measurement usually takes more than 10 hours due to the enormous number of measurement points. Shortening the measurement time is one of the most important objectives, and the specially designed high-speed microscope successfully demonstrated a 3D-DFS measurement in a few minutes in liquid[4]. A general problem in such a time-consuming measurement is that the detection of the frequency shift (Δf) is performed in time-domain although significant signals locate only at a certain separate frequency domain (harmonics).

Here, we present a rapid reconstruction of the 3D-Δf landscape with the selective detection of the harmonic signals of Δf at RT. The second flexural mode of a silicon cantilever is used for the small amplitude operation (100 pm)[5], and df_{2nd} was detected by a digital phase-locked loop demodulator with a bandwidth of 1000 Hz (Zurich Instruments: HF2LI and HF2-PLL option). While scanning surfaces with a low feed-back gain, the Z sample scanner was modulated by 2 nm with a frequency of 45 Hz. The non-linear Z distance dependence of Δf gives rise to higher harmonic signals in Δf. The harmonics were directly detected by twelve digital lock-in amplifiers (Zurich Instruments: HF2LI x 2). The measurement bandwidth of ~1.7 Hz was small enough to separate the harmonics from each other and to obtain atomic resolution. Figure 1 shows a series of the harmonic signal maps of Δf_{2nd}, measured on KBr(001). From the twelve harmonic signals at each pixel, the high-resolution 3D Δf map was successfully reconstructed. The total measurement time amounts to less than 20 min.

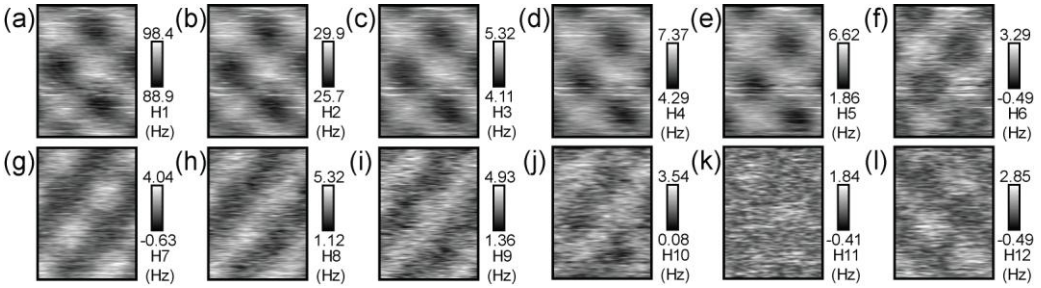

Figure 1: Higher harmonic images of Δf on KBr(001). The shift of the maxima position indicates the tip and sample deformations.

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