NANONIS APPLICATION NOTE

IMPROVED ATOMIC SCALE CONTRAST VIA BIMODAL DFM: DUAL OC4

Frequency-modulation atomic force microscopy (FM-AFM) is an efficient and already widely spread technique to obtain atomically resolved images of insulating or metallic surfaces. Typically, FM-AFM is based on scanning a sharp tip of a macroscopic cantilever over the surface, where the tip-surface distance is usually controlled by the frequency shit (Δf_1) of the first normal resonant mode (f_1) of the cantilever. The atomic-scale contrast arises from short range forces; e.g. covalent or ionic bonds, thus the detection sensitivity of the FM-AFM can be improved by using small tip oscillation amplitudes comparable to the decay length of the short-range forces, ~ 0.1 nm. A lot of efforts are put in this direction in the FM-AFM field, mainly based on the excitation of a tuning fork sensor [1] or higher flexural modes of cantilevers characterized by larger stiffness [2].

We made use of our home-built UHV RT-SPM with Nanonis SPM Control System and imaged a clean KBr(001) surface. Thanks to the Nanonis DUAL OC4 add-on, we were able to simultaneously excite via a dither piezo a commercial cantilever at the first (f_1) and the second flexural resonance frequencies (f_2), and independently demodulate Δf_1 and Δf_2. The core of the experimental setup is emphasized in Figure 1. With appropriate P/I gains for the Z-Controller and carefully chosen demodulation bandwidths for both OC4-s, we optimized the experimental conditions and we were able to control and detect extremely small signals.

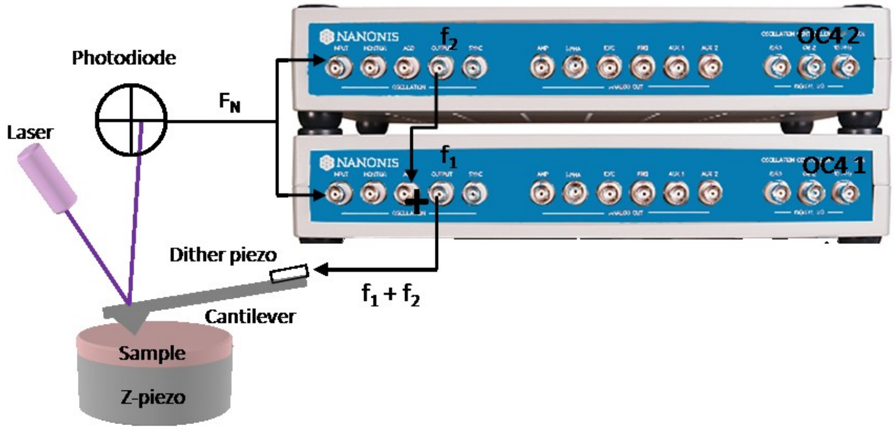

Figure 1. Core of the experimental setup. The cantilever is mechanically excited at first (f_1) and second flexural (f_2) modes with a DUAL OC4 configuration. The two OC4 devices are set as two independent phase-locked loop circuits that demodulate Δf_1 and Δf_2 from the photodiode vertical deflection signal (F_N).

The oscillation amplitudes were careful controlled to well defined values A_1 and A_2. Accurate amplitude calibration was insured by an automated procedure based on the Nanonis LabVIEW Programming Interface. When using small amplitudes for the second flexural mode compared to the first mode (A_2 ~ tens of pm, A_1 ~ tens of nm), we demonstrate that Δf_2 (z) gets

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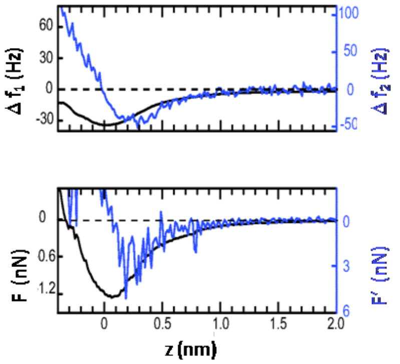

Figure2. a) Distance dependence of Δf_1 and Δf_2 measured exactly on top of an atom with amplitudes A_1 = 17.8 nm, A_2 = 25 pm. b) interaction force F calculated from Δf_1 in (a) and the corresponding force gradient F'. Cantilever parameters: f_1 = 154.021 kHz, f_2 = 960.874 kHz, Q_1 = 31059, and Q_2 = 6246.

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proportional to the interaction force gradient F′(z) averaged over the large oscillation A_1. F′ shows stronger z dependence than F, thus Δf_2 is more sensitive to the short range forces than to Δf_1, see Figure 2. Bimodal Dynamic Force Microscopy (Bimodal DFM), opposite to conventional FM-AFM with one small amplitude, enables the access to closest tip-sample distances during one oscillation cycle, moment when the frequency shift of the second flexural resonance Δf_2 becomes extremely sensitive to short-range interactions, thus enhancing the atomic scale contrast without causing instabilities.

As a proof, on a atomic step on KBr(001) surface the 2D second resonance frequency shift Δf_2 map shows increased contrast compared to the feedback error signal of the topography Δf_1, see Figure 3. The short and long-range contribution to Δf_1 strongly varies and the tip cannot follow the real topography in the vicinity of the step. As the amplitude of the second flexural mode is small, Δf_2 is more sensitive to the short-range forces and extremely sharp contrast is then obtained.

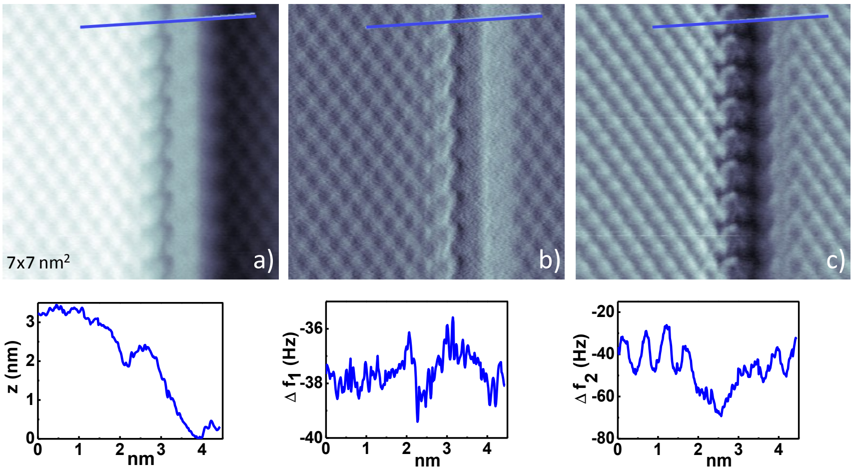

Figure 3. Atomically resolved bimodal DFM images on KBr(001): a) Topography and cross section, b) Δf_1 map, and cross section. c) Δf_2 map and cross section. Cantilever parameters: $A_1 = 10$ nm, $A_2 = 50$ pm, $f_1 = 154.021$ kHz, $Q_1 = 31059$, $f_2 = 960.874$ kHz, $Q_2 = 6246$, z setpoint $\Delta f_1 = -38$ Hz.

Bimodal DFM is definitely a step forward in the unceasing efforts of pushing the atomic force resolution to new frontiers, and why not, the starting point for multi-modal DFM, where more than two oscillations are simultaneously controlled.

References:
*[1] F. J. Giessibl, APL**73**, 3956 (1998).*
*[2]S. Kawai et al., APL**86**, 193107 (2005).*
[3] S. Kawai et al., PRL **103**, 220801 *(2009)*

Nanonis Modules in Use:

- Base Package
- Oscillation Controller OC4
- Dual OC4
- LabVIEW Programming Interface
- Atom Tracking

System:

- Home-built UHV RT-SPM

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