

Frequency-Modulation AFM with sub-Å amplitudes

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The first NC-AFM images with atomic resolution were achieved using cantilevers with a spring constant of $k \approx 10$ N/m and an oscillation amplitude of about 10 nm. The qPlus sensor based on the use of a standard quartz tuning fork with $k \approx 1800$ N/m allows amplitudes of $A \approx 1$ nm. However, optimal signal-to-noise-ratio is expected for amplitudes $A \approx 1$ Å [1] and a small A also allows higher sensitivity to short-range forces. Furthermore, at sub-Å amplitudes the frequency shift is almost proportional to the force gradient and the deconvolution of the force is greatly simplified [2]. In order to reach small amplitudes, a large k is required according to the stability criteria: $k \cdot A > \max(-F_{ts})$ and $k \cdot A^2 > Q \cdot \Delta E_{ts} / \pi$ with the force F_{ts} acting between tip and sample, the energy dissipation ΔE_{ts} occurring during the interaction tip – sample and the quality factor Q of the cantilever [1]. For this reason, sensors in the qPlus design using modified tuning forks with $k \approx 4600$ N/m and $f_0 \approx 45,4$ kHz were built as illustrated in Fig.1a), allowing stable imaging with $A \approx 1$ Å.

First tests of these stiff cantilevers were done on already intensively studied $\text{CaF}_2(111)$ surfaces [3]. Large scans show flat terraces and steps of different heights [see Fig. 1b), a $0.6 \times 0.6 \mu\text{m}^2$ -scan taken at $\Delta f \approx -38$ Hz]. On a smaller scale atomical resolution is achieved. Depending on the termination of the tip, the attractive or the repulsive mode is realised and the resulting images show atoms in disk like or triangular shape as predicted by Foster et al. in [4]. In the corresponding height profiles typical maxima and minima occur from which conclusions on the arrangement of the sublattices and thus the imaged atoms can be drawn. Even when scanning over steps with the height of a full triple layer, i.e. 315 pm, the atomic resolution can be conserved. An example is shown in Fig. 1c), imaging parameters: $\Delta f \approx -14$ Hz, scan size about $10 \times 10 \text{ nm}^2$.

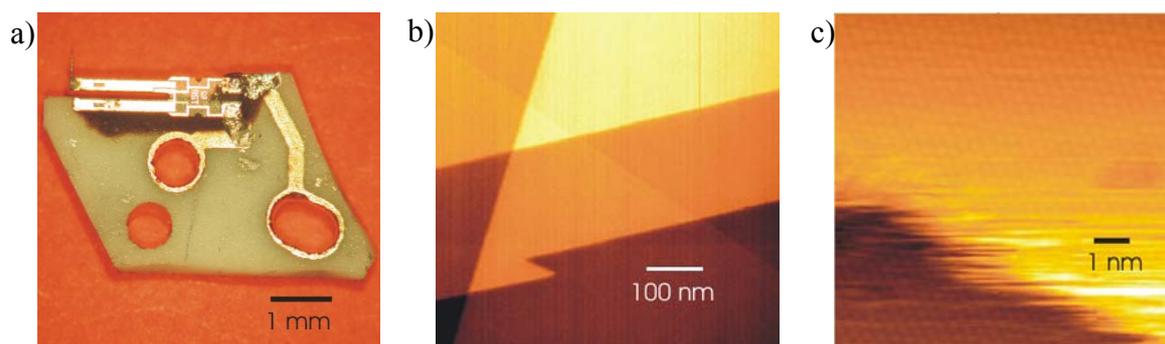


Fig.1 a) qPlus sensor with modified tuning fork; b) AFM image of a $\text{CaF}_2(111)$ surface showing steps; c) atomic resolution on a triple layer step on $\text{CaF}_2(111)$

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