NANONIS APPLICATION NOTE

DRIFT-CORRECTED 3D DYNAMIC FORCE SPECTROSCOPY AT ROOM TEMPERATURE

The ability to collect 3D dynamic force spectroscopy (DFS) data opens the door to valuable and more complete information of the interaction forces at the atomic scale. True site-specific atomic scale interaction forces and potential energies were accessible before mainly at low temperatures due to the absence of instrumentation-induced artifacts.

The 3D force field above a NaCl(001) surface has been measured at room temperature in nc-AFM mode making use of the Nanonis controller at small amplitudes. Careful drift corrections were possible by means of a special functionality of the controller, the atom tracking, used in automated way via the LabVIEW programming interface. After eliminating the drift, 2D cuts perpendicular and parallel to the surface reveal distance-dependent shifts of characteristic atomic-sized features, reflecting asymmetries of the probing tip apex, but mainly due to sub-atomic displacements induced by short-range forces (Fig. 1a-f) [1]. High resolution 2D maps allow visualizing contrast changes at a series of tip-sample distances like frequency shift Δf, energy dissipation E_{ts}, vertical force F_{int}, energy U, and lateral force components. Since high-resolution 3D DFS measurements take relatively long time, drift artifacts must be monitored and eliminated as much as possible.

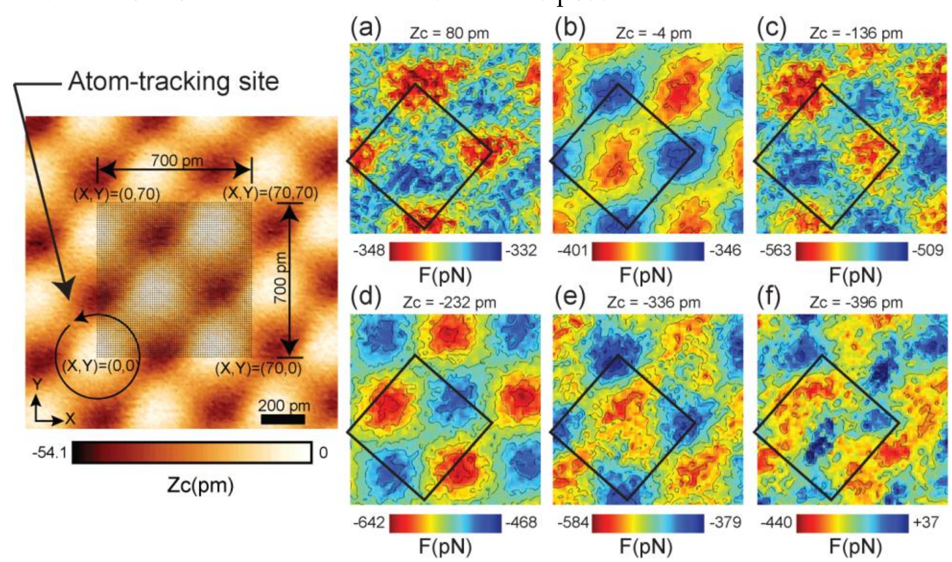

Figure 1. Constant height maps of the calculated interaction forces at various tip-sample distances (right images, a-f). NaCl(001) topography (left) The superposed array of dots (71x71) depicts the positions of the 3D DFS measurements. The second flexural resonance mode f_{2nd} of a Si cantilever was used to sense the vertical tip-sample interaction force. The high effective stiffness k_{2nd}=1450 N/m permits stable small amplitude operation with improved sensitivity [2, 3], here A_{2nd} was kept constant at 400 pm.

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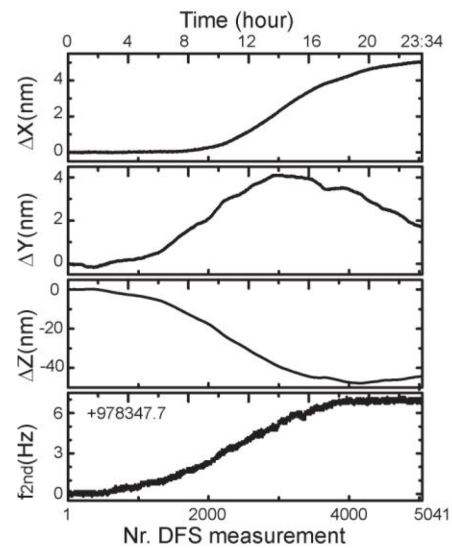

Figure 2. Drifts of the X, Y, and Z signals, as well as of the resonance frequency of the second flexural mode f_{2nd} during 23 h and 34 min measured by atom tracking. The maximum excursions in the X, Y, and Z directions were 5.1 nm, 4.3 nm, and 48 nm, respectively. The frequency shifted only by +7.4 Hz corresponding to a decreased temperature of approximately 0.15°C.

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When performing 3D DFS measurements the nonlinear evolution of the thermal drift should be taken into account. In order to visualize the range and the nonlinear nature of the artifacts introduced at room temperature the drifts of the relative tip-sample X, Y, Z coordinates and of f_{2nd} during the entire 3D DFS measurement time of 23 h and 34 min were recorded (Fig. 2) and corrected.

Spectroscopic features of the Nanonis controller can be called from the LabVIEW programming interface (Fig. 3), and before each measurement sequence an automated drift correction can be performed. The relative tip-sample position between each single measurement has been adjusted by the atom-tracking function above a particular maximum of the essentially undistorted topographic image recorded beforehand (Fig. 1 left). The required X, Y, Z adjustments averaged over 6s were recorded together with the thermal shift of the second flexural resonance frequency f_{2nd}. This shifted resonance frequency was then reset to be the reference frequency with respect to which the interaction-induced shift Δf_{2nd} is determined by a phase-locked loop (Oscillator Controller OC4).

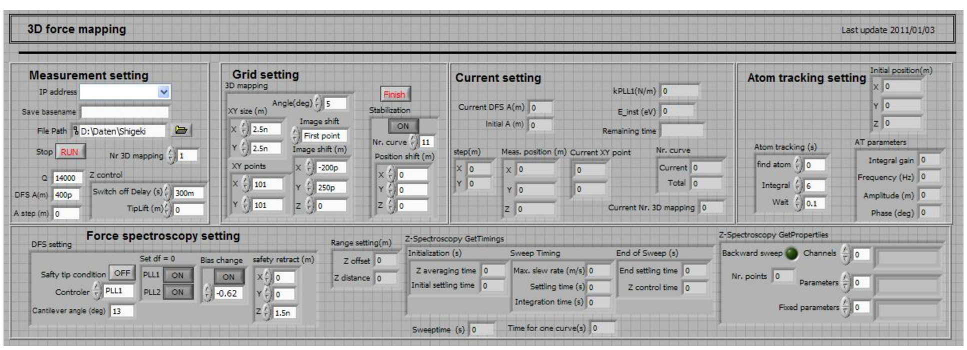

Figure 3. Illustration of the customization level offered by the LabVIEW programming interface (PI).

Room temperature 3D DFS measurements show how the tip asymmetry and atomic displacements significantly distort the force field probed by the AFM tip close to an atomically flat surface. Reconsideration of the nature and shape of nanoscale tip-sample contacts involved in AFM, together with the real estimation of 3D force field could have a real impact on applications like controlled manipulation of atoms, molecules or clusters at such temperature ranges.

Reference:

[1] S. Kawai et al, PRB 83, 035421, (2011).
[2] S.Kawai et al, APL 86, 193107, (2005).
[3] S. Kawai et al, PRL 103, 220801, (2009).

Nanonis Modules in Use:

- Base Package BP4
- Oscillation Controller OC4
- LabVIEW Programming Interface PI
- Atom tracking AT4

System:

- Home-built RT AFM/STM

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