Force Gradient Spectroscopy on C-Nanotube Tips using FM-AFM

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Today, a promising application of Carbon Nanotubes (CNTs) is the use as probes in scanning force microscopy, to name a few arguments:
- CNTs have a large aspect ratio allowing surface structures with steep edges to be investigated,
- CNTs have both mechanical strengths and a flexible behavior that prevents from wear modification of the tube end.
- CNTs are chemically inert.

The two last items give the invaluable possibility to have at disposal a robust AFM tip of well defined shape that remains unmodified over various AFM measurements. However, when a CNT lies between a tip apex and a surface, resonance frequency shift and damping signal in Frequency modulation-AFM (FM-AFM) operation are profoundly modified and should reflect the mechanical response of CNT. To add the complexity, the CNT mechanical response itself strongly depends of the contact between the free CNT end and the surface.

Approach curves were performed with the CNT tip shown in fig. 1. Approach curves were used, as the analysis of the frequency shift and of the damping signal gives direct information on the different regimes of CNT behaviour. Detailed information was obtained by systematic variations of different experimental parameters like oscillation amplitude (Fig. 2), pressure and surfaces and by use of numerical simulations with a Virtual FM-AFM. While the elastic properties of the tube can be primarily derived from the frequency shift in the intermittent contact region, the increase of the damping in this area is related to the sticking process. In particular, damping signals give direct evidence of the type of contact between the free CNT end and the surface: either a free sliding behaviour or a clamped NT one.

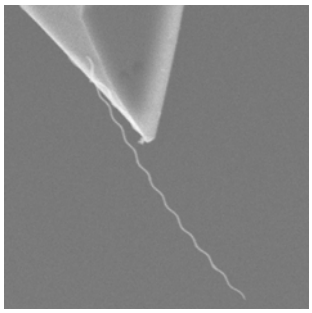

Fig. 1 SEM image of CNT-Tip

Following these results, resonance frequency shift and damping signals were readily used to image surface. On a heterogeneous surface (MBE grown GaAs Nanodots surface), a remarkable difference in topography contrast between image done with standard Si-cantilevers and coiled CNT tip (fig. 1) was found with a good lateral resolution. We found this result non intuitive and somewhat unexpected, since the coiled CNT has a large contour length, more than 10 µm and large diameter 110 nanometres. We shall discuss the origin of such contrast variation.

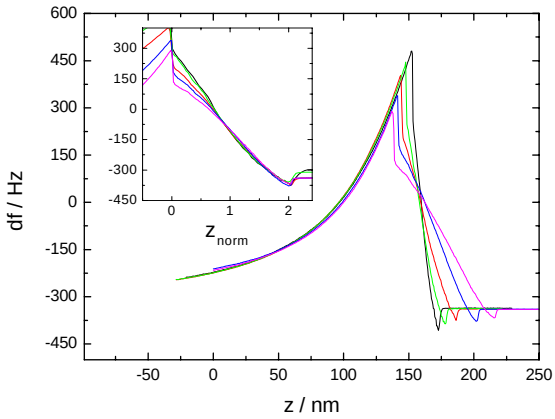

Fig. 2: Approach curves of the frequency shift for 5 amplitudes A. Inset the data are recorded with a reduced x axis where the vertical displacement is divided by A.