Noise limits in NC-AFM

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The precision of NC-AFM measurements is limited by noise generated in various parts of the experimental setup. In this talk, I will introduce and evaluate the different noise contributions, demonstrate how noise is transmitted through the measurement system and what steps have to be taken for noise optimised measurements. It is demonstrated how a careful characterisation and calibration of the measurement system yields quantitative information on the noise figures and how the noise performance can be optimised by improvements of the instrumentation, proper settings for experimental parameters, and avoiding noise amplification by the unfavourable interaction of different measurement system components.

The analysis starts with noise present in the case of negligible tip–surface-interaction [1]. It is discussed how the displacement-noise spectral density $d^{z}(f)$ at the input of the frequency demodulator propagates to the frequency-shift-noise spectral density $d^{\Delta f}(f_m)$ at the demodulator output in dependence of cantilever properties and settings of the signal processing electronics. Prerequisite to a quantification of the noise figures is the knowledge of cantilever properties [2-4], the calibration of the cantilever displacement signal and a known transfer function of the signal-processing electronics [1]. $d^{\Delta f}(f_m)$ can be predicted from the measured $d^{z}(f)$, for specific filter settings, a given level of detection-system noise spectral density $d^{z,ds}(f)$ ds and the measured cantilever thermal noise spectral density $d^{z,th}(f)$. For a system with a low-noise signal detection [5] and a suitable cantilever, operated with appropriate filter and feedback-loop settings, room temperature measurements at a low thermal-noise limit are possible with a significant bandwidth.

Additional noise components arise if there is a significant tip-sample interaction [6]. The total noise power spectral density is in this case not simply the sum of all noise contributions but its magnitude and spectral characteristics is determined by the strongly non-linear tip-sample interaction and the coupling between the amplitude and tip-sample distance control loops as well as the characteristics of the frequency demodulator. A comparison of respective experimental results and simulations yields a good understanding of noise generation and propagation in the NC-AFM and provides a quantitative prediction of noise for arbitrary experimental situations. Simple strategies for noise optimisation can be derived.

References

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