Control of tip position using co-located magnetic actuation for high-speed AFM

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AFM imaging utilizes a sensitive feedback mechanism to achieve a specific control objective by adjusting the tip-to-sample distance through z-motion control. For example, the control objective of contact mode AFM is to maintain a constant deflection of the cantilever while the oscillation amplitude or frequency is regulated in usual dynamic mode AFM. Recently, direct control of tip-sample interaction force was also proposed. In AFM imaging, as a sample is scanned at higher speed, topographic details present themselves to the z-control loop as disturbances at higher frequencies. Therefore, the bandwidth of the z-control loop is one of the key factors that limit imaging rate. The z-control loop in dynamic mode AFM involves various dynamic processes, including z-scanner dynamics, cantilever dynamics, and tapping dynamics. Over the past 15 years, smaller AFM cantilevers as well as smaller piezoelectric actuators, in conjunction with active Q-control, have been proposed, and significant improvements for high-speed AFM have been made.

In this presentation, a co-located scheme for z-motion control is proposed, in which a magnetic actuator is introduced to work together with the regular z-scanner in a dual-control-loop scheme aiming to directly control the tip position and hence the tip-to-sample distance. The magnetic actuator overcomes the bandwidth limitations of the z-scanner and does not introduce undesirable under-damped dynamics. Moreover, since the magnetic force is applied directly at the location where the motion being controlled, it is much easier and reliable to use a model cancellation method to compensate the dynamics of the cantilever and to elevate the speed of the tip-position control. This additional magnetic actuator serves to make the entire cantilever bandwidth available for tracking topographic variations at specified tip-sample interaction force. In high speed imaging, it will pick up high spatial-frequency surface topography and regulate the tip-sample interaction force while the regular z-scanner provides the necessary motion range.

A fast programmable electronics board (Field Programmable Gate Array) was employed to implement the proposed dual-control-loop scheme, in which model cancellation algorithms were realized to enhance the bandwidth of the magnetic coil and to replace the lightly damped dynamics of the cantilever with an over-damped system. It allows the cantilever to position the tip very rapidly without introducing unwanted transient dynamics. Experimental results will be presented to illustrate the effectiveness of the propose method. For tip-position control, it is shown that while an ordinary cantilever is excited by the magnetic actuator to oscillate around its resonance frequency (34.8 kHz), the same actuator is actively controlled to move up the mean position of the tip by 20nm within one cycle. Other preliminary results and potential issues in relation to high-speed AFM imaging and direct tip-sample interaction force control will also be discussed.