Control of Higher Cantilever Eigenmodes for High Speed Atomic Force Microscopy

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Introduction

High Speed Atomic Force Microscopy (AFM) is of great interest towards the real-time observation of processes and large scan areas, such as cell dynamics or inspection of semiconductor wafers. However, a major bottleneck in the topography feedback loop of AFMs is the cantilever probe itself [1]. The effective Q factor and natural frequency in the presence of a sample surface form an imaging time constant of $\tau_i = \llbracket 2Q \rrbracket_{(eff,i)}/\omega_{(eff,i)}$ in each eigenmode i. Hence, using higher cantilever eigenmodes can increase the imaging bandwidth considerably [2]. Alternatively, the Q factor could be lowered to increase the bandwidth, with the cost of higher forces exerted onto the sample surface [3]. In this work, active Q control is combined with the fast imaging capability of higher eigenmodes. The discussed compensator can be easily attached to existing AFMs and allows for flexible tuning of the imaging rates. The setup is tested in combination with active cantilevers that integrate both actuator and sensor [4].

Compensator

The developed compensator allows to modify the cantilever dynamics such that the Qi factor and $\omega_{(n,i)}$ of each eigenmode can be set to desired values. Each eigenmode is approximated by a second order transfer function, acquired by an automatic system identification approach. As the velocity proportional signal of the cantilever vibration is not measured, it is determined through an estimator operated in real-time and in parallel to the cantilever. A controller uses the estimated signals and modifies the cantilever dynamics. The discretized compensator is integrated into a Xilinx Spartan-3A DSP with connected 100 MHz ADCs and DACs. The internal compensator feedback loop rate is 3.57 MHz. This allows scanning at higher eigenmodes up to the MHz range.

Result

The cantilever Qi is modified up to the third eigenmode and used for scanning a sample structure. Figure 1 indicates the three resonances with different Q factors: Q1=10, 60, 120, Q2=120, 148, 291 and Q3=120, 210, 757. Also in the same Figure, (d) shows a modification of the resonance frequency of the first eigenmode. Figure 2 is a scan of a calibration sample (Anfatec UMG03/PtS) that has 2 μm wide and 58 nm high parallel SiO2 lines on a silicon substrate with a pitch of 4 μm at a scan rate of 15 lines/s. Here, the first eigenmode is used and modified as indicated. The tracking issues at the higher Q are clearly visible, as expected by the lower bandwidth.

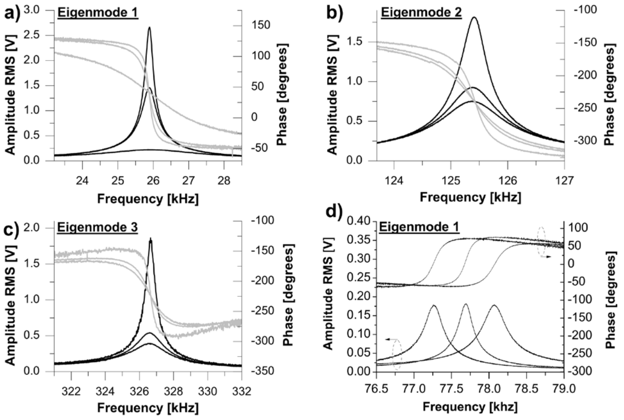

Fig. 1: (a)-(c) indicates the modified Q factors in different eigenmodes, (d) modified resonance frequ. of the first eigenmode.

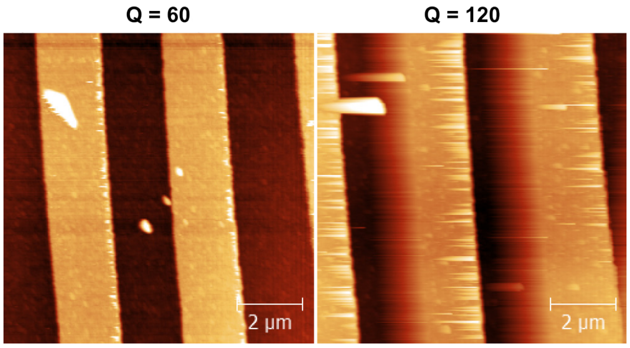

Fig. 2: Images of a calibration sample at a scan rate of 15 lines/s and Q factors as indicated.

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