Frequency Modulation Subsurface Ultrasonic Force Microscopy

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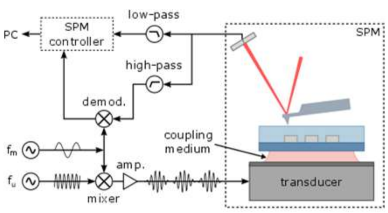
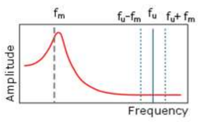
INTRODUCTION

Scanning Subsurface Ultrasonic Force Microscopy[1] (SSURFM) relies on a change in the sensing cantilever's resonance frequency to detect subsurface structures through their mechanical properties. It gains sensitivity both from exploiting the cantilevers large dynamical stiffness at high frequency and from using the sensitivity of the shifting contact resonance frequency.

[1] M.H. van Es, A. Mohtashami, R.M.T. Thijssen, D. Piras, P.L.M.J. van Neer, H. Sadeghian, *Mapping buried nanostructures using subsurface ultrasonic resonance force microscopy*, Ultramicroscopy, Volume 184, Part A, 2018, Pages 209-216, doi:10.1016/j.ultramic.2017.09.005



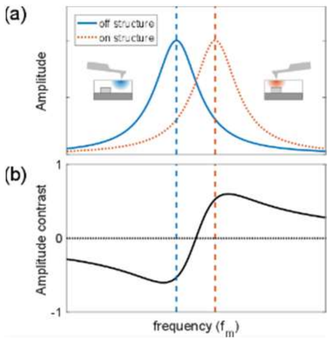


(a) Sketch of setup; (b) Sketch of excitation (blue) and detection (grey) frequencies with the cantilever's resonance (red)

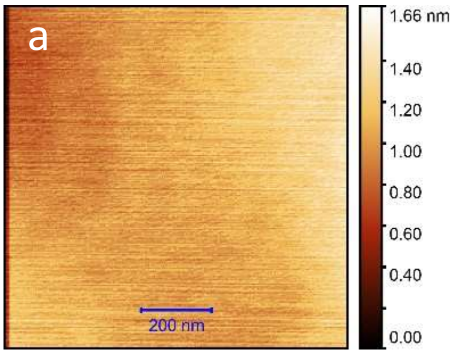
WHY FREQUENCY MODULATION SSURFM

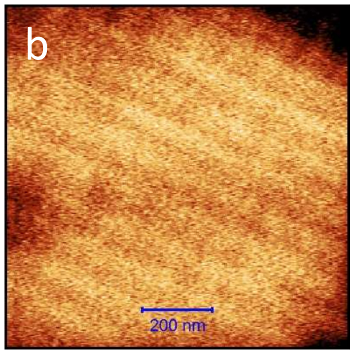
In Amplitude Modulation SSURFM, the cantilevers amplitude is monitored at a fixed frequency. In Frequency Modulation SSURFM (FM-SSURFM) the frequency is tracked instead. Advantages include

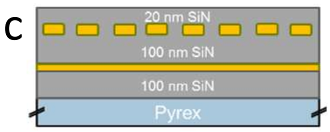
- quantitative analysis
- robust against large variations
- Maximum sensitivity by always being at the optimal frequency



(a) Shift in contact resonance frequency from on to off a subsurface structure; (b) Frequency dependent amplitude contrast associated with the shift in contact resonance when measuring at a single fixed frequency



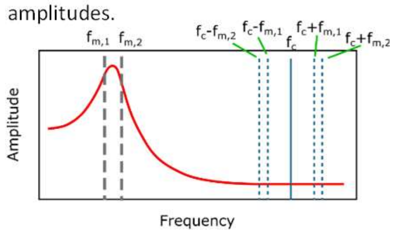




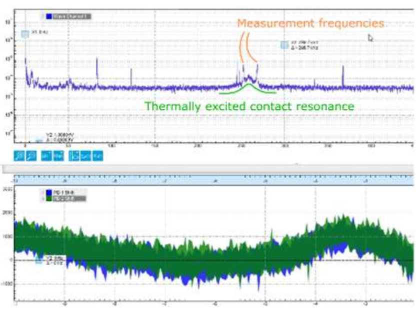
(a) Topography and (b) frequency shift image of dense gold lines in SiN measured with a SmartTip electrostatic membrane cantilever. Schematic cross section of this sample is shown in (c). Pitch of the gold lines is 100nm. Cantilever stiffness 4N/m (est.); f_u=20MHz; fm≈600kHz (1st contact resonance). Thanks to the QuTech consortium for providing these samples

IMPLEMENTATION

Dual Frequency Resonance Tracking is a FM technique which relies on keeping the amplitude at two frequencies – below and above the resonance – equal through a feedback loop which adjusts the central frequency based on the measured amplitudes.



Sketch of excitation (blue) and detection (grey) frequencies in FM-SSURFM with the cantilever's resonance (red). $f_{m,1}$ and $f_{m,2}$ are the two modution frequencies which are adjusted based on their amplitude difference



FM-SSURFM in action. (Top) Spectrum of cantilever motion showing the thermal contact resonance with both excited sidepeaks. (Bottom) Frequency shift over time, in this case due to thermal drift in the cantilever bending.

EXPERIMENTAL RESULTS

In the bottom figure in the middle column we show the signal spectrum of a working FM-SSURFM setup. For this measurement, the setup was tuned to clearly show the thermally excited contact resonance by using a soft cantilever (0.03N/m). Temperature fluctuations caused slow but large changes in contact resonance frequency through bending of the cantilever allowing a basic test of functionality of the method.

For optimal performance, FM-SSURFM needs a clean cantilever excitation spectrum. We therefore subsequently implemented FM-SSURFM with an electrostatically driven tip (see poster "Electrostatically driven cantilever tip for SSURFM"). With this equipment it was easy to setup the technique for subsurface imaging culminating in the frequency shift subsurface image above.

CONCLUSION

We implemented FM-SSURFM on our commercial AFM system with some modifications to ensure a clean frequency response of the cantilever. FM-SSURFM is a robust, quantitative tool for subsurface imaging.

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