# Frequency Modulation Sub-surface Atomic Force Microscopy

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## INTRODUCTION

Elasticity based Sub-surface Atomic Force Microscopy is a promising metrology solution for CD measurements, defect characterization and alignment and overlay applications.

One major challenge in current amplitude modulation based Sub-surface AFM techniques is the choice of the excitation frequency. The contrast and sensitivity of the subsurface signals are highly dependent on the excitation frequency. If the excitation frequency is too far away from the contact resonance frequency, the sensitivity for detecting subsurface features reduces. Moreover, also the amplitude drops, thus reducing the signal to noise ratio (SNR).

To maximize the SNR at every measurement location or pixel, the frequency modulation (FM) scheme can be used. In the frequency modulation technique, a proportional-integral controller changes the excitation frequency of the cantilever to minimize its deviation from the contact resonance frequency. In this way, every pixel of the image is captured with the cantilever at resonance, thus providing the highest SNR and sensitivity. Furthermore, since the technique provides the contact resonance frequency, quantitative interpretation of the results is facilitated compared to amplitude modulation techniques.

### Advantages

The frequency modulation technique has the following advantages over amplitude modulation:

- Higher signal to noise ratio (Fig 1 a,d).
- Better and constant sensitivity. (Fig 1 c,f)
- Easier extraction of quantitative information. (Fig 3)
- Easier to interpret AFM pictures.

### Requirements

Implementation of the FM technique requires a clean frequency response spectrum with monotonic phase near the contact resonance. Excitation techniques such as electrostatic or photothermal actuation are best suited to meet this requirement.

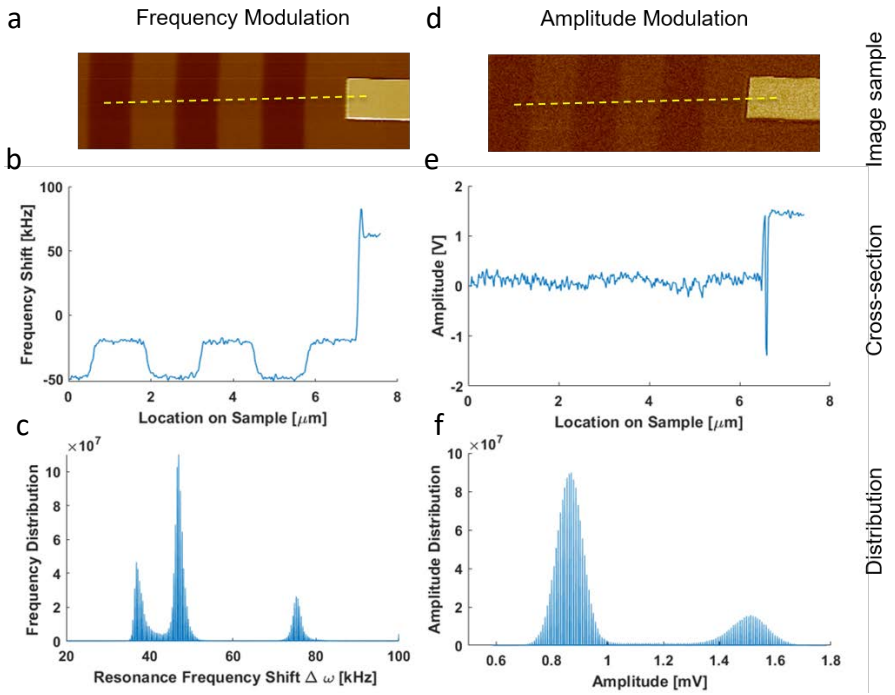



***Fig 1.*** *A comparison between Amplitude Modulation and Frequency Modulation Sub-surface AFM. The frequency modulation technique provides an improved signal to noise ratio, which enables the detection of smaller changes in local surface elasticity.*

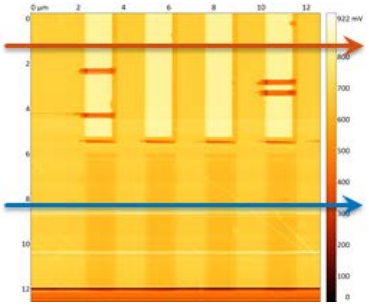
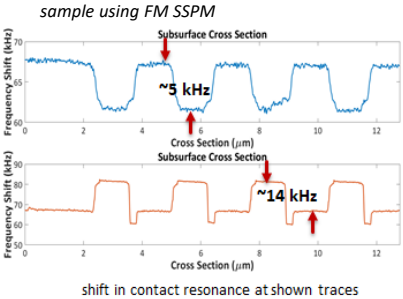


***Fig 2.*** *Sub subsurface image obtained on overlay sample using FM SSPM*




shift in contact resonance at shown traces

***Fig 3.*** *Frequency shift as function of location for two traces*

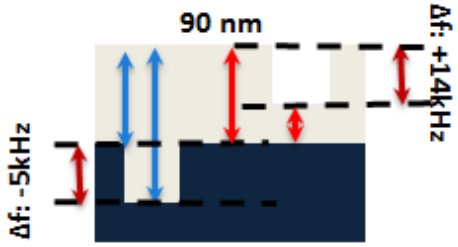



***Fig 4.*** *Sample description and frequency shift as function of location on the sample imaged in Fig 2.*

## CONCLUSION

- FM modulation SSPM successfully implemented as a new SSPM scheme
- Can be used with all (clean) excitation means
- Provides better SNR and sensitivity compared to AM SSPM scheme
- Enables quantitative imaging of subsurface features

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