

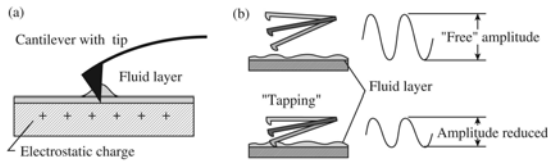
Spring 2008 MSAE E4990y
Introduction to STM and AFM

Lecture 26
Dynamic-Mode AFM
April 30, 2008

Outline

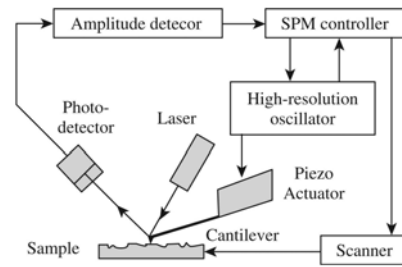
- Three modes of AFM
- Static force detection
- Tapping Mode
 - Amplitude modulation
 - AFM in liquid: acoustic actuation
 - AFM in liquid: magnetic actuation
- Frequency Modulation Mode
 - Apparatus
 - Frequency Shift
 - Second harmonics
 - Average Tunneling Current

The Tapping-Mode AFM (1)



- (a) Because of the water film and static charge, inaccuracy would occur.
 (b) In the tapping mode, the cantilever is let to vibrate at its resonance frequency.
 The force between the tip and the sample causes a reduction of vibrational amplitude, which is taken as the signal for feedback.
 The damage to the tip and the sample is reduced, but not eliminated.

The Tapping-Mode AFM (2)



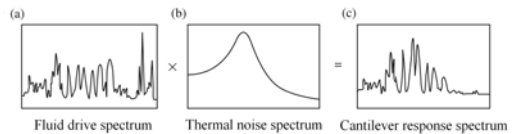
The cantilever is actuated by a bimorph piezo, and its vibrational amplitude is typically detected by the beam-deflection method.

The Tapping-Mode AFM (3)

Drive Frequency Range	10KHz to 1MHz
Drive Amplitude and Frequency Adjustment	Software control and display of TappingMode parameters allows fast, semi-automated on-screen optimization
Detector	RMS-to-DC amplitude detector provides phase-independent amplitude signal; Noise level > 0.5Å RMS
Cantilevers	Etched silicon cantilevers with or without coatings for specialized applications; typically 50-500KHz resonant frequencies
Tip-Sample Approach	Motorized approach automatically brings cantilever into TappingMode operation at low tracking force

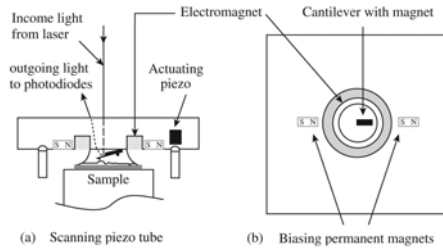
The manufacturer's notes for the tapping mode AFM.

The Tapping-Mode AFM (4)



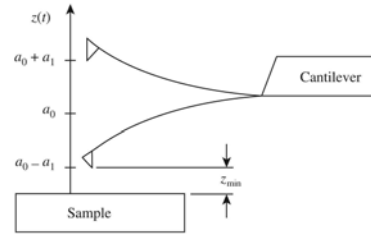
For tapping-mode AFM in liquids, the acoustic excitation method usually works well, in spite of the seemingly noisy situation.

The Tapping-Mode AFM (5)



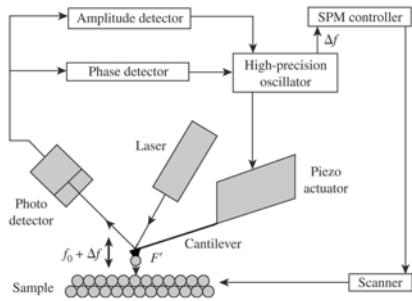
Magnetic excitation for tapping-mode AFM in liquids is tested and commercially available, but its application depends on many factors.

The Non-Contact (Frequency-Modulation) AFM (1)



In non-contact mode of AFM, the tip is probing the attractive force between the tip and the sample, without making a contact – without having the repulsive force. The shift of the resonance frequency of the cantilever is taken as the signal.

The Non-Contact (Frequency-Modulation) AFM (2)



The vibrational amplitude of the cantilever is detected. The feedback system is to maintain a constant amplitude while adjusting the frequency of actuating it.

The Frequency Shift: Small Amplitude Limit

$$m \frac{d^2 z}{dt^2} + kz = F(0) + F'(0)z + \frac{F''(0)}{2}z^2.$$

$$\omega_0 = 2\pi f_0 = \sqrt{\frac{k}{m}},$$

$$z = a_0 + a_1 \cos \omega t + a_2 \cos 2\omega t.$$

frequency shift

$$\Delta f \equiv \frac{\omega - \omega_0}{2\pi} = -\frac{f_0}{2k} F''(0).$$

second-harmonic

$$a_2 \cong \frac{a_1^2}{12k} F''(0).$$

The Frequency Shift: Large Amplitude Limit (1)

$$m \frac{d^2 z}{dt^2} + kz = F(z).$$

$$z = a_0 + a_1 \cos \omega t + a_2 \cos 2\omega t.$$

$$ma_0 + (k - m\omega^2) a_1 \cos \omega t + (k - 4m\omega^2) a_2 \cos 2\omega t = F(a_0 + a_1 \cos \omega t).$$

Introducing $\varphi = \omega t$,
multiplying by $\cos \varphi$ and integrate over 2π ,

$$\Delta f = \frac{f_0}{2\pi a_1 k} \int_0^{2\pi} \cos \varphi F(a_0 + a_1 \cos \varphi) d\varphi.$$

The Frequency Shift: Large Amplitude Limit (2)

Introducing $\zeta = a_1(1 + \cos \varphi)$,

$$\Delta f = \frac{f_0}{\pi a_1^2 k} \int_0^{2a_1} F(z_{\min} + \zeta) \frac{(a_1 - \zeta) d\zeta}{\sqrt{\zeta(2a_1 - \zeta)}}.$$

large amplitude

$$\Delta f = \frac{f_0}{\sqrt{2\pi} a_1^{3/2} k} \int_0^\infty F(z_{\min} + \zeta) \frac{d\zeta}{\sqrt{\zeta}} = \frac{f_0}{a_1^{3/2} k} \gamma(z_{\min}),$$

normalized frequency shift

$$\gamma(z) \equiv \frac{1}{\sqrt{2\pi}} \int_0^\infty F(z + \zeta) \frac{d\zeta}{\sqrt{\zeta}}.$$

The Complete System

(c) Detector:
A phase-locked loop to convert the frequency shift into an analog signal

(b) Controller:
A positive feedback loop to excite the cantilever to vibrate at its resonance frequency

(a) The AFM unit:
A piezo to actuate the cantilever, and a deflection sensor to detect its vibration

