

Spring 2008 MSAE E4990y  
Introduction to STM and AFM

Lecture 25  
Atomic Force Microscopy  
April 28, 2008

Outline

- The basics of AFM
- Cantilevers: manufacturing and calculation
- Static force detection
  - Optical beam deflection method
  - Optical interferometry
- Dynamic force detection
  - Amplitude modulation
  - AFM in liquid: acoustic actuation
  - AFM in liquid: magnetic actuation

The invention of AFM (1)

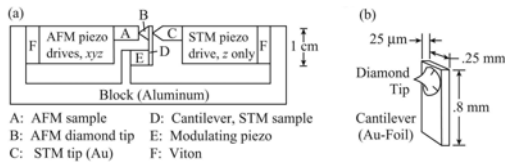
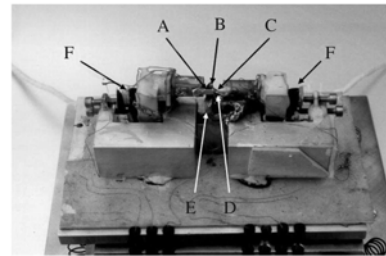


Figure 1 in the first paper on AFM.

Common elements with STM: piezoelectric scanner, feedback system, computer control and display system, vibration isolation.

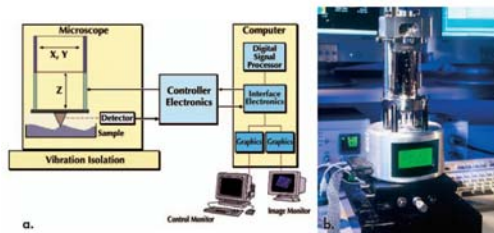
Unique elements: cantilever, modulating piezo, second tip to detect displacement of the cantilever.

The invention of AFM (2)



A: AFM sample; B: AFM diamond tip; C: STM tip (Au); D: Cantilever, STM sample; E: Modulating piezo; F: Viton.

An example of commercial AFM (1)



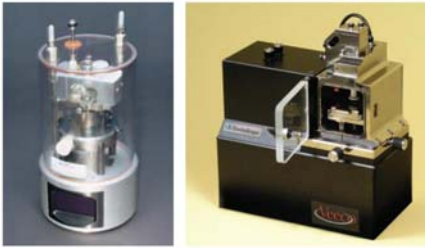
The Veeco Nanoscope III and Dimensions are the most popular AFM. It comes with electronics, a computer and related software.

An example of commercial AFM (2)

Characteristics of Common Microscopic Techniques for Imaging and Measuring Surface Morphology			
	Optical Microscope	SEM	SPM
Sample operating environment	Ambient air, liquid, or vacuum	Vacuum*	Ambient, air, liquid, or vacuum
Depth of field	Small	Large	Medium
Depth of focus	Medium	Large	Small
Resolution: X, Y	1.0 $\mu\text{m}$	5nm	2-10nm for AFM 0.1nm for STM
Resolution: Z	N/A	N/A	0.05nm
Effective magnification	1X - 2x103X	10X - 106X	5x102X - 108X
Sample preparation requirement	Little	Little to substantial	Little or none
Characteristics required for sample	Sample must not be completely transparent to light wavelengths used.	Surface must not build up; charge and must be vacuum compatible.*	Sample must not have local variations in surface height >10 $\mu\text{m}$ .

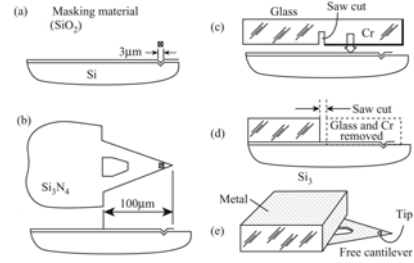
A comparison of three types of commercially-available microscopes.

### An example of commercial AFM (3)



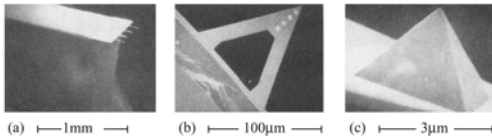
AFM could work in a controlled atmosphere, or a low vacuum.

### Fabrication of the silicon-nitride cantilever (1)



The tip, an integrated part of the cantilever, is made by differential etching.

### Fabrication of the silicon-nitride cantilever (2)



Cantilevers with integrated tip for AFM are commercially available.

### Calculation formulas for rectangular cantilevers

resonance frequency

$$f_0 = \frac{0.56}{L^2} \sqrt{\frac{EI}{\rho S}}$$

force constant

$$K = \frac{3EI}{L^3}$$

moment of inertia

$$I = \frac{1}{12} bh^3$$

cross-sectional area  $S = bh$

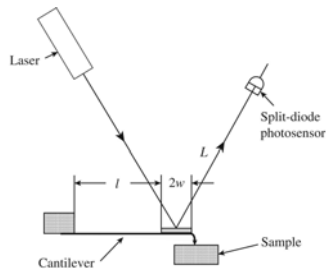
length  $L$  width  $b$  height  $h$

density  $\rho$

Young's modulus  $E$

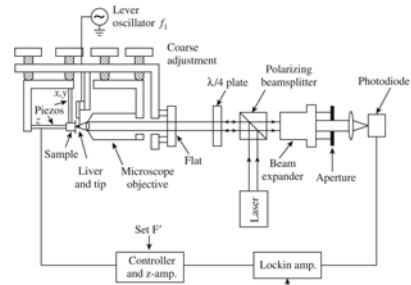
	Si	Si <sub>3</sub> N <sub>4</sub>	Steel	PZT-8	Quartz
$E$ (GPa)	188	210	200	87	97.2
$\rho$ (g/cm <sup>3</sup> )	2.33	3.29	7.9	7.6	2.65

### The Static Force Detection in AFM (1)



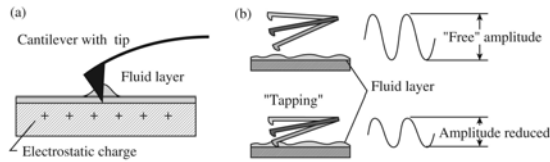
Optical beam deflection method with a laser and a split photodiode.

### The Static Force Detection in AFM (2)



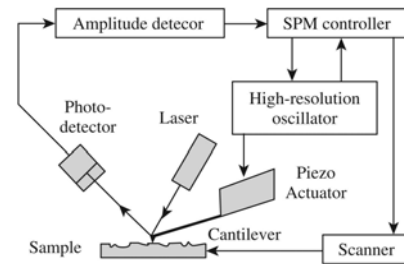
Optical interferometry is a standard method to detect small displacements. The sensitivity of displacement detection could as good as 1 picometer.

### 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)



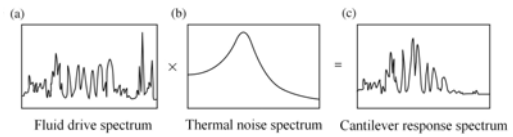
The cantilever is actuated by a bimorph piezo, and its vibrational amplitude is typically detected by the beam-deflection method.

### The Tapping-Mode AFM (3)

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

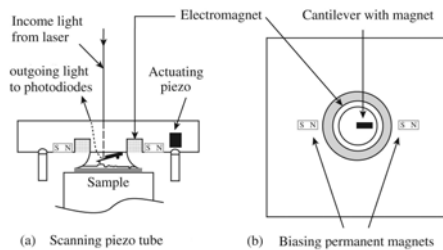
The manufacturer's notes for the tapping mode AFM.

### 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.