Scanning Probe Microscopy: Atomic Force Microscope

Fabrication and Characterization of Nanomaterials

2006 Summer Laboratory Course

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Scanning Probe Microscope (SPM)

- A group of instrument for surface measurement and other applications
  - Atomic force microscope (AFM), Electron force microscope (EFM), Scanning tunneling microscope (STM), Magnetic force microscope (MFM), etc.
- Wide range materials (hard, soft)
- Atomic to micro level
- Simple operation
- High resolution
- One equipment with multi-functions

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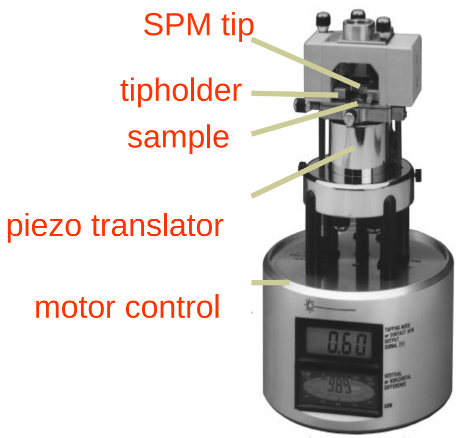
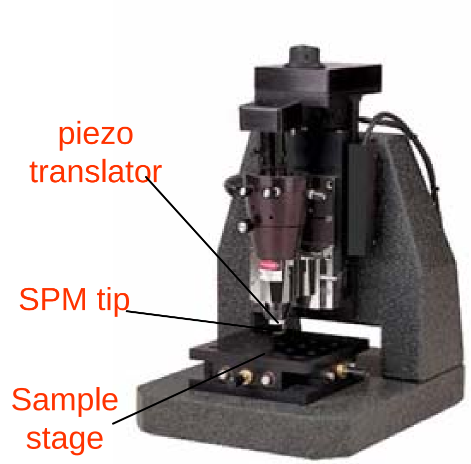
SPM Principle



a



b

SPM scanners are made from a piezoelectronic material that expands and contracts proportionally to an applied voltage

a. The piezo scanner moves the sample relative to the tip
b. The sample is stationary while the scanner moves the tip

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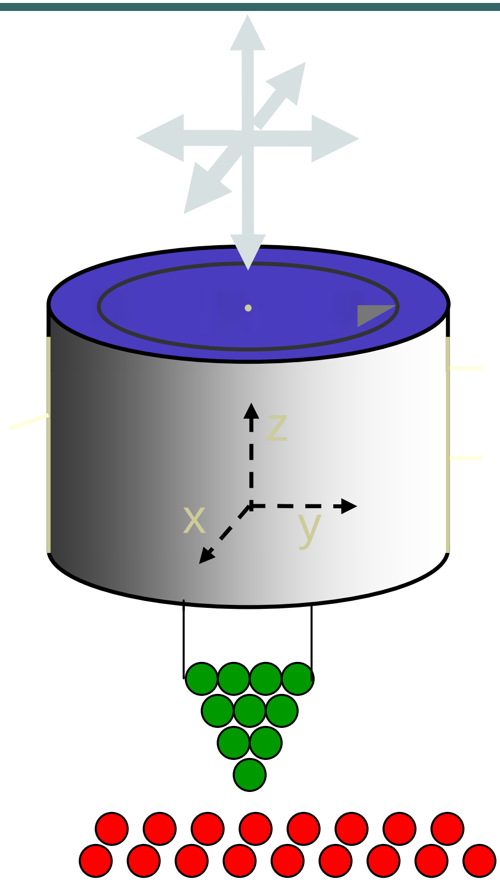
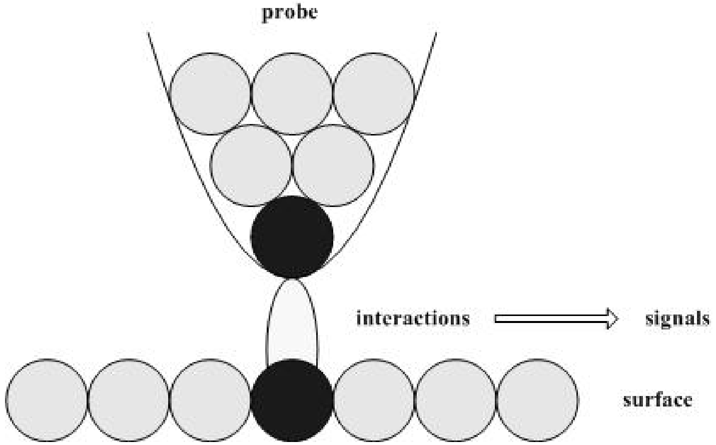
SPM Principle

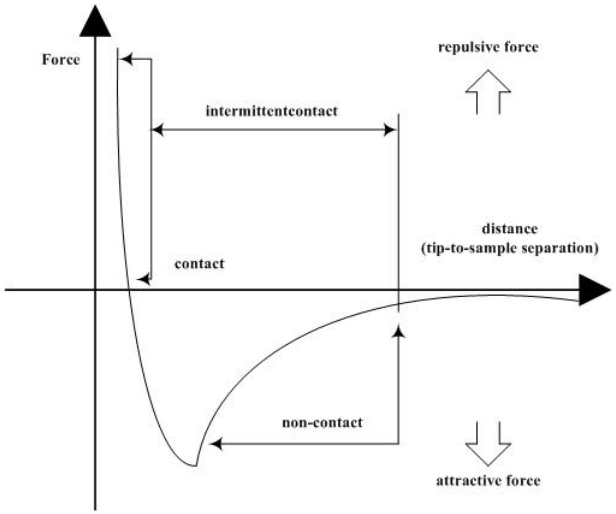


Movement of the piezo scanner and the tip

SPM principle



Interatomic force vs distance



Atomic Force Microscope (AFM)

- Measures the force between tip and sample surface
- Applies to all kinds of materials
  - insulator, semiconductor, conductor, organics, etc
- Operates in three different modes
  - Contact mode
  - Non-contact mode or intermittent mode
  - Tapping mode

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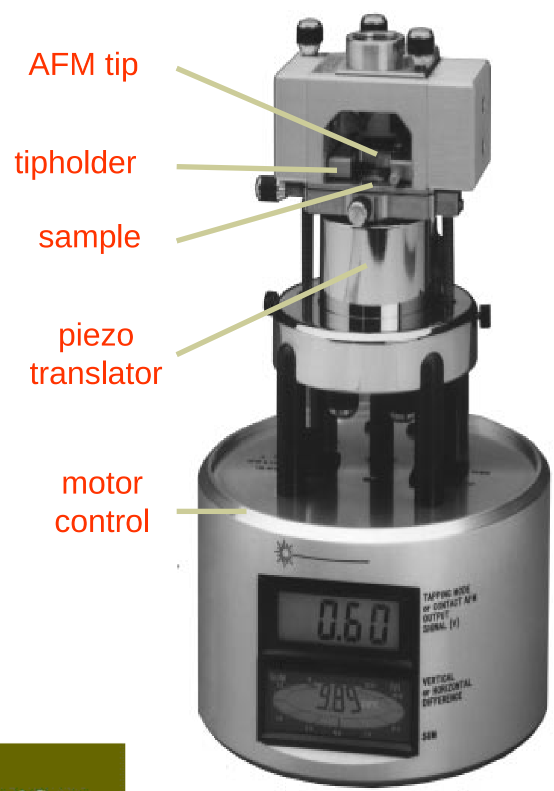
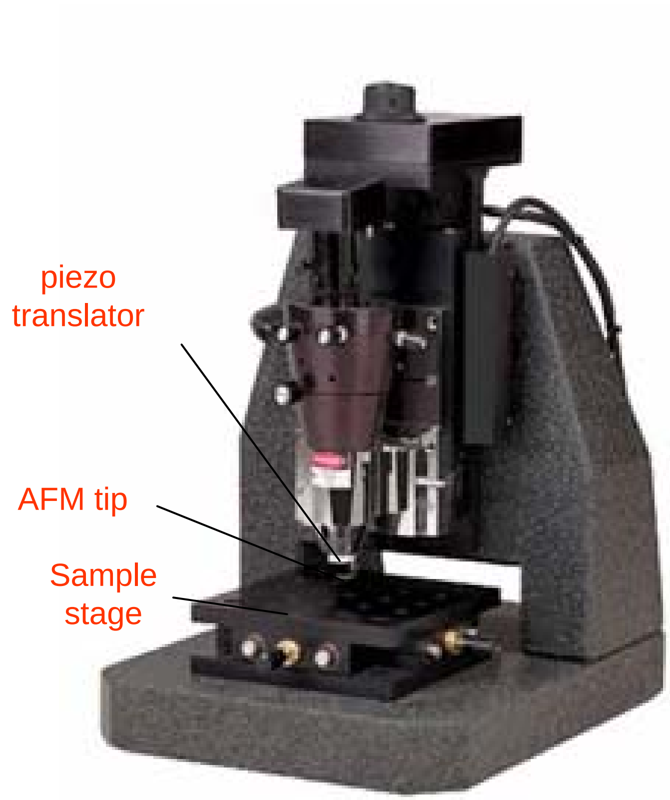
AFM





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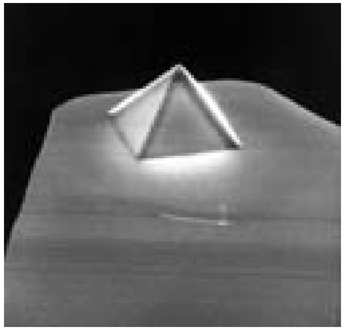
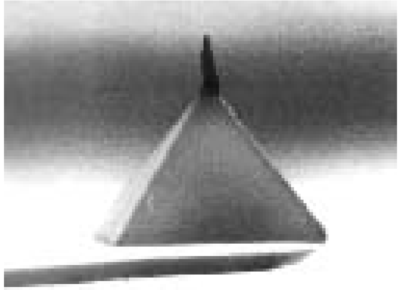
AFM



a



b

c

Three common types of AFM tip (sharper tip, higher resolution)

(a) Normal tip (b) Super tip (c) Ultra sharp tip

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AFM Operation

- Sharp tip is scanned over a surface with feedback control.
- Piezoelectric z-axis actuator (drive) maintains the tip at a constant force or height above the sample surface.
- Laser reflection from the probe head is monitored by two photo-diodes.
- Photodetector measures the difference in light intensities between the upper and lower photodiode, and then converts to voltage.
- Feedback from the photodiode difference signal controls the z-axis position through software from the computer.

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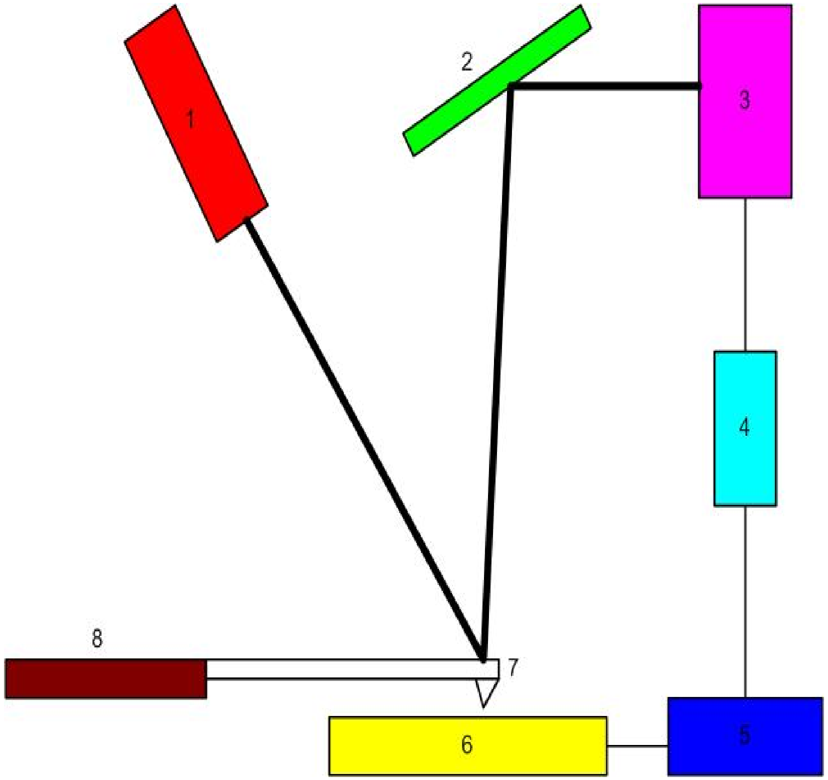
AFM Operation



1. Laser
2. Mirror
3. Photodetector
4. Amplifier
5. Register
6. Sample
7. Probe
8. Cantilever

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AFM Modes

- Contact Mode: repulsive mode
  - Soft physical contact with the sample
  - Force range from nano to micro Newton in ambient conditions
  - Tip does not oscillate
  - Reasonably hard materials
    - ⇨ most metals, ceramics, polymers, etc.
  - Cannot follow abrupt edges or tall steep features
  - Cantilever is less expensive than others
  - Easier to set-up and use with instrument than other modes
  - Able to get lateral friction forces on the sample surface
  - Possible to damage the surface

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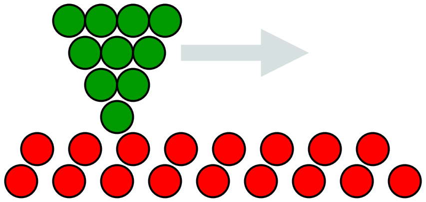
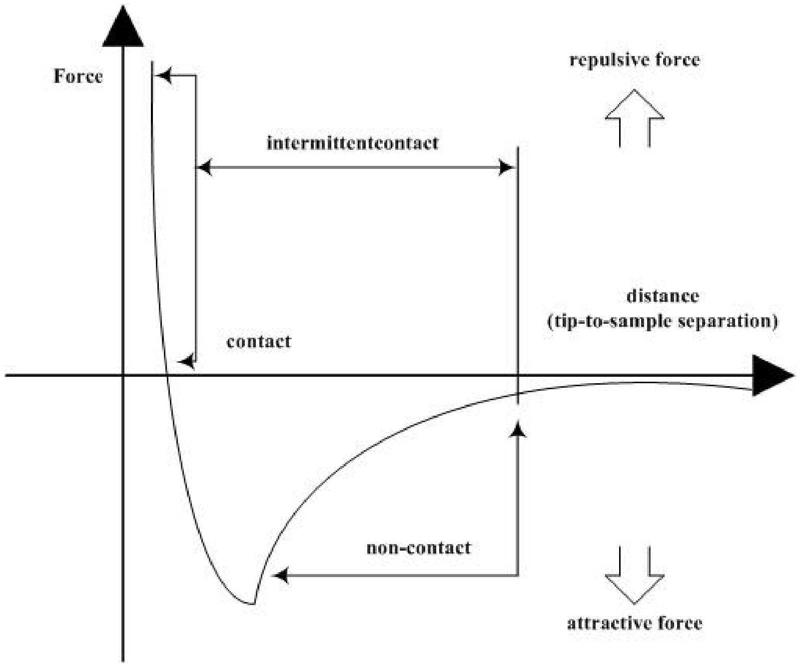
AFM Modes





Contact mode (stationary sample)

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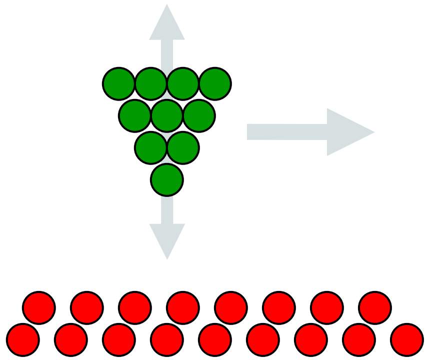
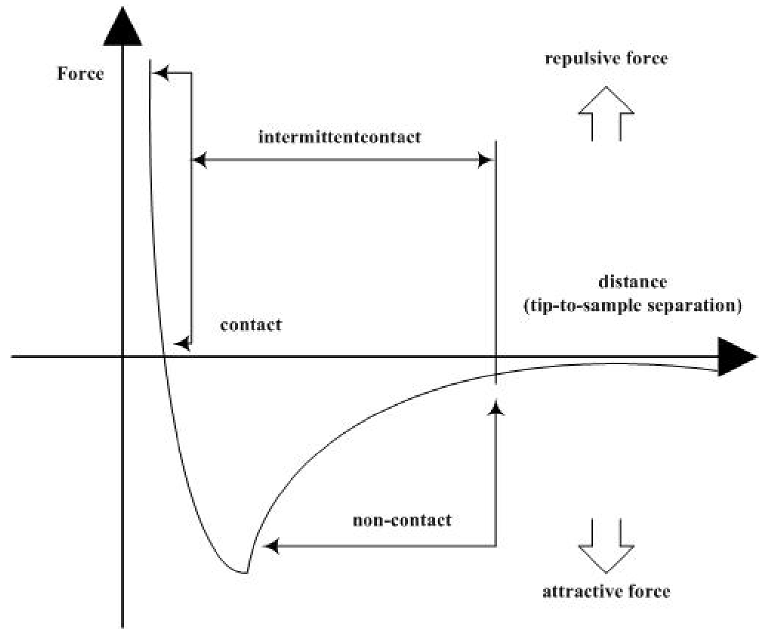
AFM Modes

- Non-Contact Mode: attractive force mode
  - One of several vibrating cantilever techniques
  - Cantilever oscillating near the surface of a sample
  - Uses Van der Waals, electrostatic, magnetic or capillary force for producing images
  - Very low force between the cantilever tip and the sample surface
  - Best for soft or elastic samples
  - Cantilever more expensive than contact mode
  - Tip does not touch the sample surface

AFM Modes





Non-contact mode (stationary sample)

AFM Modes

- Intermittent-Contact Mode: tapping mode
  - Similar to non-contact mode except the tip barely hits or taps the sample surface
  - Overcomes problems associated with friction, adhesion, electrostatic forces, and other difficulties that plague conventional AFM scanning methods
  - Works well on all surfaces
  - Less damaging to the sample than contact mode because of eliminating lateral forces such as friction
  - Tip more expensive and harder to handle

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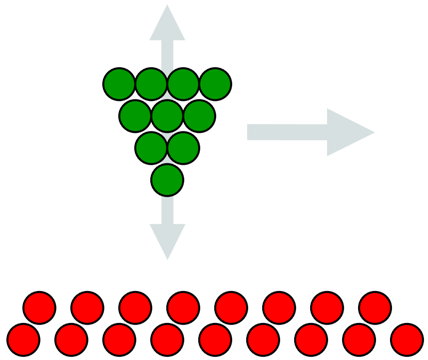
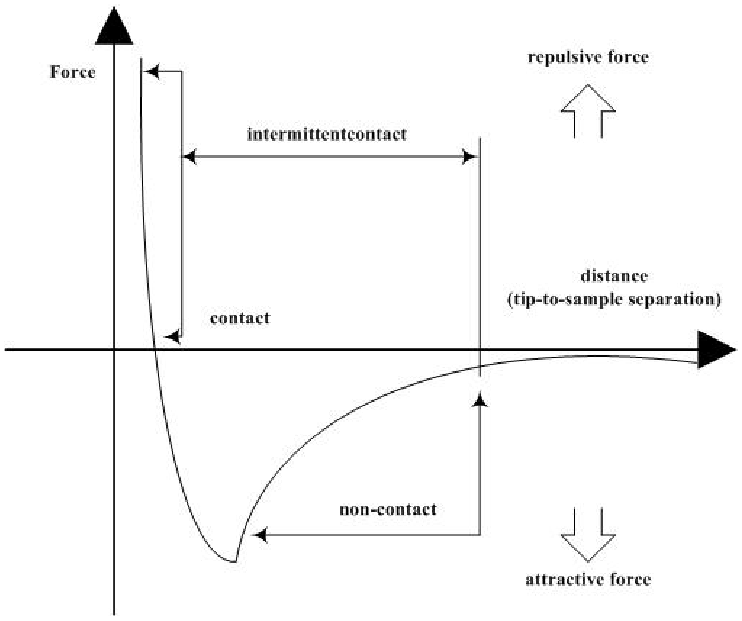
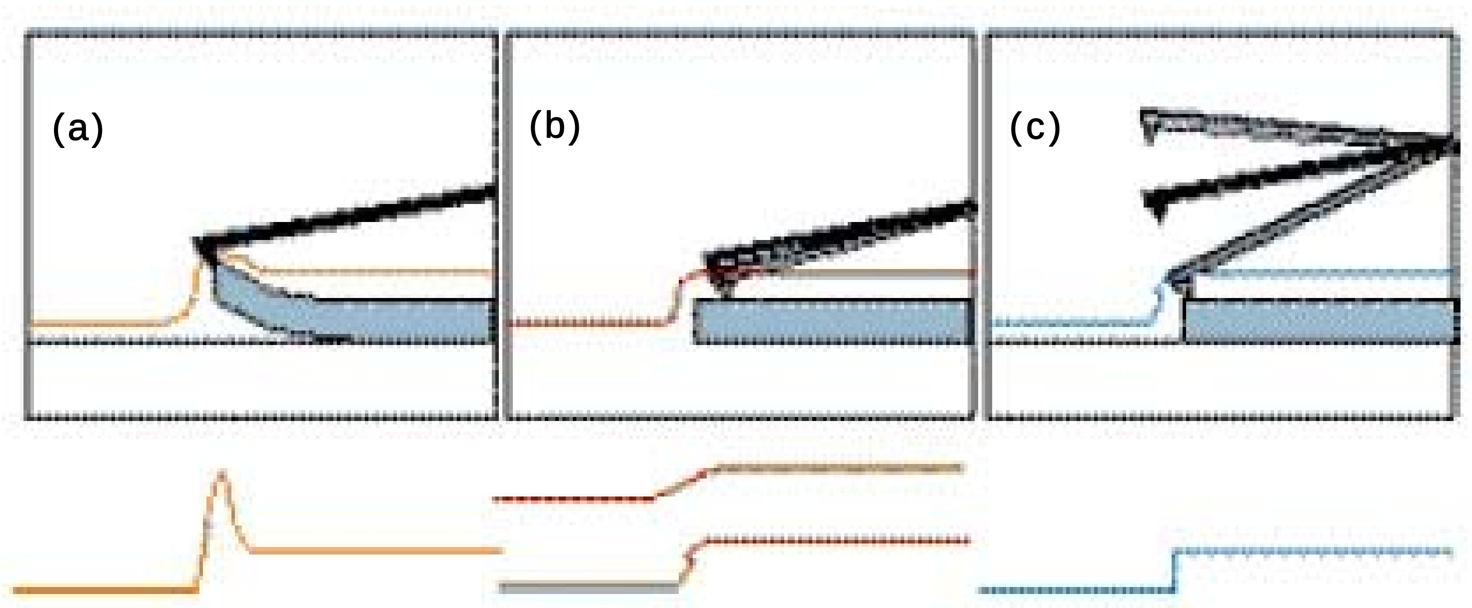
AFM Modes





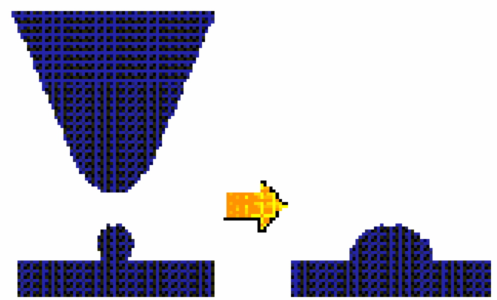
Tapping mode (stationary sample)

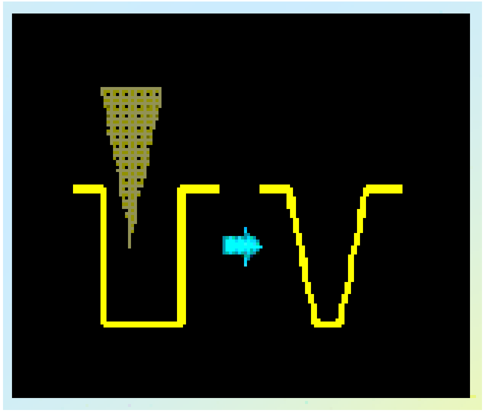
AFM Modes



(a) Contact Mode, (b) Non-contact Mode, and (c) Tapping Mode

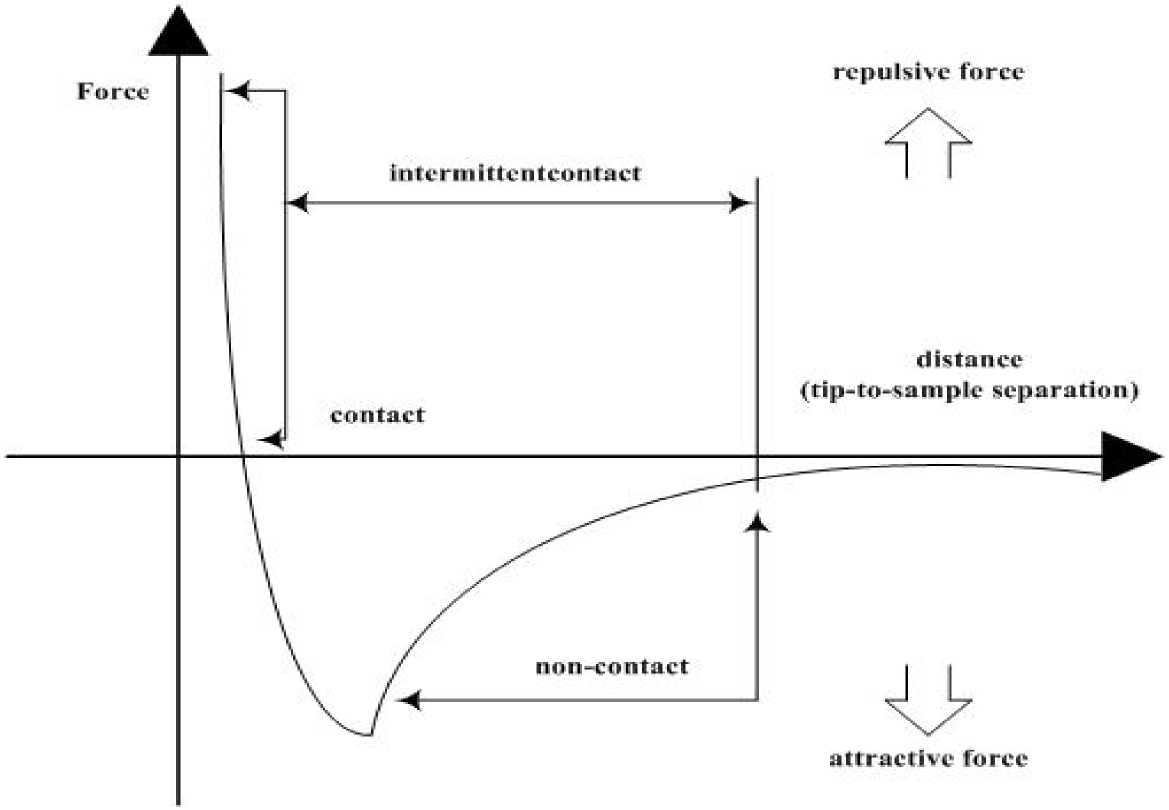
AFM Image Artifact





Tip shape and size cause image distortion, especially for small objects

Mode Summary



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Comparison of AFM and Other imaging techniques

- AFM vs. STM
  - resolution of STM is better than that of AFM
  - STM is applicable only to conducting samples
  - AFM is applicable to both conductors and insulators
- AFM vs. SEM
  - AFM provides extraordinary topographic contrast direct height measurements and unobscured views of surface features
  - No (conductive) coating is necessary for AFM samples
- AFM vs. TEM
  - 3D AFM image obtained without expensive sample preparation
  - More complete information than two dimensional profiles from TEM

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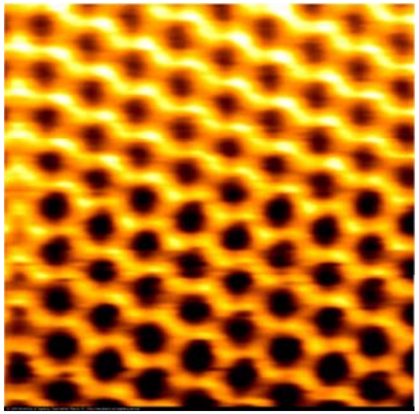
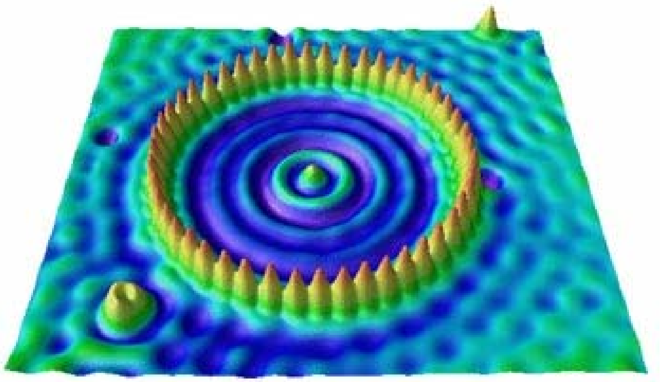
Comparison of AFM and Other imaging techniques



AFM image

- **2 nm by 2 nm area of a graphite surface**



STM image

- **A circle of iron atoms (radius = 7.1 nm) arranged on top of a copper surface**

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AFM Applications for Nanotechnology

- Measurement of nanodot, nanowire, devices, organic structures, etc
- Nanofabrication
  - Patterning
  - Deposition
  - Manipulation

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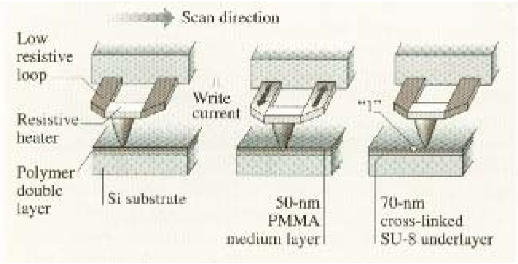
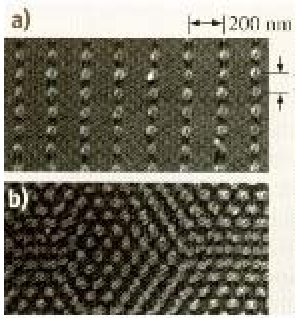
AFM Applications for Nanotechnology

- Patterning

  Memory chips

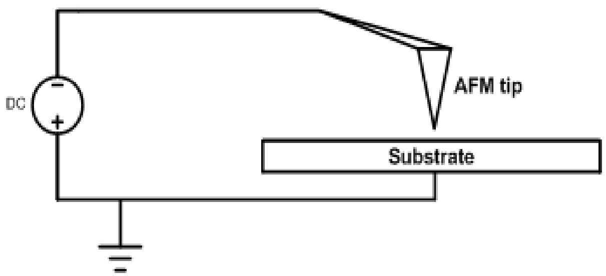


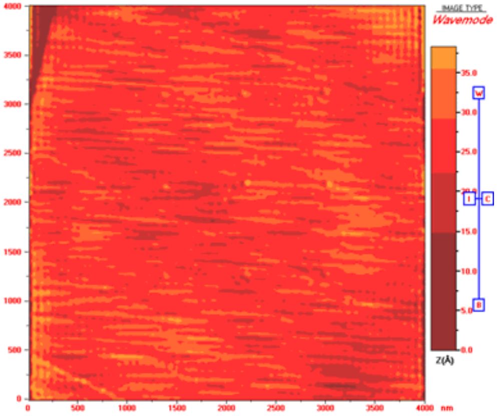


AFM Applications for Nanotechnology

- Deposition

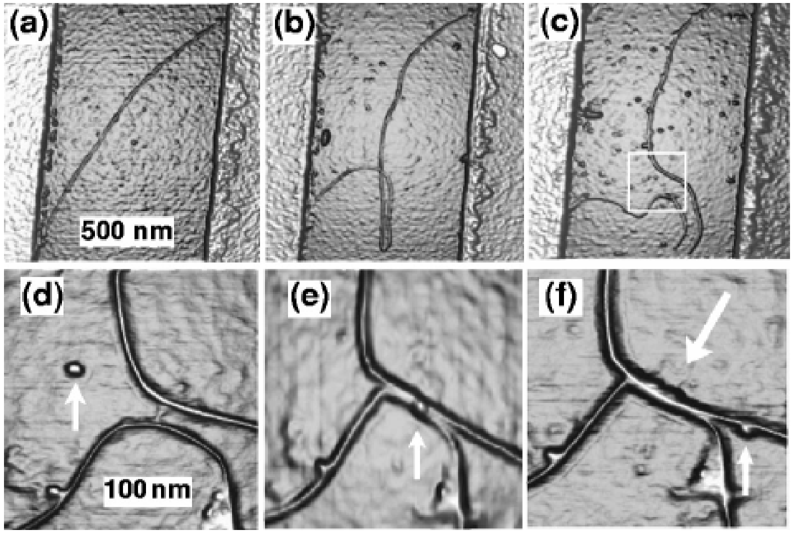
use coated AFM tips, such as Cr-coated tip





AFM Applications for Nanotechnology

- Manipulation



Our AFM System

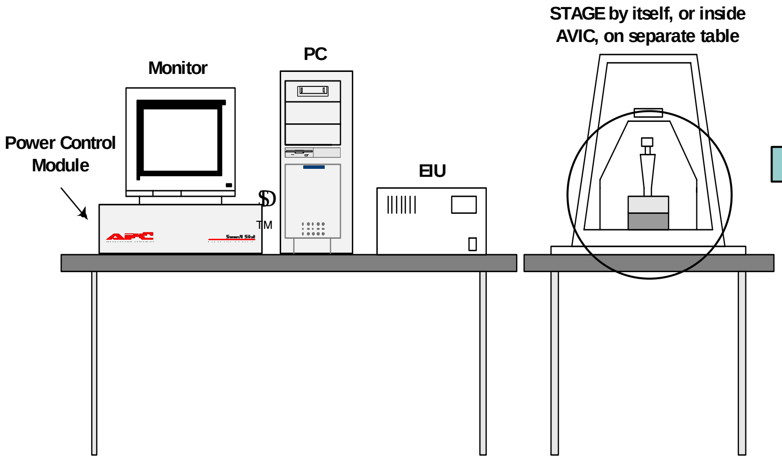
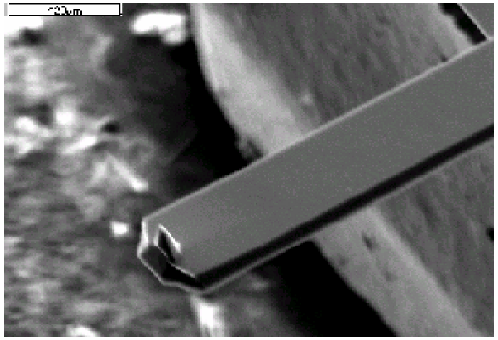


Fig. Our atomic force microscope (AFM) system

AFM Photo



SEM image of non-contact mode scanning Si tip on the AFM cantilever

- Atomic Force Microscope (AFM)
  - ⇨ **Q-scope^{TM} 250 manufactured by Quesant**
- Scanning Si tip on the AFM cantilever
  - ⇨ **contact mode and non-contact mode**
  - ⇨ **less than 10 nm radius**
  - ⇨ **low resonant frequency (150~190 kHz)**
  - ⇨ **between 31 and 64 N/m**

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