DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB103J –Semiconductor Physics

Module-V Lecture-14

Electron Microscopy-Transmission Electron Microscope (TEM)

Transmission Electron Microscopy (TEM)

Basic Electron Optics

- Electrons and ions are charged particles; they can be accelerated in an electric field
- The trajectory of an accelerated charged particle can be changed (deflected) by E and/ or B field.
- The accelerated particles also behave like waves (de Broglie)

- **Transmission Electron Microscope (TEM)**

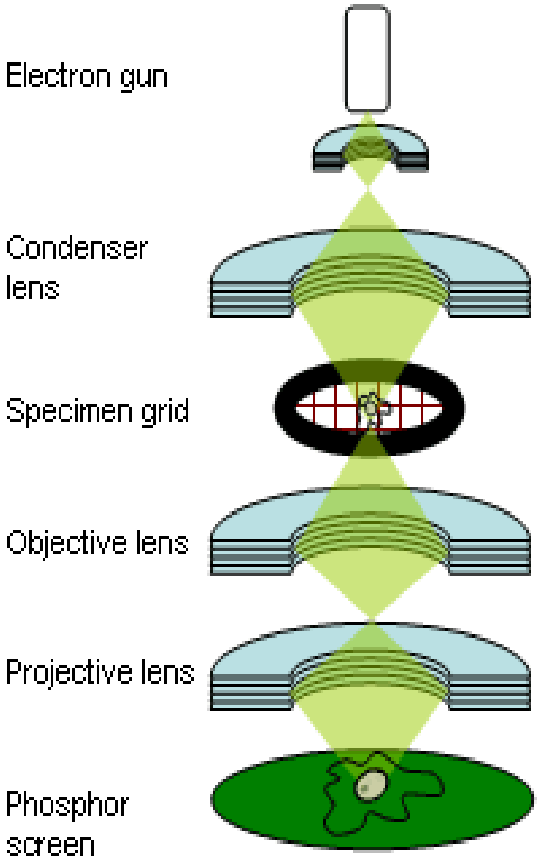
Working Concept

- TEM works much like a slide projector.
- A projector shines a beam of light through (transmits) the slide, as the light passes through it is affected by the structures and objects on the slide.
- These effects result in only certain parts of the light beam being transmitted through certain parts of the slide.
- This transmitted beam is then projected onto the viewing screen, forming an enlarged image of the slide.
- TEMs work the same way except that they shine a beam of electrons (like the light) through the specimen (like the slide).
- Whatever part is transmitted is projected onto a phosphor screen for the user to see.

Common Modes of Operation of TEM

- **Bright Field (BF) Microscopy**
- **Selected Area Diffraction**
- **Dark Field (DF)**

- The "Virtual Source" - the electron gun, produces a stream of monochromatic electrons.
- This stream is focused to a small, thin, coherent beam by the use of condenser lenses 1 and 2. The first **lens** (usually controlled by the "spot size knob") largely determines the "**spot size**"; the general size range of the final spot that strikes the sample.
- The second lens (usually controlled by the "intensity or brightness knob" actually changes the size of the spot on the sample; changing it from a wide dispersed spot to a pinpoint beam.
- The beam is restricted by the condenser **aperture** (usually user selectable), knocking out high angle electrons (those far from the optic axis, the dotted line down the center)
- The beam strikes the specimen and parts of it are transmitted



Unscattered electrons:

Incident electrons which gets transmitted through the specimen without interacting with the sample

Utilization:

Thicker sample- fewer transmitted electrons-appear darker

Thinner sample- more transmission- appear brighter

Elastically scattered electrons:

Incident electrons which gets scattrered by the atoms in the sample elastically (no loss of energy). Then they are transmitted

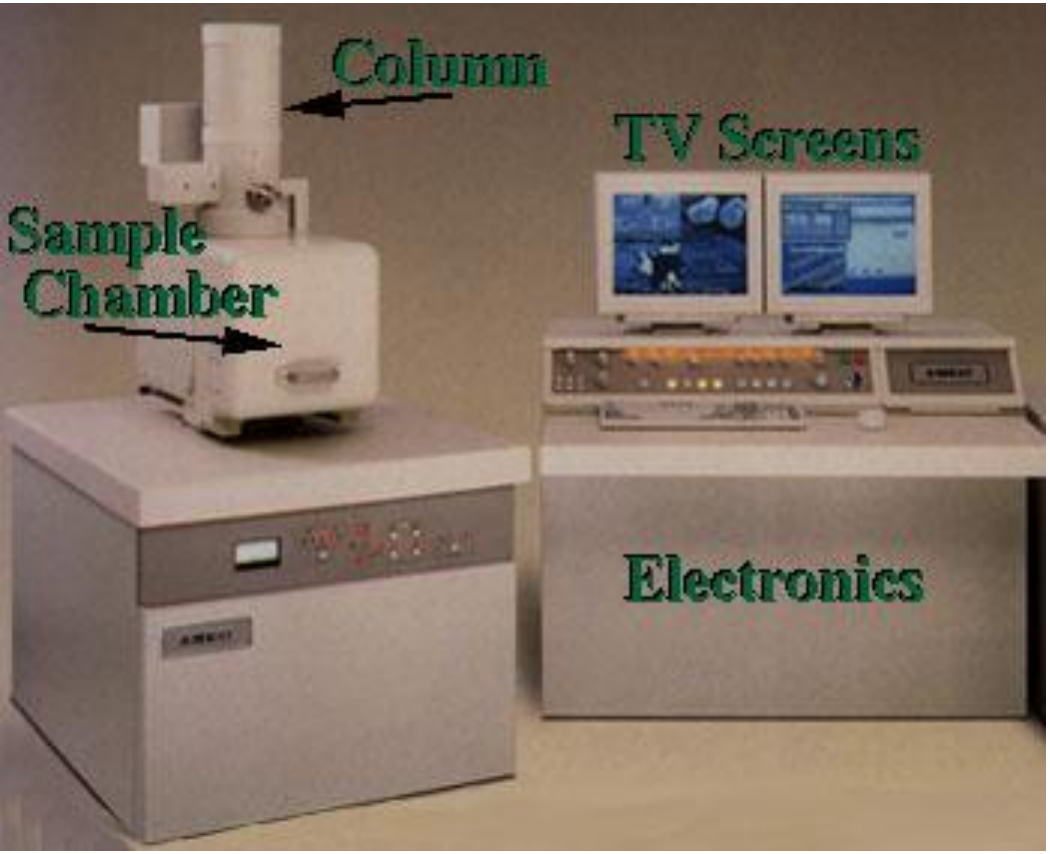
Utilization:

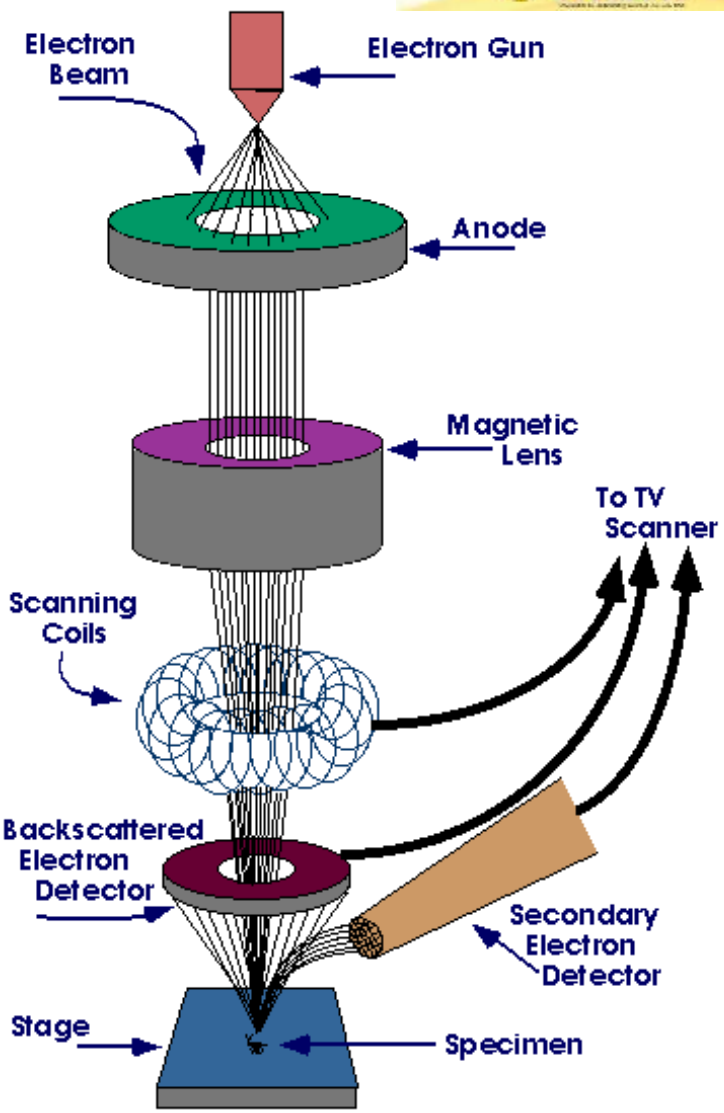
All electrons follow Braggs condition for scattering

Inelastically Scattered Electrons :

Incident electrons interact with the sample inelastically (loss of energy) and gets transmitted into the specimen

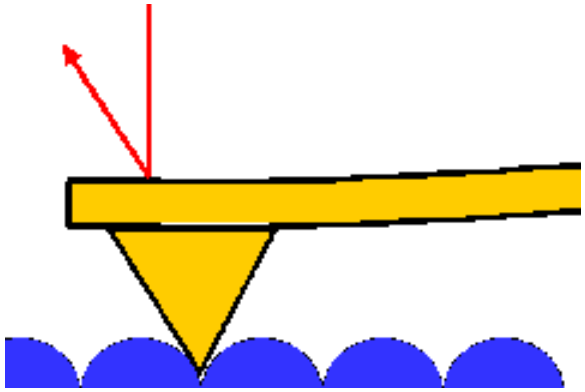
Kakuchi Bands: - Bands of alternating light and dark lines that are formed by inelastic scattering interactions that are related to atomic spacings in the specimen


Column
TV Screens
Sample Chamber
Electronics


Electron Beam
Electron Gun
Anode
Magnetic Lens
To TV Scanner
Scanning Coils
Backscattered Electron Detector
Secondary Electron Detector
Stage
Specimen

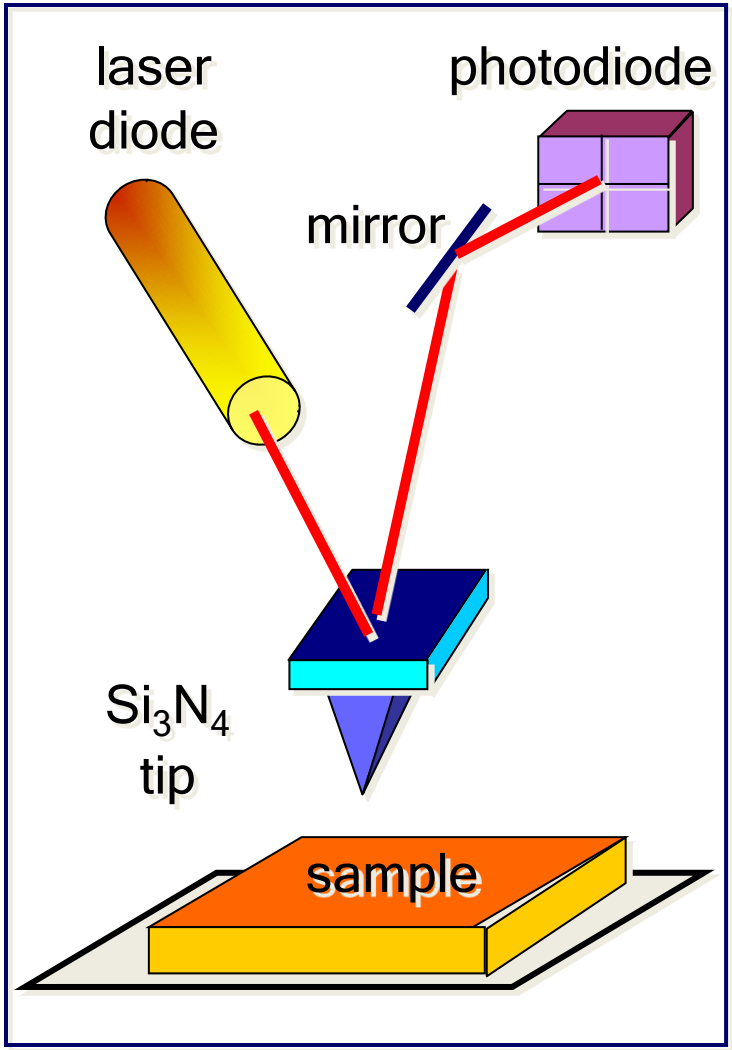
AFM - atomic force microscopy

How does the microscope work?



Tip Scans Sample

Up & down movement of the tip is recorded by position sensing photodiode



Scanning Probe Microscopy—the Atomic Force Microscope (AFM)

The AFM like the STM is a scanning microscope, but the mechanism depends on the force of attraction between molecules

Scanning Probe Microscopy—the Atomic Force Microscope

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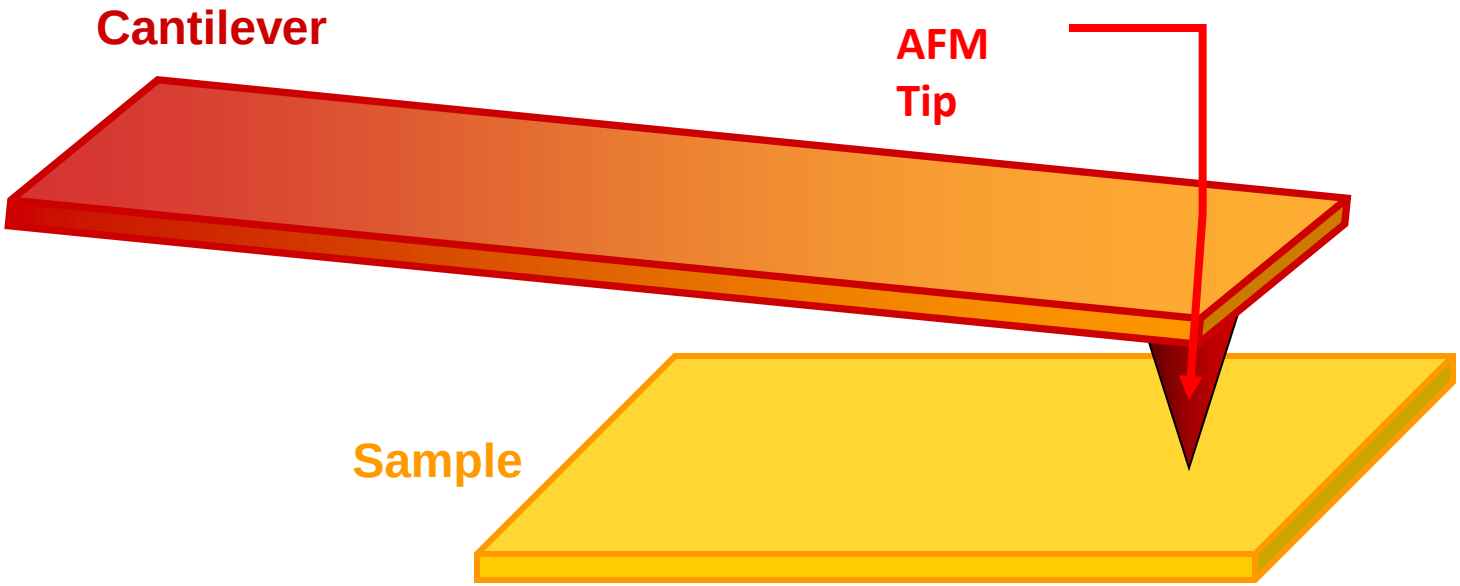

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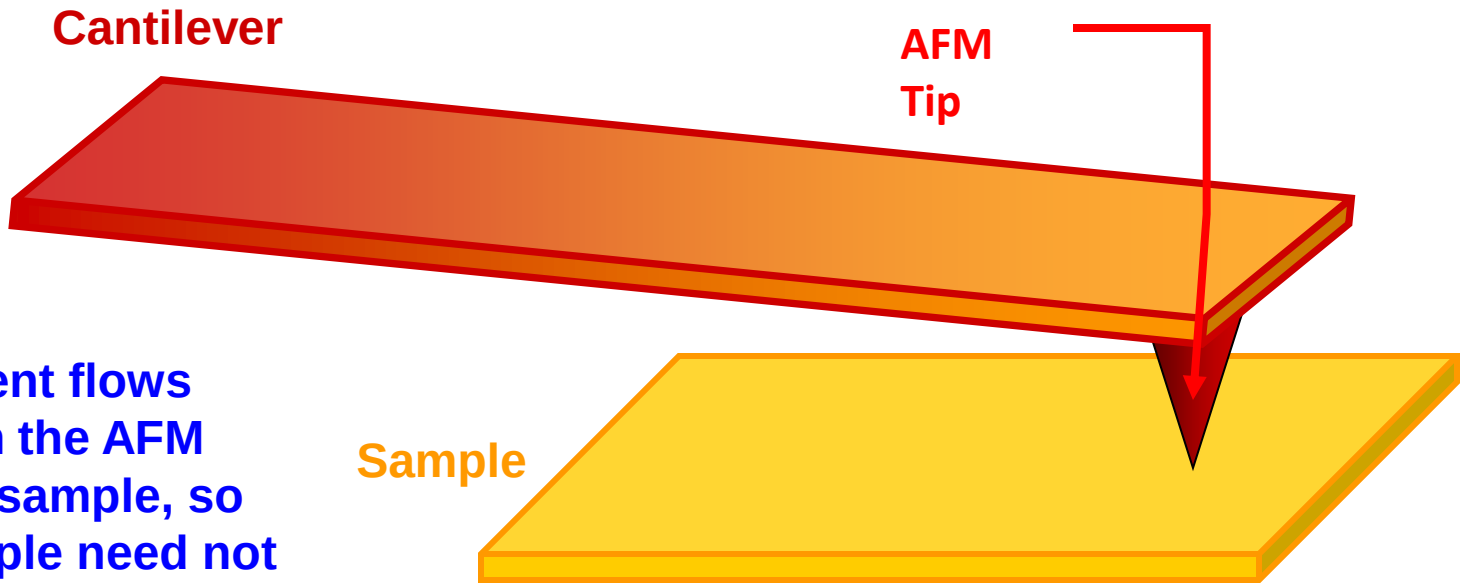

No current flows between the AFM Tip and sample, so the sample need not be conducting [a requirement for the STM.

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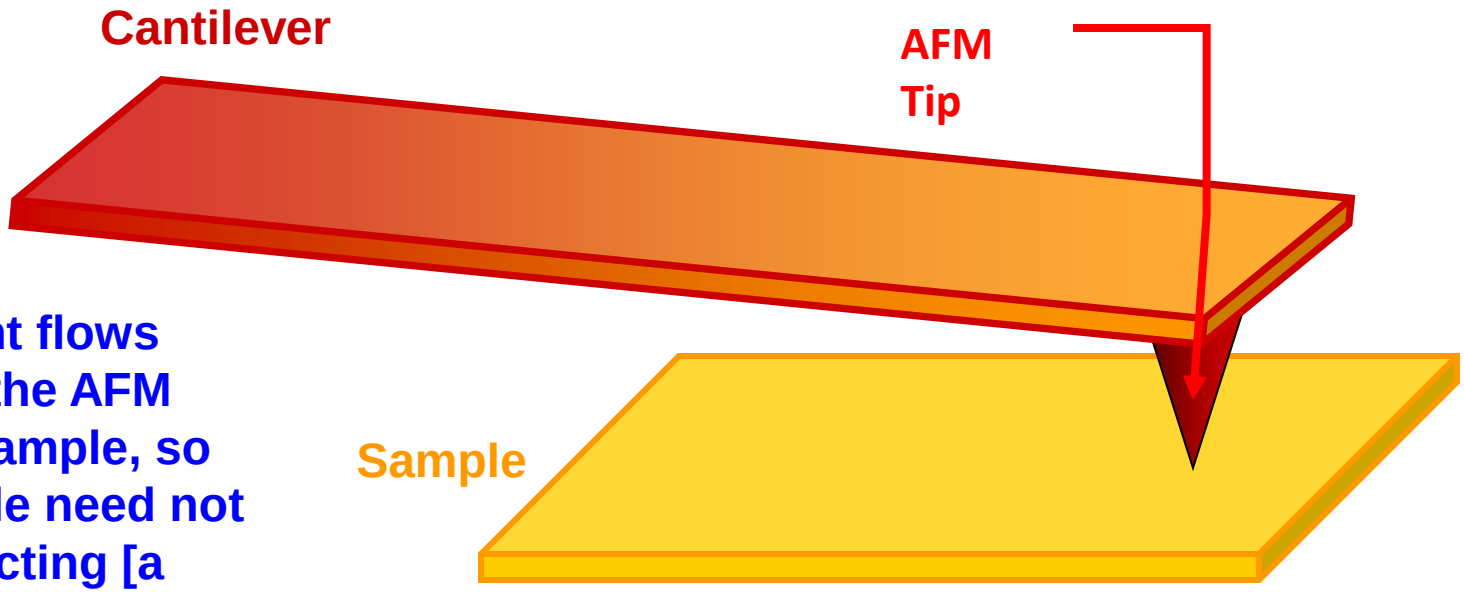

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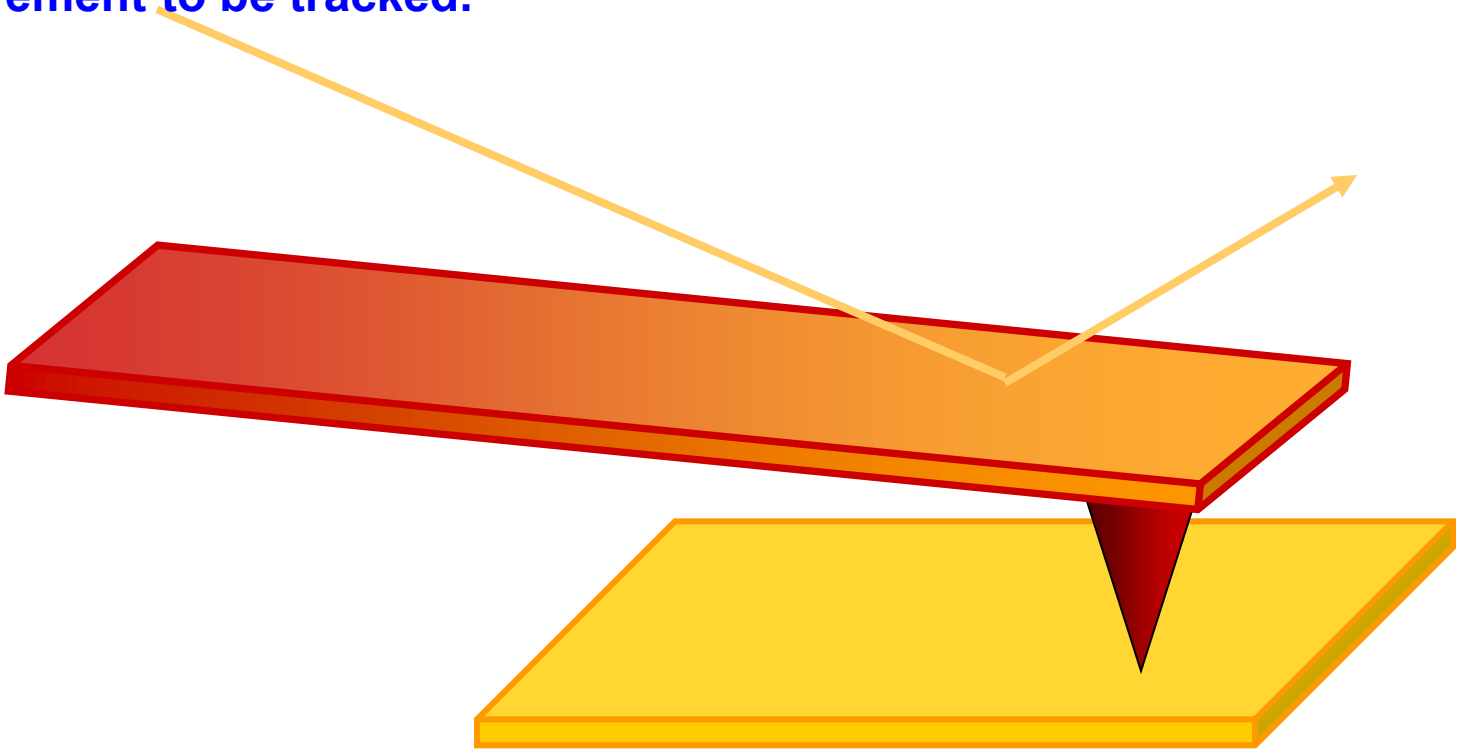
The atoms of the Tip are attracted to the atoms of the sample by the van der Waals interaction.

As the AFM tip is attracted to the surface (causing the cantilever to bend), a laser beam bounces off the end of the cantilever—allowing the tip's movement to be tracked.



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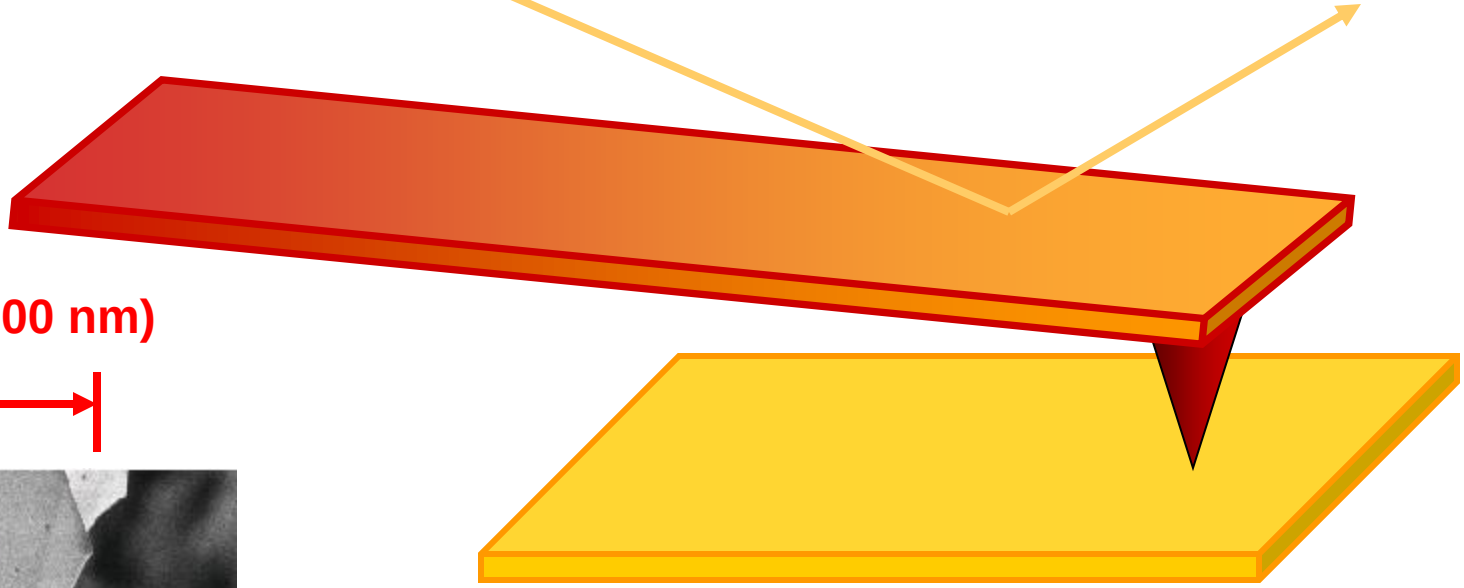
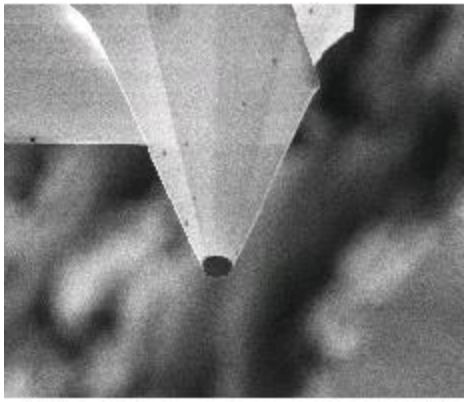
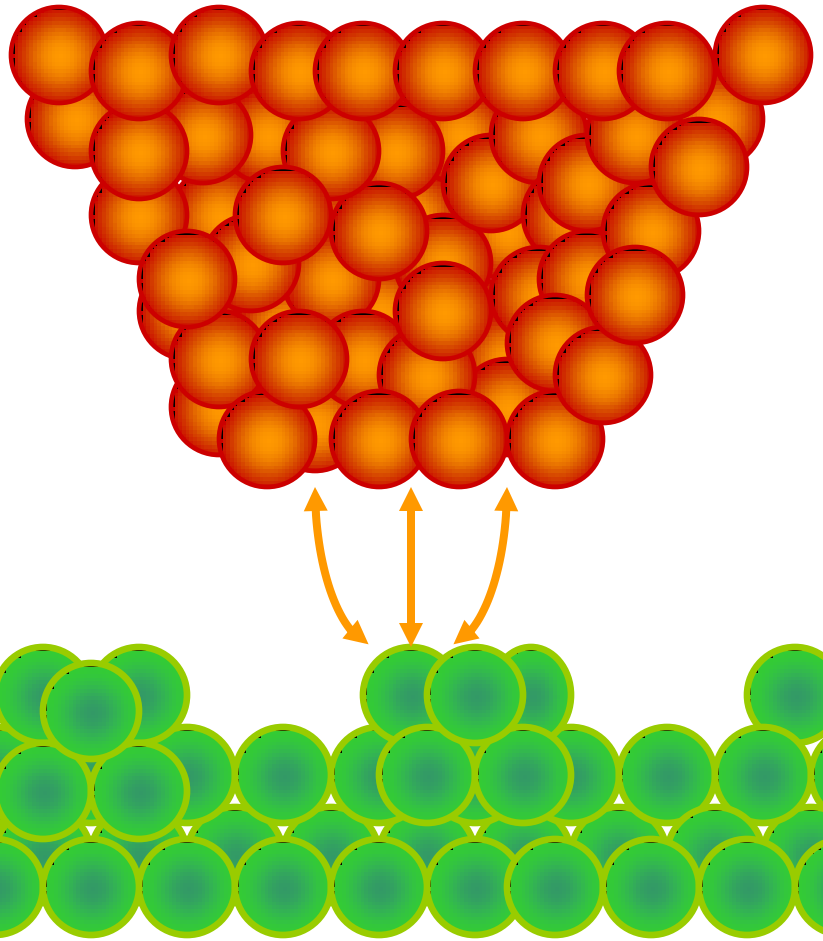


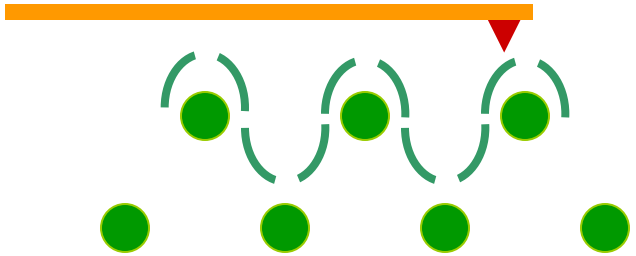
~1 μm (1000 nm)



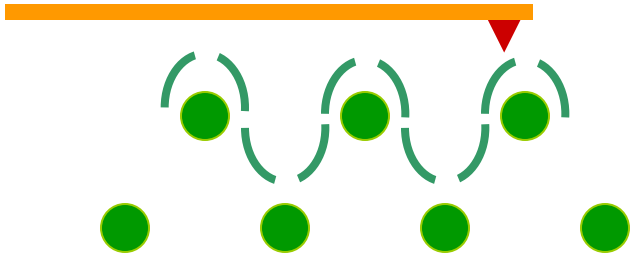
The cantilever is visible to the naked eye but the AFM tip is too small to see without magnification.



The attractive van der Waals interaction acts at a molecular and atomic level, between the AFM tip and the local atoms at the sample's surface.



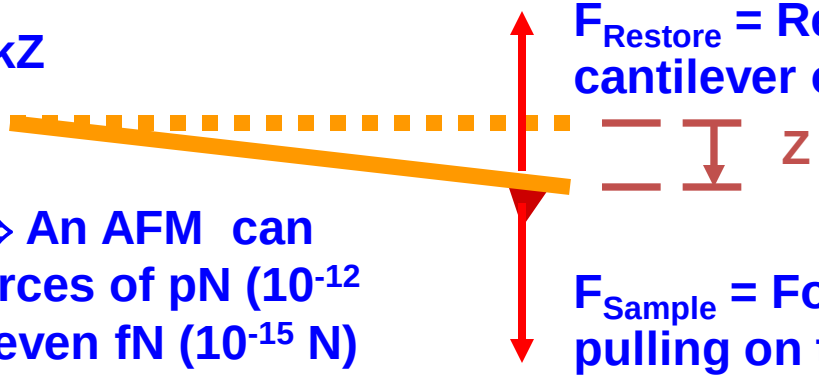
As the AFM tip scans the surface, its up and down motions map the contour of the sample—scanned line by line.



As the AFM tip scans the surface, its up and down motions map the contour of the sample—scanned line by line.

The force on the AFM tip is harmonic (spring like): the tip is displaced toward the surface a distance (Z) proportional to the van der Waals force.

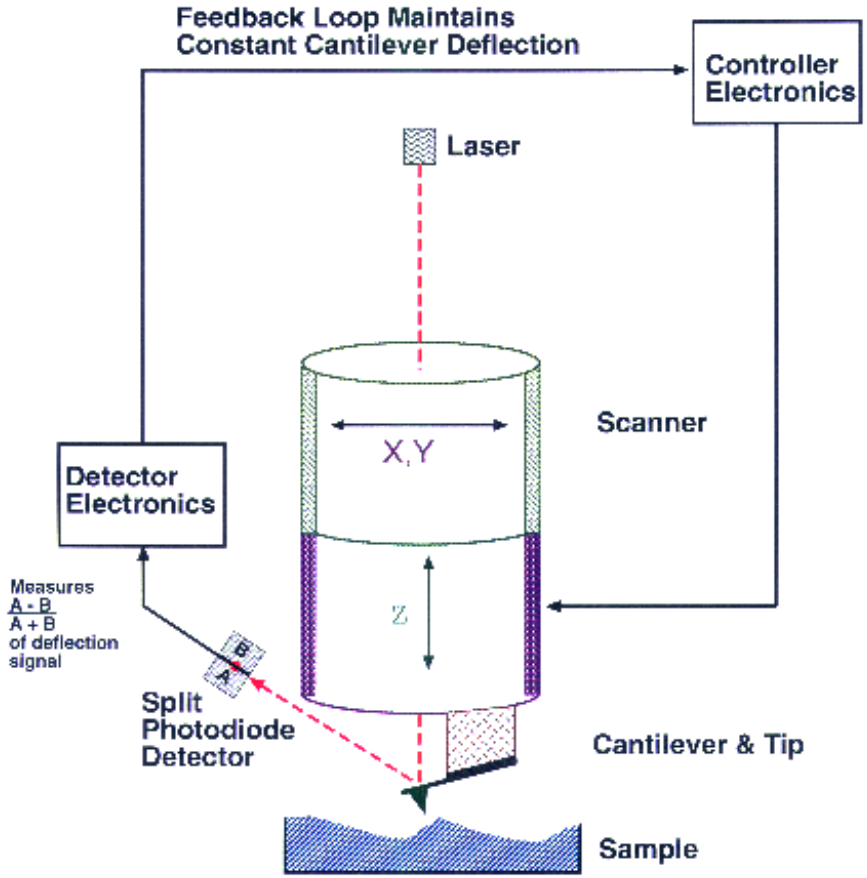
$F_{Restore} = - kZ$

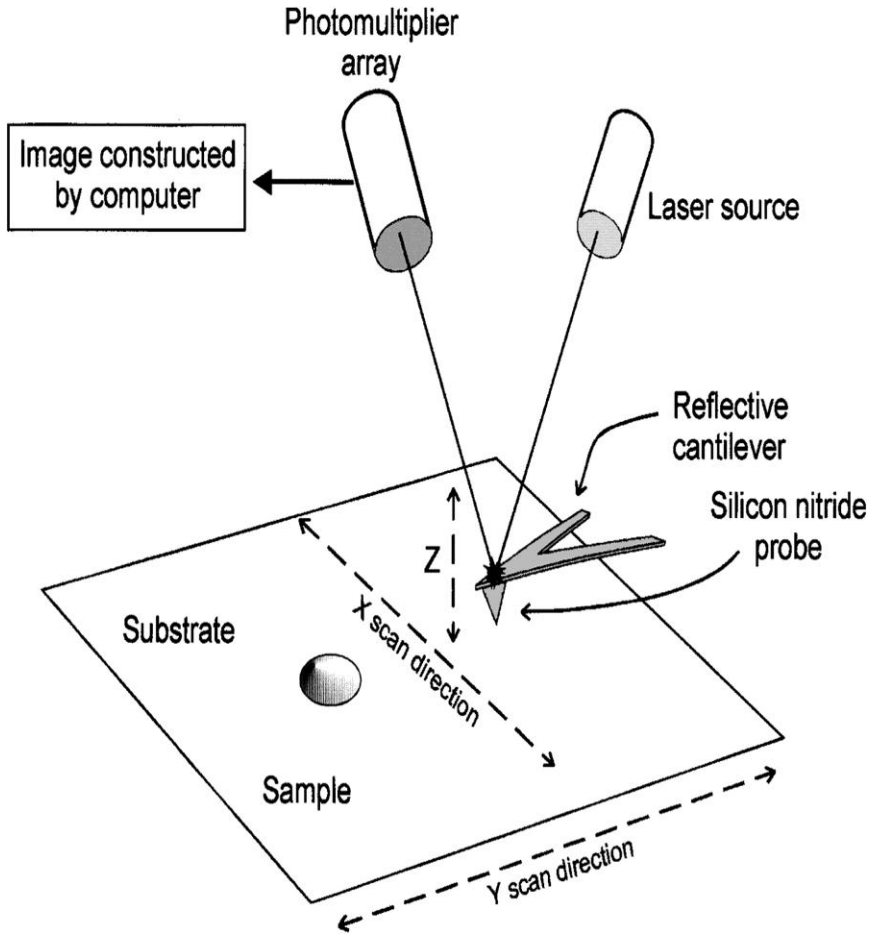


$F_{Restore}$ = Restoring force of cantilever on tip

$k \sim 1$ N/m $\Rightarrow$ An AFM can measure forces of pN (10^{-12} Newton) & even fN (10^{-15} N) size!

F_{Sample} = Force of sample pulling on tip (van der Waals)


Feedback Loop Maintains
Constant Cantilever Deflection
Controller
Electronics
Laser
Scanner
X,Y
Z
Detector
Electronics
Measures
A - B
A + B
of deflection
signal
B
A
Split
Photodiode
Detector
Cantilever & Tip
Sample


Photomultiplier
array
Image constructed
by computer
Laser source
Reflective
cantilever
Silicon nitride
probe
Z
Substrate
X scan direction
Sample
Y scan direction

IMAGING METHODS

What types of forces are measured ?

–

Modes of operation

-contact

-noncontact

tapping

The AFM can operate in three different ways

Contact Mode—the tip is dragged along a sample's surface; the cantilever deflection is measured and translated into surface shapes. Take care: this mode can damage the surface.

1. **Non-contact mode—the cantilever oscillates above the sample's surface and is affected by surface/tip forces (van der Waals) as it does so.**
2. **Tapping Mode—The AFM tip taps the sample surface during the closest point of approach of an oscillation cycle.**

Contact **Intermittent/Tapping**

ADVANTAGES AND DISADVANTAGES

CONTACT MODE- Fast scanning, good for rough samples

But deforms soft samples

TAPPING MODE- good for biological samples

Slow scan speed and challenging in liquids

NON-CONTACT MODE-low force exerted on the sample

Low resolution contaminant layer can interfere usually need UHV system for good imaging

LIMITATIONS OF AFM

- Used to study variety of samples
- Does not require a conducting sample
- Does not reflect the true sample topography
- But represents the interaction between the tip and the surface called TIP CONVOLUTION

*Tip broadening – radius of curvature of the tip >size of the feature to be imaged

*As the tip scans the sides of the tip make contact before the apex and the microscope begins to respond to the feature

- **Advantages**
  - The AFM has several advantages over the scanning electron microscope (SEM).
  - Unlike the electron microscope which provides a two-dimensional projection or a two-dimensional image of a sample, the AFM provides a **true three-dimensional surface** profile.
  - Additionally, samples viewed by AFM **do not** require any special treatments (such as metal/carbon coatings) that would irreversibly change or damage the sample.
  - While an electron microscope needs an expensive **vacuum** environment for proper operation, most AFM modes can work perfectly **well** in ambient air or even a liquid environment.
  - This makes it possible to study biological macromolecules and even living organisms.
  - In principle, AFM can provide higher resolution than SEM. It has been shown to give true atomic resolution in ultra-high vacuum (UHV).

- **Disadvantages**
  - A disadvantage of AFM compared with the **scanning electron microscope** (SEM) is the image size.
  - The SEM can image an area on the order of **millimeters** by millimeters with a **depth of field** on the order of millimeters.
  - The AFM can only image a maximum height on the order of micrometers and a maximum scanning area of around 150 by 150 micrometers.
  - Another inconvenience is that at high resolution, the **quality of an image** is limited by the **radius of curvature** of the probe tip, and an incorrect choice of tip for the required resolution can lead to image artifacts.
  - Slow scan and less scanner area
  - Artefacts/Hystersis effects or cross-talk influences the image