나노 기술의 이해
(Understanding Nanotechnology)

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Lecture 3.
나노를 보는 눈: 원자현미경

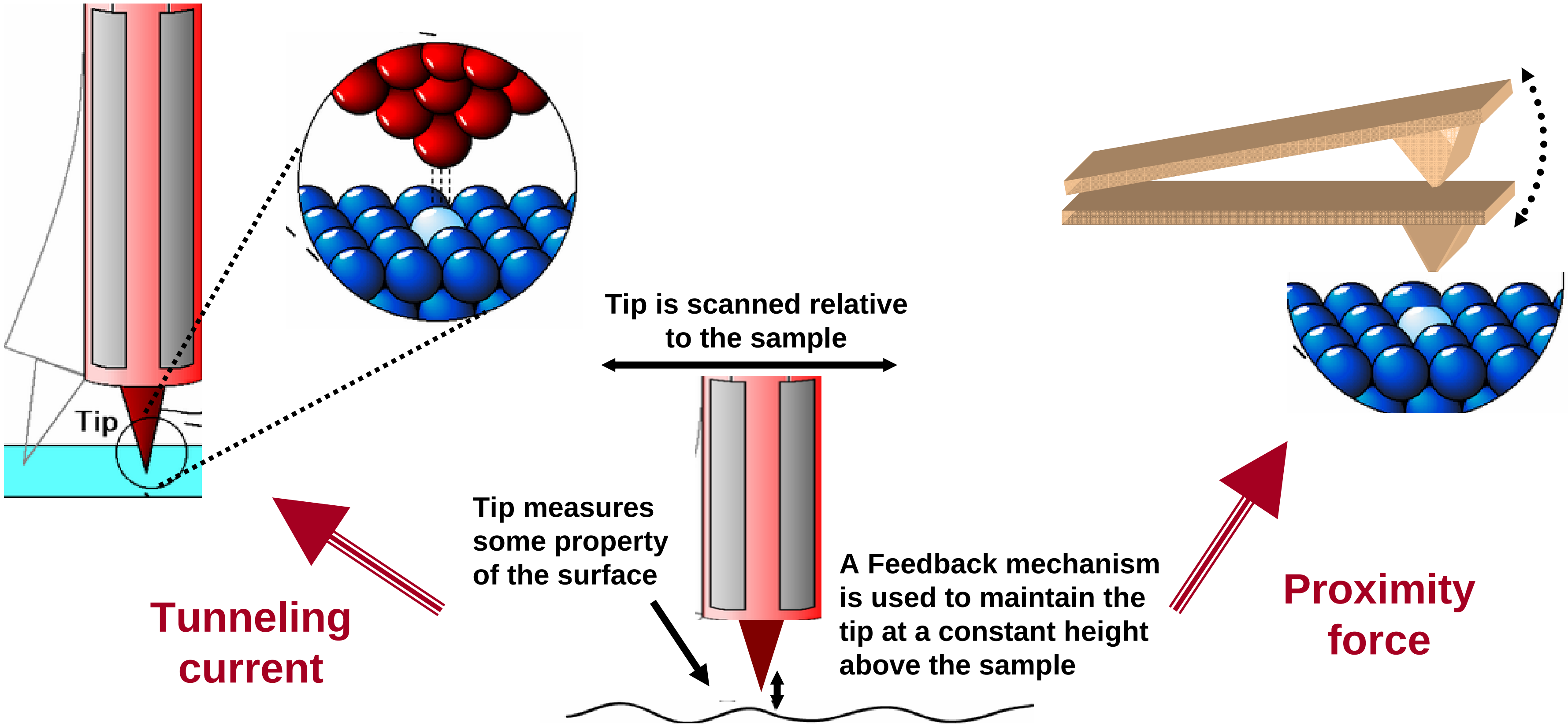
1. Scanning Probe Microscope

The best optical microscopes can see structures in the 200-400 nanometer range, at their limit resolution.

Optical microscopes are "diffraction limited"—the wavelength range of visible light (400-750 nm) sets the size of the smallest thing that can be imaged: ~ 200 nm.

Scanning Probe Microscopes don't use visible light—they depend on measuring intermolecular forces or measuring quantum tunneling. The resolution limits are at the <u>quantum scale</u> (atoms & molecules).

Scanning Probe Microscope



- Feedback control is the Key

Chronology of SPM

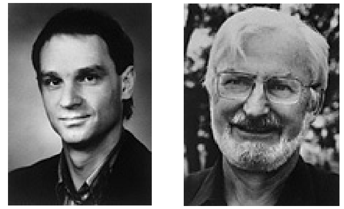
1981 — STM invented at IBM-Zurich by Binnig and Rohrer

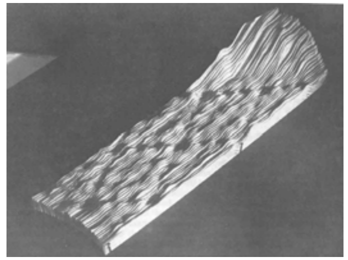
1985 — First AFM developed by Binnig, Gerber, and Quate

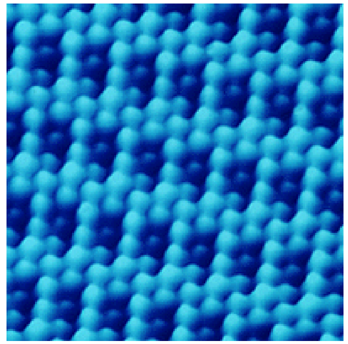
1986 — Binnig and Rohrer share Physics Nobel Prize

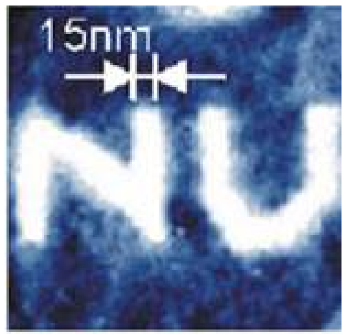
1987 — DI AFM is founded by UCSB researchers

1999 — DPN developed by researchers at Northwestern University









Scanning Tunneling Microscope

General Overview

- An extremely fine conducting probe is held about an atom's diameter from the sample.

- Electrons tunnel between the surface and the tip, producing an electrical signal.

- While it slowly scans across the surface, the tip is raised and lowered in order to keep the signal constant and maintain the distance.

- This enables it to follow even the smallest details of the surface it is scanning.

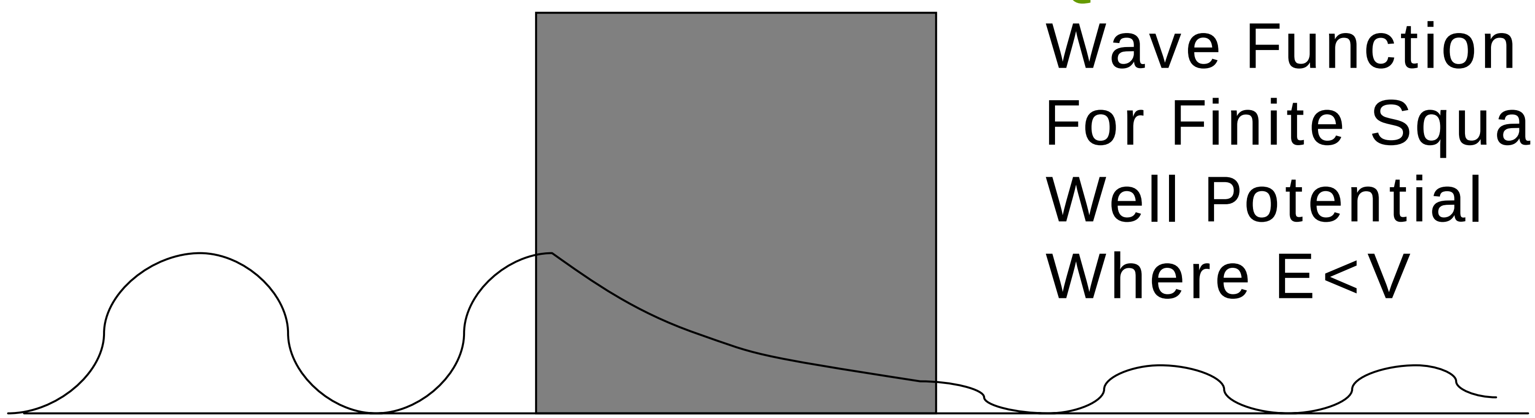
STM - Quantum Tunneling

Classical
Wave Function
For Finite Square
Well Potential
Where E<V

Classically, when an object hits a potential that it doesn't have enough energy to pass, it will never go though that potential wall, it always bounces back.

In English, if you throw a ball at a wall, it will bounce back at you.

STM - Quantum Tunneling

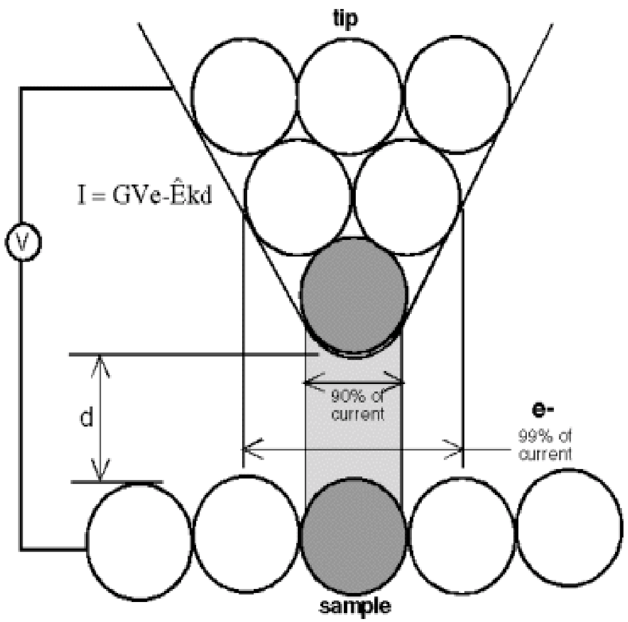


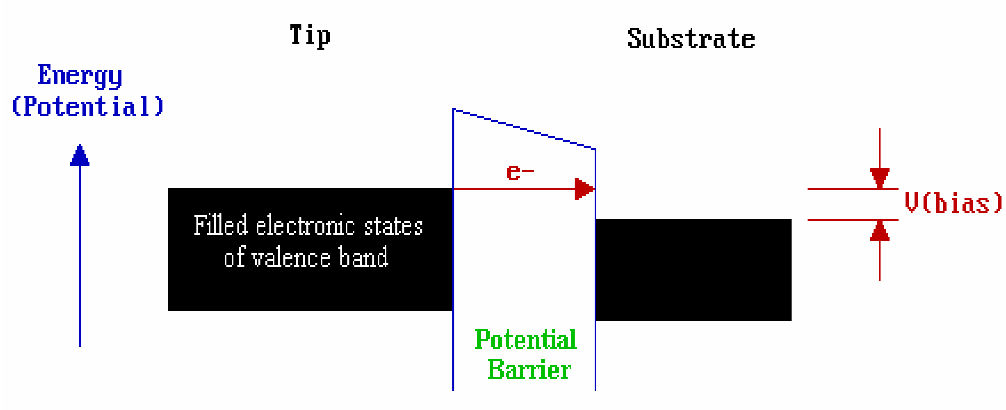
Quantum
Wave Function
For Finite Square
Well Potential
Where E<V

In quantum mechanics when a particle hits a potential that it doesn't have enough energy to pass, when inside the square well, the wave function dies off exponentially.

If the well is short enough, there will be a noticeable probability of finding the particle on the other side.

STM - Quantum Tunneling

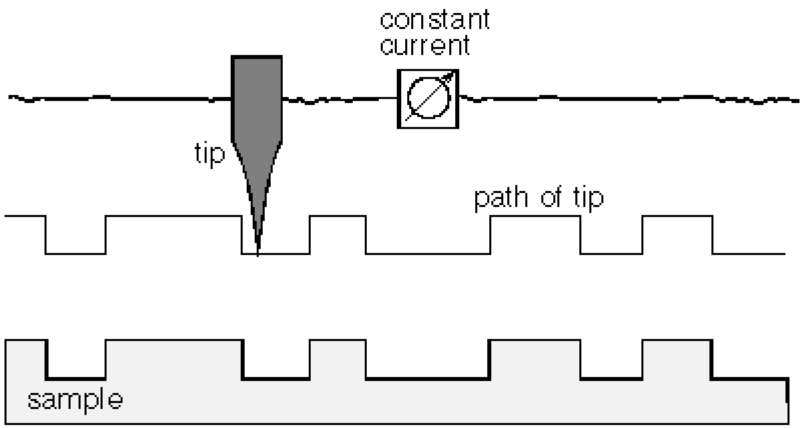




So if you bring the tip close enough to the surface, you can create a tunneling current, even though there is a break in the circuit.
The size of the gap in practice is on the order of a couple of Angstroms (10^{-10} m)!
As you can see, the current is VERY sensitive to the gap distance.

STM - Modes of Operation

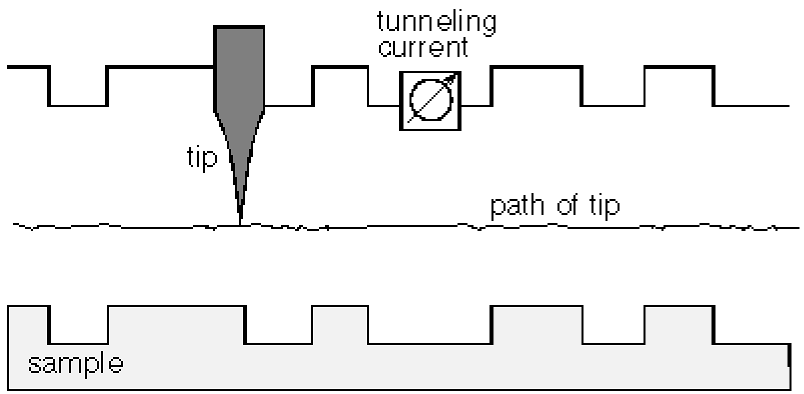
Constant-Current Mode



Tip height is ~constant: an x-y scan reveals a topographic 'image' of the surface.

- better vertical resolution
- slower scanning – may yield overall drift in x-y scan
- can be used for surfaces that aren't atomically flat

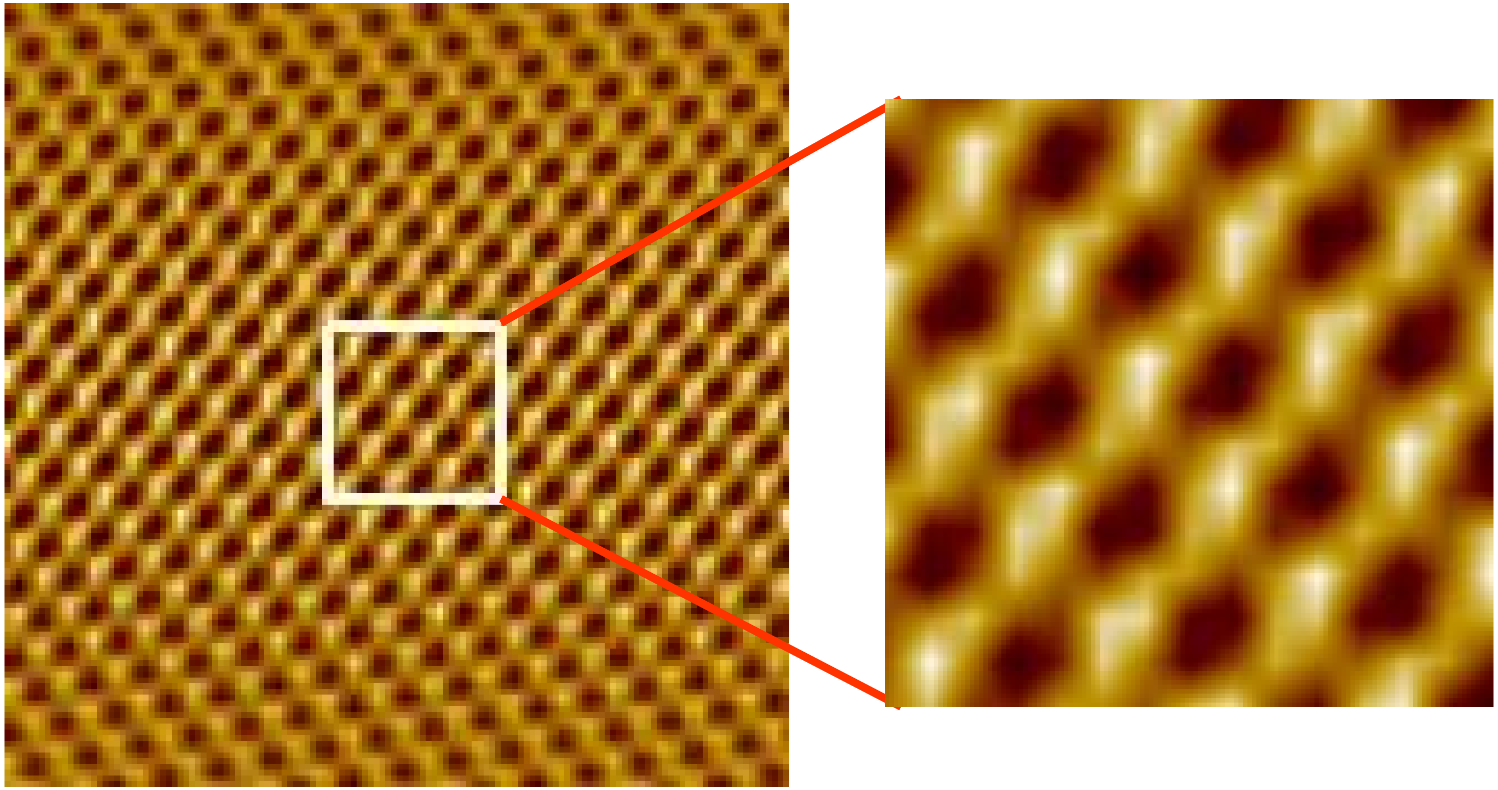
Constant-Height Mode



Tip height is kept constant and tunneling current is monitored.

- very fast scans, reduces image distortion
- lower vertical resolution
- allows study of dynamic processes

STM image

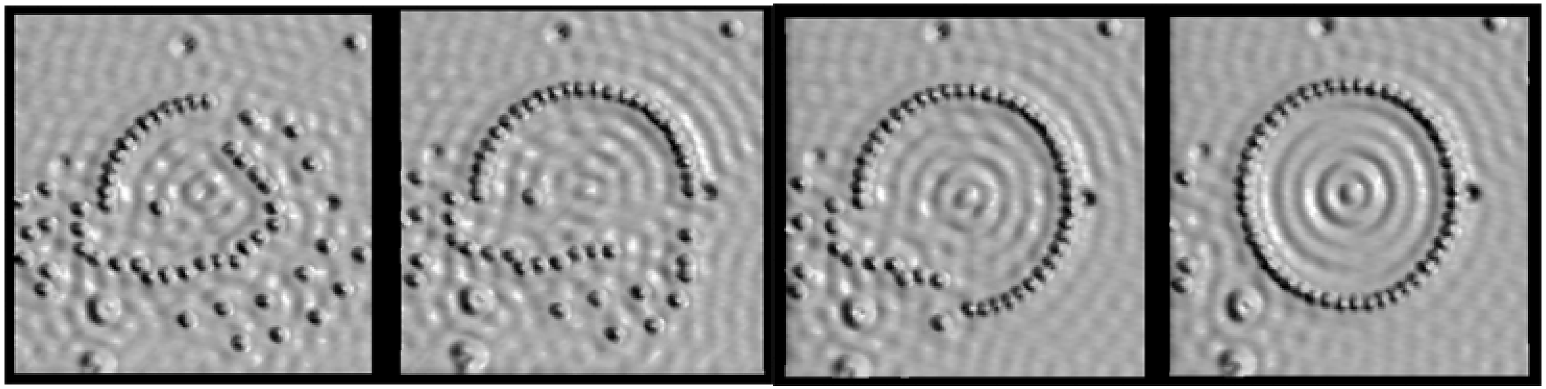


An STM image of a graphite surface

Different STM Ideas

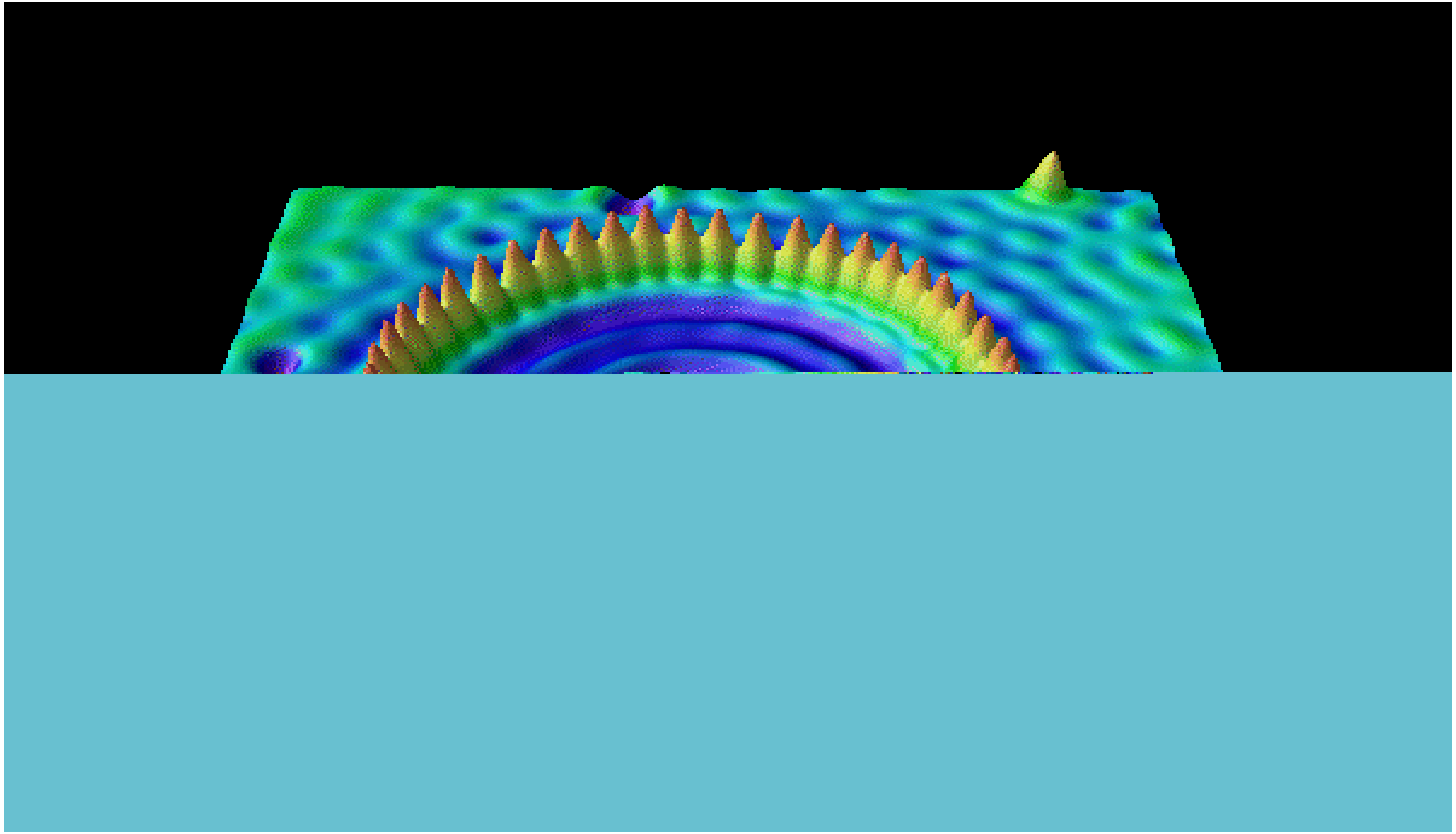
Imagine increasing the tunneling current when you are on top of an atom by lowering the tip a little. The attractive force between the tip and the atom would then increase, allowing you to “drag” atoms around.

IBM imagined this. Iron atoms were first physisorbed (stuck together using intermolecular forces, Van Der Waals forces) on a Cu surface. The iron atoms show up as bumps below.

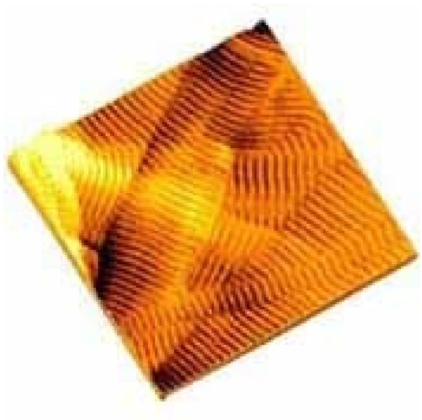


The iron atoms were then dragged along the surface of to form a circle.

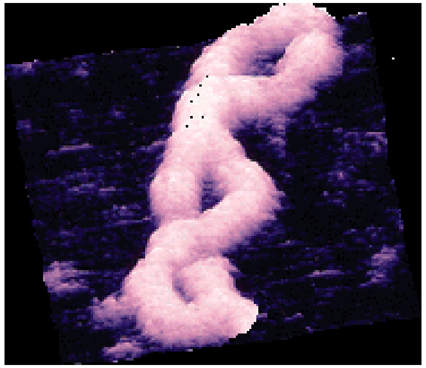
Different STM Ideas



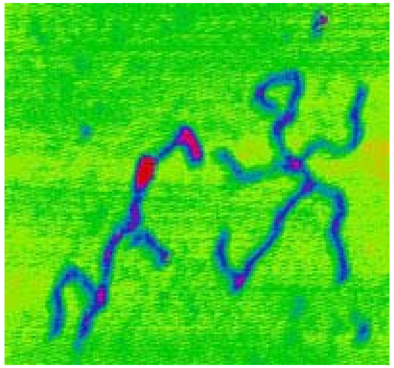
Various examples (1)



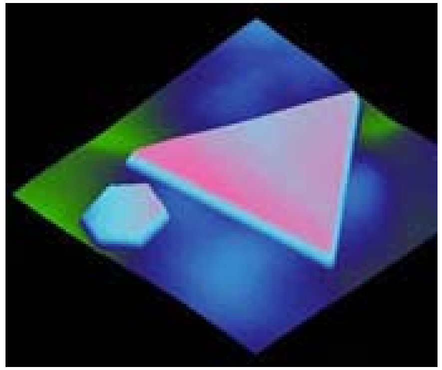
Collagen fibers
(3μm)



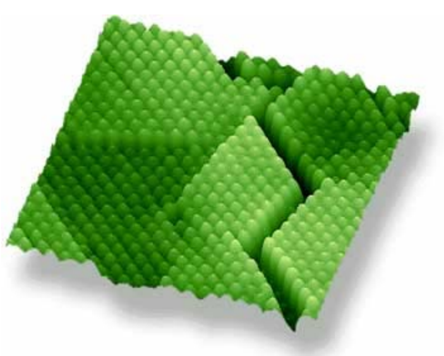
DNA (150nm)



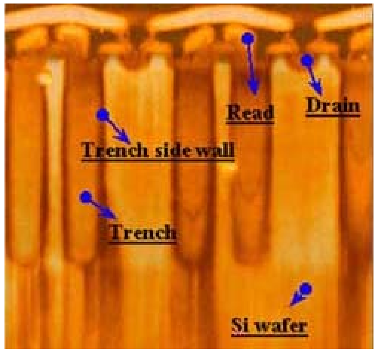
DNA (550nm)



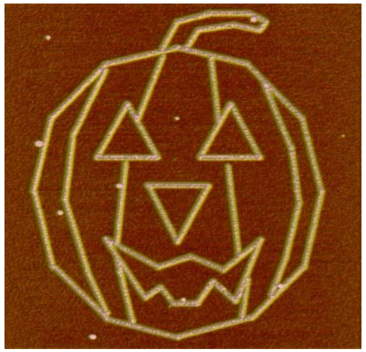
Au clusters on BTO
(3μm)



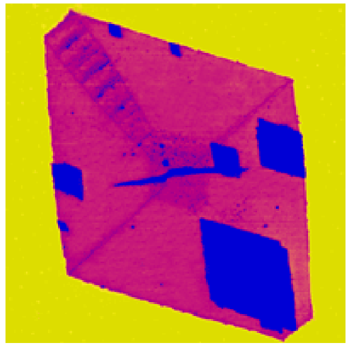
PS spheres
(2μm)



DRAM, SCM
(10μm)



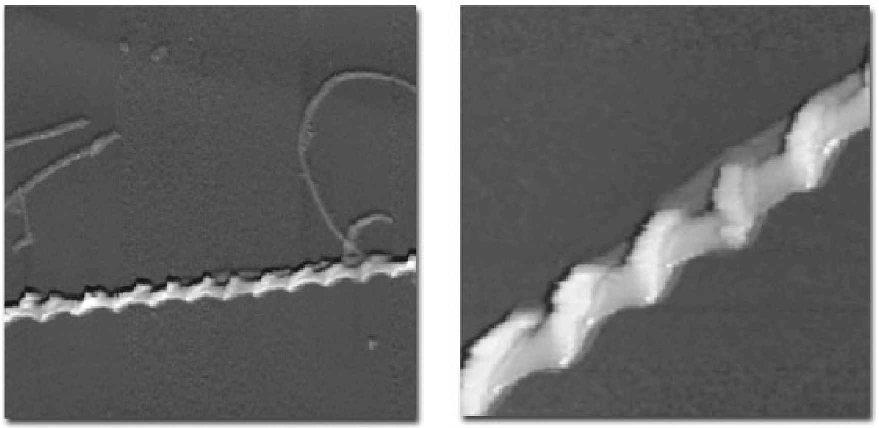
Anodic
oxidation on Si
(5μm)



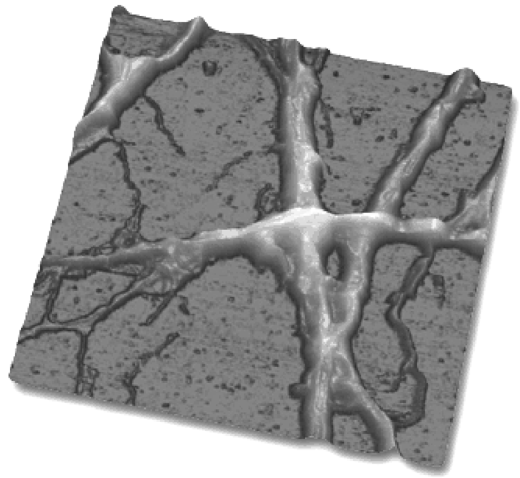
Polyethylene
single crystal
(8μm)

Various examples (2)

CD surface: depth of groove ~ 150 nm,
bit width ~ 2.5 mm, track spacing ~ 2.5 mm



Sperm head: helix pitch ~650 nm,
diameter ~ 480 nm, length up to 40 mm



Hippocampus neural network:
15 x 15 mm

Future

- Develop better tip models
  - Effects of chemical composition, shape and size

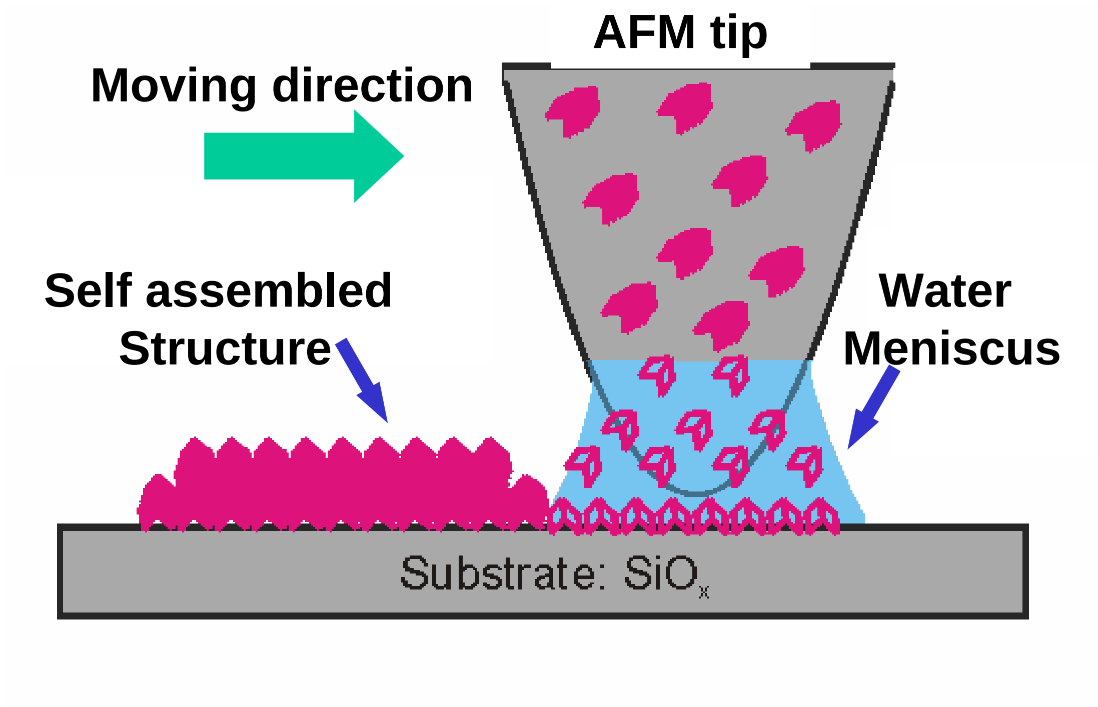
- Improve tip fabrication

  - Currently, very poor tip shapes, but still 1 atom tip
  - Predefined geometry?

- Limitations

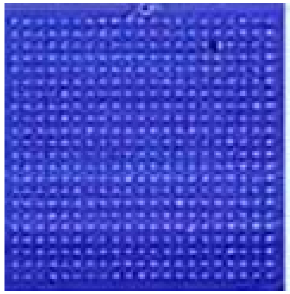
  - Finite size of tip distorts imaging of narrowly separated atoms

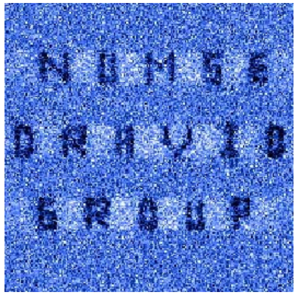
Dip Pen Nanolithography

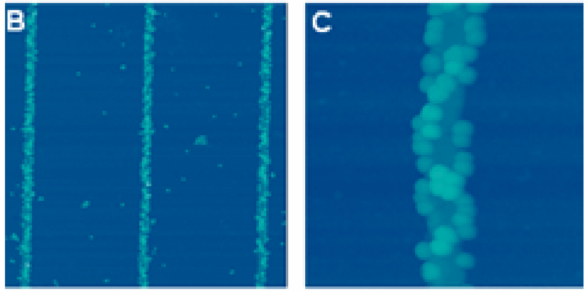


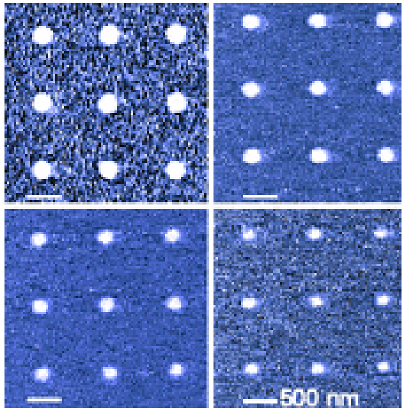
What do you think are the controlling factors in DPN?

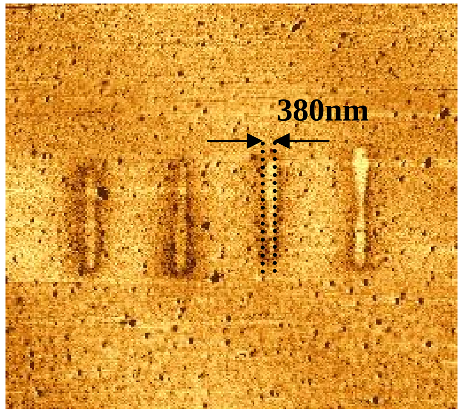
Dip Pen Nanolithography Capabilities









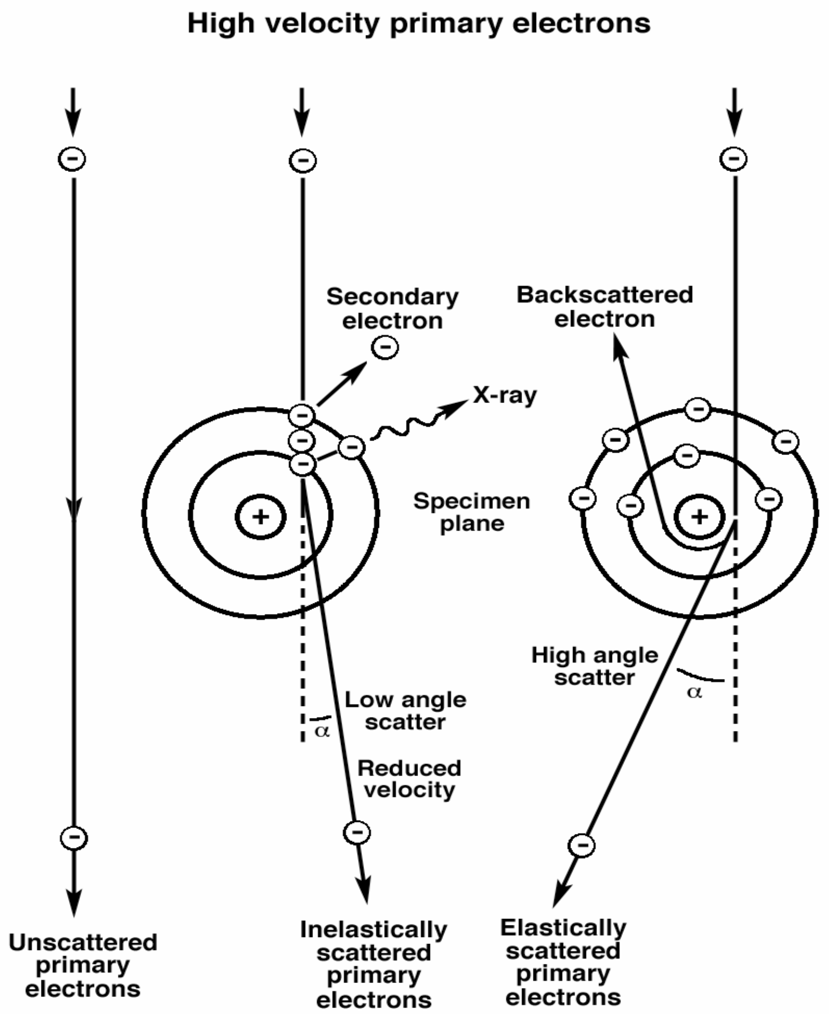


2. Electron microscope

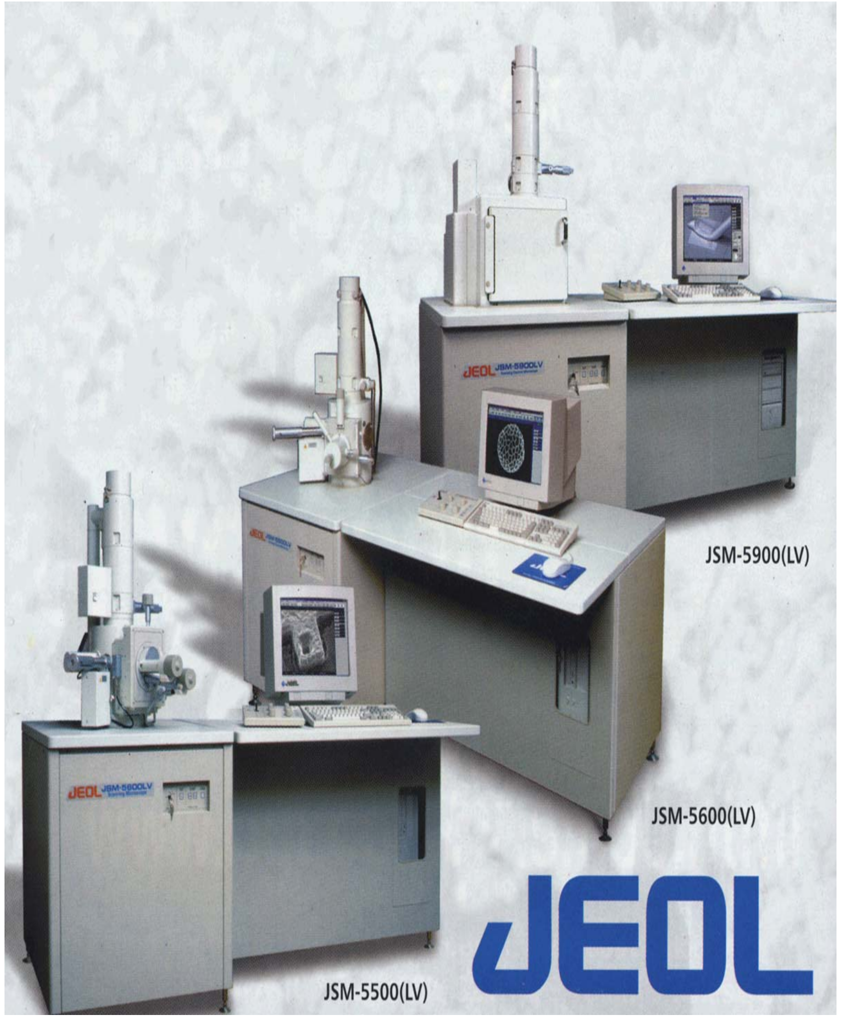
electrons scatter when they pass through thin sections of a specimen

transmitted electrons (those that do not scatter) are used to produce image

denser regions in specimen, scatter more electrons and appear darker



Electron microscope



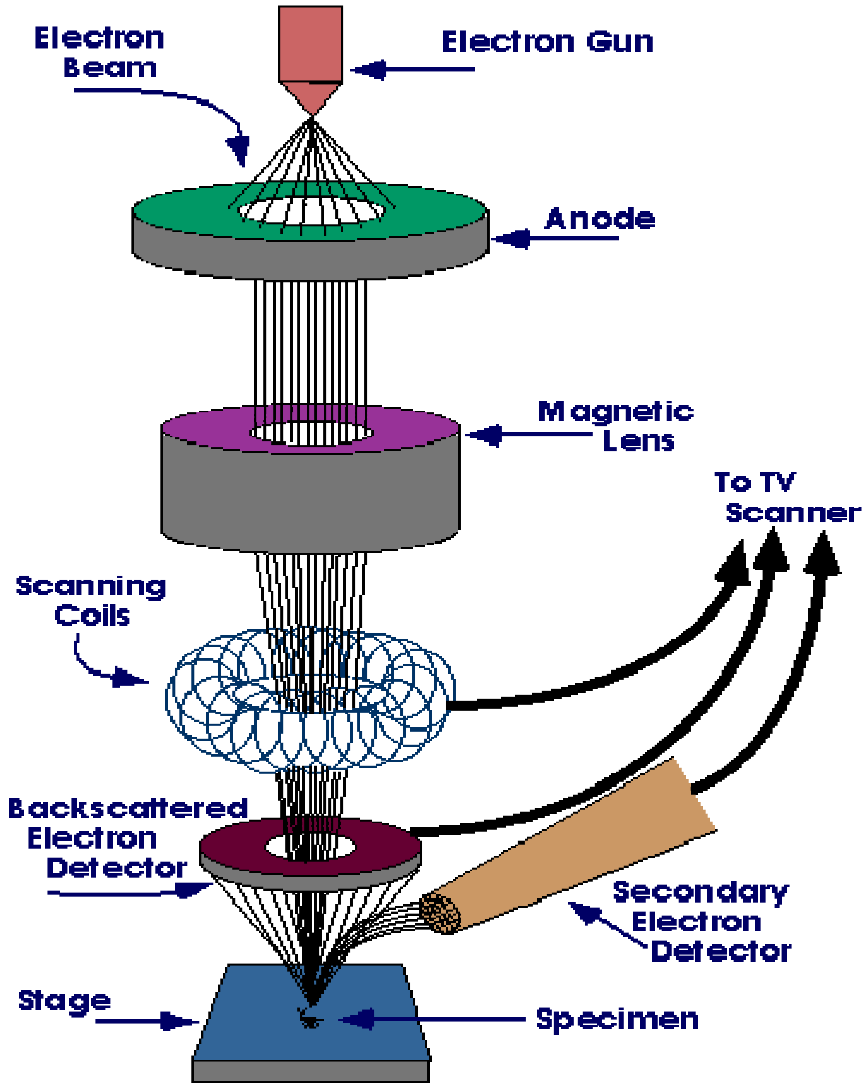
Scanning Electron Microscope

Instead of light, the SEM uses electrons to see 3-D images

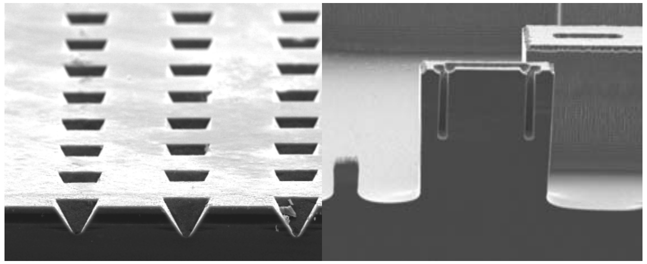
SEM operation:

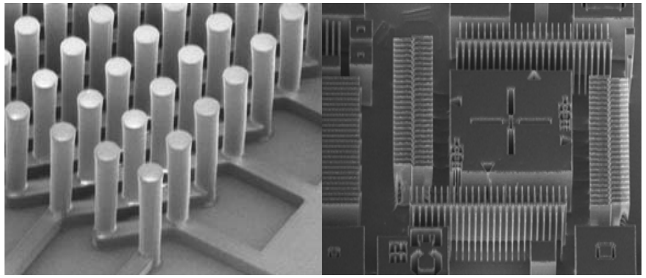
- Air pumped out (vacuum)
- e^- gun emits beam of high energy electrons
- e^- beam focused via lenses
- Scanning coils move beam across sample
- Secondary electrons are “knocked off” surface
- Detector counts electrons
- Image given by # e^-

Resolution ~5 nm

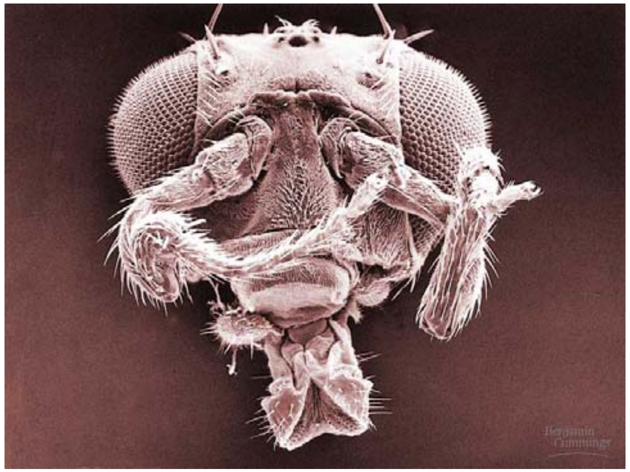


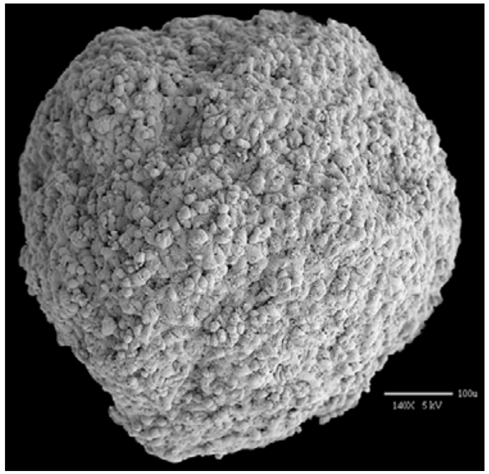
SEM images





There are various examples!





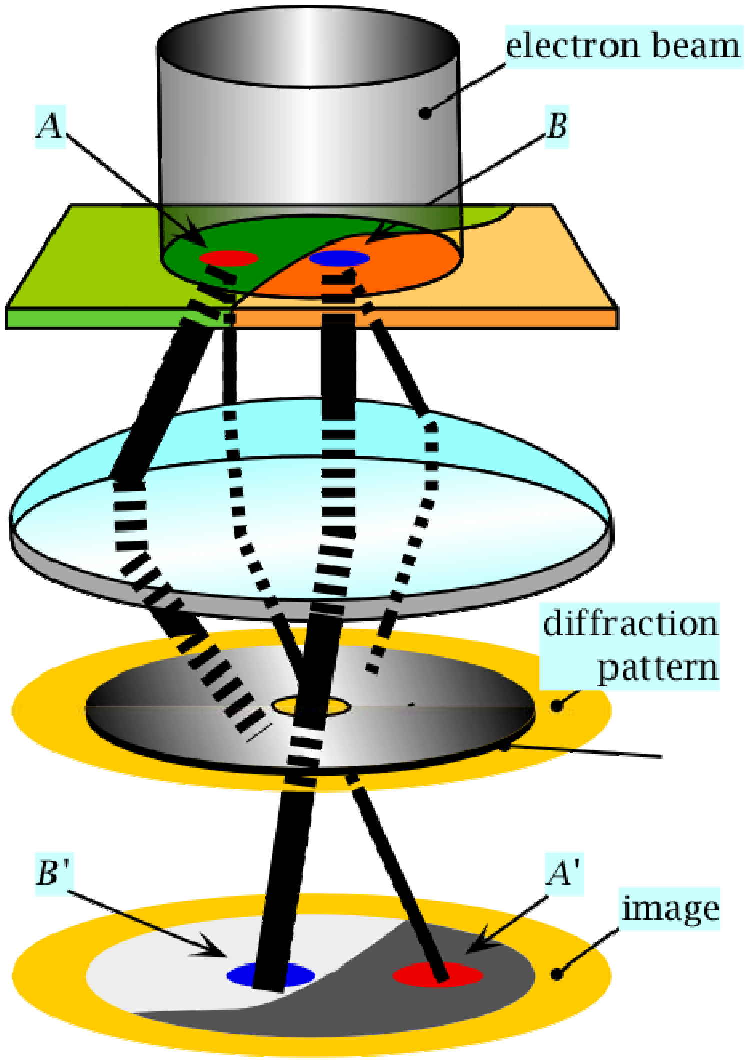
Transmission Electron Microscopy

A TEM works like a slide projector
but with e^- instead of light.

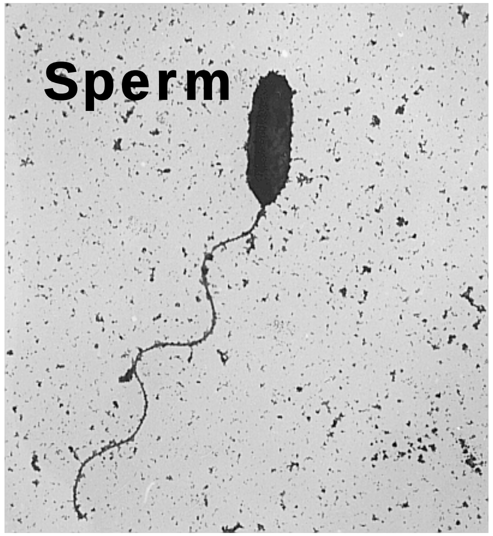
TEM operation:

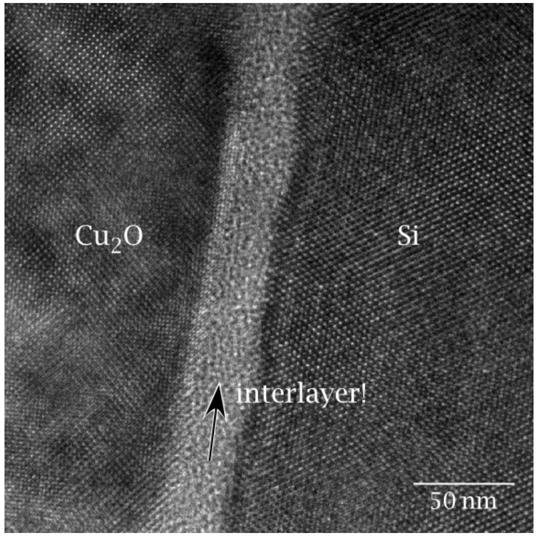
- Air pumped out (vacuum)
- e^- gun emits beam of high energy e^-
- e^- beam focused via lenses
- Beam strikes sample and some e^- are transmitted
- Transmitted e^- are focused, amplified
- Image contrast enhanced by blocking out high-angle diffracted e^-
- Image passed through lenses and enlarged
- When image hits phosphor screen, light is generated

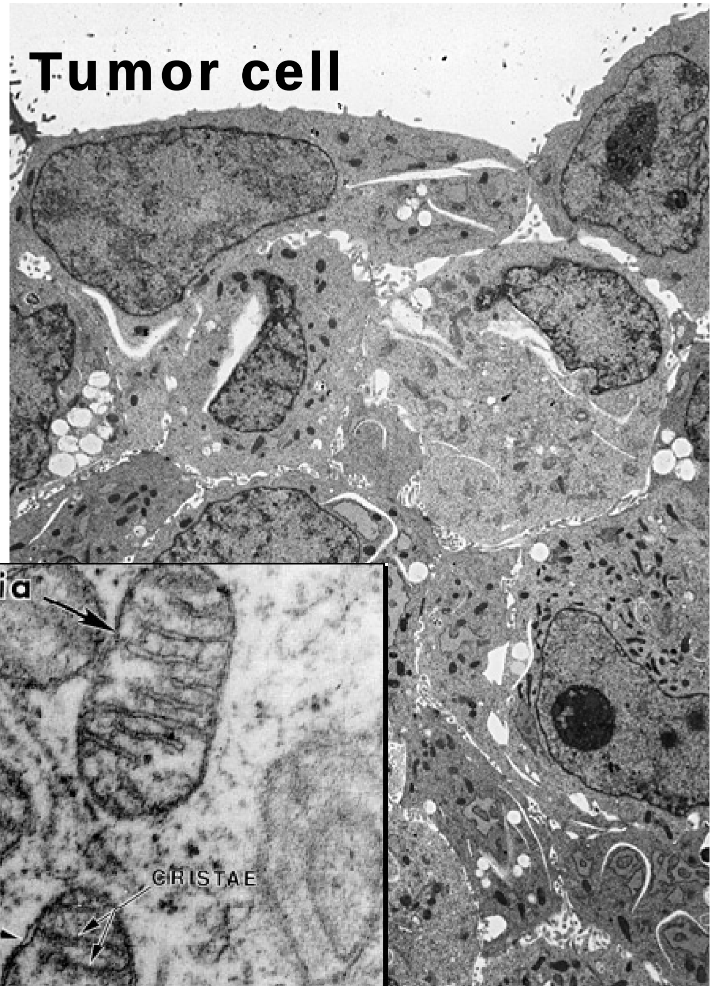
Resolution ~<1 nm

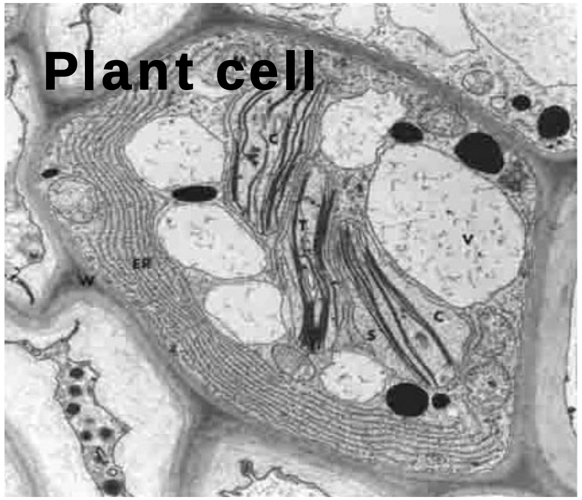


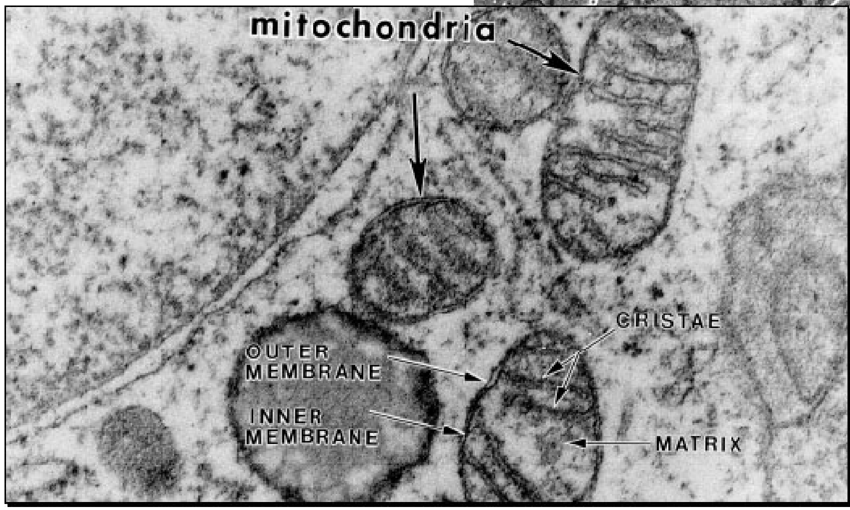
TEM images


Sperm


Cu_2O
Si
interlayer!
50 nm


Tumor cell


Plant cell


mitochondria
CRISTAE
OUTER MEMBRANE
INNER MEMBRANE
MATRIX