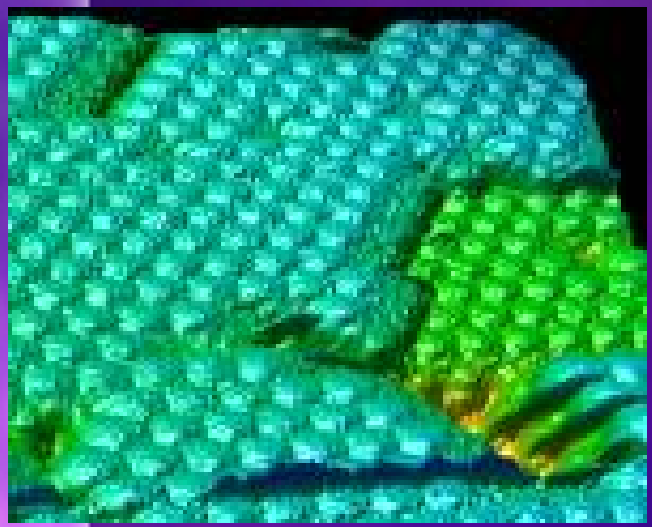
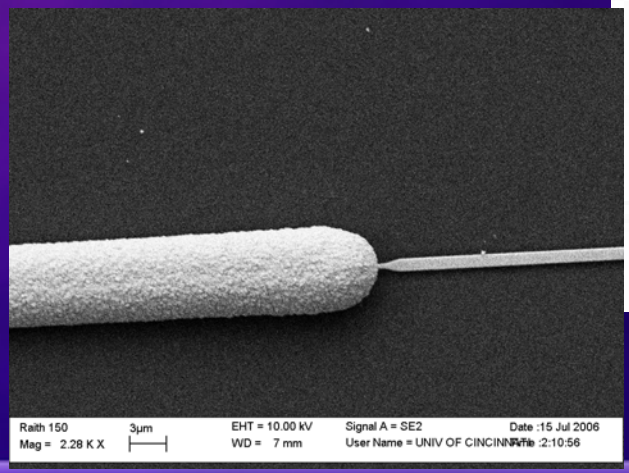
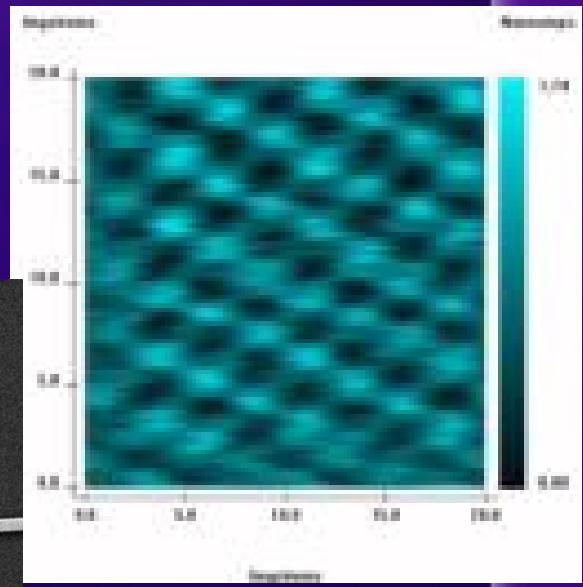
Nanoscience & Microscopies
Optical Microscope
SEM, AFM & STM

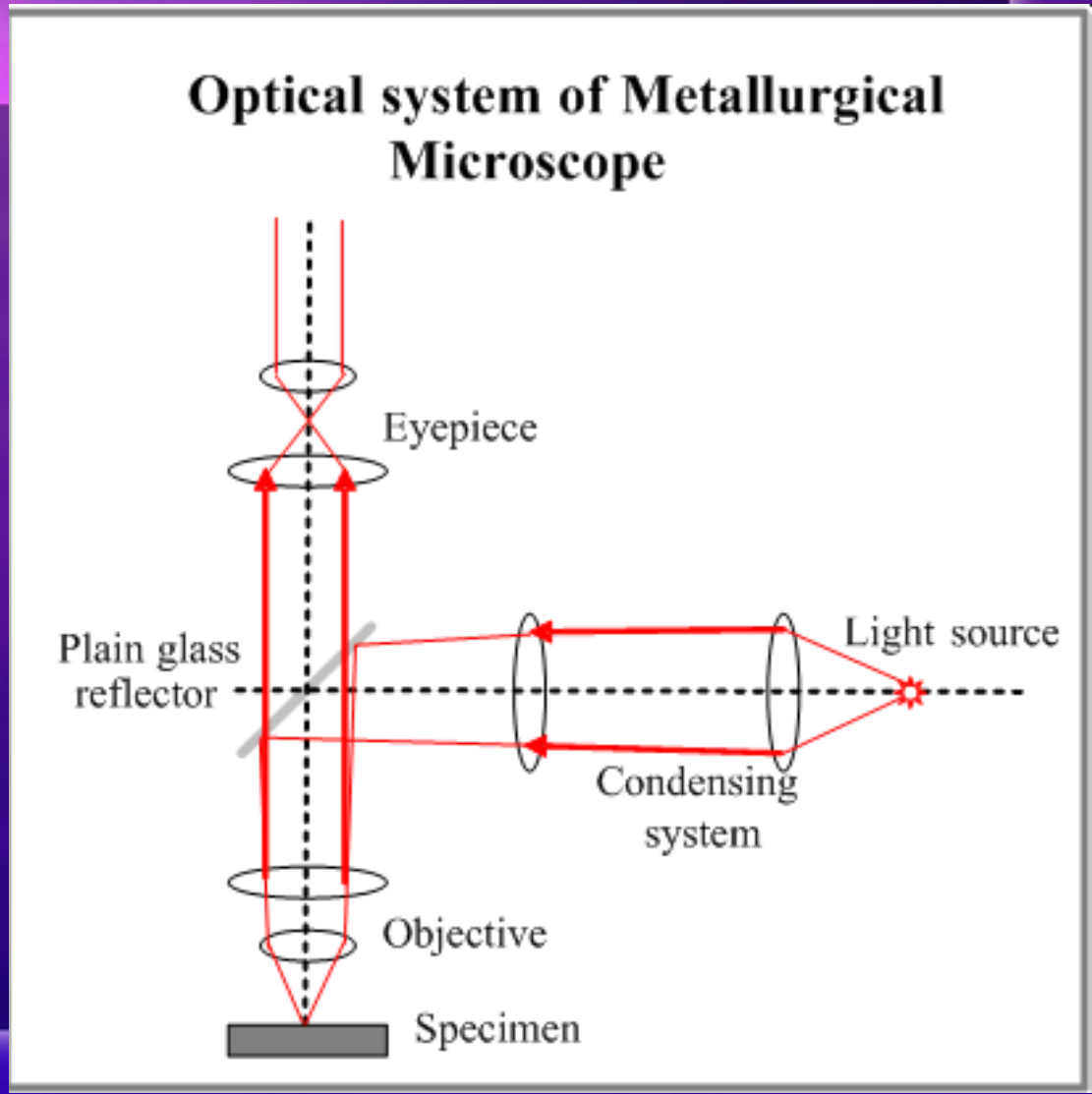






Simple Optical Microscope

A few more lenses than we used in class !



://www.substech.com/dokuwiki/lib/exe/fetch.php

Confocal Microscope

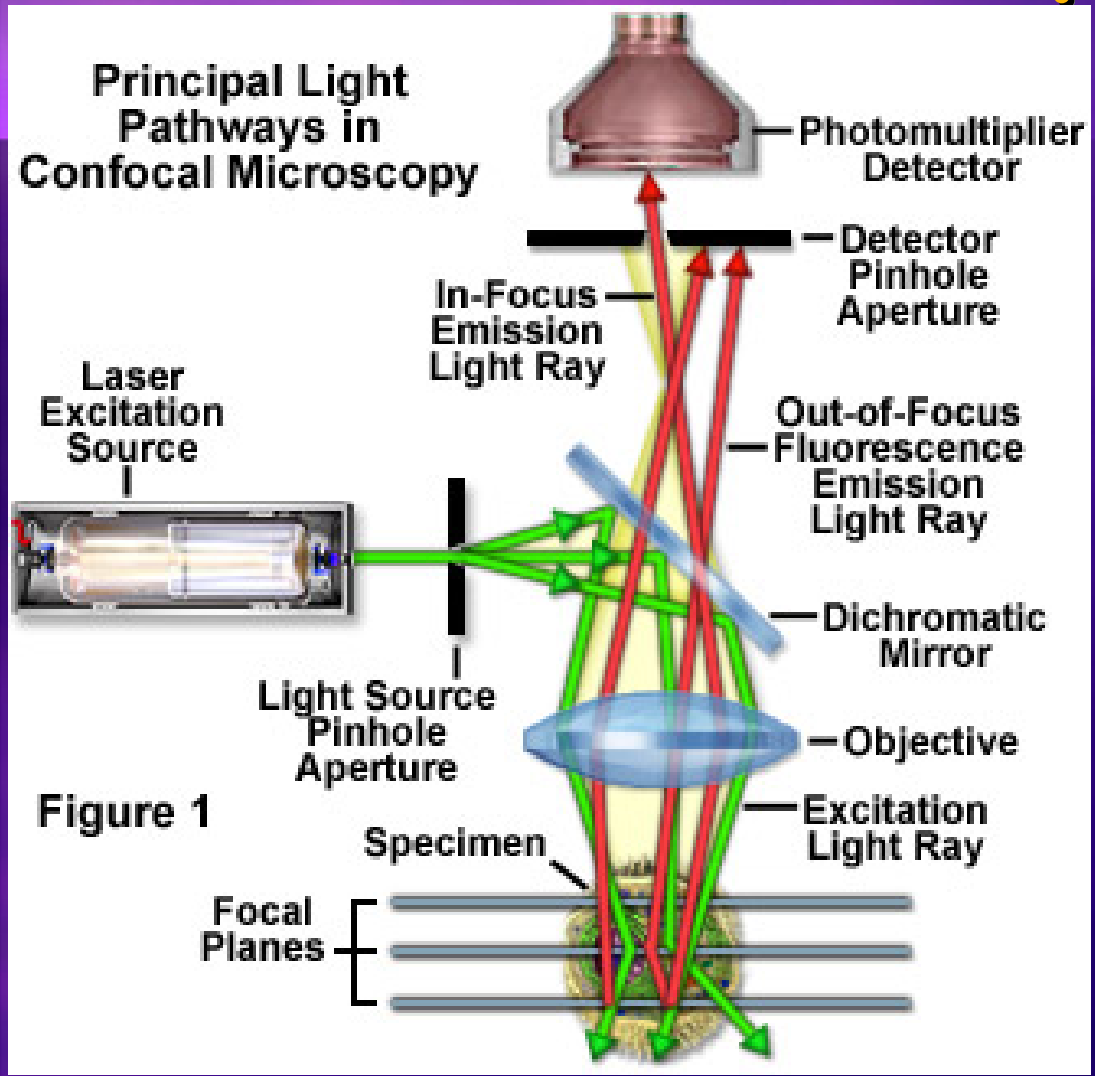


Figure 1

Used in medicine & medical research

http://www.microscopyu.com/articles/confocal/confocalintrobasics.html

Through a Microscope

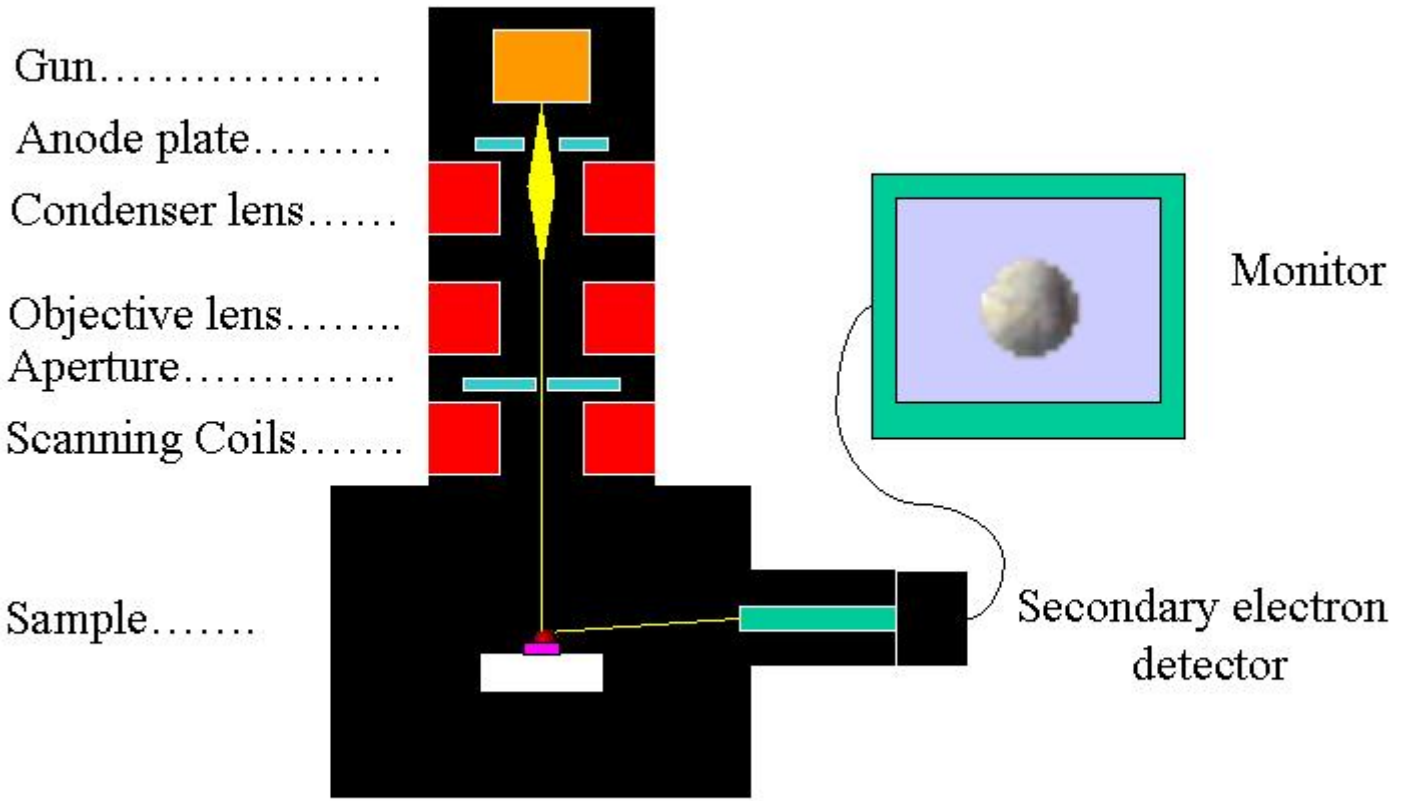
Sea urchin (left) & Pollen (below)

www.answers.com/topic/microscopy

More Optical Microscopy

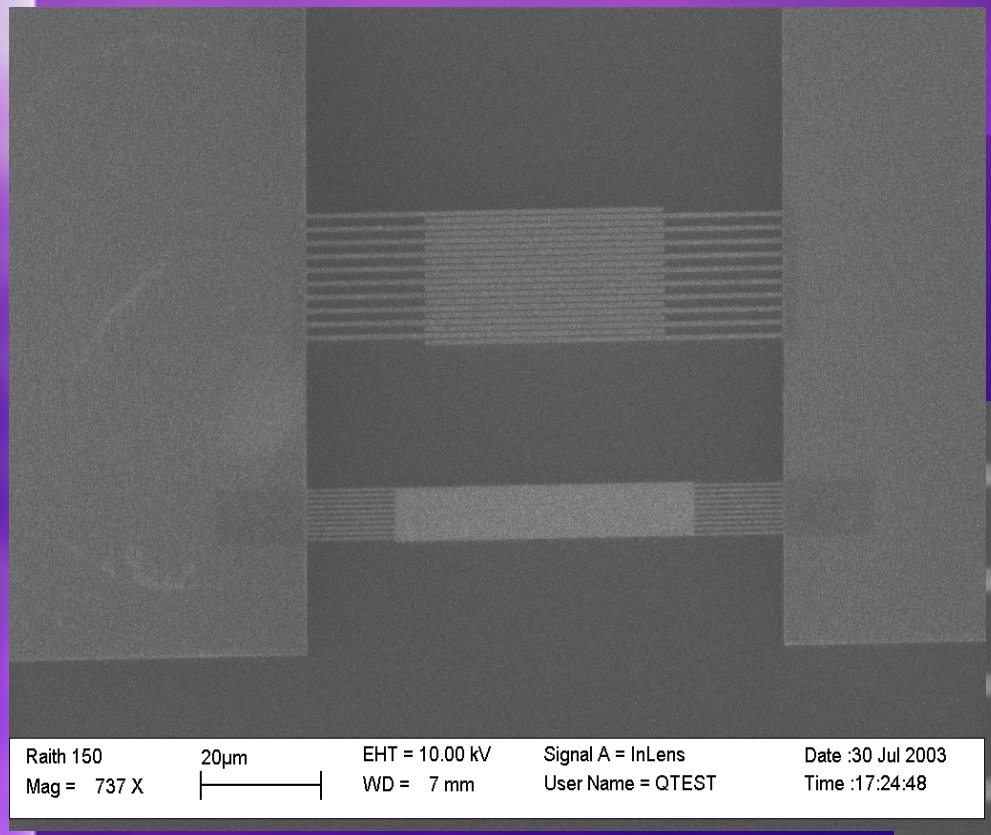
Bugs & Vitamin C (color enhanced)

Block Diagram of E-beam



Schematic diagramme of a scanning electron microscope

SEM Picts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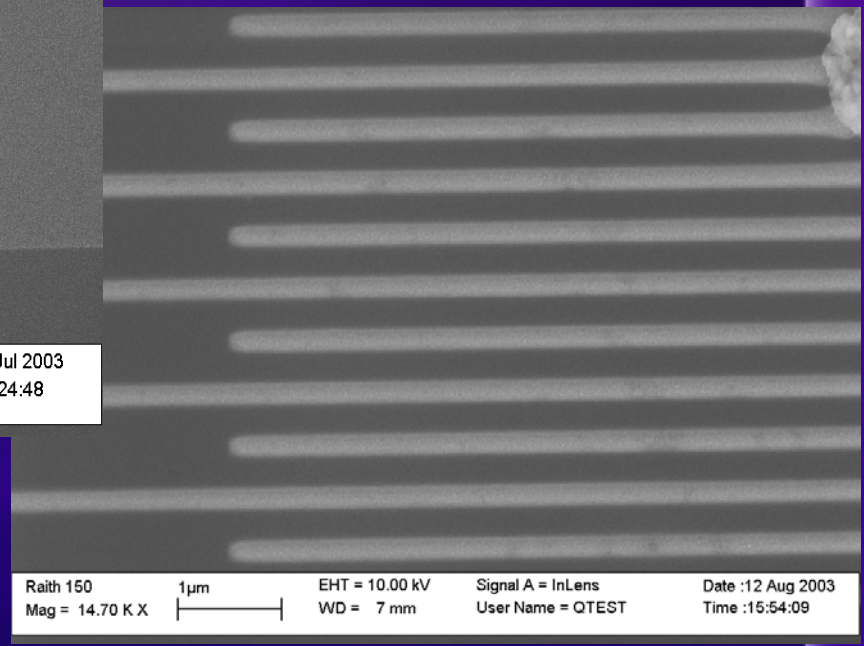
20µm
EHT = 10.00 kV
WD = 7 mm
Signal A = InLens
User Name = QTEST
Date :30 Jul 2003
Time :17:24:48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1µm
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WD = 7 mm
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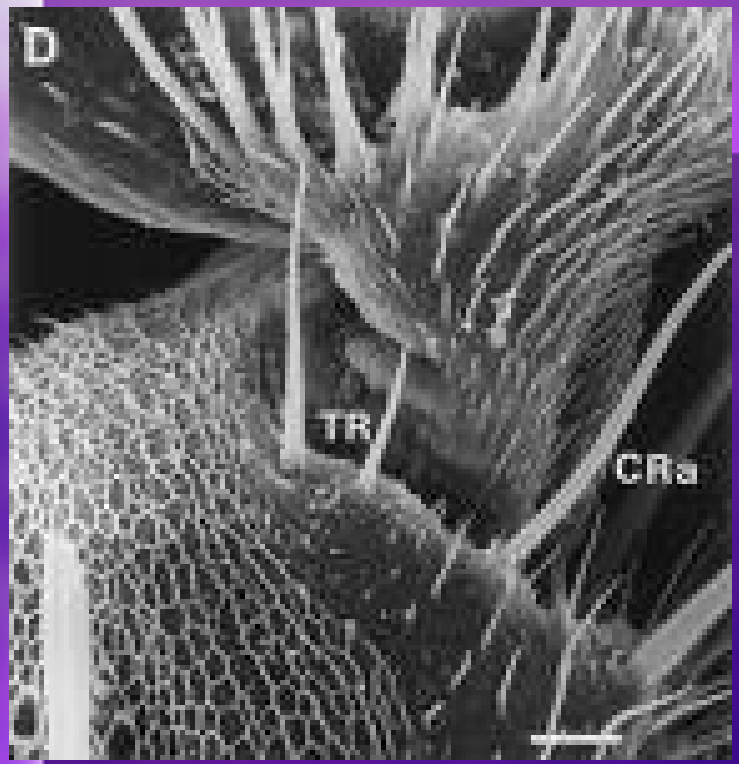
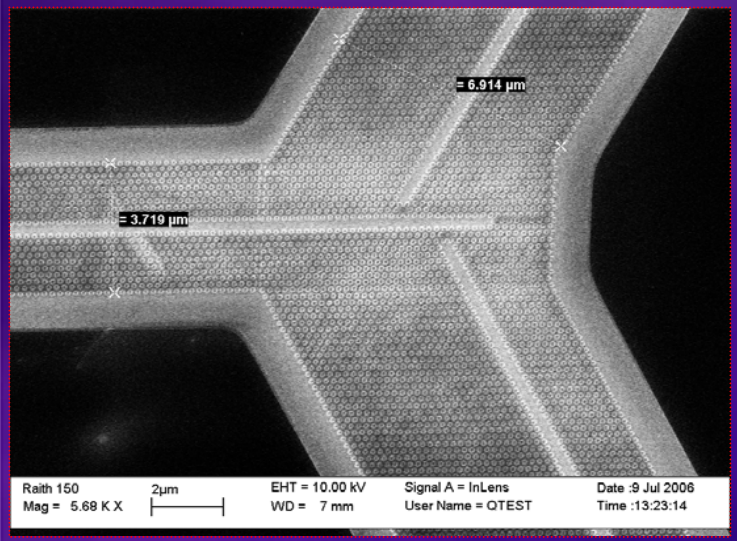
SEM Picts

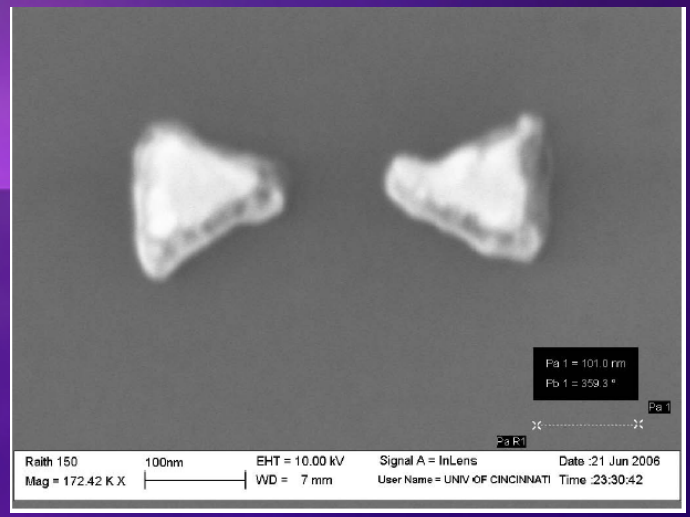


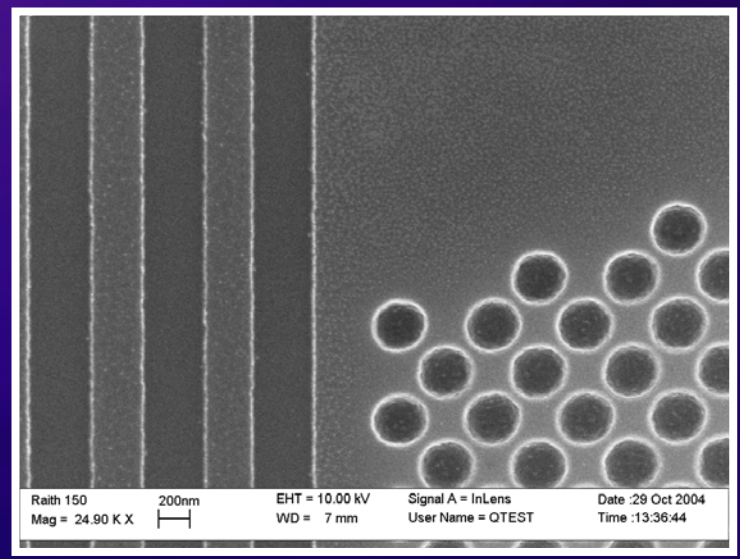
Ostrinium Nubilialis

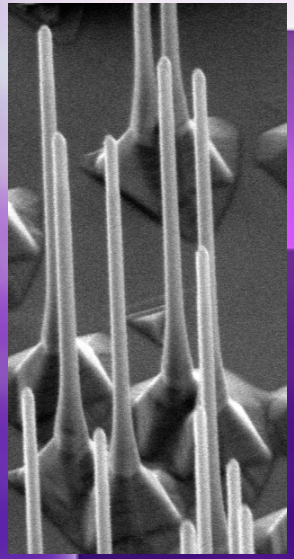
Dendritic Growth

Miami Research Results

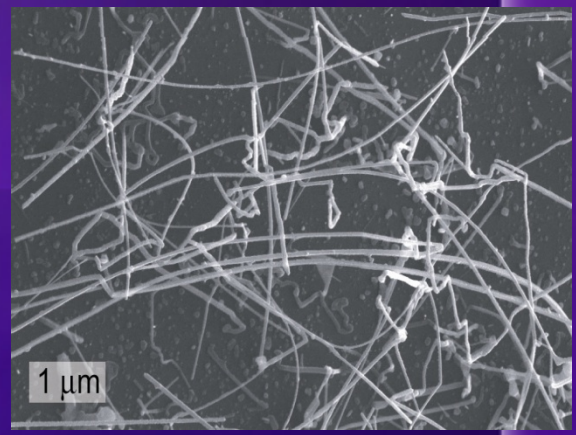


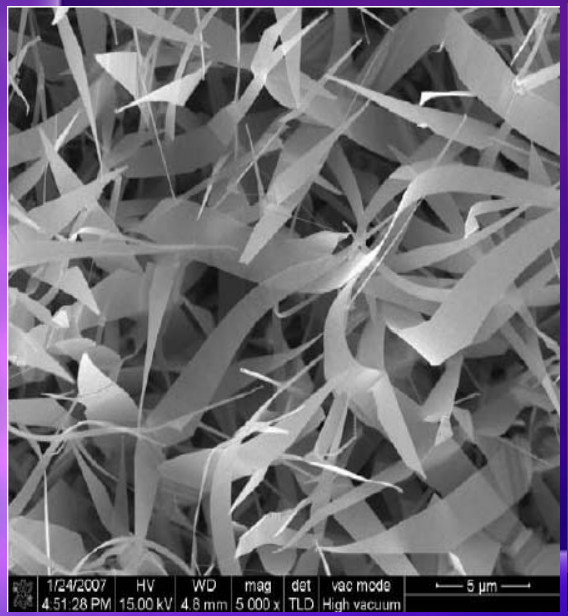


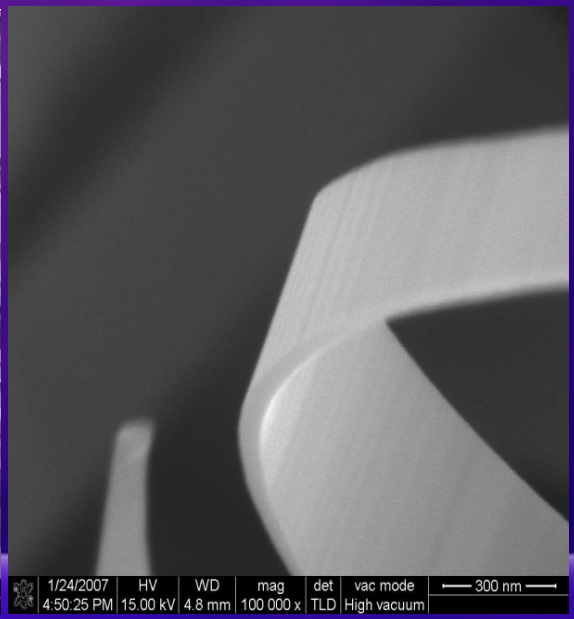


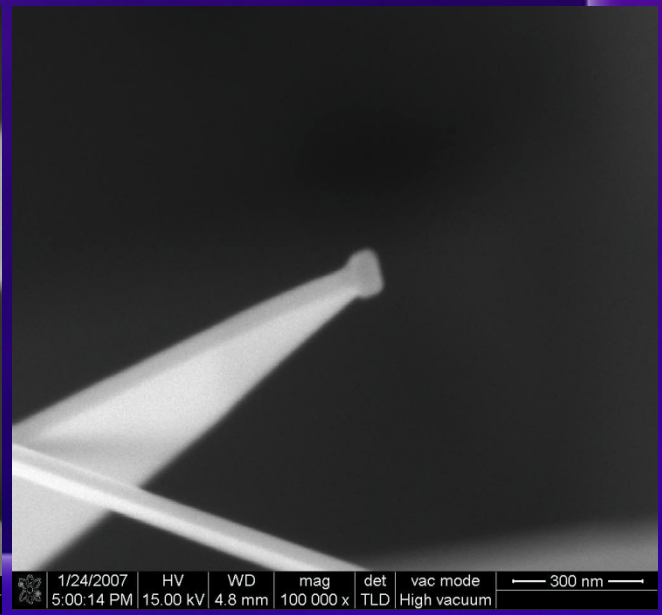


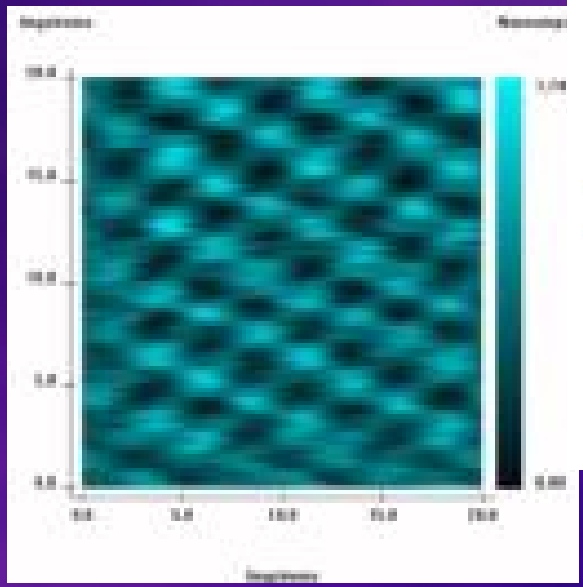
Nanowires & Nanosheets

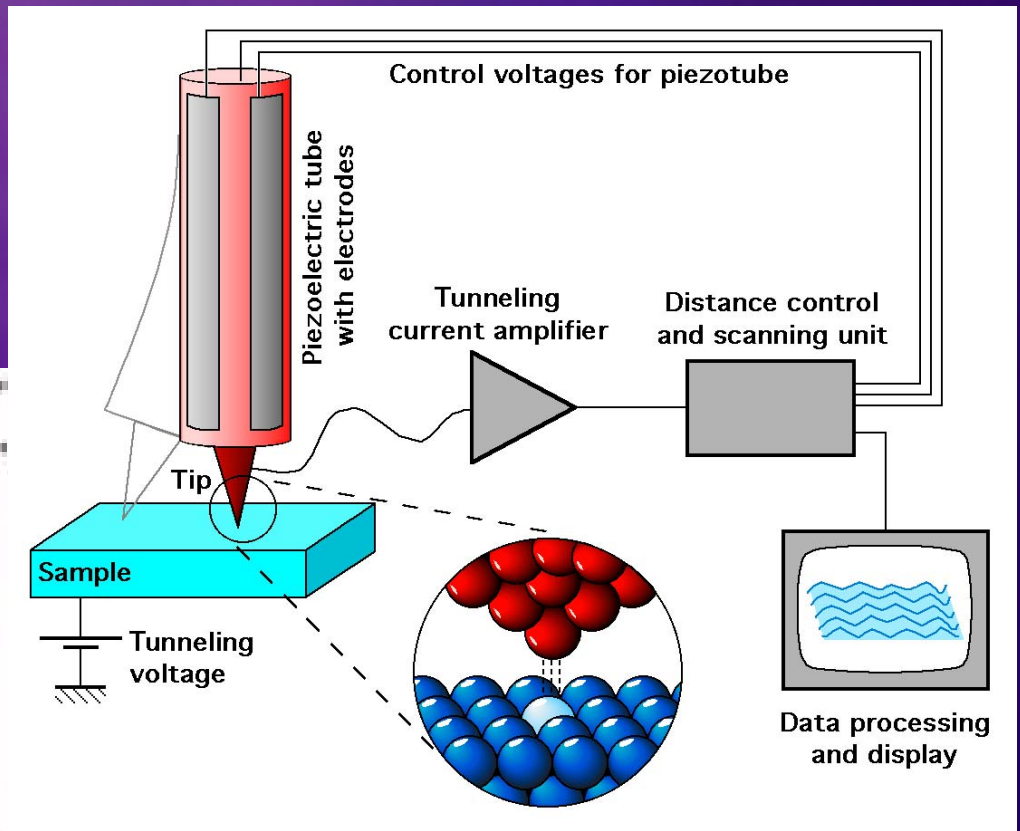











Control voltages for piezotube
Piezoelectric tube with electrodes
Tunneling current amplifier
Distance control and scanning unit
Tip
Sample
Tunneling voltage
Data processing and display

STM Basics

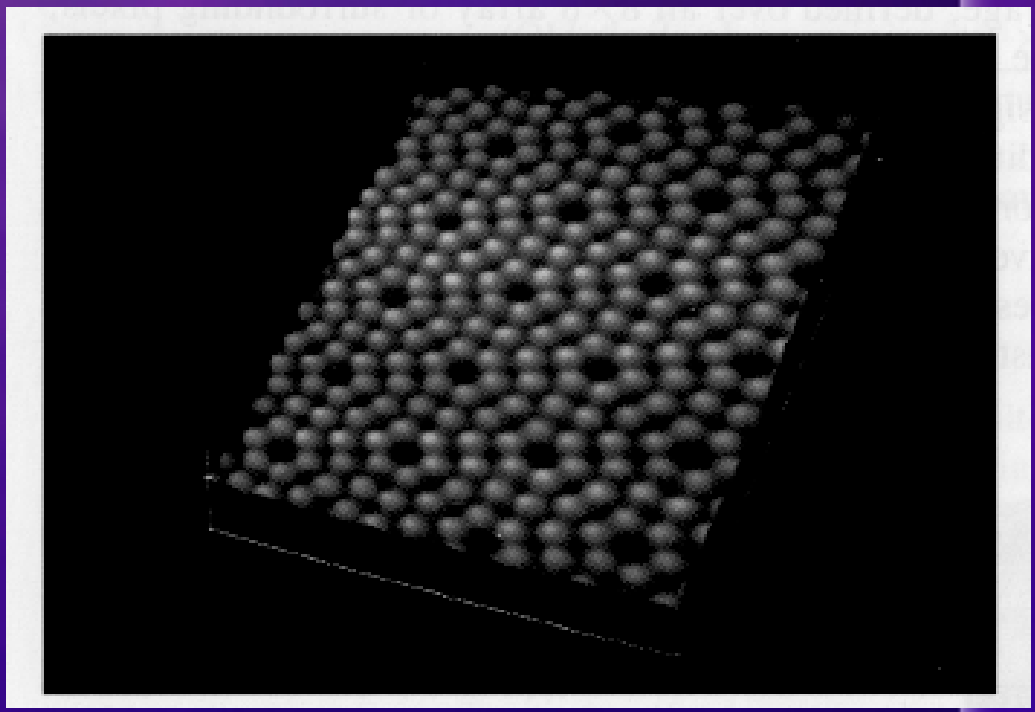
STM -=- Nobel Prize Material!

- *1981*
  - *Invention by two scientists from IBM Zurich*
    - *Gerd Binning & Heinrich Rohrer*
- *1986*
  - *Nobel Prize awarded !!*
    - *Only 5 years later -- a record !*

http://nobelprize.org/physics/educational/microscopes/scanning/

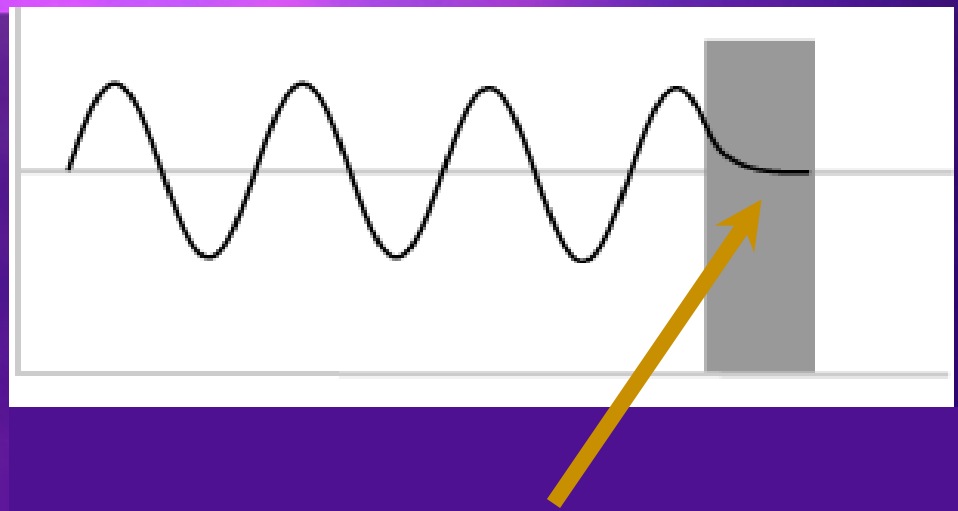
Two Principles…

- Quantum Tunneling for "seeing" surfaces
- Piezo-electric Effect for scanning surfaces



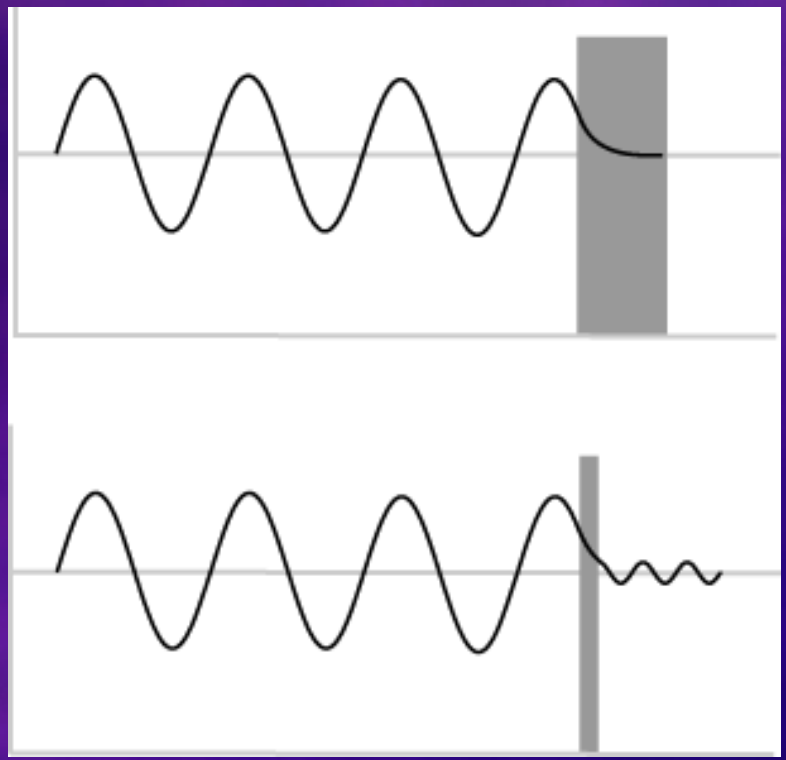
- This is the STM image of Si(111)-7x7 surface, the white spots represents the position of the atoms.

Electron Wave Behavior Outside the Barrier



Wavefunction extends outside of STM tip

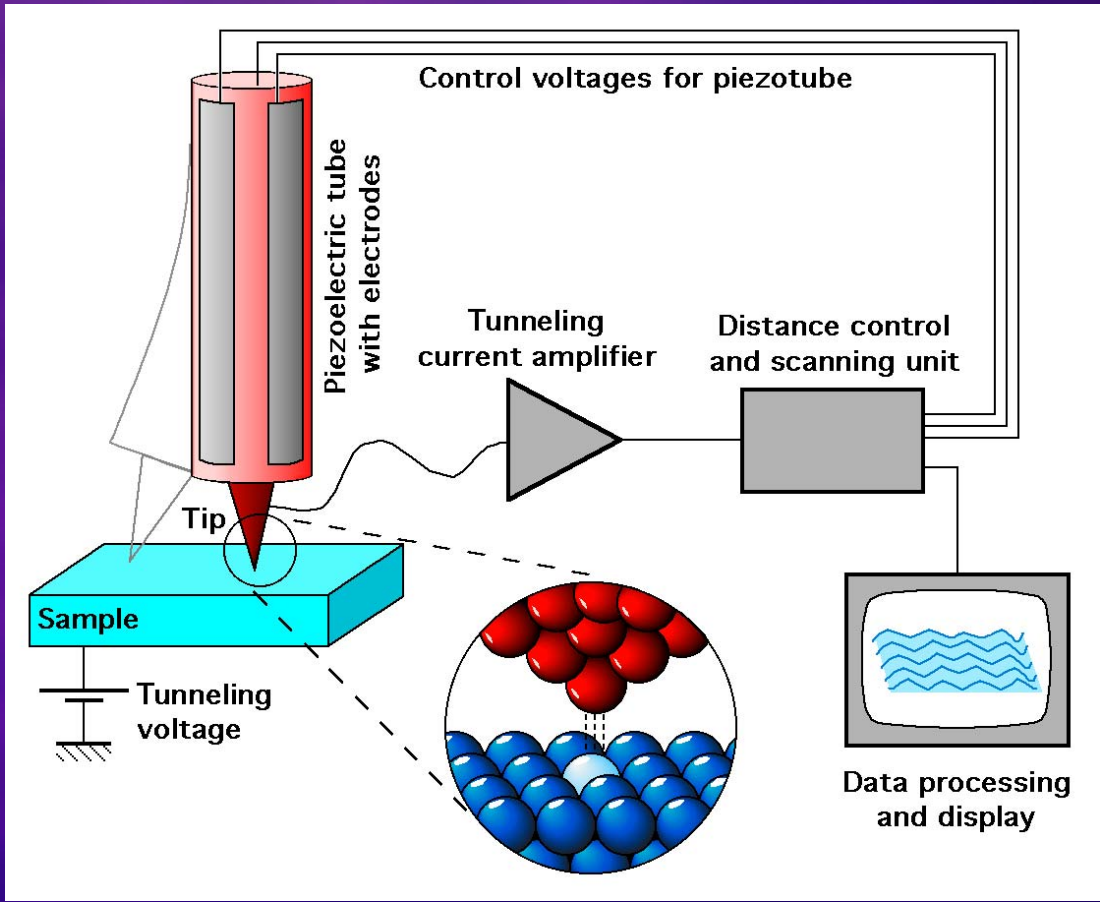
At close approach, Electron Waves can Breach the Air!



- *Electrons can tunnel through the air from tip to sample depending on…*
  - Barrier separation
  - Electron energy

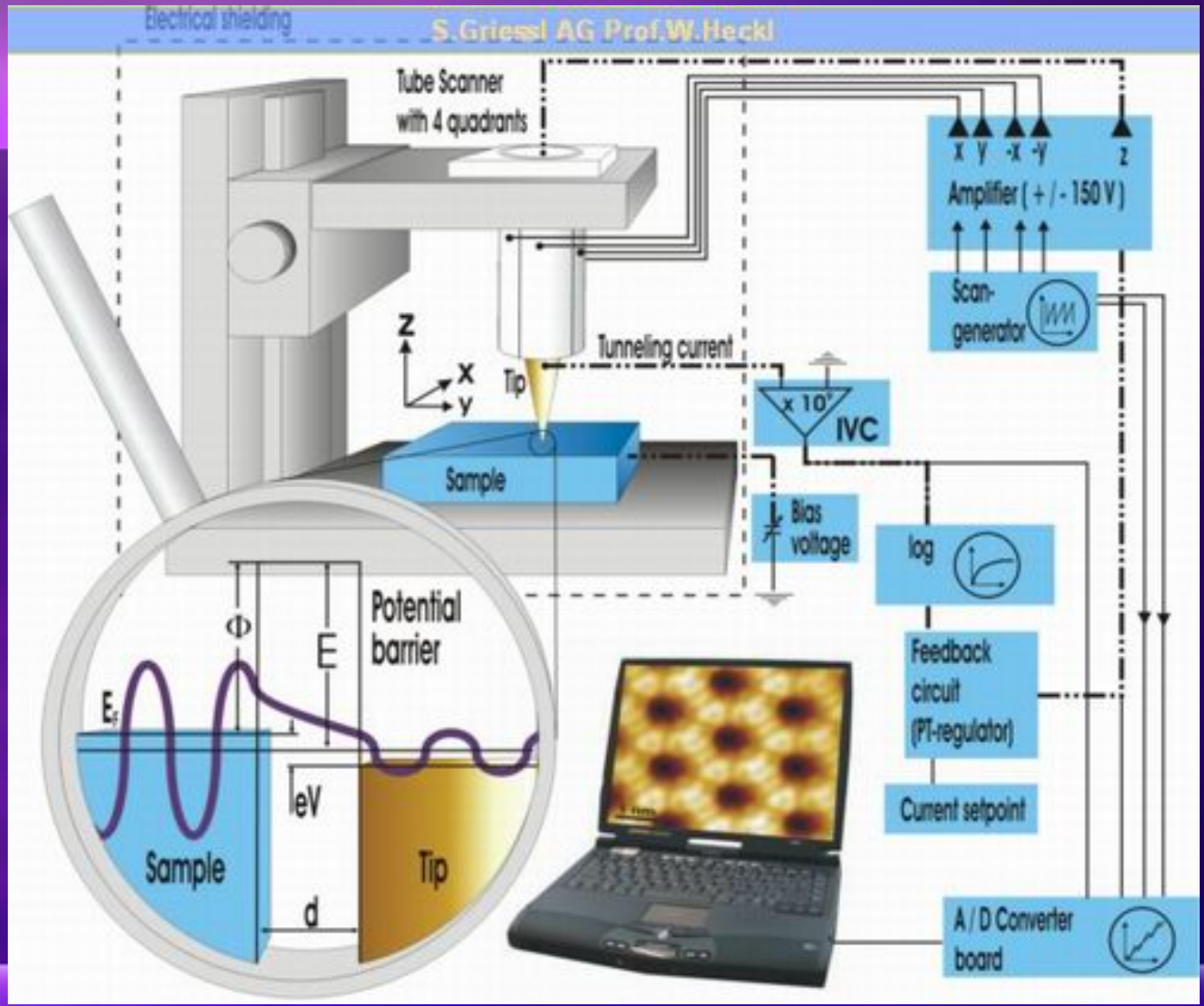
http://phys.educ.ksu.edu/vqm/html/qtunneling.html

Introducing the STM…



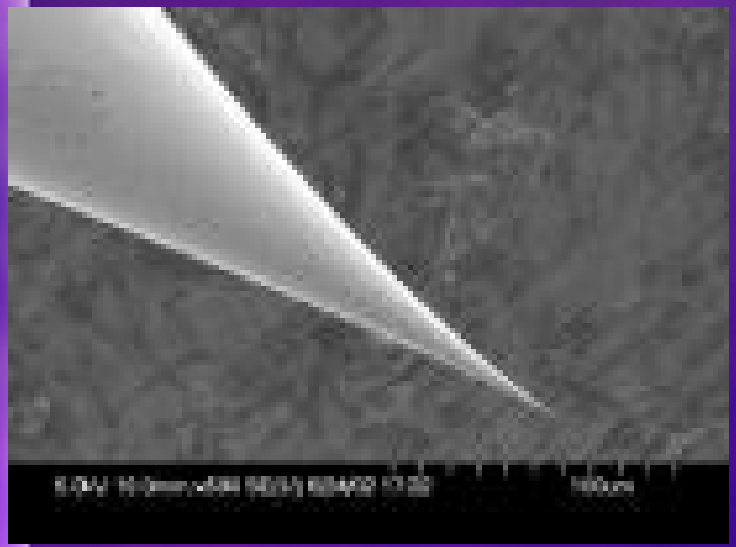
http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/stm_schematic.html

Closer look...

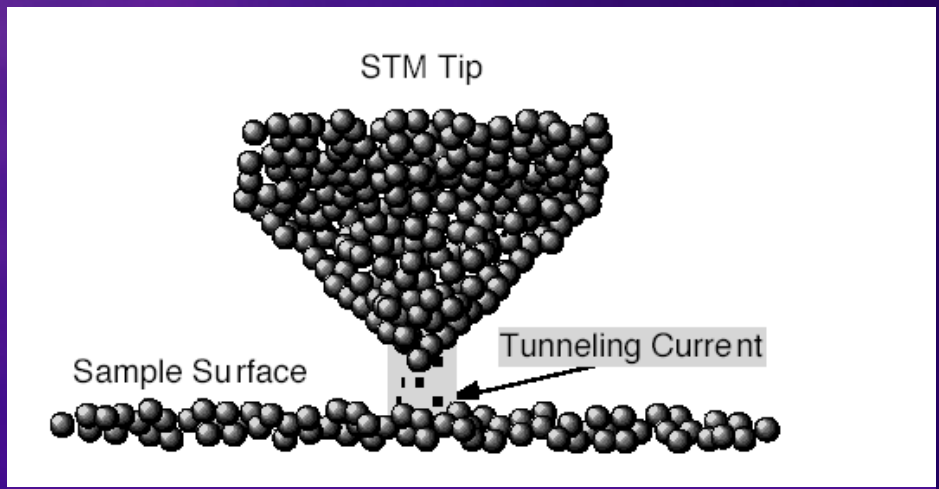


www.nano.geo.uni-muenchen.de/stm

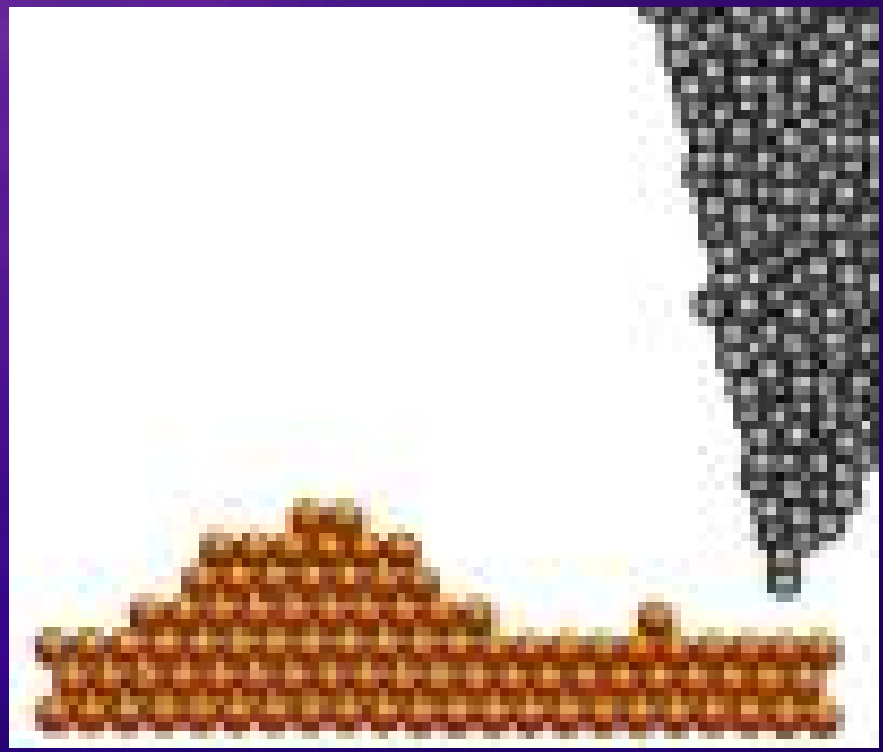
STM Tip in detail…



www.chem.ucla.edu/~kodohert/0f1b3060



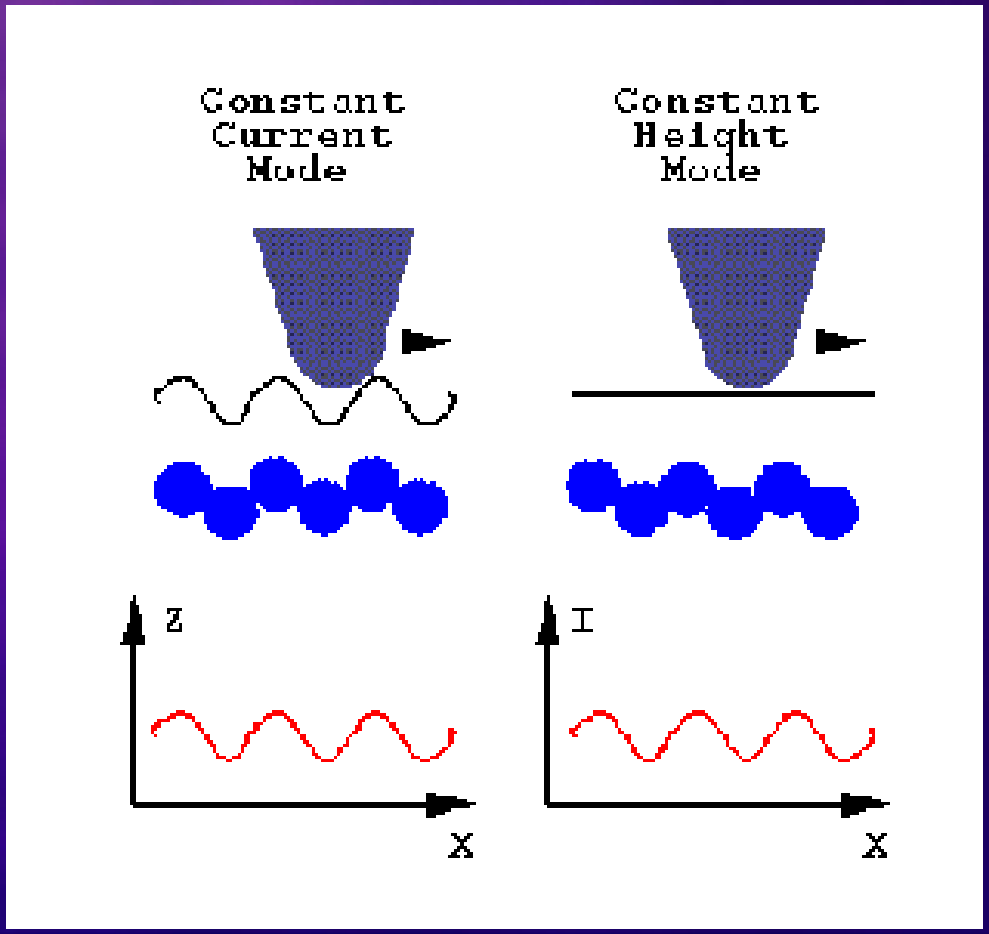
Scanning the STM tip…



www.surfaces.lsu.edu/STMoverview.html

Modes of Operation

- Constant Current
- Constant Height



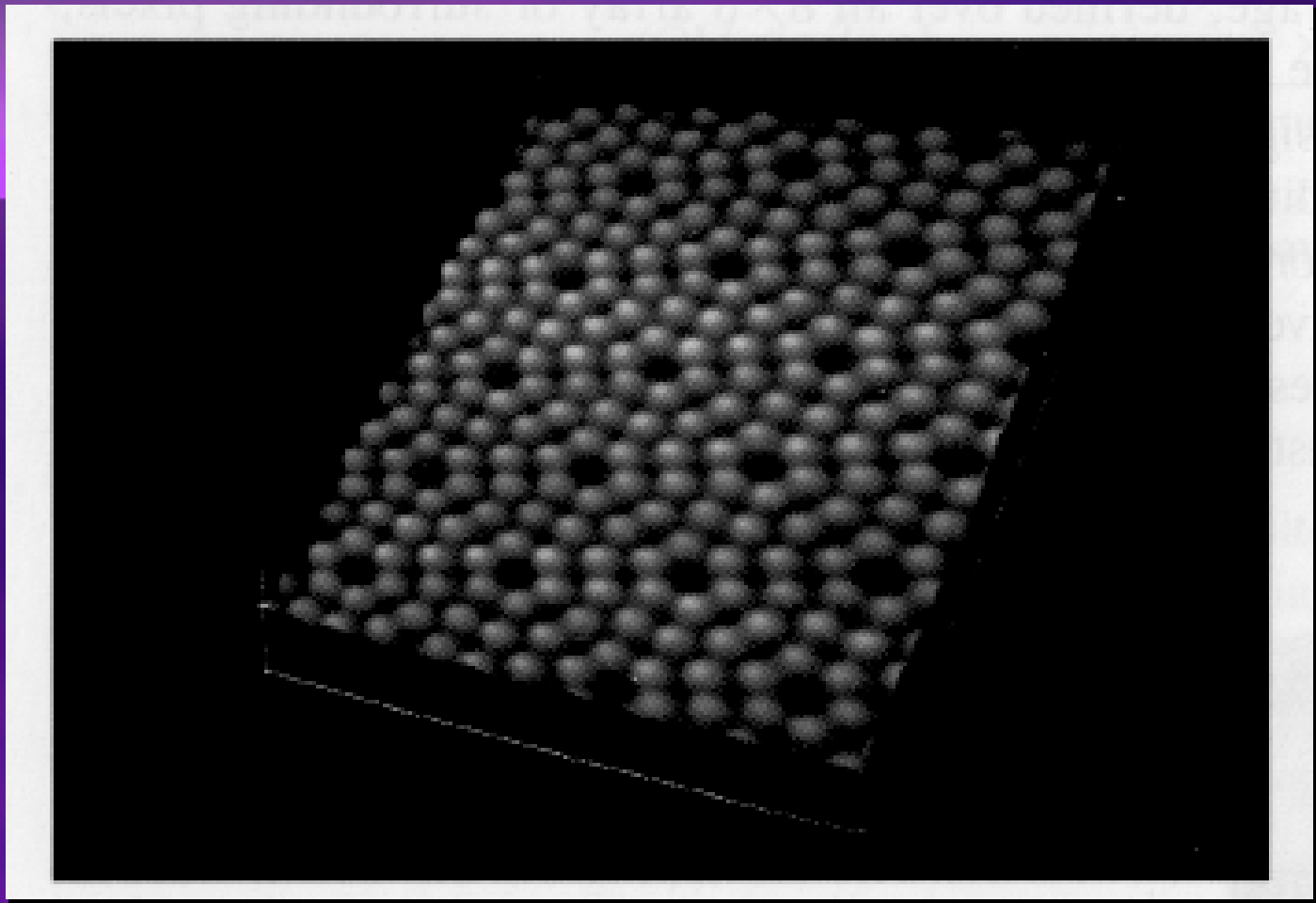
userpage.chemie.fu-berlin.de/.../html/node5.htm

Important note:

- *Remember, the STM works because of electron tunneling between the surface of interest and the scanning tip.*
- *Thus--> Nuclear position is NOT probed*
- *THEREFORE --> we are probing what?*

Use of STM

- Excitation of different vibrational modes depending on species (C_2H_2 vs. C_2D_2)
  - Science, 280, 1715 (1998).
- Single molecule chemical reactions
  - Science News, 158, 215 (2000).

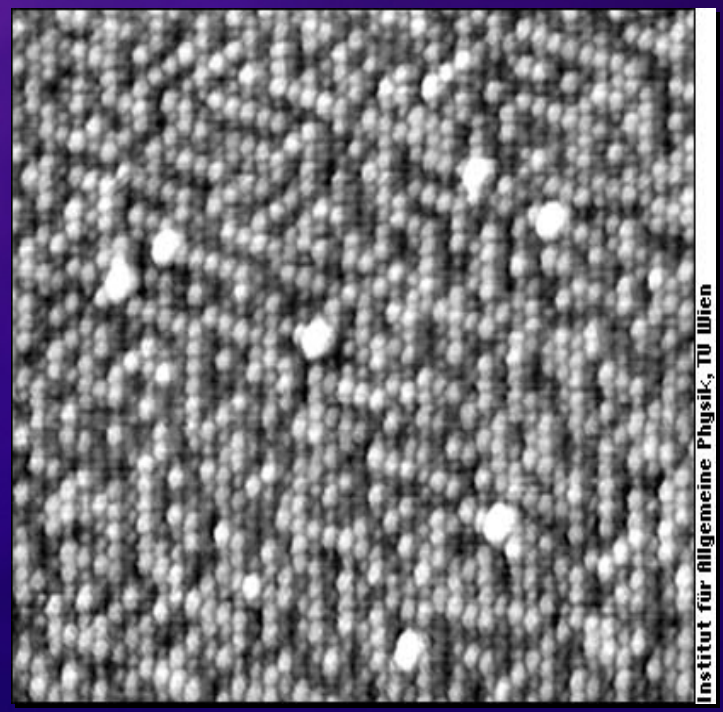


- *This is the STM image of Si(111)-7x7 surface, the white spots represents the position of the atoms.*

Use of STM- Chemical Constrast

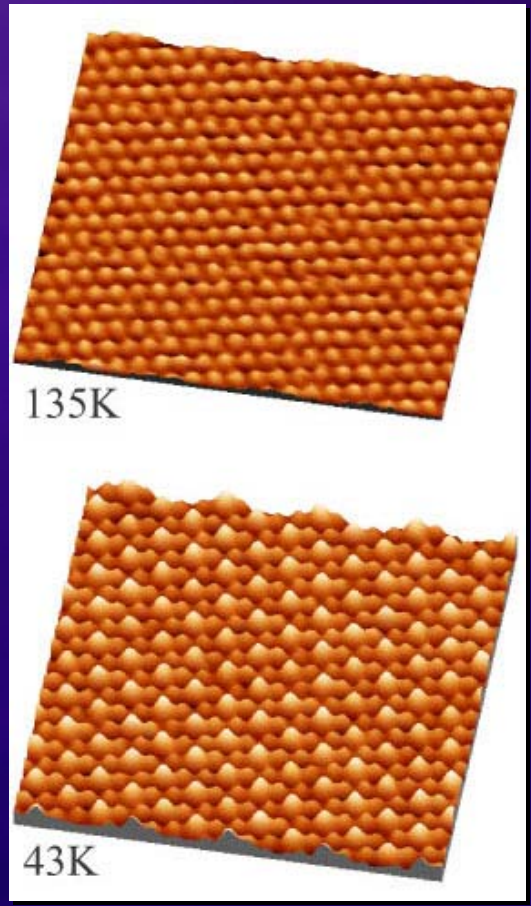
It all started with an (111) oriented surface of a PtNi alloy (bulk composition 25% Pt, 75% Ni; surface approx. 50% of each). We found that we can distinguish between Pt and Ni atoms on this surface with the STM!

The brighter species is Ni. The white blobs in the image are impurities of unknown nature.



http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/chemical_resolution.html

Researchers usually compare "before" and "after" pictures of typical regions of a material to see how it changes during a phase transition. This is now see on an atomic scale.



As the lead atoms in this 20 x 13 nanometer region are warmed from 40 to 136 Kelvin, they switch from the corrugated to the flat arrangement at the transition temperature of 86 Kelvin .
Vienna University of Technology

Phys. Rev. Lett. 94, 046101

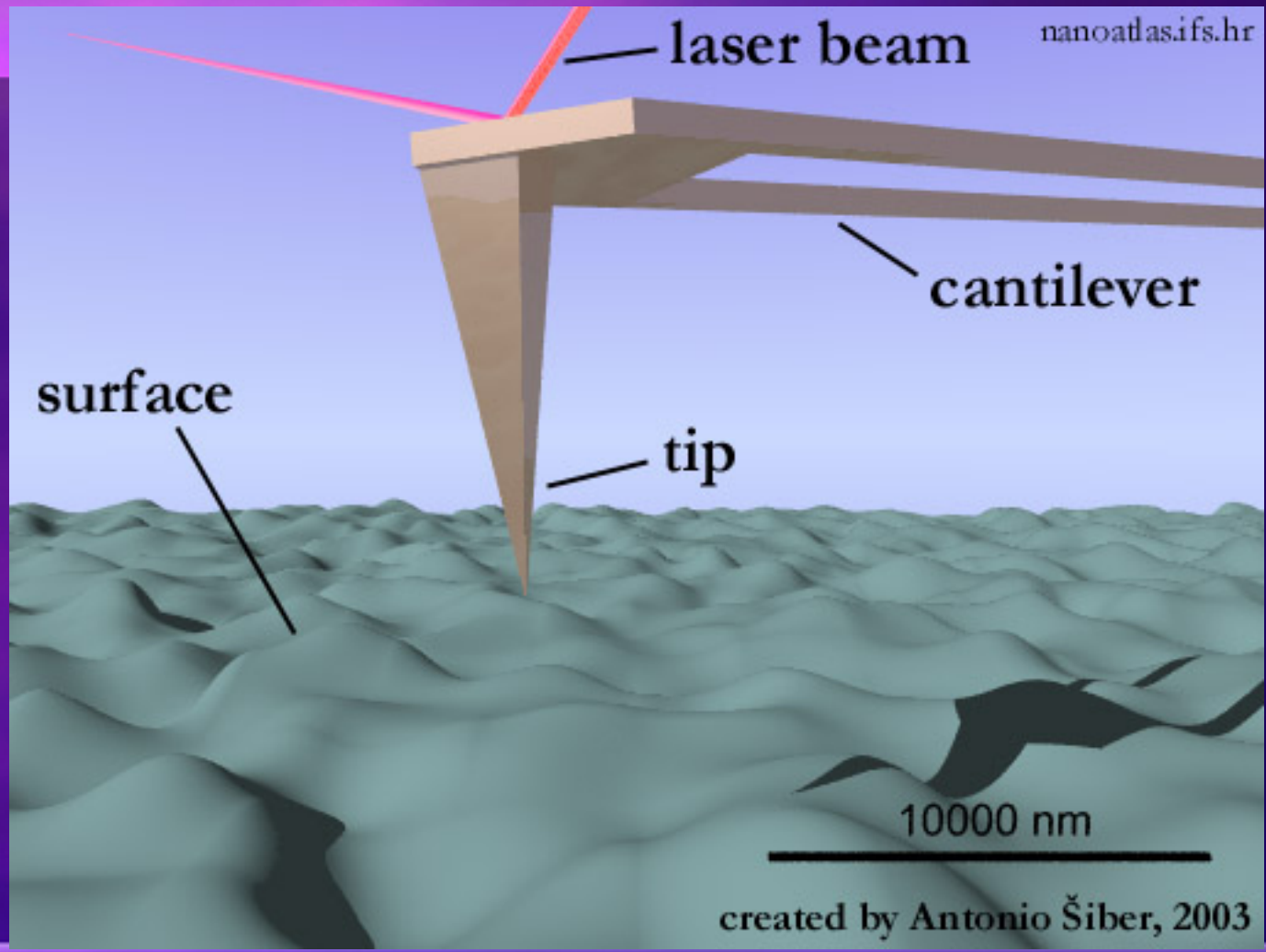
Downside to STM?

- Requires electrical path – for tunneling
- Gives information of heights of electron clouds above surface – eg. graphite structure
- Some questions cannot be explored

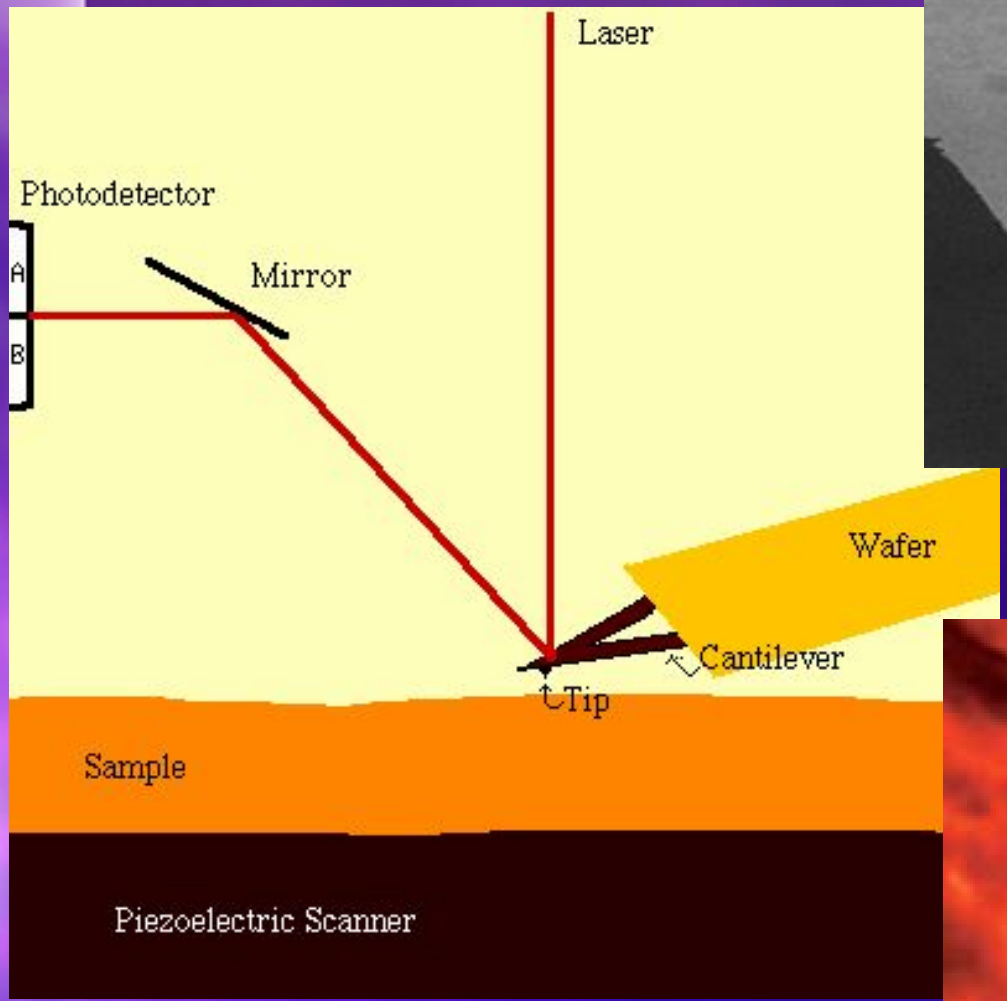
Other cool sites…

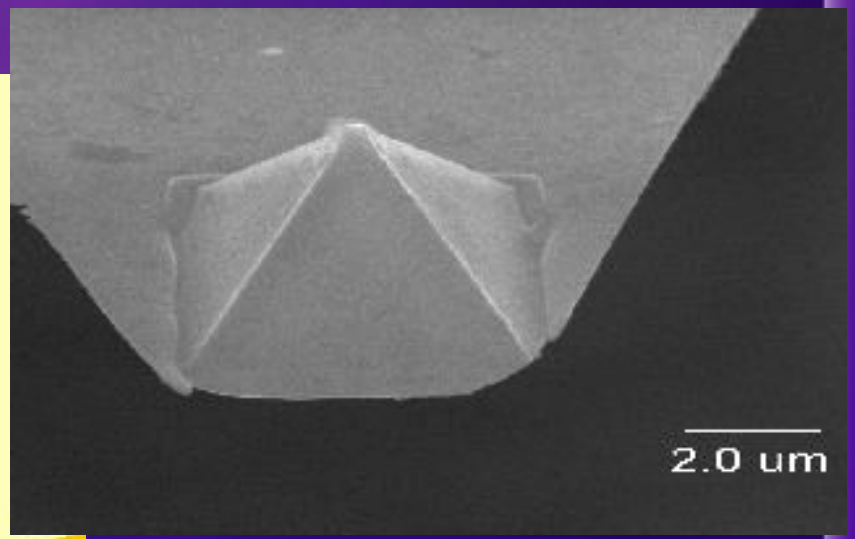
- http://www.almaden.ibm.com/vis/stm (Interesting STM images)
- http://www.nobel.se/physics/educational/microscopes/scanning/ (Interesting STM images)
- http://www.nanoscience.com/education/gallery/DDB.mpg (movie of scanned image)

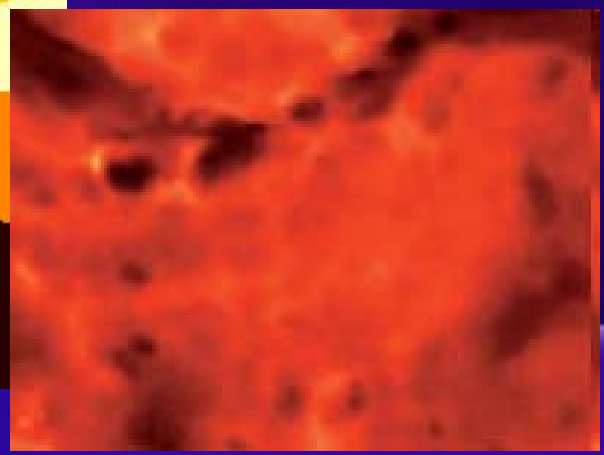
Atomic Force Microscopy



AFM Fundamentals





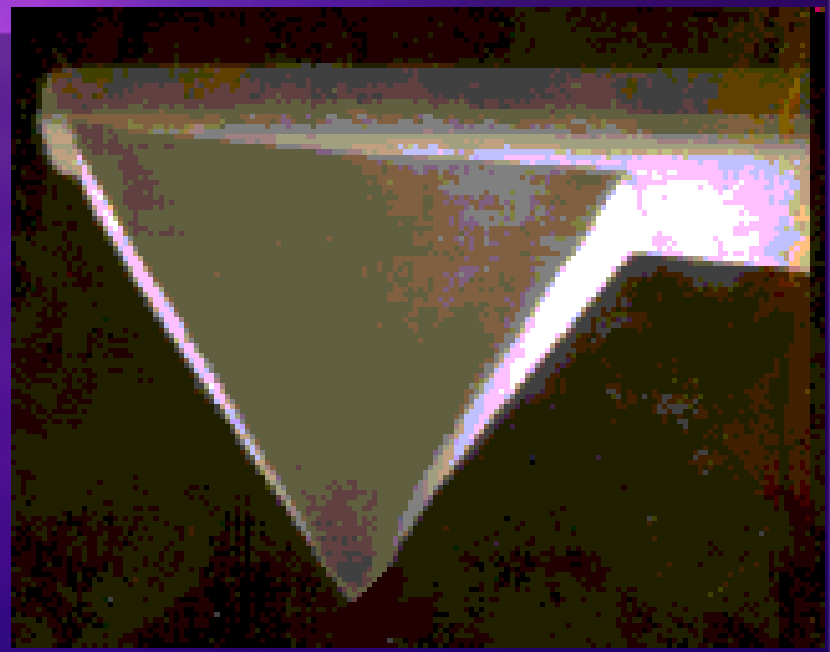


AFM

- The AFM or Atomic Force Microscope was developed in 1986 – soon after the STM
- The AFM was an offshoot of the STM which was limited to samples which were conducting in order to scan them
- The AFM can operate in contact mode or non-contact mode

THE AFM TIP

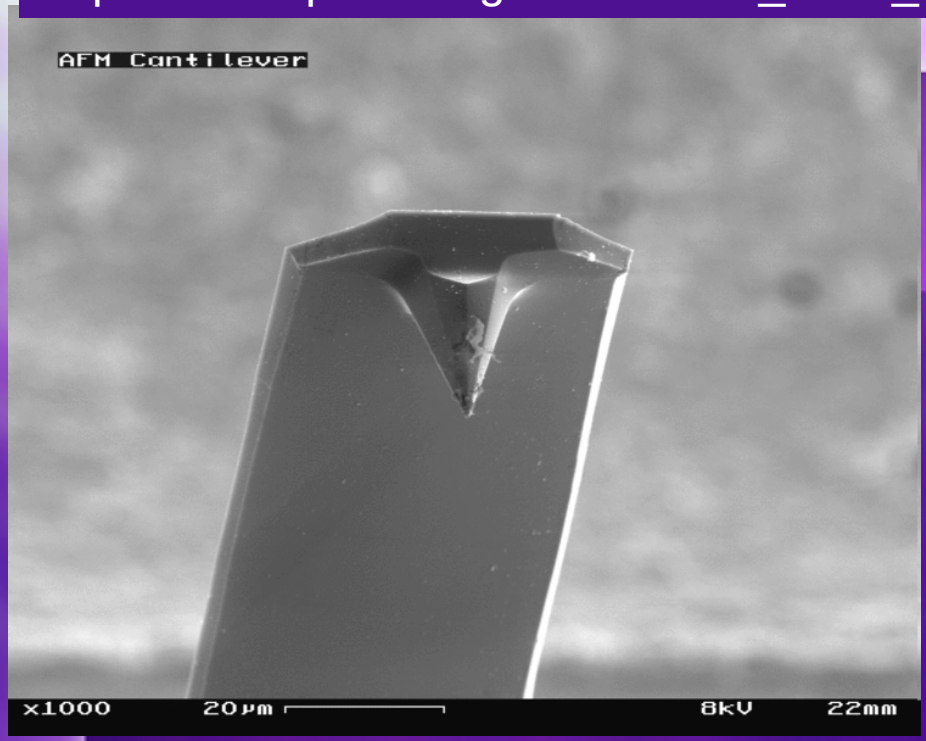
- The AFM tip is generally made of silicon or silicon nitride



- The tip is usually pyramidal or conical in shape with a ~10 nm end (~100 atoms)
- The tip must be durable, and sharp enough to see surface features

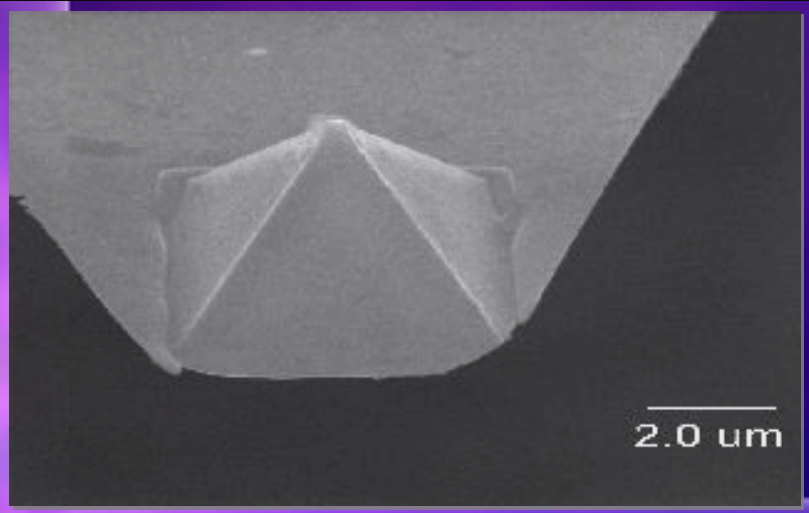
http://www.weizmann.ac.il/Chemical_Research_Support/surflab/peter/afmworks/

http://en.wikipedia.org/wiki/Atomic_force_microscope

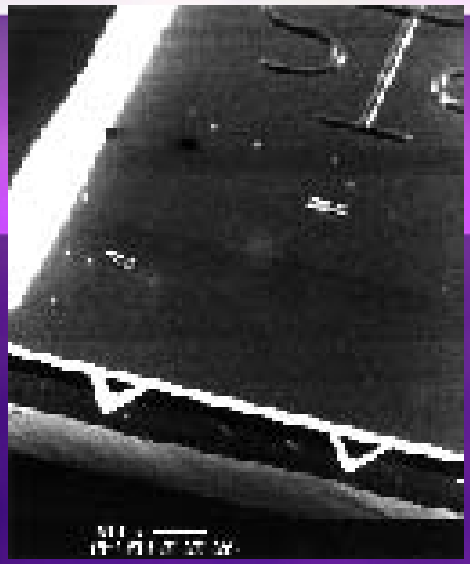


AFM Tip & Cantilever

- The AFM tip is attached to a cantilever ~10 microns long
- The cantilever must be flexible to allow for the scanning across various surface heights



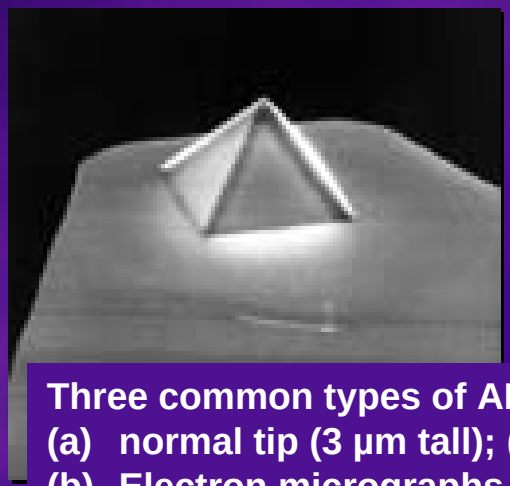
http://www.mobot.org/jwcross/spm/

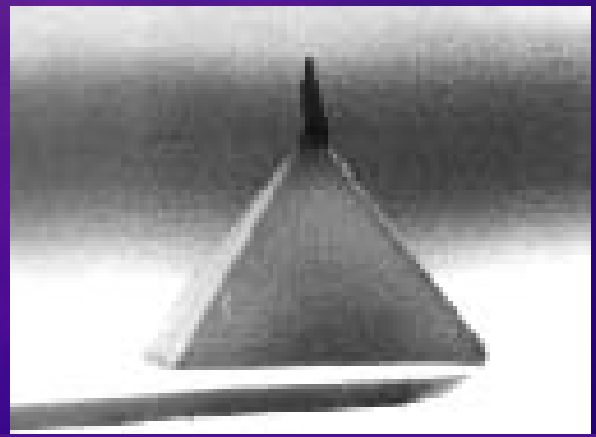


Wafer & TIP

- *Si or SiN – 10 nm at end – ~100 atoms*

Electron micrograph of two 100 μm long V-shaped cantilevers (by Jean-Paul Revel, Caltech; cantilevers from Park Scientific Instruments, Sunnyvale, CA).





Three common types of AFM tip.
(a) normal tip (3 μm tall); (b) supertip; (c) Ultralever (also 3 μm tall).
(b) Electron micrographs by Jean-Paul Revel, Caltech.

http://stm2.nrl.navy.mil/how-afm/how-afm.html

Resolution of ALL Scanning Probes

- *Tip shape AND surface shape are convolved into shape recorded by probes.*

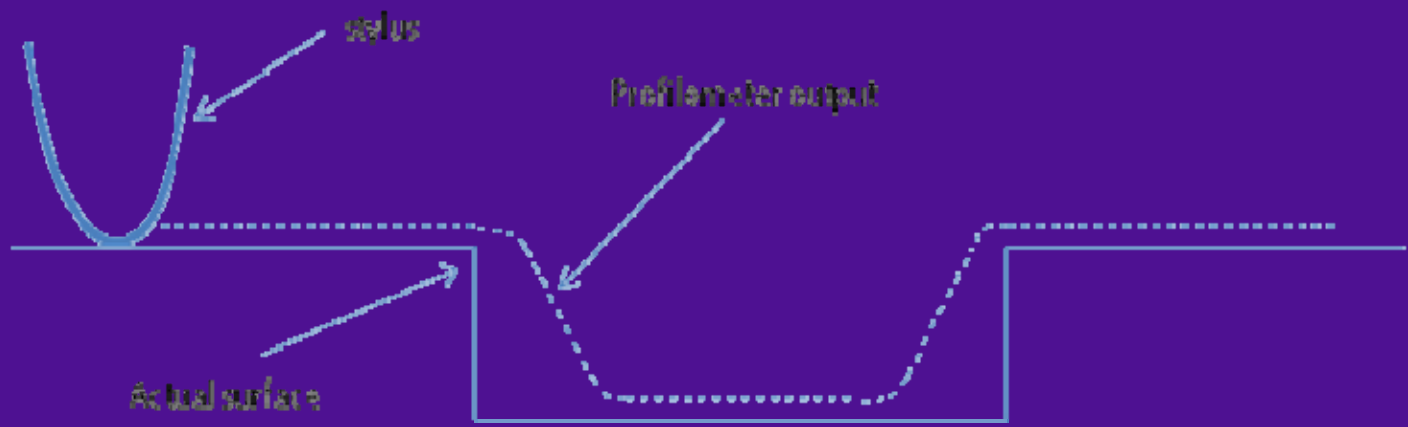
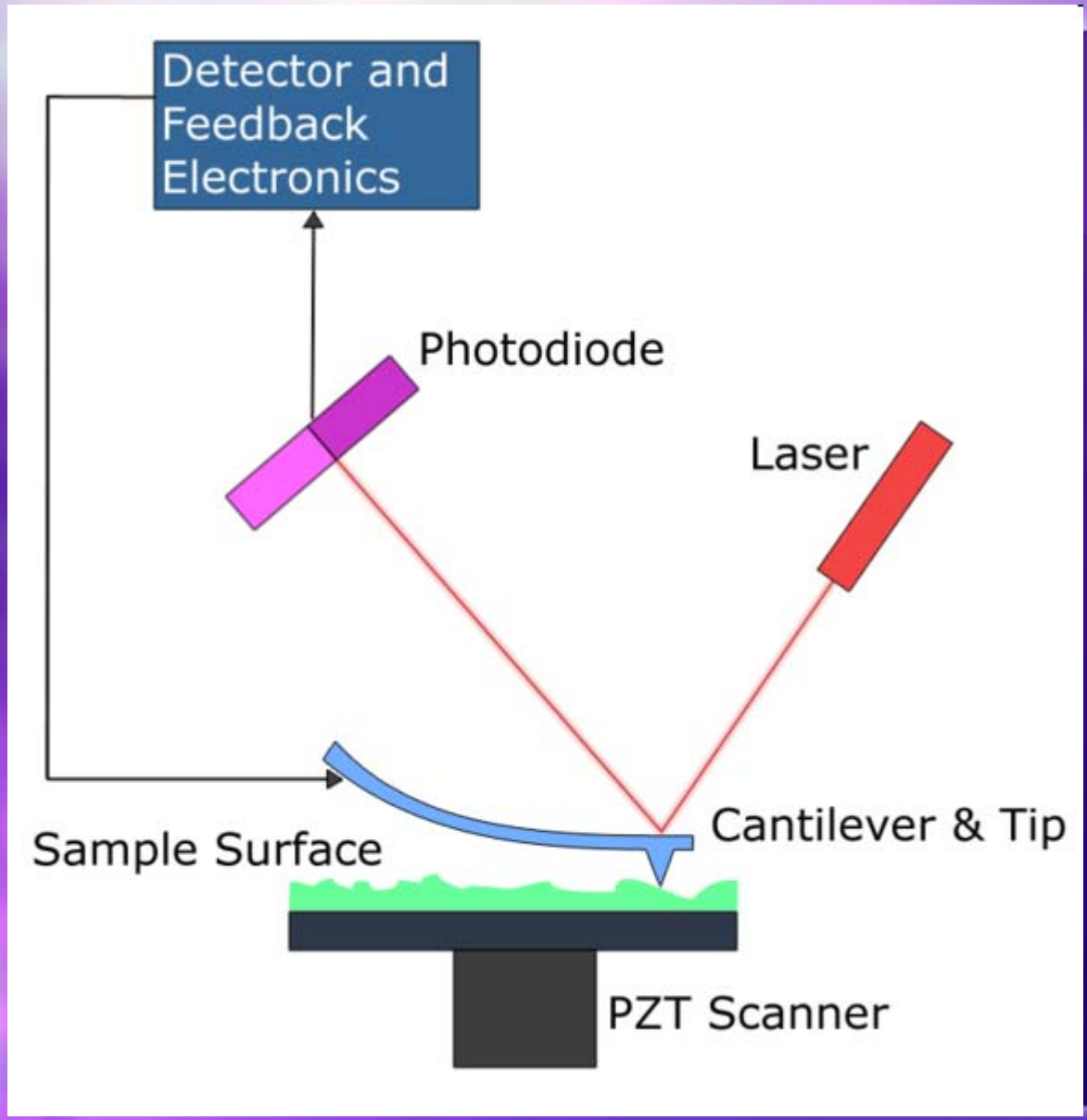


Figure 6. The relatively large stylus diameter causes some edge rounding and loss of horizontal resolution. The stylus diameter needs to be this large in order not to break easily.



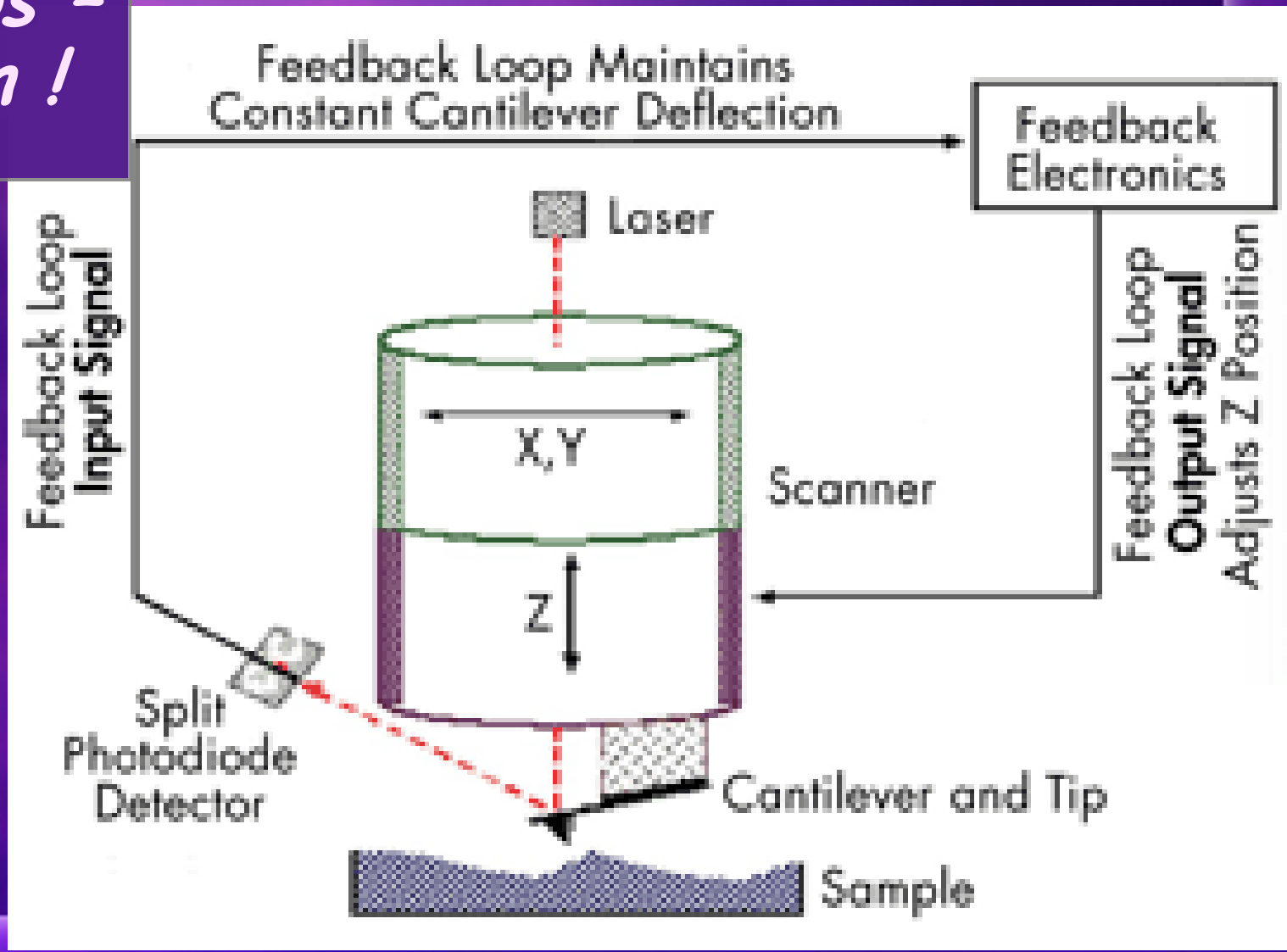
Height & the AFM

- When tip is close to surface, Hooke's Law takes over →
- Hooke's Law?
- $F = k x$
- Forces between surface and tip deflect the cantilever

http://en.wikipedia.org/wiki/Atomic_force_microscope

Feedback & Scanning

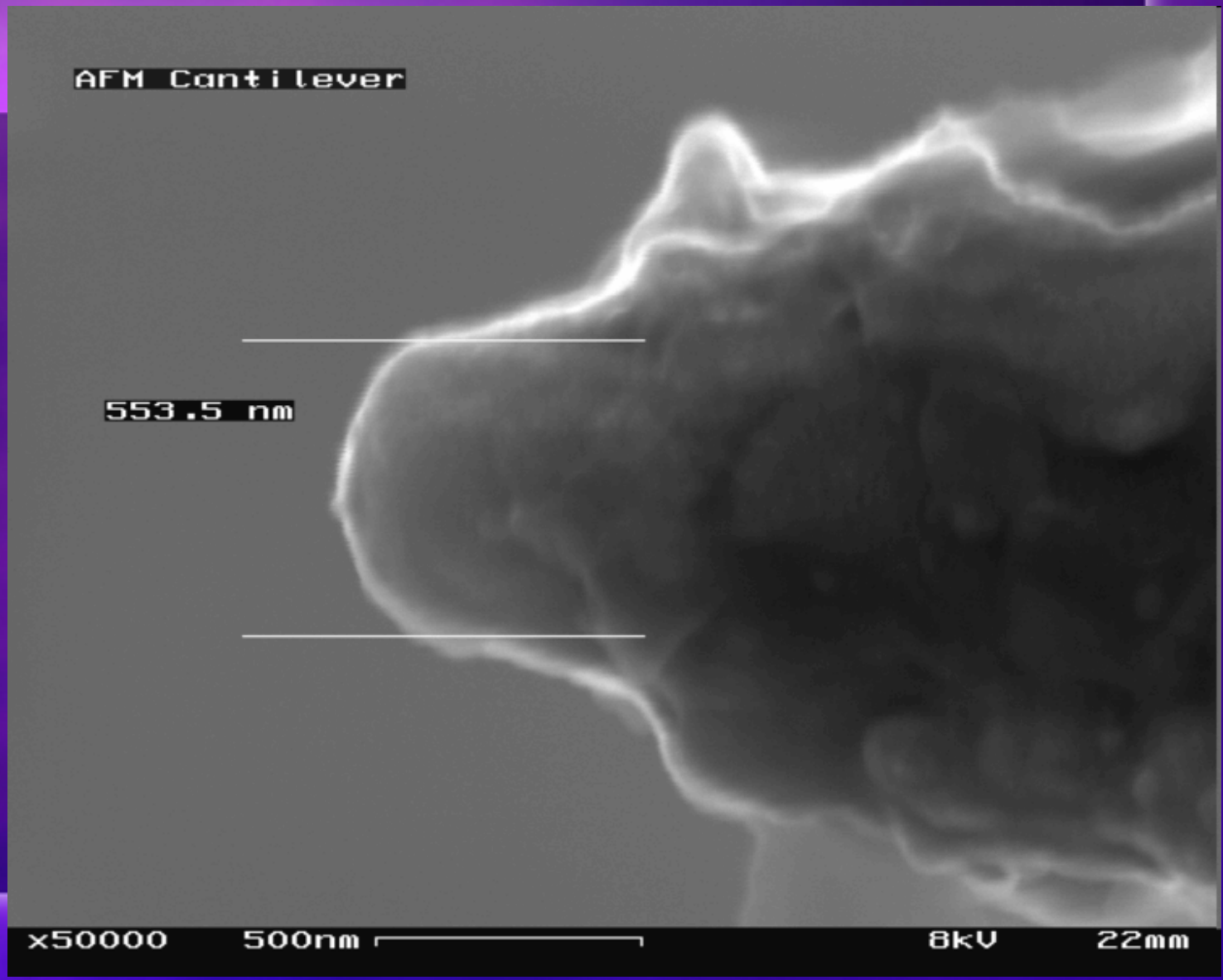
- *Piezos – Again !*

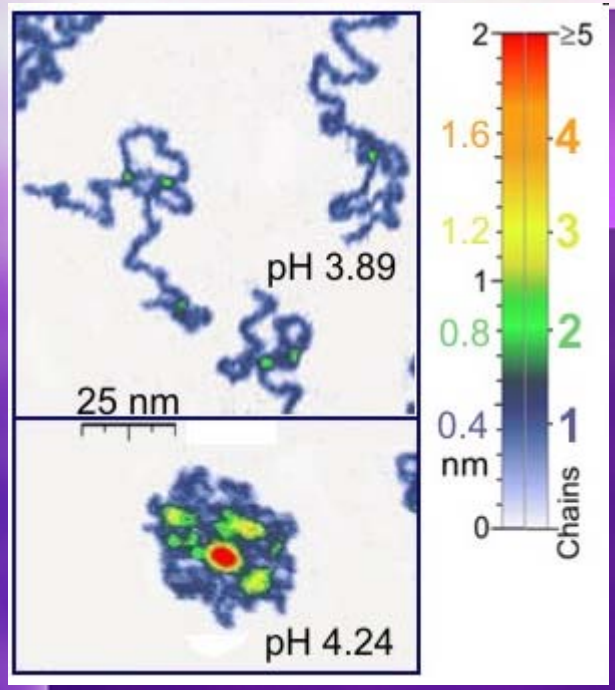


http://veecolifesciences.com/AFM_Basics.aspx

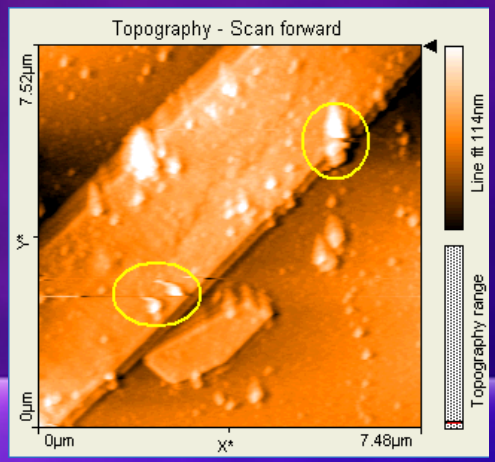
Why Feedback?

- *Used AFM tip*





- Scans microns of area
- Can be in contact mode if surface is strong
- Can be in non-contact mode if have objects on surface to scan
- Can also use tapping mode

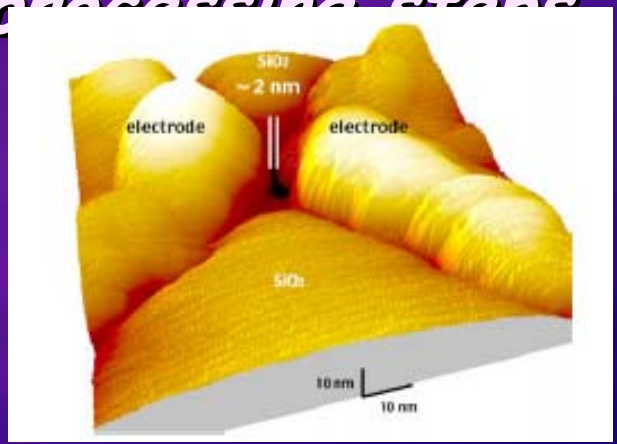


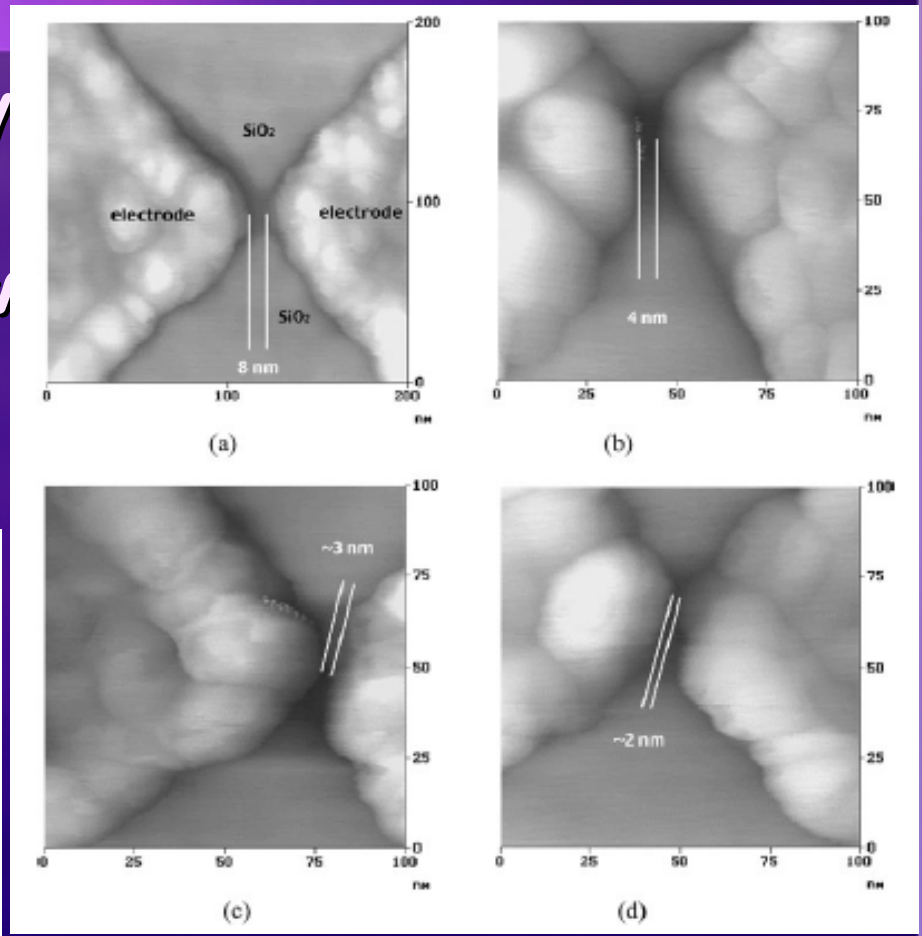
AFM Modes

- Contact
  - Low and High Gain
    - Low gain – "drag" tip across sample see deflection which is OK for relatively flat surfaces
    - High gain – tries to push down on sample to maintain a particular height which is OK for more bumpy surfaces, but not for soft surfaces
  - Tapping mode
    - Good for local surface distortions to measure friction and spring forces on surfaces
- Non-contact
  - Requires a frequency modulation technique which is good for biological samples- repulsive forces from surface

Metrology -- Fabrication

- *AFM can be used to study the success of e-beam lithography and subsequent processing steps*





Nanotechnology, **13** 659 (2002).

Journal of Inorganic Biochemistry 98 (2004) 510–521

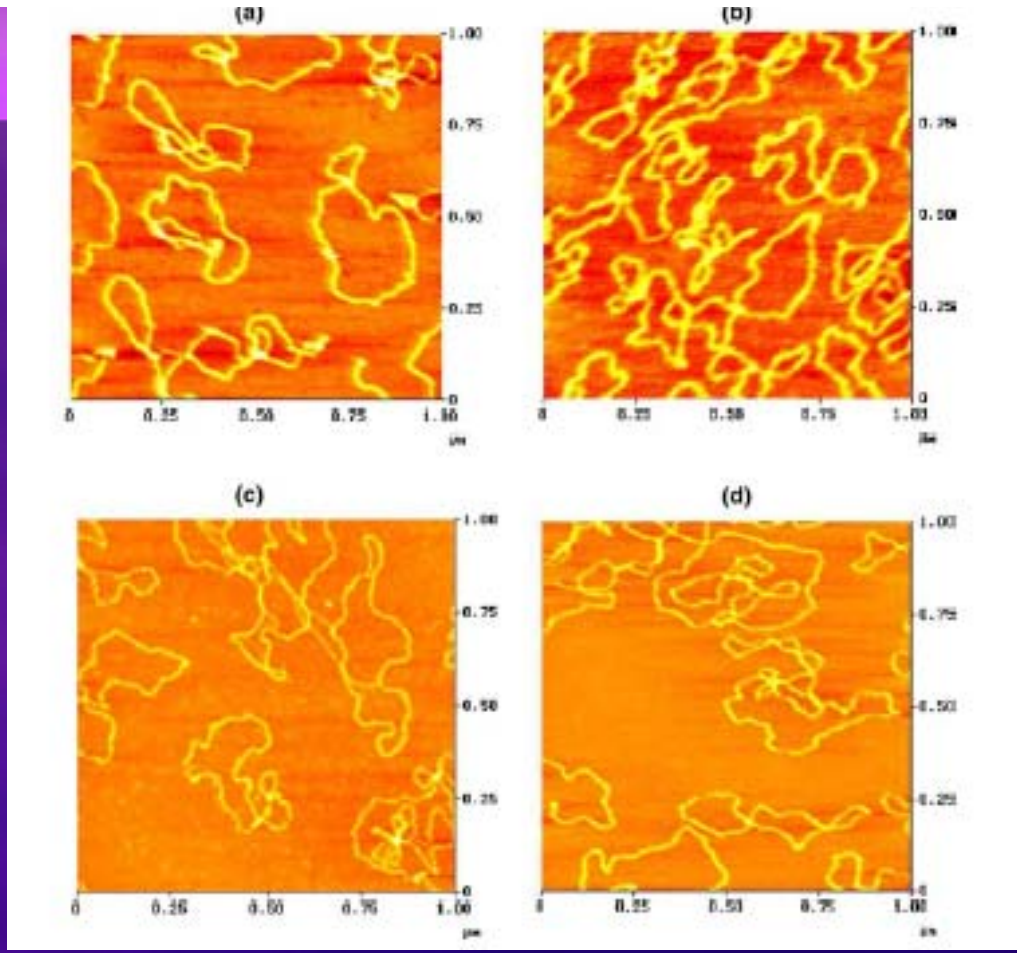
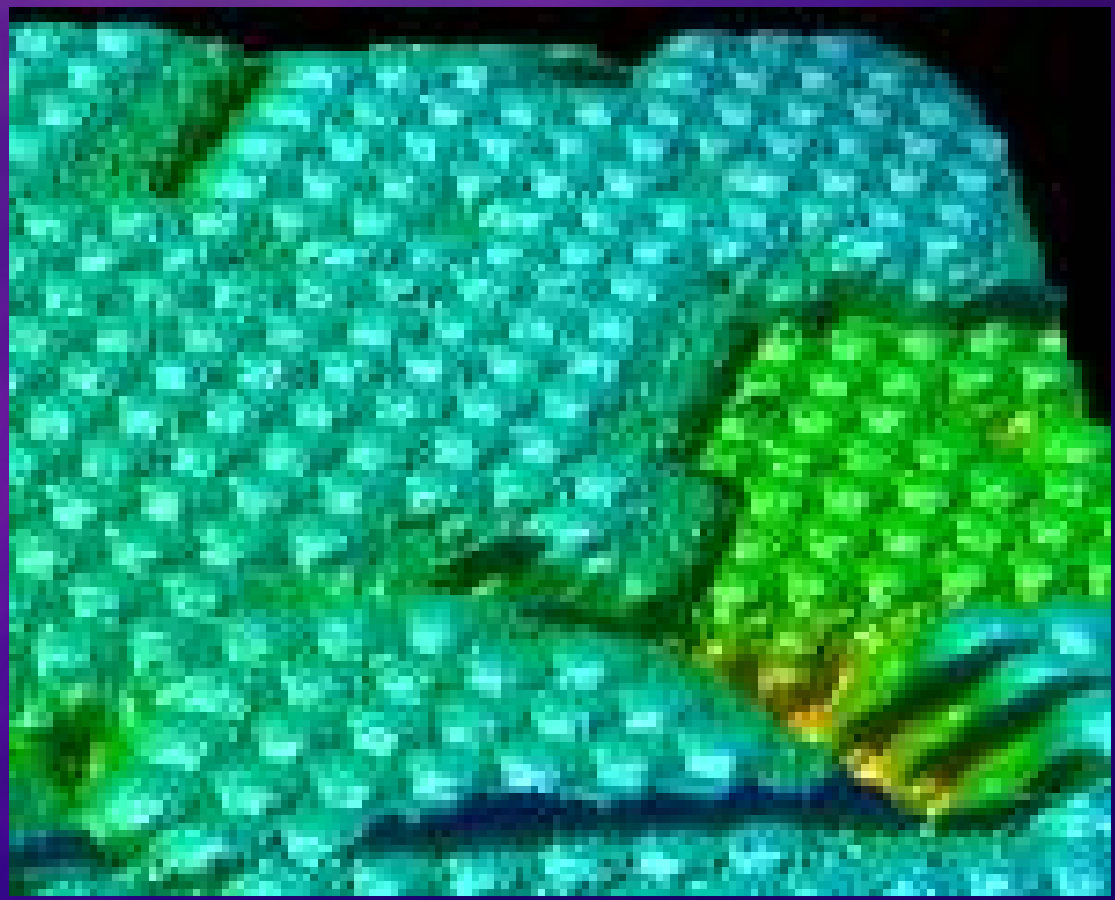


Fig. 11. TMAFM image corresponding to: pBR-[$PtCl_2$(2,3dat)] (a); pBR-[$PtCl_2$(3,4dat)] (b); pBR-[$PtCl_2$(4,5dax)] (c) and pBR-[$PtCl_2$(2,3dap)] (d).

Tobacco Mosaic Virus



Non-Contact Mode – Solid Lipid Nanoparticles

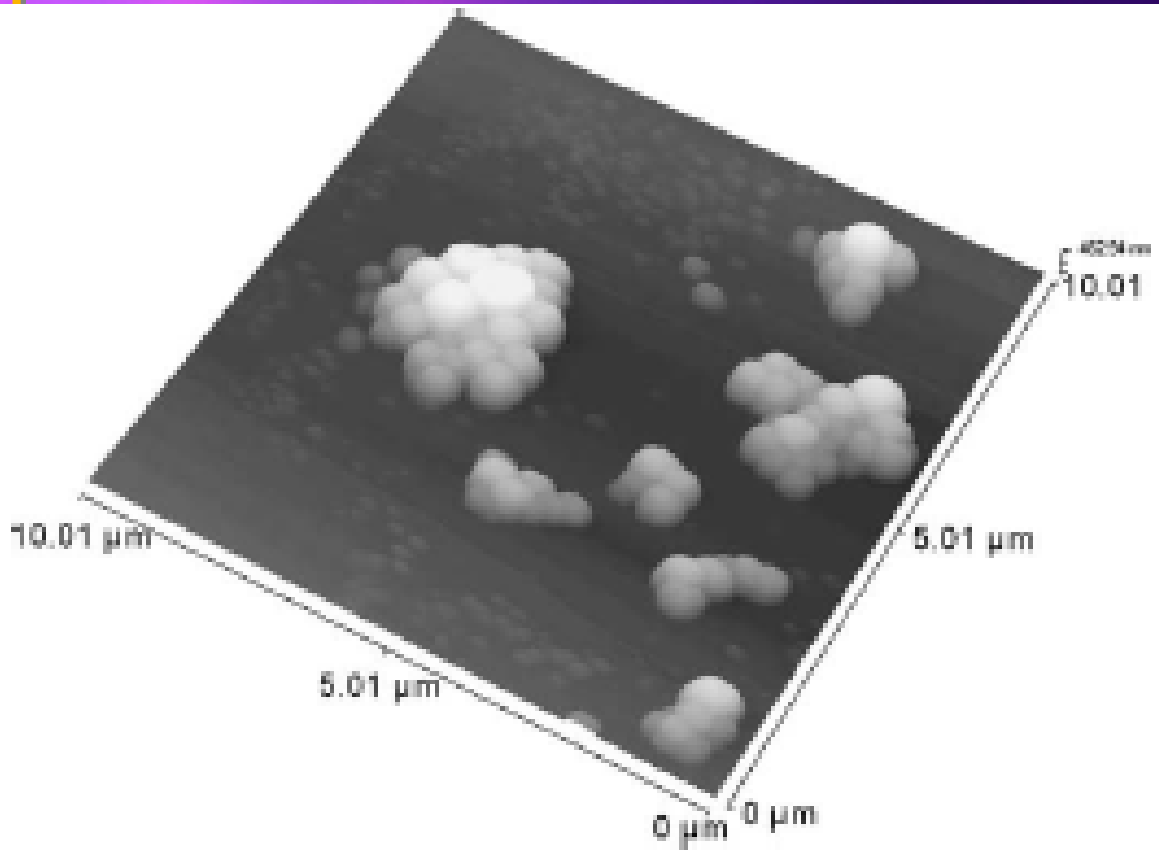


Fig. 10. Non-contact-mode AFM image of the solid lipid nanoparticles formed by βCD21C_6 on mica at scan size 10 µm.

Which probe microscope do I use?

- *Optical Microscope – good for objects in the 1-100 micron range (10^{-6}m)*
- *SEM – provides range from microns to 10 nm*
- *AFM – microns of scan range, 10s of nm resolution, tip 10nm*
- *STM – nm of scan range, angstrom resolution, tip single atom*