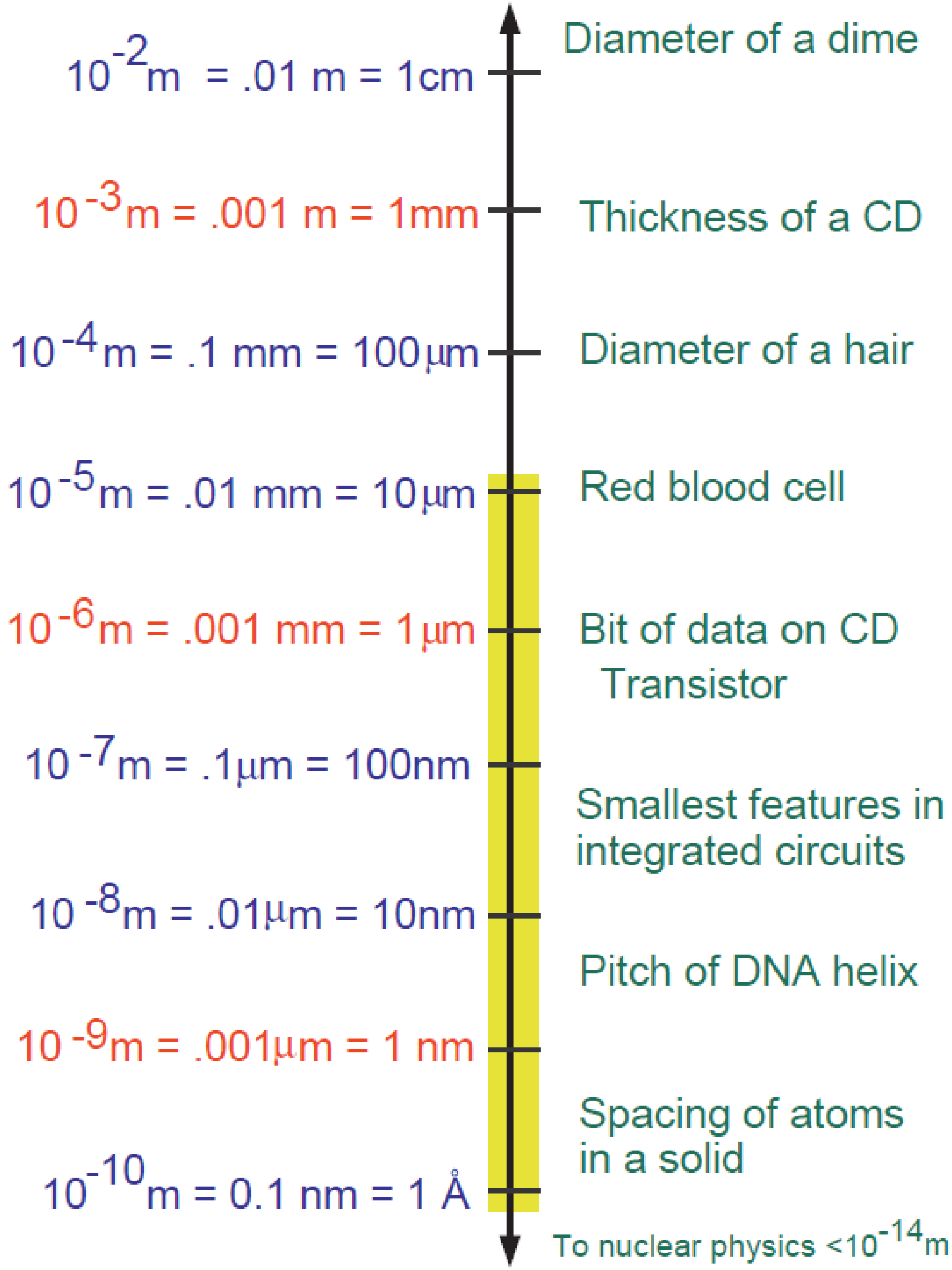
# Condensed Matter Physics – Scratching the Surface

Understanding the properties and behavior of groups of interacting atoms – more than simple molecules

Solids and fluids in ordinary and exotic states
low energy physics

- Structure of materials: Crystalline vs. Amorphous
- Electrical properties: Metals Semiconductors Insulators
- Extremes: low temperature, high pressures
- Special states & Phase Transitions:
  Magnetism Superconductivity Superfluidity
- Surfaces vs. bulk
- Evolution from quantum mechanical world of atoms to classical macroscopic stuff

# Some length scales



# Atoms at Surfaces – Macroscopic objects

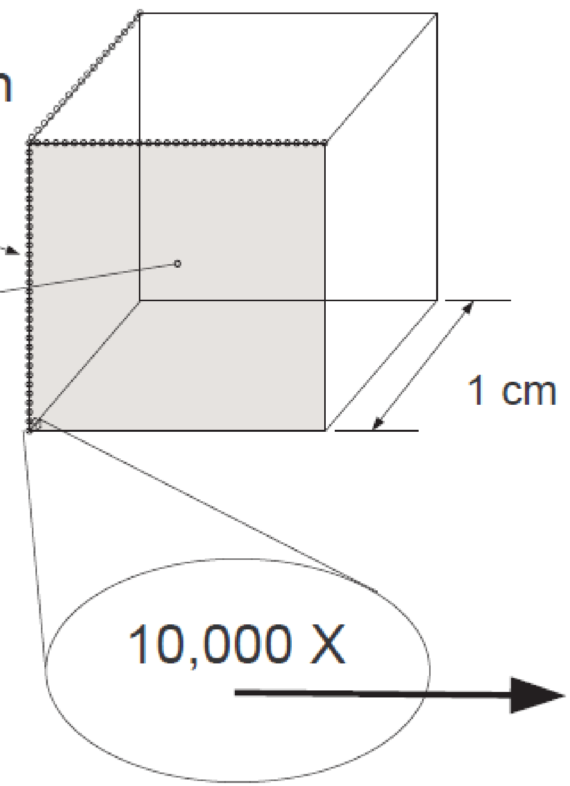
Surface atoms are in a tiny minority in everyday objects. Most atoms are unaware that the surfaces exist and are unaffected.

1 $cm^3$ holds up to $125 \times 10^{21}$ atoms with

$\frac{1\ cm}{0.2\ nm} = 50 \times 10^6$ atoms along an edge

and $25 \times 10^{14}$ atoms on a face

Roughly 1 atom in 10,000,000 is at the surface.



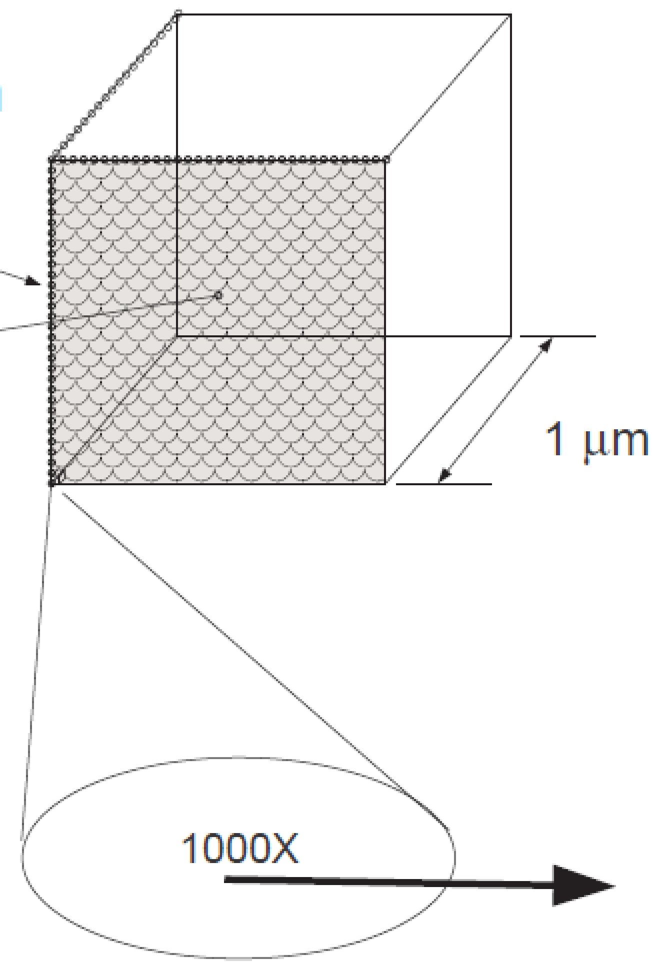
# Atoms at Surfaces – Micro-scale

1 $\mu m^3$ holds up to 125 x $10^9$ atoms with

$$\frac{1\ \mu m}{0.2\ nm} = 5 \times 10^3$$ atoms along an edge

and 25 x $10^6$ atoms on a face

Roughly 1 atom in 1000 is at surface.



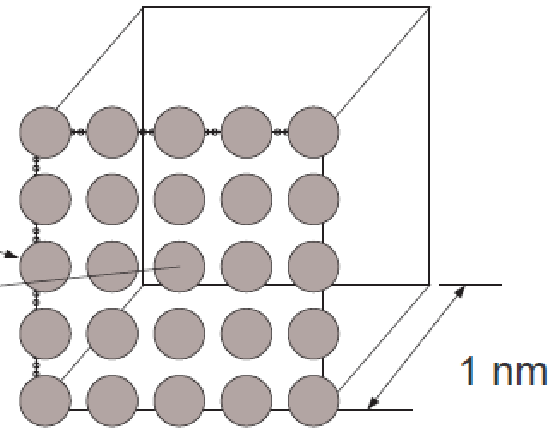
# Atoms at Surfaces – Nano-scale

1 nm$^3$ holds up to 125 atoms with

$\frac{1 \text{ nm}}{0.2 \text{ nm}}$ = 5 atoms along an edge

and 25 atoms on a face

Roughly 4 atoms in 5 are at the surface!




As structures become smaller, surface atoms become dominant in determining properties.
Nano-physics and nano-technology understanding and making small things.

# Scanned Probe Microscopes

Two tools for studying surfaces

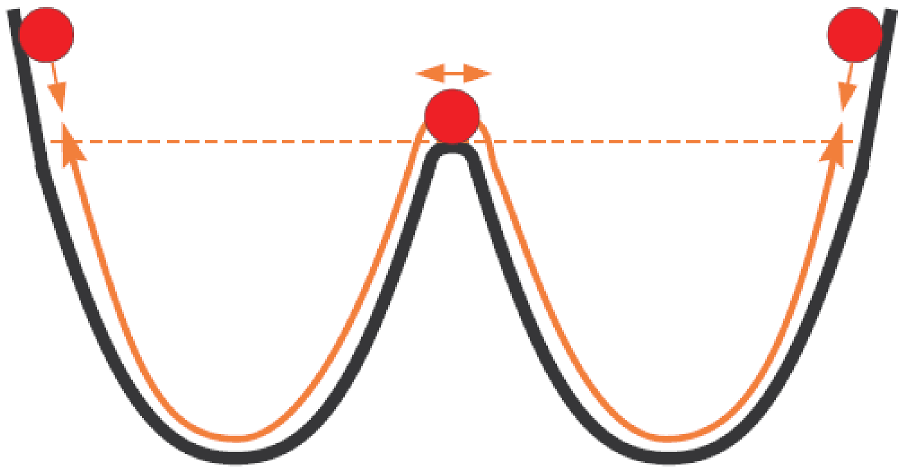
- Scanning Tunneling Microscope (STM)
  * Measures tiny electric current between sharp probe and nearby surface
  * Sample surface must be electrical conductor (metals, semiconductors)
  * Relies on quantum mechanical effect
- Atomic Force Microscope (AFM)

  Senses forces between surface and sharp probe near the surface. Very sensitive record player!

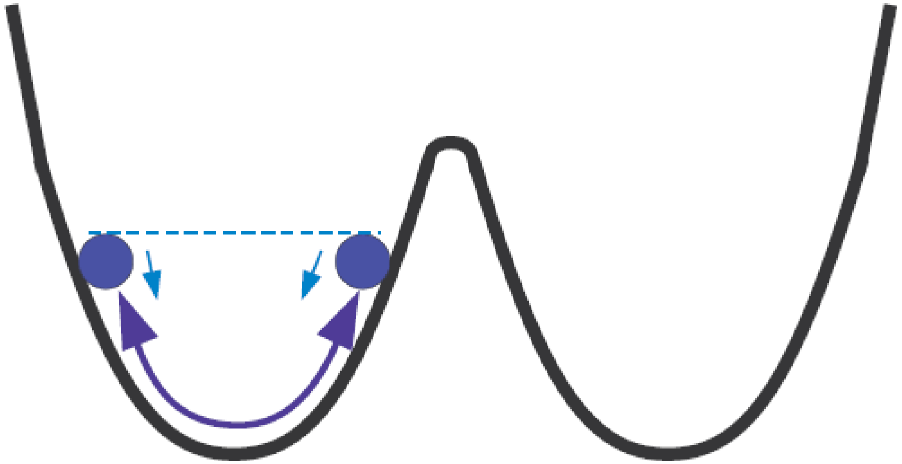
# Quantum vs Classical

- The behavior of atomic-sized systems is governed by quantum mechanics.
- Matter (protons, electrons, and neutrons) at this scale exhibits a dual personality
- Particle-like aspects familiar from every-day life becomes less obvious
- Wave-like aspects dominate
  - object no longer has sharply defined position
  - cannot know everything simultaneously (e.g. position and velocity)
  - wave nature described by probability density (e.g. electron clouds)
  - some classical rules can be broken for short times

# Classical mechanics

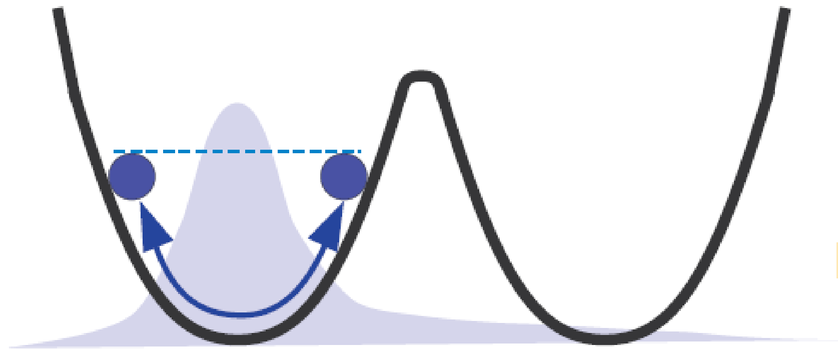


RED marble starts with enough energy to travel over hill into right valley and back.

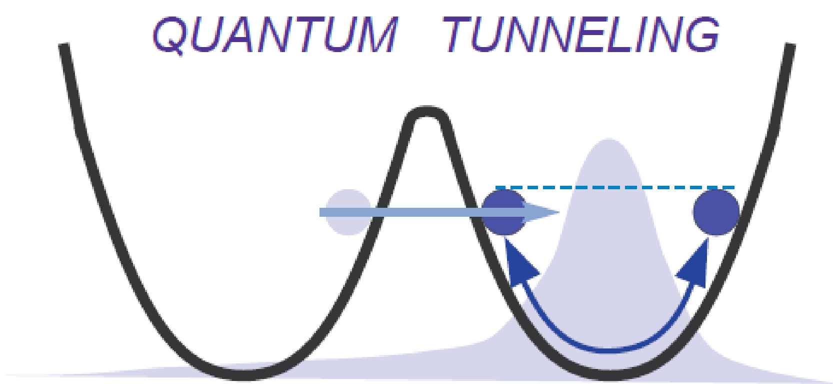


BLUE marble is confined to the left valley forever - insufficent energy to climb over the hill.

# Quantum mechanics



**BLUE marble initially on left...**




**...can appear on the right**

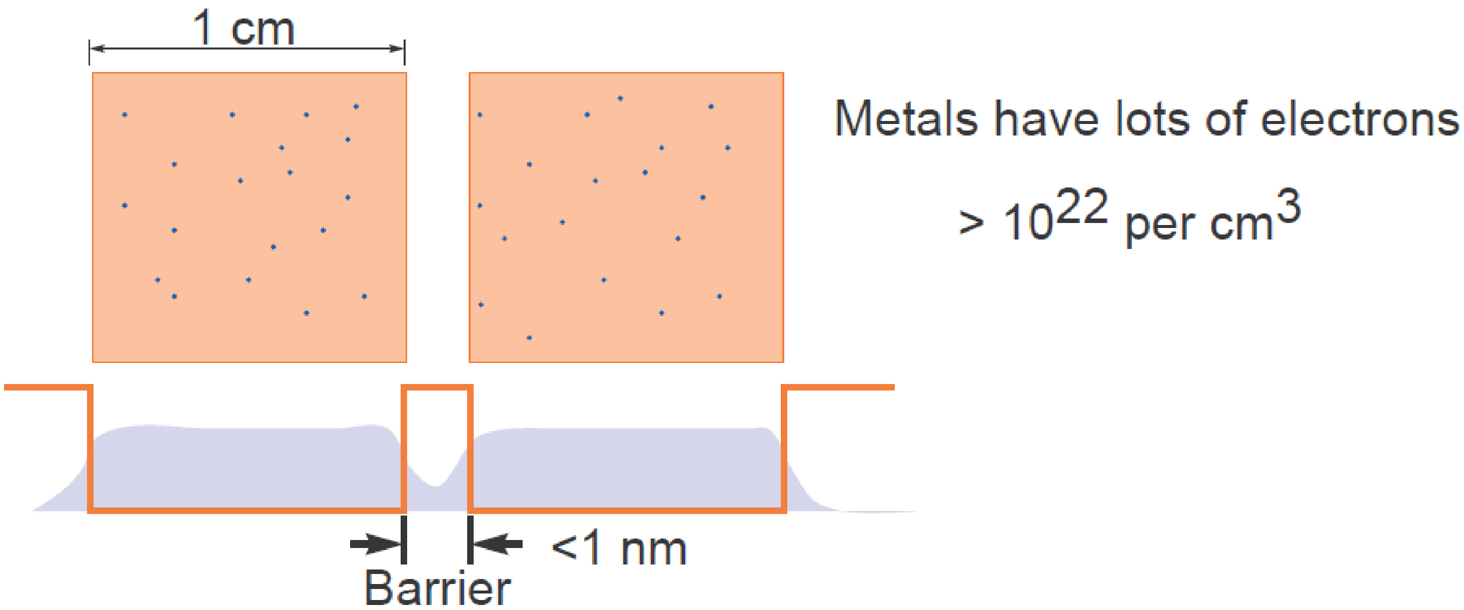
***even though its energy is insufficient to carry it over the hill!***

Marble is not localized in quantum mechanics - it behaves as if smeared out and can pass thru or *tunnel* thru barriers

For significant tunneling probability need
- very light marbles (electrons are good)
- very thin hills ( < 1 nanometer = 0.000000001 m)

# Electron tunneling - metals

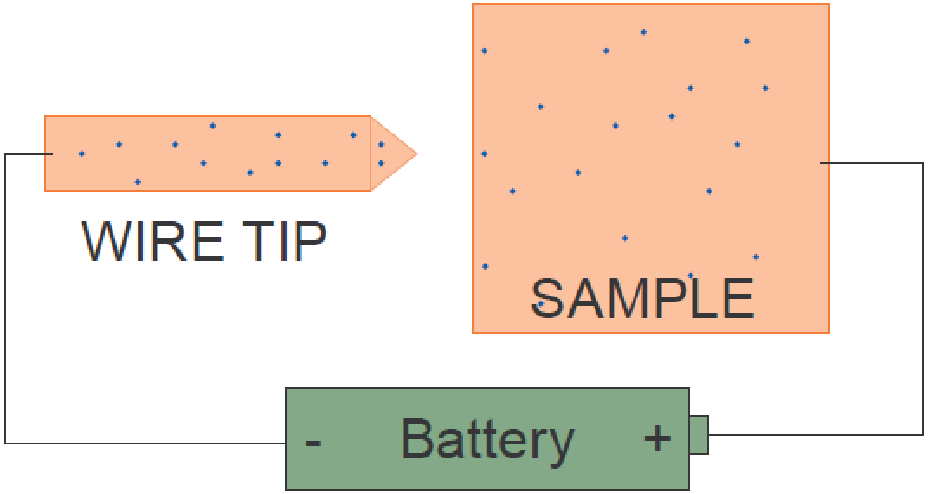
Electrons inside metal: move freely within, reflected at the surfaces.




Tunneling barrier is formed by thin space between 2 pieces of metal.

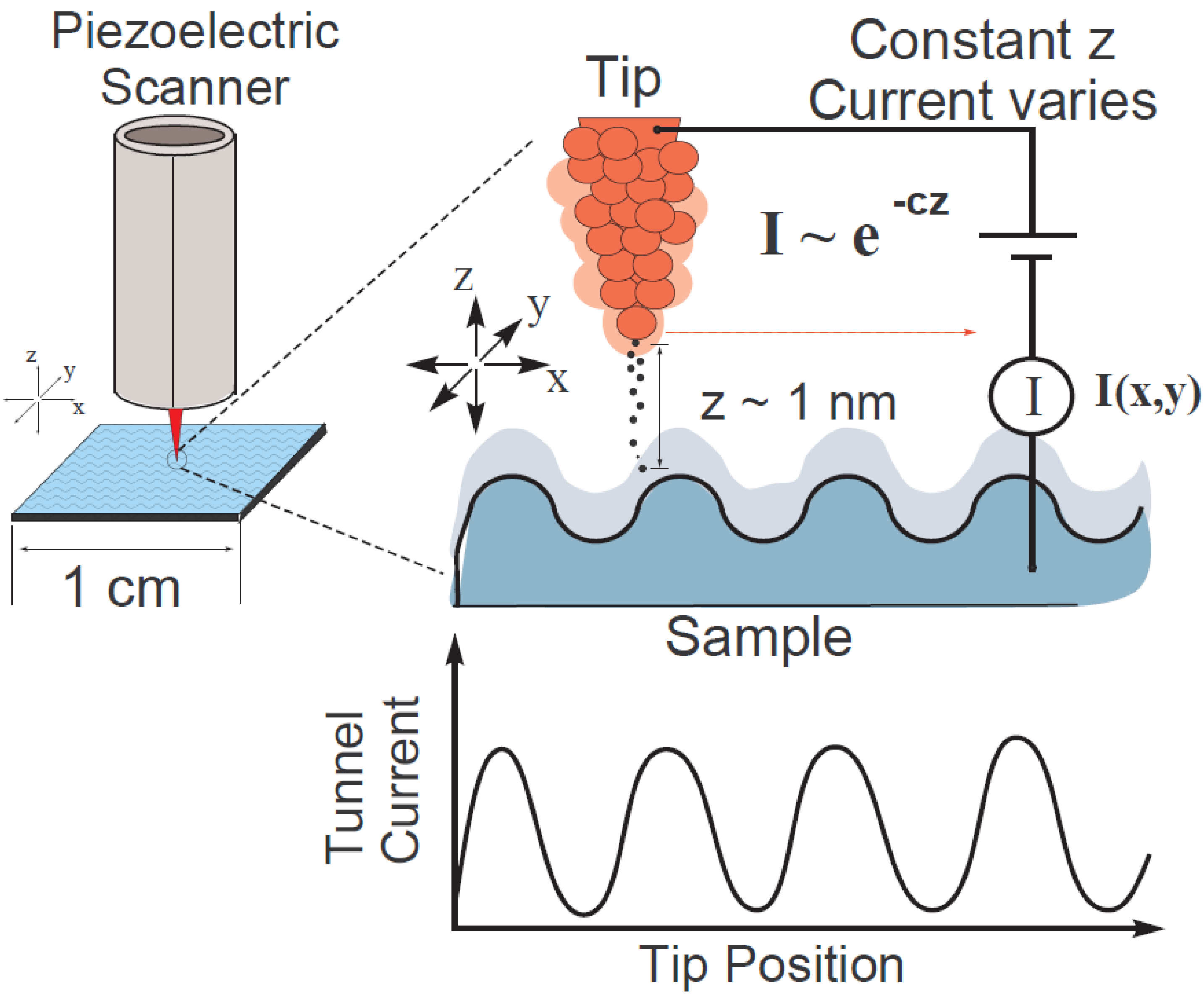
# Tunneling as microscopic probe

Tunnel between sharp wire and sample of interest

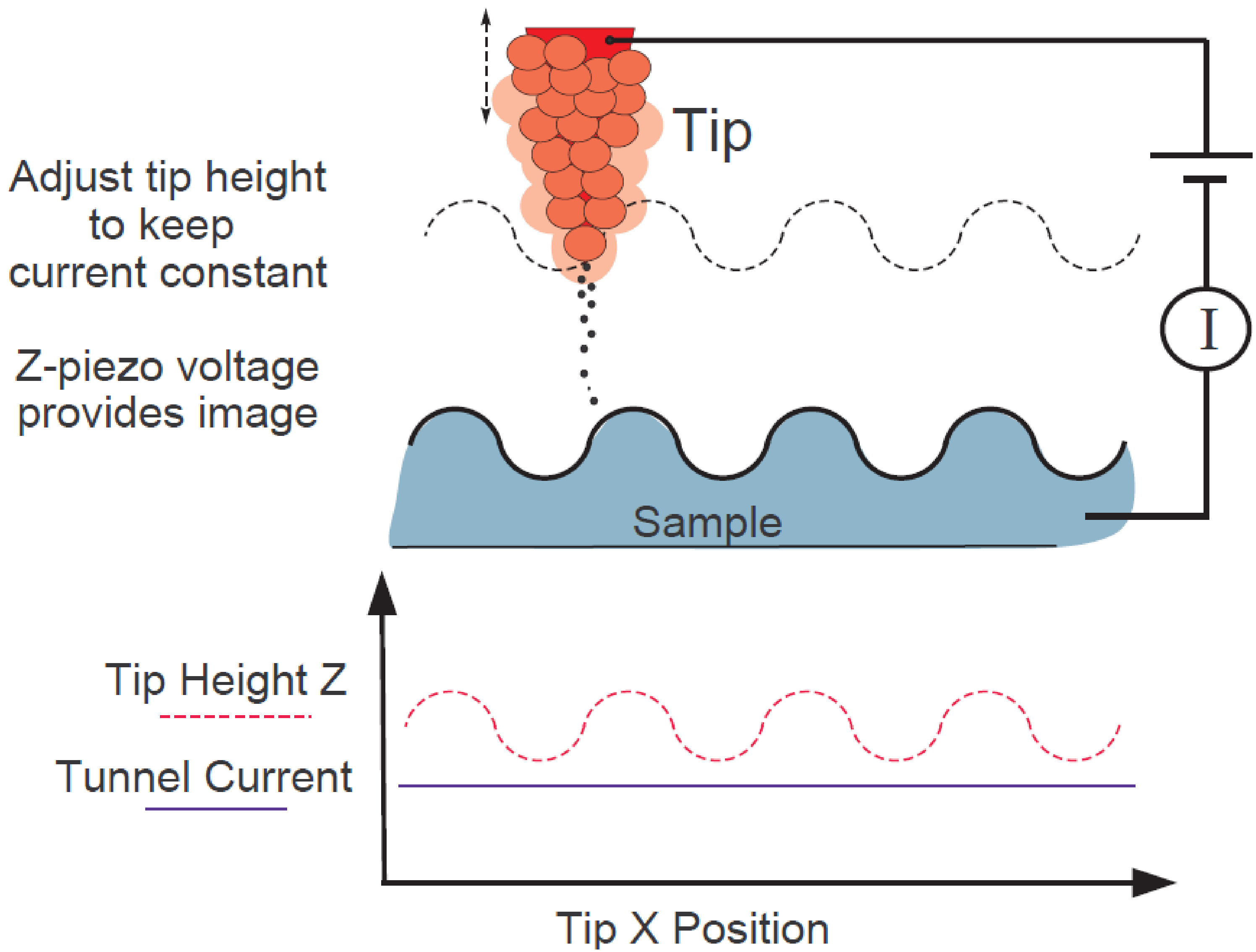



Hook up battery to sustain net tunneling from tip to sample.

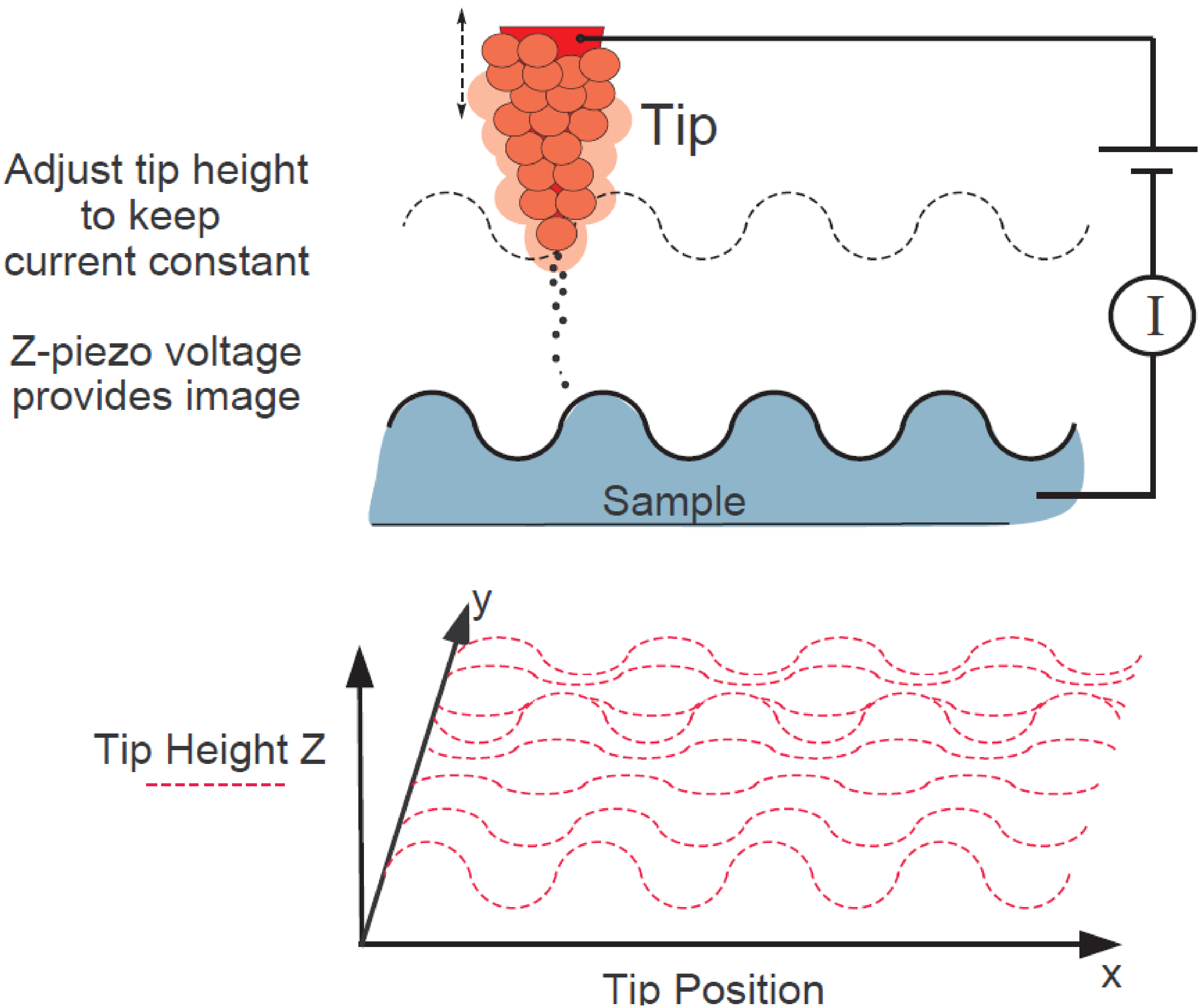
# Scanning Tunneling Microscope



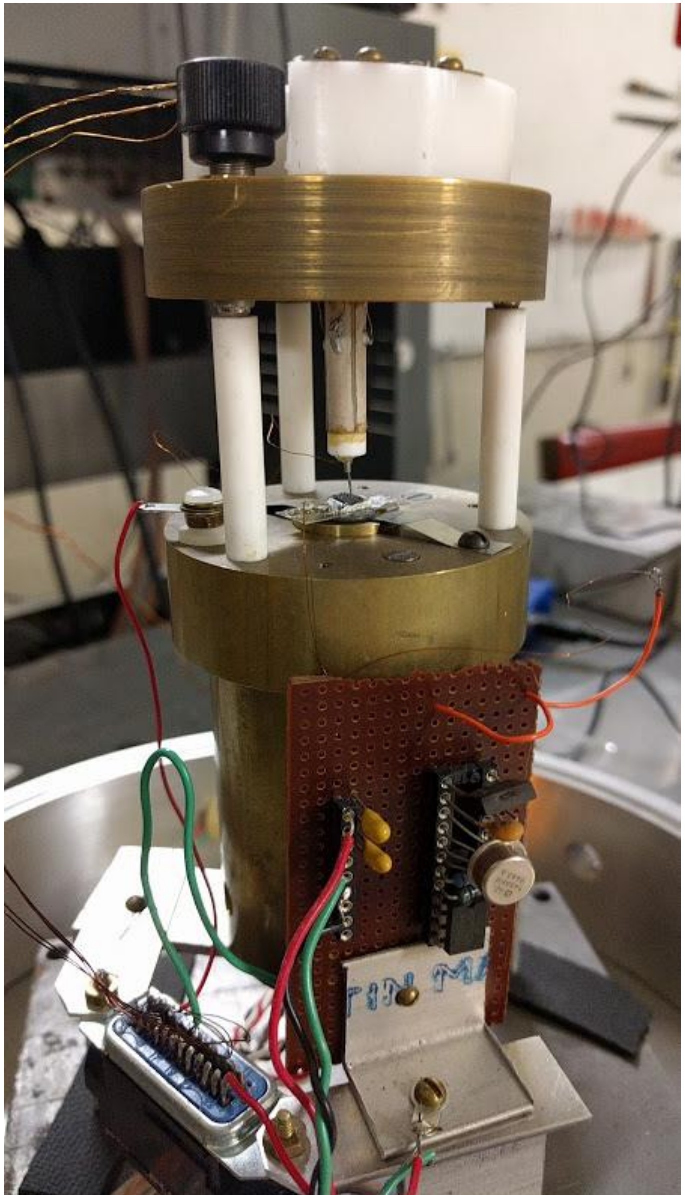
# STM constant current imaging



# STM raster imaging



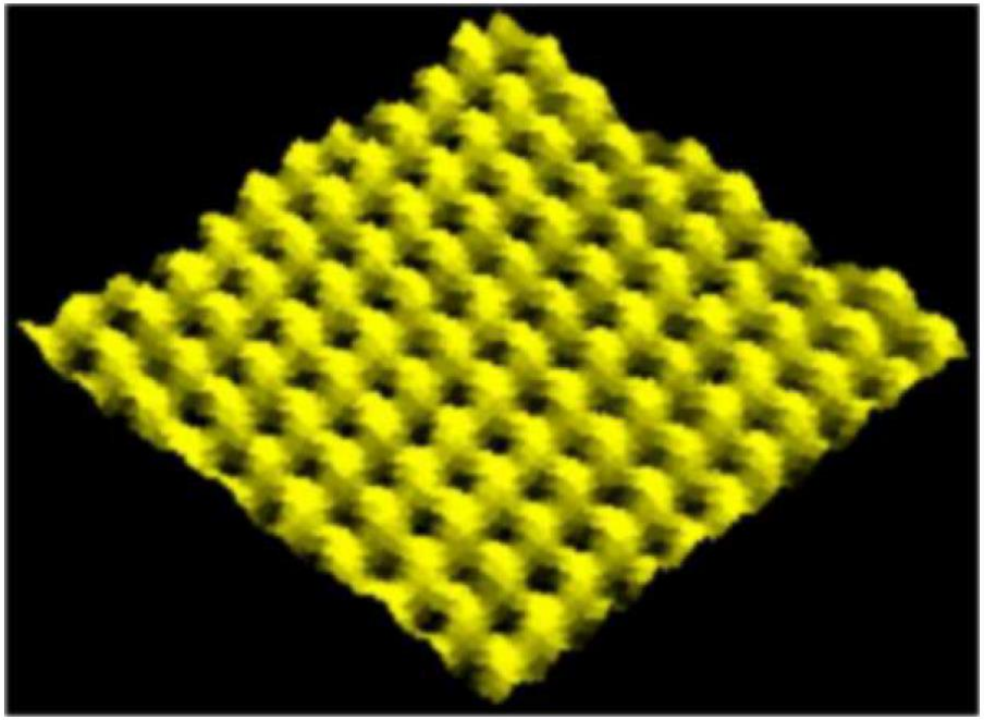
# STM

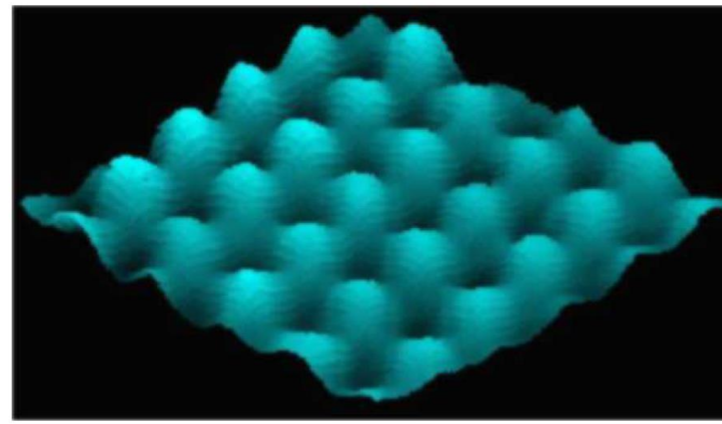


Ed Sandberg, Brandon Zink

# STM image - Graphite

2 nm × 2 nm scan



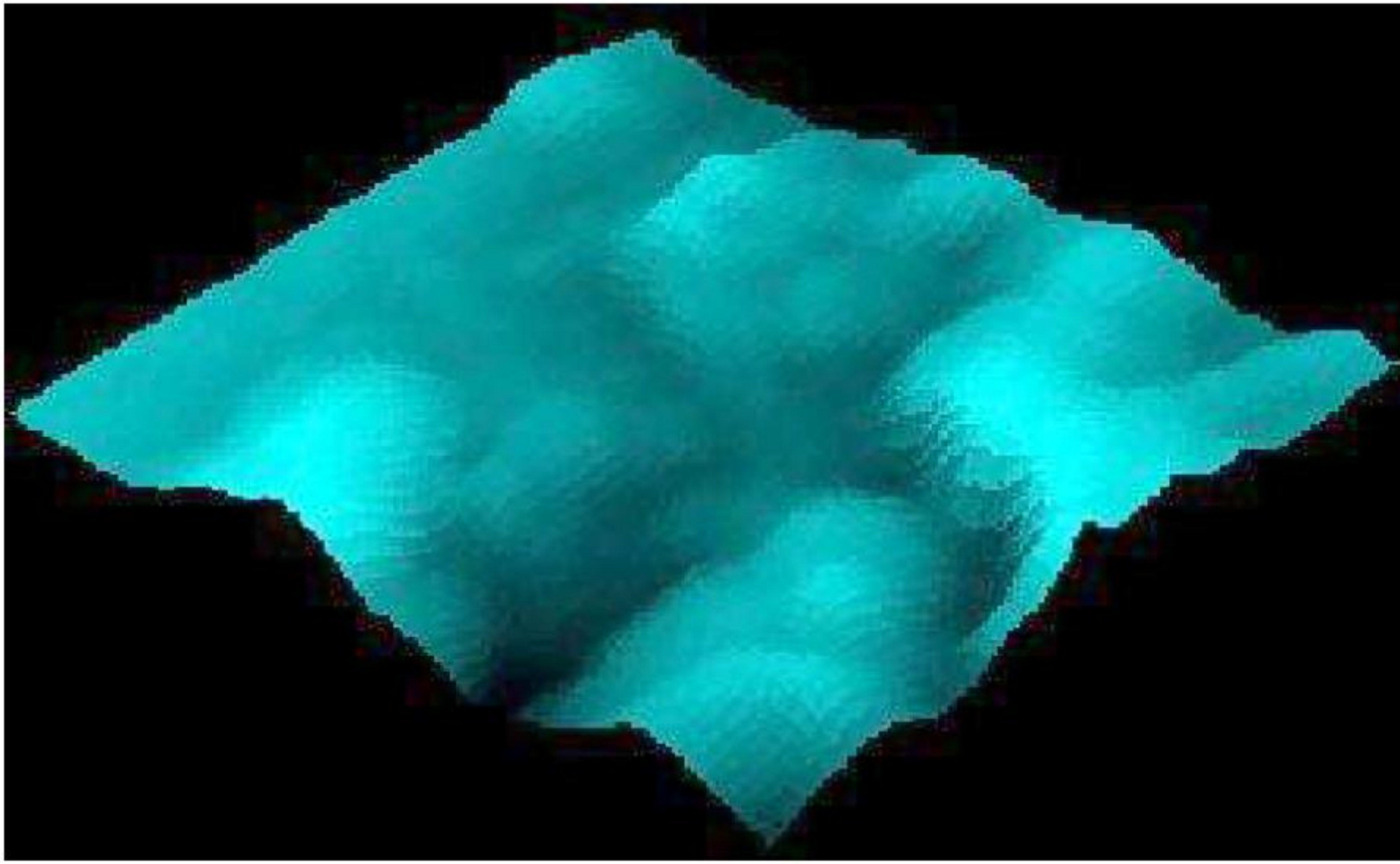


1 nm × 1 nm scan

Atomic resolution of electron clouds around each atom.

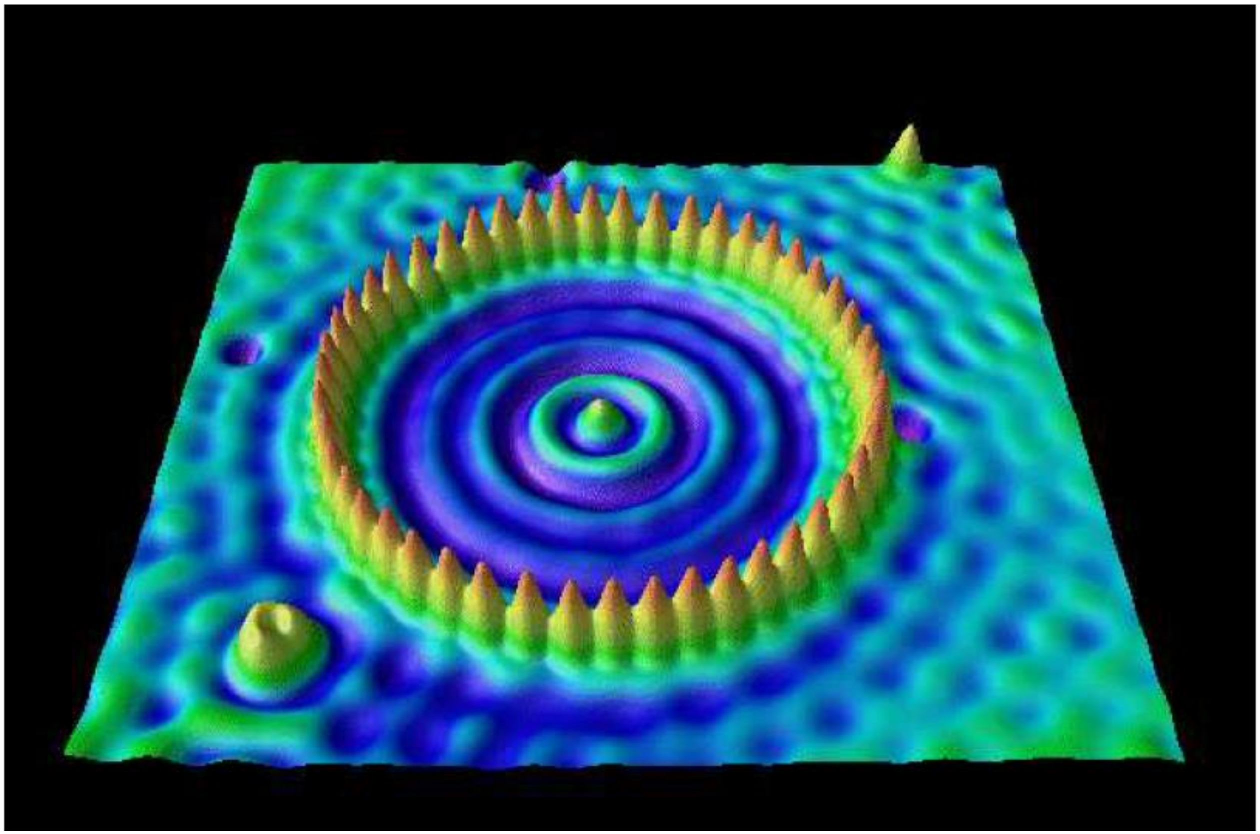
# STM image – Silver film

100 nm × 100 nm scan



# IBM STM atom manipulator

Fe atoms arranged in a ring on Cu surface by STM tip
(Eigler et al., IBM - San Jose)

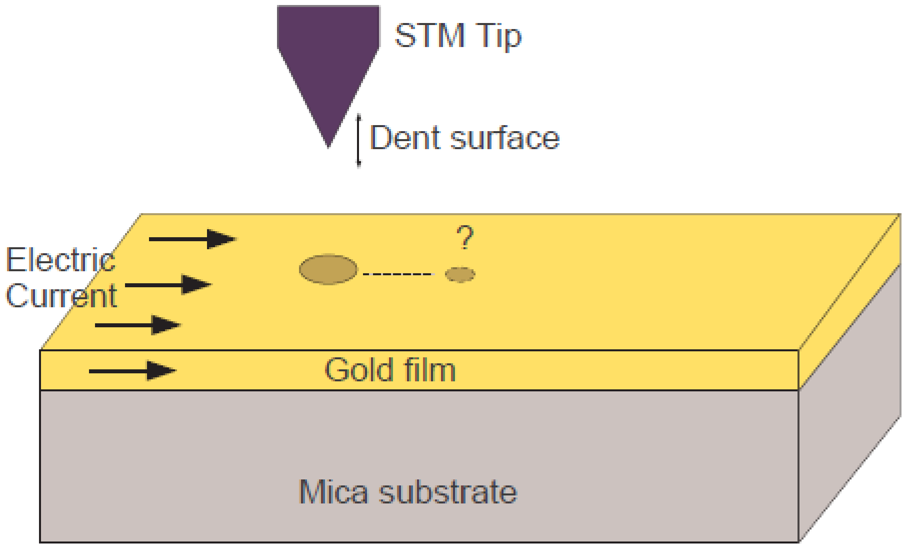


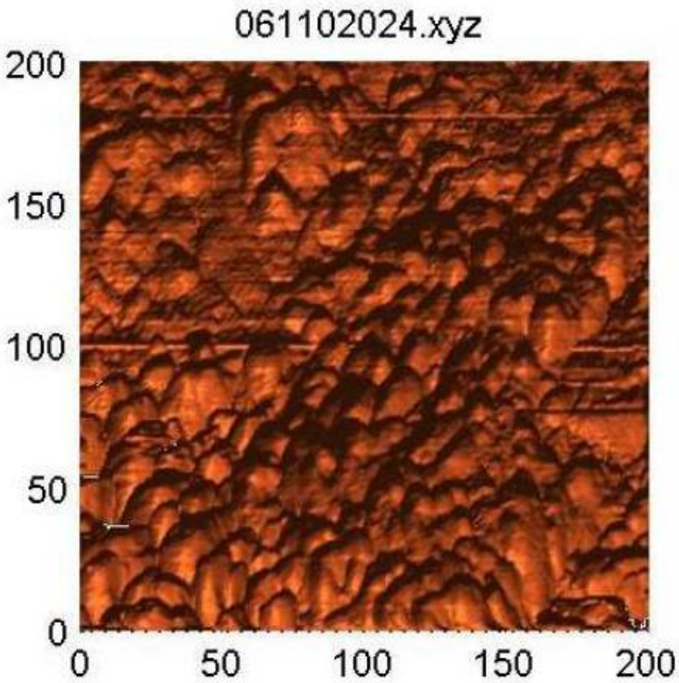
Note electron waves on Cu surface inside corral.

# Current efforts

Electromigration - the movement of atoms as a result of electrons flowing through a material as an electric current.

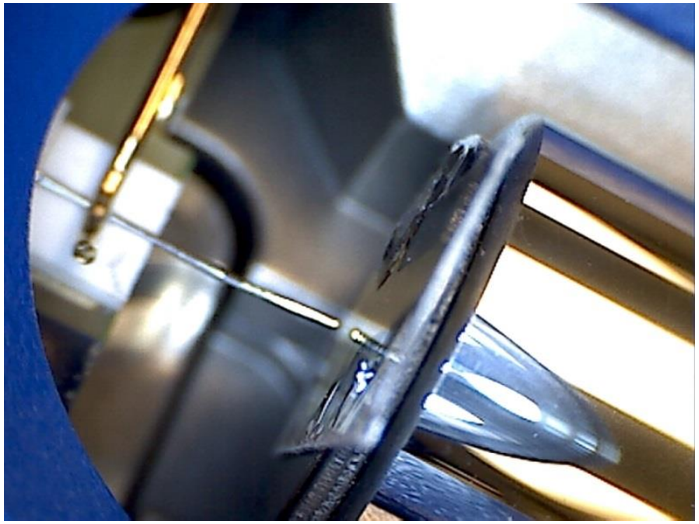
Caused rapid failure in the early days of integrated circuits STM may provide a way to make a dent in the surface and watch at the atomic level the dent move or change shape as a result of electromigration.



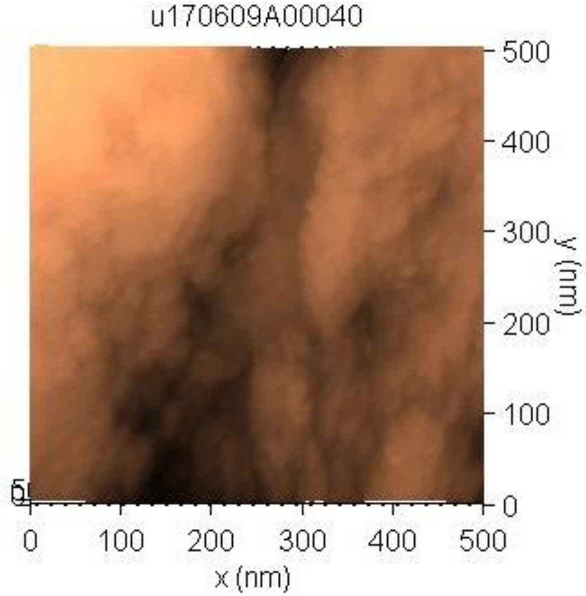
Evaporation boat

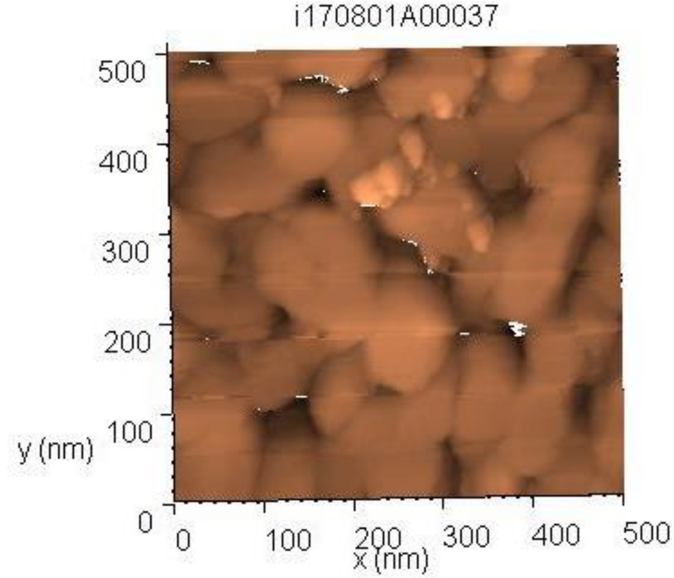
Vacuum system

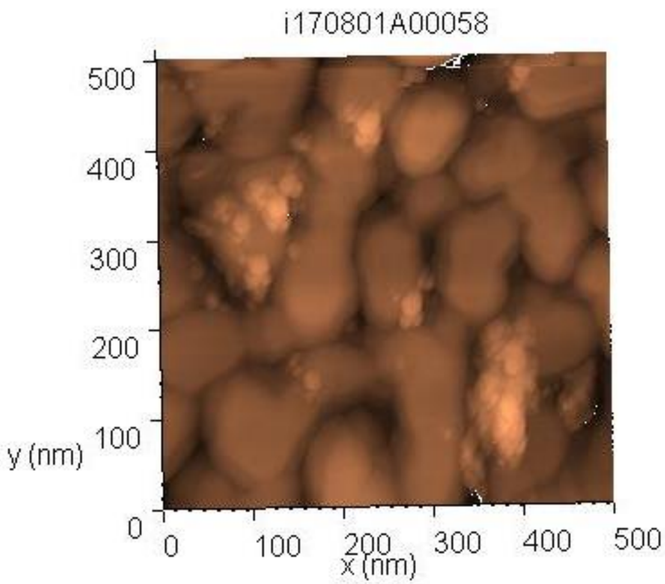


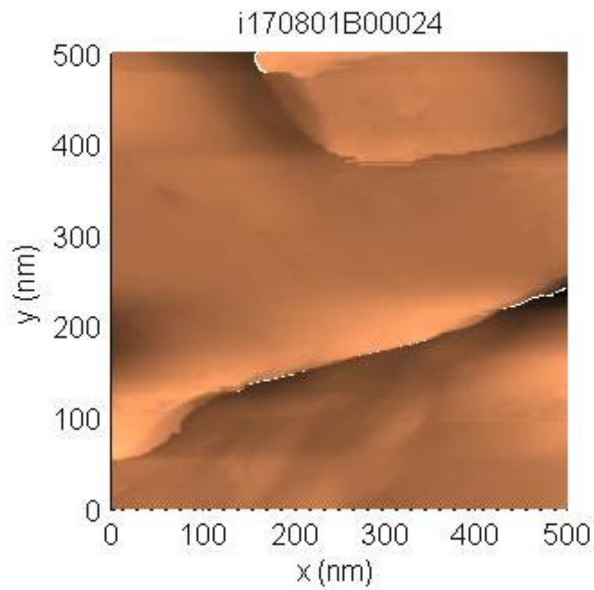
Trax STM

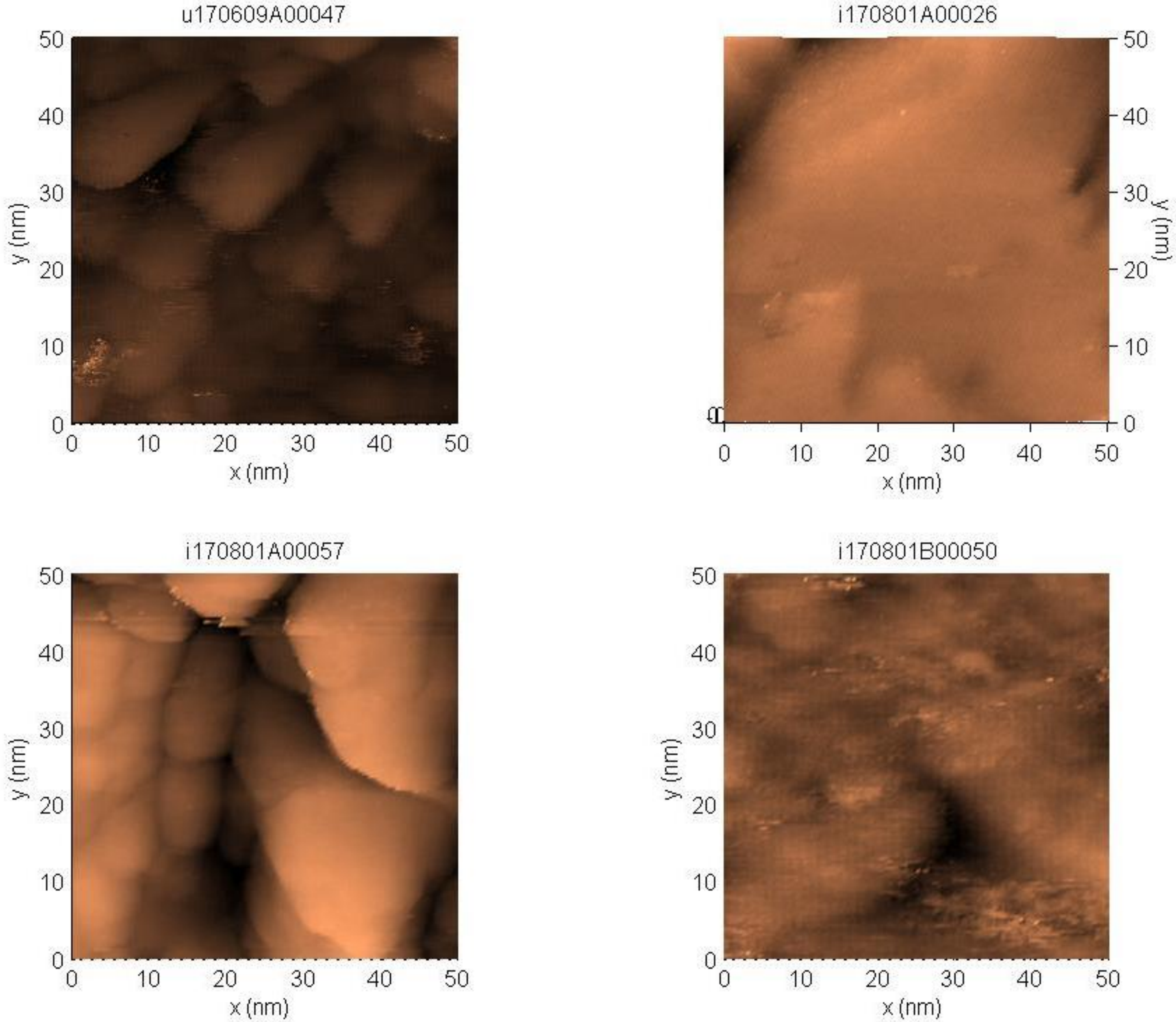
Gold films evaporated onto mica (Kurt VanDonselaar)






Gold films evaporated onto mica (Kurt VanDonselaar)

A few links to STM and nano-stuff can be found at

http://www.d.umn.edu/~jmaps/phys1021/