SCANNING TUNNELING EFFECT

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Scanning Tunneling Microscopy (STM)

Uses the principle of Quantum mechanical tunneling. Invented in 1981 by Gerd Binnig and Heinrich Rohrer at IBM Zurich. Awarded the Nobel prize in Physics after 5 years

❖ An electrically conducting probe with a very

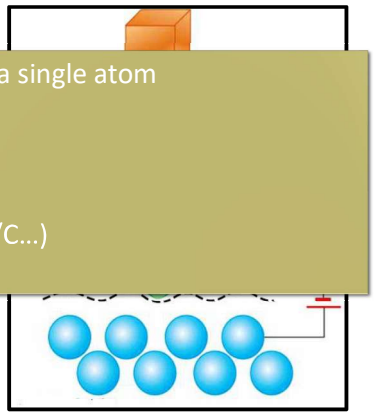
STM tip: Atomically sharp needle and terminates in a single atom

✓ Pure metals (W, Au)

✓ Alloys (Pt-Rh, Pt-Ir)

✓ Chemically modified conductor (W/S, Pt-Rh/S, W/C…)

❖ The tip and the surface are the two walls of the "potential well".



❖ When the tip is brought about 1 nm of the sample, electrons from the sample begin to tunnel through the 1 nm gap into the conducting tip or vice versa.

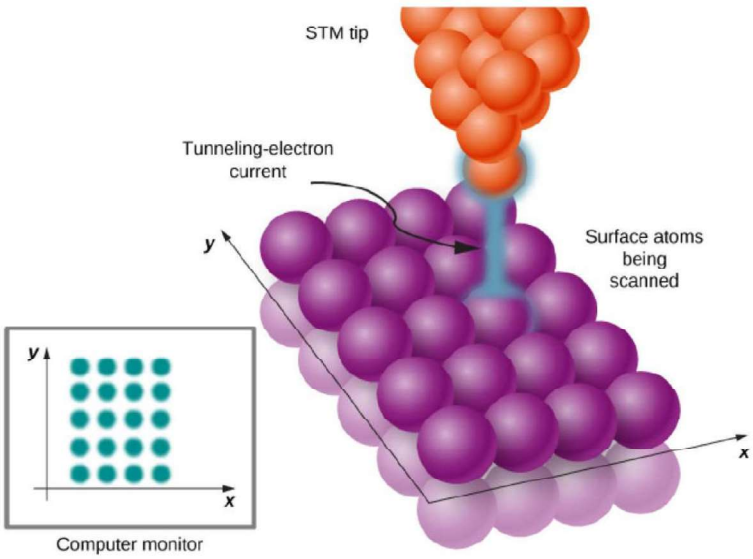
❖ The resulting tunneling current varies with tip to sample spacing and is the signal used to create an STM image.

❖ For tunneling to occur, both the sample and tip must be conductors or semiconductors. Hence, STMs cannot be used for imaging insulating materials.

❖ The Angstrom level distance control between the tip and sample surface is required which is acquired by piezoelectric motors.

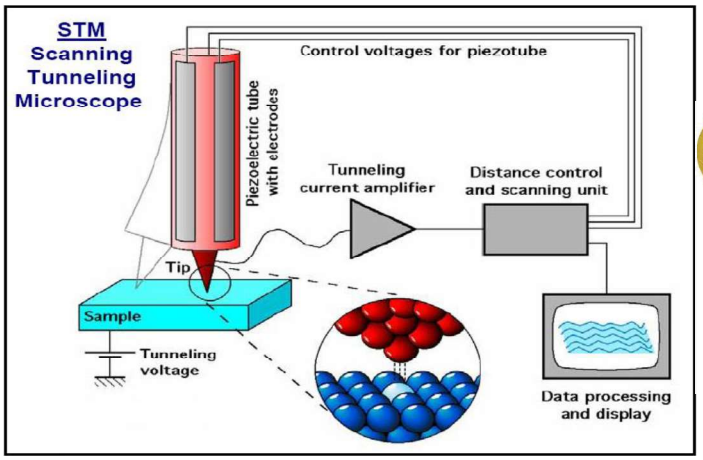
❖ A piezoelectric is a crystal that creates potential differences when mechanical stresses are imposed on it or vice versa.

❖ The piezoelectric motors can be used in a feedback system to adjust the motion of the tip in all the 3 dimensions.



In STM, a surface at a constant potential is being scanned by a narrow tip moving along the surface. When the STM tip moves close to surface atoms, electrons can tunnel from the surface to the tip. This tunneling-electron current is continually monitored while the tip is in motion. The amount of current at location (x,y) gives information about the elevation of the tip above the surface at this location. In this way, a detailed topographical map of the surface is created and displayed on a computer monitor.

UHV



The Nobel Prize in Physics 1986

Nobel Laureates Heinrich Rohrer and Gerd Binnig

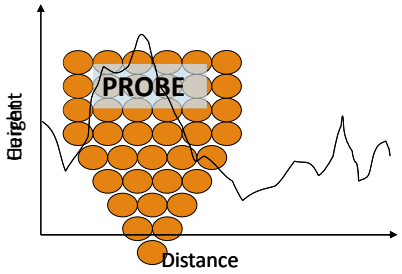
- Raster the tip across the surface and using the current as a feedback signal.
- The tip-surface separation is controlled to be constant by keeping the tunneling current at a constant value. (Constant Height Mode)
- The voltage necessary to keep the tip at a constant separation is used to produce a computer image of the surface.

Probing a surface using STM

STM can be used either in the Constant Current mode or in the Constant Height mode

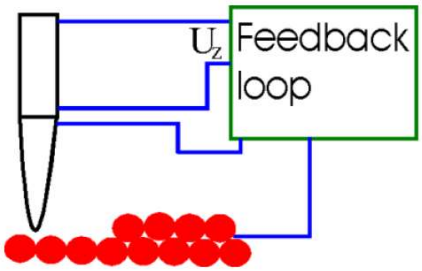
Or we could vary the height in search for constant current.

We could either probe at a constant height and look at current variations as we pass.



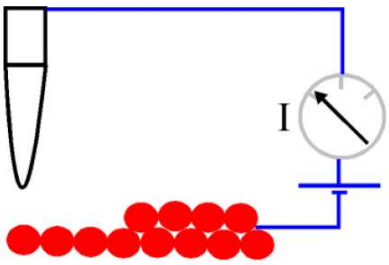
STM working procedure

Constant current mode



- ❑ *Image the surface with constant tunnel current and variable height*
- ❑ *Feed back loop help to maintain constant current*
- ❑ *Surface (height) structure can detect*

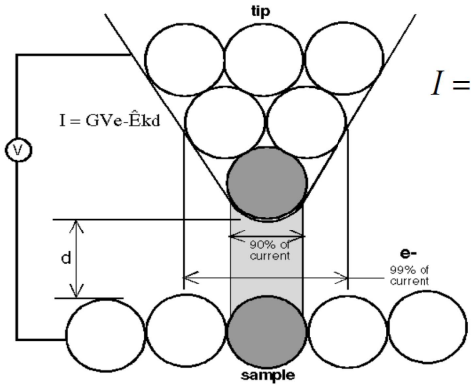
Constant height mode



- ❑ *Image the surface with constant height and variable tunnel current*
- ❑ *Electron density on the surface can detect*

STM working Principle

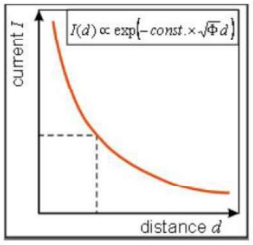
STM works on the principle of quantum mechanical tunneling



Tunneling current

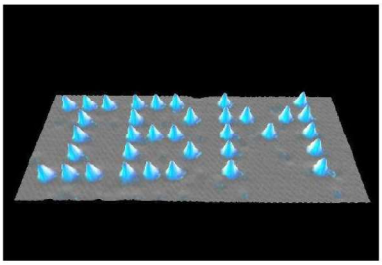
$$I = A \times eV \times e^{-2\sqrt{\frac{2m\Phi}{\hbar^2}}d}$$

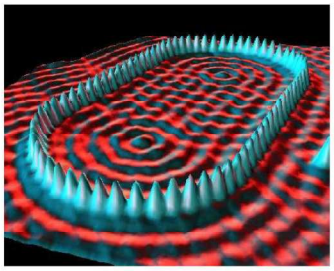
A is constant
e is electron charge
V is voltage
m is mass of electron
Φ is work function of metal tip
d is distance between tip and sample



Playing with Atoms

- At this distance the coulomb force between the tip and an atom of the sample is actually enough to move the atom.
- This has allowed physicists to create images and structures on the atomic level.





Images courtesy of IBM

Advantages

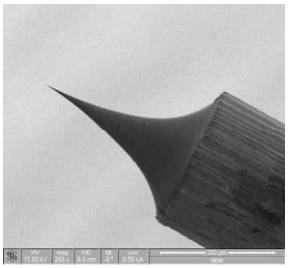
- No damage to the sample
- Vertical resolution superior to SEM
- Spectroscopy of individual atoms
- Relatively Low Cost

Disadvantages

- Samples limited to conductors and semiconductors
- Limited Biological Applications: AFM
- Generally a difficult technique to perform

Figures of Merit

- Maximum Vertical Resolution: .1 Å
- Maximum Lateral Resolution: 1 Å
- Maximum Field of View: 100 µm



It is very important that the tip of the probe be a single atom.

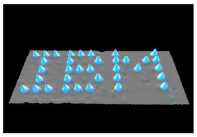
Tungsten is commonly used as Electro-chemical etching techniques can create very sharp tips like the one above.

STM Applications

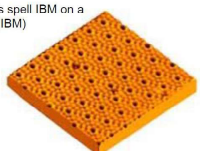
Widely used in nanotechnology

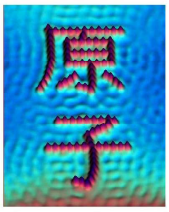
- ❖ **Image the surface structure**
- ❖ **Estimate surface roughness**
- ❖ **3D images of the surface**
- ❖ **Locate the defect on the surface of crystal**
- ❖ **Understand electric structure of materials**

STM allows manipulation of individual atoms (1989)



Xenon atoms spell IBM on a nickel plate (IBM)





Iron atoms spell "Atom" on copper in Kanji characters. (IBM)