**MSE 310 Lecture 12**

**Scanning tunneling microscope (STM)**

Scanning tunneling microscope (STM) is widely used in both industrial and fundamental research to obtain atomic-scale images of metal surfaces. It provides a three-dimensional profile of the surface which is very useful for characterizing surface roughness, observing surface defects, and determining the size and conformation of molecules and aggregates on the surface.

An ordinary microscope, which employs optical lenses, could view objects smaller than the wavelength of light. An electron microscope could view smaller things with greater clarity than an optical microscope, but still could not clearly view individual atoms.

So Binnig and Rohrer decided to build their own instrument – something new that would be capable of seeing and manipulating atoms at the nanoscale level. To do that, they began experimenting with tunneling, a quantum phenomenon in which atoms escape the surface of a solid to form a kind of cloud that hovers above the surface; when another surface approaches, its atomic cloud overlaps and an atomic exchange occurs.

By maneuvering a sharp metal conducting tip over the surface of a sample at an extremely small distance, Binnig and Rohrer found that the amount of electrical current flowing between the tip and the surface could be measured. Variations in this current could provide information about the inner structure and the height-relief of the surface. And from this information, one could build a three-dimensional atomic-scale map of the sample's surface.

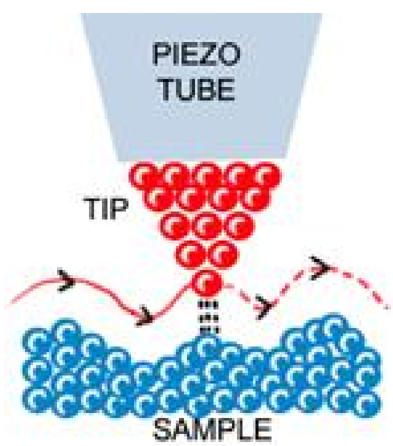
## Principle of Scanning tunneling microscope

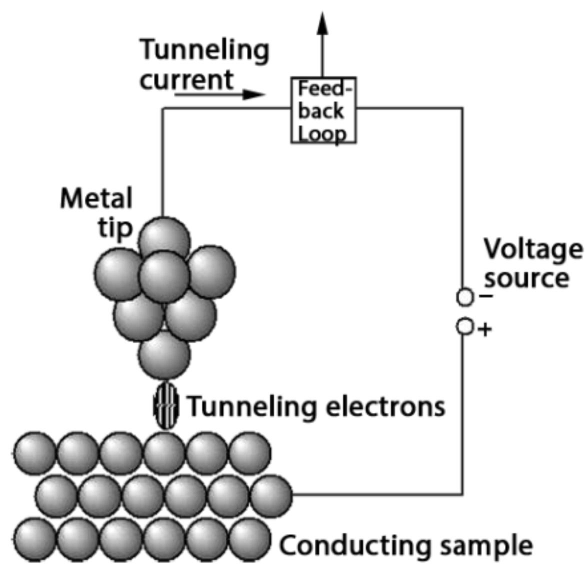
**STM** is a type of microscope whose principle of operation is based on the quantum mechanical phenomenon known as tunneling, in which the wavelike properties of electrons permit them to "tunnel" beyond the surface of a solid into regions of space that are forbidden to them under the rules of classical physics. The probability of finding such tunneling electrons decreases exponentially as the distance from the surface increases. The STM makes use of this extreme sensitivity to distance. Electrons use a quantum mechanical effect to 'tunnel' from the tip to the sample and vice versa.

## How a STM Works

The STM sample must conduct electricity for the process to work. The STM uses a tip that ends in a single atom, and a voltage is passed through the tip and the sample. The sharp tip of a tungsten needle is positioned a few angstroms from the sample surface. A small voltage is applied between the probe tip and the surface, causing electrons to tunnel across the gap. As the probe is scanned over the surface, it registers variations in the tunneling current, and this information can be processed to provide a topographical image of the surface.

The current that results depends upon the distance between the probe tip and the sample surface. The tip is attached to a piezoelectric tube, and the voltage applied to the piezo rod is altered to maintain a constant distance of the tip from the surface. Changes in this voltage allow a three-dimensional picture of the material surface to be built up as the tip is scanned back and forth across the sample.




**Feedback loop and electron tunneling for scanning tunneling microscopy (STM)**

## Piezoelectric Effect

The piezoelectric effect was discovered by Pierre Curie in 1880. The effect is created by squeezing the sides of certain crystals, such as quartz or barium titanate. The result is the creation of opposite charges on the sides. The effect can be reversed as well; by applying a voltage across a piezoelectric crystal, it will elongate or compress.

These materials are used to scan the tip in an scanning tunneling microscopy (STM) and most other scanning probe techniques. A typical piezoelectric material used in scanning probe microscopy is PZT (lead zirconium titanate).

### Feedback Loop

Electronics are needed to measure the current, scan the tip, and translate this information into a form that we can use for STM imaging. A feedback loop constantly monitors the tunneling current and makes adjustments to the tip to maintain a constant tunneling current. These adjustments are recorded by the computer and presented as an image in the STM software. Such a setup is called a constant current image.

In addition, for very flat surfaces, the feedback loop can be turned off and only the current is displayed. This is a constant height image.

### Resolution

An STM can have a lateral resolution of up to 0.1nm, and a depth resolution of up to 0.01nm, which combined is small enough to resolve individual atoms. In recent years, carbon nanotubes have been used for constructing these tips, allowing for improved resolution and reduced error in image reconstruction.