The Nobel Prize in Physics 1986
Ernst Ruska, Gerd Binnig, Heinrich Rohrer

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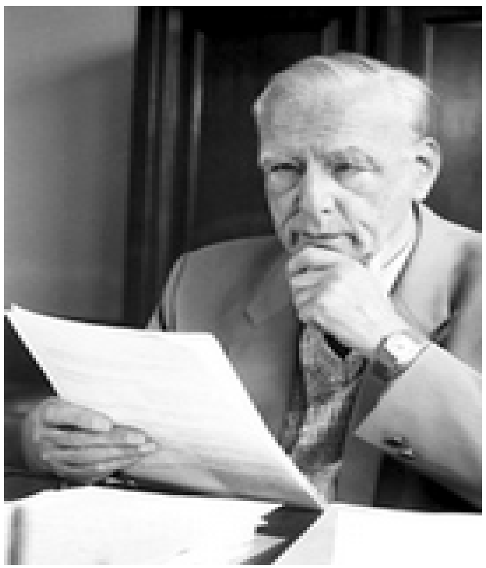
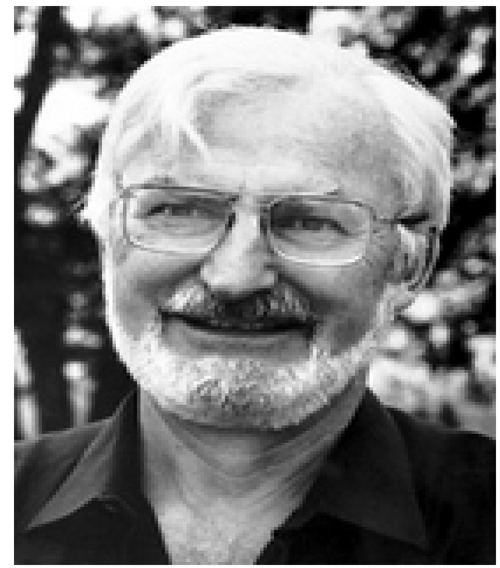

Ernst Ruska


Gerd Binnig


Heinrich Rohrer

The Nobel Prize in Physics 1986 was divided, one half awarded to Ernst Ruska *"for his fundamental work in electron optics, and for the design of the first electron microscope"*, the other half jointly to Gerd Binnig and Heinrich Rohrer *"for their design of the scanning tunneling microscope"*.

Source: Nobleprize.org

Scanning Probe Microscopy (SPM)

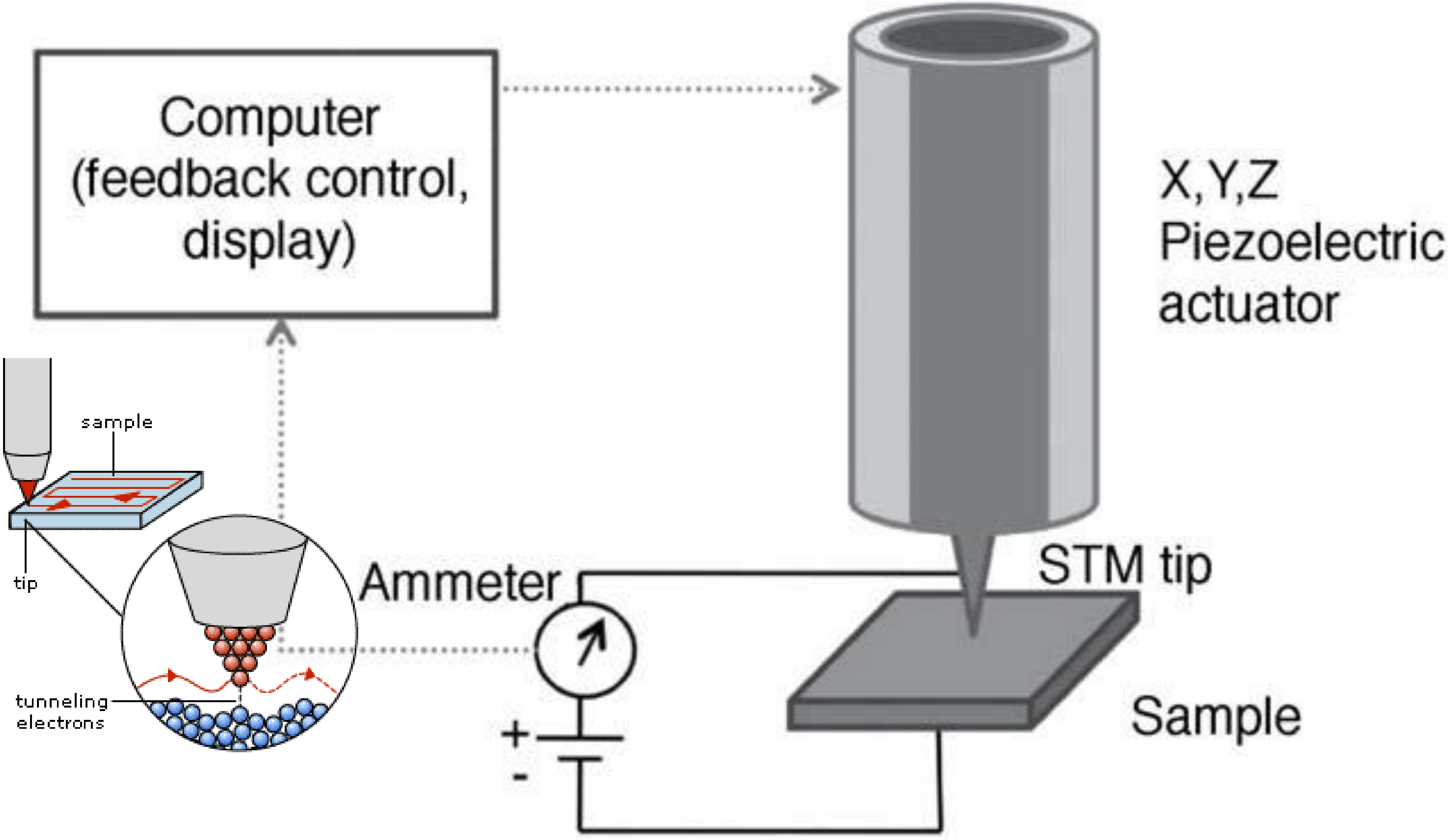
Scanning Tunneling Microscopy (STM)

Probe is scanned mechanically across the surface in a raster pattern while keeping track of the probe sample interaction as a function of tip position

Nobel Prize in Physics in 1986-
Binning and Rohrer

Quantum Tunneling of electrons between two surfaces i.e. Tip and Sample, as they are brought close together that their electron clouds begin to overlap

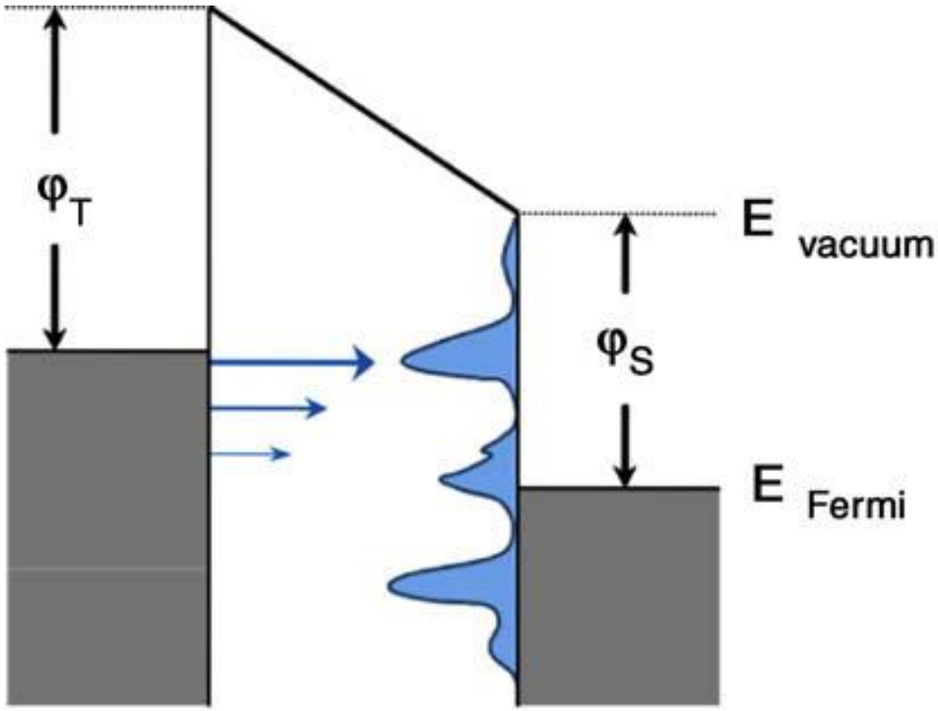
Scanning Tunneling Microscopy (STM)



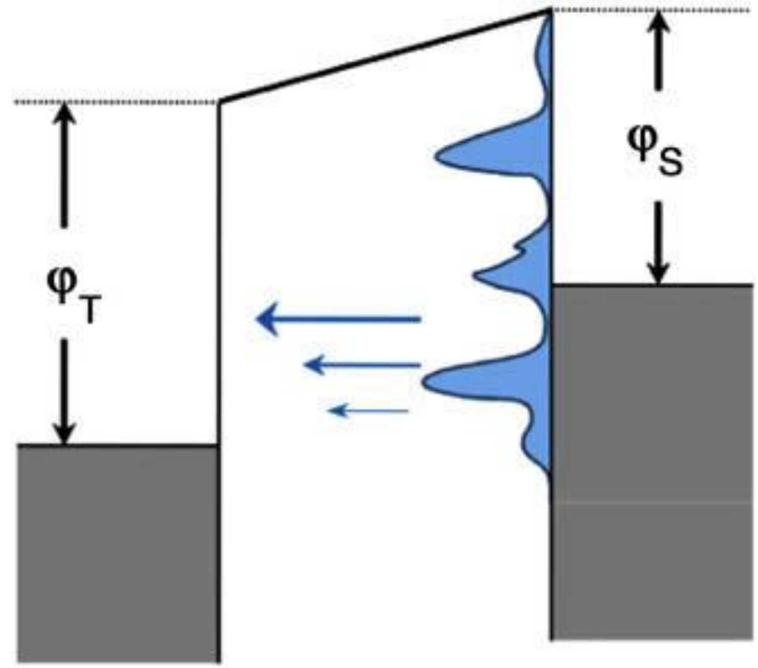
Scanning Tunneling Microscopy (STM)

- Tip of an atomically sharp electrode is positioned within a few nanometers of the surface and at low tip voltage bias probes the density of electronic states of the atoms comprising the surface by monitoring the tunneling current
- Negative Tip Bias: Current is measured through tunneling of electrons from the occupied states in the tip into the unoccupied states in the sample
- Positive Tip Bias: Electrons tunnel from occupied states in the sample into unoccupied states in the tip

Scanning Tunneling Microscopy (STM)



Negative tip potential in which electrons tunnel from the tip into unoccupied states in the sample



Positive tip in which electrons tunnel from occupied states in the sample into the tip

Scanning Tunneling Microscopy (STM)

- Atomic resolution can be achieved because of distance dependence of tunneling current
- Tunneling Current $I \alpha e^{-2\kappa z}$, z=distance b/w tip and sample, $K^2=2m(V_B-E)/\hbar^2$, V_B=potential in the barrier, E=energy of the electronic state and (V_B-E) is work function ≈4-5 eV, so K=1 $Å^{-1}$ i.e. tunneling current drops by one order of magnitude for every Å of separation
- Optimum spatial resolution for an STM is approximately < 0.1 Å vertically and < 1 Å laterally
- Depending on the tip sharpness, surface roughness, electronic noise, and level of vibration in the system

Auger Electron Spectroscopy (AES)

Piezoelectric Actuators precisely control the tunneling junction

Natural: Quartz, Topaz, Cane Sugar etc.

Man-Made Crystals and Ceramics: $GaPO_4$, $BaTiO_3$, $PbTiO_3$, $KNbO_3$,Lead-Rirconium-Titanates (PZT) has sensitivity of the order of 1-5 Å/V

Vibration free instrument using vibration isolation equipment

Dr. Bilal Rasul Warraich, The University of Sargodha

Specifications	
Maximum size of images	17500nm x 17500nm
Resolution of the images:	atomic, if tip is ok
Tip type:	Platinum/Iridium for STM, Needle Sensor with piezo for AFM
Sputter Source	
Type of Sputter-Target:	Silicon 99.999%
Diameter of Sputter-Target:	5cm
Maximum power of sputter source:	1000Watts DC / 400Watts RF
Distance to sample:	33cm
Sputter gas:	Argon
Pressure regime for sputtering:	10^{-2} - 10^{-1} mbar
Typical experiments	
Growth of silicon films on HOPG	
Scanning tunneling lithography	
Scanning tunneling spectroscopy	

Recent publications from this experiment

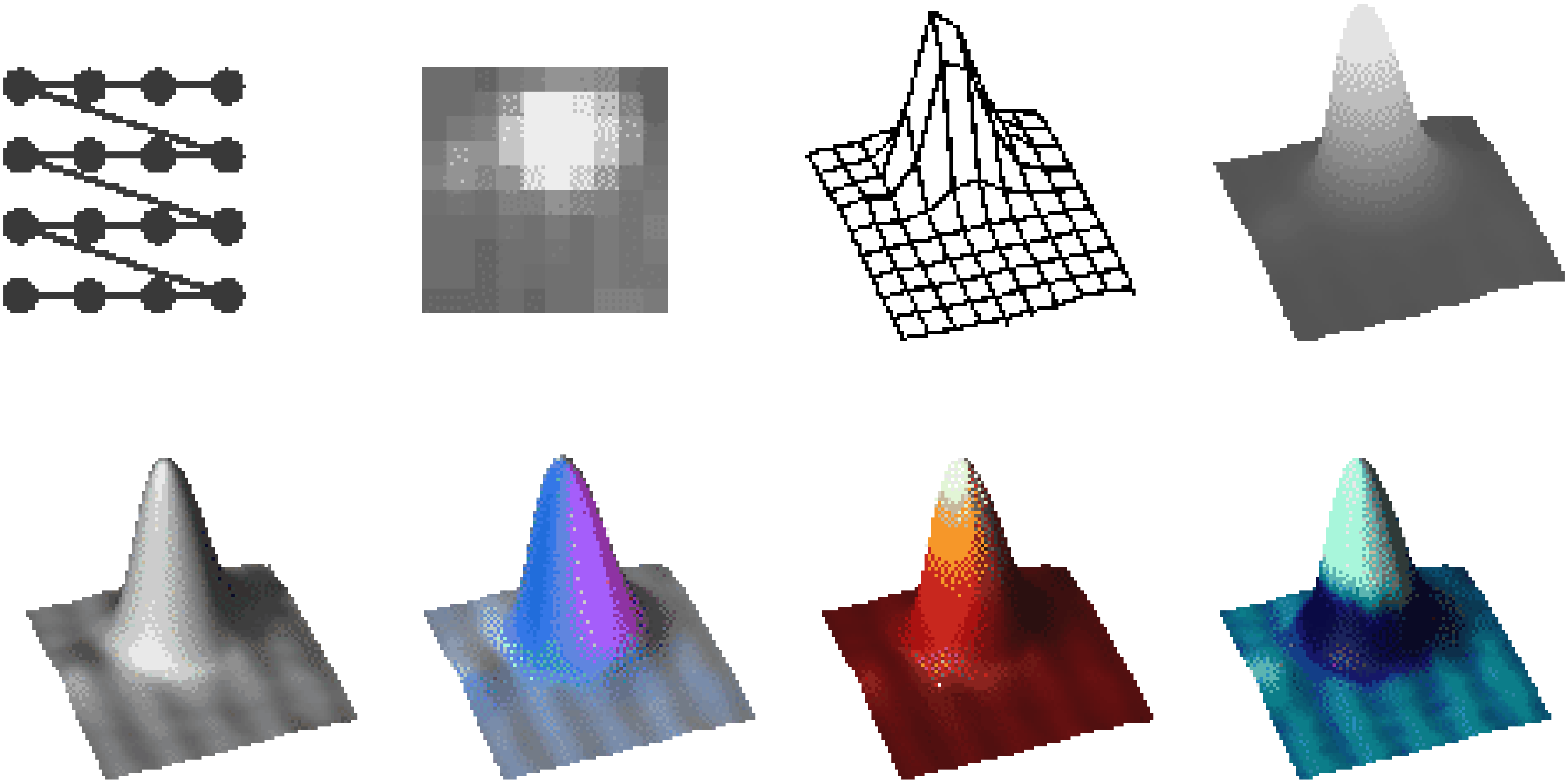
The publications are collected in the NanoBioDatabase. Loading my take some time.

Diploma and PhD thesis from this experiment

- Michaela Hager (PhD - ongoing)
- Michaela Hager (Diploma - 2009)
- Radula Stijepovic (Diploma - 2009)
- Stefan Jaksch (PhD - 2009)
- Stefan Jaksch (Diploma - 2006)

Scanning Tunneling Microscopy (STM)

How the images came to life...



Source: IBM

Scanning Tunneling Microscopy (STM)

How the images came to life...

1. A tip is scanned over a surface at a distance of a few atomic diameters in a point-by-point and line-by-line fashion. At each point the tunneling current between the tip and the surface is measured. The tunneling current decreases exponentially with increasing distance and thus, through the use of a feedback loop, the vertical position of the tip can be adjusted to a constant distance from the surface.
2. The amount of these adjustments is recorded and defines a grid of values which can be displayed as a grayscale image.
3. Instead of assigning the values to a color we can also use them to deform the grid in the direction perpendicular to the surface.
4. Now we can bring back the grayscale and paint each square according to an average of the four defining grid points.
5. Now we paint the whole surface uniformly gray and switch on the lights.
6. We can use several lights at different positions and with different colors.
7. Instead of painting the surface just gray we can use a color palette and paint it according to height.
8. Or we choose the color according to another surface property, let's say curvature. *Source: IBM*

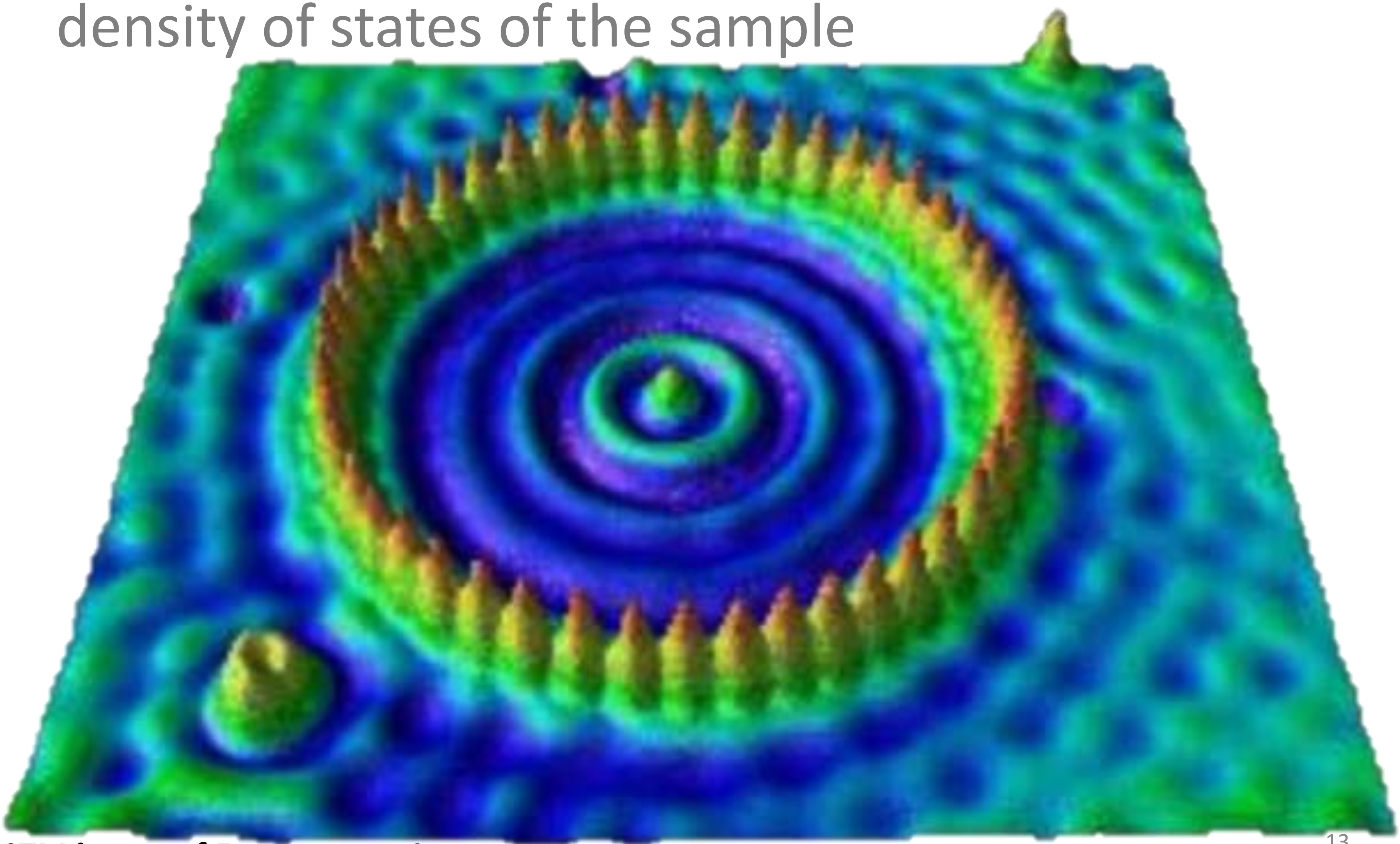
Scanning Tunneling Microscopy (STM)

- **Constant Current Mode:** Voltage bias is applied across the tunnel barrier, the tunneling current is measured and kept constant through computer-controlled feedback which controls the separation distance using the vertical piezoelectric actuator,

- **Constant Height Mode:** Tip is maintained at a fixed height above the average surface and the topography is reflected in the variations in tunneling current

Scanning Tunneling Microscopy (STM)

- STM measures not sample topography, but the local density of states of the sample



STM image of Fe atoms on Cu

Scanning Tunneling Microscopy (STM)

- Adsorbates on a sample surface, which have different electronic density of states from that of a uniform substrate, and which alter the surface topography of the sample, will change the tunneling current passing through the tip as it passes over it. This provides contrast in an STM image, allowing this technique to probe the shape, conformation, and distribution of atoms or molecules residing on the surface of an atomically flat conducting substrate

Scanning Tunneling Microscopy (STM)

Scanning Tunneling Spectroscopy (STS)

- Wentzel-Kramers-Brilloun(WKB) approximation of tunneling current
- High frequency voltage modulator is added to tip bias

$$I = \int \rho_t(E)\, \rho_s(eV + E)\, T(E, eV) dE$$

$\rho_t(E)$=density of electronic states at energy E

$\rho_s(eV+E)$=density of electronic states in the biased sample

$T(E,eV)$=Tunneling Transmission Probability

Dr. Bilal Rasul Warraich, The University of Sargodha

Scanning Tunneling Microscopy (STM)

- *Strengths:*
- Subatomic vertical resolution
- High lateral spatial resolution (atomic in some cases)
- Operates in ambient, vacuum or aqueous conditions
- Little sample preparation necessary (except UHV STM)
- *Limitations:*
- Samples limited to conductors or semiconductors
- Tip artifacts are possible
- Not amenable for samples with excessive roughness

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