

# Study of Scanning Tunnelling Microscope

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**ABSTRACT** It was found that particles with small masses such electrons could interchangeably be described as waves or as corpuscular objects. With the wave character of matter, particles exhibit a probability of existence at places, where they can classically not exist. One of these phenomena is the tunnel effect, which describes the ability of an electron to tunnel through a vacuum barrier from one electrode to the other. Since 1960 tunneling has been extensively studied experimentally. This led in 1981 to the first microscopic tool with which atoms could be observed in real space – the scanning tunnelling microscopy. In addition to the atomic resolution imaging capability of STM, tunnel currents could be studied with this tool in a spectroscopy manner providing insight into the local density of state (LDOS) of material surfaces.

## I. CONCEPTS OF SCANNING TUNNELLING MICROSCOPE

To achieve some understanding of the physical meaning of the wave function  $\psi$ , we consider the square magnitude of it, which represents the probability of finding an electron at a given location. Generally, this is visualized with electron clouds for atoms or molecules, or for condensed phases with energy levels, as illustrated with the grey shaded areas in Figure 2. In metals, electrons fill the continuous energy levels up to the Fermi level,  $E_F$ , which defines an upper boundary, similar to the sea level. Above  $E_F$  we find electrons that are activated (e.g., thermally). We can raise the Fermi level (e.g., of the sample) in regards to a second material (e.g., tip) by applying a voltage. Thus, to observe the tunnelling current  $I$  of electrons through the vacuum gap between the sample and the tip, a bias voltage,  $V_{bias}$ , is applied, as shown in Figure 1&2. At  $V_{bias} = 0$ , the electrons cannot flow in either direction since the Fermi level,  $E_F$ , of both the tip and the sample is equal, i.e., the gradient is zero. When  $V_{bias} > 0$  (positive bias), the Fermi level of the sample is raised by  $V_{bias}$ , and the electrons in the occupied state (filled with electrons) of the sample can tunnel into the unoccupied state of the tip. Similarly, when  $V_{bias} < 0$  (negative bias), the electrons in the occupied state of the tip tunnel into the unoccupied state of the sample.

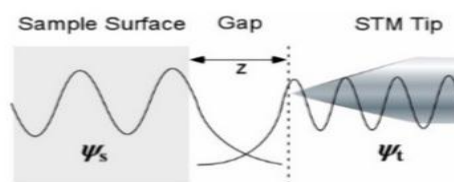


Figure 1: Schematic of STM one-dimensional tunneling configuration.

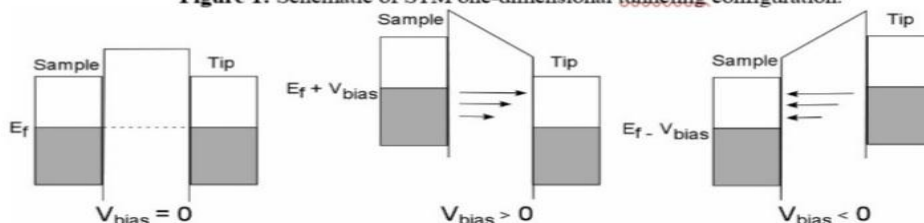


Figure 2: Schematic of a metal-insulator-metal tunneling junction. The grey area represents electron filled states (occupied level) and the white area is empty states, ready to accept electrons (unoccupied level).

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Scanning Tunneling Microscopy (STM) is one of the application modes for SPM. STM is the ancestor of all scanning probe microscopes. It was invented in 1981 by Gerd Binnig and Heinrich Rohrer at IBM Zurich. Five years later they were awarded the Nobel prize in physics for its invention. The STM was the first instrument to generate real-space images of surface with, so called, atomic resolution (atomic lattice resolution to be precise).

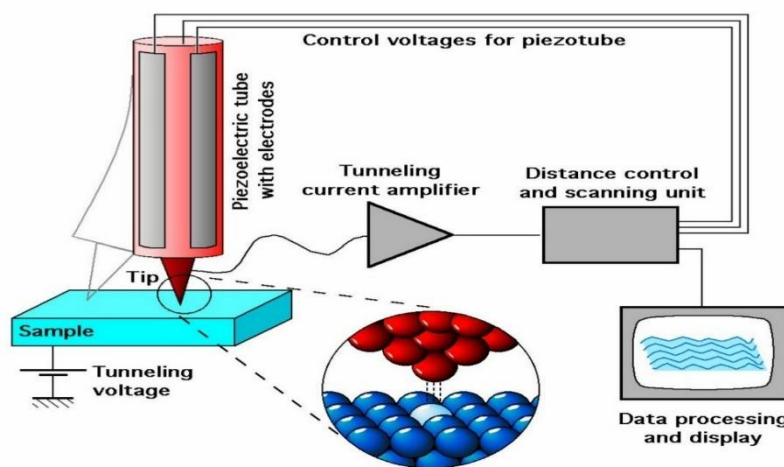


Figure 3 : Atomic resolution with STM

## II. MODES OF OPERATION OF STM

STM techniques encompass many methods: taking “topographic” (constant-current) images using different bias voltages and comparing them; taking current (constant-height) images at different heights; and ramping the bias voltage with the tip positioned over a feature of interest while recording the tunnelling current. The last example results in current vs. Voltage (I-V) curves characteristic of the electronic structure at a specific XY location on the sample surface. STMs can be set up to collect I-V curves at every point in a data set, providing a three-dimensional map of electronic structure. With a lock-in amplifier,  $dI/dV$  (conductivity) or  $dI/dz$  (work function) vs.  $V$  curves can be collected directly. All of these are ways of probing the local electronic structure of a surface using an STM. The schematics of constant-height or constant-current mode are shown in Figure 5. In constant-height mode, the tip travels in a horizontal plane above the sample and the tunnelling current varies depending on topography and the local surface electronic properties of the sample. The tunnelling current measured at each location on the sample surface constitute the data set, the topography image in Figure In constant-current mode, STMs use feedback to keep the tunnelling current constant by adjusting the height of the scanner at each measurement point in Figure 5& 6. For example, when the system detects an increase in tunnelling current, it adjusts the voltage applied to the Z-axis scanner to increase the distance between the tip and the sample. In constant-current mode, the motion of the scanner constitutes the data set. If the system keeps the tunnelling current constant to within a few percent, the tip-to-sample distance will be constant to within a few hundredths of an angstrom. Each mode has advantages and disadvantages. Constant-height mode is faster because the system doesn’t have to move the scanner up and down, but it provides useful information only for relatively smooth surfaces. Constant current mode can measure irregular surfaces with high precision, but the measurement takes more time.

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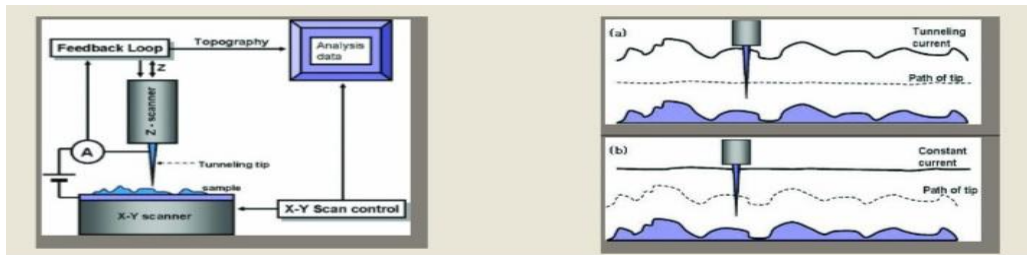


Figure 5 : Modes of STM operation

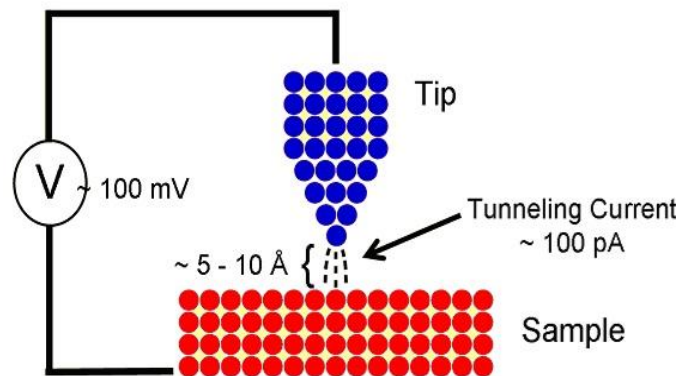


Figure6 : Tunnellingcurrent of STMTIP

A new mode of scanning tunnelling spectroscopy (STM), the atomic-site tunnelling(AST) spectroscopy which collects spectroscopic data simultaneously during a scan of the STM imaging, enables one to know how the order parameter of superconductivity varies in the atomic scale on the surface of high-Tc superconductor (HTSC). Perhaps due to the extremely short coherence length the order parameter in the HTSC has turned out to change drastically even across the terminating atomic layer on the HTSC surface.

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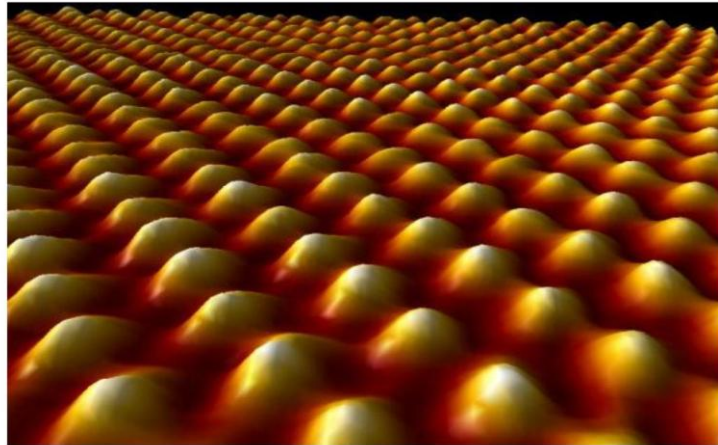


Figure 7 : Image on surface scanning

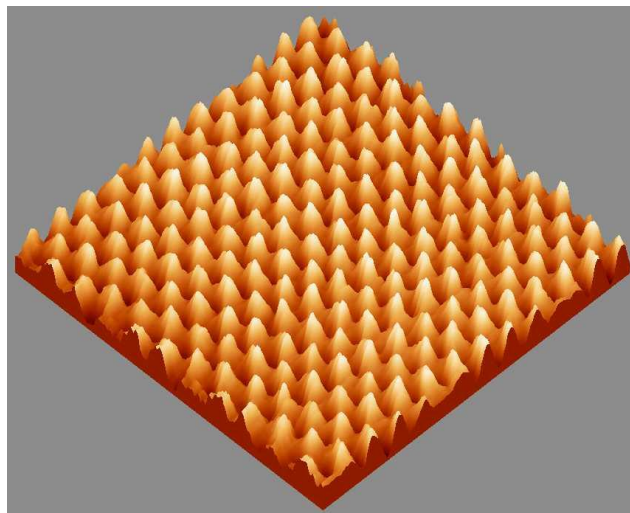


Figure 8 : Topology of a sample using STM /Atomic Force Microscopy

### III. ATOMIC FORCE MICROSCOPE

The atomic force microscope (AFM)(Figure 7 & 8) probes the surface of a sample with a sharp tip, a couple of microns long and often less than  $100\text{\AA}$  in diameter. The tip is located at the free end of a cantilever that is 100 to  $200\mu\text{m}$  long. Forces between the tip and the sample surface cause the cantilever to bend, or deflect. A detector measures the cantilever deflection as the tip is scanned over the sample, or the sample is scanned under the tip. The measured cantilever deflections allow a computer to generate a map of surface topography. AFMs can be used to study insulators and semiconductors as well as electrical conductors.

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## IV. NANOLITHOGRAPHY

Normally an SPM is used to image a surface without damaging it in any way. However, either an AFM or STM can be used to modify the surface deliberately, by applying either excessive force with an AFM, or high-field pulses with an STM. Not only scientific literature, but also newspapers and magazines have shown examples of surfaces that have been modified atom by atom. This technique is known as nanolithography.

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