Physics of Nanotechnology

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Scanning tunneling microscope: An Introduction

A **scanning tunneling microscope** (**STM**) is an instrument for imaging surfaces at the atomic level. Its development in 1981 earned its inventors, Gerd Binnig and Heinrich Rohrer (at IBM Zürich), the Nobel Prize in Physics in 1986.For an STM, good resolution is considered to be 0.1 nm lateral resolution and 0.01 nm (10 pm) depth resolution. With this resolution, individual atoms within materials are routinely imaged and manipulated. The STM can be used not only in ultra-high vacuum but also in air, water, and various other liquid or gas ambients, and at temperatures ranging from near zero kelvin to over 1000 °C.

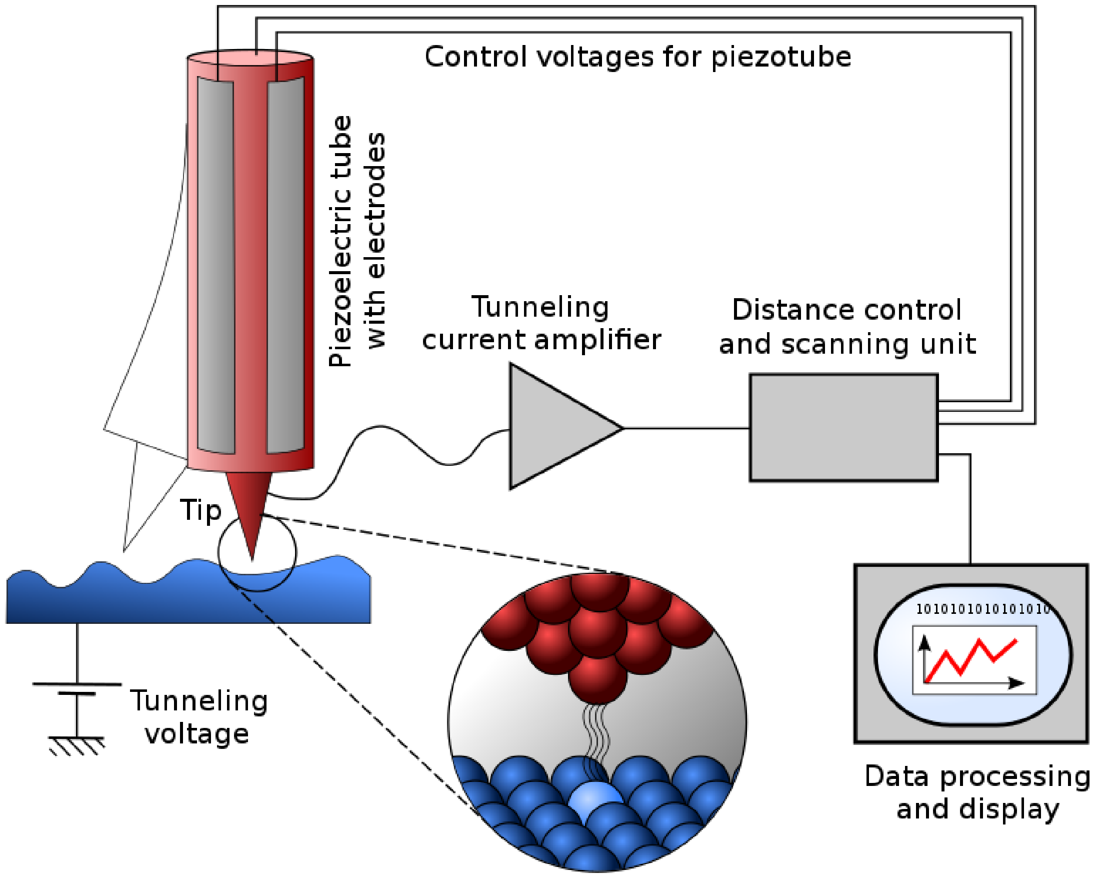
Scanning tunneling microscope: An Introduction

STM is based on the concept of quantum tunneling. When a conducting tip is brought very near to the surface to be examined, a bias (voltage difference) applied between the two can allow electrons to tunnel through the vacuum between them. The resulting *tunneling current* is a function of tip position, applied voltage, and the local density of states (LDOS) of the sample. Information is acquired by monitoring the current as the tip's position scans across the surface, and is usually displayed in image form. STM can be a challenging technique, as it requires extremely clean and stable surfaces, sharp tips, excellent vibration control, and sophisticated electronics, but nonetheless many hobbyists have built their own.

Procedure

First, a voltage bias is applied and the tip is brought close to the sample by coarse sample-to-tip control, which is turned off when the tip and sample are sufficiently close. At close range, fine control of the tip in all three dimensions when near the sample is typically piezoelectric, maintaining tip-sample separation W typically in the 4-7 Å (0.4-0.7 nm) range, which is the equilibrium position between attractive (3<W<10Å) and repulsive (W<3Å) interactions. In this situation, the voltage bias will cause electrons to tunnel between the tip and sample, creating a current that can be measured. Once tunneling is established, the tip's bias and position with respect to the sample can be varied (with the details of this variation depending on the experiment) and data are obtained from the resulting changes in current.

Schematics of STM



Procedure

If the tip is moved across the sample in the x-y plane, the changes in surface height and density of states causes changes in current. These changes are mapped in images. This change in current with respect to position can be measured itself, or the height, z, of the tip corresponding to a constant current can be measured. These two modes are called constant height mode and constant current mode, respectively. In constant current mode, feedback electronics adjust the height by a voltage to the piezoelectric height control mechanism. This leads to a height variation and thus the image comes from the tip topography across the sample and gives a constant charge density surface; this means contrast on the image is due to variations in charge density.

Procedure

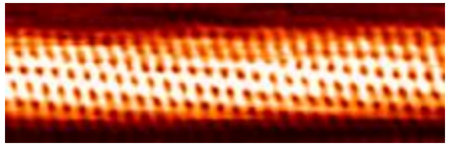
In constant height mode, the voltage and height are both held constant while the current changes to keep the voltage from changing; this leads to an image made of current changes over the surface, which can be related to charge density. The benefit to using a constant height mode is that it is faster, as the piezoelectric movements require more time to register the height change in constant current mode than the current change in constant height mode. All images produced by STM are grayscale, with color optionally added in post-processing in order to visually emphasize important features.

Procedure

In addition to scanning across the sample, information on the electronic structure at a given location in the sample can be obtained by sweeping voltage and measuring current at a specific location. This type of measurement is called scanning tunneling spectroscopy (STS) and typically results in a plot of the local density of states as a function of energy within the sample. The advantage of STM over other measurements of the density of states lies in its ability to make extremely local measurements: for example, the density of states at an impurity site can be compared to the density of states far from impurities.

Procedure

- Framerates of at least 25 Hz enable so called video-rate STM. Framerates up to 80 Hz are possible with fully working feedback that adjusts the height of the tip. Due to the line-by-line scanning motion, a proper comparison on the speed requires not only the framerate, but also the number of pixels in an image: with a framerate of 10 Hz and 100x100 pixels the tip moves with a line frequency of 1 kHz, whereas it moves with only with 500 Hz, when measuring with a faster framerate of 50 Hz but only 10x10 pixels. Video-rate STM can be used to scan surface diffusion.



An STM image of a single-walled carbon nanotube

The silicon atoms on the surface of a crystal of silicon carbide (SiC). Image obtained using an STM

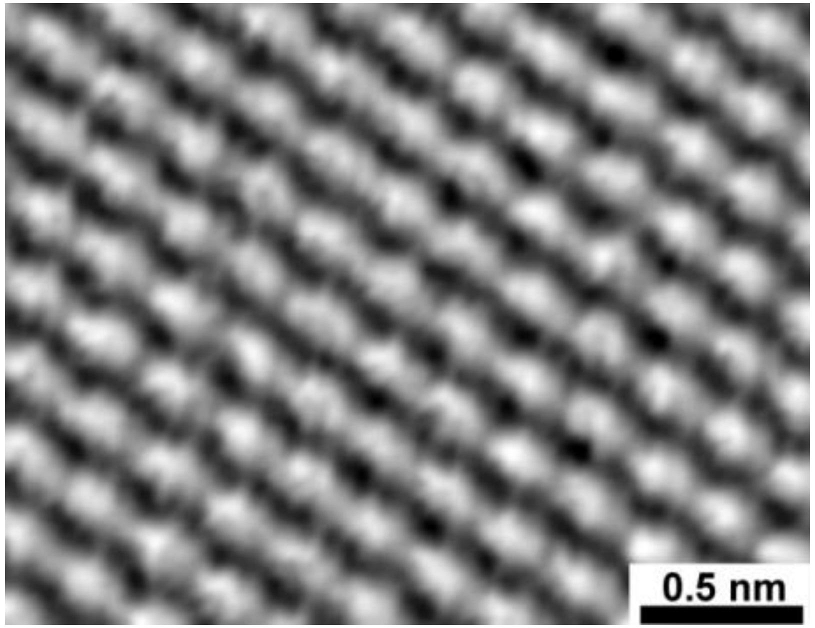


Image of a graphite surface at an atomic level obtained by an STM

A large scanning tunneling microscope, in the labs of the London Centre for Nanotechnology