REPORT ON

SCANNING TUNNELING MICROSCOPE

Course

ME-228

Materials and Structural Property Correlations

Course Instructor

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The scanning tunneling microscope

A **scanning tunneling microscope** (**STM**) is an instrument for imaging surfaces at the atomic level. It is used to demonstrate the principle of quantum mechanical tunnelling between the microscope tip and the surface of a conducting sample. It was invented by Binnig and Rohrer and implemented by Binnig, Rohrer, Gerber, and Weibel. Fig.1 shows its essential elements. A probe tip, usually made of W or Pt–Ir alloy, is attached to a piezo drive, which consists of three mutually perpendicular piezoelectric transducers: x piezo, y piezo, and z piezo. Upon applying a voltage, a piezoelectric transducer expands or contracts. By applying a saw tooth voltage on the x piezo and a voltage ramp on the y piezo, the tip scans on the xy plane. Using the coarse positioner and the z piezo, the tip and the sample are brought to within a fraction of a nanometer each other. The electron wave functions in the tip overlap electron wavefunctions in the sample surface. A finite tunneling conductance is generated. By applying a bias voltage between the tip and the sample, a tunneling current is generated.

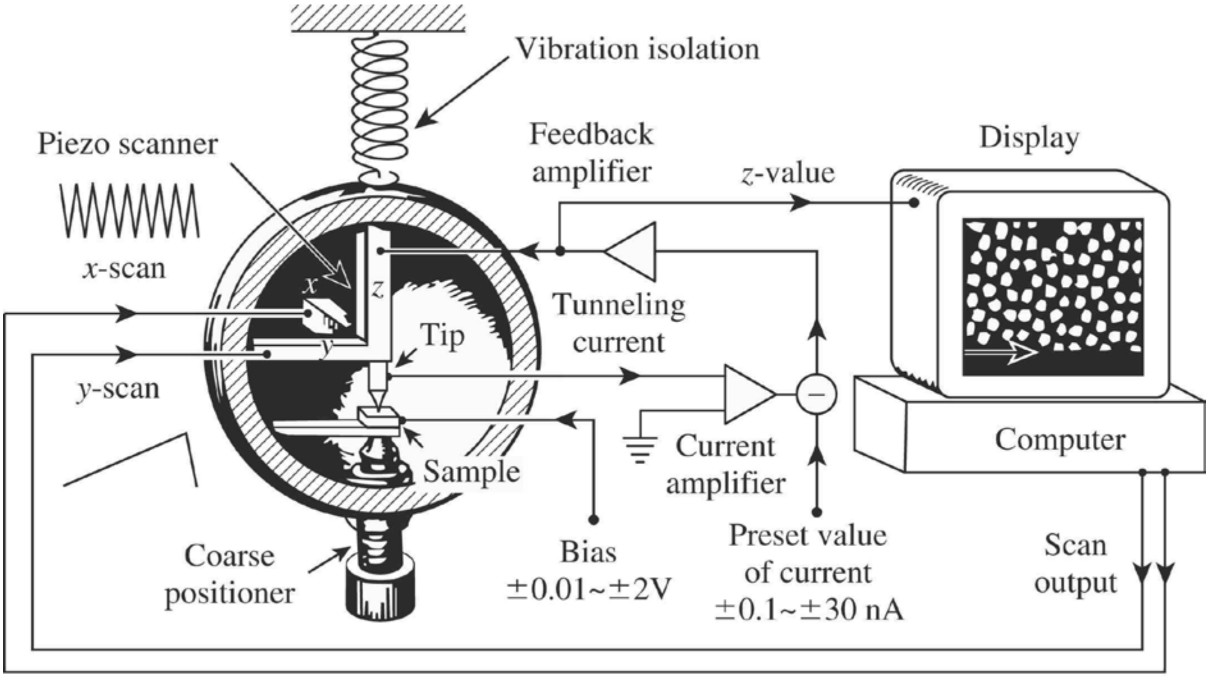

Fig. 1

The most widely used convention of the polarity of bias voltage is that the tip is virtually grounded. The bias voltage V is the sample voltage. If V > 0, the electrons are tunneling from the occupied states of the tip into the empty states of the sample.

If V < 0, the electrons are tunneling from the occupied states of the sample into the empty states of the tip. The tunneling current is converted to a voltage by the current amplifier, which is then compared with a reference value. The difference is amplified to drive the z piezo. The phase of the amplifier is chosen to provide a negative feedback: if the absolute value of the tunneling current is larger than the reference value, then the voltage applied to the z piezo tends to withdraw the tip from the sample surface, and vice versa.

Therefore, an equilibrium z position is established. As the tip scans over the xy plane, a two-dimensional array of equilibrium z positions, representing a contour plot of the equal tunneling-current surface, is obtained, displayed, and stored in the computer memory.

The topography of the surface is displayed on a computer screen, typically
as a gray-scale image, fig.2.The gray-scale image is similar to a black-and-white television picture. Usually, the bright spots represent high z values (protrusions), and the dark spots represent low z values (depressions). The z values corresponding to the gray levels are indicated by a scale bar. For a more quantitative representation of the topography, a contour plot along a given line is often provided. The most convenient unit for x and y is nanometer (nm, 10−9 m), and the most convenient unit for z is picometer (pm, 10−12 m). To achieve atomic resolution, vibration isolation is essential. This is achieved by making the STM unit as rigid as possible, and by reducing the influence of environmental vibration to the STM unit.

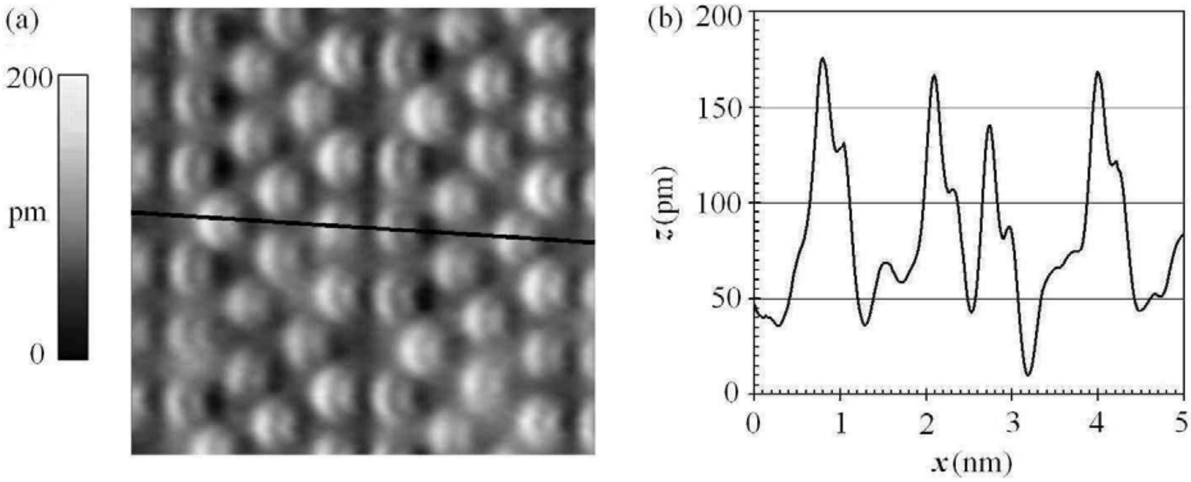

Fig.2

Applications

1. Catalysis research

Catalysis is the backbone of synthetic chemistry. It is a basic process in the production of fabrics, fuels, fertilizers and pharmaceuticals. Catalysis is also essential in environmental protection. For example, required by law,each automobile must have a catalytic converter to remove toxic exhaust gases, notably CO and NOx. Although it is well known that catalytic reactions often take place at specific active atomic sites on the catalyst surface, the research in catalysis have been mainly relying on test-anderror experimentation involving macroscopic parameters. The invention of STM enables detailed studies of the electronic structures of the active sites at catalyst surfaces. STM can even operate in an atmosphere with actual reactants, thus to observe the transformation of molecules at active atomic sites on real time. Therefore, STM research can help facilitate a full understanding and control of the constituents at the molecular and atomic levels, and to open up the possibility of designing the catalysis process at the single molecule level.

2. Atomic-scale imaging at the liquid-solid interface

The atomic-scale phenomena at the liquid-solid interface are of significant scientific and technological interest. Electrochemistry, and the related chemical industry, is based on atomic-scale reactions at the liquid-solid interface. Most of the biological objects are only active in aqueous buffer solutions. However, the traditional method for characterizing the surface relies on ultra high vacuum, which cannot access the liquid-solid interface. The invention of STM and AFM opened a wide window to study the atomic-scale phenomena at the liquid-solid interface. Experiments showed that if the liquid is clean, atomic resolution can be readily achieved. Furthermore, the well-established methods of electrochemistry can be applied to change the surface and the adsorbed atoms and molecules. The pioneering works in this field showed a great potential of operating STM in liquids by using a two-electrode system: the substrate and the STM tip. Later on, by combining STM with the standard methods of electrochemistry, a four-electrode system was introduced, which provides a powerful, general and convenient method to study the liquid-solid interface and a large number of electrochemical processes down to atomic level.

3. Atom manipulation

The basic operation of atom manipulation is to use the STM tip to move an adatom from an initial position to a new position on a substrate, as shown in Fig. At the beginning, the atom for the designed structure is deposited randomly on a substrate. Each atom is then an adatom on the substrate at a random position. In order to move an adatom to another stable location, an activation energy E must be applied to lift it across a ridge to reach another stable position.

There are three steps for a move, see Fig. Step A is to place the tip at the top of an adatom to be moved, then gradually increase the set tunneling current. As a result, the tip moves towards the adatom. A partial chemical bond is formed. When the chemical bond energy equals the barrier energy, the tip should be able to pull the adatom over the ridge. Step B is to move the tip sideways to pull the adatom to a desired location. Step C is to gradually decrease the set tunneling current. As a result, the tip moves away from the adatom and leaves it at the new position.

During the process of atom manipulation, neither the interaction energy between the tip and the adatom nor the distance between the apex atom of the tip and the adatom is known. The pioneers of atom manipulation found from experience that this can be controlled by tunneling conductance, or its inverse, the tunneling resistance. The threshold interaction energy to allow the tip to pull the adatom over a diffusion barrier corresponds to a threshold conductance, or equivalently, a threshold resistance.

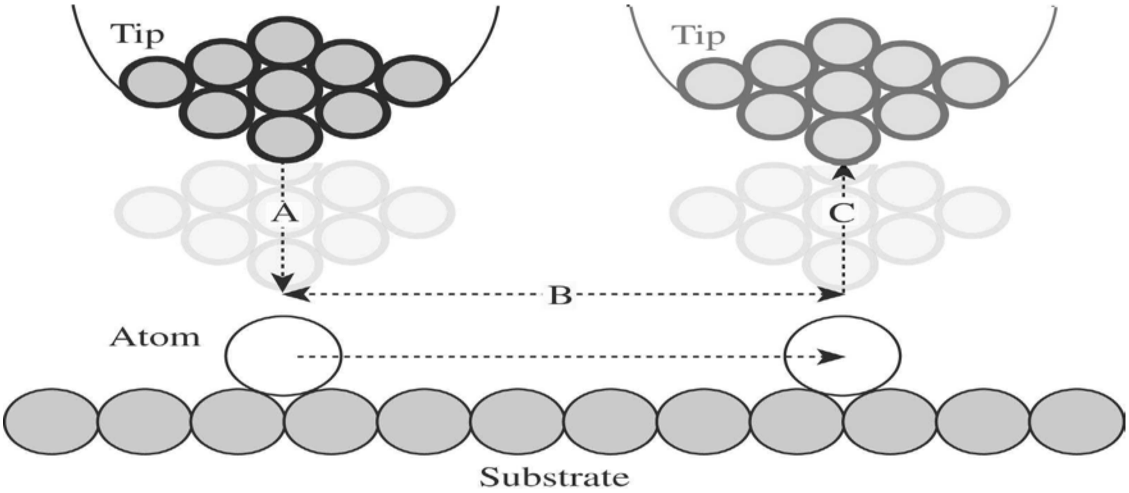

Fig.3

Some issues regarding STM

1. STM could be a challenging technique, as it needs very clean and plain and stable surfaces, extra sharp tips, high vibration control, and efficient and integrated electronic devices. These all specifications make STM expensive.
2. The resolution of the image scanned by STM is limited because radius of curvature is fixed and scanning stylus tip does not support the modification in the resolution.
3. If scanning tip has two tips than there is a chance of occurrence of artifacts instead of single atom display.
4. Because of huge sensitivity of tunnel current, proper vibration and isolation is required for obtaining best results from the STM.
5. At first, Binnig and Rohrer magnetic levitation was used to keep the scanning tunneling microscope free from extra vibrations and now mechanical or gaseous spring systems are usually used for controlling vibrations. Additional mechanisms for reducing current are also required sometime to proper implement the scan.