Scanning Tunneling Microscope

As the name suggests, the scanning tunneling microscope is based on the tunneling principle. When two metals say M1 and M2 are brought at small distance (but larger than 10 nm) as depicted in Fig.1, a even though their Fermi levels do not coincide, transfer of electrons from one metal to the other is not possible. To transfer electrons from one metal to the other, it is necessary for the electrons in the vicinity of the Fermi level to overcome the potential barrier known as the work function of the material. Typically, the work functions of metals are few electron volts (2–5 eV) and transfer of electrons at room temperature is forbidden. However, the metals brought in extremely close distance of the order of a few nanometres (usually less than 10 nm) behave differently. Electrons as shown in Fig. 1b can be transferred from one metal to the other to establish a common Fermi level without going over the potential barrier, set by the work function. At short distance of few nanometres, the wave functions of electrons from either side decay into the other metal. In other words, electrons can 'tunnel' from one metal to the other to occupy state of lower energy. This causes Fermi levels of the two metals to coincide with a small 'contact potential'. This reduces the barrier heights but changes are still small and barriers are sufficiently large for electrons to overcome them. Once the Fermi levels coincide, the electrons cannot flow from one metal to the other. However, by raising the Fermi level of one metal with respect to the other, electrons can tunnel from one metal to the other, as shown

In Fig. 1c. The energy required by electrons to overcome the energy barrier is still very high and not obtained by applying the potential, but electrons can tunnel. The tunneling probability or current depends upon the availability of the empty states in metal in which electrons flow (density of empty states) and distance between the two metals.

Fermi level positions can be altered by applying a small voltage (V <®) between the two metals. The metal (M1) which is connected to the negative terminal of the power supply has raised Fermi level with respect to the other metal (M2) whose Fermi level is lowered. This is made use of in an STM. As illustrated in Fig. 1c, the tip potential is made negative; therefore its Fermi level is raised and current flows from tip to the sample. Indeed it is possible to raise Fermi level of sample higher than the tip, so that electrons flow from sample to the tip. It is then quite obvious that by lowering the sample with respect to the tip and measuring the current flowing towards the sample, we are able to probe unoccupied states or empty energy levels of the sample. If the sample Fermi level is at higher level, electrons below Fermi level flow to the tip. Therefore, one can know about occupied states in the sample.

Thus, STM is capable of performing even spectroscopy of occupied and unoccupied levels.

The tunneling current is given as

$$I = C \exp(-kd)$$

Where C is proportionality constant, d – the distance between two metals and k is known as decay constant.

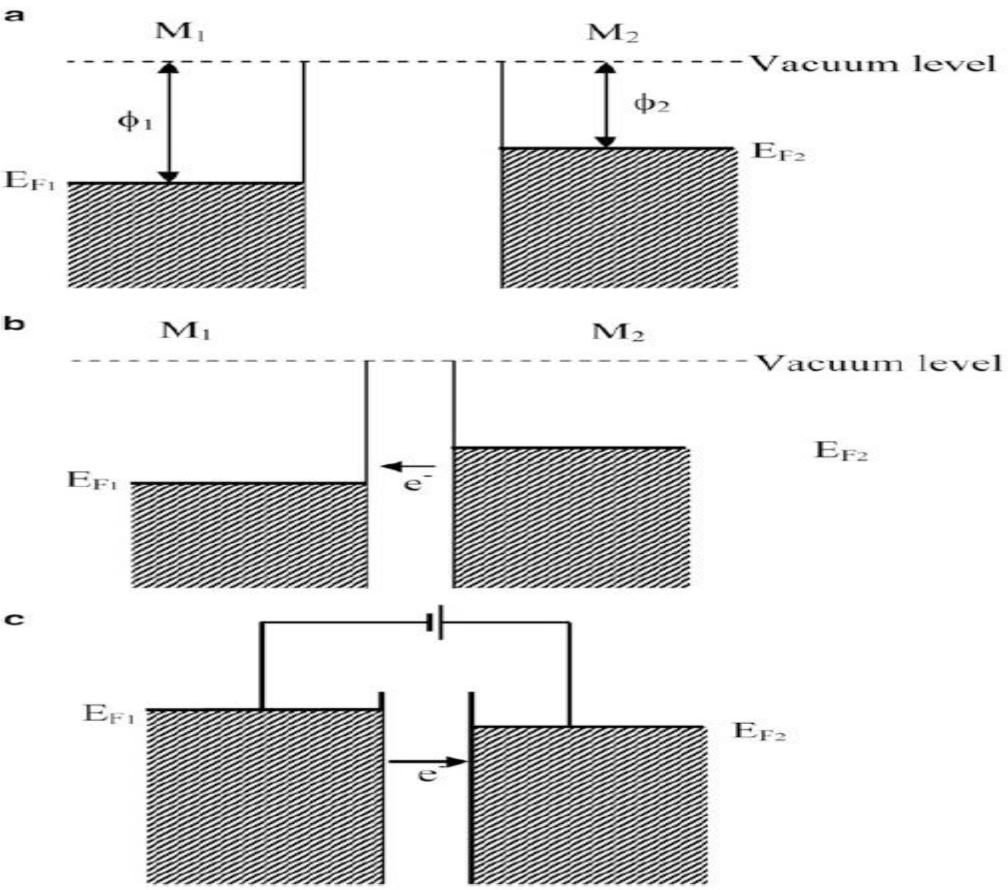

Fig1. Tunneling of electrons from one metal to other. (**a**) Metals are at small distance, but not less than 10 nm. (**b**) Metals are in close contact with each other, at a distance less than 10 nm. (**c**) Potential is applied between two metals

Usually the distance between tip and the sample is between 0.5 nm to 1 nm and current of few picoamperes (pA) to nanoamperes (nA) is expected. It is quite clear from the above equation that current is very sensitive to the distance between tip and sample.
An STM can be operated in two different modes viz.
1. Constant current mode
2. Constant height mode

Constant current mode: Probe in the form of a sharp metal tip is moved slowly on the sample surface so that the current between the tip and the sample remains constant. In order to maintain the constant current between the tip and the sample, distance between the tip and the atomic corrugations also needs to be kept constant (see Fig. 2 a). Thus the tip will have to follow the atom contours. By successively scanning the desired sample area in a raster mode, profile of surface atoms can be generated as an image, which is really the movement of the tip or the probe in an attempt to keep constant current between the sample and the tip, controlled by a proper feed-back loop. This is known as constant current mode.

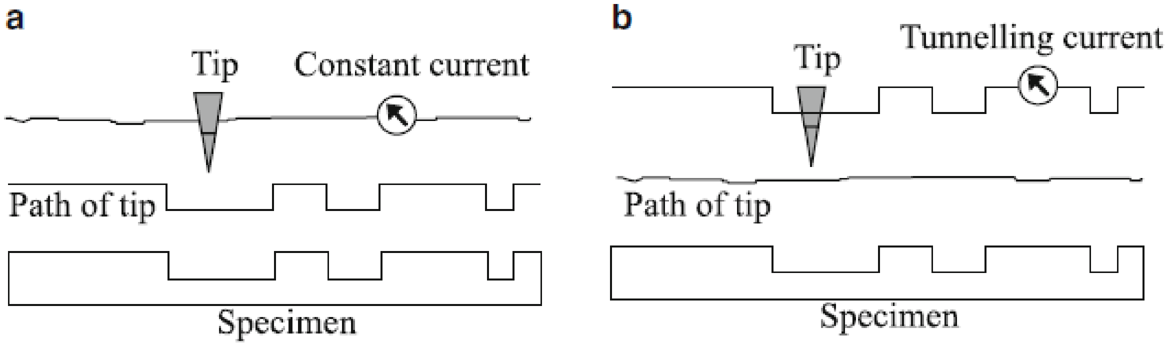

Fig2. (**a**) Constant current and (**b**) constant height modes

Constant height mode: Alternatively, the tip can be moved on the sample surface at a constant height (typically >0.5 nm) as illustrated in Fig. 7.12b. As there is a relation given by above equation, between current and the distance, a surface profile can be generated from the variations observed in the tunnel current. Thus the image
is the replica of the variation of current as the tip scans the desired area of the sample surface. Advantage of the constant height mode as compared to the constant current mode is that the tip can be moved faster on the sample surface, as there is no necessity of the feed-back circuit. Besides it is dangerous to move the tip close to the sample in constant current mode, as that can occasionally hit some rough hillocks of the sample and get destroyed. This is avoided in the constant height mode and tip can be moved faster. However this would be at the cost of better sensitivity in the constant current mode.

Major limitation of STM is that the tunnelling current has to flow between the sample and the probe. Although the current is very small (of pico ampere order), it can be detected. However, in case of insulating samples, even this much current is not possible.