Scanning Tunneling Microscopy (STM)

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Scanning Tunneling Microscopy (STM) is a new technique in microscopy that works without requiring any focusing elements and can achieve high resolution on the atomic scale, both laterally and vertically. This paper discusses the preparation of an STM setup as well as some of the obtained results.

I. INTRODUCTION

Although the theory of tunneling that the STM technique is based on, has been known since the beginning of the quantum mechanics, the STM technique was not developed until 1981 by G. Binnig and H. Rohrer (IBM labs, Zürich). The STM technique is based on the "electron tunneling" quantum mechanical effect. If a sharp metal tip is brought close enough to a sample surface (≈ 1 nm) a small current would start flowing (tunneling) between the sample and the tip (≈ 1 to 10 nA) for a small bias voltage (≈ 1mV to 4 V)[1]. Since the tunneling current is extremely dependent on the distance between the tip and the sample, the "landscape" of the atomic surface of the sample can be mapped.

The sample surface is scanned by moving the tip across the surface by means of three orthogonal piezoelectric drivers, Figure 1. The x- and y-drivers control the lateral motion, while the z-driver controls the vertical position of the tip.

II. MODES OF OPERATON

There are two main kinds of operation modes of the STM; i) constant current mode, and ii) constant height mode.

i) Constant current mode: In this mode, feedback loop system forces the tip (using the z-driver) to stay at a distance from the surface that would keep a constant current flowing between the tip and the sample surface, Figure 2. By recording the voltage, which has to be applied to the z-driver in order to maintain the current constant while scanning, a topographical image of the surface is produced. This mode can be applied to surfaces that are not necessarily flat on the atomic scale i.e. stepped surfaces. The main disadvantage of this mode is the finite time of the feedback loop, which result in slowing down the scanning process.

ii) Constant height mode: In this mood, the tip is rapidly scanned over the surface at a constant height. By recording the change in the value of the tunneling current as a function of position, a topographical image of the surface is produced. This mode has the advantage of being faster than the constant current mode. On the other hand, there are disadvantages to this mode, such as, extracting the topographical information is harder and depending on the sample kind[1]. The other disadvantage is the tip might get damaged due to a crash with a "step" on the surface while scanning at high speeds. That is why this technique is used for flat surfaces (atomic scale).

Further information from the STM can be gathered by using spectroscopic modes, such as the voltage current relation mode. In this mode, the applied bias voltage determines whether the electrons were tunneled into unoccupied states (positive sample bias) or out of the occupied states (negative sample bias). The amount of the applied bias determines which electronic states contributed to tunneling current.

Since the topographical image of the sample surface is dependent on the relation between the tip and the sample, the higher the quality of the tips the better resolution images that can be formed.

Another parameter that affects the resolution of the image produced is the slope of the sample surface. For best results, the sample surface needs to be parallel to the motion of the tip's x-y plane, Figure 3, and this can be done by adjusting the x- and y-slope settings on the STM machine.

III. EXPERIMENTAL SETUP AND RESULTS

The STM machine used was *nanoSurf* easy scan STM system. It uses a platinum tip clamped to the piezoelectric drivers as shown in Figure 1. The sample which is to be examined is brought close to the tip (or approached) to a distance of about 1 nm. If the sharp tip and a surface are put under a low voltage (U~0.1V) a very small current (I~1nA) may flow between tip and sample. The tunneling current depends exponentially on the distance between the tip and the sample $I \propto \left(\frac{V}{s}\right)\exp(-As\sqrt{\Phi})$, where "V" is the bias voltage, "s" is the gap size, "Φ" is the average barrier height between the electrodes (sample surface and tip), and "A" is a constant. Since this tunneling current is extremely dependent on the distance between tip and sample, the tip movement can accurately be controlled. The tip is scanned over the sample. By keeping the current between tip and sample constant by a feedback loop (constant current mode). This way, the distance between tip and surface is kept constant and the tip follows the structure of the sample's surface.

A graphite sample is used to test the system. In gold, atomic structures are difficult to observe because the electrons on the surface are much more homogeneously distributed unlike graphite. That is why graphite was preferred to perform the test on the STM setup. The procedure was as follows:

1) The sample is positioned manually as close as possible to the tip (without actually touching it to prevent the tip damage). An eyepiece can be used for better adjustment.
2) The parameter controlling the scan were set (according to manual[2]),
   ScanRange: fixes the scan size in x and y direction [nm] where (x=y). The value is doubled or halved when using -.
   Time/Line: sets the time taken to acquire a data line.
   Z-Range: fixes the displayed range in z-direction. For example to be able to

observe atomic features on a surface the signal in z-direction has to be amplified. This is achieved by diminishing the 'Z-Range'.

X-slope: tilts the x-axis of the scan-plane counterclockwise.

Y-slope: tilts the y-axis of the scan-plane counterclockwise (when viewed at 90° rotation).

X-Offset: sets displacement of the measured area in x-direction [nm].

Y-Offset: sets displacement of the measured area in y-direction [nm].

Z-Offset: raises the scan-plane in z-direction [nm].

By changing the X-/Y-Offsets the scanned area can be shifted. The values are always relative to the center of the entire scan range.

3) the parameters of the feedback loop were set,

SetPoint: sets the tunneling current [nA].

P-Gain: sets the proportional feedback value.

I-Gain: sets the integral feedback value of the z-distance controller.

If both P-gain and I-gain are set to 0, the feedback loop is switched off. when P-gain or I-gain are set to 16, it has maximum proportional gain or integrator speed (better resolution).

GapVoltage: sets the voltage of the tunneling gap between tip and sample [V].

A positive 'GapVoltage' means that the tip has a positive potential relative to the sample's surface and hence the electrons tunnel from the sample to the scanning tip.

4) The automatic approach of the tip was activated to set the tip close to the surface.

Figure 4, shows the first run as well as the panel setting used for it. As seen from the graph, an unclear image was produced while scanning. This could have been caused by a "bad" tip. The tip could have been damaged by during the manual approach. An improved image of the scan was produced by changing the tip, Figure 5. For a better resolution of the image, the feed back loop was put to the maximum sensitivity by increasing the values of the I-Gain and the P-Gain, Figure 6. Note that the x- and y-slope settings might need to be changed from one region to the other on the sample surface.

The tip shape (atomic size tip-end) as well as the feedback loop parameters are important for obtaining high-resolution images. As mentioned above, in the constant current mode there is a feedback loop from the tip to the STM system to observe the structure of the surface, so the higher the feedback response to the current the better the images. Bad images obtained at good feedback settings are mainly caused by a "bad" tip, a replacement of the tip would be necessary at this point. STM can also be ran on insulating surfaces, where electrons are more localized on the atom sites.

The obtained results are consistent with the expected values of the graphite lattice separation[2]. Figure 7, shows the structure of the graphite lattice. The measured distance between two diagonal white spots, Figure 6, was equal to, (0.22 ± 0.03) nm (the expected value is 0.25 nm). The measured value between the two adjacent white and gray spots was 0.10 nm (the expected value is 0.14 nm). These results show that the experiment was successfully setup and a good quality topographical images of sample surfaces can be achieved.

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References

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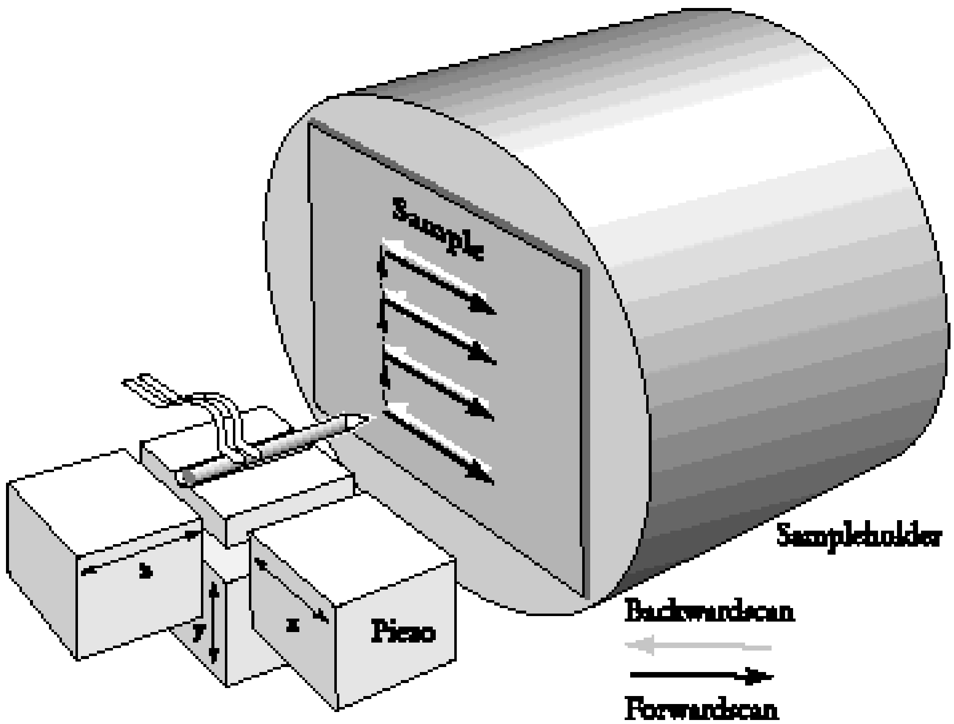

Figure 1. Tip configuration on an STM system[2].

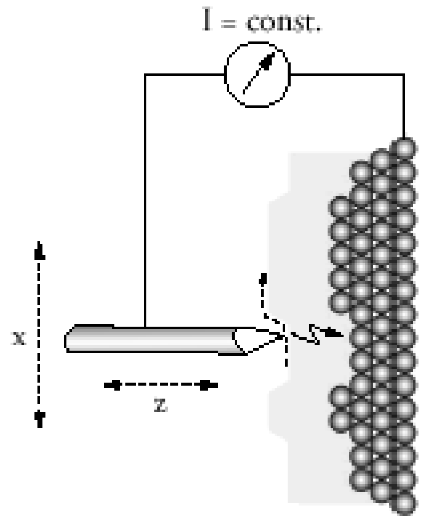

Figure 2. The probing tip while scanning[2].

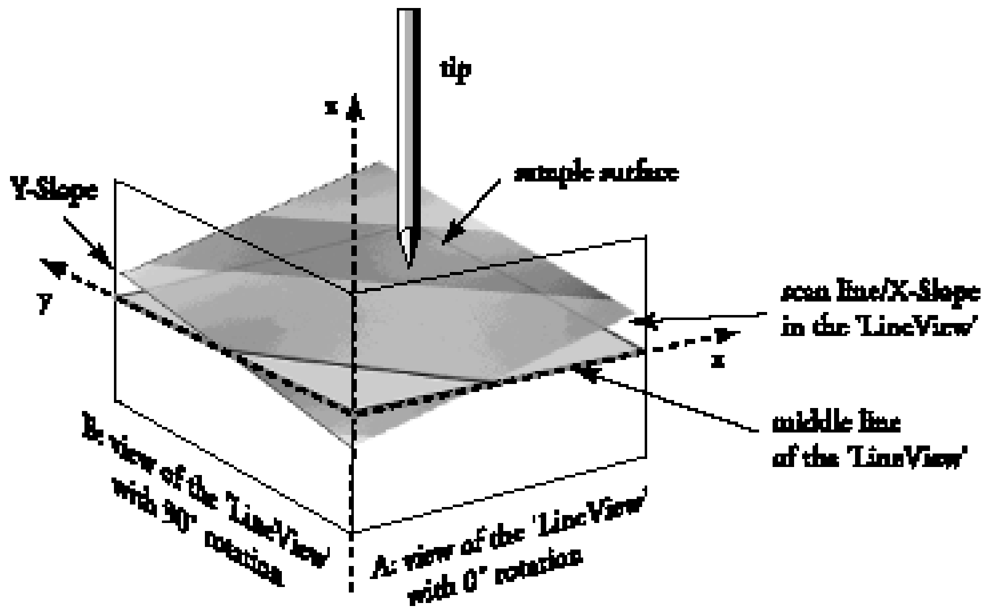

Figure 3. Sample orientation before tilt adjustments[2].

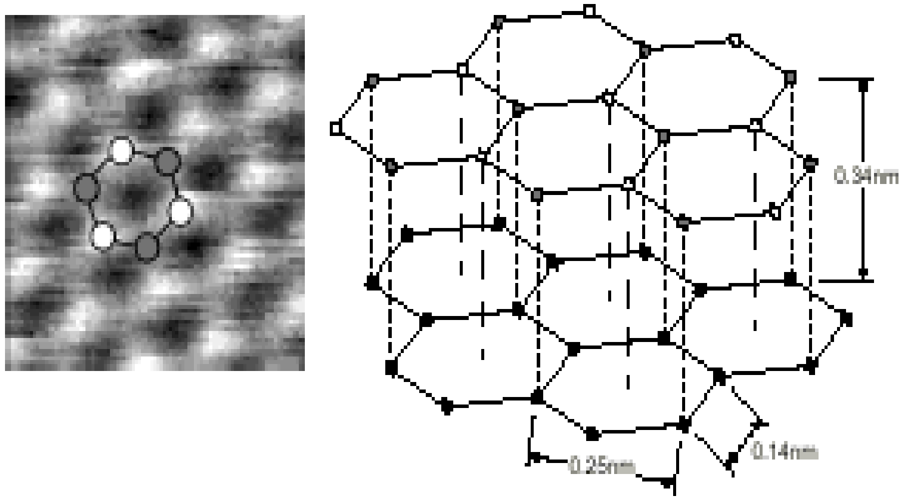

Figure 7. Lattice structure of graphite[2].