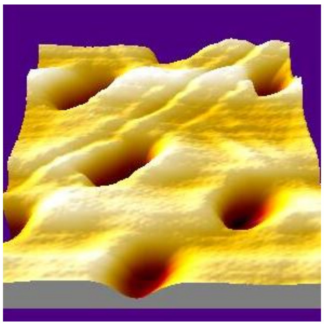
Bridge between research in modern physics
and entrepreneurship in nanotechnology

Quantum Physics

The physics of the very small with great applications

Part 2

QUANTUM PROPERTIES & TECHNOLOGY



Learning station X:
Atomic Force Microscopy

Quantum Spin-Off is funded by the European Union under the LLP Comenius programme.
(540059-LLP-1-2013-1-BE-COMENIUS-CMP).
Ernst Meyer
Contact: ernst.meyer@unibas.ch

Lifelong Learning Programme

Table of Contents

TRANSLATION BY:

SCIENTIX

www.scientix.eu

Learning station X: Atomic Force Microscopy (AFM)

A further development of the scanning tunnelling microscope (STM) is the atomic force microscope, in short AFM. You will understand what the advantages of the AFM are compared to the STM.

1 General

The conductivity of most materials found in daily use is rather poor. The surfaces are insulating in particular because they are covered with oxides or organic coating.

Task 1:

Using a measuring instrument (e.g. Fluke Digital Multimeter or a comparable current and voltage meter) try to measure the resistances of surfaces, e.g. desktop, gold ring or gold jewellery, metal frame of tables and chairs etc. Increase the pressure with the measuring probe or make small scratches on metal surfaces. Do you notice a difference? How is the resistance related to the conductivity?

The tunnel current[1] required for the operation of the STM must flow through the sample. This is only possible if the samples have a sufficiently high conductivity or low resistance.

2 Functional principle of the AFM:

The atomic force microscope (AFM) is based on measuring forces. To this end a leaf spring[2] with a tip is used which scans the surfaces with a defined contact pressure.

Task 2:

Try to estimate the size of the forces between the individual atoms.

Hint: The chemical bonding energy of molecules is in the range of 10^{-19} J. The typical size scale for compounds is in the range of 10^{-10} m.

[1] Tunnel current: According to quantum mechanical calculations a tunnel current flows through an insulating layer if the thickness of the insulator is within the nanometre range.

[2] Leaf spring: A thin strip (approx. 5-10 micrometre thick) that is some 100 micrometres long and clamped on one side

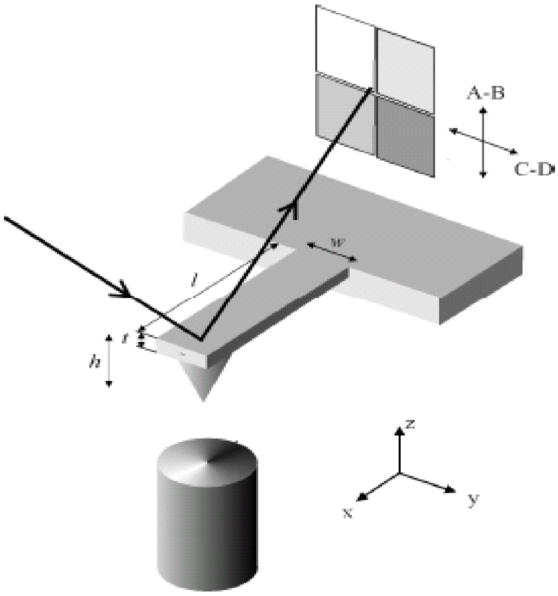


Figure 1:
Functional principle of the AFM

As shown in figure 1, the leaf spring, also called cantilever, is brought close to the sample. As with the STM, a signal is measured in the immediate vicinity of the surface. The deflection of the leaf spring is measured with the laser beam deflection. To this end a laser beam is reflected from the leaf spring. The reflected beam is caught by a 4 quadrant detector (four adjacent photo diodes[3]). By measuring the differential signals[4] it is possible to determine the deflection of the cantilever.

Task 3:

Build a model cantilever with a paper or metal tip. Watch how the strip bends if the tip approaches the surface perpendicular. What happens if the tip is moved parallel to the surface?

Task 4:

In task 2 you estimated the forces between the atoms. What size of spring constant k of the leaf spring in N/m would you chose if you knew that the laser beam deflection can still measure deflections in the range of 1 nanometre (10^{-9} m)?

The atomic force microscope is the most successful member of the scanning probe microscope family. As an application example look at the AFM image of a compact disc (CD).

[3] Photo diodes are light-sensitive electronic components. They are typically made from silicon with a doped surface layer causing a separation of charges.
[4] Differential signals are generated by the subtraction of signals from adjacent photo diodes. For the measurement of the standard force the difference is determined between the upper and lower photo diodes.

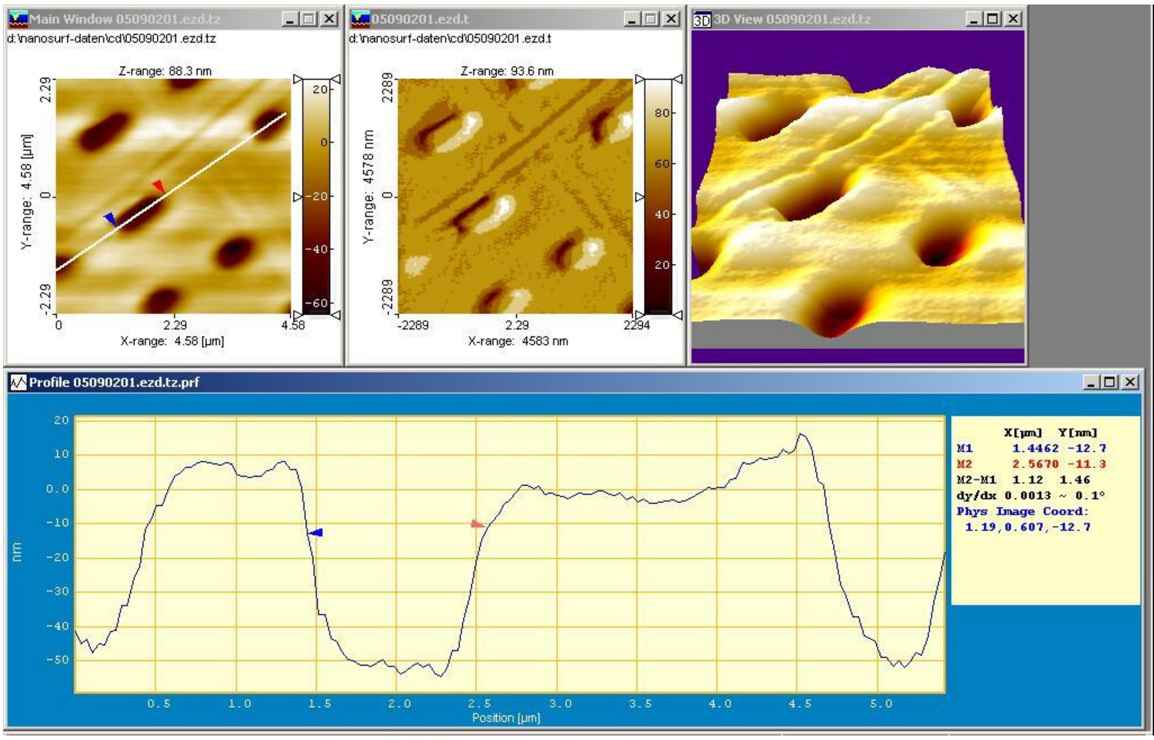


Figure 2: AFM measurements of a compact disc.

Task 5

Try to determine the length, width or depth of the bits (holes) from figure 2.

3 Solutions:

1: With the digital multimeter resistances can be observed in the range of a few ohms on highly conductive samples. Most surfaces (wood, plastic) do not have a measurable resistance. In oxidised surfaces (steel, aluminium) the oxide coating can be reduced by scratching the surface allowing smaller resistances in the kilo-ohm or ohm range to be observed.

2:
The relationship between energy and the typical bond length provides a very good estimate of the forces between atoms:

$F=dE/dx = 10^{-19}$ J / 10^{-10} m= 10^{-9} N = 1nN

E.g. the forces in cooking salt (NaCl) between the Na atoms and Cl atoms are in the range of one nano-newton. Other bond types have smaller forces. For hydrogen bridge bonds the forces are in the range of
10^{-12}N=1pN.

3:
The strip bends when approaching a surface. If the strip is moved parallel to the surface, torsion of the strip can also be observed which is due to friction forces.

4:
If a force of 10^{-9}N=1nN is to be measured and a deflection of
10^{-9}m can be measured, then the spring constant should be chosen as $k=F/x=1$N/m or lesser values. Typically spring constants of $k=0.05$-1N/m are used in static operation. In dynamic operation (oscillating leaf spring) larger spring constants of $k=10$-30N/m can also be used, because the sensitivity is improved by the resonance magnification.

5:
The length of the highlighted bit is 1 micrometre and the width approx. 0.5 micrometre. The depth can be determined from the profile and is approx. 50-70 nm.