Atomic Force Microscopy (AFM)

1. General Principle

The Atomic Force Microscope is a kind of scanning probe microscope in which a topographical image of the sample surface can be achieved based on the interactions between a tip and a sample surface. The atomic force microscope was invented by Gerd Binning et al. in 1986 at IBM Zurich based on the STM (Scanning Tunneling Microscope) already presented in 1981. While the latter depends on the conductive samples, the AFM allows also the use of non-conductive samples. In 1987, the inventors were awarded the Nobel Prize in Physics for the achievements.

A typical AFM consists of a cantilever with a small tip (probe) at the free end, a laser, a 4-quadrant photodiode and a scanner.

The surface characteristics can be explored with very accurate resolution in a range of 100 µm to less than 1 µm.

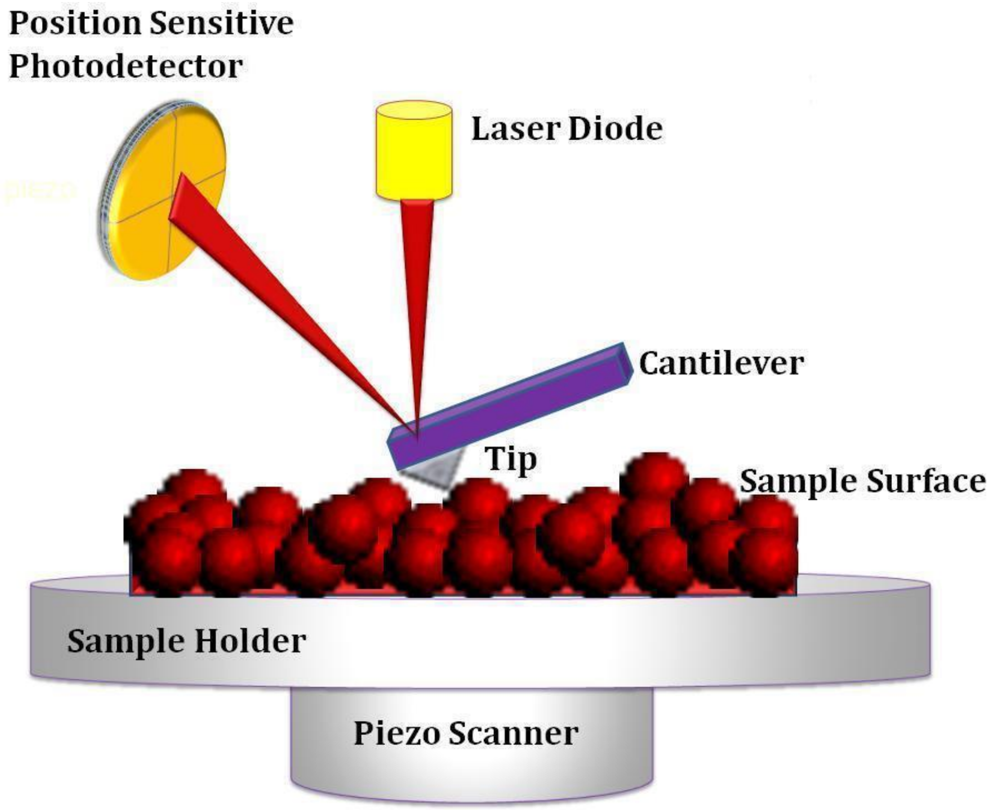

Figure 1. Principle of Atomic Force Microscopy

In AFM, a ***tip*** is used for imaging. It is generally made of silicon or silicon nitride (Si_3N_4). It approaches the sample in a range of interatomic distances (around 10 Å). The tip is commonly 3-15 microns in length. It is attached to the end of the spring cantilever. The cantilever is around 100-500 microns in length.

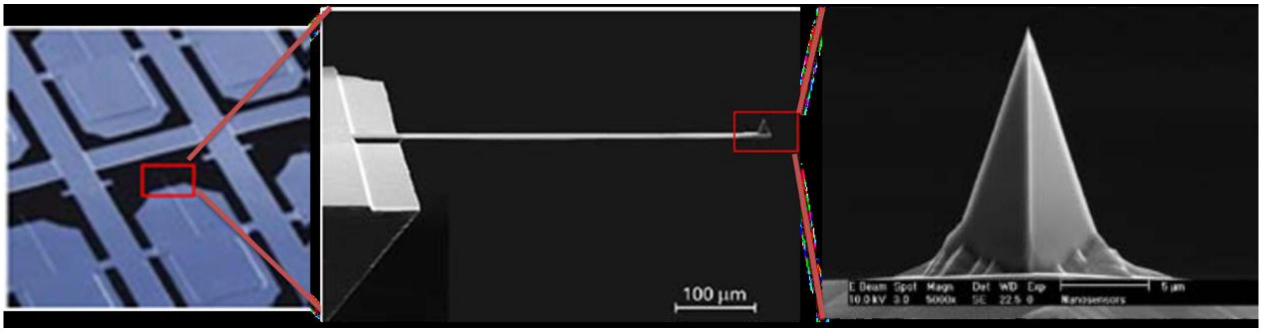

Figure 2. SEM images of microfabricated silicon AFM cantilevers and their tip shapes

When the tip, which is attached to the free end of the cantilever, come very close to the surface attractive and repulsive forces due to the interactions between the tip and the sample surface cause anegative or positive bending of the cantilever. This bending is detected by the help of a laser beam.

The cantilever can be thought of as a spring. The quantity of the generated force between the tip and the surface depends on the spring constant (stiffness) of the cantilever and the distance between the tip and the surface. This force can be characterized with Hooke's Law.

$F=-k\cdot x$ F = Force k = spring constant x = cantilever deflection

If the spring constant of the cantilever is less than surface, a bending occurs in the cantilever and this deflection is monitored. As the tip travels across the sample, it moves up and down according to the surface properties of the sample (eg. topography). These fluctuations are sourced by the interactions (electrostatic, magnetic, capillary, Van der Waals) between the tip and the sample. The displacement of the tip is measured and a topographical image is obtained.

2. Taking an Image

Generally the AFM probe does not move, instead of its motion, the sample is moved in the x,y,z direction by a piezoelectric material. Piezoelectric materials (piezocrystals) are ceramic materials that can enlarge or shrink when a voltage is applied. By this way, very precise movements in the x,y,z directions can be possible. (Position can be controlled in nanometer resolution)

A laser beam is focused onto the back of the cantilever. It can be reflected back to a 4-quadrant photodiode detector. By the help of this position sensitive photodiode, the bending of the cantilever can be measured precisely. The cantilever deflects according to the atomic force variations between tip and the sample and thereby the detector measures the deflection. The created image is a topographical illustration of the sample surface.

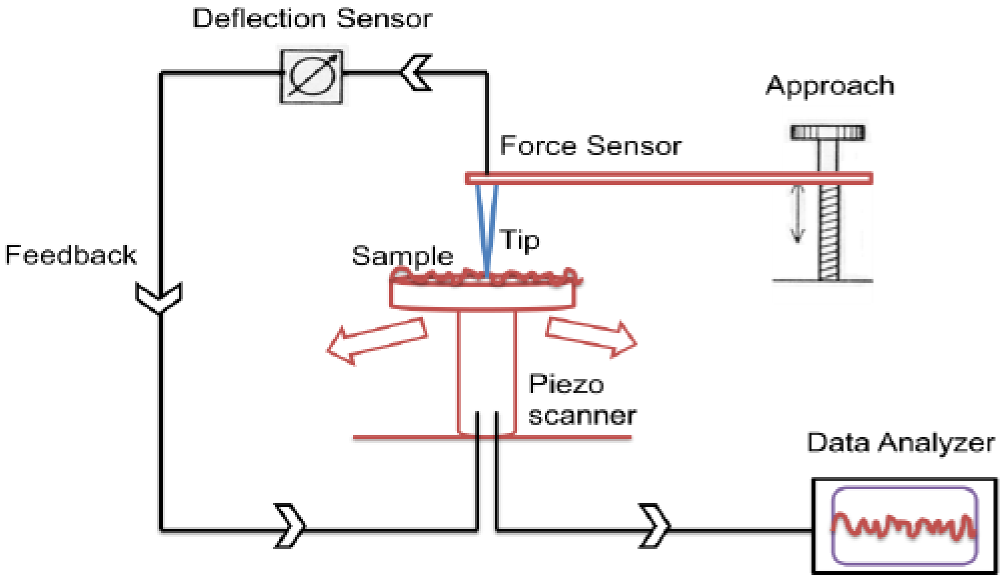

Figure 3. Schematic diagram showing the operation principle of the AFM

3. The Force-Distance Curve

When the tip approaches to the surface of the sample, van der Waals forces cause attraction. In non-contact region, the distance between probe and the surface is around tens to hundreds of angstroms. The effective forces are attractive. However as the distance becomes short in the length of chemical bond i.e. a few angstroms the repulsive columbic forces become dominant. In contact region, total Van der Waals forces are positive (repulsive force)because of the interaction between the positive nuclei and the overlap of the electron shells (Pauli Principle).The relationship between force and distance is shown in Figure 4.

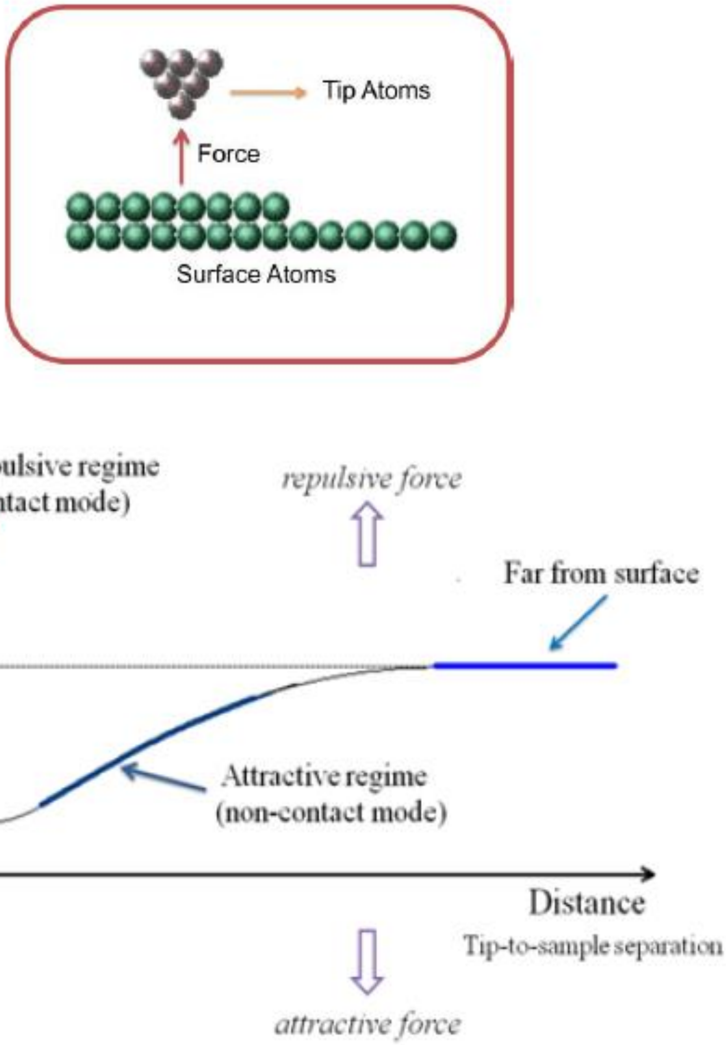

Figure 4. The relationship between force and distance

4. Operation Modes

Contact mode

In contact mode, the tip is in a soft physical contact with the surface. The tip is able to move above the surface with a specific height or under a constant force. The movement is strongly influenced by frictional and adhesive forces that can cause damage to the sample. When the spring constant of cantilever is less than surface, the cantilever bends. The force on the tip is repulsive. By maintaining a constant cantilever deflection (using the feedback loops) the force between the probe and the sample remains constant and an image of the surface is obtained.

Dynamic (Tapping) Mode

This mode eliminates the frictional force by intermittently contacting the surface and oscillating with sufficient amplitude to prevent it from being trapped in by adhesive forces. This mode of operation is less destructive than contact mode. The cantilever oscillates nearby its resonance frequency. An electronic feedback loop provides the oscillation amplitude remaining constant so that a constant tip-sample interaction is conserved during the scan.

Non contact mode

In this mode tip does not touch the sample, however it oscillates above the surface during scan. It uses feedback loop to monitor changes in the amplitude due to attractive Van der waals forces so the surface topography can be monitored. It is better soft samples.

The forces cause a change in the oscillation amplitude, resonance frequency and phase of the cantilever. The amplitude is utilized for feedback mechanism. Vertical motion of the piezoscanner is utilized as a height image.

Since AFM is highly modern and visual instrumental technique, there are a variety of websites that can help you understand the concepts related with it. For example http://virtual.itg.uiuc.edu/training/AFM_tutorial/. The animations describe the workings of the AFM.

In this experiment, AFM measurements are done in dynamic (tapping) mode. We examine the surface properties of a DVD and a blue ray piece and searched for their topographical properties.

APPARATUS AND CHEMICALS

Pieces of DVD, blue ray.

Table 1. Compact disc, DVD and Blu-Ray feature comparison

	Blu-Ray	**DVD**	**CD**
Laser Size	405 nm	650 nm	780 nm
Track spacing (pitch)	0.32 μm	0.74 μm	1.6 μm
Capacity	25 GB	4.7 GB	0.7 GB

PROCEDURE

1. Place the cantilever on the AFM head together with your assistant. Cantilevers are extremely fragile - use extreme caution when dealing with the cantilever.

2. Start SPM control program and camera program.

3. From the SPM program, choose the mode as “Dynamic”. Click on “Camera light on”.

4. Adjust the laser on the cantilever. Use the x and y probe alignment knobs.

5. Adjust the photodiode. Never look directly into the laser beam.

6. Place the first sample by positioning the metal disc with the sample in the center of the scanner.

7. After the required adjustments, start to approach the surface and find the surface. Keep the cabinet covered.

8. Start scanning by setting the scan size to in the order of 10 µm x 10 µmx

9. When you have finished with the sample, move the tip well away from the surface by pressing “up”.

10. Scan the other samples separately.

11. Remove the sample. Shut down the system.

TREATMENT OF DATA

1. Get the images and analyze them with “Image Analyzer” program.

QUESTIONS

1. Explain the working principle of AFM.

2. What are the roles of laser and photodiode?

3. What is the shape of tip and why?

4. Explain the relative position of the tip with respect to the surface for those modes. Explain the advantages of different modes over each other.

5. What are the application areas of the AFM?

References

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