Demonstration of Atomic Force Microscopy

Aim

Determination of sample surface roughness using an atomic force microscopy.

Introduction

The atomic force microscopy (AFM) is a subcategory of scanning probe microscopy (SPM). SPMs are instruments that use a raster-scanning tip to measure surface properties such as the local height, friction, electronic or magnetic properties, and construct a map of this data to form an image. Basically, an AFM is a kind of scanning probe microscope in which a 3D (three dimensional) topographical image of the sample surface on a nanoscale can be achieved based on the interactions between a tip and a sample surface. It is a versatile and powerful tool for imaging and measuring small-scale objects such as nanoparticles, single molecules, semiconductor devices and living cells and can obtain images with atomic resolutions of 10^{-10} m or one tenth of nanometre.

Principle

The AFM measures the forces acting between a fine tip and a sample. The tip is attached to the free end of a spring cantilever and is brought very close to a surface. When the tip is brought within the interatomic separation between the tip and sample, interatomic potentials are developed between the atoms of the tip and the atoms of the surface, resulting into attractive or repulsive forces. As the tip scans the surface of the sample, the force between the tip and the sample varies which is sensed by the tip. The amount of force between the probe and the sample is dependent on the spring constant of the cantilever and the distance between the probe and the sample surface. This force can be characterized with Hooke's Law.

$$\mathbf{F = - k \cdot x}$$

F = Force

k = spring constant

x = cantilever deflection

If the spring constant of cantilever (typically ~ 0.1-1 N/m) is less than surface, cantilever bends and the deflection is monitored.

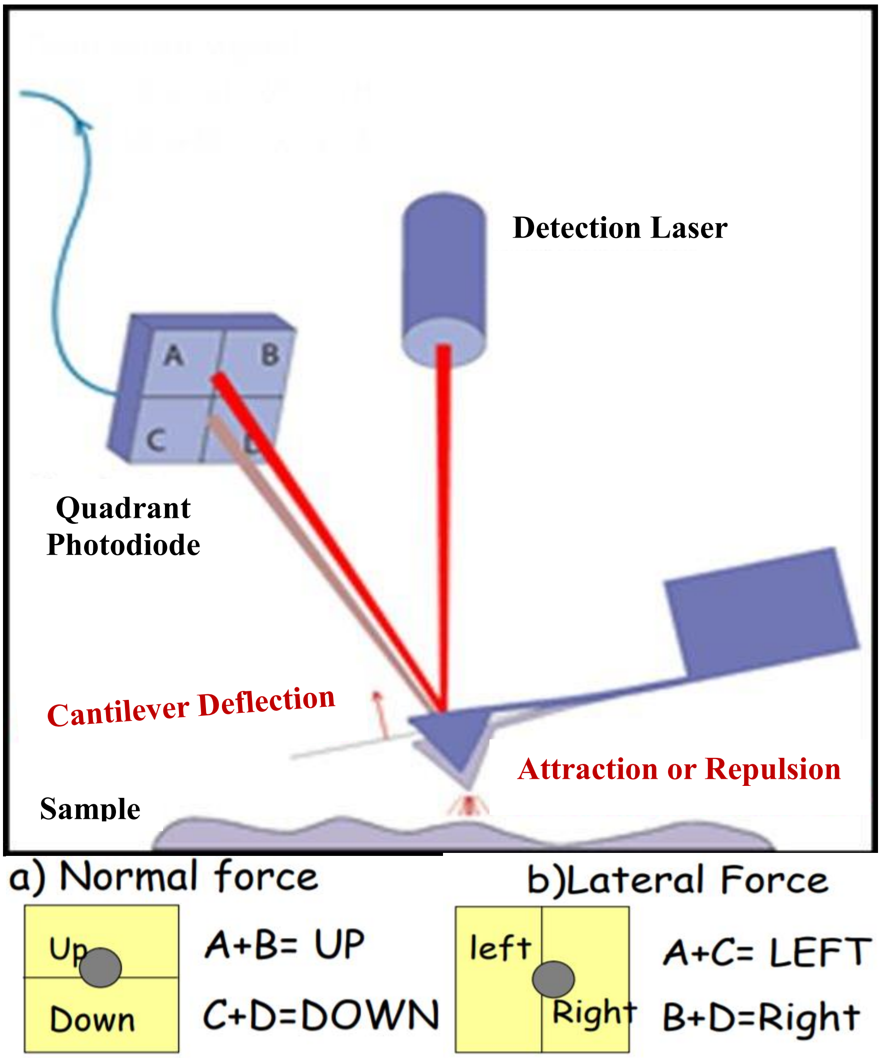

Figure 1: Working principle of atomic force microscopy

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 forces) between the tip and the sample. Accordingly, the bending of tip is then detected by means of a laser beam, which is reflected from the backside of the cantilever. The laser beam gets constantly reflected towards a position-sensitive photodetector consisting of four side by-side photodiodes. This laser beam detects the bend occurring in the cantilever and calculates the actual position of the cantilever. The vertical deflection measures the interaction forces while the horizontal deflection measures the lateral forces. Thus, AFM records a three-dimensional image of the surface topography of the sample under a constant applied force (as low as nano Newton range).

Components of atomic force microscope

1. Probe tip
2. Cantilever
3. Optical microscope
4. Laser source
5. Sample stage
6. Piezoelectric scanner
7. Position sensitive photodiode
8. Feedback control loop
9. Computer

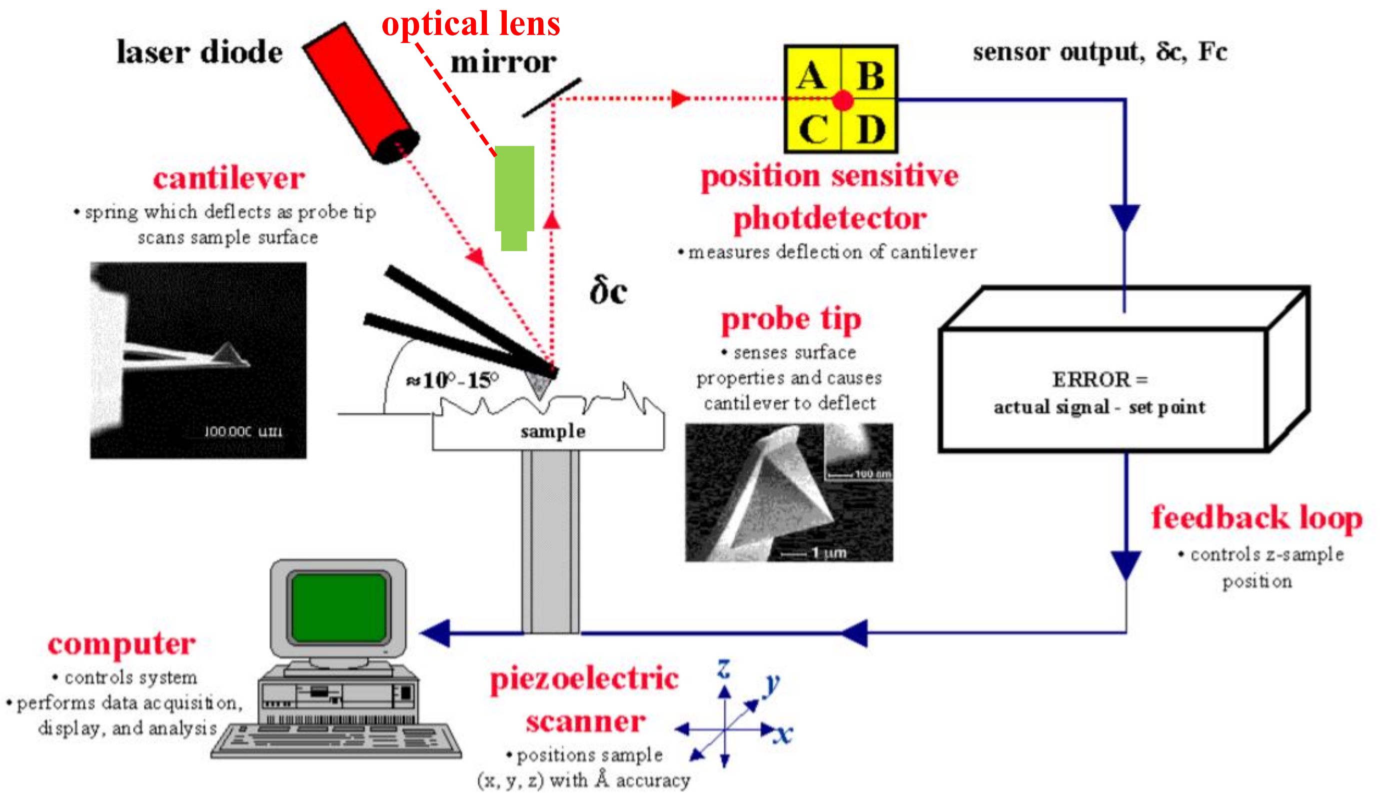

Figure 2: General components of atomic force microscopy

Operation modes of atomic force microscope

- **Contact mode**

In contact mode, the tip is in a soft physical contact with the surface. The movement is strongly influenced by frictional and adhesive forces that can cause damage to the sample. 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. The force on the tip is attractive. 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 have a constant amplitude.

Sample Requirements

- **Requires a substrate: flat and smooth**
  1. Glass coverslip **(used for demonstration)**/slide
  2. Mica
  3. Highly ordered pyrolytic graphite
  4. Silicon

- **Sample types**

  Thick and thin polymeric films, **coatings (protein: using a spin coater; shown in demonstration video)**, ceramics, composites, glasses, synthetic and biological membranes, metals and semiconductors.

Sample Preparation

Coating (Spin coating, shown in demonstration video) deposition or adsorption on the substrate. Atomic force microscope can be performed in a vacuum, ambient, gas or liquid environment.

Mica (negatively-charged) – DNA, proteins (strong electrolytic interaction)
Graphite (hydrophobic) – proteins
Glass coverslips – Proteins/cells (coating/attachment)
Polystyrene petri dishes – cells (Attachment

Observations

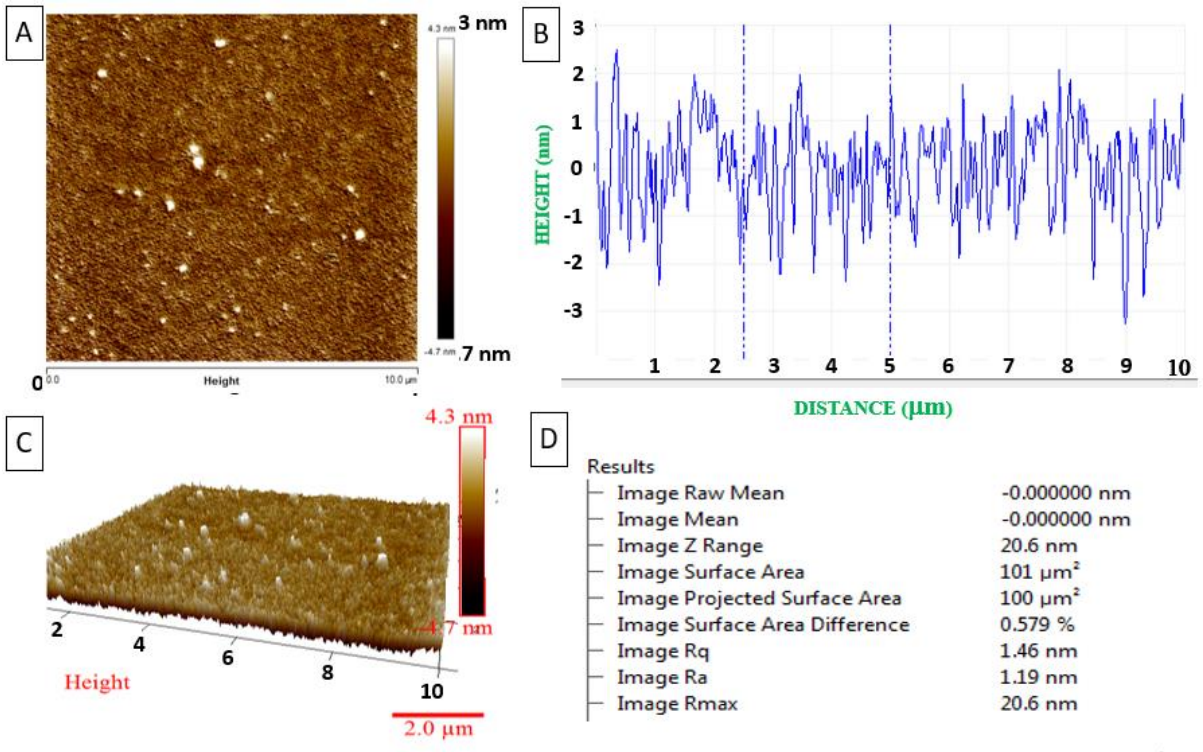

Figure 3: Analysis of surface topography: (A) 2D image, (B) Topology Plot, (C) 3D Image and (D) Measurement of Surface Roughness

The surface roughness of the sample is R_a: 1.19 nm (average value) and R_q:1.46 nm (Root mean square value).