Module 26: Atomic Force Microscopy

Lecture 38: Atomic Force Microscopy – 1
In the earlier chapters, we have discussed how to make nano and meso scale patterns, either by top down Lithographic techniques or by instability mediated self organization. Once the structures are made, it then becomes important to characterize them, which includes investigating their morphology and in some cases, certain additional properties also. The Atomic Force Microscope (AFM) is a major and extremely important instrument that is widely used for investigated nano scale structures. The AFM is a member of the family of Scanning Probe Microscope (SPM), which was invented in early 80’s. Even since its invention, the scanning probe microscope (SPM) has over the years become a versatile and very popular tool for researchers, particularly in the field of materials science and technology. Over the years the basic principle of Scanning Probe Microscopy, which uses relies on measuring the interaction forces between a material surface and a sharp probe tip has generated a complete family of scanning probe microscope techniques, such as scanning tunneling microscope (STM), the widely popular atomic force microscope (AFM), and also the state of art scanning near field optical microscope (SNOM). Research is still progressing in developing newer modes that enable collection of more information from a surface that is being scanned. Apart from enabling imaging of a surface at sub – nanometer resolution, the SPM group of methods offer the capability to measure, analyze and even quantify properties of matter on nanometer length scale. Using specially designed probes and measuring conditions, local properties such as adhesion, friction, elasticity, conductivity, capacitance and magnetic properties etc. can be quantified. The SPM also allows manipulating atoms, due to the contact established between the surface and the probe. In this course we will focus mostly on the operation of the Atomic Force Microscope (AFM) as it has certain unique properties, including the versatility of scanning or probing any sample surface irrespective of its material property, such as metals, polymers and ceramics. In this chapter, we discuss briefly the basic features and capabilities of an atomic force microscope and relate its functioning/ operation to the concept of inter atomic forces discussed earlier.

38.1 Basic Principle and Components of Atomic Force Microscope
In atomic force microscopy the probing tip is attached to a cantilever-type spring. In response to the force between tip and sample the cantilever, also called lever, is deflected. In AFM, mechanical force interactions acting between a sharp probe and a sample are used for surface imaging. The probe, which represents a micro machined cantilever with a sharp tip at one end, is brought into interaction with the sample surface. The interaction level between the tip apex and the sample is determined through precise measurements of the cantilever displacements. Initial attempts to apply STM for gauging the cantilever deflection had little success. An optical level detection, which had been originally suggested for gravimeters, appeared invaluable for precise measurements of the cantilever deflection in most commercial atomic force microscopes. In this procedure, a laser beam, which is deflected from the backside of the cantilever, is directed to a 4-segment positional photo-detector, which is divided into segments for measurements of normal and lateral deflections of the cantilever. At present the optical level detection is the most reliable way to measure the tip-sample force interactions, which is shown in figure 38.1, along with the major components.

![Figure 38.1: Typical arrangement of a beam bounce cantilever detection system, the Feed Back loop and the Piezo enabled Scanner.](image)

The cantilever acts as a spring, with the typical spring constants varying between 0.001 to 100 N/m. Vertical deflection as low as 0.1 Å can be measured by the deflection sensor, which we will discuss in details later. The typical magnitude of forces acting between the probing tip and
sample ranges from $10^{-11}$ to $10^{-6}$ N. For comparison, the magnitude of interaction forces between two covalently bonded atoms is of the order of $10^{-9}$ N at separations of about 1 Å. The low magnitude of the forces allows nondestructive imaging of the surfaces. In an AFM, the surface imaging is realized by detecting the tip-sample force in different force in different locations while the probe is rastering the sample surface with the help of a piezoelectric actuator. A feedback control applied during imaging ensures that the tip-sample force is preserved at a constant level. The error signal, which is used for feedback control, is amplified to generate height images, which reflect surface corrugations. The height image, in which brighter contrast is assigned to elevated surface locations, represents the vertical translations of the piezo-scanner needed to eliminate the error signal when the probe is moved from one sample location to the other. The error signal images, which, might be considered as maps of derivatives of height corrugations, emphasize fine surface features that are poor resolved in the height images.

From the brief description of the method it becomes clear that the main components of atomic force microscope are probes, optical detection systems, piezo-scanners and electronics for a management of scanning procedures and data acquisition, which are shown in figure 1. In the microscope, these components are assembled into a microscope stage, which must satisfy the requirements of minimum vibrational, acoustic and electronic noise as well as small thermal drift. Basic information about these components could be useful for better understanding the performance of AFM instruments, their unique features and limitations.

![Figure 38.2: Sequence of Alignment in a Typical AFM.](image-url)
Before the tip can start scanning the sample, two important operations are to be performed. They are 1) **Alignment** and 2) **Approach**. We briefly discuss these two operations for easy understanding of the instrument.

### 38.2 Alignment

In a typical commercial AFM, the tip is first mounted on a tip holder. Once the tip is mounted, two operations need to be done. The next step is to enable the optical deflection detection system. In order to do that it becomes necessary to optically couple the cantilever and the Quadrant Photo Diode along with the laser. At the beginning, they are all independent and are not in a coupled position (figure 38.2A). In order to do the optical coupling, first the back side of the tip, which contains a reflective coating has to be brought in the path of the laser light. Typically the tip holder assembly has two perpendicular screws for movement of the tip along X and Y direction. These two screws are suitably moved to bring the tip in the path of the laser, as is shown in figure 38.2 B. Once the cantilever comes in the path of the laser, the reflective coating starts reflecting the laser as shown in figure 38.2B. Next step is to bring the QPD in the path of the reflected laser light, which is shown in figure 38.2C. The instrument is considered to be aligned when the reflected laser light falls at the centre of the QPD. The reading of the QPD at this point of time is 0 mV. A somewhat detailed discussion on the QPD is provided later.

### 38.3 Approach

Once the AFM is aligned, the tip then needs to be brought in close proximity to the sample surface so that it can start scanning. This is typically done automatically, by means of a stepper motor. In a way, the step of approach can be regarded as coupling between the sample and the tip probe, so that scanning can be performed. Initially, the tip is far away from the sample, as can be seen from figure 38.3A. The stepper motor now starts bringing the tip closer to the sample (or in some models, the stepper motor may start moving the sample, towards the tip; the basic physics remains the same). Initially the tip is far away from the surface and there is no interaction.
between the two, and therefore there is no deflection of the cantilever. This is seen in figure 38.3B, where the reflected laser spot is still seen to fall at the centre of the QPD. As the tip comes in close proximity to the surface (< 100 nm), it first experiences an attractive force originating due to inter surface van der Waal’s interaction. This leads to a deflection of the cantilever towards the sample surface. With progressive movement of the stepper motor, eventually the edge of the tip touches the sample surface (figure 38.3C). This is known as the “Jump to contact”. Further movement of the stepper motor pushes the cantilever tip against the surface, eventually changing the nature of the deflection in the cantilever from attractive to repulsive. The stepper motor stops and the approach is considered to be complete when the
deflection of the cantilever tip matches the set point (figure 38.3D). Typically, the set point is pre-fixed before the sequence of approach starts. In case of intermittent contact mode (or tapping mode, which will be discussed later), the set point is typically set as a certain percentage of the free amplitude of oscillation of the tip. The approach sequence essentially follows the potential curve of interaction between two surfaces (generically similar to the well known Lenard Jones Potential curve between two particles) and the location on the potential curve corresponding to different stages of approach as shown in figure 38.3 are marked on figure 38.4. In contact mode scanning is invariably done in the repulsive regime, the reason for which will be discussed later.

Figure 38.4: The tip – surface separation on the Force curve during approach.