

Physics of Nanotechnology

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Atomic force microscopy

- **Atomic force microscopy (AFM)** or **scanning force microscopy (SFM)** is a very-high-resolution type of [scanning probe microscopy](#) (SPM), with demonstrated resolution on the order of fractions of a [nanometer](#), more than 1000 times better than the [optical diffraction limit](#) and can be used for imaging, measuring and manipulating matter at Nano scale.
- The information is gathered by "feeling" or "touching" the surface with a mechanical probe. [Piezoelectric](#) elements that facilitate tiny but accurate and precise movements on (electronic) command enable precise scanning.

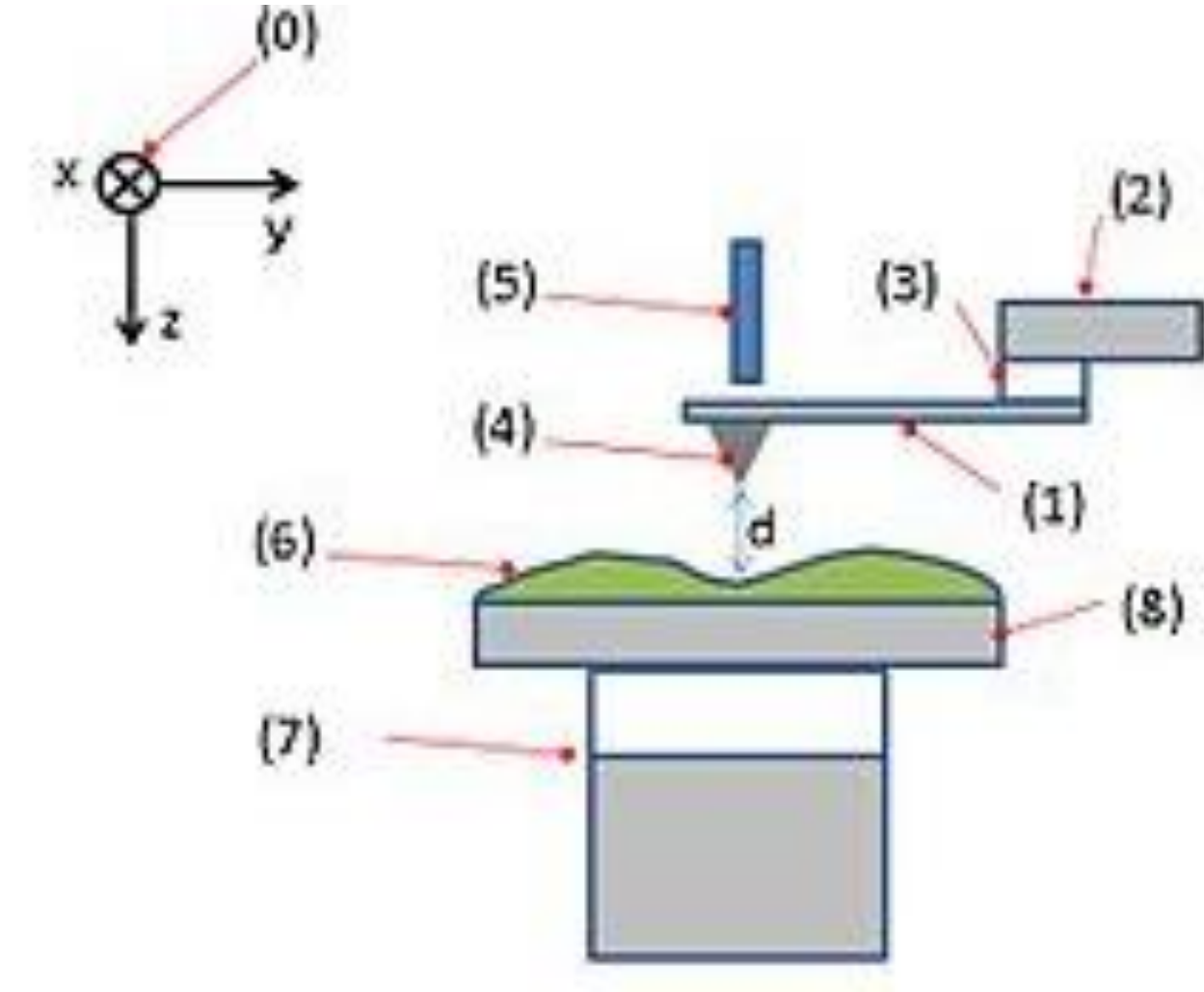


An atomic force microscope on the left with controlling computer on the right

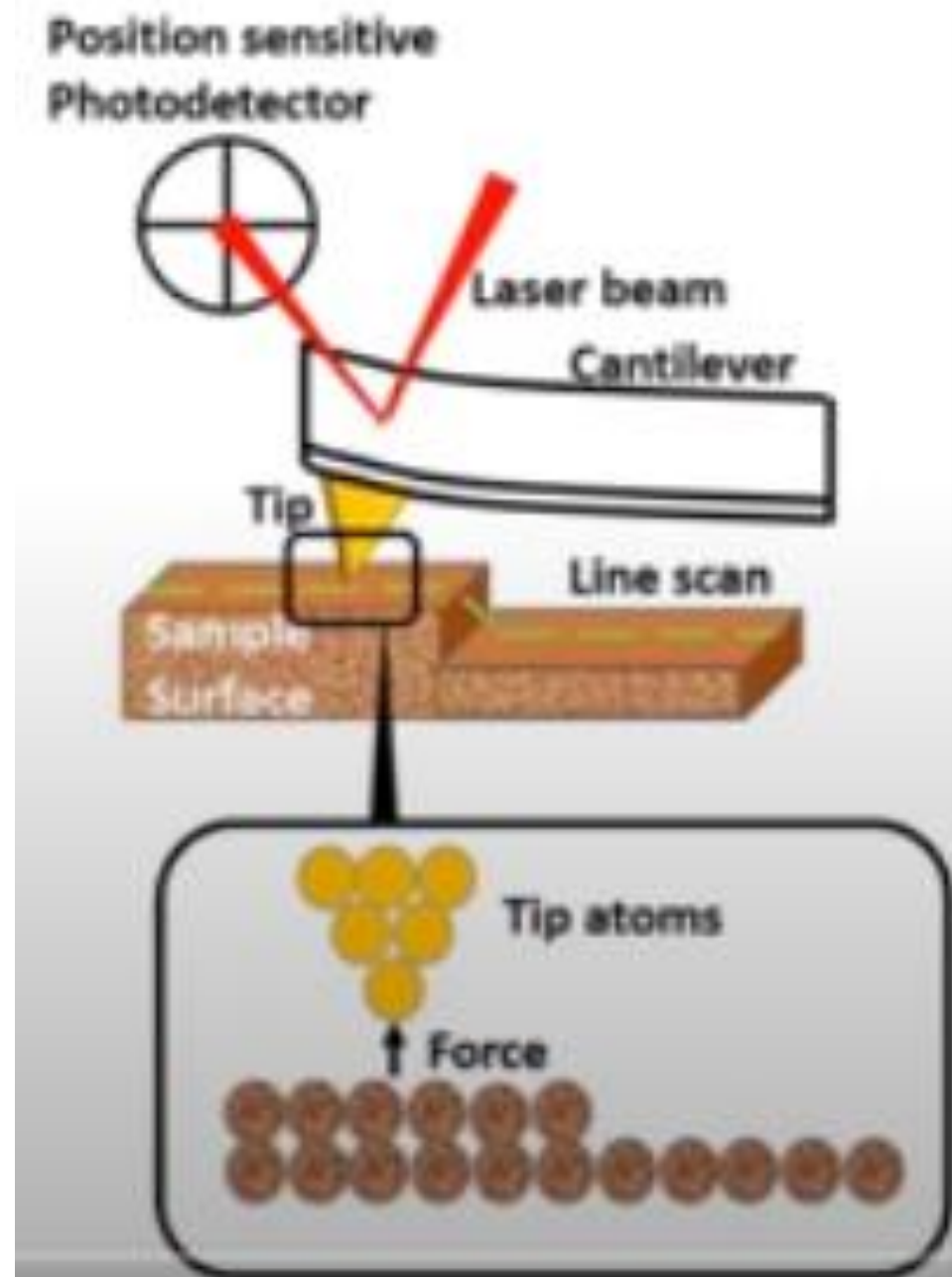
Diagram

Fig. 1: Typical configuration of an AFM.

(1): Cantilever, **(2):** Support for cantilever, **(3):** Piezoelectric element (to oscillate cantilever at its eigen frequency.), **(4):** Tip (Fixed to open end of a cantilever, acts as the probe), **(5):** Detector of deflection and motion of the cantilever, **(6):** Sample to be measured by AFM, **(7):** xyz drive, (moves sample (6) and stage (8) in x, y, and z directions with respect to a tip apex (4)), and **(8):** Stage

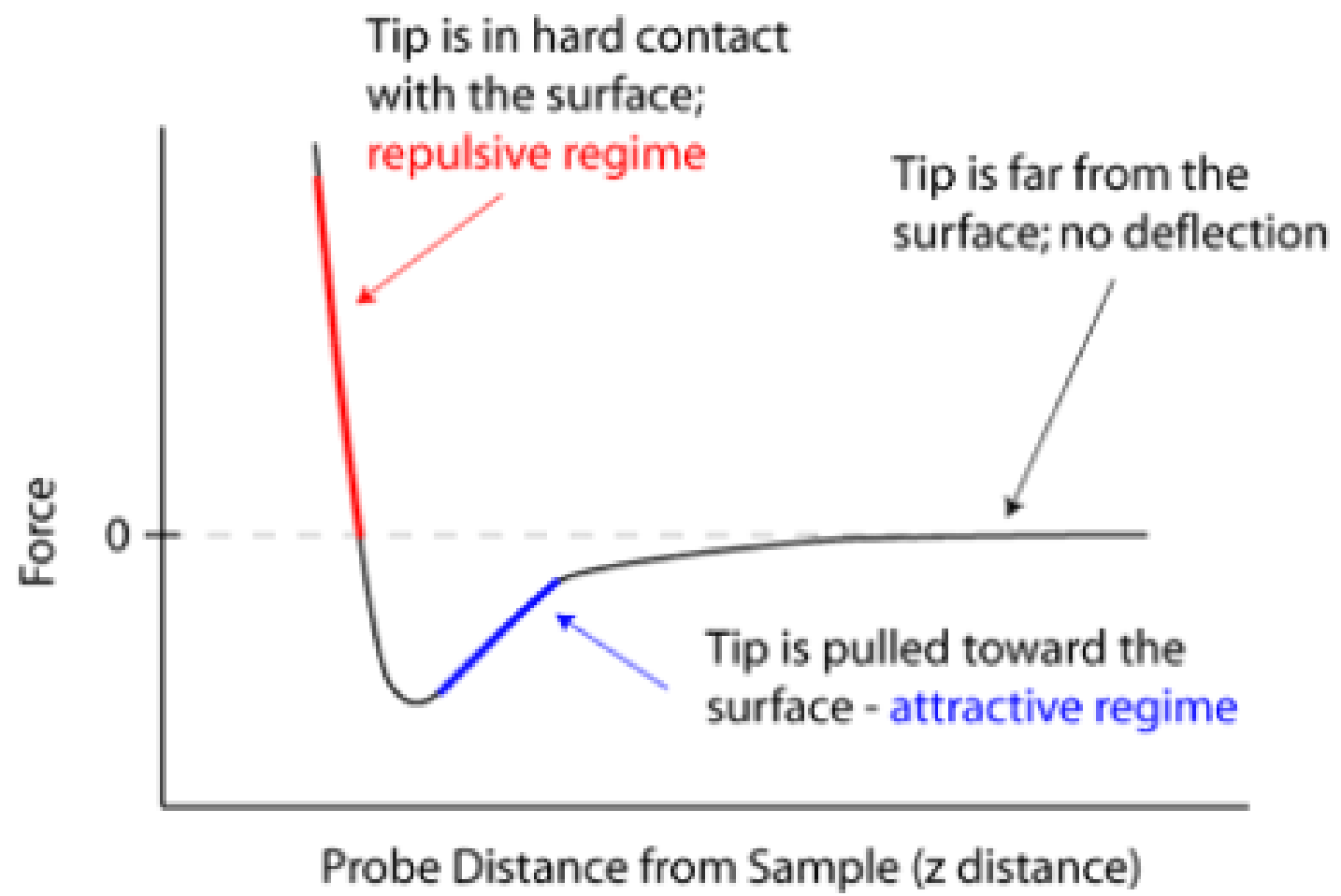


- Forces between tip and sample
- Cantilever scanning
- Laser beam
- Position sensitive photo detector.



Principles

The AFM consists of a cantilever with a sharp tip (probe) at its end that is used to scan the specimen surface. The cantilever is typically silicon or silicon nitride with a tip radius of curvature on the order of nanometers. When the tip is brought into proximity of a sample surface, forces between the tip and the sample lead to a deflection of the cantilever according to Hooke's law. Depending on the situation, forces that are measured in AFM include mechanical contact force, van der Waals forces, capillary forces, chemical bonding, electrostatic forces, magnetic forces.



Abilities

- The AFM has three major abilities: force measurement, topographic imaging, and manipulation.
- In force measurement, AFMs can be used to measure the forces between the probe and the sample as a function of their mutual separation. This can be applied to perform force spectroscopy, to measure the mechanical properties of the sample, such as the sample's Young's modulus, a measure of stiffness.
- For imaging, the reaction of the probe to the forces that the sample imposes on it can be used to form an image of the three-dimensional shape (topography) of a sample surface at a high resolution. This is achieved by raster scanning the position of the sample with respect to the tip and recording the height of the probe that corresponds to a constant probe-sample interaction.

Abilities

- In manipulation, the forces between tip and sample can also be used to change the properties of the sample in a controlled way. Examples of this include atomic manipulation, [scanning probe lithography](#) and local stimulation of cells.
- Simultaneous with the acquisition of topographical images, other properties of the sample can be measured locally and displayed as an image, often with similarly high resolution. Examples of such properties are mechanical properties like stiffness or adhesion strength and electrical properties such as conductivity or surface potential.

Other microscopy technologies

The major difference between atomic force microscopy and competing technologies such as optical microscopy and electron microscopy is that AFM does not use lenses or beam irradiation. Therefore, it does not suffer from a limitation in spatial resolution due to diffraction and aberration, and preparing a space for guiding the beam (by creating a vacuum) and staining the sample are not necessary.

Configuration

- Fig. 1 shows an AFM, which typically consists of the following features. Numbers in parentheses correspond to numbered features in Fig. 1. Coordinate directions are defined by the coordinate system (0).
- The small spring-like cantilever (1) is carried by the support (2). Optionally, a piezoelectric element (typically made of a ceramic material) (3) oscillates the cantilever (1). The sharp tip (4) is fixed to the free end of the cantilever (1). The detector (5) records the deflection and motion of the cantilever (1). The sample (6) is mounted on the sample stage (8). An xyz drive (7) permits to displace the sample (6) and the sample stage (8) in x, y, and z directions with respect to the tip apex (4). Although Fig. 3 shows the drive attached to the sample, the drive can also be attached to the tip, or independent drives can be attached to both, since it is the relative displacement of the sample and tip that needs to be controlled. Controllers and plotter are not shown in Fig. 3.

According to the configuration described above, the interaction between tip and sample, which can be an atomic scale phenomenon, is transduced into changes of the motion of cantilever which is a macro scale phenomenon. Several different aspects of the cantilever motion can be used to quantify the interaction between the tip and sample, most commonly the value of the deflection, the amplitude of an imposed oscillation of the cantilever, or the shift in resonance frequency of the cantilever.

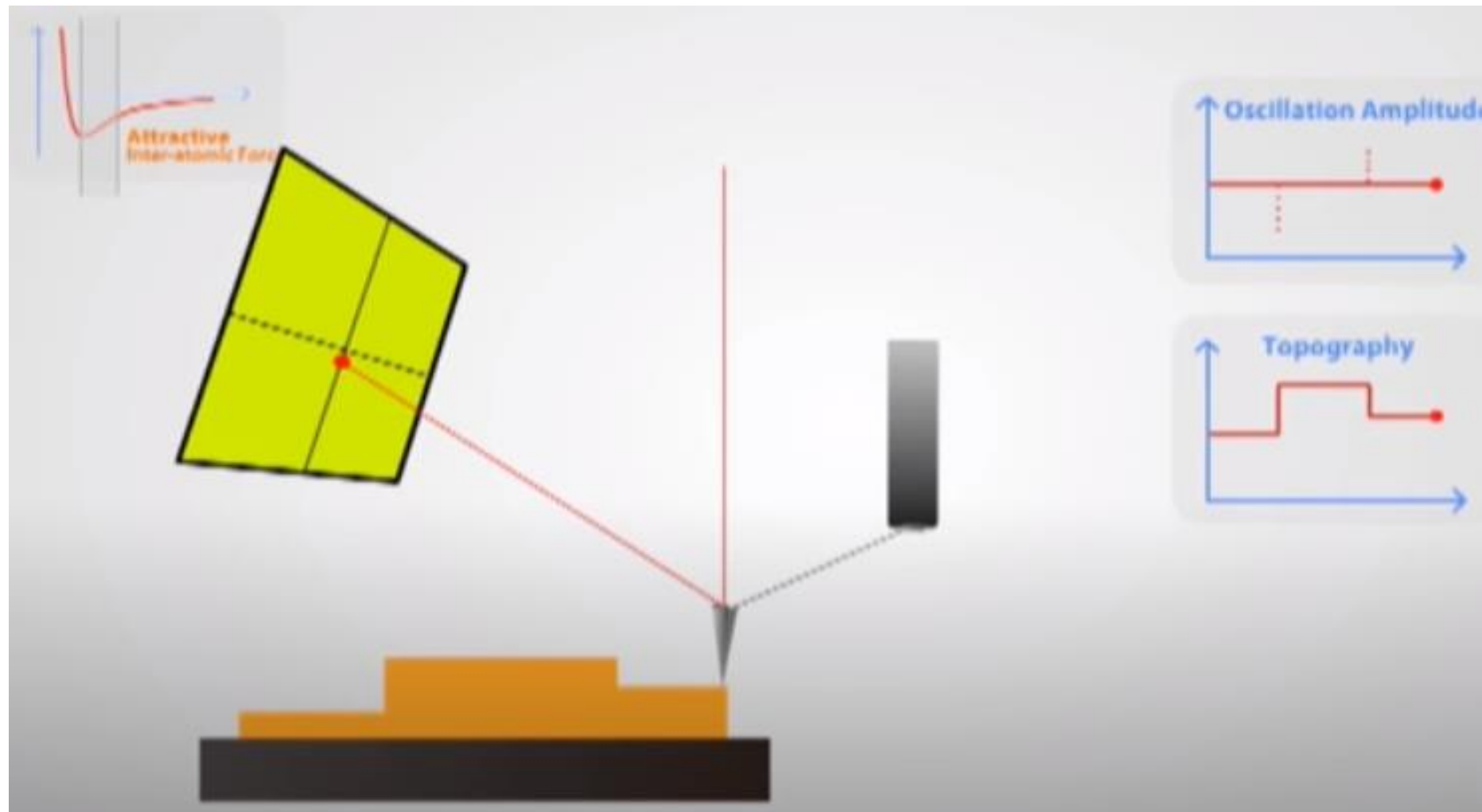
Detector

- The detector (5) of AFM measures the deflection (displacement with respect to the equilibrium position) of the cantilever and converts it into an electrical signal. The intensity of this signal will be proportional to the displacement of the cantilever.
- Various methods of detection can be used, e.g. interferometry, optical levers, the piezoresistive method, the piezoelectric method, and STM-based detectors (see section "AFM cantilever deflection measurement".).

Image

- When using the AFM to image a sample, the tip is brought into contact with the sample, and the sample is raster scanned along an x-y grid. Most commonly, an electronic feedback loop is employed to keep the probe-sample force constant during scanning. This feedback loop has the cantilever deflection as input, and its output controls the distance along the z axis between the probe support (2 in fig. 3) and the sample support (8 in fig 3). As long as the tip remains in contact with the sample, and the sample is scanned in the x-y plane, height variations in the sample will change the deflection of the cantilever. The feedback then adjusts the height of the probe support so that the deflection is restored to a user-defined value (the setpoint). A properly adjusted feedback loop adjusts the support-sample separation continuously during the scanning motion, such that the deflection remains approximately constant. In this situation, the feedback output equals the sample surface topography to within a small error.
- The AFM signals, such as sample height or cantilever deflection, are recorded on a computer during the x-y scan. They are plotted in a [pseudocolor](#) image, in which each pixel represents an x-y position on the sample, and the color represents the recorded signal.

Imaging method



Imaging modes

AFM operation is usually described as one of three modes, according to the nature of the tip motion:

- Contact mode, also called static mode (as opposed to the other two modes, which are called dynamic modes)
- Tapping mode, also called intermittent contact
- Non contact mode

Advantages

- AFM has several advantages over the [scanning electron microscope](#) (SEM). Unlike the electron microscope, which provides a two-dimensional projection or a two-dimensional image of a sample, the AFM provides a three-dimensional surface profile.
- In addition, samples viewed by AFM do not require any special treatments (such as metal/carbon coatings) that would irreversibly change or damage the sample.
- While an electron microscope needs an expensive [vacuum](#) environment for proper operation, most AFM modes can work perfectly well in ambient air or even a liquid environment. This makes it possible to study biological macromolecules and even living organisms.

Advantages

- In principle, AFM can provide higher resolution than SEM. It has been shown to give true atomic resolution in ultra-high vacuum (UHV) and, more recently, in liquid environments. High resolution AFM is comparable in resolution to [scanning tunneling microscopy](#) and [transmission electron microscopy](#).
- AFM can also be combined with a variety of optical microscopy and spectroscopy techniques such as fluorescent microscopy or infrared spectroscopy, giving rise to [scanning near-field optical microscopy](#), [nano-FTIR](#) and further expanding its applicability.