



An Introduction to Atomic Force Microscopy

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Abstract

Atomic force microscopy (AFM) is an imaging technique used to determine topography and other properties of surfaces. It is an important tool for nanoscience.

What is a nanometer?

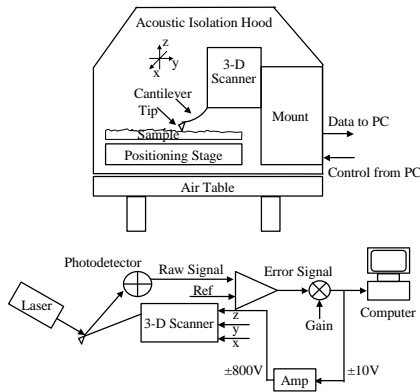
A nanometer, the unit of length associated with nanoscience, is one billionth of a meter. The ratio of a nanometer to a meter is the same as that of one millimeter to the distance between Worcester and Detroit.



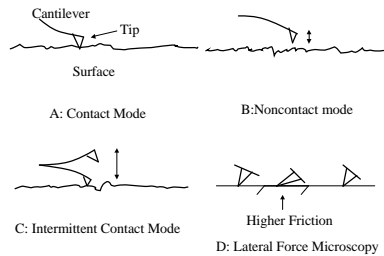
Length scales

Diameter of human hair	100 μm	Largest scan range of our AFM
Practical limit of optical microscopy	10 μm	Typical scan range of our AFM
Distance between CD tracks	1 μm	Smallest practical scan range
Wavelength of ultraviolet light	100 nm	Typical tip radius
Diameter of backbone of DNA	10 nm	Typical tip-sample contact radius
Length of naphthalene molecule	1 nm	Atomic resolution
Diameter of hydrogen atom	0.1 nm	Atomic resolution

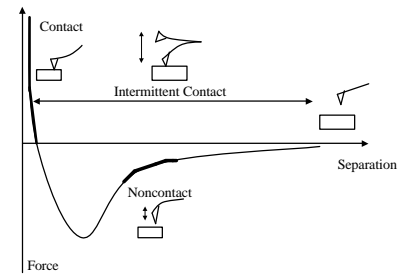
How does AFM work?



Above – our AFM setup. A photodetector records the bending of the cantilever, which reflects the topography and other surface properties. The cantilever is a flexible beam and is used as a force sensor. It is located on the scanner which can move in three dimensions.
Below – the photodetection and feedback system, which works to keep the tip-sample force steady according to Hooke's Law, $F = -kd$.



There are four principal kinds of **operational modes** according to the separation between the cantilever and the surface, the cantilever's oscillation amplitude, and the normal or torsional bending of the cantilever. Many other variations also exist.



Schematic of a typical **force-separation curve**. Far from the sample, the cantilever is not affected by interatomic forces and is in its free equilibrium position. But when brought closer to the surface, attractive forces act upon the tip to bend the cantilever towards the sample. When the tip is in contact with the surface, repulsive forces dominate, deflecting the cantilever backwards. The thick lines indicate the normal ranges of operation for contact and noncontact modes and the long horizontal arrow represents the usual amplitude for intermittent contact.

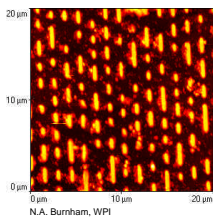
Advantages and disadvantages of AFM

- + Easy sample preparation
- + Accurate height information
- + Works in vacuum, air, and liquids
- + Living systems can be studied
- Limited vertical range
- Limited magnification range
- Data not independent of tip
- Tip or sample can be damaged

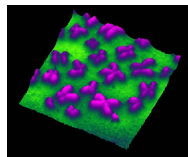
Ways of using AFM

- Imaging – determining the topography of the surface
- Measuring – characterizing the sample's materials properties
- Manipulating – purposefully changing the surface structure
- Sensing – using AFM technology for sensor applications

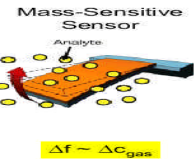
What is AFM used for?



Imaging - The AFM can be used to construct a picture of a CD stamper (left) or human chromosomes (right).

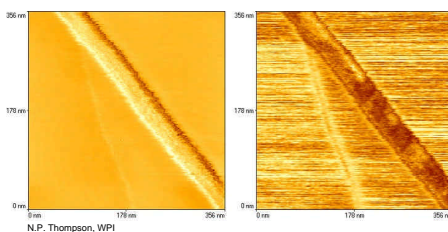


<http://spm.phy.bris.ac.uk/people/TerryMcMaster>

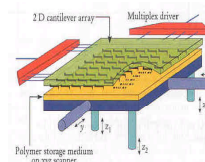


Olivier Brand, www.iqe.ethz.ch, Nature 414 (2001)

Sensing - A microcantilever bends in response to chemical adsorption. Based on this principle, AFM is used to "smell" different substances (such as whisky) in order to establish their composition.



Measuring - Carbon nanotubes are rolled-up sheets of graphite and have valuable electronic and mechanical properties. The left image reflects the topography of a nanotube near a step on a mica surface. To create the image on the right, the AFM scanner oscillated laterally a small amount and the resulting oscillation of the cantilever was monitored, reflecting the amount of shear between the tip and the sample.



www.Zurich.ibm.com, Physics Today, October 2002

Manipulating - Using 1024 cantilevers, the "Millipede" can write on a surface of polymer film. The actuators (dark blue) move the polymer-coated substrate in the xy-plane beneath the cantilever array. Each cantilever is individually controlled and can produce or erase a small pit that represents a bit of information. It is predicted that 100 GB of memory can be put on only one square inch using this technology.