



# Scanning Probe Microscopy

## What are scanning probe microscopes?

Scanning probe microscopes (SPMs) are a family of tools used to make images of nanoscale surfaces and structures, including atoms. They use a physical probe to scan back and forth over the surface of a sample. During this scanning process, a computer gathers data that are used to generate an image of the surface. In addition to visualizing nanoscale structures, some kinds of SPMs can be used to manipulate individual atoms and move them to make specific patterns.

SPMs are different from optical microscopes because the user doesn't "see" the surface directly. Instead, the tool "feels" the surface and creates an image to represent it.

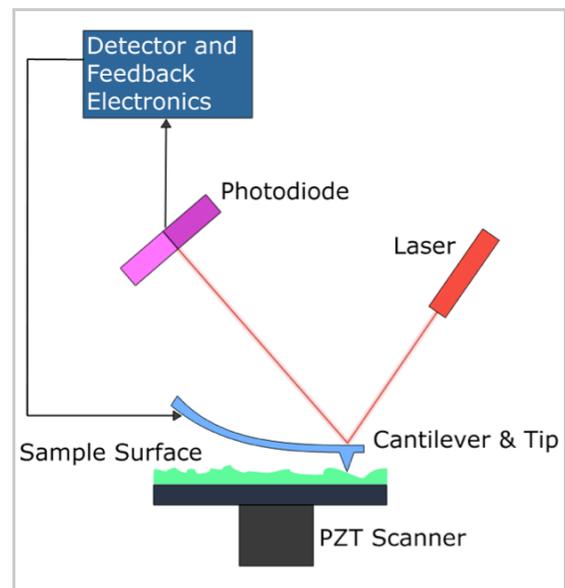
## How do they work?

SPMs are a very powerful family of microscopes, sometimes with a resolution of less than a nanometer. (A nanometer is a billionth of a meter.)

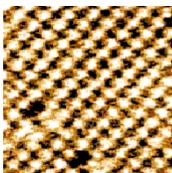
An SPM has a probe tip mounted on the end of a cantilever. The tip can be as sharp as a single atom. It can be moved precisely and accurately back and forth across the surface, even atom by atom.

When the tip is near the sample surface, the cantilever is deflected by a force. SPMs can measure deflections caused by many kinds of forces, including mechanical contact, electrostatic forces, magnetic forces, chemical bonding, van der Waals forces, and capillary forces.

The distance of the deflection is measured by a laser that is reflected off the top of the cantilever and into an array of photodiodes (similar to the devices used in digital cameras). SPMs can detect differences in height that are a fraction of a nanometer, about the diameter of a single atom.



Scanning probe microscope



SPM Image of Sodium Chloride

The tip is moved across the sample many times. This is why these are called "scanning" microscopes. A computer combines the data to create an image.

The images are inherently colorless because they are measuring properties other than the reflection of light. However, the images are often colorized, with different colors representing different properties (for example, height) along the surface.

Scientists use SPMs in a number of different ways, depending on the information they're trying to gather from a sample. The two primary modes are contact mode and tapping mode. In contact mode, the force between the tip and the surface is kept constant. This allows a scientist to quickly image a surface. In tapping mode, the cantilever oscillates, intermittently touching the surface. Tapping mode is especially useful when a scientist is imaging a soft surface.

There are several types of SPMs. Atomic force microscopes (AFMs) measure the electrostatic forces between the cantilever tip and the sample. Magnetic force microscopes (MFMs) measure magnetic forces. And scanning tunneling microscopes (STMs) measure the electrical current flowing between the cantilever tip and the sample.



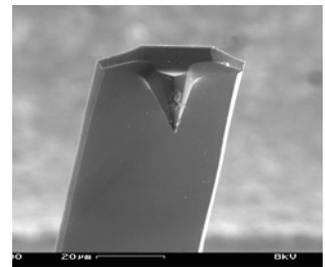
## History and Development of SPM

The first person to really study the microscopic world was a man by the name of Antoni van Leeuwenhoek. He built his own microscopes using lenses the size of a head of a pin. A world that no one had ever seen before came to life under his microscopes – a world teeming with creatures he called “animalcules”, or little animals. He made detailed drawings and wrote careful descriptions of each of the little animals. Today, we know that Leeuwenhoek’s animalcules were really protists, simple single-celled organisms, and bacteria. Other scientists followed in Leeuwenhoek’s footsteps and developed the modern light microscope in the middle of the 19th century.

Scientists soon discovered that light microscopes had a limit to what they could see. If they looked at an object smaller than 0.275 micrometers wide, it became blurred and distorted. In order for scientists to see smaller things, a new kind of microscope would need to be invented.

The electron microscope was invented in 1931 by two German scientists, Max Knott and Ernst Ruska. In an electron microscope, beams of fast-moving electrons are focused on a sample. When the electrons hit the sample, they scatter. The scattering of the electrons is what allows us to see small objects. An electron microscope can magnify objects over 500,000 times, allowing scientists to see and study viruses, DNA, and build tiny circuits on computer chips.

Scanning probe microscopy was developed in the 1980s to enable scientists to investigate surfaces with atomic resolution. Scanning probe microscopes have a very sharp tip – so sharp that may be only one atom across at the tip. By dragging this tip around on different surfaces and recording the interaction between the tip and the sample, scientists are able to piece together what each surface looks like at the atomic level. The invention of scanning probe microscopy was a great breakthrough in the field of nanotechnology. Now that scientists could see individual atoms, they could begin to manipulate these atoms to build different structures and study their properties.



SPM Tip (1000x)

Swiss scientists Dr. Gerd Binnig and Dr. Heinrich Rohrer are acknowledged to be the founders of SPM. They invented the first scanning tunneling microscope (STM) in the 1981 while working at IBM’s Zurich Research Center.

## Timeline

- 1981:** Dr. Binnig and Dr. Rohrer invent the scanning tunneling microscope (STM).
- 1982:** Dr. Binnig and Dr. Rohrer are the first people to “see” atoms when they use an STM to create an image of a silicon sample.
- 1985:** Dr. Binnig, Dr. Christoph Gerber (IBM Zurich Research Center), and Dr. C. F. Quate (Stanford University) develop the atomic force microscope (AFM).
- 1986:** Dr. Binnig and Dr. Rohrer are awarded the Nobel Prize in physics for the invention of the STM.
- 1987:** Tom Albrecht of Stanford University is the first person to use an AFM to create images of individual atoms.
- 1988:** AFM becomes available commercially.



## See Atomic-Scale Images Made by SPMs

[http://www.iap.tuwien.ac.at/www/surface/STM\\_Gallery/index.html](http://www.iap.tuwien.ac.at/www/surface/STM_Gallery/index.html)

[http://www.asu.edu/clas/csss/SPM/IG\\_gifs/gallery.html](http://www.asu.edu/clas/csss/SPM/IG_gifs/gallery.html)

<http://www.almaden.ibm.com/vis/stm/gallery.html>

<http://mrgcvd.engr.wisc.edu/lagally/>

<http://www.chem.wisc.edu/~hamers/gallery/index.html>

## Credits

The Center for Probing the Nanoscale (CPN) at Stanford University is supported by the NSF under award PHY-0425897. For more information and other activities, visit <http://cpn.stanford.edu>.

Adapted from “Exploring Tools—SPM” from Sciencenter, Ithaca, NY (retrieved on June 23, 2009 from <http://www.nisenet.org/catalog/programs/exploring-tools-spm>) and from “Probe Microscopy” from University of Wisconsin – Madison Materials Research Science and Engineering Center, Madison, WI (retrieved on June 23, 2009 from <http://mrsec.wisc.edu/Edetc/background/STM/index.html>).

Illustration of SPM by Askewmind. Image of sodium chloride by Ernst Meyer, University of Basel. Image of SPM tip by SecretDisc. All from Wikimedia Commons.

## Permissions

You are free to copy, distribute, transmit or remix this work as long as you credit the work as specified under cc-Attribution (<http://creativecommons.org/licenses/by/3.0/>)