Nanoscopes

By Rachael Harrison

To see a world in a grain of sand
And a heaven in a wild flower
Hold infinity in the palm of your hand
And eternity in an hour
William Blake (from Auguries of Innocence, c.1800)

What if we could see a world in a grain of sand; a world full of landscape and texture? While science is not completely limited by the ability to see, a visualization to accompany a theory allows a scientist to make more concrete observations and allows for better understanding of what they are observing or manipulating. The ever evolving and progressive field of science is therefore always pushing the boundaries of measurement. Humans have gone from a time of observing with the naked eye, through the time of simple magnifying glasses, and past simple electron microscopes into an era of nanoscopes; that has taken the scale of observations and indeed even manipulation to a whole new level.

Optical microscopes produce magnified images by reflecting light on a sample and using lenses to focus the light. Therefore, the optical microscope is limited by the wavelength of visible light, which is only about 200 nanometers.[1] The electron microscope was introduced in the 1930's. This microscope creates images using electrons instead of light waves. This new technique allowed for three-dimensional visualization as small as the diameter of an atom under optimal conditions. However, this technique requires a vacuum setting. This usually requires that biological specimens to be dried in a special manner that prevents shriveling from altering the sample. The sample is then usually coated with a very thin coating of something that is conductive (usually gold). This coating is necessary because the SEM uses a high-energy electron beam to knock loose secondary electrons from the surface of the sample. These electrons are detected and used to create a black and white image of the sample. This method was limited in the extent of types of samples that could be visualized on a small scale. Live objects could not withstand the vacuum, which limited actual observations of the functions of objects. The coating process would also add an impediment to direct viewing of a sample.[2]

However, between 1965 and 1971 Russell Young, of the National Bureau of Standards, created the Topografiner. The Topografiner combined detection of tunneling current with a scanning device to be able to obtain information about the nature of metal surfaces. This invention and its concepts lead to the scanning tunneling microscope. In 1986 Gerd Binnig and Heinrich Rohrer, IBM Research Laboratory, Zurich, Switzerland shared the Nobel Prize in Physics for their discovery of atomic resolution in scanning tunneling microscopy.[3]

Scanning Probe Microscopes development started in 1981 with the invention of the scanning tunneling microscope (STM). Amazingly, the STM still provides the highest resolution of all of the scanning probe microscopes that have been developed.[4] The STM does not use light to produce a magnified image as optical microscopes do. Instead, a STM drags a probe over the surface of a sample that is able to send signals to a computer, which is able to interpret the data on the atomic arrangement and construct a topographical map of the samples surface.

A STM data input consists of measuring the current flow from the tip of the STM through the sample. The "tip" of and STM is a finely sharpened metallic wire; usually one atom in diameter at its absolute tip. Scanning tunneling microscopy was so named for the electron movements from the tip to the sample known as electron tunneling. The tip must be placed such that the distance allows for electron tunneling but does not actually come into contact with the sample. The number of electrons able to hop from tip to sample surface is referred to as current. The distance between the tip and the sample surface is designated to represent z-direction.

The sample itself is positioned on a stage, which is cushioned to reduce any background noise or vibrations. A piezoelectric transducer is used to control movement of the tip across the sample. Four piezoelectric crystals surround the tip at each of the four compass points. The crystals have been designed to work like muscles in the sense that when one contracts, its opposite relaxes. The applied voltage controls the crystals movements. A uniform applied voltage across all piezoelectric pads can allow for manipulation in the Z-direction. This Z-direction movement allows for fine control over the gap distance between the tip and the sample. Non-uniform voltage application of pads allows for movement in both the X and Y directions.

The distance between the tip and the sample determines the tunneling current. The computer is able to maintain a constant distance using a feedback loop to control the piezoelectric pads to move the tip in the Z direction. The computer takes the information from changes in distance to create a two-dimensional topographic map of the surface of the sample, corresponding to the atomic arrangement of the sample surface.[1]

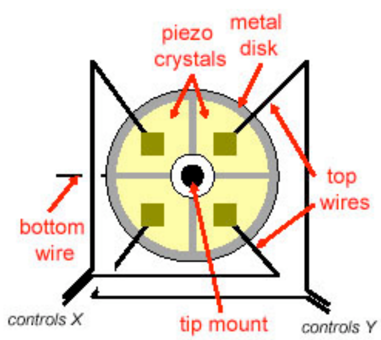

Figure 1[1]
Diagram of tip mount on piezoelectric crystals.

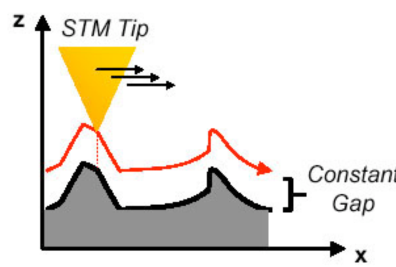

Figure 2[1]
Feedback loop keeps tip at a constant distance from the sample's surface.

In 1986 Binnig et al invented Atomic Force Microscopy (also known as scanning force microscopy).[1] Atomic Force Microscopy, or AFM, is similar to STM in many respects. A fine tip is positioned a small distance from a sample. The distance is again maintained through feedback loops that cause the piezoelectric elements to adjust the tip. However, the distance between the tip and the sample is slightly greater for the AFM in comparison to the STM. Also, the tip is positioned on a cantilever. The position of the cantilever changes as it passes over the surface of the sample. Scanning the sample relative to the probing tip and then measuring the deflection of the cantilever as a function of lateral position take the images from the AFM. A laser is reflected off of the cantilever and a photosensitive receiver interprets the laser signal and is able to produce a two dimensional image of the sample surface.[1]

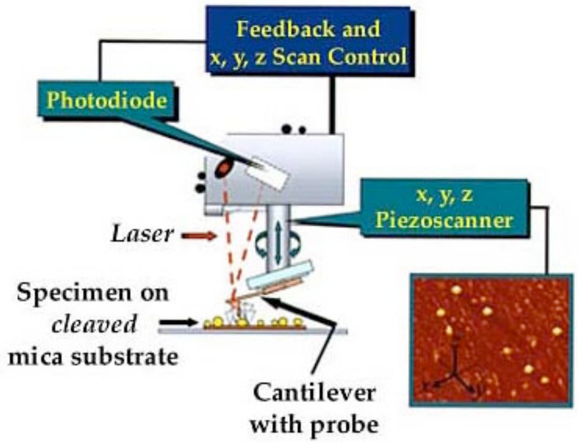

Figure 3
AFM apparatus showing the laser reflecting off the Cantilever onto the photo sensor.

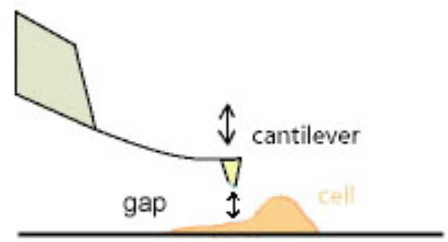

Figure 4[5]
Feedback loop keeps tip at a constant distance from the sample's surface.

Magnetic Force Microscopy (MFM) is yet another form of microscopy that allows for sample surfaces to be viewed on a nanometer scale. A MFM uses a magnetic tip. This magnetic tip is designed to have yet another relationship with a sample. This method allows for magnetic structures to be imaged. MFM has been influential in the development of small magnetic stored media.[6]

Each of the aforementioned forms of microscopy has their own benefits and disadvantages. The optical and electron microscopes have without a doubt been useful in helping scientists visualize and gain greater understanding of many substances. However, being able to observe things on the nanoscale has had a great impact on society as a whole. STM has expanded from being an imaging mode to now being able to have an imaging mode as well as a manipulation mode. This manipulation mode involves lowering the tip to create a smaller gap between the tip and the sample surface. This closer proximity allows for the electron tunneling to change interactions and the tip can in general terms be picked up by the tip. The piezoelectric elements can then be used to move the tip and drag the atom to a new desired position. The cantilever is then lifted creating a larger gap and therefore lessening the interaction with the atom and causing the tip to release the atom. In 1989, the scientists at IBM's Almaden Research Center in San Jose, California, were the first to position individual atoms on a cooled sample (-270 degrees Celsius). They were able to write the letters "IBM" with thirty-five xenon atoms. In 1991, scientists at IBM's T. J. Watson Research Center in Yorktown Heights, New York were able to manipulate silicon atoms at room temperature. This was a breakthrough and may lead to more broad practical uses for industry (such as creating chemical reactions that build functional units from individual atoms and molecules).[7] STM has also made breakthroughs through the simple interactions between the tip and the sample. Carbon-60 spheres called Buckyballs can be scratched by the STM tip. This scratch can lead to two Carbon-58's to fuse together to form Carbon-116 that has the potential to become a molecular switching device.[1]

MFM is a noncontact mode of microscopy. This aspect of MFM leads to new applications of microscopy at the nanoscale. Because MFM does not require an actual current between the tip and the sample surface, MFM can be applied to a broader range of materials that STM. Fragile samples that may have been damaged by the STM can now be imaged with minimal damage to sample surfaces. Another advantage of noncontact mode is the further advantage over the contact mode that frictional and adhesive forces do not influence the surface of very soft and rough materials as during scanning in the contact mode. That is to say that AFM will not "scratch" the surface.[8]

Microscopy has wide ranging effects throughout society. Optical microscopes and even some scanning electron microscopes have being a standard part of general science classes across America.

This has changed the way that America's youth is educated. The scale to which we should be aware is becoming smaller and smaller on a daily basis. Nanotechnology has become a profitable vein of science over the past few years. Small has become the new craze. People want smaller and more efficient cell phones, skinnier televisions sets, and better computers. Industries are doing their best to keep up with public demand and are also concerned with lowering their costs and making more efficient ways of producing their product. Scanning Probe Microscopy (SPM) has allowed for nanotechnology to be applied in a bottom-up strategy. Allowing scientists to build things atom by atom. SPM has also allowed for top-down construction. SPM has demonstrated utility in imaging a broad range of biological structures ranging from biomolecular and macromolecule structures to supramolecular structures and even living biological cells.

It is important to keep in mind that nanotechnology relies heavily on microscopy. Nanotechnology deals with things on the nanoscale. This means that humans cannot use hands on experience to manipulate systems to move how they would like. Instead, humans must use different forms of technology to manipulate things at such a small level. Microscopy must be used to observe if scientists are achieving their desired results and are indeed creating what they want. They are also using SPM to look into why substances work the way they do at nanoscale. For instance, scientists are using SPM to investigate why porous silicon will emit visible light of different wavelengths depending on different conditions.[9] In order for nanotechnology to progress, or indeed even maintain, its position in scientific standings, microscopy methods must be perfected and used to make observations and manipulations.

Today's SPM microscope base extends worldwide. There are approximately two thousand instruments available. There are between 350 and 400 new instruments sold annually, with an annual value of between 50-60,000,000 dollars in 1994.[10] This makes start up for any company (or person) very costly. There are also issues with maintenance. The tips of SPM's are very delicate. Accidental contact between the tip and a sample can cause substantial damage to the tip.[11] Therefore, methods for sharpening tips are being explored with great vigor. There are several companies that are selling SPM and AFM microscopes. A random sampling include: Accurion, Digital Instruments, Molecular Imaging, Nanonics, Omicron, and Surface Imaging Systems. There are also companies that deal in distribution of cantilevers, probe tips, and gratings. These companies are offering packages that include all of the different components needed to be able to run SPM or AFM.[12] SPM and AFM are no longer contained to the elites. These microscopes are now available to anyone who can afford them.

It is important to keep in mind that SPM's are not perfected yet. New methods and applications are still being researched. More work is needed to better understand interactions that may occur between the probe tip and samples. There is still room for improvement in the development of SPM. However, it is important to not take for granted how far we have come in the abilities to visualize our environment.

It was not so long ago that our observational powers were limited by the wavelengths our eyes could detect. Now our eyes have been opened to a whole new world. We, as humans are now able to manipulate and observe things at an atomic level. We have been able to image at a scale where materials take on different properties than those they posses in their bulk conformation. We can now use this imaging and manipulation power to construct the very world we live in. We must make sure to be responsible with this newfound power. And while society may benefit through what the genera public will consider novel conveniences, it will also result in a new level to which medical advances may be made, and military applications will be able to both save and decimate life with new and never before imagined capacity. We have indeed become aware of worlds within worlds; where something as small as a grain of sand becomes an entire world.

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