Where the Telescope ends, the Microscope begins...

by Suberr L. Chi

Since the invention of the first microscope by Zacharias Jensen in 1595, scientists have searched for ways to image the microscopic world by improving resolution. Early optical microscopes were restricted in their resolution because the wavelength of light is roughly 2000 times the diameter of an atom. Not until the mid 20th century were electrons used in microscope - due to their shorter wavelength could atomic resolution finally be realized. The recent invention and development of the atomic force microscope has contributed even more powerful imaging capabilities that can be applied to all branches of research; physics, metallurgy, materials science, molecular biology, semiconductor design, among many. The atomic force microscope is unparalleled in its potential because it is significantly cheaper than its counterparts - as physics fellow Dr. Matt Trawick explains, “Never before has it been so cheap to look at stuff so small.”

History and Development: From the STM to the AFM

The Atomic Force Microscope and many of its siblings in the Scanning Probe Microscope (SPM) family are relatively recent technologies, invented in the mid-1980’s to study surface properties of materials from the atomic to the micron level and to provide detailed three dimensional images. The microscopes in the SPM family have a probe that scans over the surface of a sample, which provides feedback data to generate an image or two.
send back material characteristics.

To understand the development of the AFM, one needs to first examine the predecessor of all SPMs, the Scanning Tunneling Microscope (STM). Invented in 1981 by Gerd Binnig and Heinrich Rohrer at IBM Zurich and awarded the Nobel Prize in physics in 1986, the STM was the first instrument to generate real space images of surfaces with atomic resolution. The height of the STM probe above the sample is precisely controlled by the expansion and contraction of piezoelectric crystals. The piezoelectric crystals are materials like quartz that change their shape when a voltage is applied to opposite faces. During operation of the STM, as the probe follows the contours of the sample surface, electrons from the surface of the sample jump onto the probe tip. This flow of electrons is known as the tunneling current, and is exponentially dependent on the distance of separation between probe and sample. When the probe is far from the sample, few electrons can hop over the large gap and jump onto the probe, and the detected tunneling current is small. When the probe is closer to the sample, more electrons can jump over the small gap, and the detected tunneling current is larger. Therefore, by scanning the probe horizontally across the surface at a constant height, the STM can generate a three dimensional image of the sample.

The problem with the STM is that the sample must conduct electricity in order for a tunneling current to exist. This significantly limits the number of possible sample materials and precludes biological applica-

Furthermore, the sample can only be imagined in a vacuum.

How the AFM Works

In 1986, Binnig, Quate & Gerber developed the AFM to address the flaws of STM. It can image any type of material, conducting or not, and provides magnifications up to 10,000,000X. This opens an entirely new realm of possibilities by extending imaging capabilities to biological molecules, including nucleic acid complexes, chromosomes, cellular membranes, proteins, polymers, and ligand-receptor binding sites. Imaging can take place under a variety of environments - in solution, on a surface, in a vacuum, or even in real-time while undergoing experimentation. The reason for this marked difference lies in the type of feedback monitoring employed. The AFM probe tip is monitored by the reflection of laser from the microscope itself, rather than by the tunneling current, so it can image any sample type. The laser projects a beam that reflects off the tip of the AFM probe, which is attached to a cantilever.

The cantilever is a miniature springboard that is fixed at one end and freely oscillates at the other to act as a microscopic force sensor. The cantilever is deflected by the atomic forces that it experiences when it is in close proximity to the sample surface, thereby causing the laser to reflect off at different angles. A position sensitive detector senses the movement of the laser beam and translates the data into a figure corresponding to the height of the sample. A 3-D image is generated by running the AFM in constant force mode or constant cantilever deflection mode. The AFM can also image in a non-contact mode to prevent damage to samples such as delicate biological molecules or integrated circuits.

Applications of the AFM

Some variations on AFM imaging include Magnetic Force Microscopy (MFM), Lateral Force Microscopy (LFM), Scanning Thermal Microscopy (SThM), and Liquid Imaging. In MFM, the probe tip is coated with magnetic material and
department have used the AFM to obtain continuous real-time liquid images of the self-ordering molecules. However, depending on the resolution desired, the AFM is sensitive to the smallest of perturbations. Even the pressure of a human voice can disrupt probe scanning— as Ku describes, “it’s an art form as much as it is a science.”

Improvements and Future Outlook

Despite its advantages, even the AFM is not perfect. For the most part, it can only image surface properties. New techniques that allow the probe tip to puncture through the surface of the material to image the interior are now being investigated. Dr. Nan Yao, director of the Imaging and Analysis Center at Princeton’s Material’s Institute, sees three improvement areas to address: image resolution, stability and sensitivity of the instrument. Resolution depends on the radius of the probe tip—using smaller radii will result in improved resolution, and ultra-fine carbon nanotubes are being implemented as probe tips. Stability and sensitivity continue to improve with advances in the electronics industry. A nascent technology, many researchers are unaware of the capabilities and applications of the AFM. Yao encourages students and faculty to take advantage of the Center’s existing equipment for a minimal fee to aid in independent work/senior theses.

Victor Hugo

writes in Saint Denis, “Where the telescope ends, the microscope begins.” The AFM’s contribution to scientific research progress is just beginning.

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