



Scanning probe microscopes were used to build this microchain drive, fabricated at Sandia National Laboratory.

as SNOM in Europe). The International Union of Pure and Applied Chemistry set up a commission to standardize the naming of such SXMs. One important vector for this proliferation has been the commercialization of probe microscopy. Microscope manufacturers have developed generic “controllers” that scan the probe, generate an image, and analyze data. From there, they either sell a variety of add-ons that adapt the controller to different variants of probe microscopy, or they sell the controller to research groups that develop variants for themselves.

The great achievement of probe microscopy has not been the remarkable imaging resolution of these instruments—other kinds of microscopes can achieve ultra-high resolution, and many probe microscopists have rather poor resolution. Instead, probe microscopy has demonstrated that the nanoscale is an information-rich environment, in which almost any material characteristic can be made visible. Visibility, in turn, means control—either directly through manipulation by the probe, or indirectly by using information from the probe to steer nanoscale processing techniques.

See Also: International SPM Image Competition; Microscopy, Atomic Force; Microscopy, Scanning Tunneling.

Further Readings

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Microscopy, Scanning Tunneling

The scanning tunneling microscope (STM), invented at the IBM Zürich Research Laboratory in 1981, was an almost-instant success. Its inventors, Heinrich Rohrer and Gerd Binnig, had to wait only five years before they were awarded the Nobel Prize alongside Ernst Ruska, who had had to wait 53 years since inventing the electron microscope. The STM’s quick appeal stemmed from early images of individual atoms resting on a well-known and famously puzzling semiconductor surface, the so-called silicon (111) 7 x 7. Thus, surface scientists were (and are) an important constituency for STM. However, Binnig and Rohrer eagerly adapted the STM for other disciplines such as biophysics and electrochemistry.

Through this broadening of its appeal, the STM became the parent instrument for a wide variety of scanning probe techniques. In the early 1990s, biophysical STM suffered a setback when claims for atomic resolution of DNA were called into question. However, 1990 also saw STM’s greatest triumph when Don Eigler and Erhard Schweizer used an STM tip to position 35 xenon atoms on a nickel surface to spell out “I-B-M.” This and other STM images offered powerful public legitimation for nanotechnology proponents, in that they offered a proof of principle that humans could visualize and even interact with nanoscale objects.

A Sideshow Becomes the Main Event

The STM arose from a multimillion-dollar IBM project to develop a supercomputer based on superconducting (rather than semiconducting) logic elements. Researchers on the project had trouble making thin oxide films and asked a colleague at the IBM Zürich laboratory, Heinrich Rohrer, to investigate. Rohrer put a newly hired physicist, Gerd Binnig onto the task. Together, they decided to develop a new kind of instrument based on electron tunneling, rather than try to understand the problem using existing instruments. Their “tunneling

microscope” consisted of a sharp metal or semiconductor probe, which approached a metal or semiconductor sample to within a few angstroms (0.1 nanometer or 1×10^{-10} meters), at which point electrons would “tunnel” between probe and sample. Tunneling is a quantum phenomenon in which there is a finite probability that a particle’s waveform will collapse in one region and re-form in another region without having to surmount the energy barrier between those regions (like moving through a wall without having to break the bricks).

A Community Forms

This instrument became a microscope when Binnig and Rohrer moved the tip back and forth, recording the strength of the tunneling current as it passed over a matrix of points on the sample. By the time they accomplished this, though, the supercomputer project was winding down. So they consulted IBM colleagues to see what other samples to look at. Some surface scientists suggested the silicon (111) 7×7 , an intriguing surface in which the silicon atoms arrange in a then-unknown pattern. When Binnig and Rohrer published images of single atoms of the 7×7 in 1983, the STM quickly catapulted to the wider scientific community’s attention. Though they did not solve the mystery of the 7×7 themselves, their work on it won Binnig and Rohrer the 1986 Nobel Prize in physics, and spurred many surface scientists and others to build their own STMs.

Setbacks and Specialization

Encouraged by Binnig and Rohrer, STM use soon spread beyond surface science, particularly to electrochemistry and biophysics. One hope in the late 1980s, as the Human Genome Project came into being, was that STM could image and perhaps even sequence DNA. At the same time, hundreds of researchers began buying commercial STMs that operated in air (rather than in vacuum, as surface science STMs did) to look at biological samples. This research was bolstered by a cover article in *Nature* in 1990, claiming to atomically resolve a double-helix of DNA. However, several researchers (Binnig, Stuart Lindsay, Thomas Beebe) quickly pointed out that this image was probably false. The graphite that most DNA samples were mounted on could itself mimic DNA.

While later studies have shown that it is possible to image (though not to sequence) DNA with an STM, these experiments are so demanding that they have not been

widely adopted. Instead, biophysical STM and air STM quickly lost popularity, replaced by atomic force microscopy (AFM). Today, the AFM is used very widely in nanotechnology, whereas the STM has a much narrower scope, centered primarily on surface chemistry and physics.

Poster Child for the Nanorevolution

Still, the narrower specialization of STM has not prevented it from making dramatic contributions to nanoscience’s public and scientific image. That was shown by another *Nature* article in 1990 in which Don Eigler and Erhard Schweizer used a low-temperature STM to move 35 xenon atoms together to form the letters “I-B-M” (the name of their employer). That STM image has become one of the icons of nanotechnology, a clear existence proof of humans’ ability to manipulate atoms. The use of STMs both to characterize and manipulate matter (“STM lithography”) has great potential—though still just potential—to revolutionize the microelectronics industry, biology, and a number of other fields.

See Also: Microscopy, Atomic Force; Microscopy, Electron (Including TEM and SEM); Microscopy, Exotic; Microscopy, Scanning Probe.

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Midstream Modulation

Midstream modulation is an instrument in the broader field of technology assessment that aims to elucidate or enhance the responsive capacity of laboratories to the broader societal considerations of their work by way of interdisciplinary collaborations among social