SCIENCE

18 MARCH 1988
VOLUME 239
NUMBER 4846

Phenomena at Interfaces

Research opportunities created by the scanning tunneling microscope (STM) and the atomic force microscope (AFM) are being addressed by an expanding number of scientists. As of 1 March 1988, about 400 papers had appeared that dealt with their design or use in studying hitherto unapproachable phenomena. These instruments are capable of lateral resolutions of 1 to 2 angstroms and can measure vertical dimensions to better than 0.05 Å. (Atomic dimensions are of the order of 2 Å.) Initially the STM was employed in studies of objects in high vacuum. But more recently atomic resolution has been obtained with both STM and AFM of solids in air and of solids covered by cryogenic fluids, polar and nonpolar solvents, conductive aqueous solutions, oils, and greases.* These observations demonstrate potential for investigating processes that occur at solid-liquid interfaces. Possible applications include lithography, catalysis, corrosion, electrochemistry, and molecular biology.

Most of the measurements have been made with STM. These studies have revealed many interesting phenomena, including mobility of atoms on surfaces and the reactivity of the dangling bonds that are present at crystalline surfaces. In one type of experiment, a fresh graphite surface in high vacuum was exposed to an amount of silver atoms sufficient to provide a small fraction of a monolayer. Subsequent observation with STM revealed islands of silver atoms on the graphite. It was as if the silver atoms had galloped over the surface to be with their friends. An experiment with crystalline gold testified to mobility of gold atoms near the surface after a crater in the gold three atom layers deep and displacing about 3200 atoms was created. The third level of the crater (25 atoms) was filled with gold atoms in 8 minutes. After 130 minutes, the second level of the crater (900 atoms) was filled. All this occurred at room temperature.

It has long been known that the arrangement of atoms at the surface of a crystal differs from that in the interior. The atoms at the interior are surrounded. Those at the surface are not. As a result, spacing of atoms at the surface is different from that in the bulk. A much noted example is that of silicon (111) which has a 7 by 7 unit cell at the surface each having 19 dangling bonds (dbs) which apparently are quite reactive. When a tiny amount of ammonia is introduced into the vacuum, H and NH_2 are preferentially attached to some particular db but to others more slowly.† Again, this is reactivity at room temperatures.

The STM involves a flow of electricity to or from a sharp tip poised about 10 Å above the conducting surface of a solid. The STM is not readily applicable to insulators or directly useful for mobile biological substances. However, for studies involving conductors, STM is the instrument of choice. It can be made rugged and dependable, and it is already being used in the United States on the shop floor to monitor a production process where precise control of tiny dimensions is paramount to achieving quality of output. It is manufactured commercially with various models costing about $30,000 to $60,000. On the order of 100 instruments have been sold, many of them to the Japanese. In a number of universities, home-made variants have been assembled for as little as a few thousand dollars.

Ultimately, because of its potential versatility, the AFM, invented in 1985, will probably come into broad use, but at present completely satisfactory models are not available. The AFM senses the force between the end of a sharp tip and the atom being observed. The tiny force causes a very small motion in a spring attached to the tip. At present, the typical forces involved when AFM is employed in monitoring are in the range of 10^{-8} newton. (A force of 10^{-8} N is equivalent to the weight of 10^{-6} g.) However, G. Binnig and C. F. Quate have suggested that an apparatus could be developed that would detect a force as small as 10^{-18} N. They point out that already displacements of 10^{-4} Å to 10^{-6} Å have been measured. A displacement of 10^{-6} Å corresponds to about 1 percent of the nuclear diameter.

Behind the success of STM, as well as a good potential future for AFM, is the ability to measure, record, and control displacements of small fractions of an angstrom. This ability is likely to be exploited further in the development of other instruments capable of exploring phenomena at the atomic level.—PHILIP H. ABELSON

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*A good sample of activities in STM and AFM will appear in the March–April issue of the *Journal of Vacuum Science and Technology*. †R. Wolkow and Ph. Avouris, *Phys. Rev. Lett.*, in press.

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