Physics

Ivars Peterson reports from Indianapolis at an American Physical Society meeting

Pinpoint splitting of molecules

The sharp tip of a scanning tunneling microscope's needle-like probe has proved a versatile tool for mapping a surface's microscopic ridges and hollows and for moving small clumps of atoms from place to place. Scientists can also use this instrument to split up individual molecules lying on such a surface. Phaedon Avouris of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., and his co-workers have now demonstrated that electrons emitted from a microscope's tip can transfer sufficient energy to excite and shake apart a decaborane molecule sitting on a silicon surface.

Each decaborane molecule consists of 10 boron atoms and 14 hydrogen atoms. When deposited on a silicon surface and viewed with a scanning tunneling microscope, these molecules appear as rounded, elongated protrusions about 7 angstroms across. Warming up the coated silicon slab frees these molecules, and they tend to migrate to certain irregularities in the otherwise orderly arrangement of silicon atoms at the slab's surface. The molecules break apart at these defects, and boron atoms slip into the silicon structure.

Instead of heating up the entire crystal to produce boron-doped silicon, Avouris and his team selectively excite individual decaborane molecules to dope only small, specific regions of the silicon surface. They use a scanning tunneling microscope to locate the surface-hugging molecules. Then, by carefully readjusting the voltage applied to the microscope's tip, they send a pulse of electrons of just the right energy to excite a particular molecule, which dissociates.

Avouris suggests that the same procedure could be used for controlling surface chemistry on a molecular scale in a variety of situations.

Glass with a memory

Traditionally, researchers have pictured a glass as a random network of chemically bonded atoms. However, some glassy materials don't fit this simple picture. Experiments show that sufficiently high pressures can convert a crystalline form of aluminum phosphate known as alpha-berlinite into an apparently disordered, or glassy, solid. But as soon as the pressure is lifted, the solid returns to its previous crystalline state. Instead of deforming permanently, the compressed material somehow retains a "memory" of its original crystal structure.

To determine why aluminum phosphate shows such a remarkable recovery when other crystalline materials do not, John S. Tse and Dennis D. Klug of the Steacie Institute for Molecular Sciences in Ottawa, Ontario, computed the effects of high pressure on an aluminum phosphate lattice. Initially, each aluminum and phosphorus atom is surrounded by four oxygen atoms in a tetrahedral arrangement, and the entire crystal consists of an orderly network of these tetrahedra. As revealed in the simulations, increasing the pressure distorts the tetrahedral units, opening them up and twisting them into the empty space within the lattice. This shift changes the relative positions of the atoms but forces no substantial rearrangement – even though the resulting structure looks quite disordered. When the pressure is lifted, the atoms simply retrace their paths to their original locations.

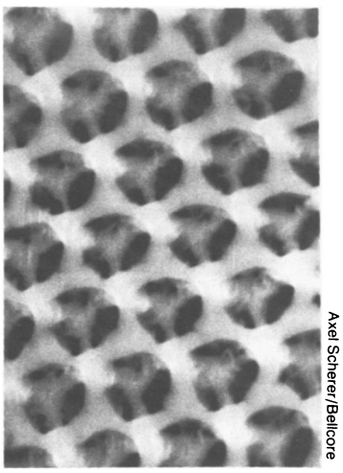
"It's like winding up a coil, then letting it unwind," Tse says.

In contrast, both experiments and simulations show that a crystalline form of silicon dioxide known as alpha-quartz, which has the same tetrahedral atomic arrangement as aluminum phosphate, fails to recover from its pressure-induced, disordered state. Unlike phosphorus atoms in aluminum phosphate, which remain bonded to four oxygen atoms throughout compression, silicon atoms end up in an arrangement in which each one is strongly associated with five oxygen atoms instead of four. This change in bonding stabilizes the disordered form of silicon dioxide, and the material retains its glassy structure when the pressure decreases.

Tse concludes that any material displaying a memory effect must contain rigid units – like the tetrahedral phosphate groups in aluminum phosphate – that preserve their bonding characteristics at high pressures. Glassy materials can indeed exhibit markedly different degrees of disorder.

Drilling into the infrared

The effort to construct a photonic crystal, which treats photons or light waves in the same way that a semiconductor treats electrons, has moved from engineered structures that exclude microwave radiation of certain wavelengths to those that forbid the passage of infrared light. Last year, Eli Yablonovitch and his co-workers at Bellcore in Red Bank, N.J., drilled crisscrossing holes into a solid slab of an electrically insulating material to produce an array of cavities that prevent microwaves of a certain narrow frequency range from penetrating the structure (SN: 11/2/91, p.277). The same team has now used ion beams to drill an identical pattern of much narrower, more closely spaced holes into gallium arsenide. Preliminary measurements show that this array has a band gap – a band of forbidden frequencies – in the infrared region of the electromagnetic spectrum.



Axel Scherer/Bellcore

This micrograph shows the top of a photonic crystal that exhibits a band gap at infrared wavelengths between 1.1 and 1.5 microns. The crystal consists of an array of microscopic crisscrossing holes, 5,000 angstroms in diameter and 7,000 angstroms apart, drilled into gallium arsenide.

Yablonovitch sees no reason why such arrays can't be engineered to exclude electromagnetic waves of any specific, narrow band of wavelengths, from the microwave region to the ultraviolet. Furthermore, by introducing suitable defects in the otherwise perfectly regular pattern of drilled holes, it's possible to construct the equivalent of doped semiconductors to obtain the components necessary for making a particularly efficient light-emitting diode or laser.

Scanning magnetic swirls

Researchers have modified the scanning tunneling microscope to permit the imaging of individual magnetic vortices that penetrate the surfaces of high-temperature superconductors. Unlike other methods used to image magnetic fields on a microscopic scale, this particular technique doesn't alter or destroy the sample being studied. "You can look at the same sample again and again," says Hans D. Hallen of AT&T Bell Laboratories in Murray Hill, N.J.

Moreover, the new magnetic probe microscope measures the strength of magnetic fields directly. Its specially patterned, gallium-arsenide probe, which is held about 0.1 micron above a surface as it scans back and forth, can detect magnetic features as small as 0.3 micron across. Hallen and his co-workers have already used the microscope to study how the depth to which a magnetic field penetrates a superconductor corresponds to the size of the vortices seen on its surface at various temperatures.