Creating crystals to study quantum effects

Small gatherings of atoms tend to behave differently from huge crowds: So-called bulk properties can change quite a bit when the sample contains just a few hundred or thousand atoms. And researchers seeking to shrink computer chips to angstrom sizes want to know exactly how these properties differ.

Toward that goal, two research groups have reported progress in making semiconductors in sizes small enough that their dimensions affect the wave-like nature of their electrons.

"We clearly see quantum-size effects in the little crystallites," says Louis Brus, a physical chemist at AT&T Bell Laboratories in Murray Hill, N.J.

Study of these crystallites may explain puzzling phenomena such as photoluminescence in silicon made porous by acid etching. Some scientists have suggested that etching leaves quantum-size wires or dots whose dimensions limit the movements of electrons and lead to light emission; others attribute silicon's glow to other causes (SN: 5/16/92, p.324).

Brus and Bell Labs colleague Karl Littau made silicon crystals with diameters ranging from less than 2 nanometers to about 8 nanometers by heating a gaseous silicon-hydrogen compound called disilane to 850°C. This high temperature yields an aerosol of crystals that the scientists sort by size.

Spectroscopic studies of the sorted crystals reveal that the tiniest crystals luminesce a visible red. Larger particles emit infrared light. "This is very similar to what you see in porous silicon," Brus says. He reported these results in Chicago last week at the Sixth International Symposium on Small Particles and Inorganic Clusters. Brus plans ever more precise spectroscopic analyses of these crystallites.

Taking a different tack, James R. Heath makes small crystals from solution. "I'm aiming for complete chemical control of the surface structure as well as of the size," says Heath, a chemist at the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y. "With wet synthesis, you can [use] a lot of different kinds of molecules and can control the parameters to a much finer degree."

Heath/IBM

Two 200-nanometer-wide silicon crystals produced by a technique that also makes crystals one-tenth that size.

Techniques such as molecular beam epitaxy also offer that kind of control, but only for building thin films, not for tiny, three-dimensional crystals, he adds.

At the Chicago meeting, Heath described success in making 5-nanometer silicon crystals from a hexane solution containing both silicon tetrachloride and a silicon compound with three chlorine atoms and an organic side chain attached. He seals the solution in a special beaker and heats it to 400°C. That high temperature causes the pressure inside to build to several hundred times that of the atmosphere, he says. Adding sodium causes the chlorine to break away and precipitate as table salt, leaving behind very reactive silicon. That silicon condenses and anneals.

The bulkiness of the organic side groups causes them to stick out from the surface of the silicon crystal that forms. Thus, by altering the proportions of these two silicon compounds in the hexane solution, Heath can control the surface-to-volume ratio and consequently the size of the crystals formed. Increasing the relative amount of the organic silicon chloride results in smaller crystals.

"If you choose your organic group wisely, you may be able to use it to size the crystal and to glue it to a surface," he adds. By attaching these silicon crystals to a metal, he hopes to make miniature circuits — like shrunken computer chips.

Last week, he succeeded in making a germanium "quantum wire," the first produced through wet synthesis, Heath told SCIENCE NEWS. This demonstrates that the technique lets researchers customize the shape as well as the size of the crystals, he says. The wire's small diameter should inhibit the movement of electrons in that direction, so that they can flow freely only along the wire's few-micron length. Heath expects to find interesting quantum-size effects on the germanium's conduction properties.

Other scientists have generated beams of clusters even smaller than Heath's or Brus', but "[ours] are the only approaches where you get macroscopic samples," says Brus. *— E. Pennisi*

New evidence of dust rings around stars

Astronomers reported new evidence this week that some young stars in the Milky Way have disks of hot gas and dust similar to the one believed to have once encircled the sun. And just as scientists speculate that clumps of material from the sun's disk formed the solar system's planets, the disks surrounding the young stars may one day give birth to planets orbiting these Milky Way bodies, the researchers say.

Vilppu Piirola of the University of Helsinki, Finland, and his colleagues deduced the presence of disks by analyzing the polarization of near-infrared light from the regions surrounding two youthful stars — V376 Cas and V633 Cas — located some 2,000 light-years from Earth in the constellation Cassiopeia. Visible-light images from the Palomar Observatory, near Escondido, Calif., had already demonstrated that a cocoon of light-obscuring dust surrounds each star, but these images lacked the resolution to detect flattened disks.

Examining the pattern of polarization — the direction in which the electric field of a light wave vibrates as the wave heads toward an observer — in the new infrared images, Piirola and his colleagues probed the environment of the two stars more deeply. Dust particles with a diameter of about 1 micron polarize near-infrared light extremely well, and the researchers found that infrared light from large areas around each star was indeed highly polarized. But they also found a relative absence of polarized light from a flattened, disk-shaped region surrounding each star. Piirola and his co-workers attribute the reduced polarization to a thick disk of dust in which each tiny particle polarizes light in a different direction, effectively canceling out any net polarization. They report their work in the Oct. 1 NATURE.

Using the 2.5-meter Nordic Optical Telescope in the Canary Islands, Piirola and his team resolved structures as small as 100 astronomical units across (100 times the Earth-sun distance) — about twice the sharpness achieved by other researchers. He adds that the disks inferred in the present study are much thicker and more massive than the directly imaged disk around the older, nearby star Beta Pictoris.

These and other findings suggest that V376 Cas and V633 Cas — just a few hundred thousand years old — are still forming their circumstellar disks from the dust cloud in which they were born. In contrast, Beta Pictoris has evolved for several hundred million years, and its thinner disk, composed of larger particles, may represent leftover material from planets that have already formed.

In a separate study, scientists have found evidence that among a class of intermediate-mass stars that includes V376 Cas and V633 Cas, the largest members form the biggest disks and do so the most rapidly. The team, led by Lynne A. Hillenbrand and Stephen E. Strom of the University of Massachusetts at Amherst, presents its results in the Oct. 1 ASTROPHYSICAL JOURNAL.

— R. Cowen