

Intermetallic superconductor

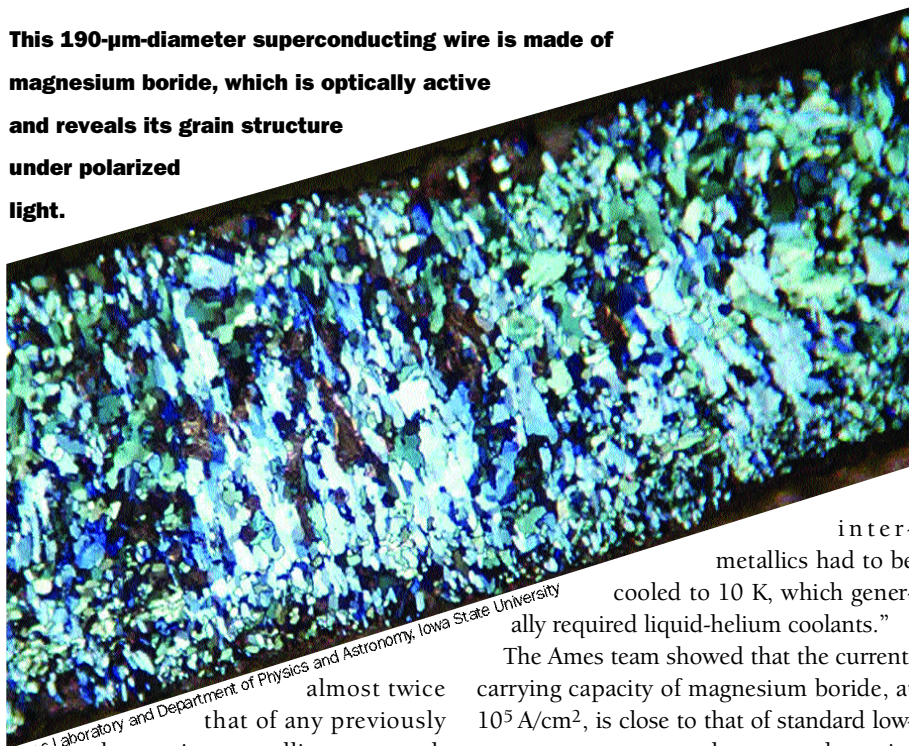
In a dramatic announcement at the Symposium on Transition Elements meeting on January 10 in Sendai, Japan, Jun Akimitsu and colleagues at the Aoyama Gakuin University (Tokyo) reported that the bimetallic compound magnesium boride had a superconducting critical temperature of 39 K,

easier to cool. "Superconductors have to operate at about half their critical temperature to get good current-carrying capacity," explains Ames researcher Paul Canfield. "So magnesium boride could operate at 20 K, a temperature that can be reached easily with closed-cycle refrigerators. Earlier

ture was 40.2 K, but when it used boron-11, the transition temperature dropped to 39.2 K, exactly what the theory predicted.

If further tests confirm the BCS behavior of magnesium boride, it may remain the record holder for such materials because, as it happens, the theory predicts a maximum possible transition temperature close to 40 to 50 K for materials that obey the predicted BCS behavior. [▶](#)

This 190- μm -diameter superconducting wire is made of magnesium boride, which is optically active and reveals its grain structure under polarized light.



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almost twice that of any previously known intermetallic compound. Within weeks, a group at the U.S. Department of Energy's Ames Laboratory at Iowa State University proved that magnesium boride had slightly different transition temperatures, which depended on whether the boron-10 or boron-11 isotope was used (*Phys. Rev. Lett.* 2001, 86, 1877). This indicated that the new superconductor probably operated according to the well-known Bardeen-Cooper-Schrieffer (BCS) theory, in contrast to the more mysterious high-temperature superconductors (HTSs) whose transition temperatures extend up to 110 K.

Although magnesium boride does not compete with HTSs in temperature, it has the advantage that as a binary, intermetallic compound, samples that can carry high currents can be made easily. In addition, given the higher critical temperature, it is

intermetallics had to be cooled to 10 K, which generally required liquid-helium coolants."

The Ames team showed that the current-carrying capacity of magnesium boride, at 10^5 A/cm², is close to that of standard low-temperature superconductors such as niobium-tin. However, magnesium boride is a much lighter material, having one-third the density of niobium-tin, so it can carry three times as much current on a weight-for-weight basis.

Unlike the HTSs that caused such excitement in the late 1980s, the behavior of magnesium boride seems explicable in terms of the standard BCS theory. This theory, named for the three Nobel laureate physicists who developed it, explains superconductivity in terms of electrons exchanging pairs of phonons, the carriers of vibration energy in an atomic lattice. The theory predicts that the transition temperature will depend on the atomic mass of the atoms in the lattice, and that is exactly what the Ames team found. When the team used isotopically pure boron-10, the transition tempera-

Fluorescing nanoclusters

One Holy Grail of information-storage technology is to store bits of information on individual atoms. Although this has never been achieved, Georgia Institute of Technology chemist Robert M. Dickson and his colleagues have come close by demonstrating the storage of bits in nanoclusters of two to six silver atoms (*Science* 2001, 291, 103). The nanoclusters exhibit "caged" fluorescence, in which the clusters fluoresce only after they have been photoactivated or "uncaged" with blue light. The information can then be nondestructively read out by exposing the particles to green light, which causes them to emit red light.

The silver nanoclusters are produced by a modification of the photographic-emulsion process in use for 150 years. In photography, silver halide grains absorb light energy, which converts them into silver. In the Georgia Tech experiments, a thin film of silver less than 20 nm thick was deposited in darkness onto a glass plate. Such thin films break up into islands, which rapidly oxidize to silver oxide when exposed to air, producing particles 10 to 30 nm across.


When the particles are exposed to continuous blue light (450 to 480 nm wavelength), they start to fluoresce intermittently, blinking and shifting their emitted light in a seemingly random fashion from red to green to yellow. "This is a clear indication that we are observing nanoclusters," says Dickson. "As the silver oxide molecules absorb energy, they break up and form silver nanoclusters of a few atoms, which fluoresce collectively in the same way a molecule would. But as more silver atoms are added to the clusters,

their energy levels change, and they start to fluoresce at different wavelengths or stop fluorescing altogether, which produces the multi-color blinking.”

But if the exciting light source is then changed to green, the fluorescent light, now emitted in the red,

becomes far more stable and the blinking stops. This is because the green light is too low in energy to excite the silver oxide molecules and break them apart, but the energy is still sufficient to excite the silver nanoclusters and cause them to fluoresce.

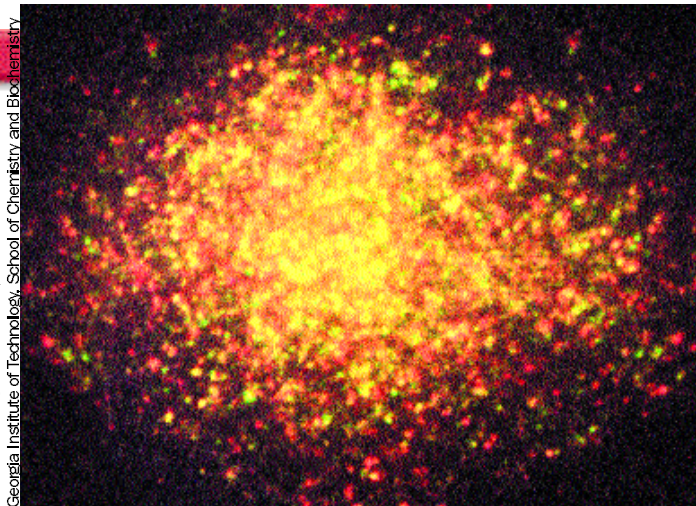
To demonstrate that information could be stored and read nondestructively, the researchers exposed the particles in the pattern of the letter “L.” They then were able to read the image out by exposing it to green light for up to two days afterward, which was as long as they tried to read it.

Potentially, nanoclusters could form the basis for ultradense energy-storage systems. But much work remains to show that the particles can be arranged into very compact arrays and that reading and writing information can be done at the extremely high speeds required by computer technology. 

Silicon cage cluster

Rather than caged fluorescence, caged metal atoms are the keys to the syntheses of the silicon equivalents of buckminsterfullerenes, the spheres of carbon atoms nicknamed buckyballs. Hideo Hiura and his colleagues at the Joint Center for Atomic Research (Tsukuba, Japan) have created a spherical compound of silicon around a “caged” metal atom (*Phys. Rev. Lett.* 2001, 86, 1733). The new compound, called a silicon cage cluster, could have application as a basis for quantum computing, in new catalysts, and possibly even as a superconductor.

Silicon, the stuff of computers, sits

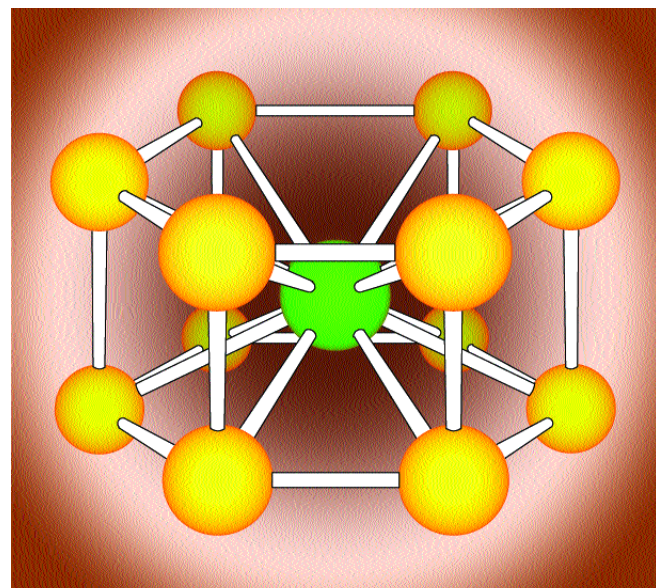


It is possible to activate nanoclusters of two to six silver atoms with blue light and then have them fluoresce red light by exposing them to green light, for up to two days later.

beneath carbon, the stuff of living organisms, in the periodic table, and the two elements share several characteristics. So it was natural that researchers sought to duplicate in silicon the spherical compounds of carbon fullerenes. But it rapidly became clear that a hollow ball of silicon atoms would be unstable and collapse on itself like a punctured balloon. To remedy this, the Japanese researchers built the basket of silicon atoms around a central metal atom.

They began by capturing tungsten atoms in an ion trap. Such traps consist of a combination of a quadrupole magnetic field and a cylindrical electrical field with both ac and dc potentials, which combine to trap ions in three dimensions in a near-vacuum. The tungsten was introduced by heating a wire, and the silicon was simultaneously introduced as a very dilute silicon hydride gas. The atoms interacted to form the

Silicon cages, such as this one with just 12 silicon atoms in a hexagonal prism around a tungsten atom, may find applications in quantum computers, catalysts, and superconductors.



silicon cage clusters, each consisting of 12 silicon atoms surrounding a single tungsten atom (see figure below). The existence of the cluster was confirmed by mass spectroscopy. Theoretical analysis showed that the most likely configuration was of a regular hexagonal polyhedron.

“The silicon-cage cluster is similar to a buckyball in that both are spherical in shape and buckyballs may enclose another atom, but there are significant differences as well,” Hiura points out. “Fullerenes are considerably larger, with a stable one having 60 or more atoms. This means the cage interacts only weakly with the central atom. But cage clusters are small, and there are strong covalent bonds between the cage and the central atom, so the whole structure acts as a novel artificial atom. With different metals in the cage, such as cobalt, nickel, or niobium, the chemical properties of the cluster can be tuned for many applications.” He suggests that one such use will be as catalysts for various reactions, and that the cage cluster may form superconductors as well.

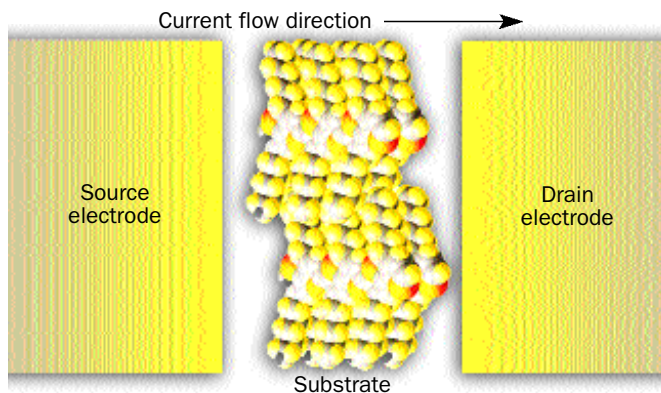
Hiura is particularly excited about the prospect that the cage clusters might provide a practical basis for a solid-state quantum computer. In quantum computing, the spin states of an atom must be highly iso-

lated from their surroundings so they can achieve “pure” quantum states. A cage made of silicon-28 isotope could isolate the nuclear spin states of the central atom. With cages made of silicon, such clusters could potentially be integrated into standard silicon chips.

The team next will study the structure of silicon-cage clusters directly with X-ray analysis and try to develop ways of synthesizing the clusters on a large scale instead of creating just a microgram a second, as it did in ion traps. [🔗](#)

Superconducting plastics

Last year, physicist Alan J. Heeger (University of California, Santa Barbara) and chemists Alan G. MacDiarmid (University of Pennsylvania) and Hideki Shirakawa (University of Tsukuba, Japan) received the Nobel Prize in Chemistry for their discovery a quarter-century ago of electrically



This semiconducting polymer, regioregular poly(3-hexylthiophene), became superconducting when injected with holes in the gate of a field-effect transistor.

conducting plastics. But the development of superconductivity in plastics, a next logical step, eluded researchers—until now. In March, researchers at Lucent Technologies’ Bell Laboratories (Murray Hill, NJ), the University of Konstanz (Germany), and the Solid State Physics Laboratory (Zurich, Switzerland) announced that they had achieved superconductivity in the polymer poly(3-hexylthiophene) by placing it inside a field-effect transistor (FET) and injecting it with holes—gaps created by the absence of electrons that act as positive charge car-

riers (*Nature* 2001, 410, 189). The entry of plastics into the world of superconductivity will most likely mimic what happened with conducting polymers, whose discovery set off a rapidly expanding field of research and development.

The very process that made polymers conducting made it difficult for them to become superconducting. For superconductivity to exist, materials must be well ordered so that no irregularities disrupt electron flow. Yet, plastics are made to conduct electricity by doping them with impurities that contribute mobile electrons. Impurities distort the regular structure of polymers and, thus, render them unfit to become superconductors.


J. H. Schön, B. Batlogg, and their colleagues took another route. They injected the holes into the plastic by placing it in the gate of a FET. The field created by the electrodes attracts the charge carriers—holes—into a thin layer of the film, which sharply

increases the polymer's conductivity.

The researchers needed a polymer that was semiconducting so that the charge carriers had some mobility within the plastic. To get a plastic with a very regular atomic structure, they chose regioregular poly(3-hexyl-

thiophene). This substance is known to self-assemble into highly ordered films, which consist of layers of ordered sheets of molecules. In fact, the plastic forms into tiny nanocrystals of rigidly structured molecules.

As the researchers increased voltage on the electrode, the charge concentration increased. When the concentration of charge carriers in the plastic passed a critical threshold, the team observed a sudden drop of resistance to zero—the hallmark of superconductivity. In effect, the plastic turned into a metal when enough electrons became available, and that very regular metal then became superconducting. The transition temperature achieved was relatively low—2.35 K.

“Right now, we are trying to understand the basic mechanism of superconductivity in this class of materials,” says Schön. “We are also trying to find other polymers that have a higher transition temperature.” The ability of the field effect transistor to change a plastic to a superconductor may open up new possibilities for electronic circuits, especially if transition temperatures can be raised. 

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The Web site for *The Industrial Physicist* has been redesigned with a new, cleaner functionality and new features, including easier ways to contact the staff. Most of the content back to December 1996 is online, and we are working to add all of the issues back to July 1995. Your comments are welcome (tip@aip.org).

