composite should be fairly easy to produce once industry begins the large-scale manufacture of quasicrystal powders used in the material.

Quasicrystals of AlNiCo Exhibit Band Structure

A team of scientists has demonstrated that the electronic states of quasicrystals are more like those of ordinary metals than theorists believed possible. Eli Rotenberg, a staff scientist at the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory, Karsten Horn of the Fritz-Haber Institute, Max-Planck Society, Berlin, and their colleagues have found that rather than moving around arbitrarily, electrons in quasicrystals travel in "bands" with distinct momentum and energy. While investigating the electronic structure of a quasicrystalline alloy of aluminum-nickel-cobalt (AlNiCo) by means of angle-resolved photoemission, the data show that electron momenta and energies are correlated with the structure of the quasicrystal.

As reported in the August 10 issue of *Nature*, bandlike properties, common in metals and other ordinary crystals, were not expected in quasicrystals. Ordinary metals are good conductors because their valence electrons can move freely from atom to atom; this freedom is facilitated by long-range periodic structure. Since quasicrystals lack periodic structure, theorists expected no such extended electronic states.

"One might imagine that from an electron's point of view the material appears disordered. If so, the electronic states would be confined to localized clusters," Rotenberg said. And theoretical considerations suggested electronic states confined to the quasicrystal's many different local structures.

Rotenberg, Horn, and their colleagues decided to test the prediction with an AlNiCo alloy consisting of stacked planes of atoms exhibiting ten-fold symmetry. By looking at the behavior of electrons in the plane, they could observe the effects of this quasicrystalline ordering; by looking at right angles to the planes, they could observe the effects of the periodic, crystalline-like ordering of the stack.

Peter Gille of the Ludwig-Maximilians-University, Munich, grew the quasicrystal, and the samples were prepared and characterized by Horn and by Wolfgang Theis of the Free University of Berlin. At the ALS, Rotenberg and Horn examined the samples by means of low-energy electron diffraction and by angle-resolved photoemission.

"We measure the emission angles and the kinetic energy of electrons scattered from near the surface of the material by soft x-rays," said Rotenberg. "These are the valence electrons, not as tightly bound as electrons near the atomic cores."

The sample is rotated to get a complete distribution of electron angles and energies. The eventual result is a plot of the electronic states of AlNiCo's valence electrons in "momentum space," the mathematical space in which such fundamental concepts as Fermi surfaces and Brillouin zones are constructed and on which much of the band theory of solids is based.

Rotenberg said, "Our principal findings were that the distribution of the electronic states in momentum space correlates with the electron diffraction pattern, just like in an ordinary crystal. The electrons aren't localized to clusters; instead, they feel the long-range quasicrystal potential."

"We found that the electrons propagate nearly freely, like conduction electrons in an ordinary metal," he continued, "and we found there is a Fermi surface, crossed by nickel and cobalt *d*-electrons. Its topology should determine some of the material's fundamental properties."

Materials with Purple Fluorite Structure may Serve Well in Long-Term Radioactive Waste Container

In a search for a group of materials that may safely contain radioactive waste for long-term storage, an international team of scientists have found that materials with the purple fluorite structure should hold up extraordinarily well under irradiation. The key seems to be that the atoms in the material's structure are relatively disordered and can shift positions with ease, thereby tolerating minute defects caused by radiation.

For several years, researchers looking for better storage materials than those currently used have directed their studies to a class of materials that belongs to a larger group of ceramics called "complex oxides." The materials in this class share a basic chemical formula: two different pairs of metallic cations and seven oxygen atoms. Depending on their size, the cation pairs may give these materials either a highly ordered or a somewhat disordered structure.

A material akin to the shiny, brown

https://doi.org/10.1557/mrs2000.194 Published online by Cambridge University Press

mineral, pyrochlore, results when the size of the cation pairs differs so much that they cannot easily trade places. A structure more similar to that of the purple mineral, fluorite, occurs when the pairs are close in size. In this case, the cations switch places readily, creating a poorly ordered pattern.

In the past, scientists held that the materials with the brown pyrochlore structure were promising candidates for use in waste containment because they would be chemically compatible with the waste constituents. Whether such storage materials would withstand the long-term effects of radiation, however, has been unclear.

Radiation-induced defects would cause more commotion in the rigid crystal structure of the pyrochlore group.

"If a material wants to be highly ordered, and the defects are putting atoms where the material doesn't want them, that raises the energy in the structure. Ultimately, the material may have so much energy that it will suffer unwanted structural change," said Kurt Sickafus of Los Alamos National Laboratory in New Mexico.

As reported in the August 4 issue of *Science*, Sickafus and his colleagues have used computer simulations in determining that in these materials, atoms can shift around to accommodate the defects with little effort.

The researchers performed some preliminary experiments, irradiating one crystal with a pyrochlore structure, and another with a fluorite structure. As the team had predicted, the highly ordered atoms in the pyrochlore structure changed into an amorphous jumble, while the fluorite structure remained intact.

Both the pyrochlore- and fluorite-type complex oxides are crystalline materials, meaning they consist of units of atoms that, overall, are regularly spaced. Sickafus and his colleagues suspect that other crystalline materials with relatively disordered structures may be resistant to radiation damage as well.

Phage-Display Libraries Allow Identification, Development, and Amplification of Binding between Organic Peptides and Inorganic Semiconductors

Living systems can be used to produce microscopically small components of uniform size that potentially can be used to build electronic devices, according to researchers at The University of Texas at Austin. By combining proteins from viruses with inorganic elements commonly used as semiconductors, the research team produced hybrid materials called electronic biocomposite materials. By extending the processes that result in naturally occurring biocomposites to substances commonly used in construction of electronic components, the scientists said they are paving the way for development of potential building blocks for transistors, wires, connectors, sensors, and computer chips far smaller than devices manufactured so far.

As reported in the June 8 issue of *Nature*, Angela M. Belcher, an assistant professor in the Department of Chemistry and Biochemistry, and her graduate student Sandra R. Whaley have been isolating viruses containing proteins that can recognize and combine with gallium arsenide, silicon, indium phosphides, and zinc selenide. Belcher and her team have identified proteins at the ends of viruses that can tell the difference between similar semiconductor alloys and bind to the ones the scientists prefer.

When the living proteins bind to the inorganic particles chosen by the scientists, the particles eventually will be "assembled" by the proteins into desired patterns. In effect, the living organisms "grow" uniform components at the nanoscale.

Belcher said her team went through 100 million viruses before slowly determining which ones worked best with certain materials. She said various virus and semiconductor combinations were tried. Only proteins that bound themselves tightly to the semiconductor survived the experiment and were cloned by Whaley.

In a commentary on this topic published in the same issue of *Nature*, Chad A. Mirkin and T. Andrew Taton of the Center for Nanofabrication and Molecular Self-Assembly at Northwestern University said that the approach used by Belcher and her colleagues can be applied to all materials; in essence, they "may have discovered a way of directly interfacing biomolecules with any inorganic structure."

"Moreover," they said, "different parts of the same biomolecule could be designed to selectively recognize and organize multiple, inorganic building blocks, creating structures with even greater spatial control." □

https://doi.org/10.1557/mrs2000.194 Published online by Cambridge University Press