semiconductors become viable, and standard solution-processing techniques can be used.

In this study the researchers investigated devices made from pentacene, PTV, and P3HT. Electrodes and interconnect lines were photochemically patterned on glass or 50-μm thick polyimide foils using 200-nm thin polyaniline (PANI) films. A 300-nm thick layer of commercially available photoresist compound was deposited on the first layer by spincoating, creating the gate dielectric and insulation for the interconnect lines. Contact holes were masked into the photoresist layer. Finally, the source and drain electrodes were masked into the top PANI layer; after spincoating, a low-ohmic via (typically $< 1\ k\Omega$) formed between the top source and drain electrodes of one transistor and the bottom-gate electrode of another. Top-gate devices fabricated for comparison using the same methods yielded vias with resistance values in the MΩ range.

The pentacene transistors gave the best results, with mobilities in the range of $1 \times 10^{-2}\ cm^2/Vs$, versus 3×10^{-3} for P3HT and 1×10^{-3} for PTV. A programmable code generator was fabricated combining over 300 transistors and 200 vias to form a clock-generator, a 5-bit counter, a decoder logic function, and 15 program pads in one integrated circuit. Again, the pentacene device performed best, achieving a transmission rate of 100 bit/s. Further research to improve the shelf life of these organic semiconductors is needed before practical devices can be achieved.

TIM PALUCKA

Quasicrystal-Filled Polymers Outperforms Other Polymer Composite in Wear-Resistance Properties

Valerie Sheares, a researcher at Ames Laboratory and assistant professor of chemistry specializing in polymer research at Iowa State University, has combined quasicrystals and polymers in a composite that outperforms similar materials in wear-resistance tests. In addition to the improved performance of the polymers, the composite offers a more versatile way of using quasicrystalline powders, which could make the materials more appealing to industry.

"It's a unique material," said Sheares, who has applied for a patent on the quasicrystal-filled polymers. "It's very hard, it's not abrasive, and it has low thermal conductivity."

To determine whether the wear-resistant properties of quasicrystals had transferred to the composite, half-dollar-sized disks of the material were placed on the turntable of a wear-testing device and a small stainless-steel ball was placed in the device's arm. A weight of 1–2 pounds was attached to the middle of the arm to hold the ball in contact with the composite material as the disk spun at a rate of 125 rpm.

Afterwards, the disks and the steel balls were examined to determine how much of each surface had worn away. Results indicated that the quasicrystal-filled polymers were between five and 10 times better in resisting wear than any other polymer or polymer composite that was tested.

Even more significant was the near-perfect condition of the steel ball. "As hard as quasicrystals are, you have to wonder what happens to the other surface scraping against it," Sheares said. "Quasicrystals outperform every other hard filler in that the steel ball remains basically unchanged. When we tested silicon-carbide fillers, the surface of the ball was completely eroded away because silicon carbide is hard and abrasive. Quasicrystals are hard and nonabrasive. Those two things don't usually go together."

Since polymer-processing techniques are already well-known, Sheares said the

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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

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