MEETING BRIEFS

Materials Scientists View Hot Wires and Bends by the Bay

SAN FRANCISCO—At the spring meeting of the Materials Research Society, held 8 to 12 April, 3000 scientists heard 2600 papers on topics ranging from semiconductors to solar cells. Highlights included a new way of making a superconducting wire and the first atomic-scale images of a crystalline bend.

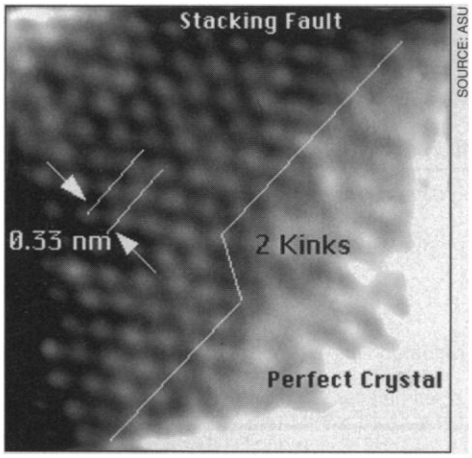
Kinky Pictures

It's easy to see that materials can bend; it's much harder to see the atomic-scale events that allow them to do so. But at the meeting, a team of researchers from Arizona State University (ASU) in Tempe and the University of Köln in Germany showed the first images to capture a few hardy atoms in the act of breaking ranks with their neighbors in a silicon wafer, initiating a bend.

The researchers, ASU physicists John Spence and Harry Kolar, along with physicist Helmut Alexander of the University of Köln, used a transmission electron microscope (TEM) to image atomic "kinks": clusters of atoms that adopt bonding and stacking arrangements that depart from those used by the rest of the atoms in their row of the crystalline lattice, much like a squad of brazen soldiers jumping ahead of an advancing front. That front is the leading edge of a so-called "stacking fault," a ribbon of atoms in a crystalline plane that have rearranged the way they pack together to reduce strain. These faults, led by the kinks, race through the bending crystal like waves moving through water, with the normal stacking pattern reforming behind them after they pass.

"The fact that they could see these kinks was quite a feat," says John Hirth, a professor of materials science and engineering at Washington State University in Pullman, who first predicted these kinks and their motion in 1959 along with physicist Jens Lothe, currently at the University of Bristol in the United Kingdom. High-powered microscopes have spotted the motion of the leading and trailing edges of the faults, known as dislocation lines. But this is the first time researchers have zoomed in on the details of that movement. Not only does the new work confirm his theory, he says, it also opens the door to making new measurements that should help researchers refine their understanding of how materials deform and apply it to making them stronger.

To capture an image of the kinks, researchers needed a microscope that could image the internal structure of a material with atomic resolution. That meant the TEM; other atomic-resolution microscopes, such as the scanning tunneling microscope, only track atoms on the surface of a material. A TEM projects a beam of electrons through a bulk sample, much as a slide projector sends light through a slide. Because electrons pass at different speeds through atom-dense and atom-sparse regions, the difference in their arrival times on the other side let researchers determine atomic positions with a resolution of a few angstroms. And because atoms in stacking faults sit in a slightly different arrangement than do those in the regular crystalline lattice, they tend to deflect passing electrons from the TEM beam in different directions. So by using a series of filtering techniques, the researchers were able to highlight just the atoms in the stacking fault.



Finding fault. As a silicon crystal bends, "kinks" advance a region of altered atomic stacking.

But first they had to catch the racing faults. To do so, Alexander froze them in place. First he heated a wafer of crystalline silicon to 1000 degrees Celsius, then bent it in a vise to create the faults and—while it was still in the vise—rapidly cooled it down. Because silicon atoms can't rearrange their bonds at room temperature, the stacking faults stopped in their tracks. Spence and Kolar then placed this wafer in their TEM and took snapshots of the faults. The images clearly showed the presence of kinks in the dislocation lines at the boundaries.

Then the researchers set the faults in motion again by heating the wafer back up to 600 degrees Celsius. They were able to capture a series of successive TEM images on video. The images allowed the researchers to determine the speed of the kinks and how much energy it takes for them to form and move forward. While this isn't essential information for silicon, which is generally used in settings where its strength isn't crucial, the same technique could be applied to high-strength materials such as the metal alloys used to make jet turbine blades, says Spence. There it could point to ways of keeping order in the atomic ranks—and creating stronger materials.

Rolling Out Superconductors

High-temperature superconductor (HTS) wires are on a roll. Last year, U.S. and Japanese researchers showed that they could forge a brittle ceramic called YBCO into wirelike strips that conduct electricity without resistance even in high magnetic fields. These fields, inescapable in devices such as electric motors and magnetic resonance imagers, wilt the performance of HTS wires made from other materials. YBCO stands up to the fields, so the ability to make wires created a lot of excitement. Unfortunately, the method used to make last year's wire is somewhat slow for industrial use. This year in San Francisco, however, researchers rolled out a faster technique—literally.

A group from Oak Ridge National Laboratory in Tennessee used a simple pair of metal rollers and a heat treatment to align the crystalline grains in a nickel strip, creating a template that gives subsequently grown crystals of YBCO (yttrium-barium-copper-oxide) a consistent orientation—a prerequisite for high-current superconducting wires. The Oak Ridge roller scheme was able to create wires that carry up to 385,000 amperes per square centimeter of cross section (A/cm^2) in a magnetic field of 4 tesla. Although that's lower than the capacity of wires made with last year's slower technique, known as ion beam assisted deposition, or IBAD—which uses a barrage of ions to etch a template for the superconducting grains—other researchers praised the new result for its relative simplicity.

"It's quite an astounding result," says Steve Foltyn, a physicist and materials scientist at Los Alamos National Laboratory in New Mexico, who helped perfect the IBAD technique. "Essentially what they have is a way to make a [YBCO wire] without the IBAD process, which is a slow and ultimately costly step. It brings this technology an important step closer to commercialization."

Templating techniques for YBCO wires are necessary because misaligned crystalline lattices in neighboring microscopic grains impede the ability of superconducting electrons to hop from one grain to the next down the wire. The IBAD method, developed by researchers at Los Alamos National Laboratory and Fujikura Ltd., applies a pair of ion beams to a crystalline compound as it grows on a metal substrate, stripping away misaligned grains one by one to create an oriented template for YBCO deposition. The Oak Ridge team, led by Amit Goyal, David Norton, Donald Kroeger, and John Budai, realized they could speed things up a great deal if they could pattern the underlying metal substrate directly.

They hit on the notion of running a metal, such as nickel, between two rollers: It's long been known that the rolling and heating process allows metal grains to minimize their energy by aligning in the direction of the rolling. Putting this simple idea to work wasn't as easy as it sounds, however. For one thing, oxygen atoms from air tend to coat the nickel surface, disrupting the carefully prepared texture and the alignment of any crystals grown on top. For another, nickel atoms have a nasty habit of trading places with copper atoms in YBCO, destroying its ability to superconduct.

To get around the oxygen problem, the researchers used a technique known as electron beam evaporation to lay down a thin sheet of palladium atop the nickel. Palladium, explains Norton, has a nonreactive electronic structure, so it doesn't attract oxygens. And to keep the nickel from swiping YBCO's copper, the scientists used high-speed growth techniques to lay down two more buffer layers—made of cerium-oxide and yttria-stabilized zirconia—on top of the palladium. The templating effect of the nickel propagates through all these layers to the YBCO layer on the top.

When the researchers tested their sample at 77 kelvin, it conducted 300,000 A/cm^2 in no magnetic field and 15,000 A/cm^2 in a 4-tesla magnetic field oriented in a way that severely damages a superconductor's ability to carry current. In a 4-tesla field oriented in a more forgiving direction, they reported that a YBCO wire with a somewhat different buffer-layer architecture conducted 385,000 A/cm^2. (They declined to give further details of the new high-powered structure until they patent it.)

Using their new rolling technique, the Oak Ridge team has already shown that they can make 1-meter-long metal strips with uniform grain alignment. Moreover, says Goyal, "there's no intrinsic limitation for making long samples." There is an extrinsic limit, however: cost. At this point, the buffer and YBCO layers need to be grown in a vacuum, which makes for expensive manufacturing facilities. The speed, however, may make it the most cost-effective way of rolling out high-powered wire.

–Robert F. Service

PLANETARY SCIENCE

Are Asteroids Flying Piles of Rubble?

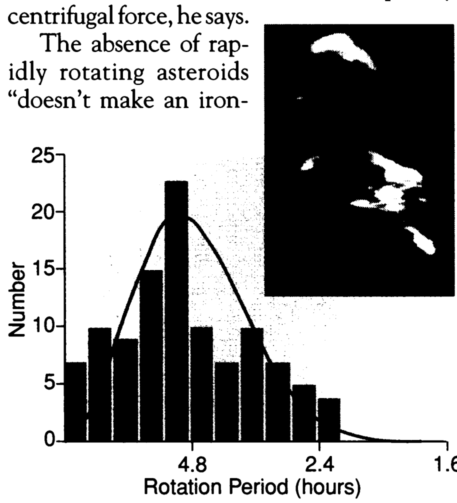
Asteroids lead a hard life, punctuated by collisions. That has led many planetary scientists to wonder whether, instead of being solid chunks of rock, asteroids are simply jumbles of rocks held together by their own gravity. The close-up views of the asteroids Gaspra and Ida sent back by the Galileo spacecraft when it passed by in 1991 and 1993 didn't settle the issue, because the asteroid surfaces were covered with debris that hid any inner structure. But at last month's Lunar and Planetary Science Conference in Houston, astronomer Alan Harris of the Jet Propulsion Laboratory in Pasadena, California, presented the strongest evidence yet that most asteroids are simply piles of rubble.

Harris's case, which researchers call intriguing if not compelling, is based on the absence of rapidly rotating small asteroids, which suggests that only gravity, not the strength of solid rock, is holding asteroids together against centrifugal force. If his findings hold up, they could shed light on asteroid evolution and behavior. But the results could also mean that it might be harder to protect Earth from an asteroid on a collision course.

Because of their small size, asteroids appear simply as points of light to ground-based telescopes. But astronomers can detect pulsations in the brightness of the sunlight reflected off irregularly shaped asteroids as they rotate. From the repetition rate of the brightness variations, they infer the length of an asteroid "day."

Using the 24-inch telescope at Table Mountain Observatory in California, Harris and his colleague James Young logged the rotation periods of about a dozen asteroids, to which Harris added results from other astronomers to get rotation data on a total of 107 asteroids ranging in size from 200 meters to 10 kilometers. These small asteroids tend to rotate faster than their bigger siblings—the average period is 5 hours—which should make them a more sensitive test of asteroid strength. And Harris found that none of his asteroids has a period of less than 2.3 hours, a cutoff that makes sense, Harris calculated, if asteroids are rubble piles held together only by gravity. Any rubble pile rotating at a speed faster than this cutoff would be torn apart by centrifugal force, he says.

The absence of rapidly rotating asteroids "doesn't make an iron-clad case," says Harris, "but it looks from this work that most asteroids 1 to 10 kilometers in diameter are rubble piles." William Bottke of the California Institute of Technology (Caltech) agrees. At the Houston conference, he and Jay Melosh of the University of Arizona argued that rubble-pile asteroids could explain close pairs of craters common on the planets. A rubble pile, they said, could be torn into two smaller bodies orbiting each other if it passed close to Earth; if it hit Earth the next time around, it would create a crater pair. "It all points in the direction of a lot of asteroids being rubble piles," says Bottke.



SOURCE: A. HARRIS IMAGE: S. OSTRO *ET AL.*/JPL

Limits to spin. A lack of rapid rotators suggests asteroids are composed of multiple blocks, as a radar view of Toutatis implies.

While piles of rubble in space may seem less threatening than huge solid rocks, they would wreak as much havoc if they hit Earth, and they could be harder to fend off. Researchers looking for applications for technology developed during the Strategic Defense Initiative in the 1980s have proposed shattering and dispersing an oncoming asteroid with nuclear bombs or other devices (*Science*, 16 June 1995, p. 1562). But in Houston, Thomas Ahrens of Caltech said a computer model of rubble-pile collisions he developed with colleague Stanley Love predicted that "it's just a heck of a lot harder to break up a bag of sand than a rock."

Still, it may be too early for the Star Warriors to start worrying. Planetary scientist Joseph Veverka of Cornell University is among those who want more evidence. "Are most asteroids rubble piles," he asks, "or just some? We don't know that yet." The rubble-pile picture will get a big test when NASA's recently launched Near-Earth Asteroid Rendezvous (NEAR) spacecraft orbits the asteroid Eros in 1999. The rate at which NEAR orbits Eros will reveal whether Eros is a solid, high-density rock or a low-density mix of rubble and fine debris. Harris already has his money down: "I would predict Eros is a rubble pile."

–Richard A. Kerr