MATERIALS SCIENCE AND ENGINEERING DEPARTMENT

Iowa State University

MSE ELEMENTS

Vol. 10, No. 2

A gem of a discovery

"We have high-speed, precision diamond saws in the lab that can cut virtually anything, and we weren't able to cut this material," Cook said. "That caught our attention."

Photo courtesy of Ames Lab

Bruce Cook (PhD'99), an Ames Lab scientist, and MSE associate professor **Alan Russell** have made a gem of a discovery—a new material that's second only to diamonds in hardness.

Russell and Cook have applied for a patent on the material, which they have tentatively called BAM (boron aluminum magnesium). Russell says tests indicate that BAM is a cheaper alternative to cubic boron-nitride, the material now ranked second. And, unlike other ultra-hard materials, the alloy can conduct electricity well.

The new material was created by introducing small amounts of silicon and titanium into an aluminum, magnesium, and boron intermetallic compound.

Cook and Russell tested samples of the alloy on several different instruments, all of which measured the hardness of the material at approximately 46 gigapascals (the equivalent of 6.67 million pounds per square inch), slightly higher than cubic boron-nitride's hardness of about 45 GPa (6.53 million psi). By contrast, diamond's hardness is estimated at between 70 and 100 GPa (10.15-14.5 million psi).

The aluminum-magnesium-boron compound could also be the least expensive of the three materials. Its estimated cost is about $700 per pound, compared to cubic boron-nitride's price tag of up to $7,000 per pound and diamond's cost of $2,000 per pound. That could mean huge savings for manufacturers that use these types of materials in abrasives and cutting tools for grinding and machining applications.

"The fact that industries are willing to pay that price for cubic boron-nitride gives some insight into what a critical industrial process this is," said Russell. "Cutting iron and steel is an enormous part of the U.S. manufacturing economy."

According to the researchers, diamond isn't an option for cutting and grinding steel at high speeds because it reacts with iron when brought into contact with iron-based materials at high temperatures.

Cubic boron-nitride doesn't have the iron reactivity problem, but it's costly because it is produced at extremely high temperatures and high pressure. "It requires pressures of 50,000 atmospheres," Russell said. "That's similar to what you would encounter 100 miles deep into the earth."

Continued on page 2

Greetings from the MSE department!

ELEMENTS

Last time I chatted with you in this column, I said we would soon implement the new materials engineering undergraduate curriculum. The end of the academic year is approaching, and I am pleased to report that the transition to our new program has been nearly seamless. I don't want to give the impression that it was easy; scheduling new courses, preparing new laboratories, and making course substitutions required a lot of hard work and sacrifice on the part of our faculty and in particular, Professor **Kristen Constant**, who oversaw the implementation of the new curriculum. I am happy to tell you that no student was deprived of a course needed this year because of the transition. Next year, we will offer several new courses and graduate our first class of materials engineering B.S. degree recipients. After this year's success, I am confident that it will be smooth sailing!

During the past year we added two new faculty members to the MSE family. We are pleased to appoint **Dr. John Snyder** as an adjunct assistant professor and **Dr. Ralph Napolitano** as a tenure-track assistant professor. You can read more about Snyder in this issue; we'll feature Napolitano in our fall issue.

I would also like to take this opportunity to ask once again for your assistance in recognizing and nominating our highly successful alumni for awards. I am sure we have many alumni, possibly yourself, who are eminently qualified for an alumni award. So, please do not be overly modest; let us know of your accomplishments or those of a fellow alum. We would be proud to nominate more of our alumni for these awards, but we often lack information about the professional accomplishments of our alumni.

On April 20th we will be holding our annual Scholarship Awards Banquet in conjunction with the MSE industrial advisory council dinner. The banquet is getting bigger and better every year. This year's banquet appears to top them all. NASA astronaut **Dr. Sandy Agnus** will be the banquet speaker this year.

As usual, we will hold a reception at the annual meeting of the American Ceramic Society in St. Louis Ballroom A, Adam's Mark Hotel in St. Louis on Monday, May 1st. If you plan to attend the meeting or happen to be in the area, please join us and meet our bright students and faculty members. Looking forward to seeing you in St. Louis!

Mufit Akinc, Professor and Chair

Continued from page 1

A gem of a discovery

Early tests indicate that the new compound doesn't react with iron the way diamond does. A company that manufactures tools, dies, and molds for the automotive industry tested samples of the material and reported favorable results. The company was especially pleased that the material didn't fracture, a common problem for many brittle, abrasive materials.

Cook discovered the hardness of the aluminum-magnesium-boron compound by accident. He was researching its thermoelectric properties in 1992 when he discovered that he couldn't cut the samples he'd made. "We have high-speed, precision diamond saws in the lab that can cut virtually anything, and we weren't able to cut this material," Cook said. "That caught our attention."

The new material has captured the attention of others as well. Russell has fielded calls from several industry representatives who are interested in the material and its possible applications. An article on the material appeared on the front page of *The Wall Street Journal* in late January.

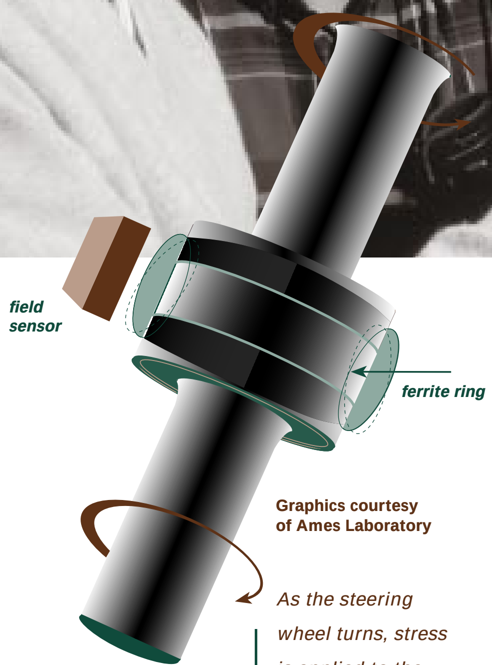
Although the material has been around for awhile, its mechanical properties were never investigated. "When Bruce discovered the hardness, it was unexpected and something that no one had thought to look for previously," Russell said.

It is also an unlikely candidate for a hard material because of the structure of its unit cell, or fundamental building block. "A diamond has eight carbon atoms in a unit cell. It's a very simple, highly symmetric structure," Russell explained. "If you gave this structure to a panel of experts and asked if it would be hard, they'd say, 'Nah, the crystal structure is all wrong.' But it's extremely hard. That's the kind of unexpected finding that excites scientists."

Cook said the complex chemical structure makes it possible to enhance the compound's hardness by substituting other elements, such as silicon. "We thought we could change the bonding environment if we added silicon to the structure, and it worked. It made the material harder," he said.

Russell and Cook hope to secure funding for an extensive study of the material's preparation and properties. Among their research priorities are a better scientific understanding of the material itself and figuring out the best, most inexpensive way to produce large quantities of the compound. They also want to investigate the possibility of producing the material as a uniform powder that could be deposited as a wear-resistant coating on surfaces such as mining equipment and surgical tools.

Making cars more fuel efficient



Graphics courtesy of Ames Laboratory

As the steering wheel turns, stress is applied to the ferrite ring in proportion to the amount of force applied by the driver. This produces a change that is detected by a field sensor, which interprets how much force should be applied to turn the wheels.

New technology could lead to a lightweight alternative to hydraulic power-steering systems.

David Jiles, MSE professor, and **Bill McCallum**, MSE adjunct professor, have developed a material that may steer automotive companies toward their goal of lighter, more fuel-efficient vehicles.

Researchers say a 1/4-inch-thick ring of the material could be used in an electronic torque sensor to regulate the steering power provided to a car's wheels by an electric motor. This would enable automakers to eliminate the heavy, energy-draining hydraulic pumps currently used in power-steering systems.

"Replacing the hydraulic power-steering system with an electrical system that uses this type of sensor should improve the fuel efficiency of a car by about 5 percent," said Jiles, who is also a senior physicist at Ames Lab. Lighter, more energy-efficient vehicles would use less gasoline, conserving fossil fuels and reducing transportation costs, he added.

Jiles and McCallum, a senior Ames Lab materials scientist, looked at a number of options during the past five years as they searched for an inexpensive sensor material that met the specifications of the auto industry. They said only one viable option emerged: a composite consisting of cobalt ferrite (a compound of cobalt oxide and iron oxide) and small amounts of nickel and silver to hold the material together.

"I think we've looked into all of the possibilities and it's difficult to conceive of a better material at this time," Jiles said. "The fact that it's also a relatively low-priced material makes it very attractive."

He said current power-steering systems use a hydraulic assist that requires the continuous circulation of hydraulic oil in order to sense and respond to steering changes. This produces a constant drain on the car's engine, even when the steering wheel isn't being turned. "The hydraulic system has to be pressurized in order to work and the car uses up energy to do that," Jiles said. "Also, the hydraulic system weighs a lot, so there's a significant weight reduction if you can replace it with an electrical system."

A sensor using a small ring of the cobalt-ferrite composite would be strategically placed on the steering column. As a driver turned the wheel, the magnetization of the cobalt-ferrite ring would change in proportion to the amount of force applied by the driver. The change would be detected by a nearby field sensor that would interpret how much force should be applied to turn the wheels and then relay the information to an electrical power-assist motor. Unlike the hydraulic system, the electrical system would consume minimal energy when the steering wheel was not being turned.

Continued on page 4

Small particles, big impact

MSE Assistant Professor Joshua Otaigbe has received funds to develop technologies for making polymers that are smaller than pieces of dust.

"The implications are astounding," said Otaigbe. "This will have as big an impact on our lives as transistors did 40 years ago."

With a three-year, $257,000 grant from the National Science Foundation, Otaigbe will attempt to produce, characterize, and model the structures and properties of nanoparticles–very small particles that are made from plastic. Polymer nanotechnology is the science of developing tools and machines that are no larger than a single molecule.

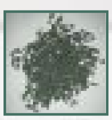
Otaigbe has been working on a method for using micro-droplets of an evaporating polymer solution that dries to form the nanoparticles. A scientist can put chemicals on the inside or outside of the particles to use in different applications, he said.

"It is a very exciting area of research that is new and evolving," Otaigbe added. "There is a need to constantly reduce the size of products and engineering materials. The smaller the size, the easier it is to engineer and use; the easier it is to control."

These materials could have a variety of uses, but Otaigbe believes that one of the first could be specially engineered molecules that would be introduced into cells within the body as part of medical treatments.

Otaigbe has filed a patent application on the micro-droplet technique. He hopes that NSF funding will allow him to improve on that technique and get a fundamental understanding of the nature and behavior of the particles.

"Only by having that understanding can we use it for useful applications," he explained. "There is a lot of interest in trying to make nanoparticles useful because they are not commercially available right now."



A molecular dynamics simulation is used to create a schematic images of polymer nano- and macro-scale particles generated from the submicrometer liquid droplets experiment. The solvent molecules (not shown) are streaming away as the polymer molecules are left behind collapsing into a nano- or micrometer particle.

Continued from page 3

Fuel-efficient cars

What makes the cobalt-ferrite composite ideal for this application is a property known as magnetostriction, Jiles said. Magnetostrictive materials undergo slight length changes when magnetized. Jiles and McCallum take advantage of that property, but in reverse. In their approach, the turn of the steering wheel would apply stress to the cobalt-ferrite ring, producing a change in the magnetic field it emits.

Cobalt ferrite maintains its magnetostrictive abilities throughout the temperature range specified by the auto industry, from minus 40˚ C (-40˚ F) to 150˚ C (302˚ F). Jiles said that's necessary because automakers don't agree on the best location on the steering column for the torque sensor. Some want it in the engine compartment, where it would be subjected to engine heat as well as winter conditions.

McCallum added that cobalt ferrite also meets the strength and corrosion-resistance requirements for the sensor material. "This ceramic-metallic composite is similar in concept to materials used in high-strength tool bits where excellent mechanical properties are needed," he said. "And cobalt ferrite is basically high-class rust, so it's hard to corrode any further."

Jiles said the composite is also a cost-effective choice. While other materials may rank higher in terms of magnetostriction, they're too costly to be used in wide-scale production. For example, "if you normalize the measurements based on the cost of the different materials, you can see that our cobalt-ferrite material is far and away the best performer," Jiles said, adding that the compound is 20-100 times less expensive than other materials they considered.

Electronic torque sensors would also allow steering systems to be fine-tuned with the addition of software and other controls. "With a hydraulic power-steering assist, there's not much that you can do," Jiles said.

Jiles and McCallum have applied for a patent on the cobalt-ferrite compound and plan to continue working with automotive manufacturers interested in using the material in an electronic torque sensor.

Glassy separators for stronger batteries

It's common knowledge that glass is a fragile material. However, *Steve Martin,* ***MSE professor, chooses to focus on its inherent strength and versatility, particularly on a type of glass that holds remarkable potential to make batteries and fuel cells more efficient.***

Martin's research, funded by a $500,000 NSF grant and a continuing grant through the Office of Naval Research, explores the nature of chalcogenide glass as a possible substitute for polymer separators in batteries.

Polymer separators, between the anode and cathode component of cells, allow for the essential electro-chemical reaction that generates power. These separating membranes, however, lose efficiency after prolonged use. They degrade and eventually decompose.

Martin and his research students are looking to chalcogenide glasses as a possible substitute because unlike common glasses that are oxide-based (for example, the glass used to manufacture windows), chalcogenide glass is based on the elements of sulfur, selenium, and tellurium.

"We've only just begun to look at this study of sulfide glasses," Martin said. "The number of combinations and possibilities is astronomical."

The solid nature of glass enables it to tolerate higher temperatures than polymers, according to Martin, and this makes it an ideal candidate for exploring its limits for use in batteries and fuel cells. A study of chalcogenide glass, which has been previously used in infrared sensors and optical components and systems, may yield a new material that is stronger and more reliable than polymers.

Longer lasting batteries spell not just an economic windfall for consumers, but also environmental benefits in reducing waste and chemical hazards in landfills.

Iowa Companies Assistance Program helps small firms

The Iowa Companies Assistance Program (ICAP), a branch of the Ames Laboratory Materials Preparation Center, provides up to 40 hours of free technical assistance on various materials, mechanical testing, composition analysis and comparison, and the preparation and fabrication of specialty materials. Here's how ICAP assisted four Iowa firms.

Welding Productivity

Workers at a firm in southeastern Iowa needed 75 minutes to prepare and butt weld the ends of large T-shaped bars of hard rail steel. The CIRAS field agent asked Paul Berge of ICAP to suggest a faster process. Berge suggested the "thermit" process, which now does the job in less than 10 minutes. (Thermit, a mixture of fine aluminum and an iron oxide used for certain welding processes, produces intense heat when ignited.)

Foundry Scrap Reduction

To keep an important customer's business, an established aluminum foundry had to reduce its scrap rate. The scrap was caused by tiny holes in the castings. When asked to help determine the cause of these holes, ICAP devised a solution for the problem in less than six weeks. The solution hinged on analyzing the gases involved. Everybody was happy with the results.

Materials Selection

After outsourcing most of its product, a conveyor-manufacturing firm began experiencing many chain failures. ICAP analyzed the metals involved and recommended a more suitable material for this application. The problem was solved in less than two weeks.

Process Parameters

ICAP is also available to analyze and perfect proposed products or processes for start-up companies. For example, one entrepreneur came up with the idea of combining the paraffin by-product of a refining process with sawdust to make fuel pellets. ICAP determined recommended temperatures and methods for the process. The client was happy with the results. In another example, an inventor sought evaluation of the thermal feasibility of a heat/cold exchange system to be used in a home-based pasteurizing machine.

Each of the preceding solutions was determined within the first 40 hours of involvement by ICAP so there were no costs to the firms requesting assistance. A review of one CIRAS field specialist's records shows more than eight recent examples of using this unique assistance program. To access this assistance program to help increase your company's productivity and profitability, contact Paul Berge or Tom Lagrasso, Ames Laboratory, Iowa State University, 111 Metals Development, Ames, IA 50011-3020. Telephone: 800/884-8548. Fax: 515/294-8727. The e-mail address is: icap@iastate.edu.

MSE grad is pioneer in U.S. steel industry

Ardella Crozier, **MetE'89, has become an indispensable link in the commercial sales department of LTV Steel, the third-largest steel manufacturer in the U.S. Last fall, the company selected Crozier to attend an eight-day International Iron and Steel Management Conference in London, England. She was one of just 34 engineers chosen from throughout the world to participate in the event.**

"I was very excited," said Crozier, who worked her way from student intern to management at the plant.

Her tenacity caught the eye of Jim Haeck, executive vice president of the Cleveland-based company, who recommended Crozier for the convention.

"Adella is very intelligent and analytical," Haeck said. "She investigates things, instead of just accepting them at face value. When I first met her, I admired that she had gotten her degree in metallurgical engineering, because it's not something that a lot of women do."

Crozier admits that she's one of a few women, and even fewer black women, working in the steel industry, but she says she's not intimidated.

"I don't really notice it," she said. The atmosphere was pretty much the same in my college courses. I've always loved math and science. And from the third grade, I knew I wanted to be an engineer."

With her sights focused, Crozier sharpened her skills with science fairs and summer workshops, occasionally winning honors for her projects.

"I was attracted to the objectivity of this discipline," said the former national merit scholar and high school valedictorian. "I like things like math and science that have a definite answer or result. I've never liked subjective things."

Her international excursion, however, found Crozier searching for her subjective, more emotional side.

"What I've learned from the conference is to appreciate the diversity with which people do and create things," she said.

That philosophy should help Crozier, who also earned an M.B.A. at the University of Chicago, as she acts as a liaison between corporations who do business with LTV and the steelworkers who fashion their products.

Snyder joins faculty

The newest member of the MSE faculty is **John Snyder**. Snyder is an adjunct assistant professor and an associate scientist in the metallurgy and ceramics program at Ames Laboratory. He joined Iowa State University after work-ing in industry as a thin-film process consultant at Commonwealth Scientific Corporation in Alexandria, Virginia. Prior to that, he was a National Research Council Associate at the U.S. Naval Research Laboratory in Washington, D.C. He has also worked for Allied Signal Corporation and as a teacher aide and substitute teacher for Maryland School for the Deaf.

John Snyder

Snyder's research interests focus on the fabrication, structure, and properties of magnetic materials, including deposition and characterization of magnetic thin films and multilayers; magnetostrictive materials; Ba-hexaferrite and other ferrites; permanent magnet materials; EXAFS characterization of local structure and anisotropy; and thin-film materials and structures for data storage, memory, and sensor applications. He has authored 21 peer-reviewed articles and 37 research proposals, and has presented his work at nearly 60 conferences. He also has two patent disclosures.

Snyder was educated at the Data Storage Systems Center, Physics Department, and Electrical Engineering Department of Carnegie Mellon University, receiving the degrees of Ph.D. in physics and M.S. in electrical engineering. His undergraduate education was at Moravian College, where he graduated with honors in physics.

Snyder has been awarded a National Research Council Associateship and an IBM Fellowship. He is a member of several professional groups and honor societies.

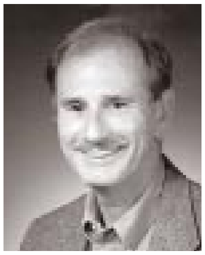
OTHER NEWS:

Science Teachers—Learn more about materials science ideas for the classroom by visiting the following Web site: **http://www.mse.iastate.edu/excel/**. You'll gain some insight on the scanning electron microscope (SEM) and the various opportunities you can explore by using it. Also, your students will be able to expand their knowledge and have fun with science all at the same time! You may contact the department main office at 515-294-1214 for further information.

Congratulations to **Scott Chumbley**, associate professor, and his wife **Amy**, who will soon be parents!

HONORS and AWARDS


Krista Briley


Larry Genalo


Brynne Kriegermeier


Martha Selby


Brad Tischendorf

AWARDS:

Members of the Engineering Student Council recently honored **Krista Briley**, secretary II, and **Alan Russell**, associate professor. The group voted Krista as the Outstanding Staff Person in MSE; Alan was named Outstanding MSE Faculty Member. The awards were presented in February at the council's first Leadership Awards banquet.

Larry Genalo, associate professor, has been awarded the LEAD Program Involvement Award for his work with minority students in the College of Engineering.

Brynne Kriegermeier, MSE undergraduate student, has been named an undergraduate research scholar and associate member of Sigma Xi, the scientific research honor society.

Martha Selby, adjunct assistant professor, has received the United Way's Spirit Award for exceptional dedication, professionalism, and commitment to volunteerism.

John Snyder, adjunct assistant professor, has been elevated to the grade of senior member of the Institute of Electrical and Electronics Engineers, Inc. Senior member status is the highest professional grade for which application may be made. In addition, Snyder has been named to *Who's Who in Science and Engineering* for the third time and will be listed in the Fifth Edition (2000/2001). He also received the Inventor Incentive Award from Ames Lab, DOE.

Brad Tischendorf, MSE graduate student, won the Norbert J. Kreidl Award for Young Scholars given by the glass and optical materials division of the American Ceramic Society for outstanding student research. (See the "What's New" section and **http://www.mse.iastate.edu/poly-comp** for more details) He will receive the award at the ACerS meeting in St. Louis on May 1st.

PATENTS:

Alan Constant, assistant professor, received a patent for "Dielectric for Amorphous Silicon Transistors."

Steve W. Martin, professor, received a patent for "Fast Proton Conducting Chalcogenide Glasses."

O. J. Whittemore, BSCerE'40, CerE(Prof.)'50, has received two patents ('97 and '99) for his work on "A Method for the Extrusion of the Ceramic Filter Media," a process used in the production of water filters. The process was listed as one of the top ceramic innovations of the 20th century by the American Ceramic Society.

Cybercontacts

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ACerS MSE Alumni and Friends Reception

Monday,
May 1st, 2000
6:00 - 7:30 p.m.

Adam's Mark Hotel
of St. Louis
St. Louis Ballroom A
Fourth and Chestnut St.
St. Louis, MO 63102

MSE Awards Banquet

Thursday,
April 20th, 2000
6:00 - 9:00 p.m.

Scheman Building
Iowa State Center
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MSE SURVEY INSERT

Parents and Alumni:

We're interested in your opinions! Please take a few minutes to respond to the enclosed survey. Complete instructions are included. The survey is also available on the web at www.mse.iastate.edu/survey.

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