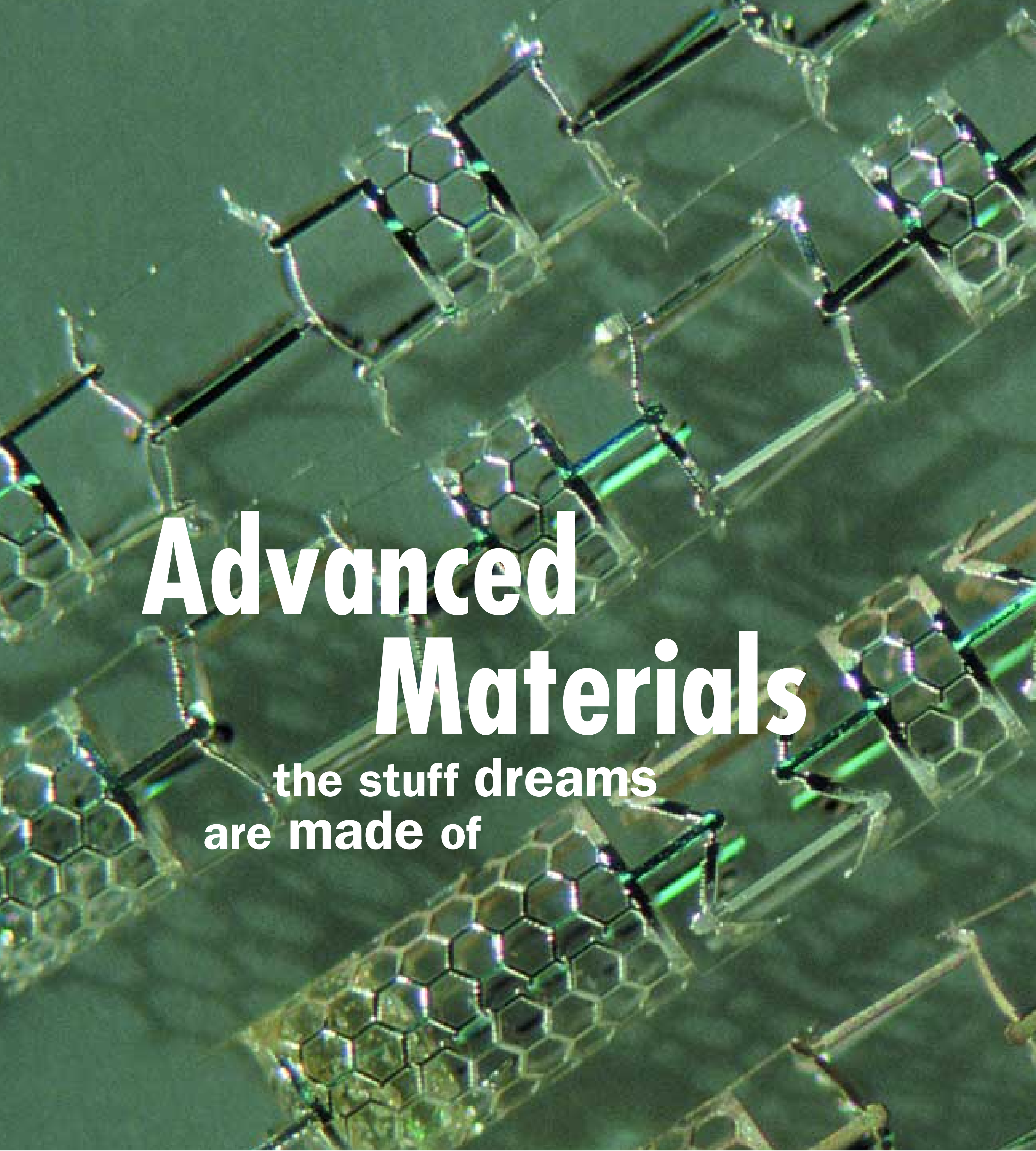
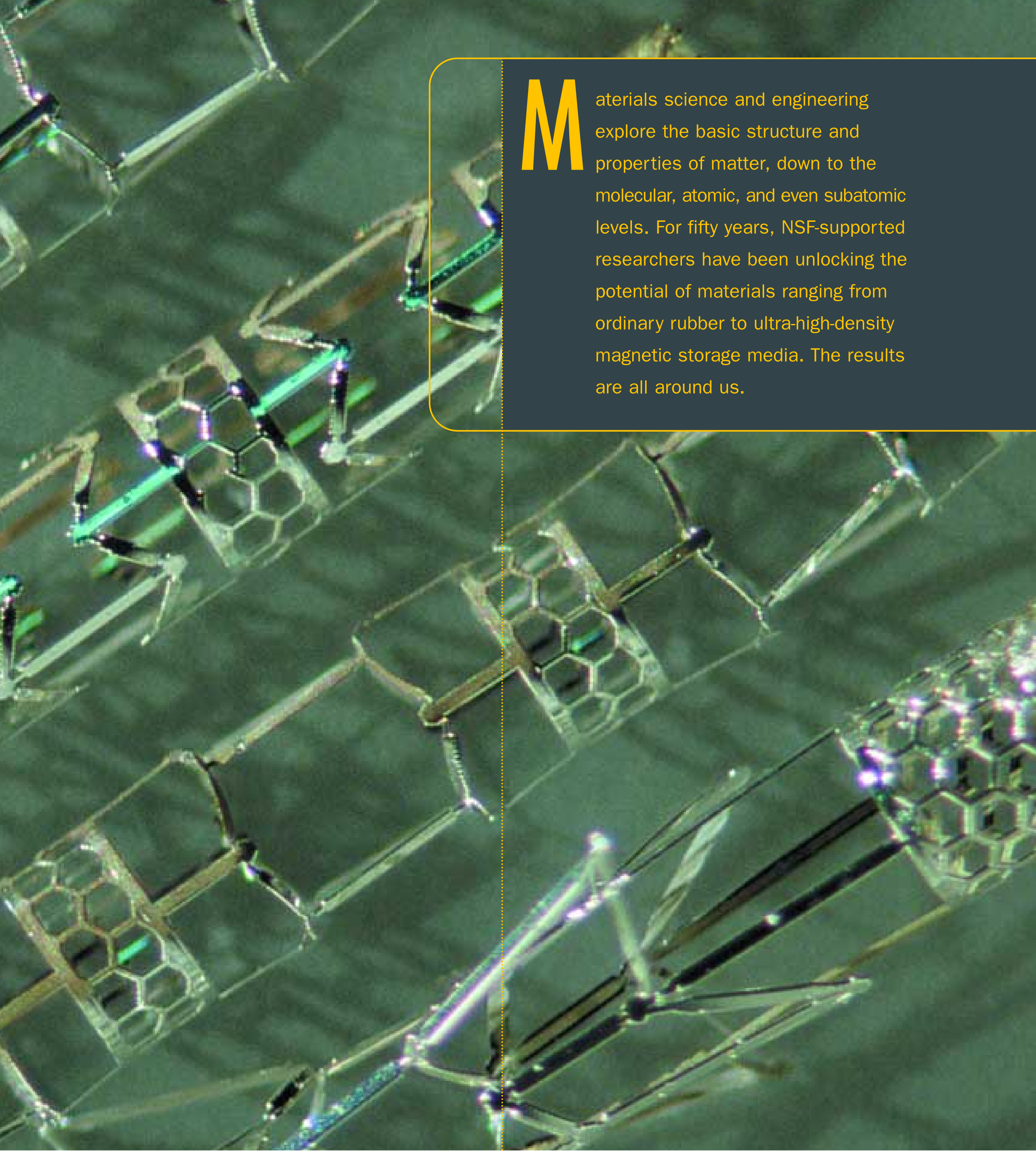
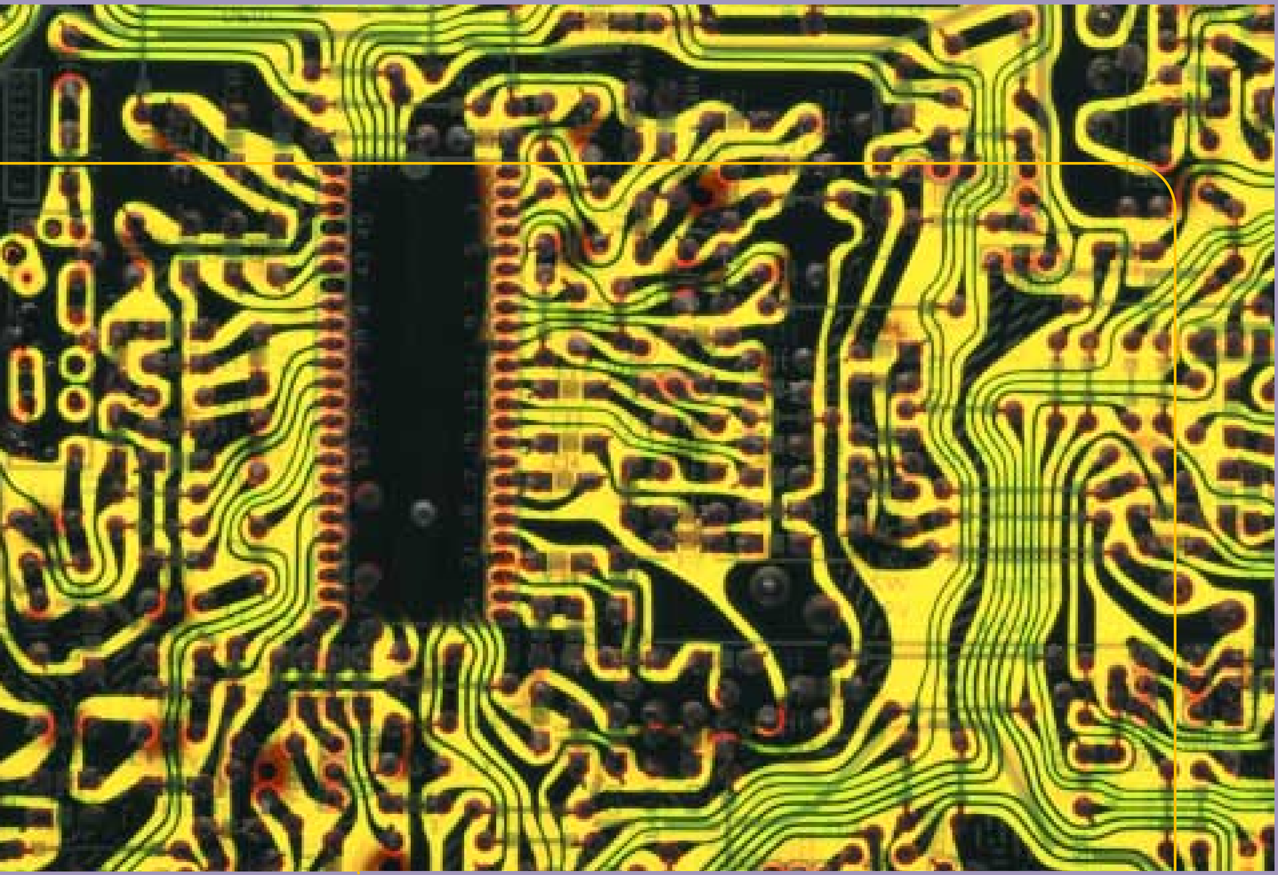


Advanced Materials

the stuff dreams are made of



Materials science and engineering explore the basic structure and properties of matter, down to the molecular, atomic, and even subatomic levels. For fifty years, NSF-supported researchers have been unlocking the potential of materials ranging from ordinary rubber to ultra-high-density magnetic storage media. The results are all around us.



NSF funds a broad array of research to discover new materials and processing methods and enhance knowledge about the structures and functions of materials. A high priority for NSF since the 1950s, materials research has led to countless innovations that now pervade everyday life. Hand-held wireless cellular telephones and oxygen-sensing anti-pollution devices in automobiles number among the breakthroughs. NSF supports both individual investigators and collaborative centers at universities, which bring together materials scientists, including engineers, chemists, physicists, biologists, metallurgists, computer scientists, and other researchers to work on projects whose commercial potential attracts significant funding from industry as well as government. Future discoveries in NSF-supported materials research laboratories will transform life in ways we cannot yet imagine. Semiconductor substrates whose storage capacity is hundreds of times greater than the current industry standard; artificial skin that the body accepts as its own; and the remarkable buckyball, a recently discovered form of carbon with unprecedented strength and hundreds of potential uses ranging from spaceships to pharmaceuticals—all these materials and more will change the way we live and work.

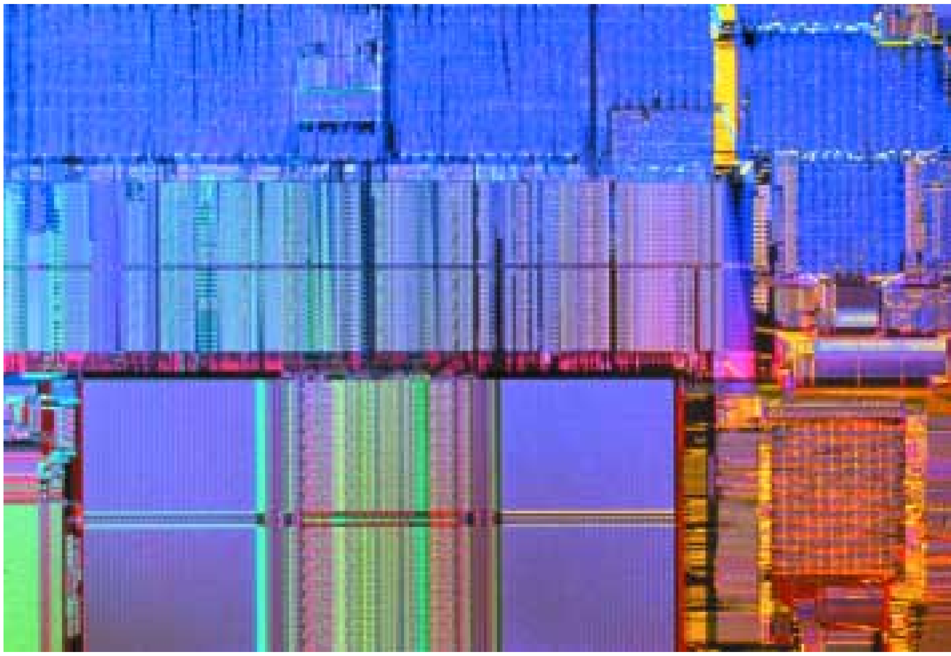
From Craft to Science in Two Centuries

What determines a civilization's ability to move forward? In large measure, it is mastery over materials. The key indicators of progress—military prowess; the ability to produce goods; advances in transportation, agriculture, and the arts—all reflect the degree to which humans have been able to work with materials and put them to productive use.

Humans have progressed from the Stone Age, the Bronze Age, and the Iron Age to the Silicon Age and the Age of Materials Science. Scientists and engineers have achieved mastery over not only silicon, but also over glass, copper, concrete, alloys or combinations of aluminum and exotic metals like titanium, plastics, and wholly new "designer materials" that are configured one atomic layer at a time.

It may seem hard to believe, but it has been only in the last 200 years that we humans have understood elemental science well enough and had the instrumentation necessary to go beyond fabrication—taking a material more or less in its raw form and making something out of it. Once we began to explore the basic structure and properties of materials, a wealth of discoveries ensued:

- Ceramics with distinctive electrical properties that make it possible to miniaturize wireless communications devices ranging from cellular telephones to global positioning technologies.
- A totally new family of materials called organic metals: conductive polymers (compounds assembled like chains, with numerous units linked together to form a whole) that are soluble, can be processed, and whose potential applications include "smart" window coatings with optical and transparency properties that can be changed electrically.
- An optic layer that fits over liquid crystal displays to maintain high contrast even when the display is viewed from an angle—now used in instrument panels of military and commercial aircraft.
- Nonlinear optical crystals of lithium niobate, a unique combination of materials that is ideal for many laser applications.
- Artificial skin that bonds to human tissue so successfully that many burn victims now heal with a fraction of the scarring that once was considered inevitable.



Microprocessors such as this one, which contains more than one million transistors, have led to advances in all areas of science and engineering. NSF support has enabled researchers to create computer chips that are incredibly tiny and can perform complex computations faster than the blink of an eye.

NSF-funded research played a pivotal role in all of these and many other innovations. Through support of individual researchers and multidisciplinary centers around the country, NSF is fueling a vast number of diverse projects in materials science and engineering. Undertaken for the purpose of advancing knowledge, many materials sciences projects also have industry co-sponsors who eagerly anticipate commercialization of the results.

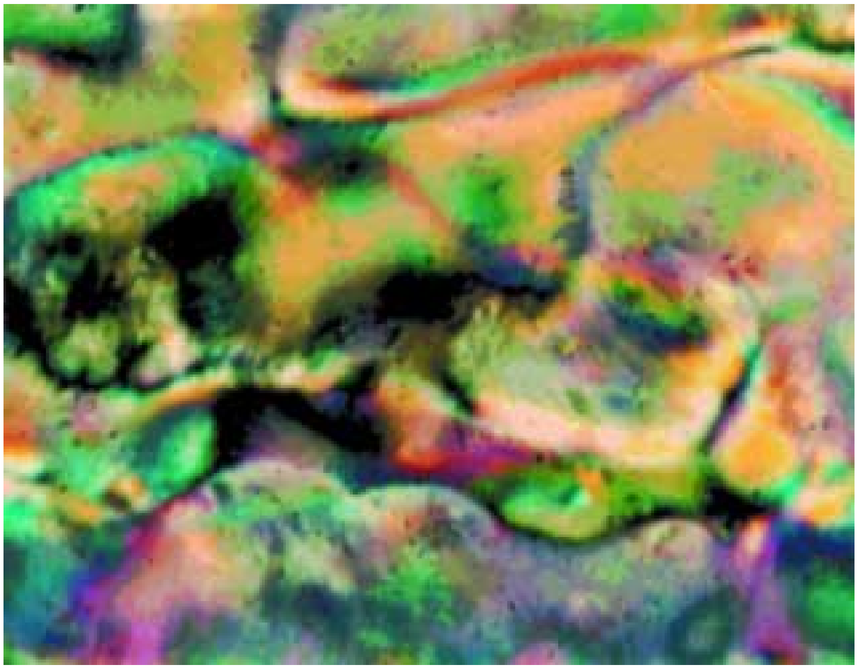
A Never-Ending Search for the New and Useful

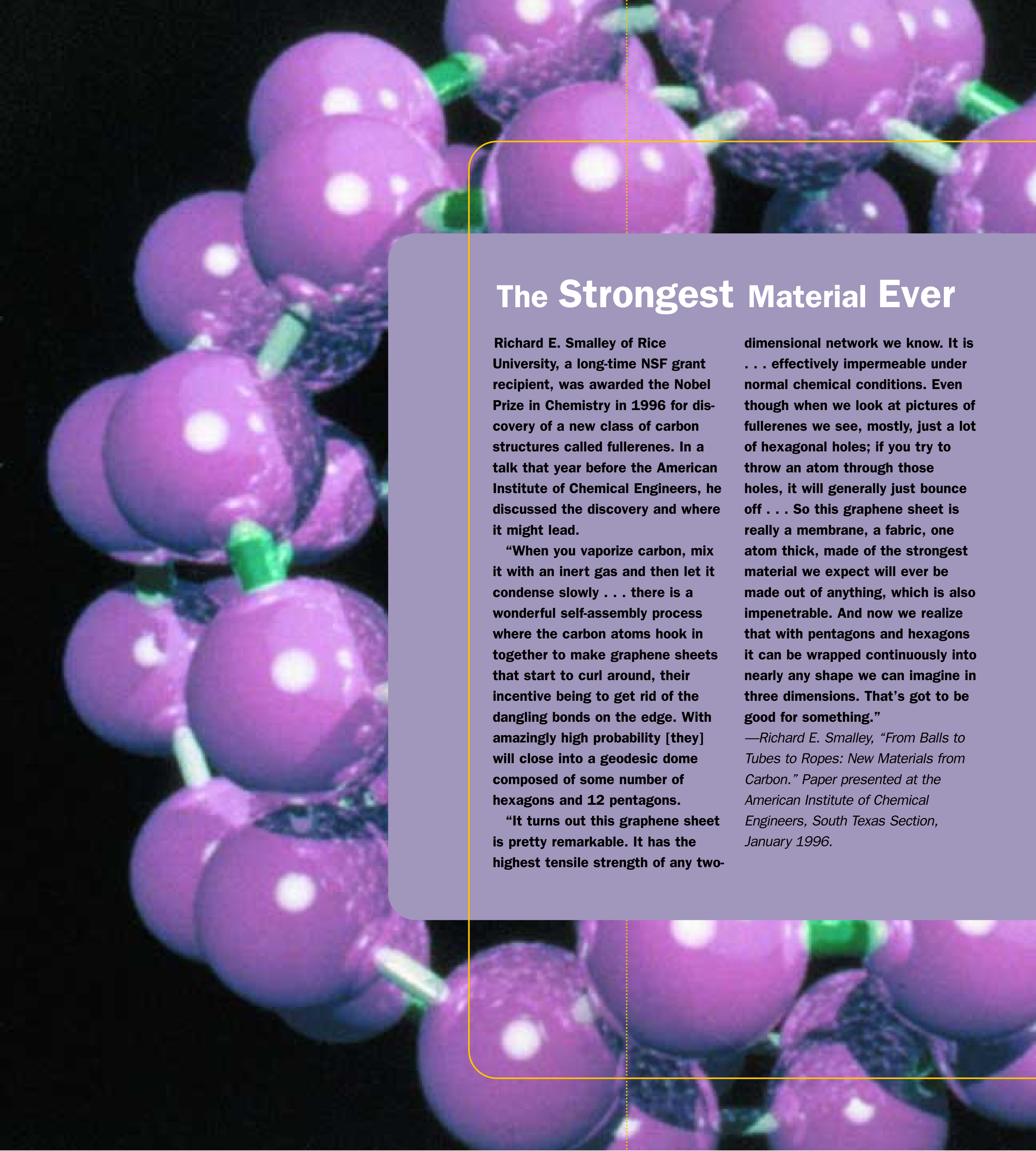
Materials research grew out of a union among physicists, chemists, engineers, metallurgists, and other scientists, including biologists. Today, the field has a body of literature and a research agenda of its own. NSF supports both experimental and theoretical research with three primary objectives: to synthesize novel materials with desirable properties, to advance fundamental understanding of the behavior and properties of materials, and to develop new and creative approaches to materials processing.

Materials have been high on NSF's research agenda since the earliest days. In the 1950s, NSF built on the momentum of the World War II effort by making grants to the University of Akron to help researchers with their work on durable forms of rubber that could withstand elevated temperatures and pressures. Rubber belongs to the class of materials known as polymers, gigantic molecules made up of single units, or monomers, that link together in chains of varying lengths. Other naturally occurring polymers include complex carbohydrates, cellulose, proteins, spider silk, and DNA. For the Akron researchers, it was a smooth transition from rubber to an ever-widening range of synthetic polymers, examples of which are found today in products ranging from clothing and packaging to automobile and aircraft components.

In the center of what is now called "Polymer Valley," Akron University's College of Polymer Science and Engineering houses a faculty whose names are legendary in the world of rubber and plastic. Known both for their own work—much of it funded by NSF—and for their students' contributions to industry, these faculty members include Alan Gent and Joseph P. Kennedy. Gent, an authority on deformation and fracture processes in rubbery, crystalline, and glassy polymers, served on the space shuttle redesign committee after the 1986 Challenger disaster. Kennedy conducted some of the earliest research on vulcanized rubber and has received two American Chemical Society awards for pioneering work in polymer synthesis.

With support from NSF, researchers are attempting to create materials that will improve the manufacturing of cars, furniture, and other items. Bruce Novak at the University of Massachusetts, is studying thin films such as the one below in an effort to test and produce such novel substances.





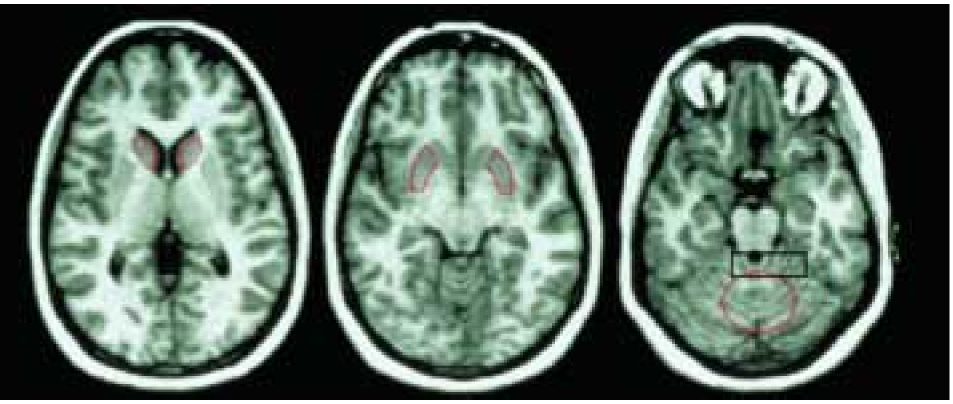
The Strongest Material Ever

Richard E. Smalley of Rice University, a long-time NSF grant recipient, was awarded the Nobel Prize in Chemistry in 1996 for discovery of a new class of carbon structures called fullerenes. In a talk that year before the American Institute of Chemical Engineers, he discussed the discovery and where it might lead.

"When you vaporize carbon, mix it with an inert gas and then let it condense slowly . . . there is a wonderful self-assembly process where the carbon atoms hook in together to make graphene sheets that start to curl around, their incentive being to get rid of the dangling bonds on the edge. With amazingly high probability [they] will close into a geodesic dome composed of some number of hexagons and 12 pentagons.

"It turns out this graphene sheet is pretty remarkable. It has the highest tensile strength of any two-dimensional network we know. It is . . . effectively impermeable under normal chemical conditions. Even though when we look at pictures of fullerenes we see, mostly, just a lot of hexagonal holes; if you try to throw an atom through those holes, it will generally just bounce off . . . So this graphene sheet is really a membrane, a fabric, one atom thick, made of the strongest material we expect will ever be made out of anything, which is also impenetrable. And now we realize that with pentagons and hexagons it can be wrapped continuously into nearly any shape we can imagine in three dimensions. That's got to be good for something."

—Richard E. Smalley, "From Balls to Tubes to Ropes: New Materials from Carbon." Paper presented at the American Institute of Chemical Engineers, South Texas Section, January 1996.



The strong magnetic properties of superconductors made it possible for researchers to develop magnets for MRI (magnetic resonance imaging) systems. NSF-funded research into superconductivity has enabled advances in MRI technology, which, in turn, have led to more accurate diagnosis of disease.

Today's vibrant materials science community began its ascent in 1957. After the launch of Sputnik by the Soviet Union, the Department of Defense lobbied strenuously to make space-related research and technology a national priority. The effort gave birth to Interdisciplinary Laboratories (IDLs) under the Department of Defense's Advanced Research Projects Agency (DARPA). DARPA took a more integrated approach than did most universities at the time and brought together physicists, chemists, engineers, and metallurgists into collaborative research teams. They were encouraged to cross departmental boundaries and use systems approaches to attack complex problems of materials synthesis or processing. Graduate students trained in the IDLs accepted multidisciplinary research as the norm, which influenced the way they approached their own work.

In 1972, DARPA transferred the management of the IDLs—600 faculty members at twelve universities—to NSF. NSF's involvement gave even stronger emphasis to the multidisciplinary team approach in the way funding opportunities were defined. "NSF makes awards to the projects that look as if they will have the most impact on science or technology, or both," explains W. Lance Haworth, executive officer in the Division of Materials Research, which is part of NSF's Directorate for Mathematical and Physical Sciences. "Those projects typically involve people from several disciplines. The field benefits from this approach—sparks fly at the boundaries."

One of the best places to see "sparks fly" is at the Data Storage Systems Center, an NSF-funded Engineering Research Center (ERC) at Carnegie Mellon University in Pittsburgh and the largest academic research effort in recording technology in the United States. Engineers, physicists, chemists, and materials science researchers at the Carnegie Mellon Center are working together to increase dramatically the data storage capacity of computer systems. Among their goals, Center researchers aim to demonstrate the feasibility of 100 gigabits (100 billion bits) per square inch recording density for magnetic and optical recording systems by 2003—hundreds of times higher than the current industry standard.

The Center recently made advances toward this goal by synthesizing two new materials. Each has led to the development of high-quality magneto-optic recording media for ultra-high densities. One is an artificially structured material made of very thin layers of platinum and cobalt. The other is a magnetic oxide. Both provide dramatically improved performance over current systems. In a recent breakthrough experiment, researchers achieved recording densities of forty-five gigabits per square inch with platinum and cobalt films.

Other NSF-supported centers also have taken the challenge of advancing high-density storage media. At the University of Alabama's Center for Materials for Information Technology, which is home to one of the twenty-nine Materials Research Science and Engineering Centers (MRSEC) that NSF supports. The MRSECs stress pioneering materials research, education, and outreach, and they foster multidisciplinary collaborations between academia and industry. One interdisciplinary team at University of Alabama's MRSEC is studying the physical properties of granular films that have shown potential as a future low-noise, ultra high density magnetic media. A second interdisciplinary team at the Alabama Center is exploring the functional limits of magnetic materials in high speed switching. The work could lead to the development of hard disk drive heads and storage media that are capable of operating at frequencies approaching a gigahertz.

Other sparks at the boundaries have developed into industry standards. For example, work on semiconductor lasers made the photonics revolution of the last three decades possible. Photonics uses light for signaling and conducting information along a pathway (electronics uses electrons for the same purpose). Researchers at several NSF-funded centers, including the Center for Materials Science and Engineering at the Massachusetts Institute of Technology, are continuing research into photonics, a field that has already produced compact disk players, laser printers, bar code readers, and medical applications, as well as new systems for displaying information.

Triumphs in Everyday Life

NSF supported many of the pioneers whose investigative triumphs led to innovations that are now part of everyday life. One example is Art Heuer of Case Western Reserve University, whose research on transformation toughening in ceramics led to a way of producing strong ceramics capable of operating and surviving in extremely demanding environments. As ceramics cool after firing, their tiny constituent particles expand slightly and cause occasional microcracks. To reduce the risk of cracking, the particles that make up the ceramics must be extremely small—on the order of one micron. Using zirconium dioxide-based ceramics, Heuer and others were able to prevent cracking by using appropriate processing to control the expansion of the particles during cooling. To the delight of the automotive industry, these tough ceramics, when integrated into catalytic converters, also increased gas mileage.

Many other founders of modern-day materials science have been longtime recipients of NSF support. Alan MacDiarmid of the University of Pennsylvania and Alan Heeger of the University of California at Santa Barbara are considered the fathers of conducting polymers, or synthetic metals. MacDiarmid, a chemist, and Heeger, a physicist, were the first to demonstrate that conjugated, or paired, polymers such as polyacetylene can be "doped," or intentionally changed to the metallic state. The process of doping involves introducing into a substance an additive or impurity that

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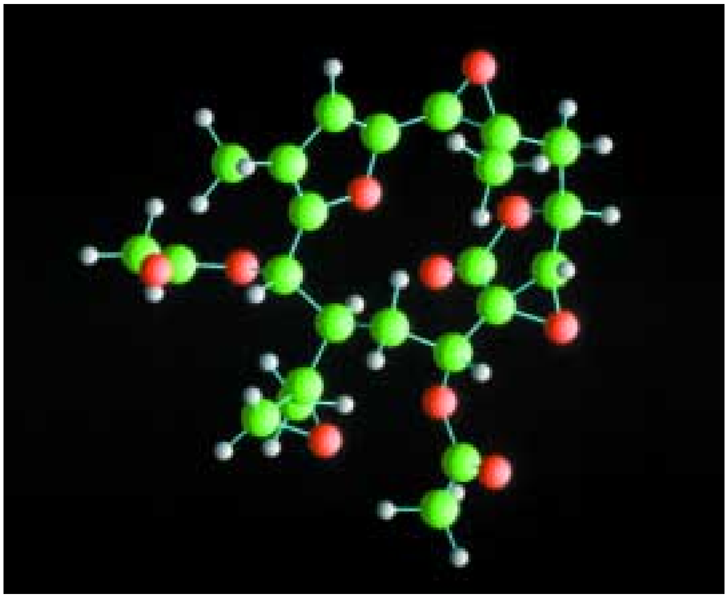
Molecular models such as this are helping researchers discover and create the next generation of superstrong materials.



Tomorrow's Materials: Lighter, Tougher, Faster

Heavy Lifting

We are familiar with composites in recreational applications such as tennis rackets, golf clubs, and sailboat masts. These materials also bring comfort to thousands of people as prosthetic arms and legs that are much lighter than wood or metal versions. At higher performance levels, the success of satellites and stealth aircraft depends on composites.

In aircraft, weight affects every performance factor, and composites offer high load-bearing at minimal weight without deterioration at high or low temperatures. NSF-supported researchers and engineers are developing tough new materials like the resin and fiber composite used in the tail section of the Boeing 777. That composite is lighter than aluminum but far more durable and fatigue-resistant at high altitudes. Use of such advanced composites reduces the weight of an 8,000-pound tail section by 15 percent, which means designers can increase the aircraft's payload and fuel capacity.

Meanwhile, down on the ground, advanced composites are being evaluated for use in building the U.S. infrastructure for the 21st century. In one test, researchers at the Center for High-Performance Polymeric Adhesives and Composites at Virginia Polytechnic Institute and State University have partnered with the Virginia Transportation Research Council, the state Transportation Department, the town of Blacksburg, and manufacturer Strongwell to test the long-term effectiveness of composites as an alternative to steel in bridges. (The center at Virginia Tech, one of the first Science and Technology Centers (STC) established by NSF, is transitioning to self-sufficiency after eleven years of Foundation support.) Deteriorating steel beams on the Tom's River bridge, located on a rural road near Virginia Tech, were replaced with structural beams made out of a strong composite. The new bridge was completed in 1997 and since then, Virginia Tech researchers have been closely monitoring it to determine how well the composite beams withstand the tests of time, traffic, and weather. Depending on the results of this field test and others that are planned or underway, bridges constructed of composites could become as familiar in the future as tennis rackets and aircraft made of composites are today.

Standing Up Under Stress

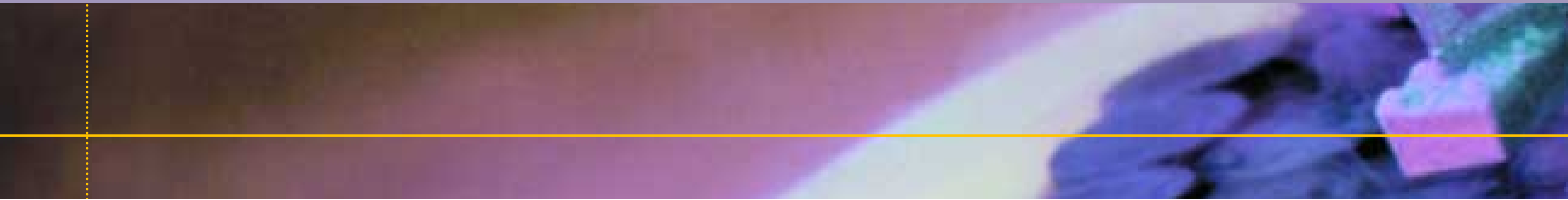
Designing composites is one method of fabricating novel materials with special properties. Surface engineering is another. Thermal spray processing—a group of techniques that can propel a range of materials including metals, ceramics, polymers, and composites onto substrates to form a new outer layer—has proven to be a cost-effective method for engineering surfaces that are resistant to corrosion, wear, high or low temperatures, or other stresses. Current applications include the aerospace, marine and automobile industries, power generation, paper processing and printing, and infrastructure building.

Despite this widespread use of thermal spray processing, the underlying science was little understood until recently. That's beginning to change, due in part to the work of researchers and students at the Center for Thermal Spray Research, the NSF-supported Materials Research Science and Engineering Center (MRSEC) based at the State University of New York (SUNY) at Stony Brook, who are studying the characteristics of various spray processes, feedstock materials, and resulting spray deposits. Their goals include the development of methodology for selecting source materials and achieving a fundamental understanding of flame-particle interactions and the physical properties of spray deposits. Earlier research by Herbert Herman, the Center's director and professor of materials science at SUNY-Stony Brook, and his students advanced the use of plasma guns to apply coatings that protect against very high temperatures and corrosive environments. Plasma-sprayed coatings are commonly used on components for aircraft engines and gas turbines and in other areas where materials are required to function under extreme conditions

Superconductivity We Can Live With

A superconducting material transmits electricity with virtually no energy loss. In a world where every electrical cord steals some of the current passing through it, a room-temperature superconductor could save billions of dollars. Superconducting computers could run 100 times faster than today's fastest supercomputers.

To compare the normal electrical system with a superconductive one, imagine a ballroom filled with many dancers. In normal material, all of the dancers are moving in different directions at different times, and much of their energy is spent bumping into each other. In a superconductive material, the dancers are synchronized, moving in



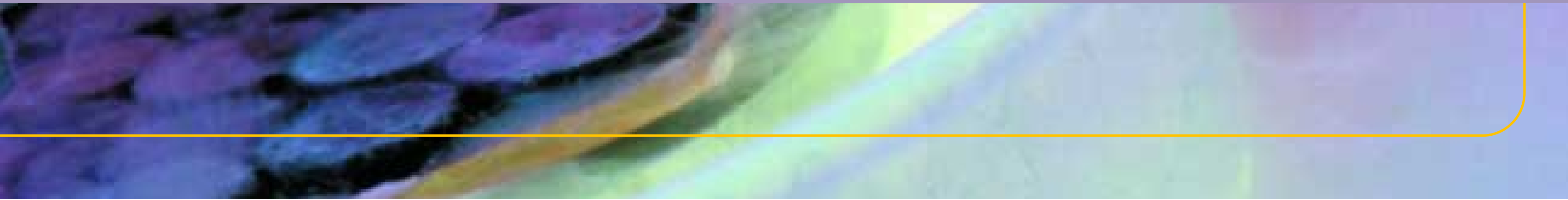
unison, and therefore can spend all of their energy on the dance and none on each other. The dancers represent the electrons of each material, chaotic in the normal setting and well-ordered when the material is superconductive. While the entire theory is more complicated, the overall effect is that the electrons in superconductive material move electrically more easily through the system without wasting energy bumping into each other.

Superconductivity, which occurs in many metals and alloys, isn't yet in widespread use, however. For most of the 20th century, the phenomenon required very cold temperatures. Superconductivity was first observed by Dutch physicist Heike Karmerlingh Onnes in 1911 when he cooled mercury down to -425°F, a few degrees above absolute zero. Until the mid-1980s, commercial superconductors usually used alloys of the metal niobium and required expensive liquid helium to maintain the temperature of the material near absolute zero. The need for expensive refrigerants and thermal insulation rendered these superconductors impractical for all but a limited number of applications. That began to change in 1986 when Alex Müller and Georg Bednorz, researchers at an IBM Research Laboratory in Switzerland, discovered a new class of ceramic materials that are superconductive at higher temperatures. So far, materials have been known to reach the superconductive state at temperatures as high as -209°F, making it possible to use liquid nitrogen coolant, a less costly alternative to liquid helium. Since the mid-1980s, much of the current research has focused on so-called high temperature superconductors. The new superconducting ceramics are hard and brittle, making them more difficult than metal alloys to form into wires. An interdisciplinary team at the NSF-supported MRSEC on Nanostructured Materials and Interfaces, based at the University of Wisconsin-Madison, is focusing on understanding the properties of the grain boundaries of high temperature superconductors. The center's research could lead to better materials processing and the development of a new generation of superconductors for high current and high magnetic field technology.

Even as research continues, superconductors are being used in a number of fields. One of the more visible is medicine. Superconductors have strong magnetic characteristics that have been harnessed in the creation of magnets for MRI (Magnetic Resonance Imaging) systems. An MRI takes images of a patient by recording the density of water molecules or sodium ions within the patient and analyzing the sources. When used for brain scans, this technique allows clinicians to identify the origin of focal epilepsy and to pinpoint the location of a tumor before starting surgery. Similar magnetic resonance systems are used in manufacturing to test components for cracks and other defects.

One of the preeminent facilities for researchers and engineers to test superconductivity and conduct other materials research is the National High Magnetic Field Laboratory (NHMFL), a unique laboratory funded by NSF's Division of Materials Research and the state of Florida and operated as a partnership between Florida State University, the University of Florida, and the Los Alamos National Laboratory in New Mexico. Since it was established in 1990, the NHMFL has made its state-of-the-art magnets available to national users for research in a variety of disciplines including condensed matter physics, chemistry, engineering, geology, and biology, as well as materials science. The NHMFL features several of the world's most powerful magnets, including a hybrid magnet, developed jointly with the Massachusetts Institute of Technology, that delivers continuous magnetic fields of 45 tesla, which is about one million times the Earth's magnetic field. The 45 tesla hybrid consists of two very large magnets. A large resistive magnet (electromagnet) sits at the center of a huge superconducting magnet, which forms the outer layer and is the largest such magnet ever built and operated to such high field. The hybrid's record-setting constant magnetic field strength gives researchers a new scale of magnetic energy to create novel states of matter and probe deeper into electronic and magnetic materials than ever before.

The NHMFL's 45 tesla magnet is cooled to within a few degrees of absolute zero using a superfluid helium cryogenic system. The discovery of superfluid helium was made in 1971 by NSF-funded researchers at Cornell University who found that, at extremely low temperatures, the rare isotope helium-3 has three superfluid states, where the motion of atoms becomes less chaotic. This discovery by David Lee, Douglas Osheroff, and Robert Richardson led to greatly increased activity in low temperature physics and furthered studies of superfluidity. Lee, Osheroff and Richardson received the 1996 Nobel Prize in Physics for their contributions to the field.



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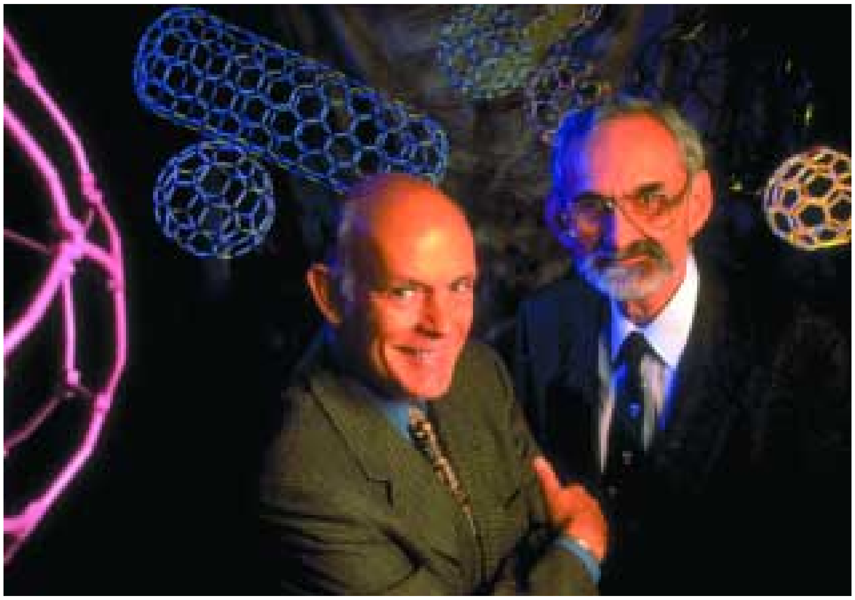
produces a specific and deliberate change in the substance itself. Their work stimulated research worldwide on metallic organic polymers; applications include rechargeable batteries, electromagnetic interference shielding, and corrosion inhibition. Heeger, MacDiarmid, and Japanese researcher Hideki Shirakawa were awarded the 2000 Nobel Prize in Chemistry for the discovery and development of conductive polymers. Another longtime NSF grantee is Richard Stein, who established the highly respected Polymer Research Institute at the University of Massachusetts at Amherst and is known for developing unique methods for studying properties of plastic films, fibers, and rubbers.

One of NSF's best known principal investigators is Richard Smalley of Rice University, who in 1985 discovered a new form of carbon with astounding properties and potential for useful applications. The Buckminsterfullerene, named for the American architect R. Buckminster Fuller, is a hollow cluster of 60 carbon atoms that resembles one of Fuller's geodesic domes. It is the third known form of pure carbon, the first two being graphite and diamond, and is the most spherical and symmetrical large molecule known to exist. "Buckyballs," for which Smalley and his colleagues Harold W. Kroto and Robert F. Curl received the Nobel Prize in chemistry in 1996, are exceedingly rugged and very stable, capable of surviving the temperature extremes of outer space. Numerous applications have been proposed, including optical devices, chemical sensors and chemical separation devices, batteries, and other electrochemical applications such as hydrogen storage media. In addition, medical fields are testing water-soluble buckyballs, with very promising results. The soccer-ball-shaped form of carbon has been found to have the potential to shield nerve cells from many different types of damage including stroke, head trauma, Lou Gehrig's disease, and possibly Alzheimer's disease.

Nobel laureates Robert Curl and Richard Smalley pose with their buckyball models. This superstrong carbon molecule may have applications to chemistry, medicine, and manufacturing.



Designer Molecules Reach New Heights

Smalley and his colleagues discovered fullerenes serendipitously while exploring the basic structure and properties of carbon. In contrast, other NSF-supported investigators deliberately set out to create novel materials with desirable properties. An example is Samuel Stupp, currently Professor of Materials Science at Northwestern University, whose successes while he was at the University of Illinois at Champaign-Urbana were described by writer Robert Service in the April 18, 1997 issue of *Science* magazine.

"Living cells are masters of hierarchical building. For much of their molecular architecture, they first string together amino acids into proteins, then assemble proteins into more complex structures. Chemists have been working to imitate this skill, in the hope of making new materials tailored right down to the arrangement of molecules. Researchers at [the University of Illinois] report taking this assembly process to a new level of sophistication, creating molecules that assemble themselves over several size scales, first forming clusters, then sheets, and, ultimately, thick films. Because the building-block molecules are all oriented in the same direction, the films' properties mirror those of the individual molecules, yielding a bottom surface that's sticky and a top that's slick. This property could make the films useful for everything from anti-icing coatings on airplane wings to anti-blood-clot linings for artificial blood vessels . . ." More recently, Stupp and his research team have had success using molecular self-assembly to change the properties of polymers. Their self-assembly method has potential for producing extremely strong polymers and polymers with improved optical properties, and it could impact such diverse fields as the plastics industry, medicine, and optical communications.

Other advances in new materials are coming out of NSF-supported basic research in the field of condensed-matter physics. Researchers at the NSF-funded centers at the University of Chicago and Cornell University are investigating the fundamental physical structure and properties of material when it is placed under extreme conditions—such as low temperature, high pressure, and high magnetic fields. Investigators look at the novel compositions and structures with extraordinary electrical and optical properties, including metals, insulators, semiconductors, crystals, and granular material. They also learn to control that structure—for example, moving electrons around on the surface of the material. Among other applications, this work will be important as engineers work at creating ultra-high performance computer chips. Other researchers at Michigan State University and Northwestern University are also looking at solid-state chemistry and have synthesized metals with highly efficient thermoelectric properties—that is, the ability to generate electricity when junctions between the metals are maintained at different temperatures. Thermoelectric materials already are used in space applications, but as they improve they may be useful in environmentally friendly refrigeration, thermal suits for diving, and cooling systems for electronic devices.

The Healing Arts Embrace Materials Science

Recent advances in NSF-supported biomaterials research are hastening the development of innovative healing aids. Researchers at Georgia Institute of Technology, California Institute of Technology, and Massachusetts Institute of Technology (MIT) are working with physicians and biological specialists to develop polymer composites for patching wounds, biocompatible casings for cell transplants, scaffolds that guide and encourage cells to form tissue, bioreactors for large-scale production of therapeutic cells, and experimental and theoretical models that predict behavior of these materials *in vivo*. Biomaterials have already been developed to block unwanted reactions between transplanted cells and host tissue and to help prevent scarring during healing. Closest to commercialization is a polymeric material, synthesized at MIT, to which biological cells can adhere. Because the human body accepts biological cells while it might reject the overlying synthetic material, this breakthrough makes possible the development of inexpensive multilayer materials that can promote healing, act as artificial skin, or temporarily replace connective tissue until the body can produce natural tissue to complete the healing process.

Another NSF-supported technology for skin replacement, developed by Ioannis V. Yannas of MIT and his colleagues, received FDA approval in 1996. The Yannas technology addresses the challenge of treating severe burns that result in the loss of dermis, a layer about two millimeters thick that lies beneath the epidermis and does not regenerate when damaged. Traditionally, patients with such severe burns receive skin transplants from sites elsewhere on their bodies, a method that results in scarring. The new technology

NSF-funded researcher Lynn Jelinski at Cornell University is using spiders' silk as a model for creating an incredibly strong and resilient polymer that will have a variety of practical applications.

involves collagen taken from animal tendons. Collagen is part of the structural scaffolding in mammals (analogous to cellulose in plants) that allows tissues to maintain their shape. This collagen is chemically bonded with glycosaminoglycan (GAG) molecules, from animal cartilage, to create a simple model of the extracellular matrix that provides the basis for a new dermis. The collagen-GAG combination "makes a simple chemical analog of the matrices in our own tissues," Yannas explains. GAG cells synthesize a new dermis at the same time that the scaffold is being broken down. Epidermis then grows naturally over the new dermis, unless the wound area is especially large. Patients end up almost completely free of disfiguring scars. The new skin also grows as the patients do, an important consideration for children who have been burned.

Materials for a Small Planet

A number of NSF-supported investigators are looking for more environmentally benign substitutes for chemically synthesized materials currently in use. Dragline silk from the orb-weaving spider *Nephila clavipes* is one of the most promising new biomolecular materials, thanks to the silk's great strength and flexibility—greater even than the lightweight fiber used to reinforce bulletproof helmets. Also attractive is the environmentally friendly process used to make the silk, which the spider spins from a water-based solution. Intrigued by this spider, which actually makes seven different types of silk, Lynn Jelinski, then at Cornell University and currently chemistry professor and Vice Chancellor for Research and Graduate Studies at Louisiana State University, had a vision that high-performance, renewable, silk-like polymers eventually can be made using the tools of biotechnology. She thinks scientists may be able to synthesize the key spider genes and insert them in plants, which then would express the protein polymers. The resultant materials might be used in products ranging from reinforced tennis rackets to automobile tires.

Discoveries of new materials lead to new questions, the answers to which create opportunities to find still more new materials. An example of this cycle is the work of Donald R. Paul of the University of Texas at Austin, an authority on the ways in which polymers interact when blended. Polymer blends are a powerful way of enhancing toughness or otherwise tailoring the performance of a given material. The information generated by Paul's research may lead to the development of high-performance polymeric alloys that could be used to replace metal components in automobiles. These lightweight and easy-to-fabricate alloys could help create vehicles that have greater fuel efficiency and produce fewer emissions.

At the same time, materials synthesis research is being used to investigate new metal alloys. To create these alloys, researchers must learn about the chemistry of the alloy, the microstructure basic to the alloy, and its macroscopic behavior. NSF-funded researchers, including those at the University of Alabama at Birmingham, are investigating how to control the alloy composition. Some of the alloys are thin films that will find their way into the electrical industry. Others may be used in newly designed vehicles. These alloys are not only stronger and lighter than their predecessors, but also more resistant to stress and fatigue, producing a more fuel-efficient, longer-lasting vehicle.

In research supported jointly by NSF and the U.S. Environmental Protection Agency, an environmentally benign method of polymer synthesis was discovered using liquid carbon dioxide in place of toxic volatile organic solvents. The work by Joseph DeSimone, professor of chemistry at the University of North Carolina at Chapel Hill and professor of chemical engineering at North Carolina University, and his graduate students received one of *Discover* magazine's 1995 Awards for Technological Innovation. The discovery led DeSimone and his colleagues to patent an environmentally friendly process for dry cleaning clothes that uses carbon dioxide instead of perchloroethylene, a highly toxic organic solvent in wide use throughout the industry. As the lead principal investigator for the NSF-supported Science and Technology Center for Environmentally Responsible Solvents and Processes, DeSimone continues to advance research into environmentally safe solvents. Meanwhile, other work in polymers focuses on finding ways to use plastics in place of silicon as the base material of microcircuits.

"Materials research is pushing the edge of the technologies of a whole array of societal systems," said NSF Deputy Director Joseph Bordogna in an interview for NSF's publication, *Frontiers.* "It's a very powerful catalyst for innovation. As new materials become available and processable, they will make possible improvements in the quality of life. And that's the heart of the leadership issue and the competitiveness issue, isn't it? That's the future."

To Learn More

NSF's Division of Materials Research (DMR)
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National High Magnetic Field Laboratory
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