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NIST  
PUBLICATIONS

# MATERIALS SCIENCE AND ENGINEERING LABORATORY

MEASUREMENTS AND STANDARDS FOR HIGH-QUALITY PRODUCTS



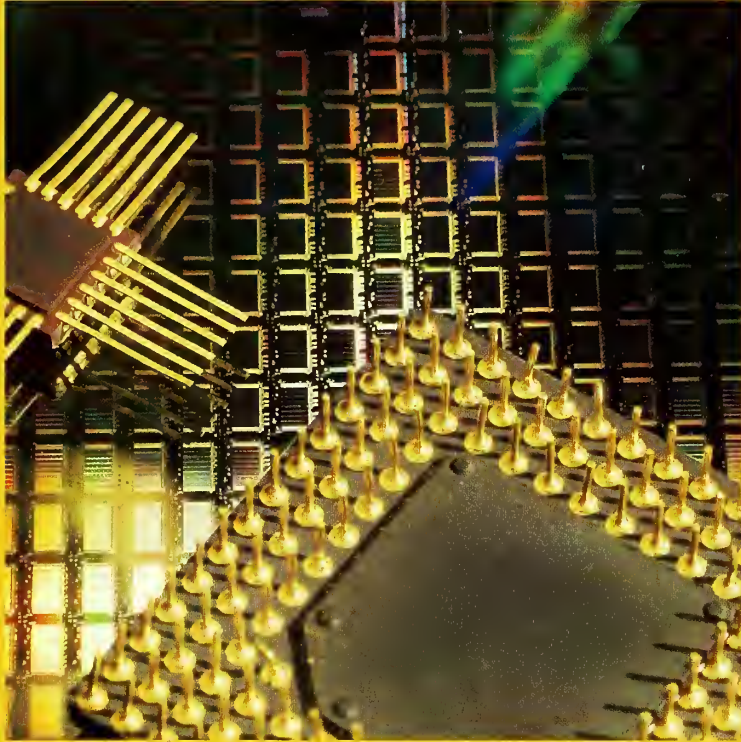
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U.S. DEPARTMENT OF COMMERCE  
Technology Administration  
National Institute of Standards and Technology

**NIST**

# MSEL

**MATERIALS SCIENCE AND ENGINEERING LABORATORY**



**W**ELCOME to the Materials Science and Engineering Laboratory of the National Institute of Standards and Technology. This brochure provides a snapshot of the wide range of materials-related services offered to customers and the multitude of technical activities carried out by the laboratory's four divisions and one center. By helping American companies design, process, and effectively use advanced ceramics, polymers, and metals, and by providing access to the latest materials measurement and research tools, the laboratory's technology and expertise promote U.S. economic growth.

Take a moment to read through this brochure and then call one of the contacts listed on the inside back cover.

**T**HE PROGRESS OF A CIVILIZATION can be gauged by its mastery over materials. Thousands of years ago when Stonehenge was built, natural materials were simply moved and shaped.

Today, materials science is an elaborate discipline in which both natural and synthetic substances are designed at the atomic scale to perform a dazzling array of functions.

In the advanced technologies of the modern world, materials are ubiquitous. From traditional window glasses to the space-age polymers that package electronic devices, from lightweight aluminum auto-body panels to hard ceramic coatings on cutting tools, materials are the foundation and fabric of every manufactured product.

Virtually every technological advance—from faster integrated circuits and more powerful communications systems to fuel-efficient cars and highly durable prosthetic devices—requires improvements in materials or processing methods. In short, advanced materials and processing technologies make better products offering superior performance at affordable costs. And that makes American manufacturers more competitive in the global marketplace. The result is a strong U.S. economy.

Such advances are possible only if materials suppliers and product designers have the tools necessary to understand and manipulate the strength, durability, electronic and magnetic properties, and other characteristics of materials. These tools include the latest techniques for measuring material properties, evaluated data presented in easy-to-use formats, and uniform property standards. Providing these tools to help U.S. industry make better products is the business of the Materials Science and Engineering Laboratory.

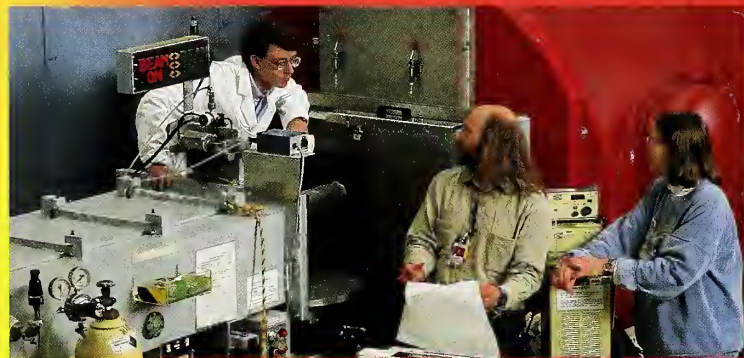
**Advanced materials offer advantages such as**

- high strength
- enhanced durability
- light weight
- heat tolerance
- corrosion resistance
- low cost

**Advanced processing methods offer advantages such as**

- high speed
- high precision
- reliability
- in-line monitoring and control
- low cost
- low environmental impact

A magnetometer is used to measure the magnetic properties of a nickel ball, which is among NIST's more popular standard reference materials. Once these measurements are completed and analyzed, the nickel balls are sold to customers for use in calibrating their own magnetic instruments.



Hundreds of guest researchers from industry, universities, and government laboratories visit the NIST Center for Neutron Research every year (above). The center's state-of-the-art instruments are used to solve problems in materials science, physics, chemistry, biology, and engineering.

MSEL researchers are working with the American Welding Society to develop interface standards that will help integrate power sources, sensors, and controllers into robotic welding cells. Arc sensors developed by MSEL for real-time monitoring and control of weld quality are being used to test and evaluate the proposed standards.





# CUSTOM

MEETING THE MEASUREMENT AND STANDARDS NEEDS OF


Companies and universities solve problems together with leadership and support from the Center for Theoretical and Computational Materials Science (left). The MSEL staff promotes the development of modeling tools and computational methods, provides forums for discussion and collaboration, makes solved test problems available, and offers advice on specific problems.

The American Dental Association's cooperative research program is co-located with the NIST laboratories. It has produced polymer-based dental restorative materials, more than 50 dental material and equipment specifications, and a drill that was later refined into today's air-driven high-speed handpiece.




**Materials Science  
& Engineering Laboratory**


MSEL works with industry, standards bodies, universities, and other government laboratories to support the nation's requirements and standards infrastructure for materials.



**Congratulations to John C. Egan**  
1998 National Model of Science Winner!

<a href="#">MSEL Research Programs/Overview</a> <a href="#">MSEL Description</a> <a href="#">Materials Properties and Data</a> <a href="#">Links to Other Materials Sites and Organizations</a> <a href="#">MSEL Annual Report</a> <a href="#">Describing Our Technical Activities</a>	<a href="#">MSEL In The News</a> <a href="#">Employment/PhD Post-doctoral Opportunities</a> <a href="#">The Student Page</a> <a href="#">Sources (Soft, Etc.)</a> <a href="#">MSEL Calendar of Events</a> <small>(coming soon)</small>
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Information about MSEL services and activities can be found on-line (left) at <http://www.msel.nist.gov>.

**M**SEL exists primarily to serve American industry. Its programs respond to industry's needs for materials-related measurements and standards—the infrastructure that enables companies to use valuable new materials and processing methods, reduce costs and time-to-market, and increase product quality. This assistance is more vital now than ever, given the rapid pace of technological change and the growing challenge to U.S. leadership in materials science and engineering from Asia and Europe.

Customers represent the entire spectrum of American industry. MSEL supports both materials producers and materials users, often serving as a link between them. MSEL scientists work with companies ranging from small startups to large corporations, help individual customers solve specific materials measurement or reliability problems, and lead industrial consortia formed to resolve common technical issues ranging from reducing the costs of ceramic machining to minimizing wear in orthopedic devices. In addition, many of MSEL's unique research facilities and equipment are available to guest researchers from industry and academia who are either working on their own or collaborating with the staff on activities of mutual interest.

The MSEL staff works closely with industry to ensure attention to the most critical needs and wide dissemination of the resulting measurements, data, and tools. Companies have many opportunities to communicate or work with MSEL scientists. Relationships are built through hundreds of cooperative research and development agreements and other collaborations designed to address particular materials or processing needs. MSEL also interacts with companies in consortia and with various industry associations in an effort to encourage the development and adoption of standards, which promote trade and economic growth.

The results of MSEL research often are disseminated by customers, such as manufacturers, instrument makers, and software providers, which apply new tools and data in their own laboratories and factories and introduce them to the wider industrial community. MSEL scientists also publish their research in scientific journals and on the World Wide Web, make presentations at technical conferences, and host and participate in focused workshops.

## Products

- measurement and characterization tools
- test methods
- software modeling tools
- standard reference materials for calibrating equipment
- databases linking material characteristics to processing parameters
- standards for commercial transactions
- assistance solving special materials or processing problems

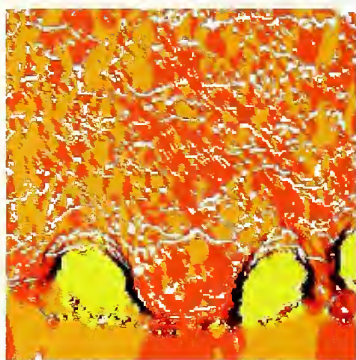
# ERS

AMERICAN INDUSTRY

# C E R A

## INORGANIC, NONMETALLIC MATERIALS WITH UNIQUE

When protected by ceramic coatings, aircraft engines (top photo below) can operate at elevated temperatures to achieve very high efficiency. Software developed by MSEL and another NIST laboratory is used to model these thermal barrier coatings (bottom photo) to improve understanding of their behavior.



The Ceramics Division's research on thin films includes close observation of processing methods, such as the deposition of barium titanate on an opto-electronic device (right, inset). Processing affects the microstructure and electronic and optical properties of these films.



Advanced ceramic membranes, which operate at higher temperatures than do polymeric and other materials, enhance the efficiency and selectivity of chemical separations and processing (left). Ceramics Division measurements of ceramic properties promote the design of reliable components.

**C**ERAMICS are like hidden treasures. They are seldom obvious to consumers or recognized for their many virtues. Yet ceramics are essential in modern products ranging from cellular telephones to fuel cells, and valuable new formulas and uses are discovered regularly.



Ceramics come in many shapes and sizes. They can be monolithic materials, composites, fibers, coatings, or films. They range from traditional porcelains and glasses to electronically active materials such as barium titanate. Ceramics are central to intriguing new technologies with outstanding properties, such as components for microwave communications.

Thin-film ceramics have electronic and optical properties that add value to computer memory, high-capacity magnetic hard disks, and data communications devices. MSEL scientists develop suites of measurement and characterization tools that help industry increase the reliability of these components and reduce production costs. They also evaluate relationships between processing methods and ceramic properties and study the effects of various modifications.

The ceramic coatings industry is worth half a billion dollars. These coatings protect against wear, corrosion, and heat in aircraft parts, heavy equipment, and cutting tools. MSEL scientists measure and characterize coatings deposited on aircraft engines and other surfaces. To help model the thermal and mechanical behavior of coatings and predict their performance,

# M I C S

## MECHANICAL, ELECTRONIC, AND OPTICAL PROPERTIES

The effects of processing conditions (left, below) on the microstructure and properties of ceramics must be well understood before products can be manufactured in a consistent, predictable manner. MSEL collects reliable information on these effects and makes it available to U.S. industry.



A grinding wheel (right) coated with small diamonds typically is used to shape ceramic parts. MSEL researchers work with industry to determine the effects of grinding conditions on material properties and find ways to improve efficiency and reduce costs.



tools are developed for characterizing pores and defects and relating these features to processing parameters. Because ceramics tend to contain complex mixtures of many crystalline phases, materials producers and product designers need accurate, up-to-date information about how these mixtures behave under various conditions. MSEL scientists help industry develop phase diagrams of material composition at different temperatures that serve as "blueprints" for processing. More than 45,000 volumes of these diagrams have been sold.

Many products can be improved if they are made of advanced ceramics instead of other materials, but only if product designers have the right data. MSEL scientists provide the evaluated data needed to design and process improved products. These databases cover the mechanical, thermal, and crystallographic properties of materials as well as their machinability. Other databases cover the physical, mechanical, and electrical properties of superconductors.

Costs can be reduced through advances in processing. MSEL works with more than 50 companies, universities, and other government laboratories to improve the measurement techniques used in powder processing, which is typically the first step in ceramics manufacturing. Particle size distribution, moisture content, and crystallographic texture are among the characteristics measured. To help industry reduce the high costs of machining ceramic parts, MSEL scientists provide models, data, and assessments of new machining and grinding techniques.

Ceramics are generally brittle, which concerns some users. To promote wider use of these valuable materials, MSEL scientists study the failure mechanisms and develop techniques for estimating material reliability and lifetime. They also develop mechanical testing procedures that eventually will become international standards.

Ceramic resonators are used in the electronic circuitry of wireless communications systems (above). Data developed by the Ceramics Division are used to select the processing conditions needed to achieve the optimum properties for these parts.

Polymer composites are replacing metal in topside piping, decking, and other components of offshore oil rigs (below) as a means of improving durability, reducing weight, and increasing fire safety. By elucidating the relationship between the structure and properties of hybrid composites, Polymers Division researchers are developing the capability to predict material behavior.

# POLY

## VERSATILE MATERIALS LIKE NYLON AND POLYETHYLENE



An instrument known as a MALDI (matrix-assisted laser desorption ionization) mass spectrometer is used to determine the molecular weight of synthetic polymers (right, inset). It is the only absolute method for determining the distribution of molecular masses.

**P**OLYMERS are a growth industry. The U.S. plastics industry and its suppliers provide more than 2 million American jobs and report about \$275 billion in annual shipments, which have been growing by 5 percent, on average, in recent years. Commercial demand is growing because scientists at MSEL and elsewhere have acquired the knowledge and tools to control the chemical composition, molecular structure, and properties of these materials.

Many sectors of the U.S. economy depend on polymers, which are used in electronics, transportation, construction, consumer products, furnishings, health care, and sporting goods. All companies that produce, process, or use polymers, polymer blends, or polymer-matrix composites can profit from the services of MSEL, which provides the latest standard reference materials,

Among their medical applications, polymers are used in the sockets of hip implants (below). MSEL works with a consortium of orthopedic manufacturers to address socket wear issues and reduce time-to-market for new materials. Tests are being run on wear machines in an effort to develop a new wear test that realistically mimics actual use.



measurement methods, and fundamental concepts of polymer science.

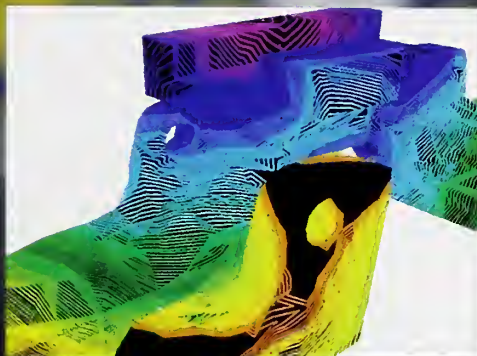
Designers of microelectronic products, for example, need reliable data on packaging materials so they can model the performance and reliability of integrated circuits, or chips. Thin-film polymers are among these materials. As electronic devices

become smaller and more complex, the space between printed metal lines is expected to become narrower than 0.5 micrometers. At that point, polymer properties—such as density and the temperature at which the material turns to glass—may differ from those of bulk materials. MSEL scientists characterize new polymeric materials and develop tools to measure their properties.

High-performance products, including those in emerging industries such as tissue engineering, often require precision blends of several polymers with additives or fillers. MSEL scientists build knowledge of

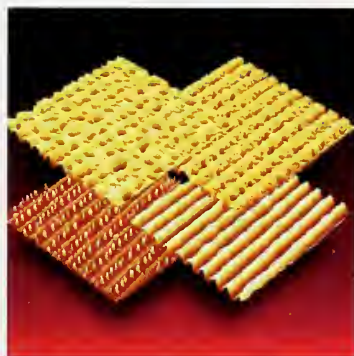
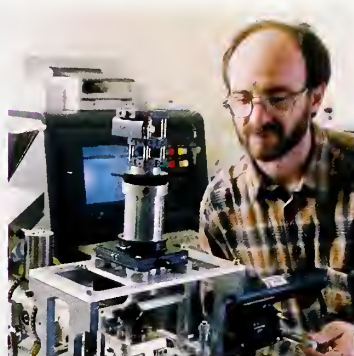
# MERS

CUSTOMIZED FOR HIGH-PERFORMANCE PRODUCTS



Liquid composite molding is a low-cost method of producing complex shapes out of polymer composites. Simulation tools (above) developed by the Polymers Division are used in the automotive and aerospace industries to design the molds and processing conditions necessary to realize the cost advantages.

One-of-a-kind instrumentation built at NIST is used to characterize the morphology of multiphase polymer materials during extrusion (below). It combines light scattering and optical microscopy to achieve real-time spatial resolution of 50 nanometers to 100 micrometers. This instrument mimics industrial equipment and therefore enables real-world measurements.



Atomic force microscopy is an emerging method for evaluating thin film surfaces. MSEL researchers use it to produce images of polymer blends separating to follow chemical or physical patterns on surfaces. Scientists can produce patterns using different materials to assess surface properties and interactions between materials.

polymer blends through research on microstructure and dynamics and develop methods of making stable mixtures. On-line sensors and other measurement tools can monitor processing in real time and characterize variables such as blend behavior at different temperatures.

Fiber-reinforced polymers could provide the high strength, light weight, and corrosion resistance needed to make better cars and other products if the parts could be fabricated cost effectively and their durability could be predicted. To help industry overcome these barriers, MSEL scientists develop models and in-line sensors to monitor, understand, and control the molding of composites in real time. New test methods are used to assess the durability of resins and fibers and to link mechanical properties to material performance. MSEL also helps companies develop customized tools, such as imaging systems that reveal details of fiber architecture.

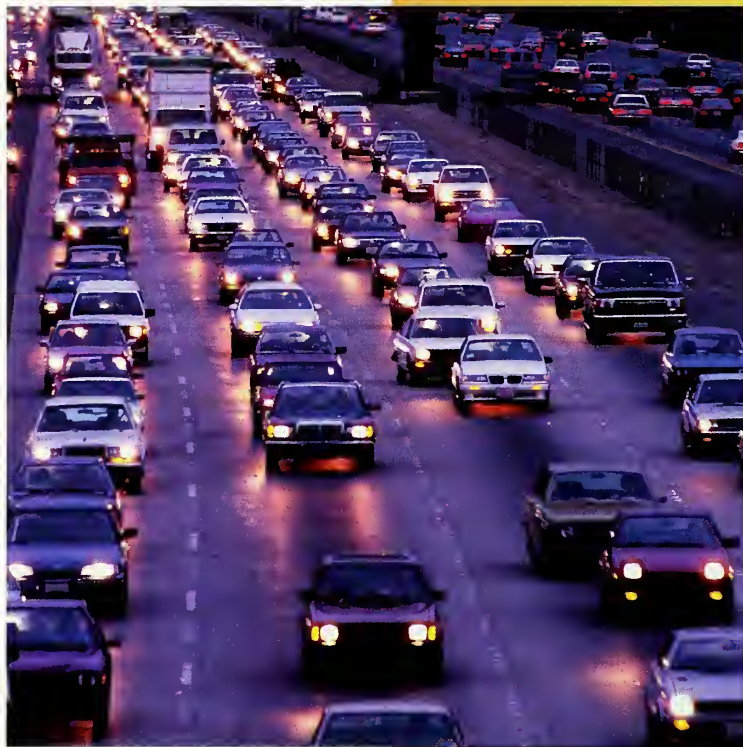
To make the most of polymers, U.S. industry needs safer, easy-to-use tools for characterizing material structure, properties, and performance. MSEL provides the latest methods, data, and standard reference materials for characterizing the solid-state structure of polymers and their mechanical behavior. Advances in mass spectrometry are exploited to measure molecular mass. The endless variety of polymers studied includes natural materials, such as ultrastrong spider silk.

Polymers are increasingly used to replace diseased structures in the body. MSEL provides basic materials science, test methods, and standards to support the development of both dental and medical materials that are safer as well as more durable and wear resistant than the current state of the art. Future projects will deal with injectable bone grafts containing biodegradable polymers for use in minimally invasive surgery, and dental coatings that provide controlled release of antibiotics and other substances.

# M E T

VITAL FOR HIGH STRENGTH, HARDNESS, ELEC

Future automobiles are likely to be made of lightweight metals, such as aluminum, once automakers have access to sufficient data on the behavior of these materials. Researchers in the Metallurgy Division develop equations that describe the "formability" of these metals to help model the shape of parts.



Several MSEL researchers work with an industry consortium to develop and characterize layered magnetic materials that can greatly increase the capacity of computer hard drives (above). Among other activities, the team has measured the thermal stability of these materials and the conditions that lead to optimum properties.



Soldering defects are common and costly problems for manufacturers of telecommunications equipment. The Center for Theoretical and Computational Materials Science leads a team of industrial and academic researchers who use computer modeling techniques to study and solve these problems. The modeling effort has helped to reduce defects in soldering of circuit boards.

**T**ODAY'S METALS are much more than a slab of steel. A wide range of metals and alloys now are engineered for powerful sensors designed at the atomic scale, lightweight frames for highly efficient cars, coatings that withstand high heat and corrosion, lead-free solders, ultrahigh-density magnetic recording media, and many other superior products.

U.S. industry depends on MSEL to provide sophisticated measurements of metal properties and behavior, which are determined by the distribution of phases, grains, and defects during processing. Electronics, automotive, and aerospace companies need this assistance to integrate new materials into production lines and effectively cast, form, or join components. Suppliers and users of steel, aluminum, copper, and many other metals need standards and measurements to achieve the best material performance.

As consumer electronics become smaller, lighter, faster, and more functional, precise data are needed on the properties of metallic components, including interconnects and thin films. MSEL scientists help companies and consortia develop methods for characterizing the interactions between solder and circuit board components and for measuring residual stresses in semiconductor packaging. In addition, processing conditions are identified that optimize the sensitivity of magnetic sensors for hard disks.

U.S. automakers need to find ways to improve fuel economy and reduce emissions while keeping costs down. MSEL scientists make measurements, develop predictive models, and compile data that promote the efficient design of metal-forming processes to make lightweight car chassis, gears, and other parts. They also develop sensor-based strategies for controlling various metal forming and joining processes. MSEL's standard test methods based on

# A L S

## MECHANICAL CONDUCTIVITY, AND MAGNETIC BEHAVIOR

In the past, the hardness of structural materials could not be measured in a consistent manner because of a lack of standards traceable to a single source. To help enhance the safety of metallic structures (below left), the Metallurgy Division is leading the development of national standards for all ranges of hardness for all types of metals.



To enhance the software used by industry to model the process of casting aircraft engine parts, MSEL researchers collected data and developed thermodynamic models of the complex alloys from which the parts would be made (above). The models incorporating these data are now part of a commercial software package.



finite element analysis may eventually enable low-cost mass production of large panels made of high-strength steel and aluminum alloys.

Magnetic materials are used in everything from credit cards and photocopy machines to motors and microwave communications equipment. To promote the use of new materials that will lead to smaller magnetic devices, MSEL scientists develop new measurement science to characterize magnetic properties, durability, and performance. Of particular interest are materials in which one or more dimensions are reduced to nanometers. MSEL measurements show how physical models can be used to predict the novel behavior of these materials.

Amid intense global competition and growing consumer demand for better products at lower costs, U.S. industry must produce new products more rapidly than ever before. MSEL develops technology to deliver evaluated data to industry in forms that are easy to use

in laboratories or factories. Thermodynamic data describing the phases present in multicomponent alloys are developed and incorporated into models describing the behavior of complex industrial alloys. These models help industry select the best materials and conditions for particular applications.

To make high-quality metal products that offer predictable and consistent performance, companies need uniform national standards for measuring material properties. MSEL leads the development of national standards for measuring metal properties such as hardness, impact strength, weld microstructure, coating thickness, magnetic behavior, and chemical composition. Such standards not only help American companies but also promote international trade.

Control of many industrial processes (above) depends on accurate knowledge of the properties and behavior of various metals as well as technologies that monitor these parameters. NIST researchers collect these essential data and develop models and sensors used to design and control industrial processes.

# NEUT

## NEUTRON BEAMS PROVIDE A UN

Before researchers can evaluate the residual stresses in a stub beam for the body-wing joint of an airplane, the part must be aligned such that the neutron beam focuses precisely on the appropriate area (below). This alignment apparatus was built at NIST.



The Federal Highway Administration collaborates with the NCNR on studies of the motion of water in cement paste (right, above). The neutron scattering studies provide unique information on the hydration reaction which is a critical element in how the material develops strength.

MSEL collaborated with a small company to develop this unique apparatus for focusing neutron beams (right, inset). By funneling neutrons through hundreds of tiny tubes to condense the beam, the equipment enables researchers to study smaller areas of weldments and other materials than can be examined with conventional systems.

**N** EUTRON BEAMS reveal secrets that cannot be discerned in any other way. Neutrons illuminate the inner structures and dynamics of virtually any material, benefiting many fields of science and a broad range of industrial



rapid (shorter than 10 picoseconds) and slower motions.

The NIST Center for Neutron Research (NCNR) maintains state-of-the-art instruments and capabilities for neutron scattering research. Scientists use the center to solve problems in materials science, physics, chemistry, biology, and

engineering. Because these facilities are too expensive for any single private organization to build, buy, and operate, the NCNR is a national facility available to qualified users (1,300 in one recent year) from U.S. and foreign companies, universities, and government laboratories.

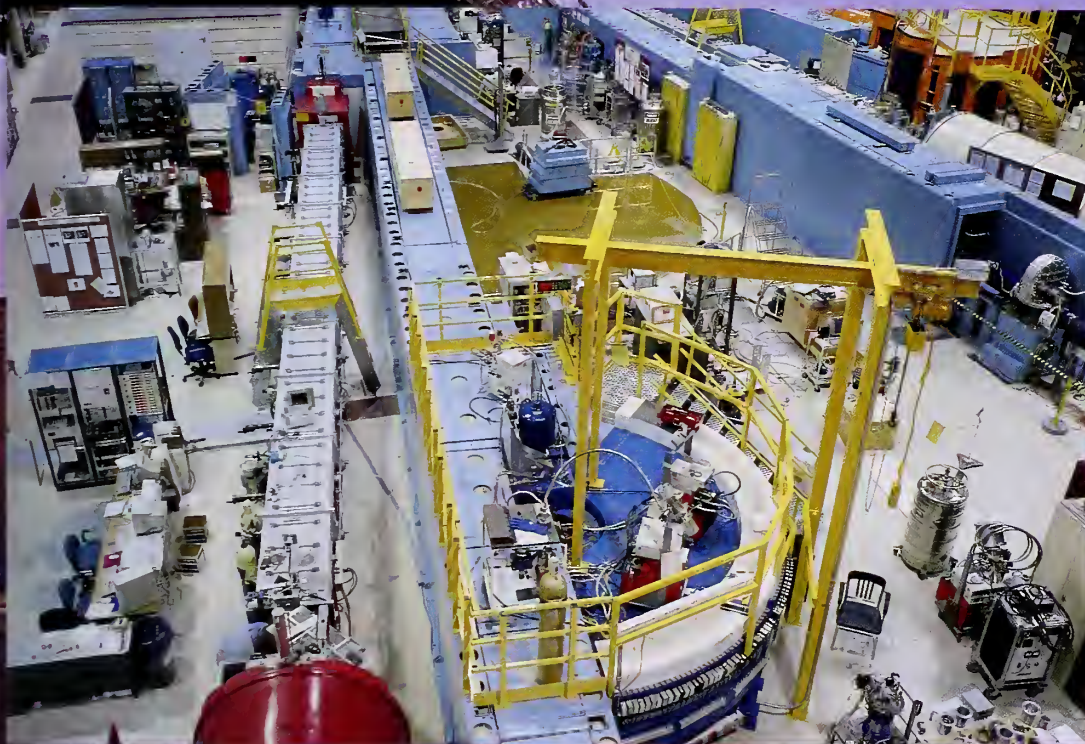
After neutrons penetrate a target material, they scatter in a distinctive pattern, providing a three-dimensional "picture" of the positions and motions of atoms as well as other features, such as magnetic structure. The special properties of neutrons enable them to penetrate large samples, identify different forms of some chemical elements, and detect both very

rapid (shorter than 10 picoseconds) and slower motions.

The heart of the NCNR is a 20-megawatt research reactor, which provides "thermal" and "cold" neutrons to more than 30 experimental stations, including the only cold neutron guide network in the United States. The temperature of a neutron beam

# R O N S

IQUE WINDOW ON THE WORLD



influences the types of experiments performed and the nature of the results.

Neutrons often are used to illuminate the structure and forms of aggregation in crystals. Researchers can use NCNR instruments to analyze atomic and molecular arrangements in catalysts, ceramics, superconductors, and other materials. MSEL scientists also compile crystal data and help companies develop related technologies, such as crystallography software.

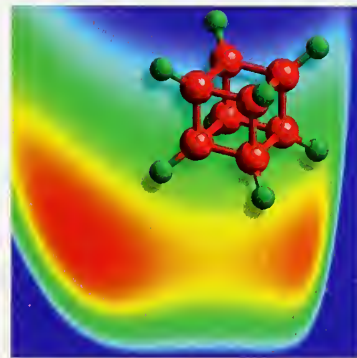
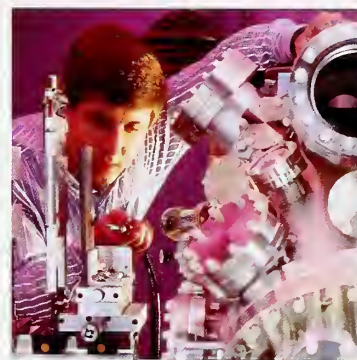
Other NCNR studies focus on molecular bonding states and dynamic processes in materials ranging from polymers for batteries and other products to buckyballs, which are soccer-ball-shaped molecules of great interest to many researchers. Such studies yield important results that can have practical implications. Studies of the motion of water in cement paste, for example, help explain the freezing process and may help scientists improve the durability of this material.

The breadth of research capabilities at the NCNR is remarkable. Unique measurement tools help scien-

tists characterize new magnetic materials, which could enable U.S. manufacturers to reduce the size and weight of data storage devices. Other tools are used to explore the extremes in material dimensions, from very long molecules, such as the surfaces of polymer films on silicon, to very small crystals, such as nanocrystalline magnets.

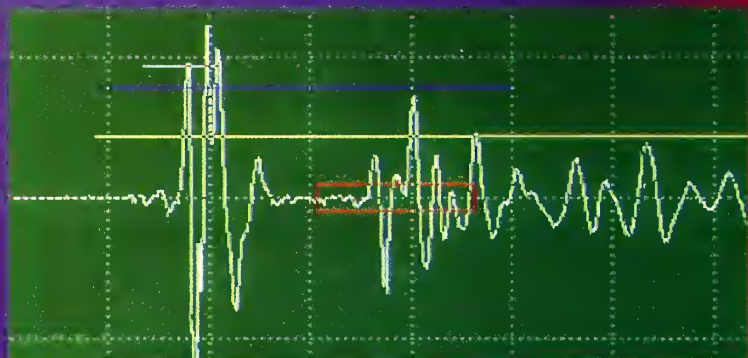
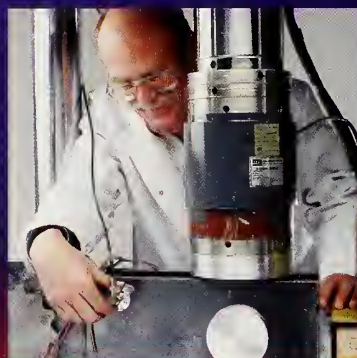
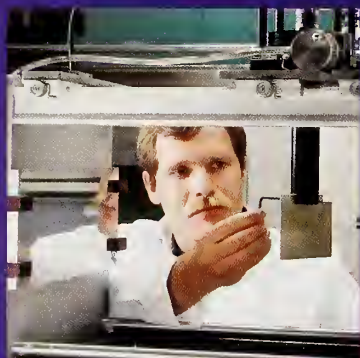
Other uses for neutrons include nondestructive evaluation of residual stress and texture, which affect material properties and performance. These studies focus on important alloy, ceramic, and composite structures and components, such as weldments and railroad tracks. NIST's Chemical Science and Technology Laboratory uses neutrons for a wide range of studies in analytical chemistry, such as measurements of small amounts of hydrogen in technologically important systems. NIST's Physics Laboratory uses the NCNR to study nuclear and neutron physics, including the fundamental laws of quantum mechanics.

Researchers gather information about new magnetic materials by taking measurements and observing interactions that occur during molecular beam epitaxy, a process of depositing thin films on substrates (below). The deposition process is performed within the neutron beam.



Neutron studies of molecular structure and vibrational states help scientists model and understand materials such as cubane, a synthetic, cube-shaped carbon array that may have biomedical applications. Cubane contains unstable, high-energy bonds between atoms (the green areas in the computer model above).

By enhancing the precision of techniques for measuring ultrasonic velocity (right and below), MSEL researchers are improving capabilities to characterize the microstructure and properties of structural materials, such as steel. The same measurements are also used to improve the precision of calibration standards.



An ultrasonic strain gauge (above) was developed by MSEL researchers for in-service inspection of bridges. A small company recently commercialized the technology as a portable instrument, which is being sold to state highway departments.



Nonlinear ultrasonic measurement tools are being developed by the Materials Reliability Division to characterize the interface integrity of films and coatings for products such as auto parts and electronics. These tools combine sensors, measurement procedures, and signal processing and data analysis schemes.



NIST researchers are refining a technique called electronic speckle-pattern interferometry to measure deformation during the mechanical testing of thin films for electronics applications. A bright laser is directed at a material, and the reflected pattern, captured by a digital camera, changes during the deformation process.



# MEASUREMENT

ENABLING IMPROVEMENTS IN MATERIAL QUALITY, RELIABILITY



The Ceramics Division uses a "clean room" similar to this one (above) for the processing and analysis of thin films that are critical to the operation of computer memory devices. The clean environment reduces the chances of dust distorting measurements or becoming entrapped in materials during processing.

**MENTS**  
**ILITY, AND PERFORMANCE**

**M**ODERN MATERIALS are often complex structures, such as assemblies of silicon, polymers, metals, and ceramics used to make computer chips; or fiber-reinforced composite materials designed to reduce the weight of airframes and golf clubs; or layered ceramic coatings that protect turbine blades in jet engines and power plants. Industry needs a continuous supply of tools for measuring various characteristics of these structures to improve commercial products and the processes used to make them. MSEL scientists are challenged to develop measurement tools that not only characterize complex materials but also reveal the nature of the interactions among the components.

Miniaturization has enabled staggering advances in communication and information technologies, from cellular telephones to computers. Measurements of material properties and behavior must be made at correspondingly smaller dimensions to ensure the reliability and requisite performance of semiconductor, magnetic recording, and opto-electronic devices. MSEL scientists devise methods for measuring mechanical, thermal, and magnetic behavior at miniaturized scales to correspond to the ever-smaller dimensions at which complex materials systems are now fabricated.

In-process measurements are key to improving productivity in manufacturing, whether in steelmaking, production of automotive parts, or vehicle assembly. Working with industrial partners, MSEL scientists develop in-line sensors and other tools for obtaining real-time information about material condition and processing parameters. These techniques enable manufacturers to produce materials and products offering improved quality and functionality and consistent properties at reduced costs. Industrial collaborations have improved aerospace castings, steel rolling, molding of polymers, and ceramics processing.

The superior properties and performance of advanced materials often are derived from tailor-made microstructures, which can be achieved only if methods are available for quantitative characterization of those microstructures. Accordingly, MSEL scientists develop nondestructive methods of making the physical measurements needed for quality assurance. Measurement tools include ultrasonics, X-rays, micromagnetics, and thermal waves. New techniques have been developed successfully for characterizing ceramic powders, composite materials, and steel products. MSEL also works with industry to develop standards for calibrating measurement tools.



**MSEL'S EXPERTISE**, facilities, and services can be tapped from almost anywhere. While remaining in their familiar work environments, customers from industry, academia, and other government agencies can join focused research teams and gain access to new tools, evaluated materials data, standard reference materials, and results of the latest materials studies. Industrial and academic scientists also can use research stations and analytical instruments operated by MSEL but located at other laboratories.

Researchers from around the world participate in multi-site working groups convened and coordinated by the Center for Theoretical and Computational Materials Science, which uses modeling and simulation to explore how materials processing, microstructure, and properties are related. The teams collaborate on the Internet and at periodic workshops to develop and apply new tools to resolve important industrial problems. Among its successes, this approach reduced costly soldering failures at a major corporation.

The latest modeling and simulation tools developed or adapted by these research teams can be obtained from the World Wide Web (<http://www.ctcms.nist.gov>). In one recent year, the tools were downloaded more than 1,300 times by academic and industry researchers. One unique tool enables users to convert an image of a material structure into a computer model, test characteristics such as fracture behavior or elasticity, and visualize and quantify the response.

The design of new electronic, catalytic, biopolymeric, and other important materials requires an understanding of the molecular arrangements and microstructures that control function. Guest researchers can perform a wide range of state-of-the-art measurements of advanced materials using NIST beam stations at Brookhaven National Laboratory in New York and Argonne National Laboratory near Chicago. The latter facility, which offers a 100- to 10,000-fold increase in brilliance over the previous state of the art, is rapidly becoming the nation's premier X-ray source. MSEL's Synchrotron Radiation Program is part of a collaborative access team at this facility.

Producers and users of ceramics can benefit from a wealth of multimedia information on the Web site of MSEL's Ceramics Division (<http://www.ceramics.nist.gov>). Descriptions and results of research on machining, processing, ultrasonics, and fractography are combined with feedback forms, e-mail links, and discussion forums to encourage dialog. Users can search databases on the properties of high-temperature superconductors and structural ceramics. The growing collection of tools and resources includes a guide to materials data centers and sources.



The design of high-quality products depends on accuracy and conformity in measurements. With markets now global, American companies rely increasingly on MSEL for standard reference materials (SRMs), which are used to develop accurate analytical methods and calibrate measurement systems. The use of SRMs ensures that measurements are traceable to a common and recognized set of national or international standards. MSEL designs, develops, and produces SRMs related to ceramics, polymers, metals, and other materials. More than 115 different types are available, and more than 66,000 units have been sold since 1982. The polymer SRM above is used as a calibration standard for tools used by industry to measure quality. A catalog is available through MSEL's Web site.

**Because of their great hardness, diamonds are used to compress samples in a diamond-anvil cell, a research tool that reveals phase transformations and other changes in materials subjected to ultrahigh pressure. NIST's synchrotron X-ray beam station facilities are used to ensure that these diamonds are defect free.**



# S E R

**EXPERTISE, FACILITIES, AND**



The Charpy impact test is used worldwide to assure the fracture resistance of steels for bridges, pipelines, and other structures where safety is critical. More than 1,000 customers verify the accuracy of their Charpy test machines using NIST's standard reference materials. This service includes an evaluation of test results and, when necessary, suggestions on how to bring a machine into compliance with national standards.



Research at the frontiers of materials characterization is carried out at the Advanced Photon Source at Argonne National Laboratory (above). MSEL customers are among those using these unique facilities, which are continually being expanded and improved.



Computer models such as this "gull-wing lead" (above) can assist in the design of reliable solder joints for electronic products. NIST's Solder Interconnect Design Team, a partnership with industry and academia, is promoting the development of modeling tools with the support of MSEL's Metallurgy Division and Center for Theoretical and Computational Materials Science.

# V I C E S

SERVICES ARE ACCESSIBLE FROM REMOTE LOCATIONS

# RESEARCH FOR THE FUTURE

## BUILDING A RIGOROUS FOUNDATION FOR NEXT-GENERATION MATERIALS

**BASIC RESEARCH** provides the new knowledge and tools that will produce the industrial materials and products of tomorrow.

Among their basic research activities, MSEL scientists address classical problems that have confounded materials scientists for decades. An ongoing effort to develop a mechanical constitutive law for the behavior of a metal single crystal, for example, has produced a general theory for the transport of dislocations through the deformed crystal and an analytical model that enhances understanding of the physics of the process. This analytical tool enabled scientists to define the deforming metal as a self-organizing critical system. Such a definition provides a statistical framework for describing the material's physical properties, which can be determined experimentally or with computer simulations.

Materials design projects concentrate on analyzing failure modes in ceramics used in heat engines, biomechanical implants, and protective coatings. New microstructures are designed, evaluated, and optimized. This work is especially concerned with enhancing understanding of fracture and deformation, which limit material lifetimes. To evaluate these properties,

MSEL pioneered the simple but powerful "indentation fracture" testing procedure, which is now used worldwide. Scientists have also developed equations that explain creep, or stretching under tension, in silicon nitride. These efforts help to establish design guidelines for the next generation of materials.

Other studies address material structure and behavior. MSEL scientists develop and apply mathematical techniques to describe and analyze crystal structure, high-resolution microscopy methods for observing atomic-scale phenomena, and models of the kinetics of microstructure development. These studies, coupled with recent increases in computing power, enable scientists to demonstrate how the basic laws of material behavior lead to the evolution of complex microstructures, which influence the materials' physical properties. Advanced microscopy methods and other tools available at NIST are used to study material behavior, such as the steady-state phase behavior and pattern formation of binary polymer mixtures under shear. Much of this research could not be carried out using conventional equipment.

The design of new tools opens up new research frontiers. Recent advances have established, for example, the world's leading capability in cold neutron reflectometry for the study of surfaces and interfaces. By offering unparalleled signal-to-noise ratio and resolution, these facilities and equipment are enabling breakthrough research, including in situ measurements of the morphology of biological cell membranes, electrochemical reactions on surfaces, and fundamental interactions between magnetic layers in a variety of novel multilayered nanostructures. In addition, new analytical methods have been developed to ensure the accuracy of the structural information derived from the reflectivity measurements.

To ensure excellence in basic research, materials scientists who are recognized world leaders in their areas of expertise are selected as NIST Fellows. Through their leadership in key areas of materials science, interactions with MSEL divisions, and collaborations with industrial and academic researchers, the Fellows help promote the development of superior next-generation materials.

### Fundamental Research Topics

- modeling of phase transitions
- optical characterization techniques for thin films
- modeling of crystal defects to interpret atomic-scale measurements
- predicting the physical properties of multiphase materials
- physical aging and structural recovery in polymers
- role of crystallization in the morphology of polymers
- modeling of interface motion to control solidification and microstructure
- development of physically based constitutive laws for sheet metal
- correlated molecular motion in glass-forming materials
- morphologies of polymer blends, complex fluids, and metal alloys

#### U.S. DEPARTMENT OF COMMERCE

William M. Daley, Secretary

#### Technology Administration

Gary Bachula, Acting  
Under Secretary for Technology

#### National Institute of Standards and Technology

Raymond G. Kammer, Director



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- Measurement and Standards Laboratories (including MSEL)
- Advanced Technology Program
- Manufacturing Extension Partnership
- Baldrige National Quality Program

News and general information about NIST programs are available on-line at <http://www.nist.gov>, or by calling 301-975-NIST or sending an email message to [inquiries@nist.gov](mailto:inquiries@nist.gov).

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Photography by Robert Rathe (NEUTRONS—Cold Neutron Research Facility, molecular beam epitaxy, aircraft body-wing joint; CUSTOMERS—guest researchers at neutron center); Geoffrey Wheeler (MEASUREMENTS—electronic speckle-pattern interferometry, ultrasonic velocity, measurement tools, strain gauge; CUSTOMERS—welder; SERVICES—Charpy apparatus); Jinfu Shu (SERVICES—diamond-anvil cell); Barry Gardiner (CUSTOMERS—Center for Theoretical and Computational Materials Science); and Argonne National Laboratory (SERVICES—Advanced Photon Source).

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The Materials Science and Engineering Laboratory helps U.S. industry improve the quality, reliability, and manufacturability of materials and the products made from them by developing and maintaining measurement tools, standard test methods, standard reference materials, and evaluated data on material properties.

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The center operates the NIST Research Reactor and Cold Neutron Research Facility, conducts materials research using neutron methods, and develops and maintains state-of-the-art instruments.

For more detailed information about MSEL services and facilities, or to obtain technical publications such as annual reports, please call or e-mail the appropriate contact listed here.

Additional information is available on-line at <http://www.msel.nist.gov>.

