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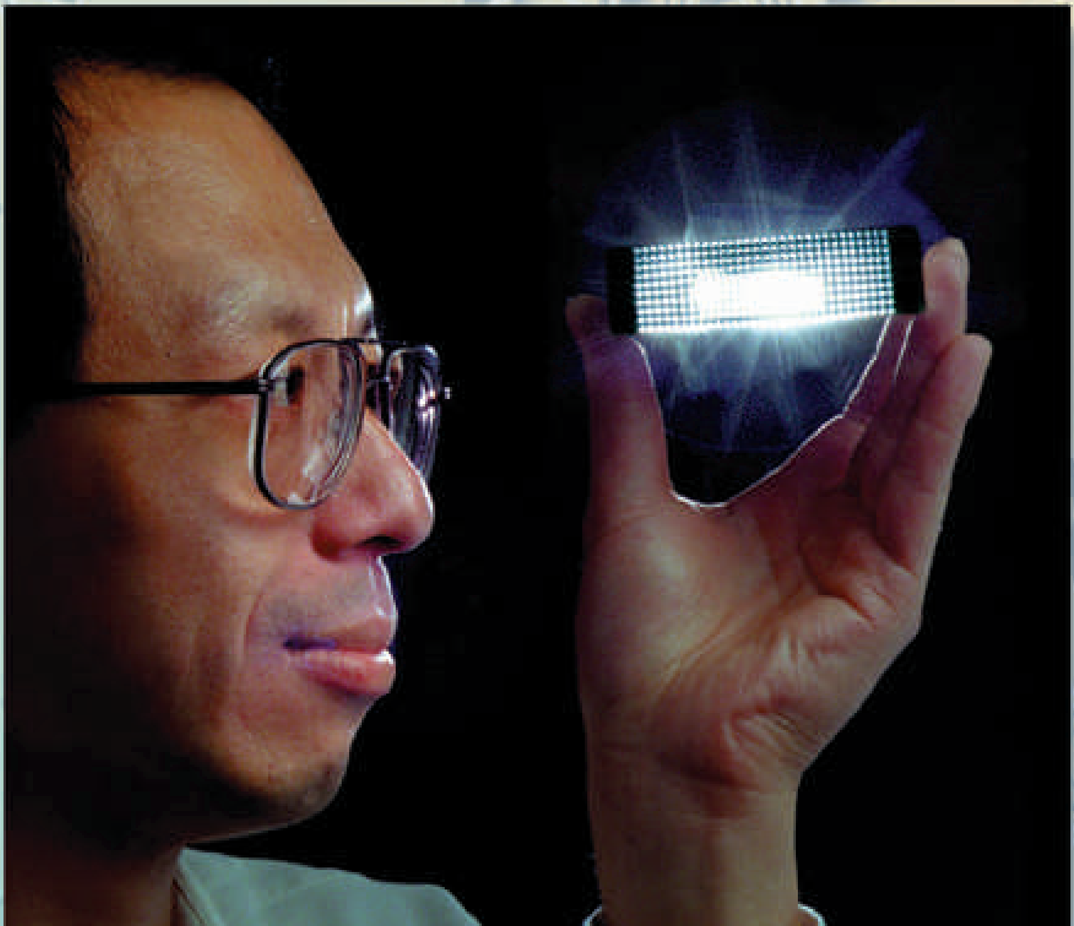
SANDIA TECHNOLOGY

A QUARTERLY RESEARCH & DEVELOPMENT JOURNAL
VOLUME 1, NO. 2

MICROSYSTEMS:
The next revolution



ALSO:

Nontoxic foam neutralizes chem-bio attacks

Nanosatellites take on bigger jobs

Sandia National Laboratories

The National Solar Thermal Test Facility (NSTTF) near Albuquerque, New Mexico is operated by Sandia National Laboratories for the U.S. Department of Energy. The facility is devoted to the development of the use of solar energy. Construction of the tower, (better known as the Power Tower), began in 1976 and was completed in 1978. The power tower rises 200 feet and is situated on 9 acres, the heliostat field accounting for about 8 acres. The current value of the entire facility is estimated at $120 million.

A microsystem is a collection of small, smart devices that can not only think, but also sense, act, and communicate. It may even know where it is and what is happening around it.

ON THE COVER: Researcher Shawn Lin at Sandia National Laboratories holds an early prototype of the photonic lattice as light passes through it.
(Story on page 11)
(Photo by Randy Montoya)

Sandia Technology is a quarterly journal published by Sandia National Laboratories. Sandia is a multiprogram engineering and science laboratory operated by Sandia Corporation, a Lockheed Martin company, for the Department of Energy. With main facilities in Albuquerque, New Mexico, and Livermore, California, Sandia has broad-based research and development responsibilities for nuclear weapons, arms control, energy, the environment, economic competitiveness, and other areas of importance to the needs of the nation. The Laboratories' principal mission is to support national defense policies, by ensuring that the nuclear weapon stockpile meets the highest standards of safety, reliability, security, use control, and military performance. For more information on Sandia, see our Web site at *http://www.sandia.gov.*

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FROM THE *Editor*

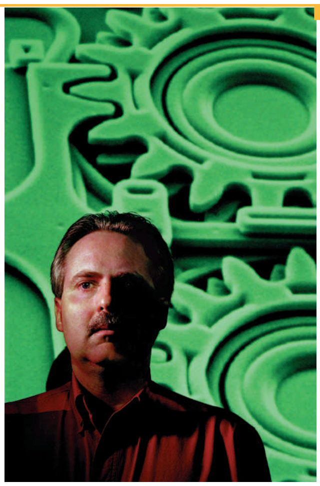
Dear Readers:

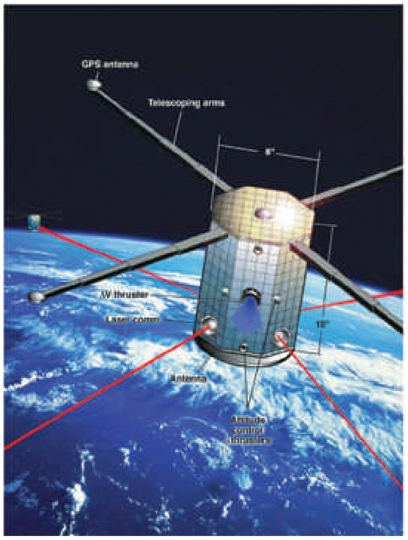
This issue of *Sandia Technology* focuses on the evolving microrevolution and the emerging field of integrated microsystems. Scientists and engineers at Sandia National Laboratories and elsewhere around the country are rightfully excited about this relatively new field of technology. While microsystems may not yet be ubiquitous, they are appearing in more and more consumer products such as automobiles, computers, ink-jet printers, and compact disk players. And it's only a matter of time before we do confront them at every turn. For instance, imagine a refrigerator that monitors what's inside and keeps an ongoing grocery list; pets with embedded chips that record information about them and their owners and monitors their movements; golf clubs that analyze the golfer's swing; running shoes that measure distance, speed, stride, and cadence; and interactive dolls that respond to children. The possibilities are endless and not that far away.

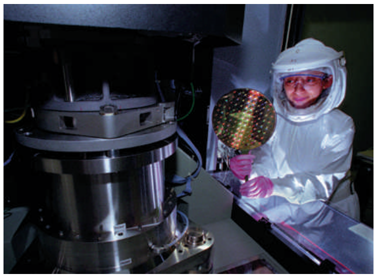
Sandia's research and development into micromachines and integrated microsystems stems directly from its work in nuclear weapons. Integrated microsystems will someday replace electromechanical systems in nuclear weapons, which will further improve their safety and reliability. They also will be used to support nuclear nonproliferation efforts through the use of miniature, low-power monitors to track nuclear materials worldwide.

This issue of *Sandia Technology* discusses these possibilities and many others. We hope you enjoy it. And please, let us know what you think of this publication and if you know of anyone who might enjoy receiving it.

Chris Miller
Editor







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MEGA BENEFITS, Microsystems

The next revolution—

You'll need a microscope to see it, but you won't have to see it to benefit because microsystems will be everywhere.

Think machine. As in a hay-gobbling baler. Steel, noise, exhaust. Big. Think Industrial Revolution.

Now, rethink machine. As in an engine so small you need a microscope to see it. Its speed: more than 350,000 rpm. Think Micro Revolution.

The move to micro — It's big. It's now.

In 1959, former Manhattan Project physicist Richard Feynman asked, "Why can't we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?"

The microrevolution has, in fact, been evolving for years. It put the computer into the average home, put a digital watch — reliability for less than $5 — on the average wrist, and recently installed smart components, such as airbag sensors, in new cars.

In 1959, former Manhattan Project physicist Richard Feynman asked, "Why can't we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?" He predicted that one day people would build small machines that, in turn, would build smaller machines yet.

Today, scientists and engineers have mastered the art of constructing small machines — so small, in fact, that in this dot (.) we could fit several. Micromachines are part of the emerging field of microsystems. And microsystems promise to create a new generation of useful devices. Already we have microsystems of varying sizes in cars, computers, ink-jet printers, and compact disk players. And we read much about the coming nanorevolution, where matter will be manipulated atom-by-atom to build useful structures.

That vision of the future, said Sandia National Laboratories physicist Wil Gauster, includes structures on the nanoscale — structures that can be inserted into living beings to monitor or perhaps even control biochemical processes.

"While this is still a distant goal, the prospects for management and mitigation of disease are enormous," said Gauster, deputy director at Sandia's Physical and Chemical Sciences Center. "We are now able to tailor the structure of simple materials on a nanoscale, achieving new ranges of optical or even electrical and mechanical properties."

But if we try to exploit the functional potential of complex molecules, Gauster said, the distinction between materials, components, and systems becomes blurred.

"Here we can turn to biological systems as guides," he said, "learning from nature how to assemble machinery. That's the biomimetic approach to meeting Feynman's machine-building challenge. We shouldn't be thinking of miniaturized versions of the machines we know from the macroworld, but rather of

"Here we can turn to biological systems as guides, learning from nature how to assemble machinery. That's the biomimetic approach to meeting Feynman's machine-building challenge. We shouldn't be thinking of miniaturized versions of the machines we know from the macroworld, but rather of completely new ways to exploit the science of the nano-world."

Sandia researcher Kenneth Gwinn displays a redesigned auto airbag, which is inflated by a micromachine.

completely new ways to exploit the science of the nanoworld."

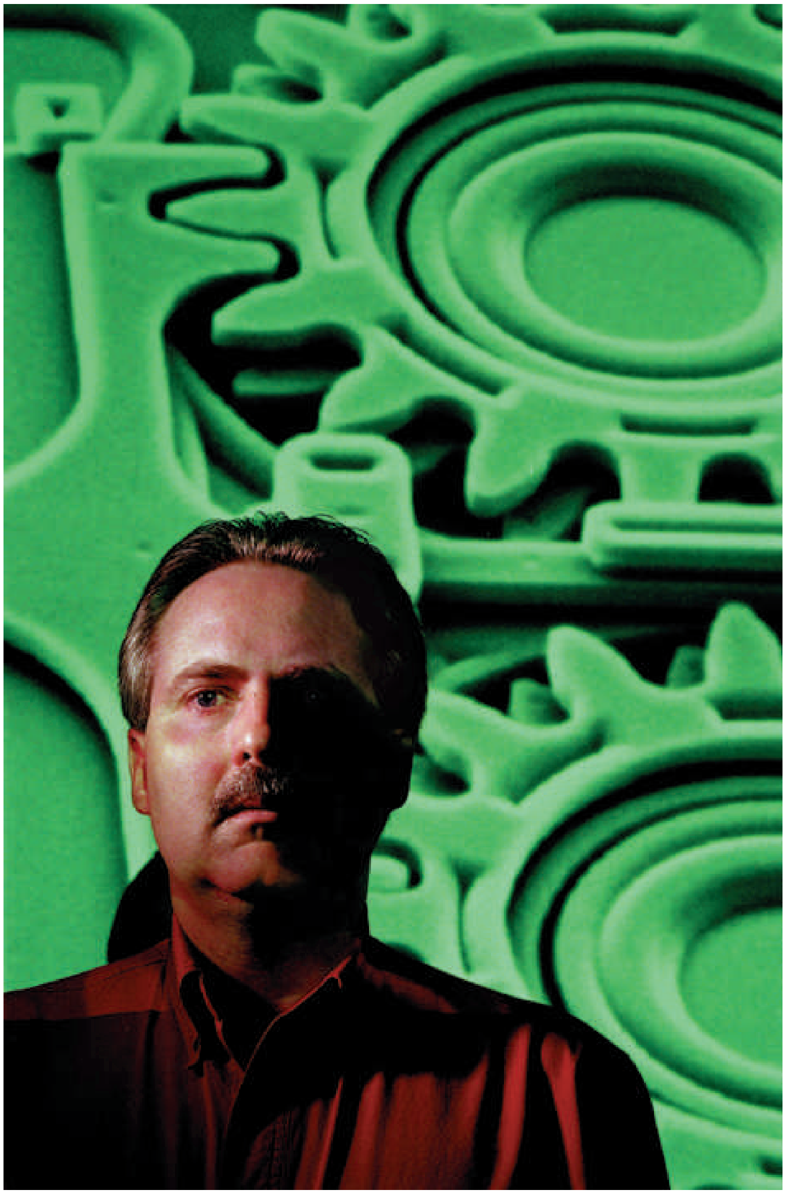
Sandia, a Department of Energy laboratory, already is exploiting functional capabilities at the atomic and molecular levels. Some examples include tailoring material porosity and surface chemistry so layers can be separated as well as prepared for catalysis, and sensing purposes; and synthesizing new materials by using self-assembled molecular layers, which can also be used as research tools.

The science underlying the micro-revolution is already on the nanoscale. "If we build things at the microscale, we have to understand the scientific principles at the nanoscale," said Paul McWhorter, deputy director for Sandia's Microsystems Center.

"Developing device concepts on the microscale dares one to truly understand the fundamental principles involved," McWhorter and co-author Sandian Tom Picraux wrote in an *IEEE Spectrum* article last December.

"At small scales, intuition often fails, and a closer look at the science is needed to exploit the opportunities. When scaled from the macro- to the microregimes ... conventional mechanical design principles may lead to surprises," Picraux said.

Building devices in the macroworld requires an understanding of science in the microworld, McWhorter said in an interview. Similarly, building devices in the microworld will require an understanding of science in the nanorealm.



Paul McWhorter, Deputy Director for Sandia's Microsystems Center.

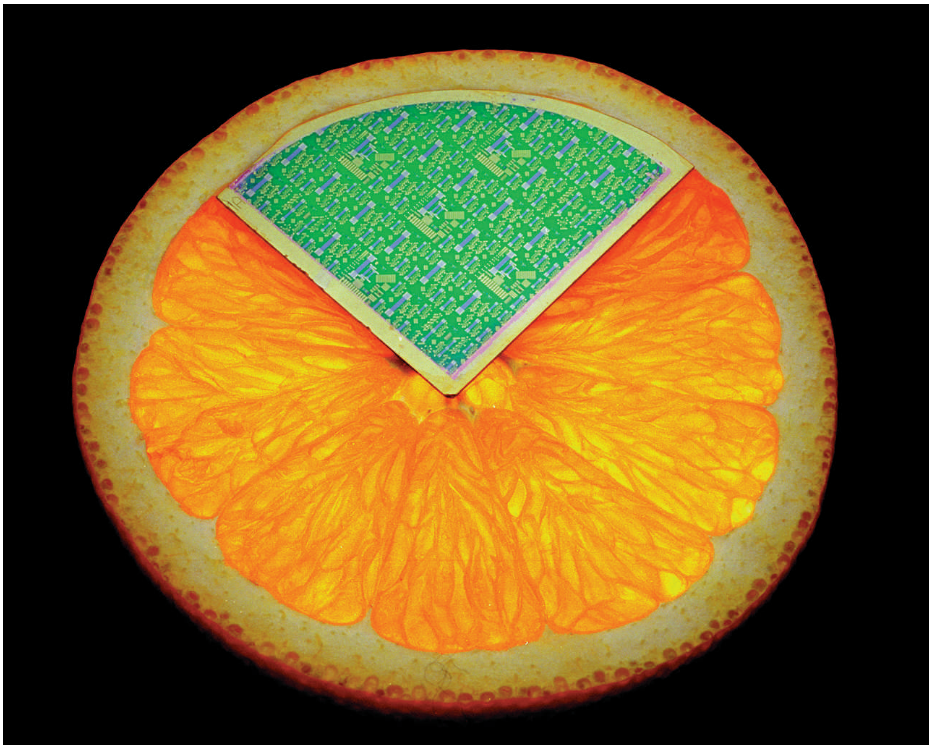
For example, in large mechanical devices, effects such as gravity, inertial shock, and vibration are all important. For microscopic devices, these effects become negligible, and new effects come into play. Microscopic devices want to stick to each other, leading to entirely new effects, such as *stiction*.

Microgears led to microengines, which paved the way for micro-transmissions. But, with a goal of integrating microdevices and functions, Sandia is developing *microsystems* — a term that will be every bit as important to the next decade as *microelectronics* was to the past three. A microsystem is a collection of small, smart devices that can not only think, but also sense, act, and communicate. It may even know where it is and what is happening around it.

The Small World

But is a microengine just a teeny copy of, say, the internal combustion engine? Actually, no. Things change when they get small. Different physical mechanisms cause wear and tear; and the issues that wear a vacuum cleaner out don't faze the microengine.

"At small scales, intuition often fails, and a closer look at the science is needed to exploit the opportunities. ...conventional mechanical design principles may lead to surprises."



Some 30 individual chips with acoustic wave sensors make up this quarter of a wafer, which fits nicely on an orange slice.

The Big Advantage of Small

The big driver toward *small* is cost. Compare: Early airbag sensors, which were macro in size, cost $1,200 each; economy cars went without. But the microsystem sensor in use today costs less than $5 and it self-tests every time the car is started.

"If it goes down to $5 or less, you can use a technology in new ways," McWhorter said. "If it's less expensive to big organizations and industries, then the technology moves into the world of the individual and everyday life."

McWhorter predicts microtechnology will be ubiquitous. Partnerships between national laboratories, industry, and research universities should create breakthroughs that replace technologies now costing tens of thousands of dollars. The replacements will be low cost and easily accessible to the consumer. Imagine interactive dolls that respond to children. Golf clubs that analyze the golfer's swing. Running shoes that track distance, speed, stride, and cadence.

Already the automotive industry uses many microsystems, such as sensors that measure manifold pressure as well as devices that detect a car crash and tell the airbag to inflate.

Microsystems will almost certainly improve medical care. Computers and accessories will continue to shrink in size and cost while increasing radically in capability.

Another cost-related benefit is that microsystems can be built in existing microelectronics manufacturing facilities. The microelectronics industry is now building microsystems in plants that have become obsolete for manufacturing modern integrated-circuit technology. This sharpens the IC-industry competitive edge.

Microsystem research at the national laboratories is also strengthening nuclear stockpile stewardship programs. The reliability of future microsystem components will be more assured due in part to Sandia's commercial partners; they adopt, test, and reapply microsystem technologies while providing data that Sandia can then apply to further weapons research. Integrated microsystems will someday replace electromechanical systems in nuclear weapons, which will further improve their safety and reliability. Standard microsystems are being developed to fit into niches and odd-shaped spaces within a variety of military systems, both new and old.

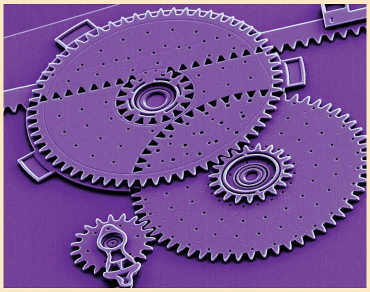
Is it micro or is it nano?

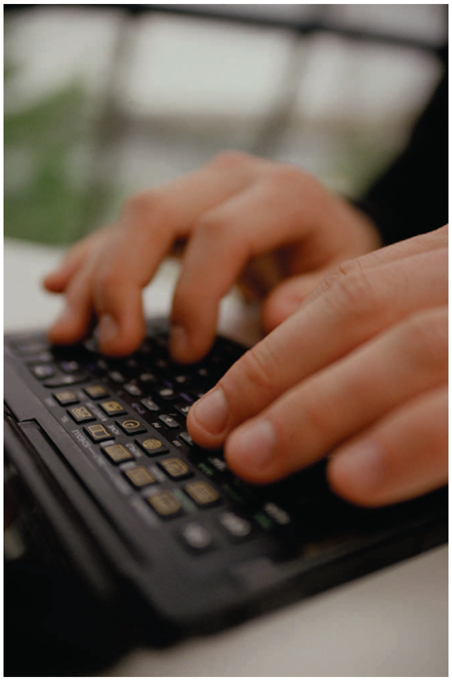
Nano and micro — these terms get bandied about sometimes loosely, but in the scientific community they have specific meanings.

Micro refers to devices too small to be seen by the unaided eye, typically measured on the scale of micrometers.

Nano refers to devices built on the scale of nanometers, typically of the atomic or molecular scale. Both require a microscope to view, but nano devices are many times smaller than microdevices.

Manipulation of materials in the nanoscale can be key to the performance and reliability of microscale devices.





Very soon, many of the consumer goods that use quartz crystals to operate — watches, TVs, computers — will use microsystems instead.

On the horizon are applications supporting nuclear nonproliferation that will use miniature, low-power monitors to track nuclear materials worldwide. The 21st century battlefield may be inhabited by swarms of miniature reconnaissance vehicles. Soldiers may wear monitors on their wrists that report their health to a medical facility. Surgery in the field is expected to advance as the microrevolution creates non- and minimally invasive surgical tools.

We can expect a cleaner environment as microsensors analyze and transmit information on the migration of radiation and toxins. The environment will benefit further from inexpensive chemical labs that check for industrial leaks and emissions.

[Small is more reliable than big. Fewer and smaller parts have less chance to fail.]

New Functions, New Options

Microsystems bring with them new capabilities that spawn new applications, said Picraux. Mechanical, chemical, and optical functions are being integrated to create microsystems that think, then act on their thoughts. In a very real sense, chips will become *aware*.

"Their impact on our lives over the next 30 years will be as profound as that of (integrated circuits) over the last 30 years," Picraux wrote in the *IEEE Spectrum* article (co-authored with McWhorter).

Small is more reliable than big. Fewer and smaller parts have less chance to fail. And when surface-science principles come into play — as they do at small scales where materials have more surface and less mass than those at macroscales — the result is components operate longer and more reliably.

Scenes such as this may one day become a thing of the past.

NEWS Notes

SELF-ASSEMBLED NANOSPHERES SHOW MEDICAL, INDUSTRIAL, AND MILITARY POTENTIAL

Self-assembling nanospheres that fit inside each other like Russian dolls are one form of a broad range of submicroscopic spheres Sandia has created in the past year. The achievement has medical, industrial, and military potential.

The spheres demonstrate an unprecedented control over organic and inorganic nanoscale self-assemblies and represent a major step forward in control of these techniques.

The durable silica spheres, which range in size from 2 to 50 nanometers, form in a few seconds, are small enough to be introduced into the body, and have uniform pores that could enable controlled release of drugs. The spheres can absorb organic and inorganic substances including small particles of iron, which means they can be controlled by magnets and the contents released as needed.

The Sandia nanospheres may be useful as coatings on silicon chips whose increasingly tiny circuits require a medium that has a lower dielectric constant and stores less heat. Some pore shapes trap materials, while others allow free flow in and out of the spheres.

The different kinds of sphere porosity may resemble slits between onion-like layers of silica, or a honeycomb's hexagonal patterns of holes, or the cubic gaps in a network of connected tinkertoys.

"The ability to control these different porosities makes them useful for all kinds of applications," says Sandia lead investigator Jeff Brinker.

The work was supported by DOE's Basic Energy Science Program and the University of New Mexico /National Science Foundation Center for Micro-Engineered Materials.

Contact: Jeff Brinker
505-272-7627
e-mail: cjbrink@sandia.gov

Sandia researcher Jeff Brinker observes the structures of a variety of submicroscopic spheres created by his team at the nanometer scale.

Machines That Get Built Tens of Thousands at a Time

Microsystems are being designed for affordable manufacturing. Sandia research is building complete systems monolithically, that is, on one chip. Such systems might be mass produced in batches for $1 to $5 per system.

Sandia's work does not stop at the microlevel. It extends to the nano as well. Already, the labs have developed a self-organizing nanostructure. It creates lattice formations when sulfur atoms are placed on a silver film that is one atom deep. The sulfur corrodes the silver by punching holes at precise intervals. Funded by the Laboratory Directed Research and Development program, this research may pave the way for creating specific patterns or predictable arrangements of atoms.

New applications come to the fore every day. Weight-constrained technologies, such as satellites, benefit from small, light, reliable systems. Communications, medicine, and skid suppression in automobiles already employ microsystems or may do so soon.

Hurdles Ahead

Because microsystems research is relatively new as a discrete discipline, the number of experts is limited while the demand is exploding. As yet few universities offer a complete microsystems engineering curriculum.

Microengineering research also needs more computer-aided design tools.

Packaging presents another challenge. Microsystems still exist predominantly in laboratories. Research and development partners are designing packaging for these new technologies as they find uses in the commercial sector.

As they find new uses outside the research laboratory, microsystems must be tested for reliability in their new applications.

Most microdevices use existing macropower sources, such as a standard battery powering a sensor in a camera. Researchers are studying how to reduce the size of power sources.

New applications come to the fore every day. Weight-constrained technologies, such as satellites, benefit from small, light, reliable systems.

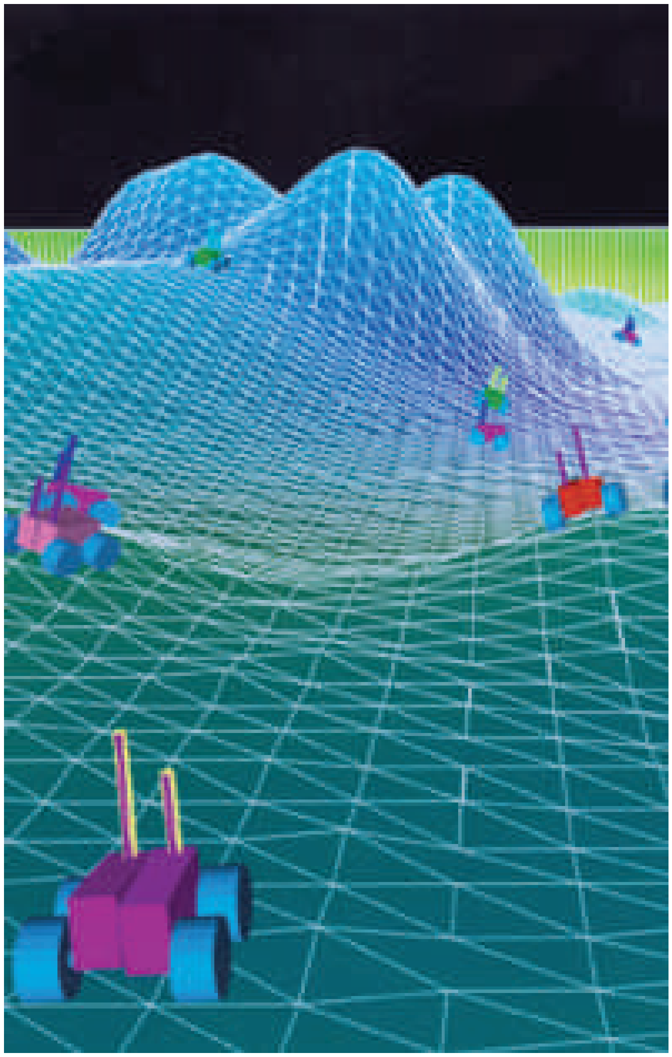
At Sandia Microsystems Abound

A spectrum of research makes Sandia a leader in the microrevolution

Microsystems are the buzz across industrial sectors. Sensors, switches, robots, optics, and other Lilliputian devices constitute microsystems made at Sandia National Laboratories. Some microsystem gears are the size of a pollen grain. These microscopic devices, which integrate electrical, mechanical, and sometimes optical devices, have evolved from the silicon revolution, which replaced big, complex, costly systems with small, affordable, high-performance microelectronics, also called integrated circuits. Microsystems are expected to further enable silicon chips to sense, "think," act, and communicate. In essence, to become intelligent machines.

Because microsystems are small, reliable, and sometimes pennies apiece, they will likely become ubiquitous in consumer products. A recent study estimated this growth industry could reach $100 billion annually. In 1997, Sandia National Laboratories signed an agreement with Analog Devices, Inc., of Woburn, MA, to begin commercializing Sandia's integrated micro-electro-mechanical systems (MEMS). Analog Devices is an industry leader in the manufacture of auto-airbag sensors.

Determining micromachine reliability is crucial, first, because these tiny components will be used in larger systems for which failure may have unthinkable consequences. Also, being an emerging field, the mechanisms that cause microsystems to fail are not well understood. And finally, because the field is advancing so fast, failure must be understood and addressed to build a strong foundation for further advancements and allow design trade-offs that don't compromise function. Sandia's microsystems have, therefore, run a gauntlet of tests.



A computer simulates a swarm of "robugs" traversing hilly terrain.

> ***Commercialized versions of Sandia microsystems are expected to be widely used in consumer products, to make them safer, cheaper, and more reliable.***

Sandia's vision is to develop microsystems to support a variety of commercial and defense applications. Microsystems projects at Sandia fall under four categories:

- *Sensors* (Example: µChemLab and hydrogen sensor)
- *Microelectronics* (Example: radiation-hardened Pentium processor)
- *Optoelectronics* (Example: photonic lattice)
- *MEMS* or micro-electro-mechanical systems (Examples: microengines and transmissions along with LIGA, MicroCooler, MicroGuardian, Micro-Navigator, and the recodable locking device)

Commercialized versions of Sandia microsystems are expected to be widely used in consumer products — such as the automobile — to make them safer, cheaper, and more reliable. The examples over the next few pages represent some of Sandia microsystem technologies that support defense research and may have applications in the commercial sector.

Sandia's Danelle Tanner tests MEMS reliability using a Sandia-developed instrument called SHiMMeR, which can test up to 256 parts at a time.

In lieu of a sixth sense SENSORS

Sensor technology, which has grown out of defense research, has a wealth of applications in industry and infrastructure. From airbag deployment in automobiles to explosive detection in airports, different kinds of sensors are adding a margin of safety to everyday life. In the future, we can expect this technology to eliminate many risks that today we must accept.

Two examples of Sandia-developed sensing technologies are the µChemLab and the hydrogen sensor. Small, light, reliable, fast acting, affordable — and intelligent — sensing devices will offer tremendous advantage on the battlefield, as well as support nuclear stockpile stewardship. They also will be useful for environmental cleanup, in medical and crime labs, and help combat terrorism in public facilities.

• **µChemLab**™ refers to a chemical-analysis laboratory housed in a device that is a little larger than a pocket calculator. A Laboratory Directed Research and Development (LDRD) Grand Challenge grant has funded its development. µChemLab™ contains multiple gas- and liquid-analysis laboratories within a hand-held device that is extremely accurate and has a low rate of false alarms.

The µChemLab™ prototype can identify chemical agents used in warfare and terrorism, as well as various explosives and their degradation products. The device uses a technique called chromatography. This technique separates a mix of chemicals into its constituents, thereby isolating target compounds from the background and from one another.

On the outside are a viewing screen and push-button controls. Inside, a small, mechanical pump draws chemical samples into the device where they are concentrated on a tiny sponge-like structure. Next, the chemicals are routed through channels, smaller in diameter than a hair, where the mixtures (target plus background compounds) are separated into their constituent compounds. This separation occurs when the mixture is carried through the channels, where the individual compounds interact differently with the walls or the channel packing. This results in different compounds coming out of the channel at different times. A tiny computer analyzes and identifies them, and in about one minute the computer displays a readout on the screen. The battery-operated µChemLab™ prototype will detect samples that weigh less than a single bacterium.

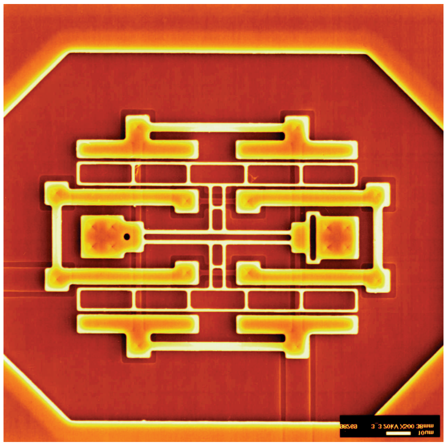
Sandian John Vitko, one of the µChemLab™ managers, said he believes that the technology will revolutionize chemical analysis. µChemLab™ allows a broad range of users equipped with this hand-held device to conduct analyses that previously required full-scale laboratories staffed with PhDs. Although the initial applications are in areas of national security, future use in drug development, medical care, and environmental monitoring are not far behind, Vitko said. *(Also see page 19.)*

For more information on µChemLab, please contact John Vitko at (925) 294-2820 or <jvitko@sandia.gov>.

• Sandia has developed a **hydrogen sensor** that can detect leaks in rocket engines and refineries, as well as monitor expensive equipment for corrosion. The device combines thermometers with heaters and, of course, hydrogen sensors on chips powered by analog-to digital electronics and accompanied by communication hardware.

This sensor won an R&D 100 Award in 1993 and has been licensed to DCH Technology, Inc., in Valencia, CA. DCH Technology has manufactured the sensor, and they are now selling hydrogen sensing systems to a wide variety of customers.

For more information on the hydrogen sensor, please contact Robert C. Hughes at <rchughe@sandia.gov>.



A tuning fork-shaped MEMS, like the one shown here, may one day replace quartz crystals used in electronic timing devices. Ten of the fine strings or tines would fit on a pinhead.

Advances in MICROELECTRONICS

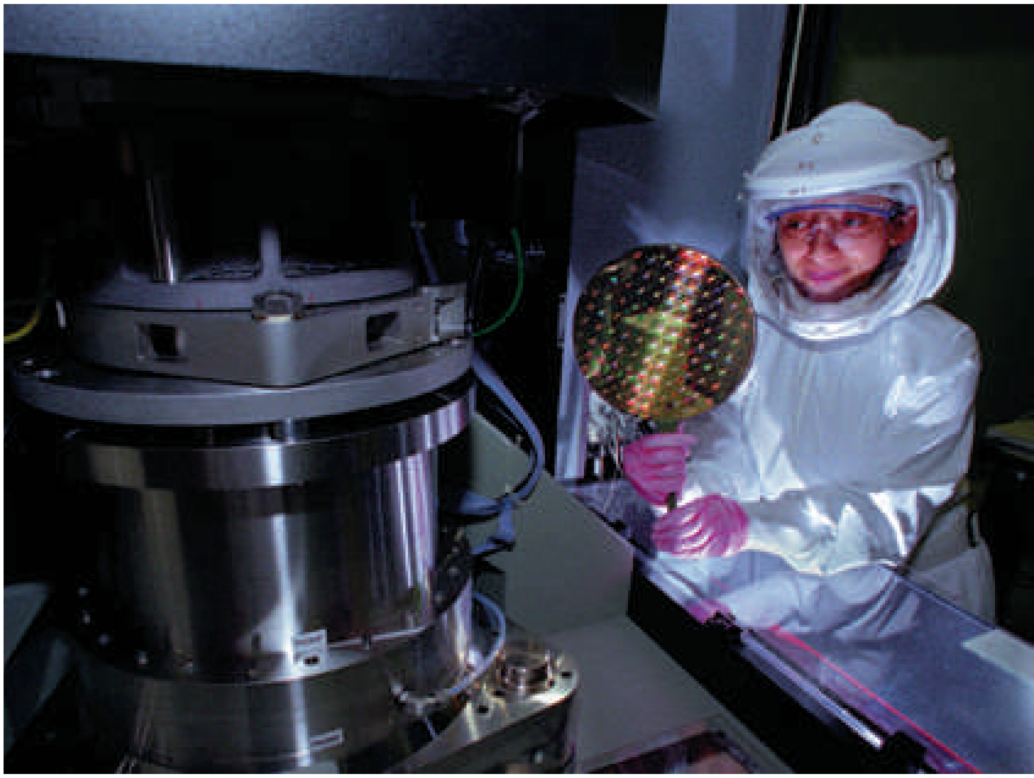
Microelectronics have been around long enough to become a household word. Even so, Sandia is making breakthroughs in this well-established field.

• Sandia will **radiation-harden Intel's Pentium chip,** one of the most widely used processors in the world. The improved microprocessor will protect critical defense systems in extreme environments where radiation compromises performance and reliability of conventional electronics. The new chip will expand computing power by a factor of 10 over existing radiation-hardened computer chips.

Already Sandia has radiation-hardened five generations of commercial microprocessor designs for use in earth satellites, the Galileo mission, and missiles. Designing and manufacturing a rad-hard version of a commercial computer chip with more than 3-million transistors presents a challenge. The process of radiation hardening is part science, part art — and is recognized internationally as an area of Sandia expertise. Years of experience in radiation hardening have helped Sandia researchers understand how different kinds of radiation affect computer chips and how various fabrication processes affect chip sensitivity to radiation.

The redesigned chip is expected to have use with the DOE for defense technologies and stockpile stewardship as well as with NASA on satellites and vehicles traveling beyond our solar system.

The redesign of the Intel chip marks a collaboration between the DOE, Intel, and Sandia. Intel has granted a no-fee license to Sandia to redesign the Pentium processor, thus, saving hundreds of millions of dollars in design costs alone. DOE Secretary Bill Richardson called the agreement a "precedent-setting show of cooperation, in which the taxpayers are among the biggest winners."



Technician Denise Carrillo inspects a newly metallized wafer in Sandia s Microelectronics Development Laboratory.

Intel President and CEO Craig Barrett said the new Pentium processor "will offer tremendous performance, flexibility, and reliability for critical government applications. We think (the agreement) is a wonderful example of how industry and government can work together in concert in such areas of importance as space and national defense."

Since 1982, Intel has transferred two other chip designs for radiation hardening and processing in Sandia's Microelectronics Development Laboratory, a unique facility within government facilities. The hardened versions of the previous Intel chips help provide the "brains" — that is, the processing power — within key systems for the nuclear stockpile and in satellites.

(The Sandia-Intel agreement was also covered in the Winter 1999 issue of Sandia Technology on page 6.) ***For more information on the radiation-hardened Pentium processor, please contact Mike Knoll at (505) 845-8525.***

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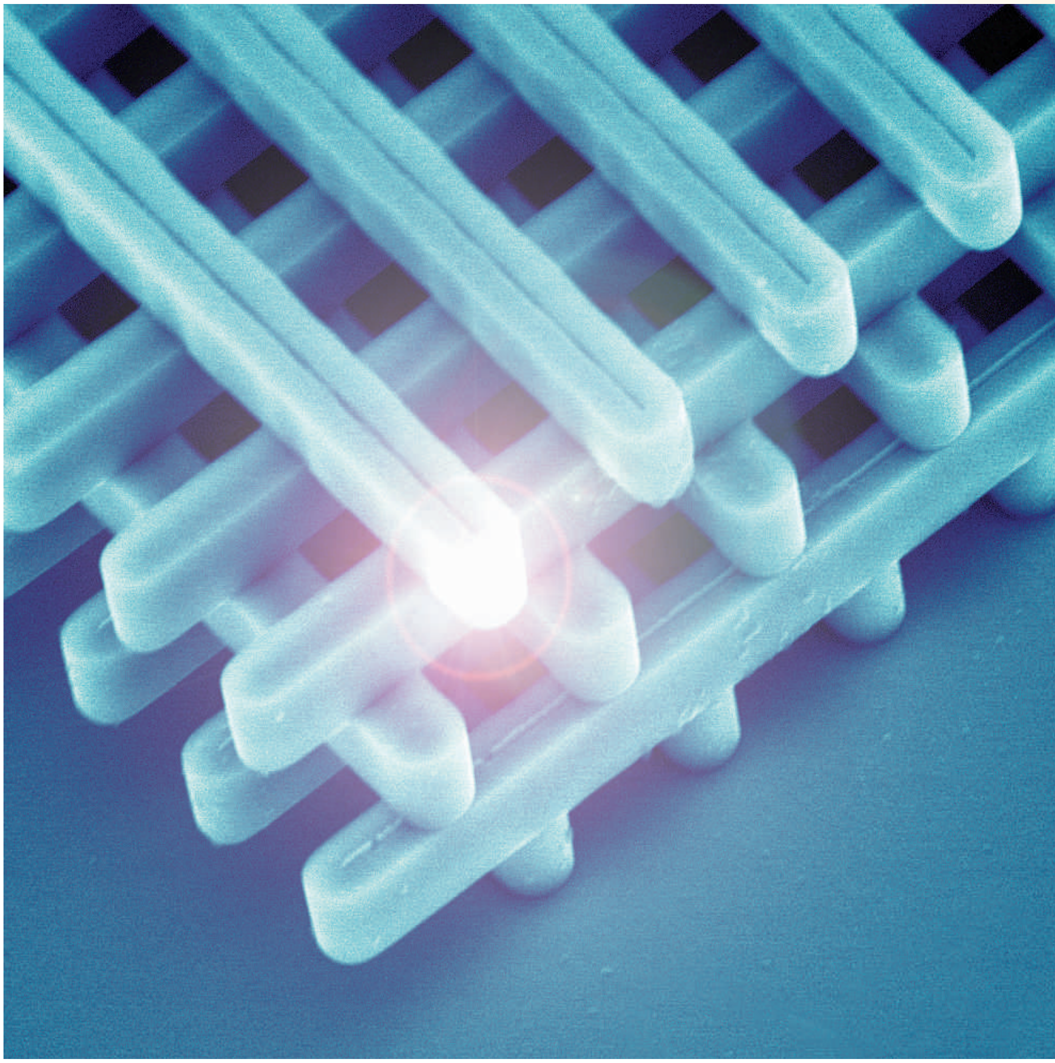
Light wave of the future
OPTOELECTRONICS

Soon light may replace electrons as the "engine" that drives many of our technologies. Recently, in a collaborative project with another national laboratory, Sandia reached a major milestone in optoelectronics.



Sandia's photonic lattice acts like a crystal in guiding light because of its tiny, regularly placed silicon "logs," which are 1.2 microns wide. (Also see cover photo.)

•The **photonic lattice**, a Lincoln log-like device, is revolutionizing what engineers can do with light. Developed at Sandia by Shawn Lin in a partnership with the Ames Laboratory (a DOE laboratory at Iowa State University), the invention belongs to a category of light-driven microtechnologies called photonics. The field of photonics has evolved around the invention of tiny lasers and may soon replace that irksome wad of wires cascading from the back of most computers — that is, what is electronic today may be photonic tomorrow.

The so-called Lincoln log structure is actually a photonic crystal that confines and bends light. It's dubbed the Lincoln log structure because it is a three-dimensional lattice of microscopic silicon slivers arranged at precise intervals. The perpendicular "logs" contain and direct the light around corners. First conceived a decade ago, the photonic crystal has been refined to use defects in the crystal to bend microwaves and infrared light around a 90-degree turn. The ability to bend light cheaply and easily without scattering it, and in such a tiny device, has stumped researchers for years. Its discovery could make photonics as much a household word as electronics has been since the 1970s.

"In the telecommunications and optoelectronics industries, there has been one mechanism for controlling light," said MIT Professor John Joannopoulos, citing additional benefits of the new technology. "This is a new mechanism for controlling light. (The photonic lattice) can make optical light to be localized in the air. If light propagates in a material (such as in fiber optics), you lose some of the light because it can bounce around. With (the photonic lattice) you lose none of the light." Joannopoulos is the Francis Wright Davis Professor of Physics at MIT and author of a book on the subject.

"This is a new mechanism for controlling light. (The photonic lattice) can make optical light to be localized in the air. If light propagates in a material (such as in fiber optics), you lose some of the light because it can bounce around. With (the photonic lattice) you lose none of the light."

Sandia has applied to patent the crystal. Probable uses include optical communications, optical (instead of electrical) computing, data transmission, and sensing. A new laser that requires little start-up power may evolve from the Lincoln log invention.

For more information on the photonic lattice, please contact Shawn Lin at (505) 844-8097 or <slin@sandia.gov>.

MEMS the Word

Micro-electro-mechanical systems (MEMS) have microfeature sizes. Using the techniques of integrated-circuit fabrication makes MEMS low cost and well suited for defense and commercial uses. Here are some examples of MEMS projects Sandia is working on:

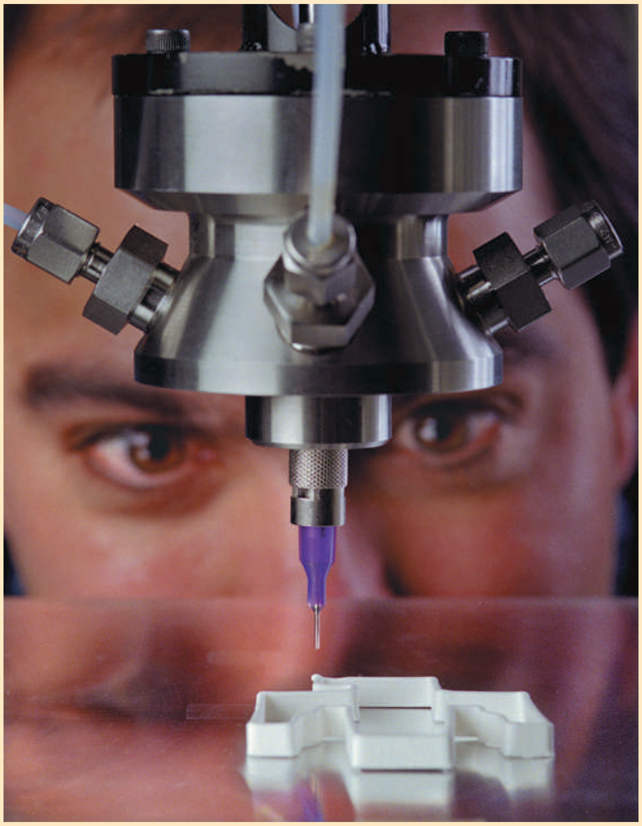
• **LIGA**, an acronym for the German words for lithography, plating, and molding, refers to a process used to fabricate precise micromachines. The LIGA process uses x-ray synchrotron radiation to create fine patterns in a polymer, which is then filled with metals and metal alloys by electroplating. These metal patterns can be filled with other materials depending on what micromachine part is being constructed. Sandia is using the LIGA process to develop metal parts that have micron-sized features. These features are smaller than previous metal machining technology that has millimeter-sized features.

Here are several examples of Sandia accomplishments using the LIGA process: Sandia has —

- Fabricated an 8-mm electro-magnetically driven rotary motor for potential use in a strong-link system
- Fabricated electrodes for use as a microdischarge machining tool-to-pattern grids applicable to neutron generator production
- Assembled 76 unique LIGA parts into a smart environmental sensing device for nuclear weapon application
- Developed prototype microparts for several industrial partners

For more information on the LIGA process, please contact Jill Hruby at (925) 294-2595 or <jmhruby@sandia.gov>.

NEWS *Notes*



Engineer Joe Cesarano has developed a new way of fabricating ceramics, called robocasting, that requires no molds or machining.

ROBOCASTING: SANDIA DEVELOPS NEW WAY TO FABRICATE CERAMICS

A Sandia engineer has developed a new way to fabricate ceramics that requires no molds or machining. Called robocasting, it relies on robotics for computer-controlled deposition of ceramic slurries — mixtures of ceramic powder, water, and trace amounts of chemical modifers — through a syringe. The material, which flows like a milkshake even though the water content is only about 15 percent, is deposited in thin sequential layers onto a heated base.

"Layer by layer the part grows before your eyes," says Joe Cesarano, the engineer who originated the concept. "The robot squeezes the slurry out of the syringe, almost like a cake decorator, following a pattern prescribed by computer software."

Ceramics are found in products that touch just about everybody's life. They're in household appliances, automobiles, airplanes, computers, and medical equipment and have a variety of functions ranging from structural to electrical to optical.

Bob Eagan, Sandia's vice president for Energy, Information and Infrastructure Technology, says robocasting may change the future of ceramics manufacturing. "It has the potential of giving us a tool for making ceramic parts that can't be built today using existing methods," he says. "Also, it may result in cheaper and faster fabrication of complex parts."

Because the new method allows a dense ceramic part to be free-formed, dried, and baked in less than 24 hours, it is perfect for rapid prototyping. Engineers can quickly change a design of a part and physically see if it works.

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• **MicroCooler: Chips keep their cool in hot, new micromachines.** Micromachines make a lot happen in the space of a shirt button. Packed together, millions of transistors overheat. So the challenge has been how to cool an integrated circuit.

To meet it, Sandia has developed a liquid-coolant–filled circuit substrate with internal micromachined features that act as embedded heat pipes to dramatically improve cooling and maintain comfortable working temperatures for integrated circuits. The embedded heat pipes in the substrate are constructed with tunnels that are activated by partially filling them with a droplet of coolant. This passive cooling method, which has a patent pending, is twice as effective and half as expensive as existing high-performance cooling techniques. It relies on tiny, solid copper tubes to conduct the heat away from working parts into the outer shell, such as the plastic casing on a computer. This substrate will be useful in lengthening the life of computers, solid-state lasers, communications-satellite equipment, photovoltaic cells, and radars.

This passive cooling method, which has a patent pending, is twice as effective and half as expensive as existing high-performance cooling techniques.

For more information on MicroCooler, please contact David Benson at <dabenso@sandia.gov>.

• ***MicroGuardian,*** a new trajectory safety subsystem for nuclear weapons, is the most sophisticated microsystem Sandia has ever developed. The technology will incorporate several micromachines, microelectronics, and micro-optics all on one chip. It will eventually be part of a microfiring system the size of a stack of three quarters.

Beth Potts views a component of the MicroGuardian through a microscope.

"Current efforts provide the first steps towards achieving a highly integrated, mixed-technology micro-system that Sandia is uniquely positioned to develop," said Kent Meeks, manager of Advanced Weapons Technologies at Sandia. "No one else in the world has capabilities to combine sophisticated micro-optics, micro-electronics and microdevices into a single integrated microsystem."

The trajectory subsystem adds to the safety of a nuclear weapon and ensures the weapon doesn't detonate unless a series of specific events indicate conditions are right for triggering. MicroGuardian acts as a miniature sentry protecting the firing system of a weapon. Light flows through an optical fiber into a locked chamber where the light bounces around, but does not trigger the weapon. The system has to sense it is flying through the air heading for the target and not, for example, being carried in the back of a semi-truck. However, when the system is flying toward a destination, a moveable mirror redirects the light energy to a photocell that charges the firing components.

MicroGardian is "a highly integrated, mixed-technology microsystem that Sandia is uniquely positioned to develop."

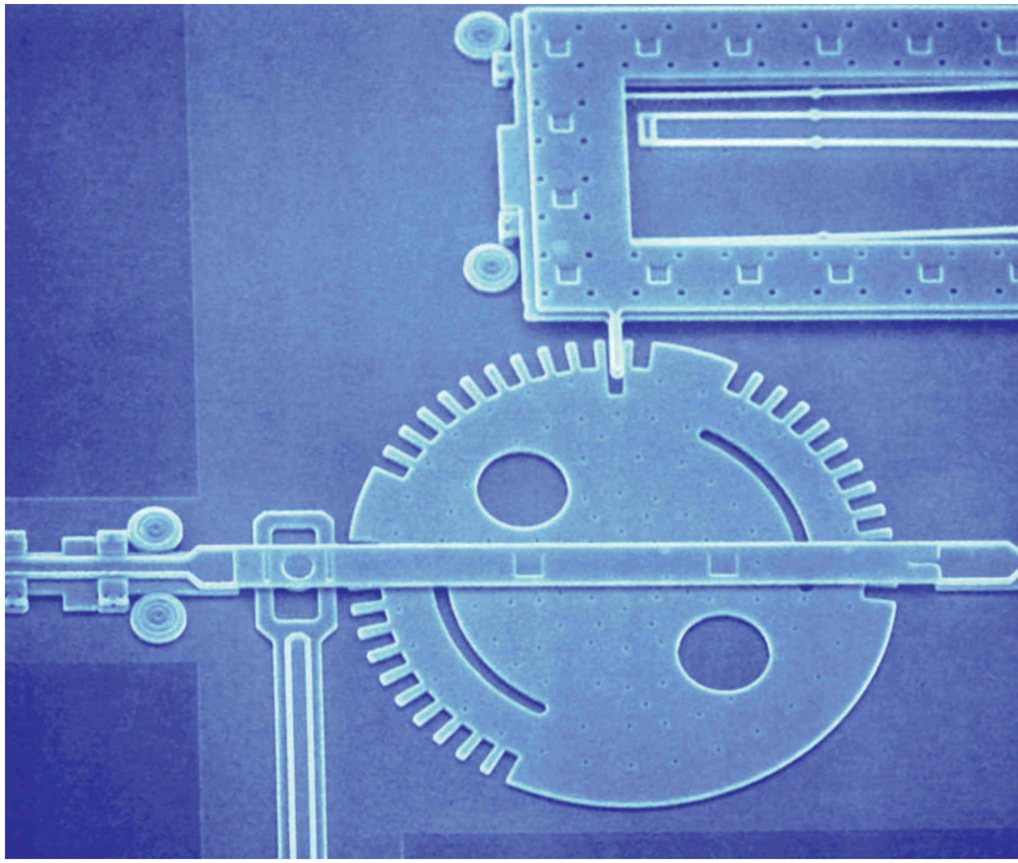
This new, smaller trajectory subsystem will be cheaper to build than older systems and will free up space in the nuclear weapons to allow other safety improvements. Fabrication costs will be lower than for previous such technologies because batch processing techniques can be used.

For more information on MicroGuardian, please contact Kent Meeks at (505) 844-1040 or <kdmeeks@sandia.gov>.

• **MicroNavigator** is an integrated microsystem under development at Sandia's Microsystems Science & Technology Center. The technology has gyroscopes to sense rotation, a global positioning system (GPS) to identify geographic location within a few meters, a navigation computer, and accelerometers (devices that measure acceleration) all on a single chip. It will require less power to run and will be 1/50th the size and weight of existing navigation technologies. Designed for use in weapons, MicroNavigator may also find applications in the space program. Additionally, the device may be put into artillery shells and small munitions to guide them to a target.

"Once perfected, these small, inexpensive devices will take the world of navigation, guidance, and control the next step beyond GPS," said Sandian Mike Daily, an electronics design engineer.

For more information on MicroNavigator, please contact Mike Daily at (505) 844-3145 or <dailymr@sandia.gov>.



Recodable Locking Device – One of six code wheels is shown here in an enabled position after the correct code was entered.

• A **Recodable Locking Device** should provide a quantum leap in software safety and security. It's the smallest combination lock in the world, but it will give computer hackers one giant headache.

Computer break-ins cost Americans big bucks every year and put confidential records at high risk. Sandia's new lock offers improvements on both counts. Having gears nearly invisible to the naked eye, the lock stores combination codes. Hackers cannot circumvent the lock. Unwelcome visitors have one chance only to break in, and even then they face one-in-a-million odds against guessing the code. The computer will not allow additional access until the lock is reset, and the lock can be reset only when the authorized user enters a new code.

In describing how the lock works, Sandian Larry Dalton put it this way: "You can break into my house and wander around, but you can't break into my safe within the house where valuables are stored."

Sandia is the world leader in MEMS technology. Dalton said Sandia resources — MEMS design expertise and facilities — made it possible to create the lock. "The Microelectronics Development Laboratory is where ideas and designs become reality," Dalton said. "MEMS technology revolutionizes how we view and solve problems. It's an extremely exciting technology with almost limitless potential. It affords such creativity that it's a great time to be an engineer."

In addition to Dalton, the lock developer, the Sandia design team includes David Plummer and Frank Peter.

The inventors have submitted a patent application, and the lock should be on the market in one to two years. The design is based on the principles of locks used for nuclear weapons safety. Beyond benefits in defense applications, the microlock may prevent losses among financial institutions, increase the safety of certain medical devices, and may reinforce the safety of commercial nuclear power plants.

"MEMS technology revolutionizes how we view and solve problems. It affords such creativity that it's a great time to be an engineer."

For more information on the recodable locking device, please contact Larry Dalton at (505) 844-2520 or <ljdalto@sandia.gov>.

Nano Is Next

The third millennium will see matter organized and manipulated at atomic and molecular levels.

At Sandia, the next growth field will almost certainly be nanotechnology, the process of creating functional materials, devices, and systems by controlling matter at the nanoscale. Today, microsystem builders must understand science and engineering at the nano level. The next decade of advances supporting national security is expected to find uses outside the defense sector in, for example, medicine, energy, and biology, with advances in clean air and environment. Sandia has begun carving a niche in the field already.

Some of the very specialized tools and processes needed to study nanostructures have been invested only recently. And these tools are often also used to make nanostructures. That's why developing the tools has been a real driver for this field of study.

"(This technology) promises significant advantages in terms of smaller size, much faster operating speeds, and enhanced functionality."

Sandia has contributed much to tool development, said Sandia physicist Wil Gauster. For example, he said, novel scanning probe microscopes can examine the molecular origins of friction and study the diffusion of atoms directly through the use of atom-tracking tunneling microscopy.

The laboratories have also demonstrated new concepts in nanoelectronics that are charting a course to the future. For example, the double electron layer tunneling transistor, based on tunneling of electrons between quantum wells that are only 10-nanometers apart. "(This technology) promises significant advantages in terms of smaller size, much faster operating speeds, and enhanced functionality," Gauster said.

Results from this forefront research and from related work going on all over the world will supply the concepts and approaches for nanotechnologies of the future.

For more information on nanotechnology research at Sandia, please contact Wil Gauster at (505) 284-3504 or <wbgaust@sandia.gov>.

NEWS *Notes*

RESEARCH PARTNERS IMPROVE CERAMICS MANUFACTURING

Sandia Labs, five commercial ceramic manufacturers, and Los Alamos National Laboratory are making ceramic history by taking the "art" out of ceramics production and replacing it with science, resulting in better products and lower production costs.

For the past three years, they have worked together under a cooperative research and development agreement (CRADA) exploring new and better ways to manufacture advanced ceramic components. It is the first time that competing ceramic companies and national laboratories have joined forces for research and development.

"We are demystifying ceramics manufacturing," says Sandia scientist Kevin Ewsuk, who is spearheading the project. "In the past, new ceramic component production involved trial and error refinement of die designs. We are developing a systematic approach to manufacturing that involves parts being designed, manufactured, and tested in a predictive mode."

The agreement, which lasts two more years, is a combined effort of Sandia, Los Alamos, and five ceramics manufacturers making up the Association of American Ceramic Component Manufacturers Consortium, Inc. The companies are Delphi Energy and Engine Management Systems of Flint, Mich.; Advanced Cerametrics of Lambertville, N.J.; CeramTec North America of Laurens, S.C.; Superior Technical Ceramics of St. Albans, Vt.; and Zircoa Inc. of Solon, Ohio.

Sandia joined the CRADA because ceramics play a key role in the laboratories' mission. Ceramics are found in products that touch just about everybody's life. They're in household appliances, automobiles, airplanes, computers, and medical equipment and have a variety of functions ranging from structural to electrical to optical.

As a result of the research, the group has already made several significant strides. One of the participating companies installed a new product line that created two new job orders and increased sales by $500,000. Another saved $50,000 in six months on a line of pressed ceramic materials. A third estimates a $100,000 savings from process improvements. Still another cut manufacturing costs by 20 percent while making a better product faster.

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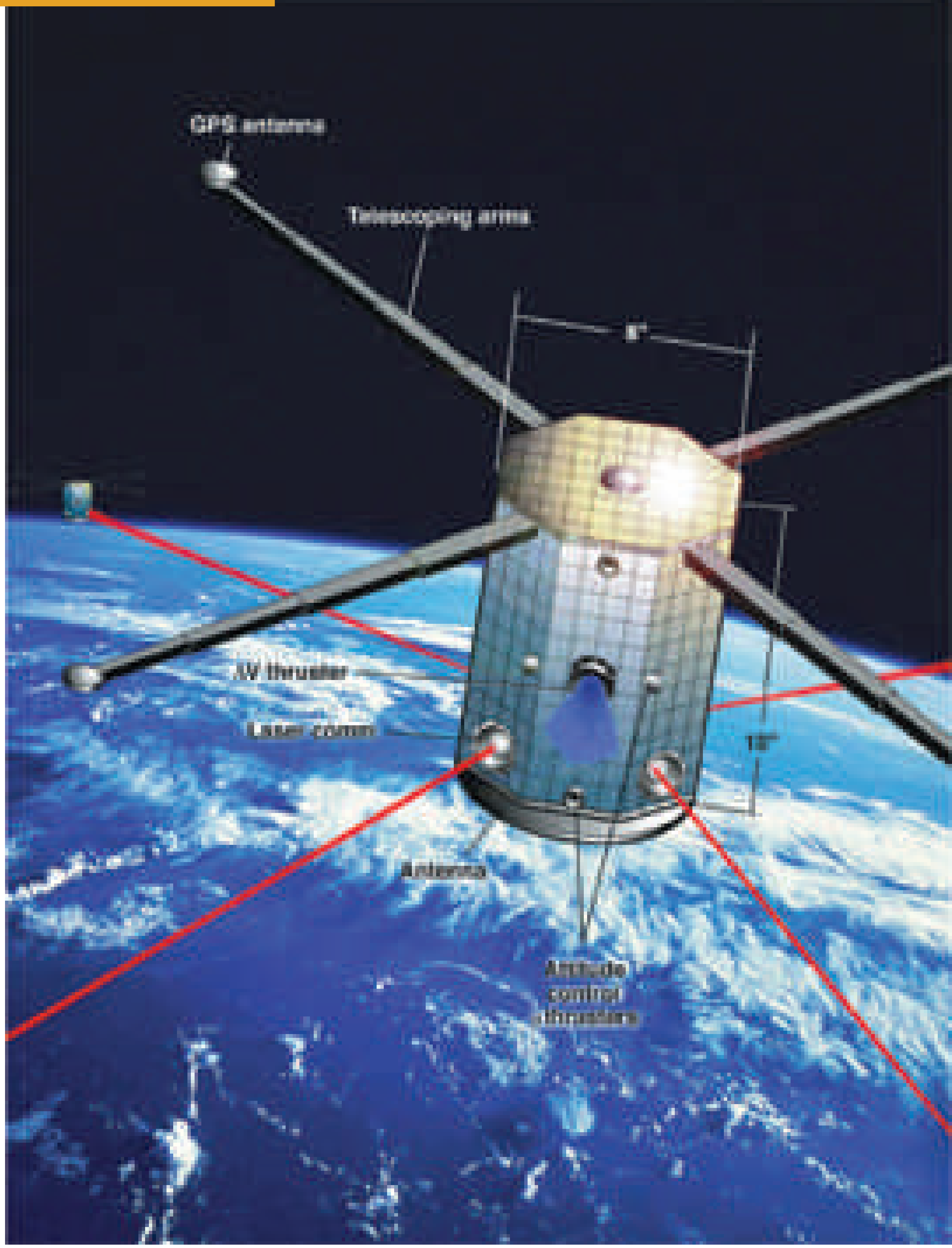
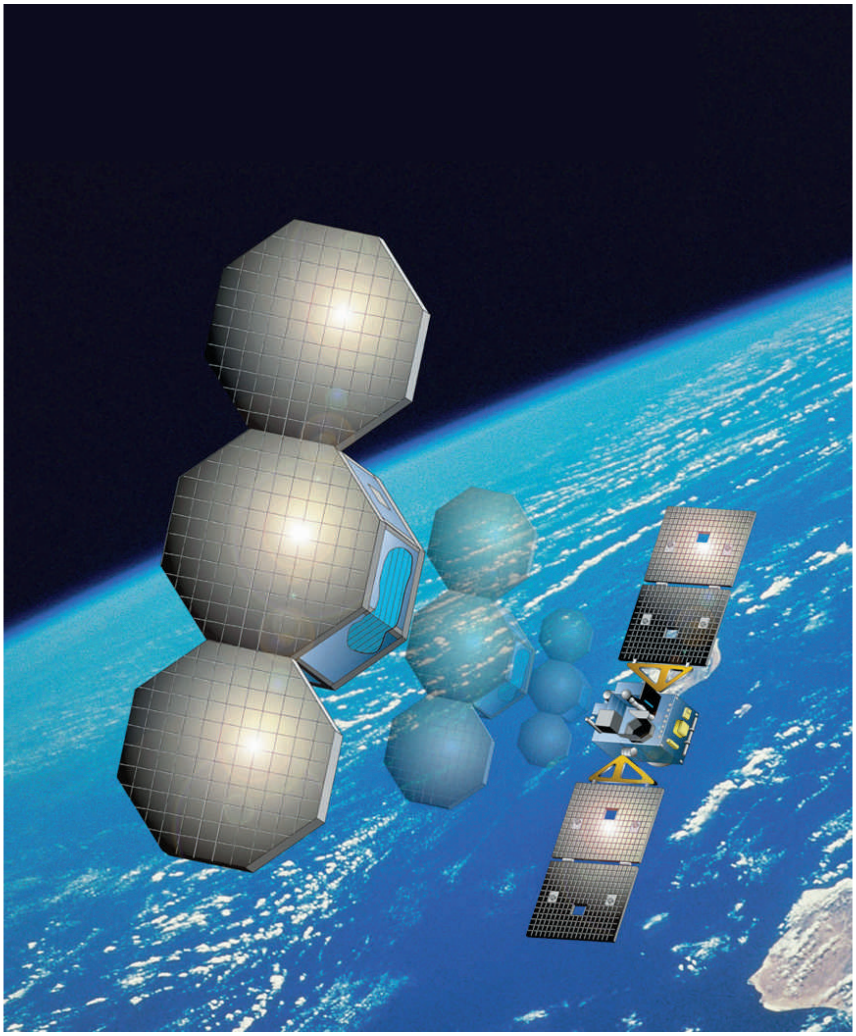
Satellites Get Smaller as They Take on Bigger Jobs



Remember Sputnik? It was one — a small satellite. Small is good. But all Sputnik did was beep.

Today satellites, although larger than Sputnik, beep and then some. They transmit phone conversations and TV shows. They communicate with global positioning receivers installed in airplanes and cars and carried in campers' backpacks. They send us pictures of the Earth for use in weather forecasting, vegetation analysis, geographic mapping, battlefield reconnaissance, and myriad other applications. However, at $6,000 per pound to launch a satellite into the Earth's orbit, the push is toward smaller, lighter satellites, even to nanosatellites.

The term *nano* gets reinterpreted with regard to satellites, none of which are on the atomic or molecular scale (to which *nano* typically refers in other contexts). Nanosatellites, also called nanosats, are defined as those of less than 10 kilograms, about the size of a basketball or volleyball. These smaller satellites require less power, and reduced power and size lowers launch cost, a key factor in satellite development. Launching a filled soft-drink can, for example, would run up an $8,000 tab to reach Earth's orbit. Getting to Mars, however, would cost more: 42 times the weight in fuel is required to launch a Mars probe.



One type of nanosat (shown in the foreground and measuring 18 inches by 6 inches) would eject from a larger satellite (shown in the background) after the craft was in space.

Sandia's Monitoring and Technology Systems Center and the Microsystems Science, Technology, and Components Center are working on a nanosatellite using a number of Sandia technologies, including microelectronics, photonics, photovoltaic batteries, and laser communication. The goal is a fully functional nanosat that could address national security missions. In a recent issue of *Aviation Week & Space Technology*, Sandian Jeff Kern is quoted as citing a goal of up to five years to launch a spacecraft that might support Sandia's role in detecting nuclear proliferation. "Anyone today could put up a 10-kilogram satellite that does nothing," Kern is quoted as saying. "Our goal is to get into the realm to use these very small satellites independently or in groups to perform the functions done (today) by much larger satellites."

"Our goal is to get into the realm to use these very small satellites independently or in groups to perform the functions done (today) by much larger satellites."

Small-satellite development faces many challenges: The nanosatellites must become smaller, but remain as effective as the larger satellites they replace. To do this for some applications, nanosats will need to become larger after they are in orbit. This may be accomplished through inflatable parts and deployable arms. To reduce the launch cost, nanosats by the dozen may have to be carried on and deployed from a single rocket booster. And to support battlefield reconnaissance and other uses, nanosats are expected to be launched on demand.

Future small satellites will have tremendous computing power. Already a Sandia-Intel partnership is creating a radiation-hardened version of the Pentium processor to function in harsh space and defense-related environments *(see the microelectronics section of Microsystems Abound, page 10)*. By using this level of processing power, small satellites will be able to run themselves and correct their own errors, thus, eliminating most need for ground control.

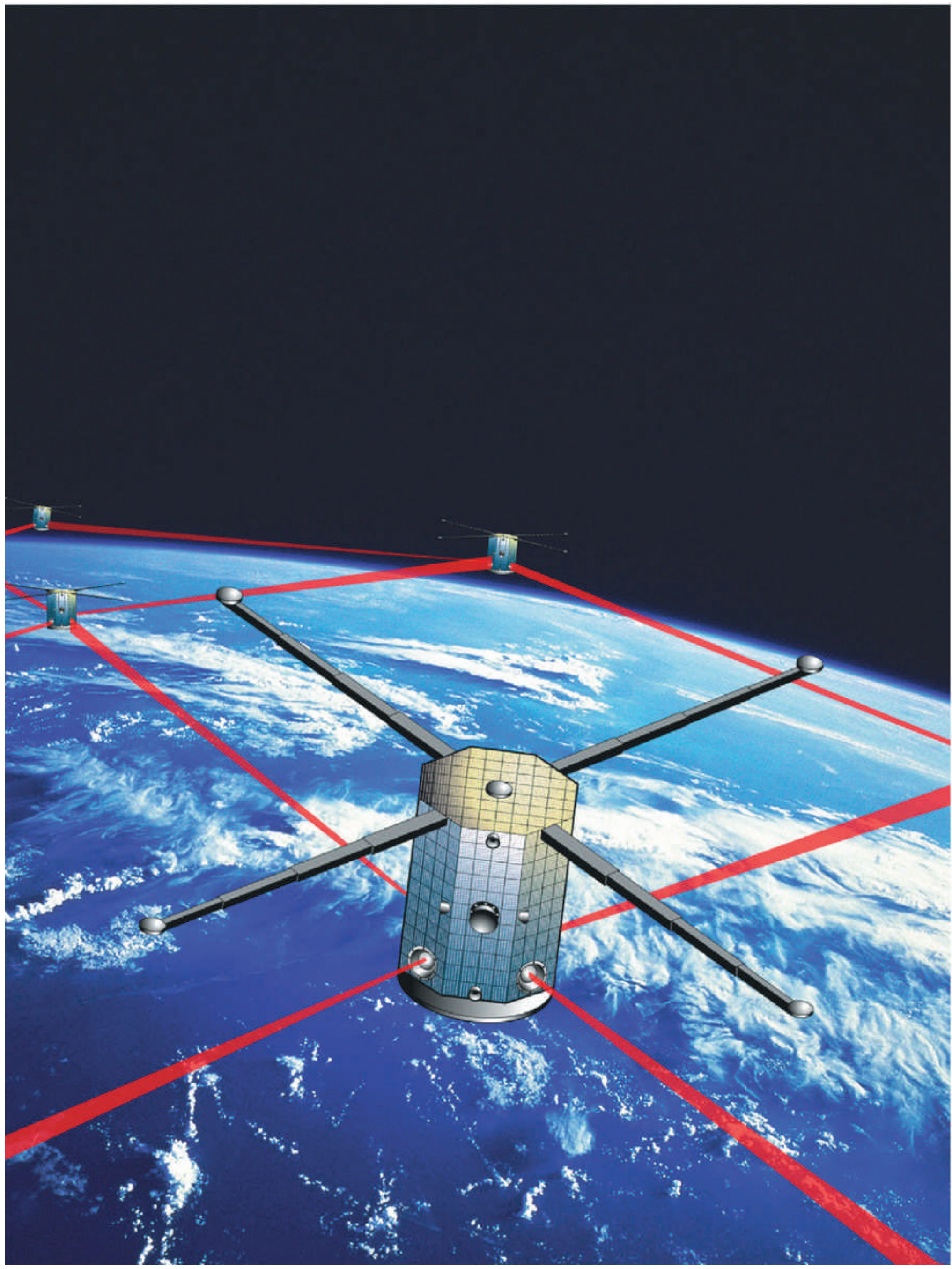
Also, nanosats are likely to perform complex missions such as monitoring the condition of and doing repairs on larger satellites. The capability to build nanosats that can inspect or in some cases repair damaged surveillance, communication, and navigation satellites is an expected outcome of Sandia research.

Today, low-Earth-orbiting spacecraft circle the globe. Their overlapping orbits provide relatively inexpensive global reconnaissance and communication. In the future these might be on the nanosatellite scale. Nanosatellites also will be used in clusters to act as a single large satellite, much as the Very Large Array in New Mexico acts as a single large telescope. Nanosatellites working in a cluster will ensure that the failure of one is not significant because others will reconfigure to compensate its loss or the failed satellite can be inexpensively replaced.

Sandia expertise in sensors, photonics, and micromachines — from our Microelectronics Development and our Compound Semiconductor Research laboratories — combine with our experience in distributed processing and satellite-systems engineering to provide a unique mix of capabilities that will have a major impact in nanosat development.

For more information, please contact Dennis Reynolds at (505) 845-8174.

Nations without sufficient land-line communication systems — for example, parts of Australia and some countries in South America and Africa — are using satellite-provided phone service on a limited basis instead of shouldering the cost to install land-line infrastructure. Nanosatellite technology, with its promise of low cost, should make this approach even more feasible.



A cluster of nanosatellites forms a sparse aperture in space, communicating via laser intersatellite links.

NEWS *Notes*

DEVICE TO SAFELY EXAMINE INSIDES OF PACKAGE BOMBS

A device that uses reflected, rather than transmitted, X-rays offers a new way to see what's inside a suspicious package.

"We'd like to get the price down where every law enforcement agency can afford one," says Sandia project manager Steve Shope, who expects the device to be commercialized in two years.

The technology stems from Sandia's work to detect plastic or metal landmines buried in the ground. A computer program developed at the University of Florida at Gainesville under contract with the U.S. Army distinguishes between degrees of reflection (backscatter) caused by objects in the case. By stripping layer after layer in a series of X-rays — a similar technique to a CAT-scan — the changes in backscattered X-rays form a complete picture.

"We can tell if it's explosives, bologna, or a can of shaving cream," Shope says.

The detector and a video camera will be placed on a mobile robotic platform. An operator will control it remotely. Even if the suspicious package explodes before transmitting a complete image, partial images useful in police work are transmitted back to the operator. And all that is lost is the video camera, X-ray machine and cart — not lives.

The device is limited in that it must repeatedly scan an object to build up an image, a process that takes about 40 minutes. A newer method, now funded and under development, will use a snapshot approach that should be much quicker.

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Sandia researcher Grant Lockwood holds a laboratory version of his off-the-shelf X-ray source to safely examine the insides of containers that could conceal bombs.

TINY SENSORS WILL DETECT MINUTE TRACES OF DANGEROUS CHEMICALS

Minute acoustic wave chemical sensors being developed at Sandia Labs will in the next two years be part of a hand-held chemical detection system, commonly called "chem lab on a chip," and other integrated microsensor systems.

The microsensors, each about the size of a grain of rice, are similar to a "canary in a mine." Like the canary, the sensors will be able to detect the presence of chemicals in the environment. But unlike the bird, they won't sicken or die when exposed to the chemicals. They will simply alert people to the potential hazard.

Chem lab on a chip, formally called µChemlabTM , is a Sandia initiative to build a hand-held "chemistry laboratory" the size of a palm-top computer. The acoustic wave sensor is one piece of equipment in that laboratory. (Also see page 9.)

"What's important here is that the chemical sensing transducer and microelectronics are integrated onto a single substrate," says Sandian Steve Casalnuovo, leader of a team of engineers and scientists who are developing the integrated sensor. The sensors can be so small that an array of four or five of them, each about 2 millimeters by 0.5 millimeters by 0.5 millimeters, and sensitive to different chemicals, could be built on a chip the size of a shirt button. Besides being incorporated into the chem lab on a chip, the microsensors may also eventually be used as mobile chemical detecting units that can be carried by robotic vehicles to the site of a chemical spill or worn by soldiers on a battlefield.

For the base material of the sensor, the researchers chose gallium arsenide (GaAs) substrates instead of the usual quartz. GaAs, which is used for special purpose microelectronics, optoelectronics, and now for integrated sensors, is the key to integrating the sensors and the electronics.

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DECONTAMINATION FOAM A QUICK DEFENSE TO CHEM-BIO ATTACK

Sandia Labs researchers have created a nontoxic foam that can quickly neutralize a terrorist release of both chemical and biological agents. Its developers think the decontaminating foam could be the best first response available in the event of a chem-bio attack.

In laboratory tests the foam destroyed simulants of the most worrisome chemical agents (VX, mustard, and soman) and killed a simulant of anthrax — the toughest known biological agent. Against the anthrax simulant, the foam achieved what the researchers call a 7-log kill — after one hour only one anthrax spore out of 10 million was still alive.

International law prohibits the Sandia researchers from possessing real chemical or biological agents, but the foam was tested against actual VX, mustard gas, and soman at the Illinois Institute of Technology in Chicago.

The foam neutralized half the remaining chemical agent molecules every 2 to 10 minutes, depending on the agent. For most chemical agents the contamination remaining after one hour of exposure to the foam was insignificant. Additional tests will pit the foam against actual anthrax and other bacterial spores.

Made from ordinary household substances, the foam neutralizes chemical agents the way a detergent lifts an oily spot from a stained shirt. The foam could be sprayed from handheld canisters and tanks of the foam could be incorporated into the fire sprinkler systems of high-profile government buildings or other potential targets.

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Foam co-developer Maher Tadros demonstrates application of the new chem-bio decontamination foam from a pressurized canister.

Sandia researcher Mark Tucker examines two petri dishes: one with a simulant of anthrax growing in it, the other treated with a new decontaminating foam.

INSIGHTS

by Nicholas M. Donofrio, Senior Vice President, Technology and Manufacturing, IBM Corporation

"...many millions of people – from end users in business enterprises to general consumer – will benefit greatly from this new computing paradigm."

Nicholas M. Donofrio, Senior Vice President, Technology and Manufacturing, IBM Corporation

A New Era Of Computing

Simultaneous with the Internet explosion comes dramatic advances in information technology – storage, memory, software, networking and, of course, microprocessors. Their ever-upward performance trajectories, and ever-downward cost and size trajectories, are creating a world in which computation will be both pervasive and invisible. Soon, virtually everyone and everything will be connected through the Internet. Tiny chips and storage devices will be embedded into cars, clothes, household appliances, and machine tools. They'll be inside networks of vending machines and the heating systems in buildings. They'll be inside virtually any inanimate object you can imagine. They'll be enabling devices everywhere to receive, process, transmit, and derive value from vast and otherwise-random amounts of digital data.

The market research firms seem to agree. Most of their forecasts say that within about three years, smart devices will account for more than 40 percent of the devices connected to the Internet and that sales of those devices will surpass personal computers within five years.

Naturally, the information-technology industry is rapidly developing strategies to capitalize on this exciting trend. Many are focused sharply on the devices that will characterize this new era. And while IBM intends to manufacture and sell a great deal of the embedded chips and storage capability to go inside those devices, we're convinced that the largest opportunity resides in the behind-the-scenes activity. Our strategy is to provide the enterprise computing technologies that will be needed to deploy, process, and manage this pervasive-computing world – from devices to the network architecture.

But how will this new world actually work? Let me outline a couple of very likely scenarios that only a few years ago would have been considered science fiction:

Imagine driving in your networked car and it develops an engine problem. Instead of flashing a warning light, it transmits a message directly to the manufacturer through a wireless connection. The manufacturer diagnoses the problem and transmits a fix back to the electronics complex in your car. In fact, the fix is transmitted to all models, everywhere in the world. Obviously a great service to the consumer. And for the manufacturer, the information is sent immediately into product development, enabling the car company to bring better cars to the marketplace faster. The implications for any producer of a physical product are truly profound. It's an opportunity to connect with customers in completely new, all-encompassing ways.

In an other scenario, it's hard to imagine how any company with its vending machines scattered around the world can know at any point in time what's selling, what's not, how much of what item is left, when a route driver should be dispatched to restock. An embedded chip in each machine could track and report all of that with ease. Plus, information gathered about customer behavior, foot traffic, and time-of-day purchases can be used for making major decisions about running the business.

Of course there are scores of other examples. The point is that many millions of people – from end users in business enterprises to general consumers – will benefit greatly from this new computing paradigm. And they won't be aware they're using a computer. This emerging world represents far more than ease of use, it delivers ease of life.

As more and more of us rely on networks and the myriad of devices to perform transactions and do business, the marketplace is demanding, perhaps more than anything, advanced microelectronics solutions. It is absolutely essential that our industry produce chips that ensure higher performance and reliability of servers, that support increased bandwidth for routers and switches, that enable multifunction, low-power networked devices and the applications to increase their value and demand.

Gladly, it seems that Moore's Law is holding up quite nicely, thank you. And it's in no danger of slowing down. The semiconductor industry will continue to cram more and more information and higher-density circuits into and onto silicon chips, and the prices of semiconductor products will continue to drop, just as they have for nearly three decades.

Clearly, the rapid advancements in underlying technologies are what will make the Internet the most valuable tool the world has ever seen. It's the most exciting time ever for the information technology industry. I'm absolutely thrilled to be part of it.

"Imagine driving in your networked car and it develops an engine problem. Instead of flashing a warning light, it transmits a message directly to the manufacturer through a wireless connection. The manufacturer diagnoses the problem and transmits a fix back to the electronics complex in your car. In fact, the fix is transmitted to all models, everywhere in the world."

Nicholas M. Donofrio, Senior Vice President, Technology and Manufacturing, IBM Corporation

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