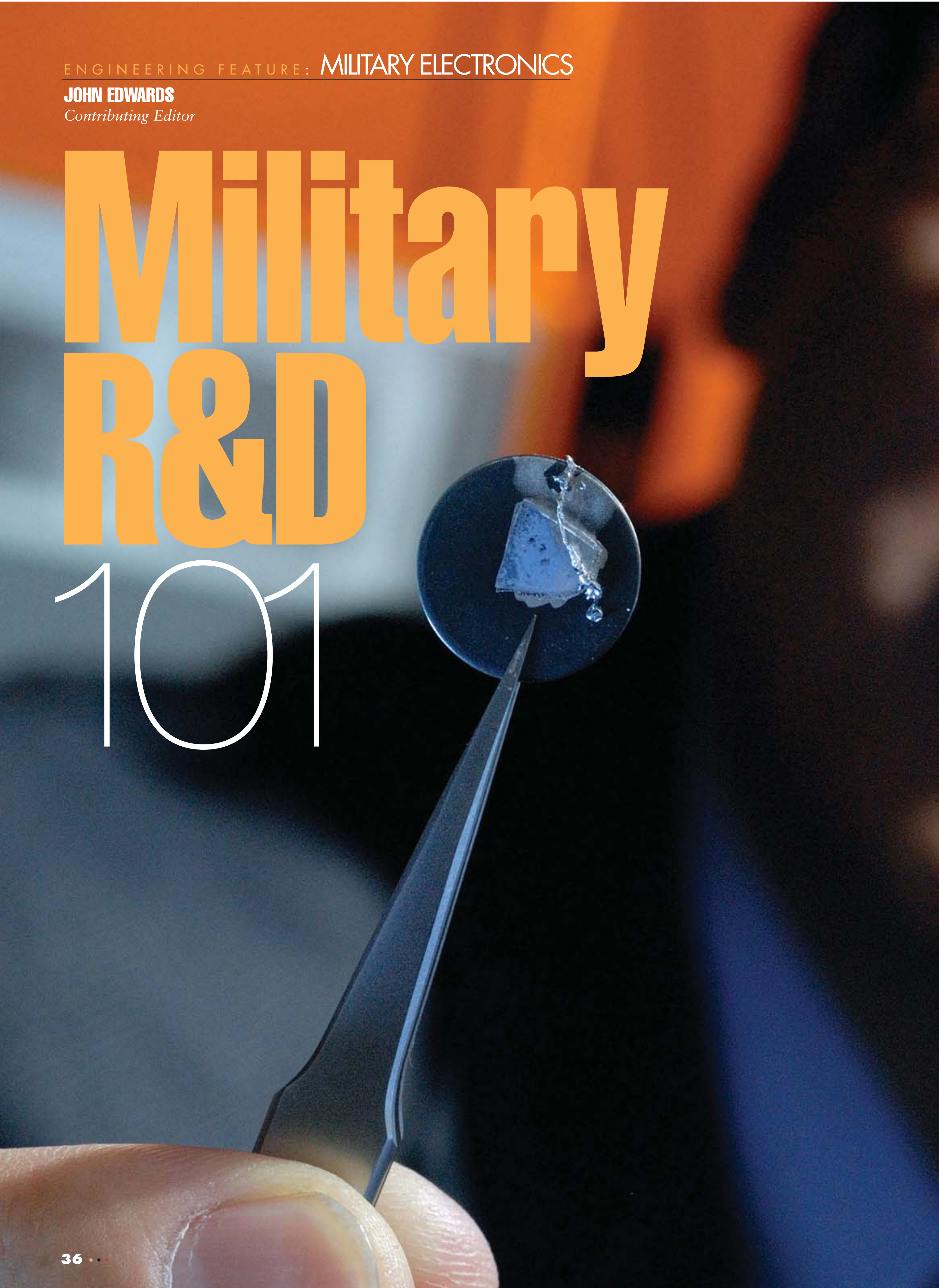
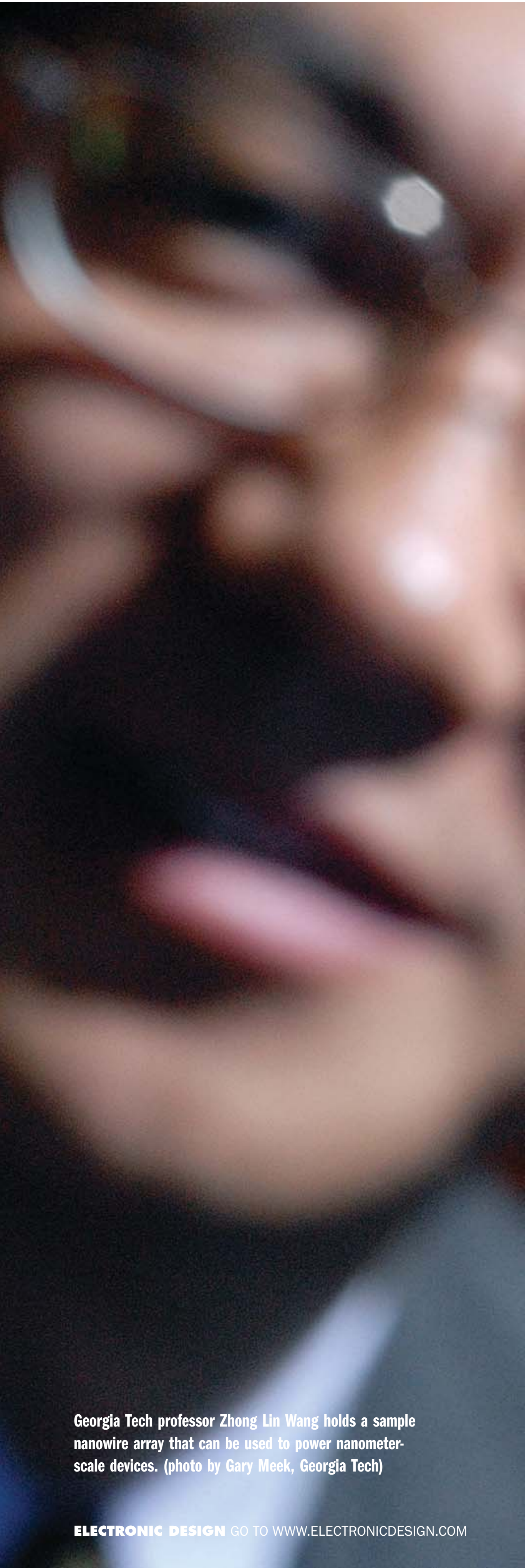
**JOHN EDWARDS**
*Contributing Editor*

# Military R&D 101





Georgia Tech professor Zhong Lin Wang holds a sample nanowire array that can be used to power nanometer-scale devices. (photo by Gary Meek, Georgia Tech)

## Many of the military's newest and most sophisticated technologies lie behind ivy-covered walls on the nation's campuses.

Ray Baughman, director of the University of Texas' NanoTech Institute, sees a time when military leaders will send robots into battle. "They could fight ahead of American soldiers, take a bullet for American soldiers, and then, after giving them a shot of alcohol or diesel fuel, will fight on."

Baughman is one of thousands of research scientists working at academic laboratories across the nation developing military-funded gadgets and systems that often end up becoming mainstream business and consumer technologies.

"Things like the Internet, GPS navigation devices, and even the Hummer," says William Ostrove, an aerospace and defense analyst at technology research firm Forecast International.With the number of corporate military R&D labs dwindling, the government is increasingly relying on university research programs to develop new and innovative ways of fighting wars. "Military technology research has become a grants-driven process," says Ostrove.

Fed by cash from the Defense Advanced Research Projects Agency (DARPA), the National Science Foundation (NSF), and numerous other government agencies, university researchers toil on projects covering the full spectrum of military needs, including health, security, decision support, communications, transportation, and tactical innovations.

The government's role in sponsoring academic military research began in the days of the Manhattan Project and continues to this day, says M. Mitchell Waldrop, an NSF spokesman. "In a sense, we're sort of a military application ourselves," says Waldrop, referring to the NSF's launch in 1950 as part of the government's plan to boost scientific research at the start of the Cold War.

Along with government money, many labs rely on funding from corporate partners. Businesses are increasingly turning to academic labs—and their skilled researchers—to develop technologies that can be sold to the government and, later on, to consumers and businesses. In fact, Ostrove says a growing number of businesses are finding it more cost effective to farm out specific projects to appropriate university labs than to conduct their own R&D.

"There are, for example, numerous projects focusing on remote sensing—seeing and hearing what the enemy is doing," he says. "This is one of many research areas with potential military and civilian security applications, and that's why there's a great deal of government and private funding."

**MUSCLE BUILDER** • Baughman is developing artificial muscles that are up to 100 times stronger than their natural counterparts. He launched the project after a DARPA representative visiting the lab mentioned the need for powerful actuators that would allow the development of autonomous humanoid robots capable of protecting people in dangerous situations. Such a technology also could be used to create exoskeletons that provide superhuman strength to soldiers, astronauts, and firefighters, as well as artificial limbs that act like the real thing.

Using funds from DARPA, the U.S. Air Force, and other organizations, Baughman led a research team that developed two different types of muscles that convert chemical energy into mechanical energy, like natural muscles. Both muscle types simultaneously function as muscles and fuel cells, eliminating the need for heavy batteries.

In one muscle type, a catalyst-containing carbon nanotube electrode is used as a fuel cell to convert chemical energy into electrical energy, as a supercapacitor to store energy, and as a muscle to transform electrical energy into mechanical energy. In the other type of artificial muscle, which is more powerful, a catalytic reaction converts the fuel's chemical energy into heat. The resulting temperature increase in the "shorted fuel-cell muscle" contracts a shape-memory metal muscle wire. Subsequent cooling completes the work cycle by expanding the muscle *(Fig. 1)*.

The shorted fuel-cell muscle may be especially easy to deploy in robotic devices, since it uses commercially available shape-memory wires that are then coated with a nanoparticle catalyst, says Baughman. The major challenges have been in attaching the catalyst to the shape-memory wire to provide long muscle lifetimes and in controlling the muscle actuation rate and stroke, he adds.

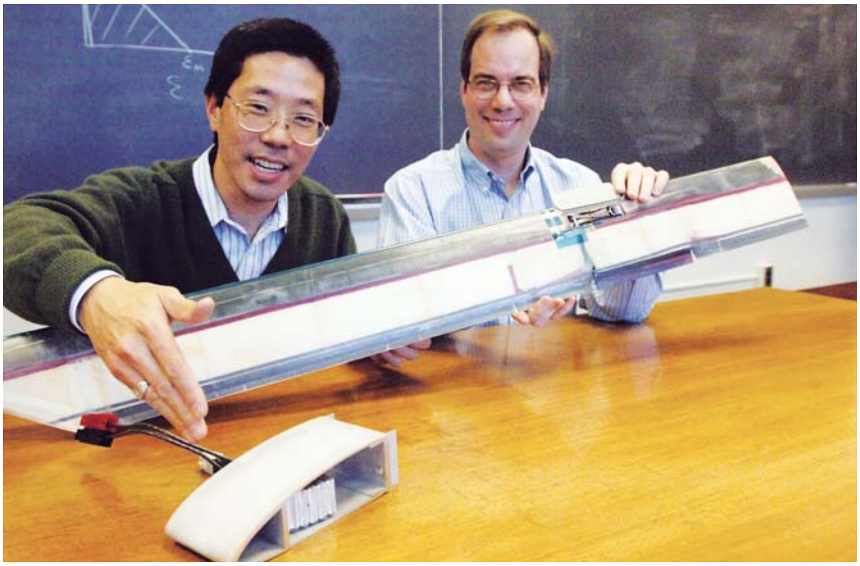
Yet Baughman is optimistic that the research will soon produce real-world products. He says the first practical applications, such as a Braille display that's powered by tiny artificial muscles, should begin arriving in less than three years. "More advanced applications, such as autonomous robots and artificial hearts, will take a bit longer," he says.

**SHAPE SHIFTER** • When Yet-Ming Chiang looks at a flying bird, he admires its beauty and grace. But as an engineer, he also marvels at how the creature can quickly change its shape to fly faster and more efficiently.

Inspired by birds and DARPA funding, the Massachusetts Institute of Technology (MIT) materials science and engineering professor is working to boost the performance of aircraft and ships by enabling them to morph from one shape into another. Strangely enough, Chiang's research is based on a detrimental battery property, the fact that power cells expand and contract as they're charged and recharged.

"We looked at this behavior and thought we could use it for another purpose: the actuation of large-scale struc-


**1. Ray Baughman, director of the University of Texas' NanoTech Institute, is developing materials that could be used for artificial muscles. For example, this NiTi spring has been coated with platinum nanoparticles (left). When it's heated to 70°C and above via a methanol/air mixture, the spring contracts and can lift a 500-g weight.**



**2. Professors Yet-Ming Chiang, left, and Steven Hall show components of their electrochemically actuated morphing rotor prototype (foreground) as well as a reduced-scale model (background) of a previous technology that uses piezoelectrics as the active materials. (photo by Donna Coveney/MIT)**

## NEED MORE INFORMATION?

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| The Center for Responsible Nanotechnology | www.crnano.org |
| Defense Advanced Research Projects Agency | www.darpa.mil |
| Forecast International | www.forecastinternational.com |
| Georgia Institute of Technology | www.gatech.edu |
| Massachusetts Institute of Technology | www.mit.edu |
| NASA Vehicle Systems Program | www.aero-space.nasa.gov/vsp/ |
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tures," says Chiang. The approach could lead to an airplane that morphs on demand from a shape designed for agility to one that aims for maximum fuel efficiency. Likewise, a ship or submarine could be designed with a hull that changes its shape in response to speed, steering, and water conditions.

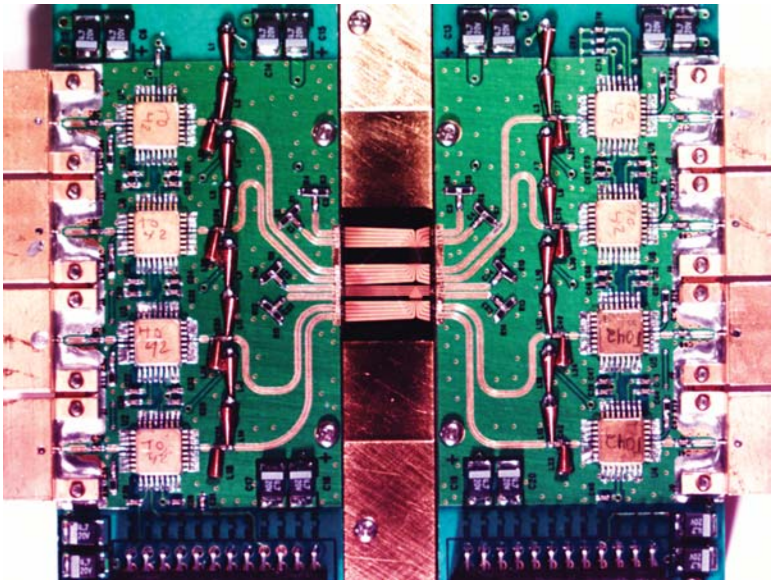
To test the concept, Chiang and co-researcher Steven Hall, an MIT aeronautics and astronautics professor, started evaluating commercially-available lithium rechargeable batteries *(Fig. 2)*. They confirmed that the batteries continued to expand and contract under tremendous stresses—a must for devices that will change the shape of structures like airplane wings, helicopter rotors, and ship hulls. The researchers also discovered that the batteries can be used as actuators at low voltages (under 5 V) and that the materials that make up the batteries are also inherently light—an important consideration for aircraft use.

Later this year, Chiang and Hall hope to demonstrate a shape-morphing helicopter rotor blade. Yet even if that test proves successful, Chiang notes that much work remains to be done before shape-shifting military or commercial vehicles become a reality. Still, he's optimistic that the research will eventually lead to a practical technology. "The fact that we've been able to demonstrate the potential of this approach using unoptimized off-the-shelf batteries is a hopeful sign," he says.

**DATA EXPRESS** • Taking advantage of $9.5 million in DARPA funding, S.J. Ben Yoo, an electrical and computer engineering professor at the University of California-Davis, plans to develop a technology that will push optical data transmission speeds through the roof. Working in cooperation with researchers at MIT and several commercial partners, Yoo's team plans to design, build, and test thumbnail-sized chips that can potentially encode data at rates of up to 100 THz, some 10,000 times faster than currently available devices *(Fig. 3)*.

"We will be prototyping a compact optical waveform generator capable of communicating at unprecedented bandwidth," says Yoo, who is director of the UC Davis Center for Information Technology Research in the Interest of Society.

Over the next three years, Yoo's research team will be prototyping a new microsystem capable of manipulating and encoding mid-infrared light carrier comb frequencies. Besides ultra-high-capacity communications, the improved



**3. This optical arbitrary waveform generator chip (center) is packaged with high-speed driver electronics (left and right). Inphi Corp. provides the high-speed electronics, and Multiplex provides the semiconductor materials. (courtesy of S.J. Ben Yoo, Davis Branch Center for Information Technology Research in the Interest of Society, University of California, Davis)**

technology could lead to the development of high-resolution light-based radars (ladars), enhanced medical imaging systems, and even electrical signal synthesizers capable of extremely rich electronic tones.

Yoo says the military envisions several future applications, including ultra-high-resolution surveillance capabilities. "They have a very keen interest in remote sensing and imaging," he says. The military would most like to nullify the enemy's ability to hide inside complex mountain terrains and cityscapes. A very compact ultra-high-resolution imaging system installed on an unmanned air vehicle (UAV), such as a Predator, could eliminate the need to send troops on reconnaissance missions into hostile areas.

"The military says they can image a tennis or soccer ball on a field from a satellite, but they want to do much better than that," says Yoo. "If they use our technology, they can make the resolution a thousand times better." That

**4. UCLA electrical engineering professor Bahram Jalali has discovered that optical amplifiers have nonlinear photovoltaic properties that enable them to recycle wasted optical energy. This could lead to silicon lasers and optical amplifiers that scale well to high power levels.**

would allow the military to not only image a ball from space, but closely examine its surface texture—or the beads of sweat on an enemy combatant's forehead. Potential commercial applications include speedier optical data networks and higher-resolution, more realistic maps for personal navigation devices.

**SMALL-SCALE RESEARCH** • Nanotechnology has emerged over the past several years as a key defense-funded research area. Military planners are tantalized by the potential of using molecular-sized machines to virtually invisibly treat and monitor injuries and diseases, provide hands-free communications systems, sense hazardous materials, and accomplish a variety of other important tasks.

Chris Phoenix, research director of the Center for Responsible Nanotechnology, a non-profit research and advocacy organization, expects many military-funded nanotechnology projects to eventually find commercial applications.

"Molecular manufacturing, the mature general-purpose form of nanotechnology, will have a significant impact on almost all parts of society," he says. "Personal nanofactories, working rapidly and directly from blueprints, may offer advanced products for a wide range of applications including home, medicine, and industry."

Like conventional technologies, nanodevices require a steady and reliable power source. Zhong Lin Wang, a materials science and engineering professor at the Georgia Institute of Technology, wants to convert mechanical energy from body movement, flowing water, structural vibrations, and other everyday sources into electricity *(see p. 36)*.

His goal is to create a nanogenerator that can power a wide range of nanodevices without bulky energy sources such as batteries. "The nanogenerator could be the foundation for exploring new self-powering technologies for in-situ, real-time, and implantable biosensing, biomedical monitoring, and biodetection [devices], with great potential for defense and civil applications," says Wang.

With funding from DARPA, NSF, and the NASA Vehicle Systems Program, Wang is building nanogenerators that create tiny piezoelectric discharges when zinc-oxide nanowires are bent and then released. Ideal for use inside the body, because zinc oxide is non-toxic, the nanogenerators could also be used wherever mechanical energy is available. The nanowires can be grown on crystal substrates, as well as polymer-based films. Flexible polymer substrates could one day allow portable devices to be powered by the movement of their users.

"You might even place nanogenerators in your shoes to produce electricity as you walk," says Wang. That could help soldiers in the field, who now require batteries to power an ever-growing assortment of radios and other electrical equipment. "As long as the soldiers were moving, they could generate electricity," he says.

**FREE ENERGY** • Another energy-related research project is under way at the University of California-Los Angeles. Bahram Jalali, a UCLA electrical engineering professor, has developed a process that enables silicon optical amplifiers to produce power that's normally wasted as heat *(Fig. 4)*. In 2004, Jalali created the first silicon-based laser, a technology with significant potential in optical communication and other fields. Yet the device's high power consumption threatened to limit its potential.

Tackling the problem through research co-sponsored by DARPA and defense contractor Northrop Grumman, Jalali discovered that Raman optical amplifiers, the same basic technology that was used to create the silicon laser, possess nonlinear photovoltaic properties that permit them to recycle wasted optical energy.

"We showed a method that consumes zero electrical power," says Jalali. "In fact, we showed that we can also recover any optical power that was absorbed in silicon. In other words, the device has negative power dissipation." Utilizing the new approach, silicon lasers and optical amplifiers should be able to scale nicely to high power levels, he says.

High power optical sources are very important to the military, notes Jalali. "They are needed in a number of systems, ranging from directed energy weapons to defense against heat-seeking missiles and the detection of biochemical warfare agents," he says.

Jalai also envisions multiple commercial applications, including high-speed, low-cost Ethernet optical modules within a few years. "A longer term application is chip-to-chip interconnects where microprocessors, graphics processors, and memory chips communicate via optical signals resulting in higher performance," he adds.

**A BETTER WAY?** • The U.S. is often criticized for the way it sponsors the development of military technologies. "Most of the time, it's the government that comes up with certain requirements and then goes to the labs and asks for the new technologies," says Ostrove. The standard operating procedure calls for DARPA or other government agencies to send out a wish list, receive proposals, and then award grants to the successful bidders.

But other nations do it differently. Some, such as Japan and the E.U., create formal research planning commissions that unite government, industry, and academic leaders to evaluate and assign research projects to specific institutions. Yet despite such careful planning, these nations have contributed relatively little to military technology over the past several years. Could it be that the U.S.'s patchwork approach is better at selecting and nurturing new technologies? Ostrove thinks so.

"It may just be that that the secret to success lies in having a certain amount of chaos," he says.

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