A sea change in small electronics

Miniaturized electronics are leaving the labs, entering production, and being integrated into military and aerospace system designs

By COURTNEY E. HOWARD

Nanotechnology, microelectromechanical systems (MEMS), and nanoelectromechanical systems (NEMS)—once only fodder for fantasy and science fiction—has in recent months reached a new milestone. Advancements in microelectronics are helping to reduce the size, weight, cost, and carbon footprint of various military and aerospace electronics in land, sea, air, and space applications.

Bigger isn't always better

Virtually all current, and even future, mil-aero platforms suffer space constraints. Defense organizations, including the U.S. Department of Defense (DOD) and the United Kingdom's Ministry of Defense (MOD), have long partnered with industry and academia to resolve the challenge of infusing military platforms with comprehensive, advanced electronics technology despite size, weight, power, and cost (SWaP-C) limitations. Many researchers, engineers, academics, and pundits say they believe nanotechnology and MEMS are the answer.

"The ability to condense the size of electronic devices while increasing their capability, features, and speed has greatly enhanced the ability to package electronics in considerably smaller, more functional form factors," Greg Jones, North American sales manager at Omnetics Connector Corp. in Minneapolis, says of nanotechnology and MEMS.

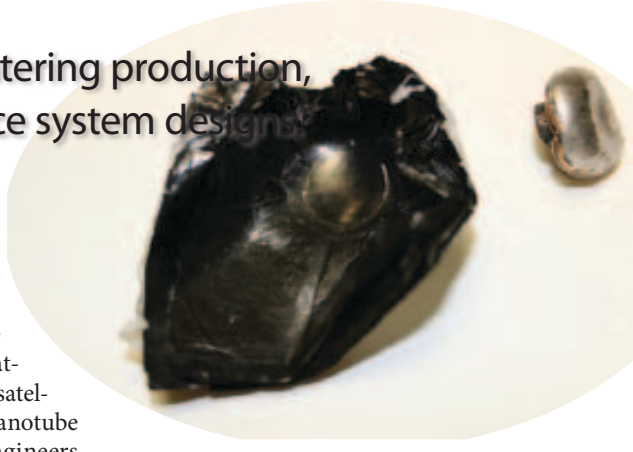
Omnetics latest dual row and circular Nano connectors are typically used for just this purpose, says Jones: "To save space, weight, and mass, while allowing for more digital signal paths in applications ranging from unmanned aerial vehicles (UAVs) to handheld devices deployed in the military, homeland security, and law enforcement."

Miniature electronics

"Enhancing performance and improving mission survivability in all areas will be impacted [by nanotechnology and MEMS], enabling light weight and improving functionality in systems in orbit and being flown," says Peter Antoinette, president and chief executive officer of Nanocomp Technologies in Concord, N.H.

Antoinette and his colleagues at Nanocomp are decreasing the weight of systems and entire platforms in the military aircraft and satellite community by using carbon nanotube (CNT) technology. Nanocomp engineers have developed thin, lightweight, electrically conductive wires, cables, and sheet materials constructed of carbon nanotubes.

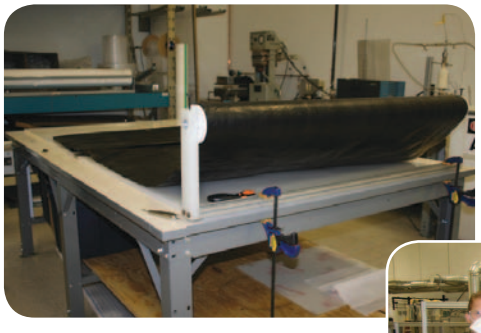
Copper cabling constitutes roughly one third the weight of a satellite and accounts for thousands of pounds of an aircraft's weight, Antoinette explains. The braided copper in the shielding alone contributes approximately half the weight of a coaxial cable. "Shielding made of carbon nanotubes makes a huge impact on mil-aero applications," he says. "Replacing the shielding in an aircraft with carbon nanotube materials can reduce the weight of aircraft wiring by as much as 30 to 50 percent, or as much as 1,000 pounds. Replacing the copper core conductor with a CNT core conductor would result in up to a 70 percent weight reduction for cables; however, this is unlikely to happen for quite some time."



Nanocomp's large-format carbon nanotube textiles are currently being evaluated by the U.S. Air Force for potential deployment in advanced electromagnetic interference (EMI) and electrostatic discharge (ESD) shielding systems on both manned and unmanned aircraft.

Nanocomp won a Phase II Small Business Innovation Research (SBIR) grant from the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base, Ohio, to continue the development of carbon-nanotube-based, lightweight, conductive wires offering electromagnetic interference/electromagnetic pulse (EMI/EMP) resistance.

Nanocomp engineers, together with officials from the U.S. government and two prime defense contractors, are working on EMI shielding based on carbon nanotube technology. "It is a very big project, in excess of $4 million and managed by AFRL, to develop



At Nanocomp, a 25-foot roll of double-wall carbon nanotube material is being prepared for delivery to a customer.

Nanocomp Technologies' CNT fabric stopped a 9-millimeter, jacketed round in controlled ballistics testing. This material, shown at right, is roughly the same thickness as six stacked business cards.

lightweight technology that enables planes to resist EMI and interference," Antoinette says. "The project is very important to the Air Force, and will enable manned and unmanned vehicles to perform in areas with lightning and EMP/EMI threats."

Shielding soldiers

Nanocomp's next-generation carbon nanotube material also could be applied to warfighters in the battlefield. Nanocomp is working with U.S. ground forces to apply its EMI shielding "skins" and high-strength sheets to protect infantry forces.

"Soldiers are putting more and more powerful radios and devices on their vests," Antoinette describes. "These are cell phones on steroids, and electric and magnetic fields (EMFs) radiate both ways. Layers of carbon nanotubes can block emissions and protect the health of soldiers."

Engineers at Nanocomp and the Natick Soldier Center in Natick, Mass., are partnering to improve soldier armor. "Our objective is to help soldiers on the ground by providing armor that offers reduced weight and provides better protection. In the past year, we have stopped handgun rounds with ultra-lightweight carbon-nanotube-based panels that are roughly six business cards thick.

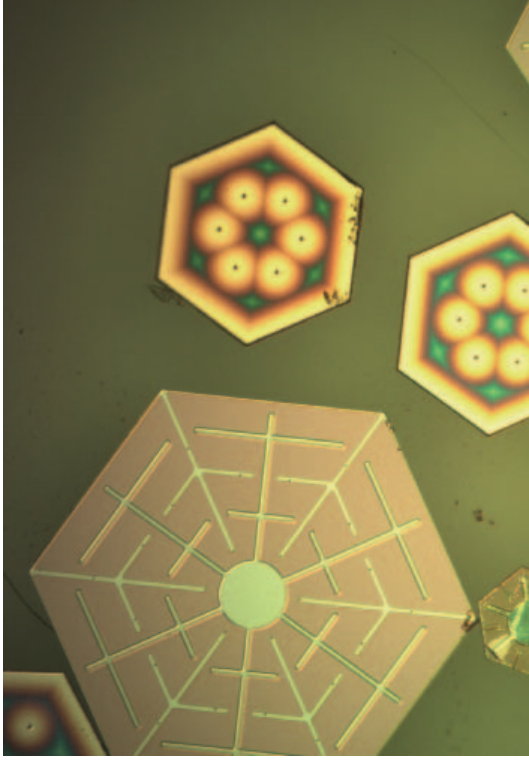
"It is still early and we still have a long way to go," Antoinette admits, "but so far, the results have been promising. In general, that's where nano and MEMS have moved—off the lab bench and into qualification phases."

Nanotechnology and MEMS, although generally considered to be emerging technologies, are already being applied in semiconductor, power storage, and component- and system-level designs. In fact, Antoinette says, Lockheed Martin's nanotube electronics flew on the last space shuttle mission, which is a strong indication of how far nanotechnology has come.

Nanotubes in space

Engineers at Lockheed Martin in Palo Alto, Calif., and Nantero Inc. in Woburn, Mass., worked together to develop radiation-resistant, carbon-nanotube-based memory, which was tested on a recent space shuttle mission.

NASA engineers, in turn, incorporated the NRAM, a nonvolatile random access memory chip, into special, autonomous testing configurations installed into a carrier at the aft end of the payload bay. It was launched into space as part of STS-125, the May 2009 mission of the Space Shuttle Atlantis that serviced the Hubble Space Telescope.



Sandia's thin crystalline-silicon photovoltaic cells measure from 14 to 20 micrometers thick and 0.25 to 1 millimeter across. (Image by Murat Okandan.)

"Carbon nanotubes have tremendous potential for a wide range of future space-based applications, and we couldn't be happier for the success of this experiment," says Dan Powell, the chief nanotechnologist at NASA Goddard Space Flight Center (GSFC) who managed the project.

"The experiment was a proof-of-concept that enabled the testing of launch and reentry survivability, as well as basic functionality of the carbon nanotube switches on orbit throughout the shuttle mission," explains a Lockheed Martin official. The NRAM devices, early prototype parts, performed consistently—before, during, and after completion of the mission. "This mission represents an important first step in the development of high-density, non-volatile, carbon-nanotube-based memories for spaceflight applications." Lockheed Martin and NASA officials are working on plans for future NRAM flights.

Nantero engineers developed NRAM high-density, nanotube-based/nonvolatile RAM using proprietary technology derived from research. The proprietary NRAM design, invented by Thomas Rueckes, Nantero's chief technology officer

Power on command

The mPower Emergency Illuminator, using mPhase's nanobattery technology, won an Innovations Design and Engineering Award in the Portable Power category at the 2010 International Consumer Electronics Show.

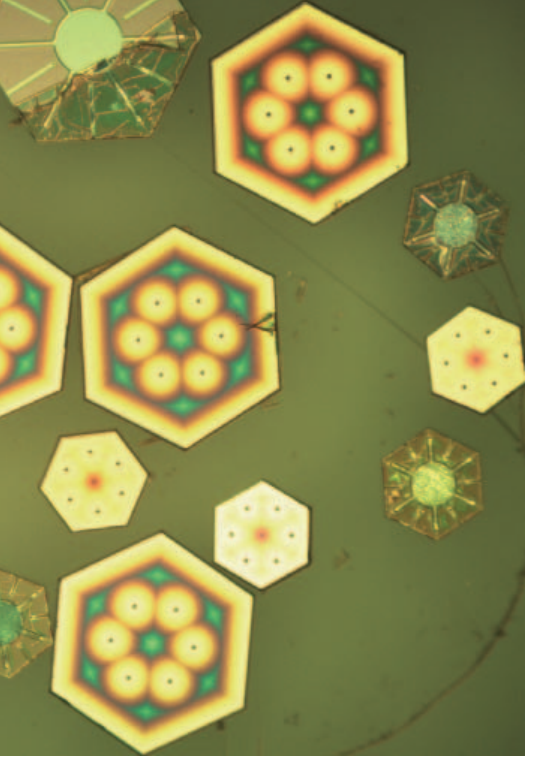
mPhase Technologies Inc. of Little Falls, N.J., won an Innovations Design and Engineering Award in the Portable Power category for its mPower Emergency Illuminator at the 2010 International Consumer Electronics Show (CES) in Las Vegas last month. The mPower Emergency Illuminator was also named an International CES Innovations 2010 Design and Engineering Awards Honoree in the Personal Electronics Design category.

"The mPower Emergency Illuminator is a precision instrument with a powerful 180 Lumens LED and two separate battery tubes," describes a company representative. One tube holds two CR123 batteries for everyday use; the second tube carries mPhase's Power On Command reserve battery that takes over after the CR123 batteries are spent, even after laying idle for 20 years. The Emergency Illuminator also sports a USB port for charging portable electronic devices.

"This award spotlights the true importance of the Power On Command technology that makes the mPower Emergency Illuminator such a distinctive product," says Ron Durando, chairman and CEO of mPhase Technologies. "Considering that the U.S. government is giving increasing priority and funding to alternative energy solutions, this is an important time to be recognized for new and innovative battery technology."

The mPower Emergency Illuminator may hold value for defense, homeland security, first responder, and consumer applications.

For more information, visit mPhase Technologies online at www.mphasetech.com.



and co-founder, employs carbon nanotubes as the active memory elements.

Carbon nanotubes not only offer the ability to conduct electricity as well as copper, but also are stronger than steel and as hard as diamond, says a company representative.

The NRAM design also combines nanotubes with traditional semiconductor technologies for manufacturability. NRAM can replace DRAM (dynamic RAM), SRAM (static RAM), and flash memory, and is expected to displace hard disk storage in the future.

"This demonstration of carbon-nanotube-based semiconductor devices in the rigorous conditions of space is an important step towards a whole new suite of future applications," says Dr. Jim Ryder, vice president and general manager of the Lockheed Martin Advanced Technology Center in Palo Alto.

Lockheed Martin is dedicated to the research, development, and application of nanotechnology to future government applications, Ryder adds. Direct benefits of nanotechnology for government customers could include stronger, lighter, and less expensive materials; more capable systems; and enhanced personal protection for military and first responders.

From left to right, Sandia researchers Murat Okandan, Greg Nielson, and Jose Luis Cruz-Campa hold samples containing arrays of microsolar cells. (Photo by Randy Montoya.)

Aerospace imaging

NASA officials, continuing to further nanotechnology and MEMS development

and application, have partnered with Boston Micromachines Corp., a provider of MEMS-based deformable mirror products for adaptive optics systems, in Cambridge, Mass.

Boston Micromachines won two NASA Phase I SBIR contracts, totaling roughly $200,000, to further space imaging research.

The first Phase I project is to develop a compact, ultra-low-power, high-voltage multiplexed driver suitable for integration with Boston Micromachines's deformable mirrors in space-based, wavefront control applications. "This project, a collaboration between Boston Micromachines and Boston University, aims for a driver to be produced with a minimum hundred-fold reduction in power consumption and a tenfold reduction in size while maintaining high precision and decreasing cost interconnection complexity," a representative describes.

"The second Phase I project involves an enhanced fabrication process for high actuator count deformable mirrors, required for wavefront control in space-based high contrast imaging instruments. This manufacturing process is expected to overcome current scalability issues associated with fabricated, polysilicon surface micromachined MEMS deformable mirrors. By expanding the size of deformable mirror devices, space imaging instruments will be able to shape more light using less hardware and less stages," explains a representative.

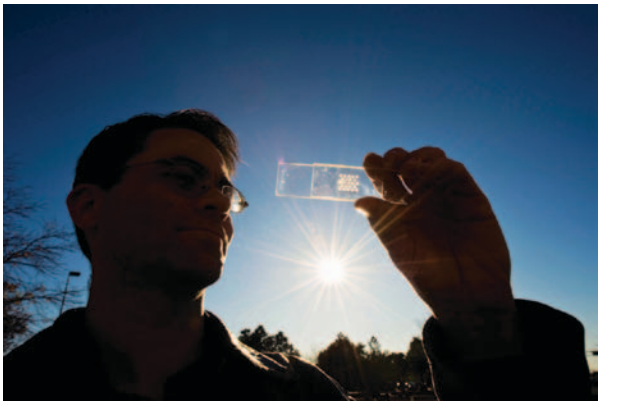
Boston Micromachines' devices, integrated into commercial adaptive optics systems, apply wavefront correction to produce high-resolution images, and to enhance images blurred by the earth's atmosphere. The company's advanced MEMS-based mirrors drive scientific discovery in astronomy, laser beam shaping, microscopy, and vision science, and support a variety of defense applications. Customers include NASA, the University of California-Berkeley, Lockheed Martin, and Boston University.

"These SBIRs mark the seventh and eighth contracts from NASA through the SBIR program," says Paul Bierden, president and co-founder of Boston Micromachines. "Our technology continues to help advance the search for extrasolar planets, which has emerged as a compelling, long-term scientific goal for NASA."

Microsolar MEMS

Scientists at Sandia National Laboratories in Albuquerque, N.M., have developed glitter-sized photovoltaic cells that could revolutionize the way solar energy is collected and used.

Sandia lead investigator Greg Nielson and his colleagues in the research team expect the microphotovoltaic cells, which are fabricated using microelectronic and microelectromechanical systems techniques, to improve performance, reduce costs, and increase efficiencies in current and new applications.



Sandia project lead Greg Nielson holds a solar cell test prototype with a microscale lens array fastened above it. Together, the cell and lens help create a concentrated photovoltaic unit. (Photo by Randy Montoya.)

"Eventually units could be mass-produced and wrapped around unusual shapes for building-integrated solar, tents and maybe even clothing," Nielson predicts. These miniature cells could make it possible for military personnel in the field to recharge batteries for phones, cameras, and other electronic devices as they walk or rest.

Microengineered panels could also be imprinted with circuits, enabling the performance of additional functions, Nielson says. Other possible applications include satellites and remote sensing.

Microphotovoltaic cells are well suited to military applications, in which size, weight, power, and cost are important considerations. These MEMS devices would take up little space, harvest and store power, and potentially reduce costs because "microcells require relatively little material to form well-controlled and highly efficient devices," according to a Sandia official.

"They use 100 times less silicon to generate the same amount of electricity," says Sandia researcher Murat Okandan. In fact, electricity can be harvested from the Sandia-created cells with 14.9 percent efficiency, whereas commercial off-the-shelf (COTS) modules range from 13 to 20 percent efficiencies.

"Since they are much smaller and have fewer mechanical deformations for a given environment than the conventional cells, they may also be more reliable over the long term," Okandan adds.

These MEMS-based cells are the product of the combined efforts of: Sandia's Microsystems Center; Photovoltaics and Grid Integration Group; and Materials, Devices, and Energy Technologies Group; as well as the National Renewable Energy Lab's Concentrating Photovoltaics Group in Golden, Colo. This work is also supported by the U.S. Department of Energy's Solar Energy Technology program and Sandia's Laboratory Directed Research & Development program.

Sandia National Laboratories is a government-owned/contractor-operated multiprogram laboratory. Sandia Corp., an autonomous Lockheed Martin company, manages Sandia National Laboratories for the U.S. Department of Energy's National Nuclear Security Administration.

Nanobatteries

Today's military missions require an ever-increasing amount of electronics, driving the need for safe and reliable power able to withstand the rigors of the battlefield. Batteries based on nanotechnology, offering small size and potentially low cost, present a compelling argument for mil-aero applications.

Engineers at Altair Nanotechnologies Inc. (Altairnano) in Reno, Nev., designed the company's advanced lithium-ion battery systems to meet specific power and energy requirements for a range of military applications, such as weapons systems, combat vehicles, ships, data centers, and military micro-grid applications.

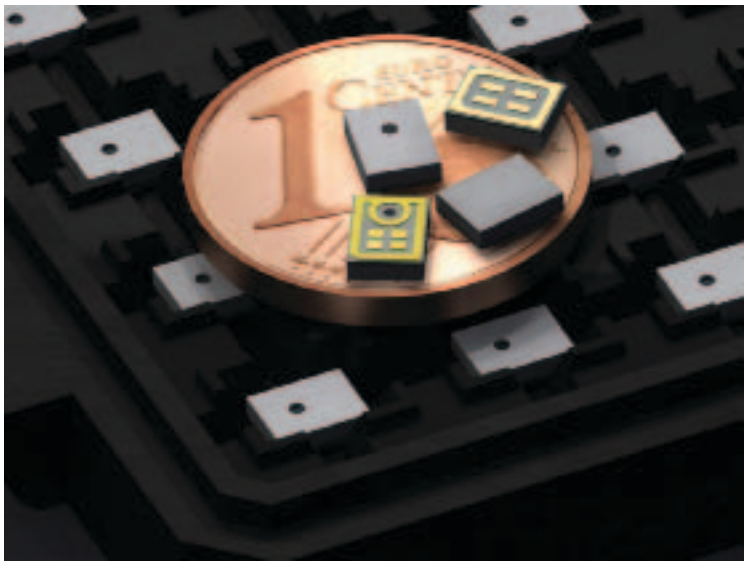
The devices are engineered to deliver safety, reliability, availability, and long-term performance in extreme temperature

and environmental conditions, as well as to help the military achieve renewable energy goals and reduce downtime and maintenance costs, says a representative.

Altairnano engineers are researching nanosensors for the U.S. Army, as part of an agreement with the U.S. Army Research, Development, and Engineering Command (RDECOM) Acquisition Center that runs through September 2010 and is worth as much as $1.75 million.

Altairnano personnel are researching sensitive and selective nanosensors to determine how single sensing molecules combined with nanoparticles respond to airborne nerve agents and toxic industrial chemicals. The goal is to incorporate nanosensors in portable sensing devices capable of protecting soldiers from the threat of chemical weapons.

"This is another important milestone in our work with the military," Terry M. Copeland, Altairnano's CEO, acknowledges. "We believe Altairnano's technologies are uniquely positioned to help the U.S. Army in the development of portable, life-saving sensors that could one day be utilized on the battlefield."



MEMS manufacturer STMelectronics in Geneva, Switzerland, introduced microphones equipped with MEMS sensor technology from Kyoto, Japan-based Omron Corp., that are less susceptible to mechanical vibration, temperature variations, and electromechanical interference than traditional electret condenser microphones.

Nanoscale for the Navy

Altairnano is involved in several military projects geared toward more sturdy, efficient, compact, and cost-effective power electronics.

The company's advanced energy storage and battery systems—which replace traditional graphite materials used in conventional lithium-ion batteries with a proprietary, nano-structured lithium titanate—have been adopted by the U.S. Department of Defense and the United Kingdom Ministry of Defense. Applications include battery backup systems that replace diesel turbine generators on U.S. Navy vessels like the Arleigh Burke class destroyer; batteries for lightweight gun digitization, including the U.S. Army M119 howitzer; and a battery system for submarine power and propulsion.

Altairnano won a $3.8 million contract from the Office of Naval Research for Phase II of a shipboard uninterruptible power supply (UPS) system. The U.S. Navy program is focused on developing, testing, and deploying 2.5-megawatt stationary power supply systems for naval destroyers. Alairnano officials anticipate development of a safe, less costly, and environmentally sustainable substitute for back-up fuel turbines, resulting in an annual fuel cost savings in excess of $1.5 million per ship and 960 metrics tons of carbon reduction annually per ship.

Long-life lessons

U.S. Army officials have renewed a Phase II Small Business Technology Transfer (STTR) Grant originally awarded to mPhase Technologies Inc. in Little Falls, N.J., in September 2008 through the SBIR program. The two-year grant enables mPhase engineers to continue developing the Smart NanoBattery through September 2010. The goal is a compact, multi-cell, three-volt, lithium-chemistry, micro-arrayed battery with a minimum 20-year shelf life and uninterruptible power output during the same period.

Engineers at mPhase have, over the past 12 months, built a functional lithium Smart NanoBattery prototype for a computer memory application. Upon completion of the program, mPhase officials plan to enter production and commercialize the battery technology.

Engineers at mPhase Technologies and the Energy Storage Research Group (ESRG) at Rutgers University in Piscataway, N.J., are working together on the project.

Military nanotechnology

Current military electronics applications require power electronics and power supplies that are not only small, safe, and reliable, but also rugged.

COMPANY INFORMATION

AeroVironment Inc.
Monrovia, Calif.
www.avinc.com

Air Force Research Laboratory (AFRL)
Wright-Patterson Air Force Base, Ohio
www.afrl.af.mil

Altair Nanotechnologies Inc. (Altairnano)
Reno, Nev.
www.altairnano.com

Boston Micromachines Corp.
Cambridge, Mass.
www.bostonmicromachines.com

Energy Storage Research Group (ESRG) at Rutgers
Piscataway, N.J.
http://mase.rutgers.edu

Lockheed Martin Nanosystems,
a business unit of Lockheed Martin Space Systems Company
Palo Alto, Calif.
www.lockheedmartin.com

Luna Innovations Inc.
Roanoke, Va.
www.lunainnovations.com

mPhase Technologies Inc. AlwaysReady Inc.
Little Falls, N.J.
www.mphasetech.com

Nanocomp Technologies Inc.
Concord, N.H.
www.nanocomptech.com

Nantero Inc.
Woburn, Mass.
www.nantero.com

Natick Soldier Center
Natick, Mass.
www.natick.army.mil

National Renewable Energy Lab
Golden, Colo.
www.nrel.gov

Omnetics Connector Corp.
Minneapolis
www.omnetics.com

Sandia National Laboratories
Albuquerque, N.M.
www.sandia.gov

Via Technologies Inc. USA
Fremont, Calif.
www.via.com.tw

Officials at AlwaysReady Inc., a subsidiary of mPhase Technologies in Little Falls, N.J., have revealed that the company's Smart Nanobattery structure survived a 50,000 G-force test at the U.S. Army's Picatinny Arsenal in New Jersey.

During the test, several Smart Nanobattery prototypes were shot from an air-gun simulator at a force calculated to be greater than 50,000 Gs. Officials confirmed that the batteries continued to function and generate the expected electrical output following the test.

"This test demonstrated that the physical structures, although micro-sized, are durable enough to withstand the most rugged conditions," says Steve Simon, executive vice president of research and development at AlwaysReady.

The test was part of a Cooperative Research and Development Agreement (CRADA) with researchers at Picatinny with the goal of using nanobatteries to power next-generation armaments and small guided munitions.

Smart Nanobattery architecture from mPhase/AlwaysReady is designed to deliver an energy source that has a decades-long shelf life and can be activated on demand for defense and other applications.

Carbon nanotubes

Carbon nanotubes (CNTs) are tiny, cylindrical carbon molecules 1/50,000th the diameter of a human hair that possess electrical and structural properties. The word "nanotube" is from nanometer (approximately 10 carbon atoms) and tubular (shape of a rolled up sheet of graphene that forms a CNT). CNTs are half the density of aluminum, 50 times stronger than steel, thermally stable in vacuum up to nearly 3,000 degrees Celsius, efficient conductors of heat, and may be either metallic or direct bandgap semiconductors. (Courtesy Lockheed Martin and Nantero.)

Promising progression

"The future of nanotechnology and MEMS is moving out of labs and into production," Nanocomp's Antoinette says. "Nanotechnology is through the incubation phase and in a true commercial phase, as companies like Nanocomp scale up to offer large volumes with attractive pricing. In general, this is the next step for nanotechnology. We are working on that, and planning to bring manufacturing online this year."

Cost-reduction efforts pose a big challenge, Omnetics' Jones explains, because "the use of MEMS technology does not yet have large commercial applications to offset the cost of development. Yet, there are a number of initiatives to meet the challenges of processing MEMS technology, funded by both private industry and the government, to further its development and applications. I fully expect this development to continue well into the future."