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INSIDE

Conductive, Shape-Shifting Material Increases Electronics' Durability—*by T. Robinson*

Conventional flexible circuits used in cell phones and laptops fail when overused, strained, or stretched. But, a new conductive material capable of elongating and returning to its original form without failure is now available for testing.

The new material, called Metal Rubber™ and developed by NanoSonic, Inc. (Blacksburg, VA), can be applied to any existing or new electronic device that requires wires to bend and stretch. The robust, low-weight, and radiation-resistant material evolved out of nanotechnology research.

Using its MDA-funded low-temperature electrostatic self-assembly (ESA) manufacturing process (see "NanoSonic Demonstrates Self-Assembly Process" *MDA Update* Summer 2001), NanoSonic developed nanocomposites, which it layered together to form Metal Rubber. ESA enables NanoSonic to customize Metal Rubber's characteristics (e.g., conductivity and modulus). The material does not fall apart when deformed and is highly conductive even though it just contains parts per million of metal.

The commercial applications using this conductive, shape-shifting material are limitless. A search on the Internet yields visionary ideas like morphing aircraft wings, flexible, roll-up keyboards, or Metal Rubber jackets that get longer or shorter according to the temperature. But, for now, NanoSonic is focused on more near-term applications such as flexible circuits and strain sensors.

Laptops and cell phones that flip open contain flexible circuits connecting the base to the screen. These circuits fail when they are bent too often. NanoSonic's Metal Rubber is much more flexible and elastic than typical flex circuits. It can stretch up to 300 percent its size and return to its original shape while remaining conductive.

Metal Rubber may also be used as flexible interconnects or strain sensors in the missile defense system. For example, it may be used in the development of flexible, conductive, and radiation-resistant components such as interconnects for flexible communication and tracking platforms like the High Altitude Airship or space-based radar. Such flexible aerospace structures may also require flexible strain sensors to determine shape and displacement, and these potentially may be implemented using Metal Rubber materials. The Lockheed Martin Corporation recently signed an alliance agreement with NanoSonic for possible uses of NanoSonic's novel materials and processes.

NanoSonic is investigating the use of Metal Rubber as a stress/strain sensor as well. With the material's good stress/strain linearity and broad range (several 100 percent strain), it could be used as jackets or coatings for cables used in wiring harnesses. Instead of having to assess each conductor of the actual cable, a maintenance technician would inspect only the Metal Rubber jacket to determine if the cable has been somehow over-strained.

NASA's Jet Propulsion Laboratory may also apply Metal

Continued on page 16

Stretched. *NanoSonic President Rick Claus and researchers Jennifer Lalli and Jeff Mecham display the capabilities of Metal Rubber™, a highly conductive material that stretches like rubber, but conducts electricity the way metal does.*

MDA Update

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FROM THE EDITOR

MIXED BAG

This issue is a mixed bag. In addition to new technology features, you will find updates of previous articles as well as some recent spinoff news.

Hole-ly War

The Airborne Laser (ABL) program needs millions of holes drilled quickly and precisely. Yet with conventional hole-drilling technology, it would take years to accomplish this task. So MDA's SBIR program funded several small businesses to innovate solutions.

In the Spring 2004 issue, we featured Clark-MXR's femtosecond Ti:Sapphire laser system. Using femtosecond, or very short duration, laser pulses essentially eliminates the transfer of heat from the laser beam to the work piece. Ultimately, machining quality is improved and hole-drilling speed is increased due to less post-processing.

In this issue, LaserFare's trepanned Nd:YAG laser approach (page 10) is highlighted. The advantage to optical trepanning is that it requires only one-third the power of standard laser hole-drilling methods to "poke" a hole through the material. Because less power is used, the single beam can be split into three. The result is a much faster hole-drilling process. It is too early to tell which technology will win the hole-ly war. But the real winner will be MDA. With only modest investments, the agency is a lot closer to a hole-drilling solution.

Mug Shot Maker

When a crime has been committed, getting an accurate image of the suspect to law enforcement officers and the public is key. If a sketch artist isn't immediately available, precious time can be lost.

New software developed by Genex Technologies (page 7) will speed up the process. The software, called 3DSketchArtist, allows users to quickly and easily create 3-D electronic images of suspects using a database of facial templates and features.

Instead of erasing and redrawing sketches, users remove features with a simple mouse click. The software also generates a code for each completed sketch. Other 3DSketchArtist users can input this code into their software to instantly generate the same sketch. A commercial product is expected in 2005.

More Dividends

In this issue, we feature two more dividends from MDA-funded research. The first dividend is a miniature thermal viewer (page 3) that is helping U.S. troops in their fight against terrorism. Key to the portable surveillance device is a stacked memory technology, which was originally funded by BMDO in the 1990s.

The second dividend is an electrically scanned phased-array antenna (page 14) for deep-space telecommunications. The antenna, which delivers images of, and data from, the planet Mercury, is a modified version of a single-stick slotted waveguide antenna originally developed for BMDO's Boost Phase Intercept program.

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UP FRONT

2004 COMMERCIALIZATION REPORT NOW AVAILABLE

The *2004 MDA Technology Applications Report* features 20 MDA-funded technologies successfully transferred to the commercial market or other areas of the Federal government. The users of these spinoffs include medical professionals, the military, first responders, commercial companies, universities, and NASA. For example:

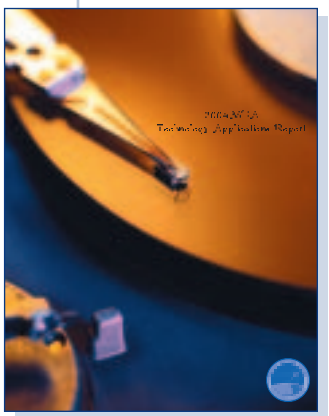
■ A Mayo Clinic neurosurgeon is testing the BioScanIR®, a medical imaging device developed by OmniCorder Technologies, Inc. (Stony Brook, NY), for its ability to provide real-time imaging of the brain during surgery.

■ Samsung Electronics Co. and Infineon Technologies AG are using the StrataGem™, atomic layer deposition equipment developed by Genus Inc. (Sunnyvale, CA), to create the next-generation of dynamic random access memory.

■ The 82nd Airborne is utilizing the OmniEye™ 360-degree camera technology developed by Genex Technologies, Inc. (Kensington, MD), to search wells and caves in Afghanistan and Iraq for enemy combatants and weapons caches.

In the 56-page report, readers will find an overview of the original MDA-funded technology, the resulting commercial product and its benefits, and other possible application areas where the technology could be used.

To view or download the report, visit http://www.mdatechnology.net/specialreports.asp. To receive a free copy of the report, call (703) 518-8800, ext. 239, or send an e-mail to pgroves@nttc.edu. Please provide your name, company name, and telephone number, as well as your mail and e-mail addresses.



Spinoffs. *The MDA Technology Applications program has just released a new document highlighting commercial products that spun off from MDA-funded research projects.*

U.S. ARMY SPECIAL FORCES OBTAIN THERMAL VIEWER WITH MISSILE DEFENSE TECHNOLOGY

A new personal thermal viewer that is helping U.S. Army Special Forces is capable of self-calibration, thanks to technology originally developed for MDA.

Irvine Sensors Corporation (ISC; Costa Mesa, CA) has sold 20 units of its personal miniature viewer (PMTV) to the Army Night Vision Laboratory and to the U.S. Army Special Forces. The PMTV is a handheld surveillance device that allows users to "see" in total darkness. Although thermal viewers are available in the market today, the PMTV offers a feature not found in any other model: self-calibration.

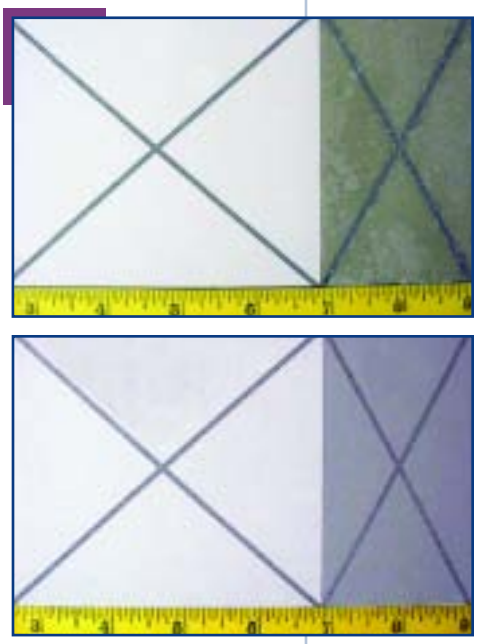
Thermal viewers are very sensitive to temperature changes. Thus, frequent calibration is required to prevent drifting, which can create noise in images. ISC solved this problem by using a stacked memory module to save calibration information within the device itself. When calibration is required, the device searches the memory for the correct temperature table and automatically recalibrates. ISC originally developed the stacked memory for MDA missile interceptor applications.

The PMTV's ability to recalibrate itself eliminates the need for additional device components, such as choppers, shutters, and coolers. Using fewer components adds to the energy efficiency of the PMTV, which can run three-times longer than conventional thermal viewers. Additionally, fewer movable components make the PMTV more robust.

ISC plans to increase PMTV production to meet growing military demand. Meanwhile, the company is exploring the device's potential for law enforcement personnel, fire fighters, and security personnel.

Sight to see. *MDA technology has been incorporated into a thermal viewing device for U.S. Army Special Forces.*

UNTIL NEEDED, THIS CORROSION PROTECTION STAYS PUT



Sheet of worms. *The telltale sign of filiform corrosion, which can build up under chromate coatings, is corrosion worms (top right). TDA's chromate-free corrosion-inhibiting material (bottom right) can outperform chromate coatings in filiform tests.*

Chromates are the most widely used and effective corrosion inhibitors, but are toxic and heavily regulated. Worse, they tend to leach out of their coatings, greatly reducing the amount of corrosion inhibitor available to protect metal while contaminating the environment.

With the help of MDA SBIR funding, TDA Research, Inc. (TDA; Wheat Ridge, CO), has developed a chromate-free corrosion-inhibiting additive that stays put in its coating until needed. The company says that an organic coating using its corrosion-inhibiting additive is a viable replacement for chromate-based coatings used to protect high-strength aluminum alloys.

For example, tests have proven that TDA's technology matches the performance of chromate corrosion inhibitors in protecting Al 2024 and Al 7075, which are primarily used in the military and commercial airframes. Cost isn't a factor because chromate-free coatings ($2 to $4 per pound) can be manufactured more cheaply than chromate coatings ($3 to $5 per pound), and there are no additional costs required for handling and disposal. TDA says that paint is one of the biggest commercial markets for its technology, and the company has been working with Sherwin Williams, the largest U.S. paint supplier, to bring the technology to market.

In addition to airframes, other potential markets include window frames and gas pipelines. TDA says that in humid areas of the United States, the windows of homes are made with extruded aluminum. However, if the coating is scratched, corrosion can quickly appear. TDA's technology would greatly extend the service life of these frames. TDA believes an extension of the technology also could be used in protective coatings for gas pipelines. Moisture tends to collect and cause bacteria to build up near pipe junctions, leading to microbial-induced corrosion. Corroding gas pipelines leak and, in some instances, explode. TDA's technology could make an excellent antimicrobial, antifungal coating.

To make the additive, TDA purchases agglomerated metal oxyhydroxide from a bulk material supplier. The metal oxyhydroxide is then chemically treated to modify the surface of the particles, reduce the particle sizes down to 20 to 70 nanometers, and anchor the organic corrosion inhibitors on the outside surface of the particles. This anchoring capability is key because it protects the corrosion inhibitor from reacting with the polymer resin while the coating cures—a major drawback that has long prevented organic corrosion-inhibiting coatings from making an impact in protective organic coatings.

MDA awarded TDA a Phase I SBIR contract in 2002 to develop chromate-free corrosion-inhibiting coatings. The agency envisioned a pollution-free product that could protect the agency's coastal and remote island testing facilities located in Hawaii and the Kawajalein Atoll. While the first phase of the SBIR project was a success, the second phase was not picked up by MDA due to a shift in priority to Alaska-based facilities. However, TDA has continued work on the corrosion-inhibiting technology for the Navy, Army, and Air Force.

Corrosion is very costly and has a significant impact on the U.S. economy. According to a 2001 Federal Highway Administration report, the total direct cost of corrosion in 1998 was estimated at $276 billion, or 3.1 percent of the U.S. gross domestic product. Sectors having the largest direct corrosion impact include drinking water and sewer systems, motor vehicles, and defense. Within the total cost of corrosion, a total of $121 billion per year is spent on corrosion control methods and services.

While seeking licensees for its organic corrosion-inhibiting coating technology, TDA continues its research and development activities. One of its current explorations is extending the technology to other metals such as steel, iron, copper, magnesium, brass, and tin.

—P. Hartary

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NEW ON THE COMPOSITES MENU: HAFNIUM CARBIDE ANGEL HAIR

In the 1980s when Ed Pope was a materials science graduate student at UCLA, his mentor gave him a list of available composites: carbon-carbon, carbon silicon-carbide (CSiC), and CSiC-CSiC. "It is the same list today," he says. But not for long. With the help of MDA SBIR funding, MATECH Global Strategic Materials (Westlake Village, CA) has invented technology for making hafnium carbide (HfC) and hafnium carbide nitride (HfCN) ceramic fiber from preceramic polymers.

Hafnium carbide is a compound with the highest known melting temperature: 3890°C. In theory, a part made with HfC fiber-matrix composite would survive temperatures that would soften or melt even refractory metal-metal alloys such as rhenium-tungsten blends. HfC has about 60 percent the density of metal alloys, so critical rocket, missile, and aerospace components made with HfC composites would be correspondingly lighter.

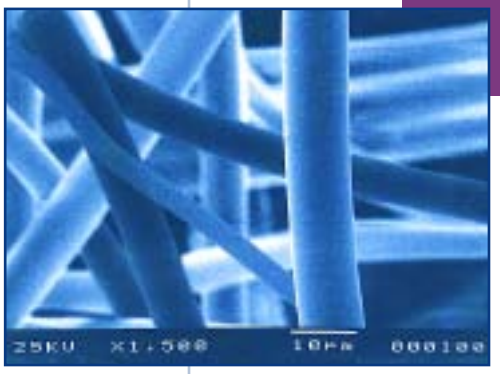
The question was, could theory be translated into reality? HfC chemistry was virtually an unknown compared to the existing body of literature on silicate carbide chemistry. Nobody had even made HfC fibers from preceramic polymer, much less understood how the fibers could be manufactured, cured, or heated in a non-oxidizing atmosphere, and then made into useful ceramic parts.

MDA awarded a Phase I SBIR contract to MATECH in 2002 to investigate the basic feasibility of making HfC fiber from preceramic polymers for rocket nozzles and engine combustion liners. The results were successful enough to prompt MDA to award the company a follow-on Phase II contract to study the strength, creep resistance, stoichiometry, and optimization and quality of parts made with HfC-HfC woven fiber-reinforced matrix.

The equipment used to make HfC fibers is conceptually not that much different from a pasta machine. MATECH starts with raw materials and synthesizes monomers and polymers in its laboratory. A solid preceramic polymer mass is placed into a piston chamber and then heated, pressurized, and forced through a fine orifice, akin to liquid being squirted out of a syringe. A strand or filament more than 30 kilometers long can be produced continuously and wound on one spool.

In the laboratory, the company equipment can produce anywhere between one and 30 fiber strands at the same time. A pilot plant would produce between 100 and 500 filaments simultaneously. MATECH has already estimated how a pilot-plant production facility could be designed and approximately how much it would cost to build. Additionally, the company has filed a patent related to the production process.

The military applications for HfC and HfCN fibers and fiber matrices are manifold, but there are some intriguing possibilities for future commercial application as well. Zero-erosion ablative liners for combustion chambers used in rocket motors is one possibility. Leading-edge surfaces on vehicles entering an atmosphere also endure the kind of ultra-high temperatures that HfC composite can withstand without degrading. As a nascent commercial spaceflight industry begins to spread its wings, aerospace engineers will be able to work with the entirely new compound to improve hypersonic craft performance. As a side benefit, hafnium is also a "high Z" material, which means it can absorb large quantities of radiation and possibly be useful in radiation shielding for long-duration space missions.



Making pasta. *As with regular organic polymers, preceramic polymer can be melted, spun, and dissolved into common solvents. When cured, a matrix transforms from a thermoplastic to a thermoset and then is locked into shape.*

MATECH has not decided to go into the business of manufacturing HfC polymers, fibers, or fiber matrices quite yet—it is still doing fundamental applied research on the new material—but it does have a memorandum of understanding with a well-established U.S. aerospace materials company to transition mature technologies from development to manufacturing. For now, Dr. Pope simply is happy to be doing something nobody else has yet done, and welcomes inquiries about the fiber and its properties.

—A. Gruen

"Our technology gives a new meaning to the term angel hair," said Ed Pope, MATECH's president. "Our fibers are one-tenth the diameter of a human hair."

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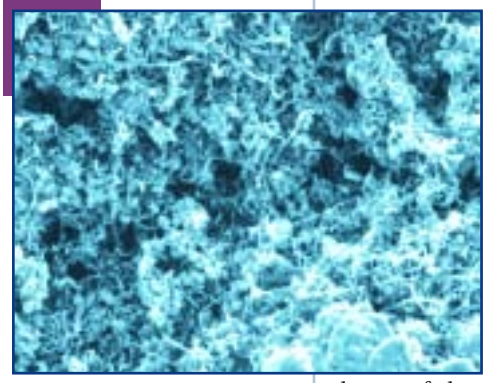
NANOCOMPOSITE IS HOT FOR HEAT SPREADERS



Special mix. *An electron micrograph shows carbon nanotubes surrounded by copper particles in a copper matrix. This material, now under development at Omega Piezo, addresses thermal-expansion and thermal-conductivity issues.*

Omega Piezo plans to fabricate its heat-managing composite and sell it alongside the company's other thermal-management products.

In heat-dissipating applications, diamond can be a chip's best friend. But a new copper/carbon-nanotube composite—with potentially a lower cost and greater thermal conductivity than diamond composites as well as excellent thermal-expansion properties—could capture the hearts of electronics designers everywhere.

With MDA SBIR funding, Omega Piezo Technologies, Inc. (State College, PA), is developing the nanocomposite to manage heat in high-power MDA radar systems. The company also believes the material can be used in heat spreaders for computers and other heat-generating electronic devices. Diamond has shown great potential in materials for heat spreaders, and at least two companies have introduced diamond-copper composite products. But diamond composites are relatively expensive and difficult to machine. In addition, the copper/carbon-nanotube material that Omega Piezo is developing has the potential for even greater thermal conductivity.

David Pickrell, Omega Piezo's president, said company researchers are on track to develop a material that will have thermal conductivity of 1300 watts per meter Kelvin (W/mK), compared with 600 W/mK to 1200 W/mK of competing diamond-copper composites. The higher the thermal conductivity, the more quickly a device can spread heat. And by using carbon nanotubes instead of diamond, the Omega Piezo material should offer a more cost-efficient alternative, according to Pickrell.

Within a year, Omega Piezo expects to produce a prototype material that meets its planned specifications, with full-scale production likely to follow.

The nanocomposite may also offer benefits over materials other than diamond composites that already are popular for heat spreaders. Such materials—copper molybdenum, for example—are relatively inexpensive but have a thermal conductivity of only about 200 W/mK. Pickrell said that Omega Piezo's material would cost more than copper molybdenum. But he added that the benefit of much greater thermal conductivity still should make the nanocomposite more attractive, as long as the price remains no more than two or three times that of copper molybdenum.

Companies developing heat-spreading materials have turned to composites because they can marry the useful trait of one material, such as copper's high thermal conductivity, with the useful trait of another material, such as molybdenum's low thermal expansion. The goal is to produce a material that conducts heat as fast as possible while matching the thermal expansion of components to which the material is attached. If the heat-spreading material expands more than or less than the component to which it is attached, the disparity in thermal expansion could stress or break the component.

Pickrell said that in addition to offering high thermal conductivity, Omega Piezo's material should offer a coefficient of thermal expansion that matches the performance of materials in chips, processors, or other heat-generating electronic components. That combination should make the copper/carbon-nanotube composite attractive to equipment makers who want to pack more chips into their products or run the products at higher power—two scenarios that would generate additional heat in electronics.

Company officials expect that original equipment manufacturers would buy materials from Omega Piezo and incorporate them into their own devices or systems. Some work still lies ahead before the company's nanocomposite emerges from the development stage. One obstacle is refining and sorting the raw nanotube material it gets from suppliers, since a batch of nanotubes often comes in various shapes and sizes. Omega Piezo seeks suppliers of carbon nanotubes that can provide a more refined product and can guarantee the product has the required thermal conductivity.

—S. Tillett

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SKETCHING CRIME SUSPECTS GETS EASIER IN 3-D

Using new software that sprang from MDA-funded technology, more people can now play the role of sketch artist and quickly produce more realistic images of crime suspects—a potential plus for law-enforcement agencies and police departments everywhere.

The technology, 3D SketchArtist by Genex Technologies, Inc. (Kensington, MD), grew out of work on the company's 3-D imaging camera (see "*Countering Terrorism with Technology*" Summer 2002 *MDA Update*). The camera uses light to capture full-frame, 3-D color images, collecting more than 440,000 data points in the process. MDA funded the camera project for its potential in simulation training and battlefield management. The company has applied knowledge and capabilities gained from the camera project to 3D SketchArtist. It has used the camera to create an extensive database of 3-D facial features tapped by the software.

3D SketchArtist will give more law-enforcement officials and professional sketch artists the ability to create and alter electronic sketches of suspects easily. It uses a "wizard" interface to guide users through the steps of selecting a facial template, adding features, and then modifying parts of the sketch. But it also allows police artists to create a face on their own, without being prompted by the wizard. A toolbar included in the program lets users morph facial features—enlarging them, elongating them, etc.—to produce the desired sketch. After a sketch is completed on screen, an artist can distribute it in any number of ways: by printing and faxing it, by e-mailing it as an attachment, or by sending fellow 3D SketchArtist users a special code they can use to replicate the sketch instantly on their own desktops. And since the software program creates a 3-D model of the suspect, the user also could choose which view of the suspect to distribute.

Scheduled for release in 2005, 3D SketchArtist offers key advantages over traditional charcoal drawings and images created with other software. Compared with charcoal-pencil-on-paper sketches, Genex' product offers speed. Users can pull up a facial template instantly and alter features such as noses and hair with a click of a mouse instead of erasing and redrawing features.

The program also allows users to generate a code—a string of characters—to represent a sketch. The code can be passed along by e-mail to users of the program in other cities. Users receiving the code can simply plug it in to the 3D SketchArtist on their own computers and generate the same sketch instantly. They also could alter the sketch based on fresh information from local witnesses. Jason Geng, CEO of Genex, said the company's code-based approach for allowing users to share and alter sketches is much less cumbersome than other electronic methods, which might involve receiving a JPEG file and then exporting it to another application for modification. (With 3D SketchArtist, if users prefer, they still will be able to save and e-mail sketches in various formats—including JPEG.

Producing images in color is another advantage of 3D SketchArtist, although users who want to create a black-and-white sketch still can do so. Color, coupled with the 3-D functionality, should allow users to create more realistic images of suspects. The product even will allow users to alter shadows on the sketch, from any angle on the 3-D model of the face, to show how a suspect might look in different types of lighting.

Genex is positioning its product for the law-enforcement, security, and homeland-security markets, but Geng said he also sees potential for the product to be modified for use in the entertainment industry (to create animated films, for example) and in the video-game industry (to allow game players to create characters that look like themselves, for example).

Genex worked with universities, systems integrators, police departments, and other institutions such as the Department of Justice to collect and study 3-D facial data, as well as to determine appropriate descriptors for use in police sketch work. The company continues to look for partners to collect more facial data. Genex also wants more input from the law-enforcement community and other potential users.

—S. Tillett

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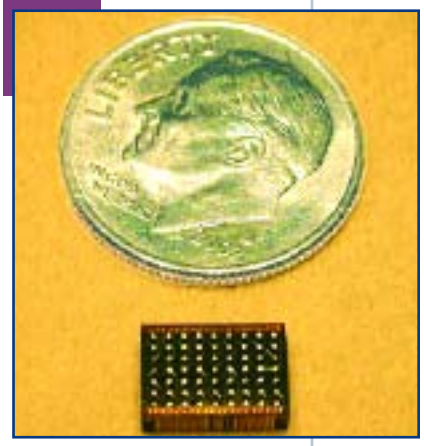
Face time. *Genex's 3D SketchArtist software allows users to quickly and easily create and alter electronic images of suspects.*

Genex claims that no other software allows users to produce images in full 3-D, meaning that users can alter sketches based on witnesses' accounts from various angles and also produce sketches that show a suspect from more than one angle.

ELECTRONICS

ULTRATHIN ELECTRONICS PACK MORE FUNCTIONS INTO LESS SPACE



Mini system. *Irvine Sensors' "system-on-a-chip" packs up to five heterogeneous devices into a miniature 3-D configuration. The tiny system can be made as small as a grain of rice.*

In the consumer electronics industry, big players like Nokia and Blackberry want the same functionality on personal digital assistants as on computers. Thinning and stacking heterogeneous devices in 3-D structures can pack more capabilities into a miniature "system-on-a-chip."

Irvine Sensors Corporation (Costa Mesa, CA) is developing 3-D electronics by creating ultrathin heterogeneous devices and stacking up to 150 of them in a single cube. MDA awarded Irvine Sensors a Phase II SBIR to develop ultrathin missile seeker devices for Boeing Company and Raytheon Company. The Defense Advanced Research Projects Agency is funding the company to stack the ultrathin devices into a 3-D electronics cube.

The devices that make up an electronics system—memory, microprocessors, logic arrays, and passive components—come in packages of different sizes and shapes. This makes it difficult to stack the devices in a uniform 3-D configuration. Irvine Sensors' unique process assembles bare dice (devices that have not been packaged) and/or packaged dice into an ultrathin structure called a Neo-Chip™, which is optimized for stacking. The largest device, typically a memory or processor chip, makes one Neo-Chip. The remaining devices are mounted in Neo-Chips of identical size; each of these can contain five or more devices. The Neo-Chips are then stacked and interconnected to form a single 3-D electronics cube comprising the complete system.

In the consumer electronics industry, there is a race to eliminate parts and package devices closer together while increasing functionality. Using its process, Irvine Sensors can replace entire circuit boards. For example, a 6-inch x 9-inch x 3-inch board can be replaced with a 3-D electronics cube that is 1-inch x 1-inch x 1/4-inch. As a result, size and weight requirements are reduced, and power needs are eased by shorter interconnect distances between devices. Fitting multiple cubes where one circuit board used to be also enables a large jump in functionality. For less than the cost of conventional circuitry, 3-D electronics can enable personal digital assistants to have graphics and broadband capabilities the same as personal computers.

On a smaller scale, Irvine Sensors has developed a 3-D electronics cube about the size of a grain of rice for a hearing aid application. Conventional hearing aids cannot fit digital signal processors, but Irvine Sensors developed a cube that contains a processor, memory chips, resistors, and capacitors. These devices enable hearing aids to adjust to each individual's unique hearing capabilities. A hearing aid does not only make the sound louder. When the cochlea of an ear is damaged, it makes noise. When it is excited, it makes more noise. With signal processing, the hearing aid can cancel frequencies created by cochlear noise, and tailor the frequency response of the rest of the audio spectrum.

Soon, Irvine Sensors plans to migrate its 3-D electronics to its high-volume, low-cost manufacturing environment, which already fulfills orders for the MDA-funded stacked memory chips. The ultrathin electronics and the 3-D electronics cube development are based on the MDA research on stacked memory chips. The company was recently qualified to manufacture its stacked memory chips and is filling orders of 50,000 units per month for original equipment manufacturers. Eventually, the orders are expected to grow to one million units per month in a year.

To get 3-D electronics to be as successful, Irvine Sensors needs companies to submit their electronics designs for miniaturization. Users can submit wafers or packaged devices since Irvine Sensors' process works on either form.

—T. Robinson

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MAGNETS MAKE TINY CAMERA MOVE LIKE AN EYEBALL

Eyeballs use muscles to move swiftly and precisely in any direction. But digital cameras aren't so lucky. Panning and tilting requires motors or software tricks that often result in less than ideal vision. An electromagnetic technology, however, could be the key to creating cameras that move more like a real eye, allowing human-machine interaction to take on a more natural feel.

The technology, developed by MDA-funded IC Tech, Inc. (Okemos, MI), includes a tiny camera and a grid of electromagnetic coils. The grid can be formed into a socket to house an eyeball-shaped camera, the back of which is fitted with a magnet. IC Tech's innovation lies in applying magnetic actuation to a ball-and-socket design and adding a camera as well as software to control multidirectional movement of the camera. The software created by IC Tech switches individual coils on and off to guide the magnet on the back of the camera, effectively moving it as if it were an eyeball in a socket.

By producing a device that moves more like the human eye, the company's pan/tilt technology could extend the domain of videoconferencing by making participants feel more immersed in a remote environment, according to Dr. Gail Erten, president of IC Tech. "The camera moves very much like your eye would move if you were in that environment," she said. "The movement would seem more realistic to your eye."

The innovation also advances the concept of "smarter" human-machine interaction. For example, a particular application might use movement-tracking software and a camera to follow the body movements of a computer user—whether as part of a video game, a teleconferencing application, or a telemedicine session. Tracking the movements would allow the software to take cues from the user. For example, a certain gesture or movement could take the place of a mouse-click or a keystroke. Users could effectively give commands based on their movements or gestures. But such an application requires a camera that moves fluidly to keep up with human movement.

MDA originally funded the company to develop an ultra-low-power motorless pan/tilt control for single-chip cameras. Such cameras could be useful in applications such as robotics, teleconferencing, or other "telepresence" applications in which humans use machines to interact with other humans or to monitor situations. The electromagnetic actuation mechanism that IC Tech has developed also could apply to robotic wrists or other forms of ball-and-socket actuation.

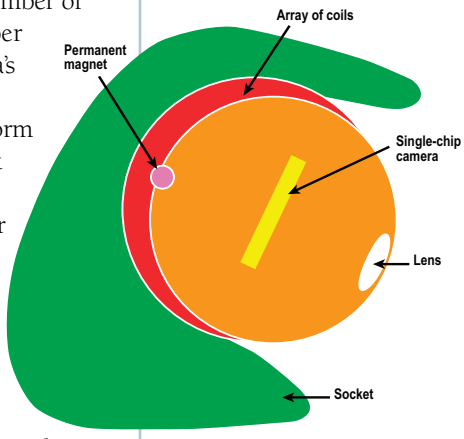
IC Tech's device seeks to address problems associated with two existing technologies: digital pan/tilt and motorized pan/tilt mechanisms. Some cameras digitally crop or zoom to give the illusion of panning and tilting. The drawback of such an approach is that the camera does not move and provide angles as realistically as the human eye. It also can offer less than ideal resolution, since cropping and zooming, unlike true panning and tilting, does not maximize the number of sensor pixels used per degree in the camera's field of view.

Since IC Tech's form of actuation does not use motors, the final device can be smaller than competing motorized pan-tilt devices. Another benefit of the new technology relates to power. IC Tech's device should operate at less than 1 W while competing products might operate at 4 W or as high as 11 W. Lower power requirements mean the device could find its way into low-power portable electronic devices.

IC Tech's patent-protected invention so far is not part of a commercial product. But the company has developed a prototype and wants to miniaturize the technology further to make it more suitable for commercial applications. Smaller devices mean such cameras ultimately could be integrated unobtrusively into other products such as video-game hardware and phones.

The company continues to seek partners that can help with funding as well as with materials needed for miniaturizing the technology.

—*S. Tillett*



Simply magnetic. *IC Tech's innovation marries an array of magnetic coils with a tiny camera to create an actuation device that moves more like the human eye.*

Two IC Tech cameras working in conjunction could provide stereoscopic vision with excellent depth perception—a capability that could prove useful for robots performing precision tasks.

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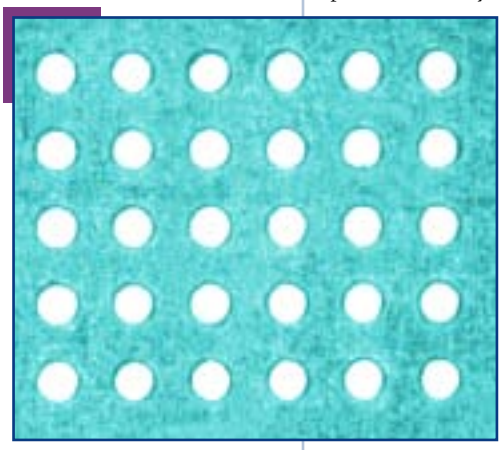
A LASER DRILL BIT NEVER DULLS



Boring image? *Actually, Laser Fare's precision high-speed system combines beam splitting and low-power optical trepanning to cut holes with submillimeter diameters.*

If it took a single machine two minutes to bore a nearly perfect microcylinder through a material and you needed to do it more than 24 million times, it would take that machine over 91 years to finish the job—assuming the apparatus didn't break down first. Using a new laser drilling technique combining beam splitting and low-power optical trepanning, a lone Laser Fare, Inc. (Smithfield, RI), precision high-speed system could do the same job in less than one year.

The Missile Defense Agency's Airborne Laser Program has a need to drill more than 24 million holes into almost 2,000 Inconel 600 injector plates. The agency hopes to find somebody who can do that task very precisely, with an extraordinarily high degree of uniformity, at a rate of no more than one second per hole, and using a system that would not be prohibitively expensive. Nothing even close to it has previously been achieved. Machine drilling or EDM (electrical discharge machining) can operate on Inconel 600 plates, but drill bits and EDM electrodes wear out, need replacing, are expensive, and are currently too slow. State-of-the-art titanium sapphire lasers can also drill precision holes, but at such a slow rate that a host of them would need to run simultaneously and at staggering expense.

In 2002, MDA awarded a Phase I SBIR contract to Laser Fare and three subcontractors, to address the hole-drilling requirement. Dr. Paul Jacobs, the principal investigator, was so daunted by the ambitious objectives set by MDA that he didn't think they could be achieved. Four months into the project, he recalls, "the performance at that time was not all that terrific." But then he had an idea, borrowing two concepts from some of his partners on the project and combining them into one system.

Anything But Boring

The traditional method of boring a cylinder with a laser beam, known as percussion drilling, is simply to use a great deal of power to vaporize the material itself, akin to melting a hole in a stick of butter. But what if, instead of melting the entire hole, one just trepanned around the circumference of the hole instead? It would be as if a solid cylinder of butter fell out the bottom of the stick instead of melting, leaving a perfect cylindrical hole behind.

Optical beam splitting divides a normal Nd:YAG laser beam into three low-power beams, and then optical trepanning reduces power requirements by over 60 percent.

The advantage to trepanning is that it requires only one-third the power of the direct method. Using mirrors, a single beam from a normal Nd:YAG laser could be split into three low-power beams, each trepanning their own circle in the target. Still, that left the nightmare of the hundreds of motions normally required to execute a trepanned circle.

Jacobs and his associates realized that optical trepanning—using optical-quality glass lenses to refocus a Gaussian beam into an annular beam (or ring pattern)—removed the need to make hundreds of individual motions of the laser spot to burn each hole. This approach was originally envisioned by Dr. William Latham at the U.S. Air Force Weapons Laboratory. Optical trepanning had been done before, but never for holes on the submillimeter level.

In December 2003 MDA awarded Laser Fare a Phase II SBIR contract to investigate the technique of low-power optical trepanning using beam splitting, which, to Jacobs' delight, has shown promising results. "I'm a great believer in the notion that skill and hard work count for a lot in life but it never hurts to be a little lucky," he said.

Was this technique something that Laser Fare would not have pursued without MDA funding? "Definitely," Jacobs replied. "We wouldn't have even bothered with it, because there wouldn't have been enough of a payoff. It's the old story in life, sometimes you are

Continued on page 11

A Laser Drill . . . from page 10

dragged kicking and screaming into doing something that you really don't think you want to do, and then when you get it done and your are successful you suddenly look around on the horizon and realize you are in a unique place and now maybe you can use this for other things."

Commercial Applications

Laser Fare has filed two process patents on this precision high-speed laser-trepanning breakthrough that potentially has a wide range of industrial applications. One application that is very similar to the original technology for which the technique was invented is fuel injection. A single automotive fuel injector does not require millions of holes, but millions of cars would benefit from highly precise and smooth microcylinders that make for a uniform spray into a combustion chamber. Another similar application is precision holes for inkjet technology. As the uses for inkjet technology go beyond printers, demand will rise for the ability to create holes with diameters in the submillimeter range.

A third application, and one that the company has pursued in discussions with several aerospace companies, is shaped holes for cooling jet engine components. Industrial lasers have been used to drill holes in turbine blades and shrouds before, but it is a time-consuming process. Given the expense, the task is usually left to electrical discharge machining. The reason why this work is slow and expensive, aside from the difficulty of multiaxial machining, is that most turbine blades are coated with a thermal barrier to help resist high-temperature malfunction. This coating is nonconductive and EDM cannot be used to drill through it. So the hole-drilling needs to be a careful, painstaking, multistep process. High-power lasers would work, but can cause collateral damage to surrounding material. However, using low-power optical trepanning, it might now be possible to use lasers to cut complex three-dimensional shapes inexpensively and quickly.

A fourth application is futuristic but potentially a huge market: modifying the surface of airplane wings. Microholes drilled into the skin of a wing far enough to reach a plenum at a negative pressure can create boundary layer suction. This in turn overcomes boundary layer separation, one cause of drag. Remove that drag, and the efficiency of a wing surface can be improved by several percentage points, which translates into improved capability and fuel efficiency. The problem is that many millions of holes would be required on each wing section. To date, nobody has developed a cost-effective means to accomplish this challenging requirement.

Courtesy of Boeing

Hole truth. *The MDA Airborne Laser Program needs 24 million holes drilled into almost 2,000 Inconel 600 injector plates. Laser Fare's laser drilling technology is fast and precise enough to do the job.*

Laser Fare welcomes inquiries about techniques and results for its new laser technology and hopes to find future commercial partners as well as to serve customers directly with improved laser cutting, drilling, welding, and engraving services.

—*A. Gruen*

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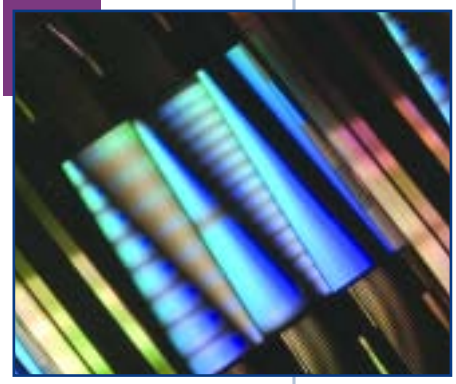
OPTICAL SIGNAL PROCESSING

HOLOGRAPHY-IN-A-CHIP ENABLES FAST, CHEAP DEMULTIPLEXING



Guiding light. *LightSmyth's device sorts light-borne information. This image shows test silica on silicon wafers with lithographically scribed holographic devices. The triangular-shaped regions are holograms through which light enters.*

LightSmyth's device does not require a computer to perform signal matching, making it less susceptible to damage, misalignment, or bugs.

Demultiplexer components can cost as much $6,000 each. But MDA-funded LightSmyth Technologies, Inc. (Eugene, OR), has found a way to knock down the price to perhaps less than a dollar.

LightSmyth's innovation relies on using common photolithography techniques—adopted from the microchip-fabrication arena—to produce an optical device that should be more affordable than those produced with physical scribing common in conventional holographic devices. The LightSmyth device also should operate at faster speeds than competing technologies.

The device uses holographic technology to filter and direct information carried in beams of light. It promises to significantly reduce the cost of demultiplexing for data communications and also improve sensor technology.

LightSmyth's device stands apart from competing devices because it combines three existing technologies as never before. The company combines holography (the recording of information tied to individual beams of light) with common photolithography techniques for making computer chips and related devices. The innovation also includes planar waveguides, devices that transmit light within a structure. LightSmyth's vision is to integrate optics the way electronics are integrated today.

For filtering and directing information, LightSmyth's device uses holographic patterns, but not quite the kind of holography used in 3-D projected images or novelty photographs. Rather, the holographic patterns serve as a sort of software—a matrix or filter—through which channels of light can pass and be compared with known patterns. Using photolithography processes for the holograms enables finely detailed filters and gratings to be deposited onto a suitable surface, rather than relying on more expensive and less reproducible physical scribing common in conventional devices.

The holographic patterns allow the device to instantly scrutinize the frequency spectra of the light to verify whether it contains a predetermined frequency pattern that a user might be searching for—whether it's particular information that needs to be routed along a data network or, in remote-sensing applications, a signal that indicates the presence of a particular chemical. If that preprogrammed frequency is present in the light, the hologram lights up at a particular point and projects onto a photodetector, thereby registering the presence of the frequency.

When a single beam of light carrying multiple channels of information (such as spectral content or spatial properties) flows through a device, the channels of information are sorted to a final destination to register an input. An input can be a simple piece of information carried through an optical data network, or it can be a signal that can be matched instantly with information from another source as a means of identification. For example, in a sensor, a spectral signal from exhaust or a gas could flow through a LightSmyth device. If the signal matches signal information already programmed into the device's holographic structure, the device will instantly register a match.

The holographic technology from LightSmyth has an advantage over computer-based sorting because it operates at nearly the speed of light. Traditional spectrum analysis might require light to pass through a spectral splitter such as a prism and then be projected onto a CCD or a detector array, which measures power and frequency of the light signal and then feeds that data to a computer for comparison with a list of referenced spectra to determine the type of source that emitted the light signal.

As for optical data transport, LightSmyth's device will compete with thin-film filters in demultiplexers. The filters can run as high as $3,000 to $6,000. Company officials say that with their technology all optical-filtering components could be integrated onto a single chip, eventually driving filter costs to as low as $1.

The company has received financial support from Intel Corporation as well as MDA, which funded the technology for its potential in sensors. LightSmyth has produced and tested devices but is not in full commercial production. The company continues to look for

Continued on page 16

SECURE TRANSMISSION

DEVICE ENABLES FAST, EXTREMELY SECURE WIRELESS TRANSMISSION

An integrated data compression/encryption device that enables fast, extremely secure wireless transmission could be a boon to MDA, other military branches/government agencies, and the commercial sector.

The compact device, which is being developed with MDA SBIR funding by Asier Technology Corporation (Plano, TX), accepts raw, unencrypted data input from synchronous (sensor and telemetry input) and asynchronous (video input) sources. Software is used to compress the video data stream at ratios between 150 to 1 and 300 to 1 and the telemetry data stream at a ratio of 3 to 1. The two data streams are then combined into a single synchronous data stream, which is operated on by high-performance encryption software. Compressed/encrypted synchronous data is then output from the encryptor to an existing telemetry transmitter.

MDA programs need fast, extremely secure telemetry and video during missile interceptor tests. So the agency awarded a Phase I SBIR contract to Asier in October 2002 to prove the concept of integrating data compression and security algorithms. In the Phase II SBIR contract awarded in 2004, Asier researchers intend to develop and test 10 secure telemetry and video device prototypes. The U.S Army's PAC-3 program also has expresssed interest in evaluating this technology.

Unmanned aerial vehicles appear to be a natural fit for the compression/encryption device. These platforms produce multiple types of data with different compression requirements. Data transmitted to the ground must have a high level of security or U.S. military assets could be compromised. And any device that is added to the platform must be small enough to fit inside the airframe. Asier's technology meets all of these requirements.

The commercial sector offers many insertion opportunities, too. Banks are interested in the technology to encrypt transactions at automatic teller machines. Secure facilities may test it for remote security management. A surveillance company wants to use the technology to monitor the border between the United States and Mexico.

Asier's device can use either the Advanced Encryption Standard with 256-bit key size or the company's proprietary algorithm—which incorporates a 40,960-bit key size to provide extreme encryption while handling throughput rates of hundreds of megabits per second. Conventional encryptors with key sizes as large as 1024 bits cannot match this high performance because any effort to increase key size decreases throughput. Because of the large key size of Asier's extreme encryptor, key changes are not required during transmission and thus, additional security is provided. Asier's technology is presently being reviewed with an eye towards full certification.

The first compression/encryption prototype, with dimensions of 4 in. (H) x 4 in. (W) x 1.5 in. (D), is nearing completion. With such a small physical size, the device will fit into existing airframes without costly redesign. The size will shrink further as development progresses. Additionally, the device could be completely implemented in software. In this form, it could be directly embedded into other devices and systems.

The modularity of the device's design allows for some interesting modifications, such as more video inputs. For example, video data for six different cameras could be monitored and, if something of interest happens in one of the video feeds, the bandwidth to the other five cameras can be "squeezed" out. Then, operators could increase the frame rate or quality of pictures for the single camera.

Asier intends to develop the device to augment its existing product line of data compression/encryption solutions. To facilitate this, the company seeks up to $5 million in capital funding. Some of this funding will come from development partners interested in licensing the technology for specific commercial and/or military applications.

—P. Hartary

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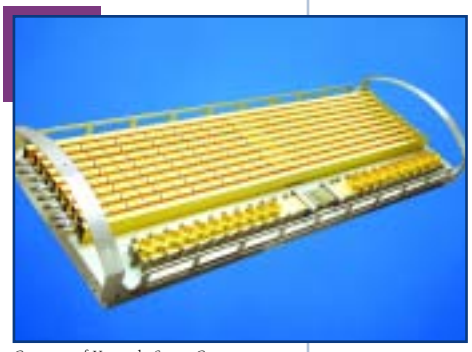
Security in a box. *Asier's compression/encryption device enables fast, extremely secure wireless transmission. In addition to military applications, the device could be ideal for use in the medical, security, and banking industries.*

Hospitals could use Asier's encryption/compression device for wireless transmission of patient medical records within facilities or viewing of in-hospital procedures by remote medical personnel.

MERCURY GETS A SECOND LOOK USING MISSILE DEFENSE TECHNOLOGY



Courtesy of Kennedy Space Center

Phone home. *Johns Hopkins Applied Physics Laboratory developed the first electrically scanned phased-array antenna for deep space communications. This technology is based on single-stick slotted waveguide antenna technology originally developed for BMDO.*

The mission name MESSENGER was selected because of what it stands for: MErcury Surface Space Environment GEochemistry and Ranging.

The Johns Hopkins Applied Physics Laboratory (APL) is using ballistic missile defense technology on NASA's MESSENGER mission to deliver images of, and data from, the planet Mercury to the international scientific community. In the mid-1990s, the Ballistic Missile Defense Organization (BMDO) funded APL to develop a single-stick slotted waveguide antenna. The MESSENGER spacecraft, which was launched this summer, carries a modified version of that BMDO technology to investigate one of our closer neighbors that can be as far as 120 million miles away.

Mercury is named after the swift messenger of Roman mythology (hence the name of the mission) and is well known for its very high density, short planetary years, and close proximity to the sun. The Mariner 10 fly-by captured images and information about the elusive planet in the mid-1970s but lacked the technology to shed light on the many questions that still baffle scientists. When MESSENGER arrives in 2011, we will learn more about our neighbor one rock from the sun. APL's antenna is the first electrically scanned phased-array antenna for deep-space telecommunications. It is expected to carry the spacecraft's highest data-rate downlink signals that will allow scientists to obtain images of Mercury's surface, answering questions such as "How can the planet closest to the sun have what appears to be ice in its polar craters?"

A Steerable, Lightweight, and Robust Alternative

The BMDO-funded phased-array antenna is essential to MESSENGER because it is steerable (without moving parts), lightweight, and robust, addressing thermal issues inherent to Mercury's location. Mercury not only has the shortest orbits, but is also the most extreme planet: Its "days" last twice as long as its 88 Earth-day years, with the sun-facing side of the planet peaking at temperatures above 400ºC (752ºF) while on the other side it tumbles to a toe-numbing -200ºC (-328ºF). Because the spacecraft must look at the planet, the antenna must be able to withstand such a change in temperatures. Even when hiding behind the spacecraft's sunshade, the antenna's typical operating temperatures will range from -150ºC (-238ºF) to almost 300ºC (572ºF). A conventional, gimbaled dish antenna was not used because of the risk that its internal components and steering mechanism would fail.

The MESSENGER mission uses two phased-array antennas, each holding a row of eight antenna sticks. The beam from the antenna is electronically steerable through 90º in one plane, so one antenna array transmits signals on the front of the spacecraft, while the other sits on the rear. Between the two, one antenna array is always available to beam information back to Earth, even when the spacecraft's orientation, required to shield its instruments from the sun, is not ideal for downlinks to Earth.

While each of the two X-band antenna arrays used on the spacecraft are approximately two by one foot in dimension, they are also very light, as required for a deep space mission. There are extreme penalties for carrying mass to Mercury. To enter Mercury's orbit, the spacecraft must lose most of Earth's orbital energy to meet the tiny planet's speed – and fuel is needed to do this. More than half of the spacecraft mass is fuel to accomplish this extreme velocity change.

The antenna technology is but one part of a much larger data-gathering mission. MESSENGER will return more than just images. It also carries spectrometers, particle detectors, and a magnetometer, all which will help answer key scientific questions about Mercury.

A "Win-Win" for Defense and Space Exploration

The use of the antenna on MESSENGER helps the Nation's defense because it enhances DOD's investment and proves it out. Dr. Paul Ostdiek, an APL technology manager, commented on the frequent necessity of multiple forms of funding to make a technology such as this successful. "Our job for BMDO was to explore the idea of using a radar on UAVs to create a fence through which the passage of a missile would

Continued on page 15

Mercury Gets . . . from page 14

be noted. We developed the slotted waveguide antenna stick with the idea of making a radar system from a set of sticks—but we never got that far in hardware. We got as far as one stick, and we tested it." The results were very promising, but National priorities were about to change.

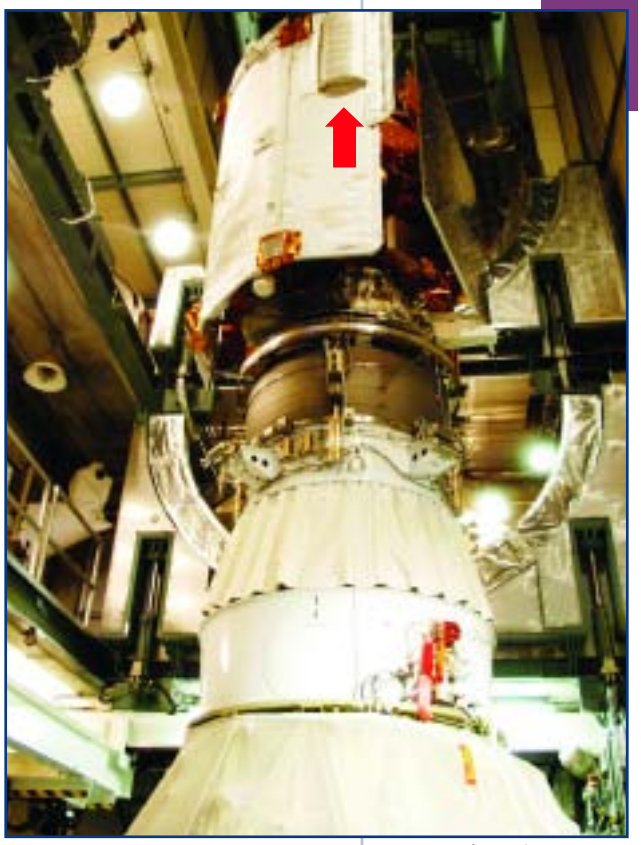
When BMDO cancelled the program in the mid-1990s, APL continued developing the sticks, and associated amplifiers, to make an antenna for deep space communications under the NASA funded MESSENGER Program. After demonstrating electronically-steerable operation, APL used a combination of NASA Technology Development funding, MESSENGER Program funds, and its own internal research funding to enhance the antenna's throughput. By converting the inherently linearly-polarized antenna into a circularly polarized structure, the spacecraft's antenna was better matched to NASA's listening antennas here on Earth. APL engineers designed parasitic stub radiators that were brazed onto the outside of the antenna tube between each slot, converting the linearly polarized signals into circularly polarized signals. This design doubled the data rate and therefore the throughput of scientific data, enabling the spacecraft to double the amount of science data sent back to Earth—twice the amount of science that NASA expected when the mission's implementation was awarded to APL.

The BMDO-funded phased-array antenna is essential to MESSENGER because it addresses issues with speed and heat inherent to Mercury's location.

Although APL successfully demonstrated a laboratory version of the antenna, they still needed to learn how to translate this achievement into a rugged, space qualifiable device. At this point the MESSENGER Program adopted the baselined linearly polarized antenna, and stopped funding the advanced circularly polarized antenna. "We then spent our own money to continue advancing the circularly polarized version because we had confidence in the concept. However, we needed to ensure that we could produce the new antenna in the required time, and that the technology could withstand the heat of 11 suns," Dr. Ostdiek further explained, citing Mercury's roughly 3/10 Astronomical Unit distance from the sun. "Once proven, NASA funding returned to manufacture and implement the flight unit."

This summer APL launched MESSENGER and has confirmed the operation of the antenna in space. And that may mean it can be used in defense applications later at a much lower risk. What started as high-temperature, rugged BMDO antenna enabled an exciting NASA mission to one of the hottest places in our solar system. As this technology proves out, it may be used in applications going beyond planetary missions by playing a role in destroying a missile with a missile—right here at home.

—L. Aitcheson



Courtesy of Kennedy Space Center

Sticking out. *Pictured above is the MESSENGER spacecraft mounted on the third stage of its carrier vehicle. One of the two phased-array antennae onboard is covered with a sun shade (top center). The other is on the back side of the spacecraft.*

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MDA Update
WINTER 2004-2005

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NanoSonic seeks funding to scale-up production of the Metal Rubber material and to explore other new materials that could be created using the company's manufacturing process.

Conductive . . . from page 1

Rubber to its research and development of motion-producing devices called artificial muscles. When stimulated electrically, artificial muscle materials react by flexing and changing shape and could replace bulky motors, electromagnets, and other actuators. But wires, which are not as flexible as artificial muscles, need to be attached to provide the electric charge.

NanoSonic president Rick Claus has been the keynote speaker at many artificial muscle conferences recently to describe the benefits of using Metal Rubber instead of wires on artificial muscles. To accommodate their inflexibility, multiple wires are used to weigh down the artificial muscles and mechanically constrict them. Instead of doing this, NanoSonic's Metal Rubber may be a low-weight, robust replacement that can match the movements of the artificial muscles and conduct the electrical charge.

—T. Robinson

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Holography-in . . . from page 12

partners and plans to target telecommunication and data-transport markets first, with a focus on demultiplexing.

—S. Tillett

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