SUMMER 2003
ISSUE #46

MDA Update

Linking American Businesses to Missile Defense Technology
www.mdatechnology.net

INSIDE

The Heat Is On —*by Adam Gruen*

New phase-change technologies will provide better thermal management options.

The harder you work, the more you sweat. Your body generates heat that needs to go somewhere; liquid water efficiently transports heat by evaporating into surrounding air. In engineering terms, your body uses a two-phase, open-loop, mass-transfer thermal management system to maintain a constant internal temperature

Technology is working harder, too. Designers are cramming higher power devices into smaller spaces; machines are generating more heat per unit of volume. The old standbys that serve nature admirably—convective, conductive, radiative, or evaporative cooling—don't work well for modern electronic systems.

If you are engaging in strenuous activity and you can't sweat, that's a big problem. People die from heat stroke because cells don't function at elevated temperatures. Likewise, strange things start to happen to some materials as they get hot. They may melt, diffuse into their surrounding cladding, or lose the properties that made them useful in the first place. While advanced materials may be more heat resistant, heat is still an enemy that has the potential to wreak havoc on finely tuned, delicate components that operate efficiently only within a very narrow range of temperatures.

MDA is addressing this problem by looking at some radical new ideas in thermal management that go beyond evaporative spray cooling or simple closed-loop liquid cooling. The technologies that are being developed today may be the next step to ensure that future machines can operate more efficiently and reliably.

Keep the motor running hot

Electric vehicle industry analysts have written so much about hydrogen fuel cells and batteries that it sometimes seems they have forgotten about the electric motor—the part of the engine that converts electrical input into mechanical work output. What if automobile designers could double their horsepower in the same space under the hood, simply by improving the mechanism that cools the electric motor?

SatCon Applied Technology, Inc., a subsidiary of SatCon Technology Corporation, (Cambridge, MA), funded by the BMDO (now Missile Defense Agency) to study advanced technology for cooling motors, may have found the answer with its passive phase-change cooling techniques. By using a patented "pumpless" method of moving liquid coolant through its stator windings, with very little extra weight or expense, an induction traction motor that normally has a maximum power output of 50 kilowatts can be modified to operate at a maximum power output of 100 kilowatts (about 130 horsepower).

Tough on the outside. *SatCon's thin-walled stainless steel shell envelopes a stator core, wick, and phase-change working fluid.*

In 1997, MDA awarded SatCon an SBIR Phase I contract to study four different

Continued on page 14

A QUARTERLY PUBLICATION OF THE MISSILE DEFENSE AGENCY
TECHNOLOGY APPLICATIONS PROGRAM

MDA Update

Editor
Patrick Hartary

Production Manager
Lisa Hylton

Graphics
Lan Crickman

Contributing Writers
Leslie Aitcheson, Adam Gruen, Patrick Hartary, Tabatha Spitzer, Scott Tillett

Advisors
Jamil Albertelli, Bill Meyer, Joel Price, Jeff Reynolds, Duane Zieg

The MDA Technology Applications program sponsors publication of the *MDA Update* to encourage the transfer of missile defense technology to American businesses and other government agencies.

Readers are encouraged to copy or reprint articles in the *MDA Update,* under the following conditions: Context is preserved and MDA is credited for providing the information. Our staff also requests that you send us a copy of any publication using information from the *MDA Update*, whether it does so in whole or in part.

Please address inquiries and mailing list corrections to:
National Technology Transfer Center-Washington Operations
2121 Eisenhower Avenue, Suite 400
Alexandria, Virginia 22314
Attn: Editor, *MDA Update*
Tel: (703) 518-8800 x500
Fax: (703) 518-8986
E-mail: pat@nttc.edu
Web sites:
- www.acq.osd.mil/bmdo/bmdolink/html/transfer.html
- www.mdatechnology.net

The *MDA Update* is written and produced for MDA by the National Technology Transfer Center-Washington Operations.

This project is sponsored by MDA. The content of the information does not necessarily reflect the position or policy of the Government; no official endorsement should be inferred.

FROM THE EDITOR

PUSH AND LOVE

The MDA Technology Applications program produces this newsletter to reach many audiences. We produce it for technology seekers. We produce it for technology investors, such as angels and venture capitalists. And we produce it for MDA personnel.

But there's another group targeted by this publication—one that may not be apparent to most readers. It's the media.

The great thing about this newsletter is that every article is written as a technology primer. After reading each article, you will know what the technology is, what's so different about it, and why it matters to MDA, industry, and/or the military. In a nutshell, each article gives you all you need to know about a particular technology.

Editors love this. They read our newsletter, which features articles about leading-edge MDA-funded technologies with promising commercial and military applications. They contact and interview the MDA technology developer. Then, they write articles for their own publications, such as trade magazines, industry newsletters, or national or regional newspapers. Sometimes, they even produce radio and television news segments based on newsletter articles.

We, of course, encourage this. It gives the MDA technology developer added visibility. And this visibility can be quite extensive, depending on the publication or broadcast. This newsletter has a select readership of about 8,000, but *R&D* magazine and the *Wall Street Journal* have audiences in the 10s or even 100s of thousands.

We encourage the media to use our material. In fact, we push it to them using the *MDA Update* Media Tip Sheet, which contains a nugget of information about each technology article in an upcoming issue. In short, these tips put interesting story ideas in editors' laps. The Media Tip sheet is e-mailed to media representatives at least three weeks *before* the newsletter is printed and mailed.

The first two Media Tip Sheets already are generating new media articles—and much appreciation coming back from the MDA-funded companies featured in them. For example, the April 2003 issue of *Sensors* magazine featured an article in its Research and Development column on Pacific Advanced Technologies' infrared gas-leak-detection camera. In another, *Small Times* magazine recently interviewed Dr. Gary Tompa of Structural Materials Industries for a future article. The editors of *Sensors* and *Small Times* subscribe to the Media Tip Sheet.

If you are a member of the media and would like to receive the *MDA Update* Media Tip Sheet, drop me a note via e-mail.

Patrick Hartary
pat@nttc.edu

TA PROGRAM INTRODUCES NEW DISPLAY BOOTH

The MDA Technology Applications (TA) program has recently introduced a new display booth for conferences and meetings to disseminate information about MDA-funded technologies with promising commercial applications and to highlight MDA's technology contribution to both defense and the economy. The booth was designed by staff of the National Technology Transfer Center-Washington Operations (NTTC-WO) in support of MDA's TA program objectives.

"We designed the display booth to have a very contemporary and inviting look," commented Lisa Hylton, NTTC-WO's outreach manager. "Black and blue are the dominant colors, and a brushed silver has been used for various accents and lettering. Overall, the combination of colors is very eye-catching." Hylton added that a free-standing podium was incorporated in the design to allow staff to display selected MDA technology transfer materials while they speak with interested visitors about the program and its mission.

To stand apart from other displays, NTTC-WO designed a unique fiber-optic header box with motion graphics that sits atop the booth. The front of the box contains an outline of the MDA logo defined by double rows of white lights. Inside the logo, a missile intercept scene is depicted by red and yellow lights that turn off and on in sequence to simulate a successful missile intercept. The words "Missile Defense Agency" are stacked with a double row of twinkle lights that transition from white to blue to green then back to white.

The new display booth was delivered in July 2002 and has already seen action at several defense and industry events, including the 2002 Space and Missile Defense Command Conference and Exhibition (Huntsville, AL), and the 2002 Materials Research Society Fall Meeting (Boston, MA). At these shows, NTTC-WO staff were told many times by visitors that they noticed the booth because of its eye-catching design and were intrigued enough to find out more about the MDA TA program and its mission.

Want to see the new booth for yourself? Below is a partial list of conferences and meetings that the MDA TA program is planning to display the new booth.

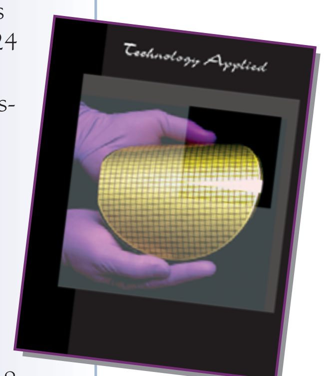
Where to Next?

- August 18-21
  2003 Space & Missile Defense Command Exhibition
  Huntsville, AL
- October 27-29
  Photonics East
  Providence, RI
- December 1-5
  Material Research Society Fall Meeting
  Boston, MA

Meet-n-greet. *The MDA TA program booth was designed by NTTC-WO to support MDA technology transfer objectives.*

NEW REPORT HIGHLIGHTS COMMERCIAL SUCCESS STORIES FOR 2003

When a small technology company takes its MDA-funded research and commercializes it, a great success story is created. Now, add 23 more success stories and you get the MDA *2003 Technology Applications Report*. This publication highlights 24 small technology companies that have successfully commercialized their MDA-funded research in areas such as materials, computing, electronics, electronics processing, imaging, optics, and photonics. To receive a free copy, call (703) 518-8800, ext. 239, or send an e-mail to pgroves@nttc.edu. Please provide your name, company name, mail and e-mail addresses, and telephone number.



SIMPLE, AFFORDABLE TITANIUM PRODUCTION

Metal magic. *Vartech researchers are developing a vapor-phase process to produce titanium alloy powders at lower cost. Current activities include running tests on coating fibers and filaments and studying reactor thermodynamics, cost projections, and yield.*

Titanium alloys have a greater strength-to-weight ratio than aluminum alloys and much higher temperature capability; as a result, they are ideal for high-temperature environments where high strength, low weight, and high-temperature performance are important. But titanium alloys can be pricey to produce. However, a new titanium reactor being developed by Vartech, Inc. (Idaho Falls, ID), with MDA SBIR funding, could lead to more affordable titanium materials.

Although titanium is much stronger than aluminum, when it comes to cost, aluminum has a definite advantage. Pure aluminum ingots sell for less than a dollar per pound, while aircraft-quality titanium billets sell for 5 to 10 times that amount. And producing titanium in more specialized alloy powder form results in much higher production costs, with prices rocketing up to as much as $75 per pound.

The titanium production process is expensive because of titanium's high reactivity with other elements such as oxygen and carbon, according to Dominic J. Varacalle, Jr., president of Vartech. The conventional method of production requires lengthy steps to overcome that reactivity. The traditional method, known as the Kroll process, reacts titanium tetrachloride in a liquid or gas state with magnesium metal (which by itself is expensive) to produce crude titanium metal "sponge" mixed with magnesium chloride. Electrorefining the titanium sponge under vacuum is then required to remove oxygen, magnesium, and chlorine to purify the titanium metal for subsequent alloy production. If a titanium alloy is intended for use in alloy powder—for application in aircraft or missile parts, for example—the desired titanium alloy must be melted and blasted with an inert gas such as helium or argon to atomize the material.

Vartech has a simpler and therefore cheaper solution. The company has developed a reactor that uses a vapor-phase process to produce titanium alloy powders directly. The process uses a vapor-phase reducing agent to generate alloy powders directly from titanium tetrachloride vapor. The technique could take place as a vacuum process, but Vartech operates its reactor under normal atmospheric conditions to reduce capital costs. Company officials have released few details on its process while it is being developed under an MDA SBIR contract.

One of Vartech's key objectives is to make bulk titanium alloy powders at costs of $3 to $5 per pound in a large plant generating significant quantities. So the company is searching for capital and partnerships that will allow it to grow into that capacity. Vartech researchers imagine their cheaper, commercially available titanium alloys would find use in products such as automotive valves and turbochargers, as well as aerospace and missile components, where strength and weight considerations are important—as is cost. Through SBIR Phase I and II contracts, MDA funded the company's titanium production project for its potential in producing more affordable materials for military aerospace structures.

Vartech is working with the University of Idaho in performing the MDA contract and is working with TechConnect East of the Idaho Governor's Office and Idaho State University to study market sizes and opportunities. Ultimately, the company would on its own seek to produce high-value coated materials and other products—such as superalloy materials that would demand a high dollar-per-pound value. Coated materials might include titanium carbide as well as silicon carbide or tungsten carbide coated with titanium alloys. Vartech's plan calls for licensing out other titanium production technology to companies such as large metals producers.

The company continues to experiment with a newly completed reactor and expects to fine-tune production techniques throughout the summer.

—S. Tillett

CONTACT INFORMATION:

Dominic J. Varacalle, Jr.
Vartech, Inc.
2230 N. Yellowstone Highway
Idaho Falls, ID 83401
Tel: (208) 552-5655
Fax: (208) 528-7127
E-mail: djv@iictr.com
Web: www.srv.net/~djv/varhome.html

CABLE-FREE APPROACH BRINGS SAVINGS TO COMPRESSION-MOLDED DESIGNS

MDA-funded SpaceWorks, Inc. (Carefree, AZ), has developed techniques to incorporate features such as conductive-fiber thermal paths and cabling into the structure of compression-molded components to create "cable-free" spacecraft components—ones without exposed, attached cables. The practice could save space on vehicles by creating a more compact design. Embedding also might cut down on mass by eliminating the need for some fasteners while also making assembly simpler.

The company now is focusing on the design, fabrication, and qualification of a full-scale, flight-quality, multifunctional spacecraft structure. It envisions its molding technology as particularly suited for commercial and government space projects where each pound of payload can cost thousands of dollars to put into orbit.

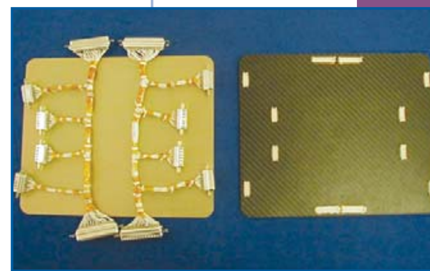
The new approach could also bode well for makers of consumer electronics, assemblies for industrial machinery, and perhaps even automobiles. Making lighter components could give manufacturers more bang for their buck—allowing, for example, the designers of satellites to include more sensors or subcomponents when planning a launch.

Through an SBIR Phase II award, MDA funded SpaceWorks' technology for its potential in producing lower-mass space systems. Space commercialization philosophy is leaning toward multiple small and inexpensive satellites, as well as launches that involve high-value payloads carried aloft by smaller rockets. The ultimate goal is higher profits and a reduced cost of doing business. Current practice uses aluminum for structures and electronics enclosures. But composite structures and enclosures made by a compression-molding process could do a better job of achieving that ultimate goal.

SpaceWorks' methods compete with conventional construction techniques. The traditional approach to building components for spacecraft and aircraft can involve a meticulously manual construction process using geometric shapes and flat or smoothly curved surfaces. Conventional methods—involving casting, stamping, machining, and welding—are time-consuming, taking several days to build structure or components. And traditional materials such as aluminum, although light, weigh more than composites. A compression-molding approach using composites, therefore, could result in components with 60 percent of the mass of components made with aluminum, according to SpaceWorks.

The compression-molding approach shows cost and time savings when applied to mass production. SpaceWorks says an organization making at least 10 to 20 parts with composites and a mold will spend less than if the organization made the same number of parts using aluminum.

Once a mold is made, it can be used repeatedly and can generate a custom component in as little as an hour. Granted, a mold might take several days to make, but making a single component using traditional methods could also take several days.



Light, flexible. *Compared to an aluminum part with traditional wire harness (left), SpaceWorks' multifunctional part (right) is about 57-percent lighter and flexible enough to accommodate component mounting.*

With molding, shapes can deviate beyond the more straight-line geometrical configurations used in spacecraft, allowing parts makers to more easily duplicate new designs that might better suit their needs. The molding approach also allows a designer to embed subcomponents such as wire harnesses, flex circuits, radiation shielding, or thermal conductivity inserts (heat pipes) within a molded part. But such embedded subcomponents might be tricky to access for maintenance if they are embedded. Such a drawback can be overcome by embedding backup or redundant subcomponents, according to SpaceWorks officials.

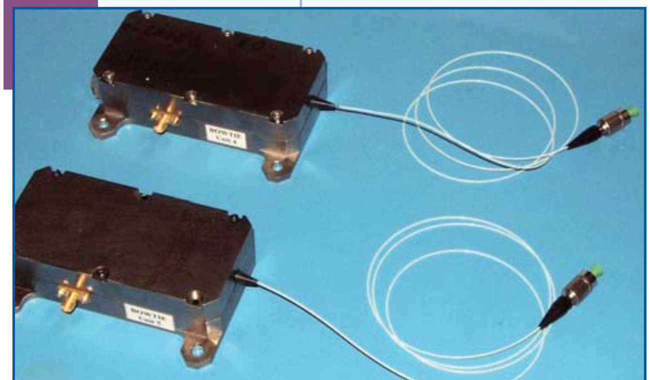
SpaceWorks has delivered electronics enclosures for sensors to NASA's Jet Propulsion Laboratory and the Air Force Research Laboratory for the TechSat 21 satellite program, a project to develop clusters of microsatellites. SpaceWorks continues to seek customers, and company officials say they welcome help in identifying possible new markets for the technology.

—S. Tillett

CONTACT INFORMATION:

Jeffrey C. Preble
SpaceWorks, Inc.
P.O. Box 2014
Carefree, AZ 85377
Tel: (480) 575-1676
Fax: (480) 575-1677
E-mail: jpreble@spaceworksinc.com
Web: www.spaceworksinc.com

HYBRID FIBER RADIO DAYS



Twin peaks. *Outputs from a pair of low-noise lasers are optically combined to generate a desired millimeter-wave frequency.*

Hybrid fiber radio (HFR) is a hot topic in the wireless networking and cellular telecommunication industry. It's a proposed marriage between fiber-optic and microwave radio technology, and a new device that is an outgrowth of MDA-funded research could be the matchmaker.

Typically, a radio frequency (RF) radio base station must be within a few hundred feet of an antenna due to waveguide (RF cable) losses. On the other hand, standard, single-mode fiber-optic cable can transmit signals over distances up to about 30 miles. If RF signals could be sent to the antenna by fiber instead of waveguide, radios could be consolidated into one cost-saving location. The difficulty is in putting the RF signals on the fiber.

Photera Technologies (San Diego, CA), based on research performed under contract to BMDO, now MDA, has patented a solid-state laser design that uses a heterodyne laser technique to convert an optical signal to an electrical one. The company has filed for two additional patents covering specific applications for using the laser as a tuning mechanism for broadband tuning over the telecommunications C- and L-bands. The technology is, in effect, a new method for carrying an RF signal over fiber-optic cable.

MDA awarded Photera Technologies an SBIR Phase I contract in 1999 to test the idea of laser optical microwave signal synthesis—that the difference in the frequencies of a pair of lasers could be controlled with a precision of less than one hertz, and that the difference would be exactly equal to a desired microwave frequency. In 2000, MDA awarded an SBIR Phase II contract to Photera to prove it was possible to encode a microwave signal upon a fiber-borne optical carrier using the heterodyne technique to generate extremely low-noise signals at frequencies ranging from 20 GHz to 60 GHz.

The result is a technology Photera calls BOWTIE (Broadband Optical Wireless Transmission with Integral Emitters). Its advantage over competitive techniques of sending out high-frequency microwave signals is relatively simple: it generates them with extremely high fidelity. With low noise and high power, the dynamic range of the system is greater.

BOWTIE has potential defense and security applications. It could make "software radio" (the ability to change microwave radio frequencies at a single control station) easier and less bulky. Traditional radar transmitters use metal waveguides, which have a limited range of possible transmission frequencies. With BOWTIE, fiber would allow an operator the luxury of a much wider range of microwave frequencies without replacing waveguides. Additionally, fiber-optic technology, being glass or plastic, is lighter than its metal waveguide counterparts and produces less of an electromagnetic interference signature.

Photera Technologies is interested in commercializing the potential of its BOWTIE technology and invites inquiries from engineers and managers designing next-generation, high-frequency wireless networks.

—A. Gruen

Contact Information:

Eric Takeuchi
Photera Technologies
10070 Carroll Canyon Road
San Diego, CA 92131
Tel: (858) 578-9400 ext. 1124
Fax: (858) 578-9402
E-mail: etakeuchi@photera.com
Web: www.photera.com

"When I am working on a problem, I never think about beauty. I only think about how to solve the problem. But when I have finished, if the solution is not beautiful, I know it is wrong."

—Buckminster Fuller

MILLIMETER-WAVE IMAGING ON THE CHEAP

Millimeter-wave imaging systems have long been used to observe distant objects in the universe. Now security personnel have started using them to detect hidden people and objects. The accuracy of these devices could significantly improve safety at airports, schools, and building entrances. However, they are bulky and expensive; as a result, only a limited number are up and running.

With the help of MDA SBIR funding, Sophia Wireless, Inc. (Chantilly, VA), has developed a prototype of a millimeter-wave imaging system that would significantly reduce the size and cost of this type of machine. Once the system is fully developed, it could be used in security and screening applications to detect hidden weapons, explosives, and contraband without exposing the object(s) being scanned to an external radiation source.

The prototype imaging system is mechanically steered and was designed to test the performance of a single miniature receiving element operating in the 126- to 154-GHz range. Sophia's long-term goal is to integrate many of these elements into high-resolution imaging arrays having small apertures, eliminating the need for mechanical steering.

Sophia plans to produce a linear array of these elements to gather information about the scene in one direction, while using frequency steering to obtain the data necessary to construct a two-dimensional image. This would result in a high-resolution, small-aperture imaging system requiring no mechanical steering. Elimination of mechanical steering would increase the speed at which images can be acquired, with video imaging in the millimeter-wave region being possible. The speed of data collection could be increased further by producing two-dimensional arrays that do not use either mechanical or frequency steering.

The novelty of Sophia's invention is the design of the broadband receiving element. Today's high-frequency receivers are limited in bandwidth (e.g., they can only observe at a preselected wavelength). A few broadband receivers exist but they can cost $5,000 to $10,000 per single channel. Sophia Wireless has designed its broadband receiving element with a target price of under $10 per channel.

Additionally, the receiver is very small so it can be laid out along a straight line and fit inside a very narrow space. One hundred receivers could fit side-by-side on a six-inch board to create a linear array. The receiver is manufactured on a standard circuit board and thereby can be easily assembled using conventional microelectronics manufacturing techniques.

Through an SBIR Phase I contract, MDA funded Sophia Wireless to develop the prototype imaging system. Millimeter-wave imaging systems are needed for ballistic missile interceptors because they are less prone to signal jamming than infrared imagers. But to get high-resolution images, very large apertures are required—a big problem for space-limited interceptors. Sophia's invention will allow reduced aperture size without sacrificing high resolution.

Sophia Wireless believes its millimeter-wave imaging technology has significant potential in both commercial and military applications. As the company overcomes remaining engineering issues and refines its prototype, it is looking not only for development and marketing partners interested in potential collaborations but also future customers.

—P. Hartary

Large demo. *Pictured above is a prototype of the millimeter-wave imaging system. The final system will be much more compact—about the size of a loaf of bread.*

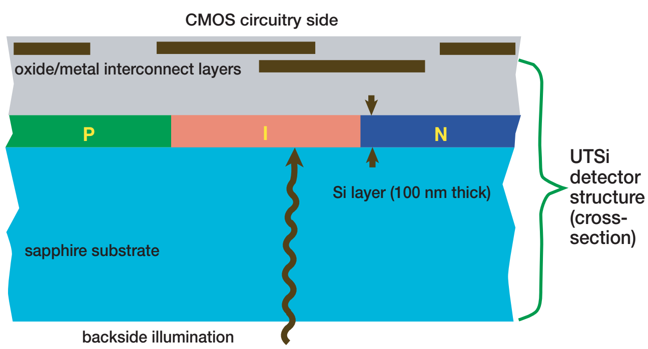
Sophia Wireless' compact, low-cost millimeter-wave imager could be used in a wide variety of security and screening applications.

CONTACT INFORMATION:

Dr. Philip Koh
Sophia Wireless, Inc.
14225 Sullyfield Circle, Suite C
Chantilly, VA 20151
Tel: (703) 961-9570
Fax: (703) 961-9576
E-mail: pkoh@sophiawireless.com
Web: www.sophiawireless.com

PEREGRINE DEVELOPING A RADIATION-HARD UV AND BLUE CMOS IMAGER

The first radiation-hardened complementary metal-oxide semiconductor (CMOS) imager sensitive to ultra-violet (UV) and blue wavelengths will soon be available.



Fully integrated. *Peregrine's patented UTSi® process integrates interface circuitry and an active pixel sensor array to create rad-hard CMOS circuits on a silicon-on-sapphire substrate.*

Peregrine Semiconductor Corporation (San Diego, CA) is developing a UV and blue imager using a standard, commercially established CMOS process that enables the integration of control and process logic on a single chip and produces a high yield.

The company was funded by MDA to develop a solar-blind charge-coupled device (CCD) imager that allowed daytime space-based navigation and for high-dynamic range focal plane array imaging used in space-based remote sensing. Through its MDA SBIR projects, the company found that it was more advantageous to create a UV and blue CMOS imager, because CCDs are expensive and require custom manufacturing processes to fabricate.

Peregrine's patented ultra-thin silicon-on-sapphire (UTSi®) process is a standard, commercial CMOS process that is very sensitive to wavelengths below 450 nm. It enables the integration of interface circuitry and an active pixel sensor array to create rad-hard CMOS circuits on a thin layer of silicon epitaxially grown on a sapphire substrate. Typically, silicon-on-sapphire has poor manufacturability due to a high defect density in the silicon layer. However, Peregrine's UTSi process eliminates those defects, allowing very thin layers (1,000 angstroms or less) of high-quality silicon to be achieved.

Peregrine's sapphire substrate is transparent to wavelengths down to 200 nm, which allows direct optical access to the silicon layer when back-illuminated. Adding optical coatings to sapphire enhances the rejection of undesired wavelengths. The UV and blue imager's circuits operate with a single supply of 3.3 volts or less. It is more reliable and uses up to 100-times less power than a custom UV and blue CCD imager.

Commercial applications such as biomedical and semiconductor processing are possible. However, Peregrine is currently focused on the technology's missile detection capability. Due to absorption in the ozone layer, the solar spectrum near Earth's surface has a sharp drop in intensity for wavelengths shorter than about 290 nm. CCDs and photomultiplier tubes (PMTs) are the conventional tools used to manufacture solar-blind detectors, which enable the detection of missile threats in full daylight. CCD processes are not high yield or high integration, and PMTs are bulky, fragile, and expensive. MDA is seeking solar-blind technologies that are more rugged and reliable.

Using its CMOS imager, Peregrine can develop a single heterogeneous imaging array that detects light outside the solar spectrum at both short and long wavelengths. Attaching a long-wavelength detector to Peregrine's CMOS imager allows detection of wavelengths normally absorbed by the atmosphere, resulting in more accurate detection of missile plumes and other manmade target signatures.

Peregrine has completed evaluating the spectral sensitivity of the sensor device. The company seeks additional funding to develop the technology for a specific application.

—T. Spitzer

CONTACT INFORMATION:

Charlie Kuznia
Peregrine Semiconductor Corporation
6175 Nancy Ridge Drive
San Diego, CA 92121
Tel: (858) 455-0660
Fax: (858) 455-0770
E-mail: ckuznia@peregrine-semi.com
Web: www.peregrine-semi.com

"Obstacles are those frightful things you see when you take your eyes off your goal."

—Henry Ford

COMPACT BEAM-STEERING DEVICE PROVES HANDY IN TIGHT PLACES

Generating a laser beam that suits your needs can be tricky enough. But what if you want to steer or aim that beam without upsetting the platform on which the laser rests or physically moving the laser?

Accomplishing that feat with mirrors can prove cumbersome. To change the direction of a beam only slightly, you'll need at least two mirrors. The first mirror projects out-of-plane onto a second, movable mirror that does the beam directing. This out-of-plane sequence adds volume and complexity to the beam director. If the goal is to maintain the original projection axis, three or even four mirrors can be used. But with any of these mirror schemes, at least one mirror is off-axis, resulting in a bulky mechanization.

One company has a different solution that, instead of mirrors, uses transparent components mounted along a beam's axis. MetaStable Instruments, Inc. (St. Charles, MO), was funded by BMDO, MDA's predecessor, to develop a compact beam director for high-power lasers. The device holds promise for saving space in missile-tracking systems. But the technology also could work well for any laser application in which a beam must be directed, tweaked, or steered over a limited angular range. Company officials say their beam-steering mechanism could prove useful in research environments and also in commercial products such as sophisticated cameras, projection displays, or sensors that use lasers to stabilize images.

MetaStable, whose BMDO funding came from the SBIR program, holds one patent for its beam steerer and has applied for a patent on a faster version of the device. The company already has begun marketing its creation as a commercially available product, placing ads in industry publications and displaying the product at trade shows. "The nice feature of this approach, and any of the refractive approaches, is that you just drop this device in the existing beam," said George Dubé, president of the company. "You don't have to reroute the beam to bounce it off a mirror."

MetaStable's invention, which in the laser industry can be termed an "adjustable optical wedge," uses two lenses with a thin layer of transparent lubricant between them. One lens is convex and fits into a concave lens. The size of the lenses used in the device, called the Matched Lens Refractive Beam Steerer, varies depending on the diameter of the beam being steered.

As a beam passes through the lenses, one of the lenses is shifted to form a wedge that steers the direction of the transmitted beam. The transparent lubricant between the two lenses adheres them together but also allows the lenses to slide without scratching each other. MetaStable has a database of about 100 lubricants suitable for the laser applications. No single lubricant is transparent for all laser wavelengths, but suitable lubricants have been identified for the prevalent laser wavelengths.

Some competing wedges include a fluid sandwiched between two windows, one of which tilts to steer a beam. The liquid can distort the beam being steered, however. Another type of competing device, called a Risley wedge, involves two glass or crystal wedges. The two wedges spin around the axis of a light beam to steer it. But Risley wedges, unlike MetaStable's device, steer light in a circular pattern. Counter-rotated Risley wedges steer light approximately in a straight line, but close examination reveals a bowtie pattern instead of a straight line. MetaStable's technology meanwhile steers beams in a cartesian pattern (along X and Y axes), with no blind spots.

MetaStable continues to look for new customers and resellers. The company also continues to explore the potential for its technology in new markets, such as laser surgery.

—S. Tillett

Beam tweaker. *MetaStable's beam director is manually controlled and uses simple screws or, for more precise applications, micrometers. This summer, company officials plan to introduce a unit with motorized controls.*

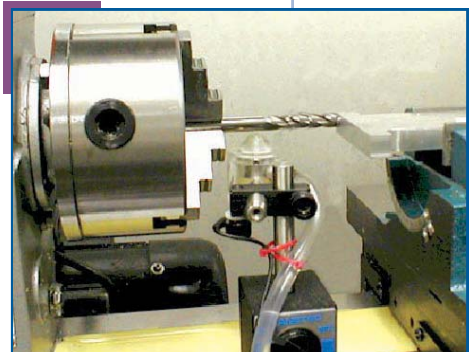
CONTACT INFORMATION:

Dr. George Dubé
MetaStable Instruments, Inc.
5988 Mid Rivers Mall Drive, Suite 236
St. Charles, MO 63304
Tel: (636) 447-9555
Fax: (636) 447-8267
E-mail: gdube@metastableinstruments.com
Web: www.metastableinstruments.com

DIAGNOSING MACHINE TOOL HEALTH WITH ULTRASOUND

Ultrasonic technique shows promise for determining optimum machining parameters.

Machining has always been more art than science. Now, an ultrasonic method that diagnoses and monitors machine tool health could bring more science to this mystical art.



A cut above. *Lasson Technologies tested its ultrasonic fluid probe by simulating a milling operation at both low and high spindle speeds.*

Lasson Technologies, Inc. (Culver City, CA), is using ultrasound to monitor high-speed machine tool vibrations in real time. This innovation could allow machinists to eliminate machine tool chatter and increase feed rates, spindle speeds, and cut depths—all of which greatly improve process throughput in manufacturing applications.

"Ultrasound has been widely used for many years to observe and gather compositional data about materials and products," said Dr. Marvin Klein, president of Lasson Technologies. "We believe our company is the first to use the principle of ultrasonics to monitor vibrations during high-speed machining. We are now moving toward creating hardware and software tools that help determine optimum machining parameters."

Bad vibrations

Cutting machinery that suffers from excessive vibration is a serious problem. Uncontrolled, vibration can degrade surface finish, limit dimensional accuracy, increase tool wear, and create high forces—which, in turn, lead to increased machine wear, reduced process throughput, and higher scrap rates. The urgency to solve these problems continues to grow as machinists opt to machine at higher speeds, use smaller tools, and process more difficult-to-machine materials.

The manufacturing industry has long been concerned with vibration. Since the birth of the industrial revolution, it has sought ways to characterize the condition of machining tools and to control vibration and chatter during machining processes.

Today's machinists use various methods to control vibrations. They can increase the stiffness of the tool or decrease the material removal rate by reducing feed rate, depth of cut, and spindle speed. However, these remedies clearly reduce production throughput and are often not acceptable on the shop floor.

More sophisticated approaches involve the use of sensors placed on the machine tool itself and the workpiece. These sensors may include contact strain gauges/accelerometers, capacitive probes, inductive probes, fiber-optic displacement sensors, laser Doppler vibrometers, and acoustic pickup devices (i.e., microphones).

But these devices have their limitations. Some cutting tools are so small that they cannot be equipped with contact accelerometers or other sensors for static testing. Optical probes can be used on rotating tools, but they are best-used on fixed surfaces. Rapidly moving surfaces create speckle noise that overwhelms the optical probe's signals and significantly degrades sensor performance.

Ultrasound principle

Realizing that working at optical wavelengths creates a speckle problem, Lasson Technologies considered using ultrasound. "Since our business is laser ultrasonics, we already had a familiarity with this technology," commented Dr. Klein. "The wavelength of sound waves is 3 to 4 orders of magnitude larger than optical wavelengths. That means a surface that is rough to an optical beam could easily look smooth to an ultrasonic beam." Simply put, the speckle problem disappears.

The other major issue is attenuation. An ultrasonic wave launched in air would be attenuated. This led the company to consider the simple yet elegant idea of using the cooling fluid stream that is directed at the cutting tool as a coupling medium to guide the ultrasonic wave.

In 2000, the National Science Foundation funded Lasson Technologies with an SBIR Phase I contract to test the feasibility of this idea. The research was successful, but the company had only proved their concept could work at low spindle speeds (up to 1,600 rpm) whereas today's machining processes typically operate at much higher spindle speeds (up to 30,000 rpm).

Continued on page 11

Diagnosing . . . from page 10

In 2002, MDA funded the company through an SBIR Phase I contract to develop an active ultrasonic fluid probe for vibration monitoring at higher speeds. Using a megahertz-frequency ultrasonic transducer, an ultrasonic signal is propagated through the cooling stream. This signal is reflected off of the cutting tool back through the stream, where it can be detected and analyzed.

If the cutting tool does not vibrate, the reflected ultrasonic wave has the same frequency spectrum as the incoming ultrasonic wave. If the tool vibrates, the frequency spectrum of the reflected ultrasonic wave is shifted. Tool vibration is thus measured by comparing the transmitted ultrasonic carrier with the reflected ultrasonic signals.

An investigation of this technique was performed at various speeds using a rotary tool. Data were successfully gathered with the tool remaining stationary, rotating at low speeds, and then finally rotating at high speeds (up to 20,000 rpm). One important finding was that the increased noise levels at higher speeds should not interfere with the signals.

In April 2003, MDA awarded Lasson Technologies an SBIR Phase II contract to further refine their ultrasonic fluid probe technology. Work to be performed includes refining the high-speed test bed, improving electronic circuitry for signal modulation and demodulation, enhancing the piezoelectric transducers, refining the fluid delivery system, and performing additional high-speed machining vibration assessment and characterization. Ultimately, the Phase II research will produce a working prototype system that will be tested at end-user facilities.

Potential applications

MDA recognizes that high-speed machining is becoming a more critical technology. Many manufactured components, such as rocket engine parts, radomes, and windows for missile interceptors, are subject to very strict manufacturing tolerances that cannot be held if excessive vibration is encountered during machining. The ultrasonic fluid probe technology can be used as a real-time manufacturing engineering tool to monitor and control these vibrations.

In fact, the technology is already being considered by Boeing-Rocketdyne for MDA's Theater High-Altitude Area Defense (THAAD) system. THAAD thruster components are made with Inconel®, a nickel-chromium alloy designed to withstand extreme heat and stress. "When machining Inconel, speeds must be limited to 7,000 rpm," says Dr. Klein. "Exceeding this limit may subject the machine tool to excessive chatter, breaking it or the part being machined. Using our fluid probe technology, Boeing-Rocketdyne can more effectively monitor and control vibrations, and thus reduce units costs and improve production throughput for THAAD components."

In the commercial arena, the ultrasonic fluid probe is a technology that ideally can be used in any industry with critical machining requirements. As part of its MDA SBIR Phase II proposal, Lasson Technologies will test its prototype on high-speed machining equipment owned by Cincinnati Machine, which manufactures and sells machining centers. Additionally, the company is working with Manufacturing Laboratories, Inc., a leader in machine tool characterization and machine tool vibration monitoring, to incorporate the probe technology into hardware and software such as MetalMAX™.

Lasson Technologies is hopeful its ultrasonic fluid probe will become an essential tool for high-speed machining operations. The company is looking for organizations interested in partnering to explore new machining applications.

—P. Hartary

CONTACT INFORMATION:

Dr. Marvin Klein
Lasson Technologies, Inc.
6059 Bristol Parkway, Suite 150
Culver City, CA 90230
Tel: (310) 216-4046
Fax: (310) 216-4051
E-mail: mbklein@lasson.com
Web: www.lasson.com

"Great minds discuss ideas. Average minds discuss events. Small minds discuss people."
—Admiral Hyman Rickover

The ultrasonic fluid probe, developed by Lasson Technologies with MDA SBIR funding, could bring more science to the mystical art of machining.

DETECTING RADIATION: THE PHOTON FACTOR

New approach for detecting radiation eases electron woes, promises greater accuracy.

Radiation detectors are figuratively stuck in the vacuum-tube era. But using photons instead of electrons in the devices could be the key to bringing radiation detectors into the semiconductor age. And Sentor Technologies, Inc. (Glen Allen, VA), has a plan to do just that.

Prototype. *Sentor's radiation detector should provide high energy resolution, operate at room temperature, and have a large working volume.*

Semiconductor technology for decades has been fulfilling the promise of building smaller, more efficient tools—from computers to lasers. But some of the benefits of semiconductors ironically are lost on radiation detectors.

Size, electrons create problems

Basing a radiation detector on semiconductor technology creates an unwanted side effect: While a semiconductor-based radiation detector may be similar in structure to a diode found in a computer chip, it must be thousands of times larger than a computer chip to work properly, according to Sentor scientists. It must be large because radiation detectors need relatively large sample volumes, and capturing such volumes requires a relatively big detector with big components. The bigger the detector, the greater the chance of capturing the deeply penetrating gamma rays that indicate radiation. But large detectors also create more traps into which critical charge carriers could fall.

The problem with large semiconductor-based radiation detectors really emerges when electrons enter the picture. In a typical semiconductor-based detector, an absorbed gamma-ray photon is captured, and the device applies a DC electric field. The DC field causes a small "cloud" of charge carriers to migrate toward an electrode, with electrons moving toward the positive end and holes toward the negative.

The collected charge carriers are then converted into a signal that can be analyzed, generating a final readout on the detector. Specifically, the amplitude of a pulse serves as the measure of the original gamma-ray energy.

The problem occurs, however, when material imperfections prevent some charge carriers from making it to the collecting electrode. And since detectors must be large, the chances for such electron "scavenging" increase. In effect, electrons traveling across large expanses of semiconductor materials stand a good chance of getting trapped in material imperfections.

Photons offer solution

But the prototype for Sentor's radiation detector—developed with help from an MDA SBIR Phase II award—uses an AC electric field, entirely changing conditions inside the detector. Application of the AC field allows for the establishment of resonance in the detector. Resonance is akin to pushing a child who is "oscillating" back and forth in a swing. Pushing the child at the frequency that matches the natural oscillation of the child and swing results in large "amplitudes," with the child and swing soaring into the air.

In the case of the Sentor radiation detector, resonance occurs when the frequency of an AC field matches the natural frequency of a cylindrical cavity housing a semiconductor. Specifically, the resonance occurs at a frequency in the microwave range, near 5 GHz. The resonance makes the cavity capable of absorbing electromagnetic energy. When a gamma-ray photon is absorbed within the semiconductor, the semiconductor conductivity increases. That increase in conductivity alters the resonance condition of the cavity. (Any minute changes that occur within the cavity alter the resonance frequency.)

Sentor's radiation detector monitors which frequency is absorbed by the cavity and which frequencies are reflected. Sentor researchers claim this technique has accuracy advantages over the DC method of radiation detection because the signal is not created by the slow migration of charge carriers toward an electrode, but by changes in the electromagnetic field. So unlike other detectors, the Sentor detector requires absolutely no electrical contact with the semiconductor.

Both types of detectors start with photons, but Sentor's detector does not have to convert photons into electrons. So

Continued on page 13

Detecting . . . from page 12

the Sentor approach also has a speed advantage over detectors that rely on electrons instead of photons to generate signals.

Electrons travel at about 100,000 centimeters per second. Photons, meanwhile, travel at billions of centimeters per second. And since the Sentor detector measures photon activity instead of electron activity, it can generate readings more swiftly.

The greater speed is important because it ensures that signals flow smoothly through the detector, allowing the device to process a large volume of energy—which is key when detecting gamma rays accurately. "It gets the signal out of the semiconductor, whereas the biggest problem with competing technologies is that the signal never gets out of the detector," said Dr. Gary Tepper, president of Sentor and professor of chemical engineering at Virginia Commonwealth University. "When you lose your signal, your detector stops functioning."

Proving useful

Radiation detectors are used in a wide variety of applications, including nuclear medicine, geological exploration, astrophysics, nuclear nonproliferation, and homeland security. They are expected to become increasingly important as state and local emergency-management officials seek to arm themselves with the tools needed to respond to possible threats involving radiological hazards. Moreover, teams charged with the task of inspecting sites for radioactive materials, in accordance with international nuclear nonproliferation treaties, might require improved technologies to do their jobs better amid new challenges. Missile-defense-related applications include possible use in surveillance equipment.

Sentor researchers expect their technology to meet three requirements users want in radiation detectors. The device is expected to provide high energy resolution. They also expect their device, still in the prototype stage, to operate at room temperature and have a large working volume. "That's sort of been the holy grail of radiation detector research for at least the last decade—to realize a detector that can satisfy all three of those very important performance characteristics," Tepper said.

High energy resolution is important because it allows a user to distinguish between two different radioactive atoms that might be very similar in terms of the energy they release. "For many applications, that's important—to determine the source of the radiation in a mixed environment where you have multiple sources," Tepper said.

Room-temperature operation is important because it eliminates the need for additional components such as coolants. And large volume, of course, is needed for capturing deeply penetrating gamma rays.

Commercial appeal

Tepper said most of the commercial opportunity for the Sentor detector would come in from government users such as emergency responders, treaty inspectors, and environmental overseers. But he said private-sector users such as environmental engineering or consulting firms also could use the technology. He conservatively estimated the company's market at $500 million.

But there is a much larger market that eventually might be tapped. Radiation-monitoring equipment also abounds in the medical field—for use in nuclear medicine imaging. Sentor, however, is not especially focusing its commercialization efforts in the medical realm, since such medical technology must also have imaging capabilities, not just detection capabilities. Still, Tepper said the company would be open to licensing its technology for incorporation in medical equipment.

Sentor has developed a prototype detector and now is building special circuitry to stabilize the device for environmental changes. The more sensitive the detector is to target materials, the more sensitive it is to environmental changes, Tepper said.

Company officials also expect they will need help packaging their prototype, turning it into a more marketable product with a more streamlined appearance. The company, meanwhile, is looking for ways to market its other technologies, which include thin films and chemical sensors.

—S. Tillett

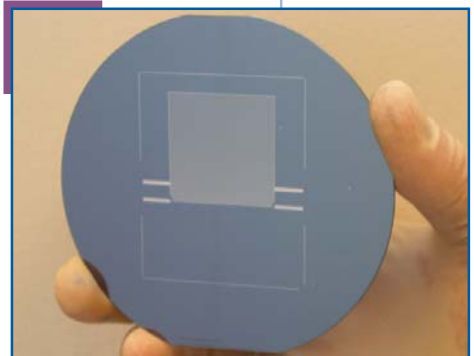
CONTACT INFORMATION:

Dr. Gary Tepper
Sentor Technologies, Inc.
11551 Nuckols Road, Suite Q
Glen Allen, VA 23060
Tel: (804) 270-1411
Fax: (804) 270-3578
E-mail: gpteppers@aol.com
Web: www.sentortechnologiesinc.com

Sentor's radiation detector measures photon activity instead of electron activity. Thus, it can generate readings more swiftly.

The Heat Is On from page 1

concepts for advanced cooling of electric motors, which are used widely in many industries beyond that of automotive. The pumpless coolant technique seemed to offer the best approach for the least cost. The company decided to focus on electric motors that had specific applications in automobiles because this seemed to be the quickest route to commercialization. With an interest in proving out the manufacturability of such improved motors, MDA awarded a follow-on SBIR Phase II contract to SatCon in 1999.



Cooling on a chip. *Pictured above is a wafer with a deposited array of electrohydrodynamic electrodes.*

Liquid coolant usually needs to be pumped away from its heat source, but the SatCon method is unusual because it relies upon capillary action to draw coolant through windings, and to wick condensed vapor on an outer shell back into the loop. All electric machines dissipate power in their windings as well as in their magnetic materials. Realizing that as much as half of the power losses occurred in the stator windings, designers decided to cool them directly. A non-electrically conductive liquid perfluorinate coolant such as those made by the 3M company provided desirable properties including high heat of vaporization and relative inertness. The windings draw the fluid through capillarity, vaporize it, and the vapor condenses on a stainless steel shell. A second wick takes the condensate back to the windings. The whole chamber is hermetically sealed.

SatCon hopes to produce a 100-kilowatt electric motor that would provide about 130 horsepower, but for now has created a prototype that should deliver about 10 to 11 kilowatts, based on a motor design that originally was designed to produce 5 kilowatts of power. This smaller unit measures approximately 7 inches in length by 5.5 inches in diameter. Company engineers recognize that beyond a 100-kilowatt motor—beyond 12 inches in diameter—there are some scalability issues that could reduce the efficiency of their passive phase-change approach.

Higher power density allows for a reduction in material costs. Designers estimate that given a fixed electric motor power requirement, up to one-third of the magnetic material and one-third of the manufacturing cost could be eliminated. In addition to cost savings, the lighter weight and greater power density of a smaller motor in a smaller volume would appeal to engineers in the aerospace and missile industries. SatCon has not ruled out any possibility about where and how its unique cooling technology could be applied, and invites those who might have design requirements and specific applications for electric motors to contact the company directly.

Spray cooling without the spray

As anyone who has ever spray-cleaned a window knows, one major problem with spray is that the fluid goes all over the place. In technical terms, the droplets are "stochastic." When it comes to putting out a fire, this is desirable; but when it comes to cooling electronics very precisely in a confined space, such as inside a computer, a different approach works better. That approach is to use an electric field to make a liquid thin enough that it is easy to evaporate, right at the source of the heat—the processing chip itself.

ATEC, Inc. (College Park, MD), with funding from MDA, is developing an electrohydrodynamic (EHD) device which it hopes will remove heat up to 100 watts per square centimeter. That is enough to cool not only today's chips but also the next generation of processors as well. The basic patent is owned by the University of Maryland, but the company has filed two provisional patents for improvement and preferred embodiment on the original design.

MDA's predecessor, BMDO, awarded ATEC an SBIR Phase I contract in 2000 to demonstrate the feasibility and performance solely of a micro-evaporator. This did not address a micropump or condenser. In 2001, BMDO awarded an SBIR Phase II contract to design, fabricate, and integrate all components into a single compact cooling device.

Rather than using a spray nozzle to generate a thin film of fluid, ATEC uses electrohydrodynamics to pump a thin (2 to 3 microns) layer of liquid over the hot surface to be cooled. Once thinned to that degree, the liquid can evaporate efficiently because the amount of

Continued on page 15

The Heat Is On from page 14

heat removed from a surface increases as the thickness of the liquid layer decreases. In contrast, heat pipes with fluid film thicknesses of 30 to 40 microns have some inhibition of evaporation, as cooler fluid tends to trap warmer fluid.

ATEC uses 3M's HFE-7100 perflourinate as its cooling liquid. The trick is to deliver a thin layer of coolant as fast as possible across the source of heat. The faster it can flow, the more heat it can remove. To get it flowing, ATEC uses an electrohydrodynamically driven thin-film evaporator that can pump fluid to a height of 35 millimeters, which should be enough to remove 100 watts of power per square centimeter using inert liquids such as HFE-7100. However, that is only half the battle. Once heated and vaporized, the coolant needs to go somewhere to condense back into liquid and be returned to the loop. A second pump might be necessary to bring the condensate back to the evaporator.

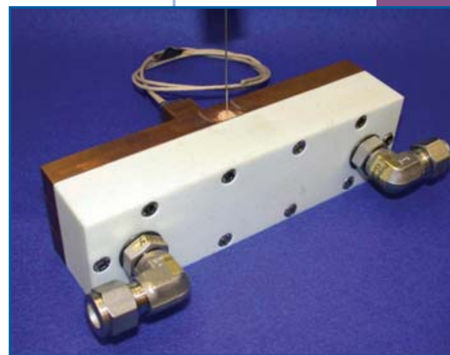
Assuming that all the design problems are solved, ATEC will have invented what amounts to a new paradigm in thermal management. Instead of using a combination of a long thermal conduction path and forced air convection, ATEC's two-phase cooling loop will effectively remove a large heat flux across a minimum temperature difference as close as possible to the heat source.

While cooling chips directly as they produce heat would obviously be important to computer electronics, ATEC's microcooling technology might be useful for other kinds of electronics as well, such as radar systems. The company seeks thermal management engineers and electronics system designers who might have problems that spot cooling can solve.

Making water cooling efficient on many levels

Perfluorinates are specialized liquids that are designed to work directly in contact with electronics. But if you cool a system using the most abundant liquid on Earth—water—then you may wish to contact Mudawar Thermal Systems, Inc. (West Lafayette, IN). The company has recently developed, in one package, a set of methods that can remove up to 1,900 watts per square centimeter. The unit might be cost effective, too: it's made out of high purity copper.

Mudawar's new technology, called Multi-Level Enhancement, uses several methods of evaporating and condensing water to remove large quantities of heat quickly. First of all is geometry: the evaporator structure is built with extended surfaces. Second, the extended surfaces have small features on the order of one millimeter. Third, those finely textured extended surfaces are then bombarded with silica particles to create a microstructure favorable to nucleation (essentially the formation of very tiny bubbles). Fourth, the system uses subcooled boiling, which means the coolant is supplied well below its boiling point and can extract much more heat. Combined with the microstructure, this means the evaporator component can rely on the advantages of boiling without generating too much vapor. The combination of these four main features and others into one package is what the company provisionally patented in 2002.



Copper pipes. *Mudawar's thermal test module promises to remove up to 1,900 watts per square centimeter.*

One of the advantages of subcooling and controlling vapor separation from liquid is that such a system can operate in unusual gravity conditions, such as the microgravity of space or the high G-forces created by maneuvering aircraft. The potential for cooling airborne electronics or lasers under variable G-force conditions is of great potential interest to MDA, which awarded Mudawar an SBIR Phase I contract in 2000 and an SBIR Phase II contract in 2002.

Water is an ideal liquid to use for cooling, if possible, for two reasons: it has a very high heat of vaporization; and it is environmentally benign. The water cooling unit is made of high-purity copper because it is a very conductive metal that tarnishes slowly; company engineers believe they can reduce oxidation even further and ensure consistent performance over time by depositing a thin layer of nickel on the copper. A full-size module would measure approximately 5 x 1.5 x 0.5 inches.

One potential stumbling block is not so much the design of the unit but rather what method to use to attach it to its heat source. Whatever

Continued on page 16

MDA Update
SUMMER 2003

Missile Defense Agency
c/o National Technology Transfer Center
Washington Operations
2121 Eisenhower Avenue, Suite 400
Alexandria, Virginia 22314
www.mdatechnology.net

Address Service Requested

"One of the advantages of subcooling…is that such a system can operate in unusual gravity conditions, such as the microgravity of space…"

The Heat Is On from page 15

the interface material, it needs to be very thin to lower thermal resistance—otherwise, the material melts long before the unit fails. In fact, in the laboratory one of the problems facing Mudawar engineers is finding test equipment that can survive the heat the evaporator is able to remove. This is a good problem to have—it means the technology works so well that other factors become limiting ones. The company invites inquiries from any engineer addressing thermal management problems to find out more about how Multi-Level Enhancement works.

Contact Information:

Carl Fisher
SatCon Applied Technology, Inc.
161 First Street
Cambridge, MA 02142
Tel: (617) 349-0930
Fax: (617) 349-0961
E-mail: carl.fisher@satcon.com
Web: www.satcon.com

Dr. John Lawler
ATEC, Inc.
387 Technology Drive, Suite 2110
College Park, MD 20742
Tel: (301) 403-1748
Fax: (301) 403-1745
E-mail: j.lawler@atec-ahx.com
Web: www.atec-ahx.com

Dr. Issam Mudawar
Mudawar Thermal Systems, Inc.
1291 Cumberland Avenue, Suite G
West Lafayette, IN 47906
Tel: (765) 463-6516
Fax: (765) 463-6516
E-mail: info@mudawar.com
Web: www.mudawar.com

MDA TECHNOLOGY NEWS ONLINE

Is this information below news to you?

- Pacific Advanced Technologies' gas-leak detector is featured in *Sensors* magazine.
- Boston Applied Technologies introduces the Eclipse Micro Variable Optical Attenuator.
- Picolight and IBM achieve unprecedented bandwidth density for optical data transmission.
- CoreTek members form new company, Ahura Corporation.

If so, be sure to visit our Web site at www.mdatechnology.net. Under the Company News section, you'll find hyperlinks to more press releases from MDA-funded companies.