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INSIDE

Cryocooling Technologies: Looking Back, Looking Ahead

—by Adam Gruen

For infrared sensors, whether they look at planets and stars or missile plumes, the build-up of heat surrounding operating equipment is a crippling problem. Sensor and focal arrays have to be colder than what they are observing or they don't work at all. The sensitive arrays need cryogenic cooling to temperatures usually below 100 K.

The Missile Defense Agency (MDA) funding since the 1980s has directly resulted in improvements in cryogenic cooling (or "cryocooling") technology that support current spacecraft such as the Hubble Telescope, Aqua, and Aura, as well as future spacecraft and space platform missions including space-based surveillance.

The remarkable thing is that the need for all of this technology development was anticipated and foreseen almost two decades in advance. As early as 1984, managers at the earliest incarnations of MDA anticipated that cryocooling would become an enabling technology for long-duration spacecraft.

Wanted: Radical Reductions

The entire field of cryocooling needed to be radically improved. The first generation of cryocooling technologies (c. 1960-1985) used liquefied, pressurized gas to absorb heat and then simply vented it away. These couldn't last very long for the reason that eventually the gas supply ran out. To the extent that many spacecraft were not designed for very long missions, having a limited coolant supply was not considered a major problem. However, once spacecraft designers started contemplating longer missions of more than four years, they realized that the old cooling technologies wouldn't work without paying a massive weight penalty to orbit. Liquefied gases such as helium and nitrogen are light, but the vessels used to contain them under pressure are heavy.

If spacecraft and space platforms were usefully to exist in orbit for long periods of time, the old idea of heating gas and venting it had to be scrapped. The new generation of coolers would recycle gas (by evaporating it and then condensing it) in a closed loop system.

Recycling gas sounds like a simple idea but it has two major drawbacks: cryocooling compressors, evaporators, and heat exchangers draw power and create vibration. The latter problem in particular disturbs onboard sensors and cameras that need very low vibration environments. So as early as the mid-1980s, thermal engineers knew they needed smaller and more efficient pumps/engines, and far fewer mechanical parts that would last without wear and tear as long as possible.

Light package. *Northrop Grumman's high-efficiency cryocooler unit weighs less than 7 kilograms compared to previous state-of-the-art at 22 kilograms. Sixteen units have been ordered for various flight programs.*

The Early Years

From 1984 to 1987, the Strategic Defense Initiative Organization (SDIO) recognized

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MDA Update

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FROM THE EDITOR

MORE SPACE SPINOFFS

The wealth of advanced technology that comes from ballistic missile defense research has proven quite valuable to space and aeronautics programs.

Perhaps the best example of this can be found in our lead story. Cryogenic cryocoolers—devices that cool equipment to extremely low temperatures—owe a large part of their existence to research conducted for ballistic missile defense. In fact, nine U.S. cryocoolers flying in space today were all, directly or indirectly, developed by the Missile Defense Agency and its predecessors.

Writer Adam Gruen has done an excellent job of sifting through a vast amount of historical information and documenting key cryocooler breakthroughs funded on MDA's dime. I urge you to read his story for two reasons.

The first is that it shows the U.S. aerospace community really can anticipate a need, draw up a road map of how to get there, and then, patiently and consistently over time with adequate resources, satisfy that need.

The second is that anyone interested in astronomy or Earth observation, both of which have a constant demand for increasingly sophisticated infrared sensing, owes a debt to the MDA community. Whether they seek to explore the universe or want to measure heat on Earth (e.g. for improvements in agriculture or land management), cryogenic crycoolers are needed to make the new generation of IR sensors work.

More space spinoffs are coming. In this issue, you can read about Full Circle Research's rad-hard CCD technology (see page 8) that allows star trackers and imagers with high frame rates to withstand more space radiation; Applied Technology Associates' advanced optical IRU (see page 10) that steadies laser communications beams transmitting data over extremely long distances in space; and Morgan Research's damage sensor (see page 12) that monitors the structural health of composite rocket motor cases. Hopefully, some of these innovations will benefit space and aeronautics programs as much as cryogenic cryocoolers have.

In our Spring 2005 issue, we will reveal more details about another exciting space spinoff. Johns Hopkins Applied Physics Laboratory (APL) is using ballistic missile defense technology for its MESSENGER mission to deliver images of the planet Mercury to the scientific community. In the mid-1990s, BMDO funded APL to develop a single-stick slotted waveguide antenna for the Boost Phase Intercept program. MESSENGER, which was launched this summer, carries a modified version of that BMDO technology to investigate one of our closer neighbors some 4.9 billion miles away.

Now is an exciting time for MDA spinoffs. The dividends of advanced technology development are paying off handsomely for the space industry.

—Patrick Hartary
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BUSINESS MISCONCEPTIONS JEOPARDIZE COMMERCIAL SUCCESS

—by Tim Bennett, Joel Price, and Patrick Hartary

In the Spring and Summer 2004 issues, articles appeared describing the marketing and technical misconceptions that could prevent researchers from successfully commercializing their MDA-funded technologies. The following article, the last in the series of three, describes some business misconceptions that often hinder successful commercialization.

Misconception #1: "I don't need an intellectual property strategy."

Many first-time technology entrepreneurs make the mistake of handling this issue incorrectly by taking an extreme position. Either they spend countless thousands of dollars building a large patent portfolio, believing they have locked out the competition and can speak openly about their discoveries. Or, they refuse to divulge enough information to be understood, paranoid that everyone will steal their great idea.

Like most things in life, moderation is prudent. Patents and trade secrets are valuable business assets only if funds are available to defend them. The cost of a patent infringement investigation and negotiation can easily exceed $100K, while the actual court procedures average about $2M to pursue. Developing an intellectual property (IP) strategy early is extremely important. In all cases, once a company has assessed the viability of their technology and marketable products they should seek legal counsel in developing their IP strategy.

Misconception #2: "Our employees are loyal, so they won't reveal confidential information."

It is just as wrong to steal IP as it is to break into a home, steal a car, or rob a bank. But that doesn't stop some employees intent on making a buck from side-stepping their integrity.

Small technology businesses should have all founders and employees sign an employment agreement that contains terms and conditions specifically addressing the protection of company IP. Additionally, a non-compete clause should be included, in case the employee leaves the company. Employers should understand that confidentiality or non-disclosure agreements (NDA) should be signed prior to discussions with third parties about any aspect of their business. If closely guarded information becomes public knowledge, businesses can be irreparably damaged.

Internal procedures should be established to define how best to protect the company's intellectual property. Founders and employees may initially be considered friends, but relationships and loyalties change over time so it is best to execute an agreement in writing while all parties are on good terms.

Misconception #3: "Our intellectual property position will prevent any competitors from moving in on our territory."

Patents, copyrights, trademarks, and trade secrets are all forms of IP that—when properly protected—can help raise capital, create business opportunities, and limit competition. But small tech researchers must remain vigilant in protecting proprietary technology.

Play detective. *Stay ahead of your competitors by doing some investigative probing with experienced industry professionals. Ultimately, it could help you protect against patent infringement.*

Nearly all patents can be designed around or simply ignored. The larger the market opportunity, the more likely companies will ignore your patent rights to exclude others from practicing the technology. They will attempt to quickly capture significant market share, and utilize the revenues to help support necessary legal actions.

You will also find that the larger corporations are less inclined to sign an NDA. Mainly, they fear your company will come back to them at a later date claiming to have provided the original idea, even though they may have been internally developing something similar. Although the majority of companies consider it bad business practice to steal the ideas of others or infringe upon patents, those few unethical companies that only follow the money can dramatically change the game for everyone. A little investigative probing with experienced industry professionals can help warn you ahead of time.

The term "public disclosure" defined by the U.S. Patent and Trademark Office must be well understood so as not to jeopardize future patent applications.

RHENIUM-TUNGSTEN ALLOY CASTS WELL USING LAM

On the lam. *Pictured above is Aeromet Corporation's computer-controlled Laser Additive Manufacturing (LAM) system, which uses an 18 kW CO_2 laser in a high-purity argon-filled chamber.*

While-u-wait. *A laser-formed rhenium thruster shape was fabricated in 45 minutes.*

Rhenium was one of the last elements discovered, but for future aerospace engineers, it may be one of the first elements they consider.

Using a laser-assisted manufacturing (LAM) process to produce near-net shape parts, Rhenium Alloys, Inc. (Elyria, OH), with assistance from MDA SBIR funding, has developed a method for alloying rhenium and tungsten to provide material with superior overall thermal resistance and mechanical properties. Near-net shape casting avoids the problems associated with bonding and welding separate components and promises rocket and jet engine components with lighter weight and reduced cost.

In 2000, BMDO (MDA's predecessor) awarded a Phase I SBIR contract to Rhenium Alloys to produce spherical rhenium powder with desirable properties such as low oxygen content and high density. They did so, and in 2001 BMDO awarded a Phase II contract to Rhenium Alloys, working with partner Aeromet Corporation, to see which manufacturing techniques produced samples with optimal thermal and mechanical properties. LAM techniques using rhenium powders (with large particle sizes) mixed with tungsten powders appeared to be a good candidate for further testing.

The LAM process emerged as the one that could best use rhenium powders with large diameter (of 75 to 300 microns). It offers the promise of a more affordable way to produce high-heat components such as hot gas valves.

Rhenium is an important element because it has properties similar to tungsten, such as high melting point, but also recrystallizes well even when partially melted and then cooled. A part made with rhenium would fare better than tungsten over long periods of time, requiring less maintenance and replacement.

However, rhenium is relatively expensive compared to tungsten—less than $2 per gram as opposed to 3 to 4 cents per gram—so any process that reduces waste in rhenium powder while still enabling the production of usable rhenium-based parts is desirable. LAM is a very precise way of producing complex shapes in parts, with an order of magnitude reduction in waste.

Aerospace manufacturers of rocket and jet engines such as Honeywell and Pratt & Whitney are already interested in testing parts produced by Aeromet Corporation made with rhenium-tungsten alloy. If the parts provide better performance over a longer life cycle, rhenium may end up becoming a by-word among aerospace engineers in much the same way as aluminium replaced steel and wood in aircraft design.

Rhenium-tungsten alloy also can be used in arcane areas such as crucible design or heat pipe applications. However, the sheer size of the rocket and jet engine market dwarfs any other potential application. Rhenium Alloys hopes to become the dominant supplier of rhenium powders to an expanding rhenium-tungsten alloy market. The company is already seeking to double the size of its facility, and intends to double its revenues in five years.

Rhenium Alloys officials invite interested parties to contact them directly to learn more about the properties of rhenium-tungsten alloy using the LAM process. They want aerospace engineers to know that rhenium can be affordably used to create superior, long-lasting components.

—A. Gruen

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> *"An invincible determination can accomplish almost anything and in this lies the great distinction between great men and little men."*
>
> —Thomas Fuller

NEW MATERIAL PROMISES BENEFITS FOR MEMORY, PROCESSORS

A new approach to making materials could lead to improved computer memory as well as computer processors that operate at 10 GHz or higher—far faster than the technology in today's desktops.

This new capability would introduce the proverbial chicken to the egg, inviting emerging applications after its release by enabling a computer to do many sophisticated tasks at once. For example, such a technology could allow a computer to process user commands instantly via voice recognition, handle large multimedia data downloads, and manage data for other devices such as security systems, televisions, and stereos—all at the same time.

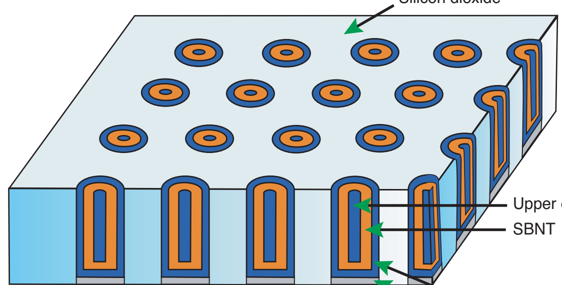
The materials technology, being developed by Advanced Technology Materials, Inc. (ATMI; Danbury, CT), promises more manufacturable and functional components for products ranging from low-voltage smart cards to full-blown computer systems. The company envisions use of the technology for two separate applications—one for memory chips and one for high-speed on-chip capacitors like those used in computer processors.

Devices made with ATMI's material will be nonvolatile and rad-hard, and operate at a low voltage. Those features make the technology appropriate for a wide range of applications, from flash memories in consumer products to radio-frequency identification tags and tiny one-chip computers called "microcontrollers." MDA's SBIR program funded the company's material technology for its potential in rad-hard memory devices needed for the missile defense system.

To make this material, ATMI used a new technique to incorporate niobium into strontium-bismuth-tantalate (SrBiTaO) to produce strontium-bismuth-niobium-tantalate (SrBiTaNbO or SBNT), which can be deposited on iridium electrodes for use in ferroelectric random access memory (FeRAM) devices. In FeRAM, devices are "trained" with an electric field to store binary information in memory—similar to the way a piece of iron can be switched with a magnetic field to develop north and south poles.

Production of the material involves chemical vapor deposition (CVD) instead of typical "spin-on" techniques, in which a liquid material is deposited onto a wafer by spinning it on and then transforming it into the film by a series of heat treatments. Instead, CVD, as its name implies, involves depositing materials chemically using a vapor deposition process. The CVD approach makes the material more compatible with the CVD processes already used in the chip industry, according to ATMI.

By incorporating niobium, the material does not fatigue as easily when information is written and read over and over again on a memory device. The material also is not as susceptible to a condition known as "imprint," in which the device can have difficulty replacing a new bit of information with another much older bit of information that has become imprinted in memory. Meanwhile, the inclusion of iridium electrodes, as opposed to platinum, helps keep the bismuth from diffusing out of the SBNT material.



The hole truth. *ATMI's technique produces strontium-bismuth-niobium-tantalate (SBNT) material in holes or cups etched into a layer in a silicon chip. Ultimately, this allows for more memory in the same space.*

The shape of devices that can be made with ATMI's material also brings benefits. Instead of a sandwich shape, devices produced with the company's technique can have a waffle-like shape, which allows for more memory in the same space. Devices that use this material, therefore, could become smaller.

Materials produced with SBNT also have a high dielectric constant, which leads to applications beyond FeRAM. The material has a dielectric constant near 50, compared with 25 for amorphous tantalum oxide, a competing material. To reach dielectric constants of 50, tantalum oxide must be crystallized via high-temperature processing. The high dielectric constant of SBNT—and the fact that material can be deposited at low temperatures—means the material might be used for a variety of capacitors in integrated devices. Specifically, the material would be appropriate for on-chip, integrated capacitors that could enable computer

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POLYMERS PROMISE NEW LIGHTING POSSIBILITIES

Making lighted flatscreen displays cheaper and more durable is an ongoing challenge. But a new family of plastics may offer a viable solution.

RGB on display. *Maxdem's polymers, originally developed for structural applications, emit colored light that would be suitable for displays and white lighting. The picture above shows the photoluminescent properties of three of Maxdem's polymers (red, green, and blue).*

The materials, which are being developed by Maxdem, Inc. (San Dimas, CA), could lead to a future in which large-screen televisions and displays are more affordable. The technology also opens up creative possibilities, such as pizza-box tops that light up like electronic billboards to draw your attention to a special offer or lighted signs and room lighting panels that could be applied like wallpaper.

Maxdem is basing the display materials on an existing proprietary line of super-hard, super-strong polymers called Parmax®. Parmax is a registered trademark of Mississippi Polymer Technologies, Inc., a subsidiary. Maxdem is tailoring the polymers, originally developed as structural materials, for use in polymer organic light-emitting diodes (P-OLEDs).

Already, OLEDs are being pioneered as a core technology for very thin, flat electronic displays. And like OLEDs, P-OLEDs offer thinness. In fact, the thickness of material layers for P-OLEDs is on the nanometer scale, meaning that material cost per display could be held relatively low.

But P-OLEDs also offer the strength advantages of polymers. Moreover, for larger-size displays, P-OLEDs offer a cost advantage over OLEDs. When display screen size approaches 15 inches, regular OLEDs prove too costly—since OLED manufacturing involves high-temperature vacuum processing, which can be expensive when making larger OLED displays. "When you get to larger displays for computers and for televisions, with 15-inch diagonal and higher, one really has to think of going to a polymer approach to make the processing and manufacturing reasonable," said Dr. Matt Marrocco, vice president and chief technology officer.

Maxdem is not alone in its work on materials for P-OLEDs, as other companies are working in the field. Maxdem, however, is pursuing a hybrid approach to make P-OLEDs, combining inorganic and polymeric materials. The approach allows polymers in a P-OLED to act like antennas, picking up energy from electrodes and funneling it down to a metal center to get efficient use of metal complexes, the actual emitters of the light. Company officials expect that P-OLEDs with Maxdem materials will result in more efficient and brighter devices than those made with a purely polymer approach. Maxdem also boasts good control over P-OLED color with its material, since color is tied to the inorganic component and therefore can be adjusted independent of polymeric processing.

Maxdem officials do not envision themselves as makers of P-OLEDs. Instead, the company will continue development activities and seek nonexclusive lincensees. It already has granted a nonexclusive license to a multinational chemical company interested in using its materials.

MDA's SBIR program partly funded the company's technology for its potential in electronic displays for the missile defense system. The company also is working on a project funded by the Department of Energy to produce materials for white-light P-OLEDs.

—S. Tillett

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nGIMAT SHOWS CVD PROCESS CAN IMPROVE CELL PHONES, RADAR

Playing with fire—but not working in a vacuum—can help improve talk time for cell phones and also help guarantee they will operate across more frequencies.

The approach, called combustion chemical vapor deposition (CCVD), is being pioneered by MDA-funded nGimat Company (Chamblee, GA), which is using the technique to produce materials that can be used for tunable filters in cell phones. The materials also can work well in tunable capacitors and phase shifters for higher-end equipment such as radar systems. Company officials compare a tunable filter to the tuner on a TV: It's much more convenient than having individual tuning knobs for each and every channel the TV can receive.

nGimat's process deposits barium-strontium-titanate (BST) on economical sapphire substrates to produce devices for use in communications equipment. nGimat (formerly MicroCoating Technologies, Inc.) continues to refine its technique but already has provided cell-phone makers with sample filters. A single tunable filter, produced with nGimat's process and materials, would replace the multiple filters used in many cell phones today. Company officials say that such a tunable filter would allow handset makers to simplify cell phone design and, therefore, drive down costs.

Producing a cell phone with a single tunable filter also solves functionality and power problems. Cell phones today have several filters, allowing them to operate over the range of frequencies for various communications standards. In theory, the phones could have even more of such filters, allowing them to operate over a wider range of frequencies and thereby functioning across many more communications protocols. More filters in a communications handset would allow users such as emergency-response personnel to switch handsets to different frequencies, depending on network traffic or special needs. But producing a communications handset or phone with multiple filters to reach all necessary frequencies would require a lot of cost and space while consuming significant power—close to 30 volts. A typical cell phone has about two hours of talk time. nGimat, however, has produced a tunable filter that can do the job of many filters while using less than 3 volts of power and increase the talk time by 50 percent, representing a potential breakthrough for makers of cell phones.

The company's process begins with inexpensive metal salts dissolved in an organic solvent. The resulting solution flows through a pump to a Nanomiser® apparatus that turns the solution to a nano-aerosol. The aerosol then combines with a flame similar to the one created by a blowtorch in the open atmosphere. The flame contains barium, strontium, and titanium, which are impinged upon the surface of a sapphire substrate to deposit a BST film. nGimat can deposit the film onto the substrate to create capacitors, transmission lines, or other circuit elements. The final product is a tiny piece of clear sapphire with a very complex metallization pattern on the BST film.

nGimat produces BST that has a dielectric constant between 1100 and 1200, compared with competing techniques that produce materials with a dielectric constant between 300 and 350. The difference is important because a higher dielectric constant means the company can produce smaller capacitors, which are required for the smaller structures that would be needed in tunable filters.

MDA's SBIR program funded nGimat's technology for its potential in improving radar systems. nGimat officials say the MDA project served as the foundation for a new nGimat business unit that focuses specifically on wireless applications. The devices hold promise for military communications systems as well as radar.

nGimat leaders envision the business ultimately becoming a components supplier, and they continue to look for strategic partners such as systems integrators for military systems. The company has patents on its process, materials, and applications.

—S. Tillett

Courtesy of FreeImages.uk.com

Hear me now? *nGimat's process could enable tunable filters in today's cell phones, allowing operation over a wider range of frequencies and communication protocols.*

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RAD-HARD CCDs NOW AVAILABLE FOR SPACE APPLICATIONS

Star search. *FCR's rad-hard CCDs are being developed for star trackers used in satellite navigation. Conventional CCDs are susceptible to radiation, which creates hot pixels that inhibit a tracker's ability to identify a star.*

FCR concentrates on research and development of government-funded technology, specifically rad-hard devices. Upon completing the projects, the company teams with manufacturers to turn the research into products for commercial purposes.

Do you know how many rad-hard charge-coupled devices (CCDs) are in space? Zero. Before now, they weren't an option.

Full Circle Research, Inc. (FCR; San Marcos, CA), is developing rad-hard CCDs for use in star trackers and imagers with high frame rates on satellites in space. FCR's technology can withstand the effects of space radiation 10-times better than conventional CCDs. As a result, it can significantly reduce disturbances and smearing in image output. It may also diminish the number of bright spots dotting the image (known as hot pixels), caused by radiation damage. (The latter point has yet to be proved, but FCR scientists believe that it will be.)

When conventional CCDs are exposed to protons in space, the silicon crystal is damaged, forming defect centers, which trap signal carriers and delay their transfer to the output amplifier. This degrades an important parameter of the CCD, called the charge transfer efficiency (CTE), which is the fraction of the signal charge transferred from one pixel to the next during the output transfer process. This delay causes smearing of the image, making it impossible to identify the pixel in which the signal originated, and resulting in distorted images. Current methods for reducing CTE degradation include reducing the number of transfers that are required to get the signal to the output by using multiple output ports and then reconstructing the data externally, greatly complicating the signal processing required. This technique for reducing radiation damage is not necessary when using FCR's P-channel CCDs.

P-channel CCDs achieve their improved radiation hardness because they use positive charge carriers (called holes) as the signal carrier, the same type of carrier used in PMOS transistors. Traditional N-channel CCDs use electrons as the signal carrier, the type of carrier used in NMOS transistors. Using radiation-inclusive technology computer aided design (RH-TCAD) techniques, FCR found that when P-doped silicon is damaged by proton irradiation, only one hole trap is formed. This trap only degrades CTE when the CCD temperature is around 125 K. Thus, P-channel CCDs will not suffer CTE degradation at or near room temperature because the hole trap is inoperative there. This is unlike the situation with N-channel CCDs, where the electron traps formed by radiation affect CTE near room temperature.

FCR scientists also believe that P-channel CCDs will reduce the occurrence of points in the image where bright spots, known as hot pixels, appear. These hot pixels can inhibit the ability to identify a star, and their fluctuating brightness makes them difficult to remove using software algorithms. This is a major problem for star trackers, which are the main application of FCR's P-channel CCDs.

The MDA SBIR program funded FCR to develop rad-hard CCDs for star trackers. Star trackers are used to determine a satellite's position with a high degree of accuracy. A satellite's star tracker holds a library of reference stars. Electronic circuitry in the star tracker will exclude all stars that do not fit specific criteria, for example, stars with magnitude less than a specified value. The star tracker can then compare the positions of the stars being seen in the CCD image to the pattern stored in non-volatile memory. Upon verifying that the patterns match, star trackers can determine the position of the satellite similar to how early sailors pinpointed their locations using a sextant. The other application for FCR's technology is imagers with high frame rates. FCR designed a rad-hard 1024 x 1024 P-channel CCD chip that can produce 100 frames per second. FCR's CCD was integrated into a rad-hard, high-performance visible sensor test bed for star tracker and space imaging systems.

FCR has contracted with Dalsa Semiconductor, a Canadian CCD manufacturer, to produce the rad-hard P-CCDs. Dalsa is currently fabricating a wafer lot of the devices. The CCDs being manufactured are primarily intended for test and evaluation purposes. The company is searching for more industry partners to collaborate in further product development.

—*T. Robinson*

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ALGORITHMS ADVANCE IMAGE AND SIGNAL PROCESSING AND LOSSLESS DATA COMPRESSION

New algorithms capable of using multiple filters simultaneously—unlike conventional algorithms that employ one at a time—have applications in image and signal processing, data compression, and signal restoration.

The developer, BSEI (Vienna, VA), has shown its signal processing/filtering algorithms can enhance specific characteristics (e.g., contrast, texture and granularity) of medical images and luggage scans. Further, the all-purpose algorithms can compress data for transmission over narrow bandwidths and restore old and damaged signals (images or electrical and sound signals), capabilities that are needed for space communications. The technology was originally funded by MDA's SBIR program for automatic target recognition.

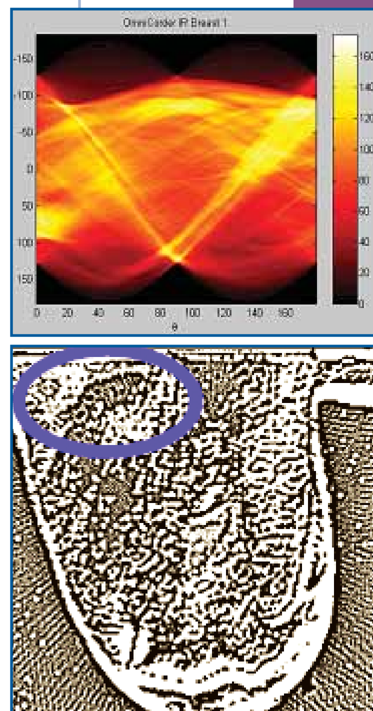
BSEI's algorithms include a new type of mathematical transform used to analyze a signal's specific and unique characteristics. Conventional transforms use one type of wavelet (filter) at a time, which requires experimentation with different kinds of wavelets to bring forward only the relevant information in a signal. However, BSEI's universal transform employs a hierarchical series of wavelets that simultaneously analyze a signal to bring all of the relevant information to the foreground at once, thus reducing computation time. Furthermore, the transform does not require the time-consuming steps of signal decimation that is required by present wavelets. To explore the algorithms' medical imaging applications, BSEI worked with medical doctors to make it easier to identify brain tumors. Among other methods, doctors identify these tumors by spotting grainy areas in medical images. But these areas are difficult to see. Using its algorithms, BSEI revealed tumors in images of the brain that had been previously hidden. To pursue this application further, BSEI is performing pro bono work with Baylor College of Medicine in Texas and other institutions, with whom it is also working to launch a company that would market the algorithms to radiologists.

BSEI is also applying the algorithms to another image processing application: luggage scanning. Security algorithms spot "suspicious" objects by recognizing telltale signs. If they cannot recognize an object at all angles, particularly in a cluttered background such as a suitcase full of clothes, detection accuracy is significantly reduced. BSEI's algorithms can detect a suspicious object at all angles no matter how it is oriented. If detected, security personnel are alerted to physically inspect the luggage. Working with Raytheon in a similar detection application, BSEI is using its algorithms on infrared images to find tanks in the desert when the heat makes them blend into the background.

A third application is lossless data compression, which may be a major benefit to space exploration. NASA is branching out deeper into space to gather data from distant planets like Mars and Saturn. BSEI's algorithms could help NASA collect data in shorter time periods by using significantly less computation to compress an image. It also can transmit data over long distances without losses. And a fourth application is signal and image restoration

BSEI is interested in licensing its technology to applications developers and research laboratories. The algorithms are packaged and available in Mathematica and Matlab.

—T. Robinson



Hide-n-seek. *BSEI's transform employs a hierarchical series of wavelets that simultaneously analyze a signal (top) to bring all relevant information to the foreground at once. Not only does this capability reduce computation time, it also makes it easier for doctors to detect cancerous tissue (bottom).*

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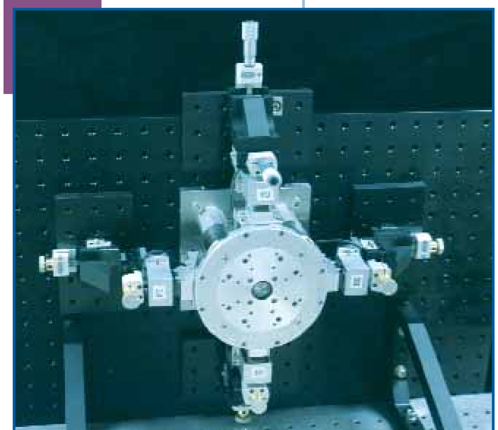
> ***"Many of life's failures are people who did not realize how close they were to success when they gave up."***
>
> **—Thomas A. Edison**

DEVICE ENABLES LONG-DISTANCE LASER COMMUNICATIONS



Point taken. *ATA's inertial reference unit is capable of pointing a laser with nanoradian accuracy. At this level of accuracy, a laser beam from geosynchronous orbit could be held steady on a silver-dollar-size object on Earth.*

Have you ever tried to focus a laser-pointer beam on a specific bullet-point while giving a presentation? Even the slightest motion of your hand makes it virtually impossible. Now, imagine steadily aiming a laser beam from a jittery satellite to a distant place on Earth. Good luck.

Addressing the need for jitter correction, Applied Technology Associates (ATA; Albuquerque, NM) has developed an advanced optical inertial reference unit (IRU)—a navigational tool for space-based laser systems—capable of pointing a laser with nanoradian accuracy. ATA's IRU detects and corrects for satellite jitter, allowing a laser beam from geosynchronous orbit to be held steady on a silver-dollar-size object on Earth. The technology can be used in laser communication systems to transmit data over extremely long distances.

ATA is incorporating its IRU into an orbiter intended to provide a continuous data link from Mars to Earth. The company is working with NASA's Jet Propulsion Laboratory, NASA's Goddard Space Flight Center, and the Massachusetts Institute of Technology's Lincoln Laboratory (MIT/LL) on the project. ATA is assisting with the orbiter's laser communication flight terminal, which is designed to provide a continuous data link between 1 and 30 Megabits/ second for a distance up to 400 million kilometers. A highly accurate IRU was required because the allowable jitter in the transmitted laser beam is only 3.5 microradians. ATA's IRU is projected to provide platform stability to less than 100 nanoradians, or 35-times more accurate than required for the system.

The main user of laser communications is currently NASA. But, if laser communications begins to gain momentum in the commercial market, the steady beam ATA's IRU provides could save money by reducing power and weight requirements on communications satellites. It would also provide the military with secure communications in a theater of operations. Tapping a laser communications signal is hard; if the signal were intercepted, the intrusion would be easily detected.

MDA is interested in a highly precise IRU for aircraft- and satellite-based high power laser systems such as the Airborne Laser, which is designed to engage and destroy missiles at long range. Its SBIR program funded ATA to develop a next-generation IRU (NGIRU), which is being used as testing hardware. Through an MDA-funded Advanced Systems Broad Agency Announcement, ATA is using the NGIRU test data to create a flexible and inexpensive design for the advanced IRU.

Unlike conventional IRUs, ATA's approach keeps the gyroscope separate from the IRU platform. Keeping it separate allows a user to choose a gyroscope based on application and cost instead of IRU design. ATA's design also simplifies integration; the gyroscope remains in its housing and is mounted next to the IRU. The information provided by the gyroscope is relayed to the IRU through a linear displacement sensor.

ATA designs, develops, and manufactures all of the components in its optical IRU except for the gyroscope, which is bought commercial-off-the-shelf and integrated. The company's goal is to have a product line of optical IRUs. It needs additional customers to further advance its technology and complete its commercialization efforts.

—T. Robinson

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LUNA'S SENSORS TAKE THE HEAT

Structural health monitors, like strain gauges and temperature sensors, are built to withstand high temperatures, typically up to 750°C. As engineers look to place these devices in even hotter environments, the hunt is on for more durable options.

Luna Innovations, Inc. (Blacksburg, VA), has developed fiber-optic-based strain and temperature sensors that significantly extend the temperature limits of structural health monitoring. The new sensors can operate between -269°C and 1400°C, a range that few, if any, sensors can match. Other important features include millisecond response time and compact size about the width of a human hair (about 160 microns). The sensors were developed with MDA SBIR funding to assess damage to stainless steel targets from high-energy laser weapons such as the Airborne Laser.

The first application of Luna's temperature sensors is in hypersonic aircraft research. The Air Force Arnold Engineering and Development Center is using the company's sensors to measure the very high rate of change in temperature on the surface of a hypersonic vehicle. The temperature of the air when it stops at the leading edge surface of hypersonic vehicles can range up to 3000°C. High-response-rate sensors are essential for making these measurements. Luna's temperature sensor has demonstrated the ability to track temprature changes at a rate of up to 2.4 million °C per second.

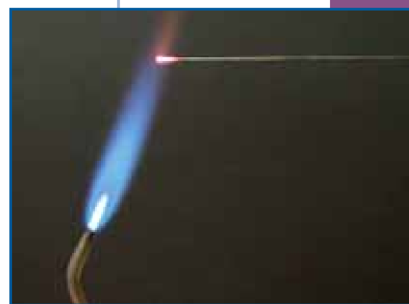
Aircraft manufacturers that use carbon-carbon composite materials are using Luna's sensors to make strain measurements in environments that are more than 1100°C. An engine manufacturer may also use Luna's strain sensors to measure the deformation in and around gas turbine aircraft engines. Conventional strain sensors are based on piezo silicon carbide, which degrades at around 700°C to 750°C. A turbine engine structure approaches around 1000°C. Luna's strain sensors have a high-temperature measurement capability demonstrated at more than 1100°C.

The sensors and their associated cabling are fabricated using fiber optics. To measure both strain and temperature, a broadband light source is transmitted to the cleaved end of a single-mode fiber. To perform the strain measurements, upon reaching the end of the fiber, the light is partially reflected while the remaining light travels past the end of the fiber and is reflected off a secondary reflector. The reflectors (also fibers) are aligned with the main fiber in a capillary tube and attached to a substrate. The two reflected light signals interfere with each other forming a fringe pattern. As the substrate strains, the distance between the two fiber end-faces vary, causing the fringe pattern to change. Using a spectrometer, the changing gap is measured to obtain the strain. The sensor is less prone to failure because the fiber itself is not being strained by the substrate.

The temperature sensor has a small, single-crystal chip on the end of the fiber. The two faces of the chip are reflectors. Precise temperature can be obtained by measuring the temperature-dependent optical path length through the chip.

The company welcomes any inquiries regarding either sensor.

—T. Robinson



Flame on. *Luna performed many tests to learn how fast its temperature sensors could be heated and still track the temperature. The sensors accurately tracked the temperatures of propane torches, wind tunnels, and machining laser beams.*

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"Sell Stuff People Want To Buy! There you are. Six words that will solve 85% of the 'so called' marketing problems in the world."

—Gary Halbert

SENSOR INDICATES "GO" FOR LAUNCH

Sensing trouble. *Morgan Research is working with ATK Thiokol to test its damage sensor in composite rocket motor cases. The sensor can locate hidden structural damage that could ultimately jeopardize rocket launches.*

Current structural health monitoring techniques may detect the possibility of damage in a rocket motor, but pinpointing the "where," "when," and "how bad" can be an elaborate process.

A damage sensor being developed by Morgan Research Corporation (Huntsville, AL) for composite structures may provide the information needed to make critical launch decisions. The sensor is an event monitor that allows the user to quickly interrogate a structure, locate potential problem areas, and then employ a more sophisticated system to characterize the damage. For example, Morgan Research's sensor can first pinpoint where possible damage has taken place, thereby allowing an eddy current system to analyze a small 2- or 4-inch section instead of the entire rocket motor.

Morgan Research is developing the damage sensor using commercial-off-the-shelf optical fibers that maintain polarization. Unlike Bragg gratings, which require a predetermination of where the damage could take place, the entire length of Morgan Research's optical fiber is a sensor for global monitoring of a structure. Damage is determined by monitoring stress-induced changes in the local index of refraction. Furthermore, the company worked with Diamond SA, a Switzerland-based manufacturer of fiber-optic connectors, to develop a ruggedized fiber-optic ingress and egress system that allows the optical fiber to be reliably and safely connected to the instrumentation for interrogation.

MDA's SBIR program funded Morgan Research to develop a structural health monitoring system using inexpensive embedded optical fibers and instrument miniaturization technologies for use in composite structures. The optical fiber that Morgan Research uses costs about $10 to $12 per meter and provides distributed sensing along its entire length whereas Bragg gratings, which typically cost $200 to $300 each, are point detectors that have to be dispersed throughout the structure. The use of this single optical fiber with no discontinuities will also minimize the amount of disturbance to the structure into which it is being integrated.

Morgan Research is currently working with ATK Thiokol to test the damage sensor in composite rocket motor cases. Characterization tests are being performed on a prototype unit. Morgan Research expects to have a product in 8 to 12 months for ATK Thiokol to purchase for prototype test builds of new composite structures.

Morgan Research needs funding to get the sensor into other test articles that will be exercised to obtain real-world data on its sensor use and applicability. Edwards Air Force Base, which provided $250,000 in matching funds for the MDA project, is interested in using the sensor in some of its structures and is working towards involving it in some simulated field tests of potential structures. These tests will demonstrate sensor performance under conditions that simulate real-world flight temperatures, pressures, and vibrations.

Since Edwards does not work with all types of structures that the sensor may be applicable to, Morgan Research is working with ATK Thiokol to find other opportunities. One possibility being explored is integrating the sensor into a propellant-loaded rocket motor demonstration, which is a test article in an ATK Thiokol program.

Morgan Research is also interested in using its sensor in spacecraft for NASA. The sensor can monitor damage to vehicles such as the space shuttle. It also has the potential to monitor stress or strain levels and cycles throughout the spacecraft's lifetime. Since the technology does not require power distribution through the composite structure, external skin, or with the structural system, it may also be applied to satellites or weather balloons.

—*T. Robinson*

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Cryocooling . . . from page 1

that detecting and tracking targets with infrared sensor technology posed a most significant technical challenge. For the whole idea of strategic defense to work, sensors needed to operate reliably in ways that had not yet proven to be reliable, and under environmental conditions in which they had not yet been tested. SDIO recognized cryogenic cooling as one of seven major technology challenges that stretched across almost every aspect of the program.

Long-wavelength infrared (LWIR) technology was the toughest nut to crack. In the original Strategic Defense System Phase I Architecture plan approved in September 1987, the Space-based Surveillance and Tracking System (SSTS) was envisioned as a network of satellites occupying medium Earth orbit for the purpose of detecting and tracking targets in their post-boost and midcourse phases. Proposed SSTS tracking sensors using an LWIR arsenic-doped-silicon focal plane array design would have demanded removal of approximately one watt in an ambient heat environment of approximately 10 K.

The U.S. Air Force Space Technology Center was the principal lead for SDIO cryocooling research. Two programs were run in parallel, one with Arthur D. Little, Inc. (Boston, MA), and the other with Garrett Air Research (Los Angeles, CA). The two design concepts were both "active mechanical coolers" that operated with motors and worked like freezers. The old cooler concept of venting gas was dead—from that time forward, cryocooling would work with refrigerant in a closed loop.

After several years of funding, both programs reached the protoflight assembly stage but were terminated when the SSTS was cancelled in 1989. Large satellites in medium earth orbit were considered too vulnerable to anti-satellite weaponry.

There was a new emphasis on smaller, lighter satellites and cryocooling technology. SDIO and the U.S. Air Force Research Laboratory (AFRL) initiated a new research program called the Standard Spacecraft Cryocooler program in 1990, aimed at meeting cooling needs in the 60 to 150 K range for medium-wavelength infrared (MWIR) sensors. However, at AFRL and NASA, research did continue on techniques for cooling in the 10 K environment.

The 1990s

During the 1990s, SDIO/BMDO (Ballistic Missile Defense Organization) managers and contractor engineers designed, developed, and deployed a new generation of cryocooling technologies that resulted in successful operation of many long-lived spacecraft that even now remain in orbit doing useful work.

The driving force behind SDIO/BMDO cooling requirements was the proposed Space-based Infrared System (SBIRS) Low satellite program, intended to support both national as well as theatre missile defense by tracking midcourse targets with both MWIR and LWIR sensors. The requirements for the tracking sensors included removing 0.5 watts at 35 K and 0.7 watts at 60 K, increased cooling loads for optics (as high as removing 12 watts at 100 K), 10-year design life, high radiation tolerance, and low system mass penalty.

Mutual benefits. *Joint MDA, Air Force, and NASA funding led to the development of a single-stage Stirling and two-stage (35/65 K) unit for MDA's SBIRS Low program.*

Reducing system mass penalty was an important objective. It was not enough to simply design and develop an active mechanical cryocooler to chill IR sensors sufficiently to permit their effective operation. The cryocooler technology had to make sense within the limits imposed by the design of the whole spacecraft. It wasn't just the mass of the cryocooler itself that was to be considered, but also the mass of the electrical power system necessary to drive it, of the control electronics, and of the radiator area needed to reject waste heat.

An early 1992 foray into this research area was a project co-funded by SDIO, the Phillips Laboratory (predecessor to AFRL), and NASA's Goddard Space Flight Center called the 65 K Single Stage Reverse Brayton (SSRB) cryocooler, a test machine built by Creare, Inc. (Hanover, NH). This cryocooler

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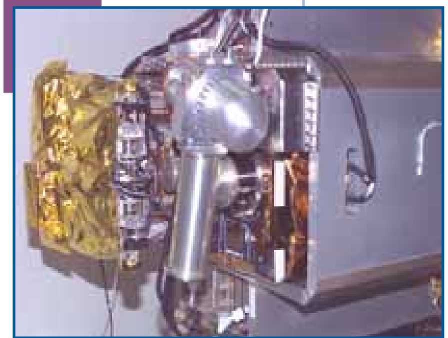
was designed to maintain a single temperature of 65 K, using a combination of centrifugal compressor, recuperative heat exchanger, expansion turbine, and thermal interfaces to the load and heat rejection devices.

There was also missile defense interest in "dual-load cooling," that is, designing a single cryocooler for two different temperature environments (both 35 K and 60 K). It promised some important technical advantages. A dual-temperature cryocooler could cool focal planes for both MWIR and LWIR tracking sensors, allowing them to look simultaneously at a target. Furthermore, a standard design could be used to outfit a satellite with redundant cryocoolers, so if one failed, the other one could still cool both kinds of sensors.



Thermal imager. *Sandia National Laboratory developed a multispectral thermal imager containing an NGST mid-size, pulse-tube cryocooler. The project was jointly funded by MDA, Air Force, and NASA.*

BMDO took the next step and the AFRL contracted with Creare to create a Miniature Reverse Brayton Cryocooler (MRBC) based on the success of the SSRB. The MRBC project had the objective of dual-load cooling of one watt at 35 K as well as 60 K, with total input power not greater than 125 watts, to operate over a lifetime of more than 10 years. Some of the work performed for this contract had an immediate payoff.

The Hubble – NICMOS Dividend

"Nine U.S. cryocoolers flying in space today were all, directly or indirectly, developed by the Missile Defense Agency," says Thomas M. Davis of the Space Cryogenic Cooling Technologies Group at the AFRL in Kirtland, New Mexico.

Probably the most well-known of these spacecraft is the Hubble Space Telescope (HST), launched on April 25th, 1990, and designed to last for 15 years. In 1997, one of the pieces of equipment onboard the HST, the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS), began to fail when its coolant element (solid nitrogen) depleted faster than anticipated.

NASA funded accelerated development of a replacement cooling system for NICMOS. The agency leveraged some of the work performed for the SSRB and MRBC projects, and chose a Creare-designed, reverse-Brayton cycle turbo cryocooler. It was space-tested in October 1998, and installed successfully during an HST servicing mission in 2002. Within six weeks, the Creare cryocooler had cooled the NICMOS detectors down to their optimum operating environment of approximately 75 K. NICMOS still operates today.

The key technologies in that case were miniature turbines (of 2 to 10 mm in diameter)

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In July 2004, with the launch of the Aura Spacecraft, the number of U.S. cryocoolers in orbit is now 12.

Cryocoolers With MDA Heritage Flying in Space (as of June 2004)

MANUFACTURER	COOLER TYPE	AGENCY (MISSION)	INSTRUMENT	# OF UNITS	LAUNCHED
Northrop Grumman Space Technology (TRW)	Mini Pulse Tube	Sandia National Laboratory	CX	2	JAN 1998
NGST (TRW)	Mini Stirling	Naval Research Laboratory	HTSSE (ARGOS)	1	FEB 1999
NGST (TRW)	Mid-size Pulse Tube (6020)	Sandia National Laboratory	Multi-Spectral Thermal Imager	1	MAR 2000
NGST (TRW)	Mini Pulse Tube	NASA/Goddard Space Flight Center	Hyperion (NMP E01)	1	NOV 2000
NGST (TRW)	Mini Pulse Tube	NASA/Langley Research Center	SABER (TIMED)	1	DEC 2001
Creare	Reverse Brayton	NASA/Goddard Space Flight Center	NICMOS (Hubble Telescope)	1	FEB 2002
NGST (TRW)	Mid-size Pulse Tube (6020)	NASA/Jet Propulsion Laboratory	Atmospheric Infrared Sounder (AQUA)	2	MAY 2002

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that floated on a thin-film gas bearing, rotated at speeds of between 1000 and 10000 revolutions per second, and expanded and compressed coolant gas. By precisely balancing the low-mass rotors, Creare engineers figured out how to almost completely eliminate vibration. Since the rotors floated on the gas and came into physical contact with no other moving parts, there was no wear on them and they generated no debris.

Will History Repeat Itself?

The challenge is to repeat history: to continue the momentum of the 1990s into the 2000s and prepare for the next generation of spacecraft and sensors. Thus, even as MDA incorporates the results of the last decade into today's plans, it continues to refine its requirements and mission objectives and fund new cryocooler developments.

The Creare success with reverse-Brayton cycle designs was only one of many projects which BMDO funded during the 1990s. There were many other companies involved in creating cryocooler technology including Ball Aerospace, ETA Incorporated, Honeywell, Hughes, Mainstream Engineering Corporation, Mitchell/Stirling Machine Systems, Northrop Grumman, Raytheon, Ricor, Swales Incorporated, and TRW. Other technologies included Stirling Cycle, Joule-Thomson Cycle, and pulse-tube designs.

The Northrop Grumman Space Technology (NGST) single-stage High Efficiency Cryocooler (HEC) program may very well have been the most successful to date, a joint effort funded by MDA, NASA, and the U.S. Air Force. Initiated in 1998, the program had an objective of removing 10 watts at 95 K. Sixteen units have been ordered for various flight programs although none of them have yet been launched into space. The cryocooler and accompanying rad-hard electronics controller weigh less than 7 kilograms compared to previous state-of-the-art at 22 kilograms.

The current development programs for a multitemperature, high-capacity cryocooler look promising. A 35/85 K NGST High-Efficiency Pulse Tube Cryocooler is intended to simultaneously cool both focal planes and optics, removing 2 watts at 35 K and 16 watts at 85 K with a single cooler. A parallel program with Raytheon has similar objectives but uses a hybrid Stirling upper stage and pulse-tube lower stage for lower mass and improved efficiency. The Raytheon program leverages work done under the MDA Small Business Innovative Research program by South Bay Science and Technology Corporation (Huntington Beach, CA) and Modern Industries (Phoenix, AZ) and will deliver a spaceflight-qualifiable cryocooler in early 2006.

Under the sponsorship of MDA, the USAF is working with NGST to develop a 10 K cryocooler that will enable advanced space-based LWIR sensors. This project should be completed in 2005. The USAF is also separately funding a parallel project with Lockheed Martin. If successful, these technologies will be available just in time to support the improved LWIR sensor arrays now being developed. Space historians will one day look back on this period as the cryocooler revolution.

What's hot. *Multi-temperature, high-capacity cryocoolers like the NGST High-Efficiency Cryocooler are slated for development in the next few years.*

SMALL BUSINESSES ARE ALSO INVOLVED

Since 2000, BMDO/MDA has awarded SBIR contracts to investigate promising cryocooling technologies including:

- a high-efficiency, electronically controlled valve actuator design capable of removing 2 watts at 10 K with input power of less than 1000 watts (AMTI, Watertown, MA);
- a hybrid reverse-Brayton and regenerative pulse-tube design providing high-reliability cooling below 10 K (Atlas Scientific, San Jose, CA);
- dual-load cooling at 35 and 60 K, with the potential for multistage cooling at even less than 35 K (Beck Engineering, Gig Harbor, WA);
- a high-efficiency, reverse-Brayton turboalternator design aiming to remove up to 1 watt in the 10 K range (Creare, Hanover, NH); and
- continued miniaturization of traditional designs using MEMS technology promising increased efficiency in the 35 K range (Technology Applications, Inc., Boulder, CO).

Special thanks to Thomas Davis, Chief of AFRL's Space Vehicles, Space Cryogenic Cooling Technology Group of the Space Vehicles Directorate, Kirtland AFB, for guidance during the research and writing of this article.

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New Material . . . from page 5

processing speeds of 10 GHz or higher. (By comparison, fast processors in typical desktop computers run at close to 3 GHz.) And the low temperatures used in production make the material appropriate for integration in devices with copper and aluminum, according to ATMI. The amorphous nature of this material also suggests that it would behave in a linear fashion at high frequencies, which is important for some applications.

The material has yet to be commercialized in an actual device, although the company has supplied material to researchers and manufacturers that are still in the development phase. Meanwhile, ATMI waits for market awareness to grow. The company plans to commercialize its technology by providing precursor materials and process expertise to the semiconductor and microelectronics market.

—S. Tillett

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Wide-Bandgap Technology Report Now Available

Over the past three decades, industry and the U.S. Government—including the Missile Defense Agency (MDA)—have invested hundreds of millions of dollars in an emerging area called wide-bandgap technology. The MDA Technology Applications program has just released a 40-page electronic report called *Venturing Through the Forbidden Band*, which highlights many of the stories describing MDA-funded research in wide-bandgap technology being commercialized. Download the free .pdf version at http://www.mdatechnology.net/specialreports.asp. To receive a free CD of the report, call (703) 518-8800, ext. 239, or send e-mail to pgroves@nttc.edu. Please provide your name, company name, and telephone number, as well as your mail and e-mail addresses.