

Defining Moments

Selected Highlights from 25 Years of Missile Defense Technology Development & Transfer
A Technology Applications Report

1980

1985

1990

1995

2000

2005

*“We the People of the United States,
in Order to form a more perfect Union, ...
provide for the common defence, promote the general Welfare,
and secure the Blessings of Liberty to ourselves and our Posterity ...”*

The United States Constitution, 1787

Defining Moments

Selected Highlights from 25 Years of Missile Defense Technology Development & Transfer
A Technology Applications Report

Foreword

The United States is an ongoing political experiment in people getting together and agreeing to work toward common objectives. It is not a dictatorship, a totalitarian state, or a despotism backed by the power of the gun. The U.S. economy is not run by command. There are no five-year plans, no production quotas, no consumption orders.

We are a people who thrive on uncertainty, on changing plans, on responding to market conditions and market forces. Our objectives are not hard and unyielding like concrete, brittle and easily cracked. Nor are they soft and plasticine, swayed by any passing fancy or manipulated by the slightest pressure. Rather, we occupy a middle ground, like a young oak tree growing to the sky, its structure determined by both internal and external conditions.

The flexibility that makes the United States strong provokes unique challenges for government sponsorship of technology. U.S. leaders want to encourage, not dictate. If there is a pressing need, a requirement for the common defense, it must be met. But it must be met in a way that takes advantage of openness, the exchange of ideas, rational critique and criticism, and respects the commercial interests of its best and brightest citizens.

In this way, the U.S. taxpayer wisely supports efforts that not only provide for the common defense and secure liberty, but also promote the general welfare. Both are necessary, and both contribute to each other.

Providing a defense against ballistic missiles has required an immense research effort that has been compared to the Manhattan Project or the Apollo program. However, with the help of the Missile Defense Agency's Technology Applications program, the research for the common defense is also being applied to promote the general welfare.

Many key technologies needed for missile defense are benefiting our everyday lives. High-power laser technology, conceived in the early days of the Strategic Defense Initiative to knock down missiles, is being used in medical treatments. Electronics that use materials called wide-bandgap semiconductors were pioneered for advanced radar systems and are now essential to modern communications equipment from satellites to cell phones. These new semiconductor devices are even being used in new, brighter and more reliable traffic lights and next-generation DVD players. Advanced communications systems, such as fiber optics, diode and tunable lasers, optical amplifiers and switches, and communication protocols, were also focused research efforts because of the massive amount of data to be transferred between missile defense radars, sensors, and command locations. Today, many communications technologies such as code division multiple access (CDMA), which is used in cell phone systems worldwide, owe part of their success to missile defense research.

There are many stories of successfully commercialized missile defense technologies that now serve the common good. These stories, along with more than 500 success stories that have been told in other Technology Applications program publications, illustrate why missile defense research is not conducted in a vacuum of simply providing for the "common defence." The Technology Applications program has been striving to ensure that these technologies also advance the "general welfare."

Table of Contents

Foreword	
Table of Contents	4
Technology Applications	7
Section One: Cold War 1980-1989	8
Cold War Introduction.....	10
'Focusing' on Solar Power (ENTECH, Inc.)	14
Take This Heat and Shove It (Thermacore, Inc.)	16
Cells, Bones, and Rockets? (Ultramet, Inc.)	18
Nanofibers Before Nano Was Cool (Applied Sciences, Inc.).....	20
Safely Making Semiconductors (Advanced Technology Materials, Inc.)	22
Workable Wide-Bandgap Wafers (Cree Research, Inc.).....	24
Tools to Build the Future (EMCORE Corporation)	26
Section Two: Changing Times 1990-1999	28
Changing Times Introduction	30
Actuators into Generators (Aura Systems, Inc.)	34
Tracking Missiles and Eyes? (Autonomous Technologies Corporation)	36
Chips for Hearts, Ears, and Satellites (NVE Corporation)	38
Holding Steady (Sagebrush Technology, Inc.)	40
(Heat) Sinks in Space (Metal Matrix Cast Composites, Inc.).....	42
Clear Voices Through the Fog (Thermotrex Corporation)	44
Seeing the Wind (Coherent Technologies, Inc.)	46
Strong and Bright Polymers (Maxdem, Inc.)	48
What Goes Around Comes Around (SpacePower, Inc.).....	50
Listen Up (IC Tech, Inc.).....	52
120 Volts AC Under the Hood! (Raven Technology LLC).....	54
Seeing the Heat (Pacific Advanced Technology)	56
Solar Cells—Foil-ed (DayStar Technologies, Inc.).....	58
Going Up: Rockets and Ropes (Quoin International, Inc.)	60

Section Three: The Modern Era 1999-2005 and Beyond	62
The Modern Era Introduction.....	64
Ouch! Materials that Feel (Acellent Technologies, Inc.)	68
Bulking-up on Silicon Carbide (Bandgap Technologies, Inc.).....	70
A Check-up for Healthy Missiles (Morgan Research Corporation)	72
Flexing Polymer Muscles (Composite Technology Development, Inc.)	74
Here's Looking at You (Advanced Optical Systems, Inc.).....	76
Converting Light to Electrons (Opel, Inc.).....	78
New Film Makes Better Boards (Oxazogen, Inc.)	80
Transistors With a Short Gate (Spinnaker Semiconductor, Inc.)	82
Reach Out and Touch . . . A Wall? (InfoValley Corporation)	84
Small and Fast Encryption (Asier Technology Corporation)	86
Not Just the Usual Suspects (MATECH Global Strategic Materials)	88
Shake It Up, Baby (Resodyn Corporation).....	90
Corrosion Resistance on Demand (TDA Research, Inc.)	92
Turning Coal into Foam (Touchstone Research Laboratory, Ltd.).....	94
Quick Chips See Images (EUTECUS, Inc.).....	96
Is it Solid? Is it Liquid? (QED Technologies, Inc.)	98
Shooting Missiles or Film (Sequoia Technologies, Inc.)	100
Fabric of the Future (Cuben Fiber Corporation)	102
Conclusion	105
Acronyms	106
Photo Credits	108

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Technology Applications

The Technology Applications program has grown up with ballistic missile defense. As you will read in more detail in the next section, the Technology Applications program was created in the early days of the Strategic Defense Initiative Organization (SDIO). Then, in the 1990s, it transitioned with the Ballistic Missile Defense Organization (BMDO), and today it remains an innovative and resourceful program within the Missile Defense Agency (MDA).



Some of the program's most memorable examples of technology transfer success are highlighted in the pages that follow. These stories are arranged by first funding date and have been broken out into three historical sections: Cold War (1980-1989), Changing Times (1990-1998), and Modern Era (1999-2005). If the progression through the three organizations (SDIO, BMDO, and MDA) is a bit confusing, remember they all have had the mission of ballistic missile defense and the responsibility for developing and fielding an operational ballistic missile defense system.

And the Technology Applications program has been doing its part to provide business and outreach services to the MDA-funded companies whose technologies are helping to make this country the formidable nation that it is.

A handwritten signature in black ink, appearing to read "Paul Koskey". The signature is stylized with large, sweeping loops.

Paul Koskey
Director, Technology Applications Program



Section One

**Cold War
1980 - 1989**



Cold War Introduction

On July 31, 1979, United States presidential candidate Ronald Wilson Reagan visited the North American Aerospace Defense Command (NORAD), what could be considered the command center for the Cold War between the United States and the Soviet Union (U.S.S.R.). After viewing a simulation of U.S. capabilities of detecting and tracking an intercontinental ballistic missile (ICBM) fired from the Soviet Union, Mr. Reagan was reportedly struck by the lack of any U.S. defense against even a single Soviet missile.

More than a year later on November 4, 1980, Reagan was elected the 40th president of the United States, marking a new era in U.S. and world history. And although missile defense was not discussed in the election, Reagan would make it center stage in 1983, and it would cause domestic controversy and factor heavily in arms-control negotiations with the Soviet Union.

Pre-1980 Missile Defense

The German V2, the first ballistic missile, terrified London during World War II. Allied leaders determined that a massive barrage of antiaircraft fire (12,000 rounds of all calibers) could destroy an incoming missile, but the allies overran the V2 launch sites before the British could employ their planned V2 defense. Later efforts also had serious disadvantages. In the 1970s Sprint antiballistic missiles were designed to destroy or deflect incoming ballistic missiles using a nuclear explosion high in the atmosphere, but there could be negative effects for the cities these weapons protected. These systems also had political problems: The Soviets developed their own such system, which could only lead to the two superpowers

building ever-greater numbers of ballistic missiles to overwhelm the opposing nation's defenses. The escalation of the nuclear arms race was slowed in 1972 with the Anti-Ballistic Missile (ABM) Treaty, which limited where and how many antiballistic missile systems could be deployed.

Research continued in antiballistic missile systems, and the Soviet Union continued to field its own ABM system around Moscow. In a July 1985 speech, President Reagan said, "But in that very year [1972], Soviet Marshal Grechko testified to the Supreme Soviet: 'The treaty on limiting ABM systems imposes no limitations on the performance of research and experimental work aimed at resolving the problem of defending the country against nuclear missile attack.'" In fact, the Soviets violated the ABM treaty in the late 1970s by building a large phased-array radar site well within their borders at Krasnoyarsk, something prohibited by the treaty.

In November 1982 the Reagan administration issued a statement on ICBM development. The statement included a hint at the coming missile defense policy.

"We plan to continue research on ballistic missile defense technology — the kind of smart, highly accurate, hopefully nonnuclear, weapons that utilize the microelectronic and other advanced technologies in which we excel. The objective of this program is stability for our ICBM forces in the nineties, a hedge against Soviet breakout of the ABM treaty, and the technical competence to evaluate Soviet ABM developments. We currently have no plan to deploy any ballistic missile defense system."

1979

Reagan visits NORAD.

1982

The administration hints at having a missile defense policy.

1980 1981 1982 1983 1984 1985 1986 1987 1988 1989

Although there was no plan to deploy a missile defense system, the administration continued to explore the feasibility of developing one and its implications. In 1983 a panel of experts recommended an enormous research program similar in size and scope to that of the Manhattan Project or the Saturn/Apollo missions. President Reagan would later say, "I know this is a formidable technical task, one that may not be accomplished before the end of this century. ... I call upon the scientific community in our country, those who gave us nuclear weapons, to turn their great talents now to the cause of mankind and world peace, to give us the means of rendering these nuclear weapons impotent and obsolete."

Then, on March 23, 1983, President Reagan formally announced his missile defense plans to the American people. He put the argument for missile defense in terms of the larger Cold War, saying that even if nuclear arms reductions are achieved with the Soviet Union, "it will still be necessary to rely on the specter of retaliation, on mutual threat, and that's a sad commentary on the human condition. Wouldn't it be better to save lives than to avenge them?"

In January 1984 the effort was put into law by Presidential National Security Decision Directive 119 establishing the Strategic Defense Initiative (SDI). The immediate goals were to create a management structure within the Department of Defense and "to appoint a dedicated program manager of considerable stature in keeping with the high priority of SDI." That person was Lt. Gen. James A. Abrahamson, U.S. Air Force, who reported directly to Secretary of Defense Caspar

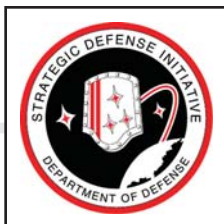
Weinberger. The directive outlined the major long-term research goals of the SDI organization, which continue to be important to the program to this day. They are:

- sensing and tracking attacking missiles;
- destroying attacking missiles and warheads;
- command and control;
- and survivability and sustainability.

The promise of the program was seen in the fruits of an antiballistic experiment already in progress in 1983. The Army Homing Overlay Experiment (HOE) used two stages of the three-stage Minuteman ICBM, but instead of using a nuclear explosion to destroy an incoming missile, the HOE opened a structure resembling an umbrella that would strike the incoming missile. Three tests in 1983 failed due to malfunctions, but on June 10, 1984, the umbrella made impact with a test ICBM.

By 1985 the program was commonly called "Star Wars" by the press. But Reagan defended the program, and in 1987 said, "I have repeatedly pledged that SDI capabilities will never be used for offensive purposes. It can reduce the danger of accidental warfare and give us the kind of insurance policy we need against violations of a future arms reduction treaty." He also added that SDI was contributing to the administration's foreign policy. "And it has been a singularly effective instrument for bringing the Soviets to the bargaining table."

Five years after the Strategic Defense Initiative Organization (SDIO) officially started, President Reagan commended the project's efforts and lauded its success, even its commercial



successes. "The SDI program is progressing technologically even faster than we expected . . . We have made rapid progress on sensors, the eyes and ears of a future defensive system. And our research has produced useful spinoffs for conventional defenses and for medicine, air traffic control, and high-speed computing."

Commercialization: The Office of Technology Applications

The commercial spinoffs cited by President Reagan were no accident. As SDIO emerged, it consolidated many programs and efforts that had been spread out in various parts of the Department of Defense. Lt. Gen. Abrahamson, charged with bringing this organization together and conducting research toward particular goals, understood the need to keep track of research efforts and researchers. Therefore, a small, specialized unit within SDIO, called the Office of Technology Applications (TA), was formed.

This office created a database of researchers and program abstracts called the Technology Applications Information System (TAIS), which was accessible by modem throughout the United States using an electronic bulletin board system. The database was essential because SDIO had no laboratories of its own, and unlike other divisions of the armed forces, it had to contract with national labs, universities, or companies across the country to conduct its research efforts.

But TAIS also proved to have other uses. Researchers could learn from one another and combine their technologies with the fruits of other projects. Other government agencies, and even U.S. companies, could benefit from SDIO research,

and making the research accessible would facilitate this technology transfer. In keeping with the national priorities of the time, access to TAIS was controlled by certification and complied with the Military Critical Technology List (MCTL) criteria.

The Office of Technology Applications started offering Technology Applications Reviews, which had grown out of SDIO briefings to other Defense organizations (Army, Navy, Air Force, DARPA, etc.). The TA program would review its ongoing research and development programs in an effort to keep the services and agencies current on SDIO progress, and to share that progress and minimize duplication of effort. The meetings then became brainstorming sessions to imagine spinoff applications for MDA-funded research.

But soon these meetings became more focused reviews of a government researcher's or private company's plan for commercializing a technology. The reviewers included volunteers from industry, academia, and government who served as an ad hoc advisory board, and to date more than 500 people have volunteered as advisors. Several times a year, meetings would be organized by subject or application area, and companies with commercialization ideas would be invited to come and present their plans and gain insights and suggestions from a wide range of experts.

Original areas of focus for TA Reviews included applications in power and energy, electronics, optics, space, materials, and biomedical, among other areas. In biomedical applications, the TA program managed two projects peripheral to ballistic

1983

Reagan announces his missile defense plans.

1984

The Strategic Defense Initiative is established.

1980 1981 1982 1983 1984 1985 1986 1987 1988 1989

missile defense: the medical free-electron laser, and the positron emission tomography (PET) programs. The first applied a high-energy laser research tool to medical applications; the second used a unique SDIO-developed radio-frequency quadrupole linear accelerator to produce radioisotopes for PET scanners.

However, the Office of Technology Applications soon became more involved with companies that were conducting research on behalf of SDIO. Col. James Ball (USAF), first director of the Office of Technology Applications, saw an opportunity to help small companies that won contracts through SDIO's Small Business Innovative Research (SBIR) and Innovative Science and Technology (IS&T) programs to commercialize their technology. Commercialization would allow private funds to mature the technology that SDIO might one day need, while also letting Federal research serve American taxpayers by providing a better quality of life and giving U.S. businesses a potential edge in the increasingly globalized economy.

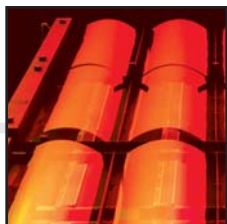
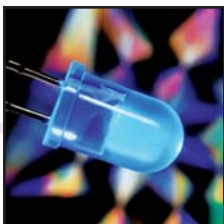
Successes

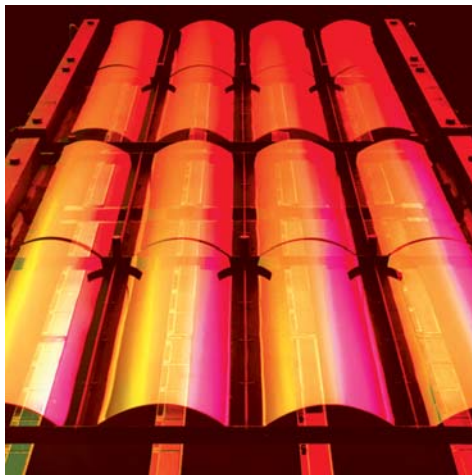
A number of commercially successful spinoff technologies were originally funded by SDIO, even in these early days of the program. Several of these technologies are featured in the pages that follow and are organized by the date they were first funded by SDIO. For instance, ENTECH, Inc., received its first SDIO funding in 1986, and today its lens-based solar cells (see page 14) are used in numerous satellite and terrestrial applications. Ultramet, Inc.'s tantalum-coated porous metal scaffolding (see page 18) has found applications far from

missile defense: growing human bone and culturing cells. And others include thermal heat pipes for laptop computers and even reliable electrical generators for cars and trucks.

Several of the technology transfer success stories highlighted here show SDIO's special focus on certain technologies, one of which was, and remains, wide-bandgap semiconductors. "We [SDIO] put over \$50 million into wide-bandgap semiconductors, and it's been less than 20 years since we started making major investments in that area," said Dr. Dwight Duston, former director of the Innovative Science and Technology program. "You go look up gallium nitride [a wide-bandgap semiconductor] and see how many companies are using it now. We started out with three universities and maybe one or two small companies and there must be 200 companies now working on blue LEDs, [which are] blue laser diodes."

In the following pages keep an eye out for wide-bandgap technology. Cree Research, Inc., has been extremely successful in producing electronics, such as blue LEDs (see page 24), and provides jobs for more than 1,000 people. EMCORE Corporation, with SDIO's help, has developed an instrument to make highly precise wafers for wide-bandgap electronics (see page 26), enabling more companies to develop products with the new technology. And Advanced Technology Materials, Inc., has developed a safer way to handle the very dangerous gases used in making some of these electronics (see page 22), thus cutting costs and, more importantly, saving lives.





‘Focusing’ on Solar Power

ENTECH, Inc.'s line-focus concentrator technology focuses more light onto advanced solar cells, generating more energy.

Missile Defense Needs. Since the 1957 launch of the Soviet Sputnik and the dawn of the Space Age, aerospace engineers have grappled with ever-growing demands for electrical power to run space platforms and satellites. Solar-power panels seemed an obvious solution, but arrays of photovoltaic cells have significant problems: they need to be deployed (unfolded), they create drag, and they degrade over time from radiation and plasma effects. So the search was on for smaller, lighter, more efficient, and cheaper ways of powering spacecraft using the sun's energy.

In 1986 SDIO funded ENTECH, Inc. (Keller, TX), to investigate an idea to

combine three new ideas in solar-cell array design. First, a prismatic cover for each solar cell could minimize losses due to reflection. Second, if this cover were made in the shape of a Fresnel lens, it could act as a magnifying glass and shine more light on the small, expensive, solar cell. And third, a new material called gallium arsenide promised improved cell efficiency, producing more electricity from the same amount of light.

The hope was to provide an operational power output of 275 watts per square meter of array area, about twice as high as planar silicon photovoltaic arrays provided in 1986.

Thus began a relationship that SDIO, along with NASA, continued to foster from 1987 until 1992, funding improvements in the prismatic material and the lens concentrator. The result of this work: the “line-focus” lens, which concentrates sunlight onto a narrow strip of photovoltaic cells.

Technology Solutions. The line-focus concentrator lenses were first space-qualified in 1994 on the Space Shuttle and in the Photovoltaic Array Space Power Plus Diagnostics (PASP Plus) experiment flown on a U.S. Air Force satellite, which evaluated vulnerability to space radiation and plasma hazards. With only 7 percent power-output

1986

SDIO funds
ENTECH, Inc.



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degradation after one year in orbit, PASP Plus proved that the concentrators' performance was steady and reliable.

SDIO and its successors, along with NASA and the U.S. Department of Energy, sponsored additional work with its Solar Concentrator Array with Refractive Linear Element Technology (SCARLET) projects. Twin solar arrays on SCARLET II—720 ENTECH concentrator lenses in all—provided 2,500 watts of power to the NASA/JPL New Millennium Deep Space 1 spacecraft launched October 24, 1998. Deep Space 1, using an electric ion engine powered by the

solar arrays, returned valuable information about the asteroid Braille in 1999 and the comet Borrelly in 2001.

Cashing In. The success of this solar technology has been nothing less than spectacular. Not only did the U.S. space program benefit, but ENTECH technology also found its way into electric utility and power-generation systems across the United States. Its SunLine product line can be found in small, remote power units, and its SolarRow product is used in large multi-megawatt utility power plants. ENTECH systems have been installed for utility companies such as

Pacific Gas & Electric, TU Electric, Central & Southwest, and the Tennessee Valley Authority.

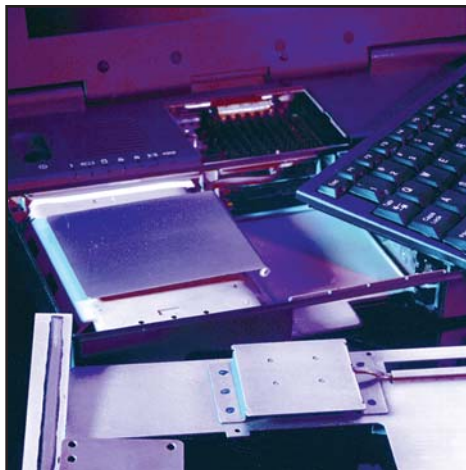
Today, the company thrives in its facility in Keller, TX, and announced in April 2005 that the NASA Marshall Space Flight Center in Huntsville, AL, awarded ENTECH three contracts related to the development of advanced solar-power arrays for exploration of the moon and Mars.

For more information visit:
www.entechsolar.com



The World in 1986 ... Voyager, an airplane designed by Burt Rutan, flies nonstop around the world in nine days. Halley's Comet passes Earth.

At SDIO in 1986 ... SDIO's management structure is reorganized. The National Test Bed is chartered.



Take This Heat and Shove It

Thermacore, Inc.'s heatpipes pipe heat away from hot electronics, from lasers and image sensors to the Pentium processors in laptop computers.

Missile Defense Needs. As soon as the SDIO was formed, planners knew that space-based optical systems, such as telescopes or directed energy systems, would need to be cooled to allow them to work effectively. In 1985 SDIO funded Thermacore, Inc. (Lancaster, PA), to develop methods to reject heat from spacecraft. This was followed the next year by a project that would become Thermacore's primary business, heat pipes.

Heat pipes provided an excellent way for MDA to reliably cool a wide range of electronics and optical systems and, as a result, SDIO and BMDO funded heat pipe technology with 10 SBIR Phase I and Phase II awards between 1986 and 1999.

Technology Solutions. Heat pipes are pipes that move heat from a heat source to a cooler area where the heat is expelled. The pipe is completely sealed on both ends and contains a liquid such as water, acetone, or methanol under a vacuum. The heat source heats the liquid and boils it, producing steam or vapor. This vapor expands, filling the tube, but it condenses on the walls of the pipes, which are cold. These colder walls are far away from the heat source. The condensing steam loses its energy to the cold end of the pipe, thereby heating the cold end of the pipe and cooling the heat source. The inside of the pipe is lined with a wicking material that, through capillary action, pulls the liquid back to the heat source.

Thermacore received other SDIO awards for more specific cooling needs. The directed energy work SDIO was conducting in attempts to use lasers to destroy incoming missiles from space required high-powered laser mirrors. This and other applications required a cooling solution that could handle wide variations in heat and still provide a constant surface temperature. Liquid film evaporation cooling provided a solution. The devices are related to the two-phase heat pipes that Thermacore was already developing.

Another example of SDIO's need for cooling came from research into lasers that showed that heat was a limiting factor in the power output of semicon-

1986

SDIO funds
Thermacore, Inc.



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Today Thermacore's heat pipes are used throughout the world in applications primarily in the electronics field, showing up in laptops and servers, and everything in between.

ductor laser arrays. Therefore, in 1993 BMDO (SDIO was renamed BMDO in 1993) funded Thermacore to investigate the possibility that forcing a liquid through a porous metal device attached to the heat source could effectively remove enough heat from the laser diode. The porous metal allows extremely high-surface area contact with the heat-transferring liquid. The end result was a device Thermacore called Thermo-Cube™, which has been used to cool laser diodes and other devices that must remain at constant temperature.

Cashing In. As a result of these SDIO- and BMDO-sponsored research projects, Thermacore has become a key player in

producing heat-removal systems for today's high-performance electronics. By 2000, Thermacore had manufacturing facilities in the United States, Mexico, Taiwan, and Korea to meet the demands of the electronics industry. Thermacore's success was crowned in 2001, when Modine Manufacturing Co. (Racine, WI), a U.S.-based global provider of heat-dissipation systems for larger applications such as automobiles, purchased Thermacore for \$110 million.

Today Thermacore's heat pipes are used throughout the world in applications, primarily in the electronics field, showing up in laptops and servers, and everything in between. The company offers numerous different heat pipes

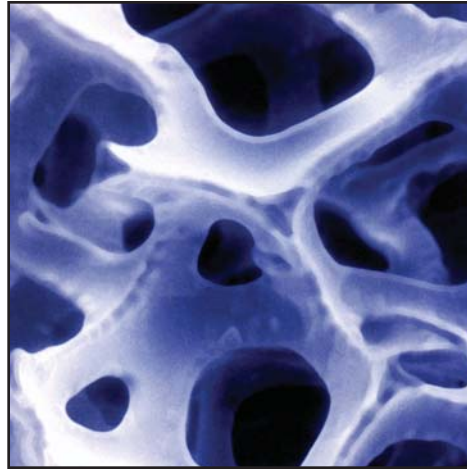
and devices, including a low-cost heat pipe for Pentium 4 mobile processors, many of which show ancestry to the understanding of heat transfer furthered by missile defense funding between 1985 and 1999. In fact, if you are using a laptop today, it most likely contains heat pipes to remove excess heat from the processor to, unfortunately, your lap.

For more information visit:
www.thermacore.com



The World in 1986 ... One reactor at the Chernobyl nuclear plant in Ukraine explodes in the world's worst nuclear accident. The Iran-Contra Affair breaks.

At SDIO in 1986 ... SDIO completes the Delta 180 experiment boost-phase intercept, which tests sensors, including those in space. Gorbachev pushes for limitations on SDI.



Cells, Bones, and Rockets?

Ultramet, Inc.'s innovative metal coated foam was originally designed for rocket engines but has found uses in medicine from joint replacement to a culture medium for cells.

Missile Defense Needs. To make faster missiles, rocket motors need to burn hotter and the entire missile needs to be lighter. Therefore, SDIO provided Phase I SBIR funding to Ultramet, Inc. (Pacoima, CA), for the development of lightweight materials that could withstand the high temperatures and the oxidizing environment of a rocket engine without eroding like conventional materials. Today, Ultramet provides the military and satellite industry parts that are lightweight and able to withstand high temperatures. However, one technology developed by Ultramet and funded by SDIO has made the leap to the medical field, serving as bone implants and cell growth mediums.

Technology Solutions. Ultramet developed a process that heats a polymer-based foam until only a carbon structure remains, and then coats this carbon structure with metal using chemical vapor deposition. But because chemical vapor deposition could not be used with some metals, such as tungsten and tantalum, Ultramet developed a chemical vapor infiltration process to deposit these elements. The resulting foam, regardless of which process is used to coat it, is up to 90 percent open space, making it very light.

Cashing In. During the development, researchers at Ultramet realized that the structure of the foam resembled that of human bone. After further development

and testing a tantalum coated carbon foam bone implant outperformed existing bone implants by providing high compression strength and a low modulus of elasticity, which are comparable to normal spongy bone. The structure encourages bone-building cells to take up residence in the foam's voids, and these cells eventually form new bone that connects the implant to the existing bone.

Zimmer Holdings, Inc., is marketing the implants under the name Trabecular Metal™ for full- and partial-knee replacement and hip replacement. According to Zimmer, the connection between the Trabecular Metal implant and the bone is twice as strong as con-

1986

SDIO funds
Ultramet, Inc.



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In 2005 Cygenics started Phase I and II clinical trials for using this technology to rebuild a patient's immune system.

ventional implants, and after eight weeks bone filled most of the foam's pores.

Bone-building cells were not the only cells that thrived in the foam. The foam makes an environment conducive to cell growth for several reasons including, a large surface-to-volume ratio, nanoscale features in the tantalum surface for cells to adhere, and large continuous pores for nutrients to reach the cells. Cytomatrix, LLC, has licensed the technology from Ultramet and is selling the material for culturing cells.

In April 2003 Singapore-based CordLife, which is a division of Australian-based

Cygenics, acquired Cytomatrix. Later in 2003 CordLife introduced disposable cell growth devices that use Cytomatrix's foam. These devices cut the time and preparation involved in culturing human and animal cells and produce better results. In 2005 Cygenics signed an agreement with Corning Life Sciences for Corning to sell the disposable devices made by Cygenics.

In addition to selling devices for cell growth, Cygenics is currently working with the Department of Defense on culturing cells (T-cells) that could be used for testing prototype vaccines. In 2005 Cygenics started Phase I and II clinical trials for using this technology to

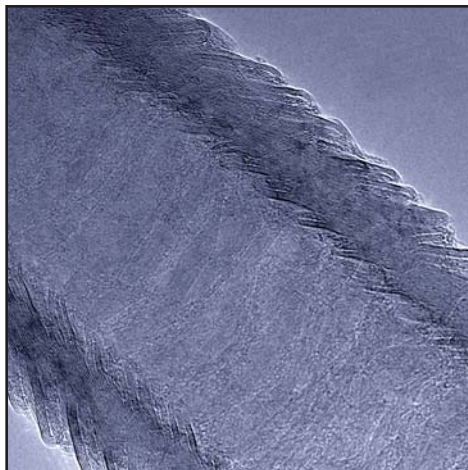
rebuild a patient's immune system by culturing the patients own immune cells (T-cells) outside their body, which could save the lives of patients with AIDS or recovering from cancer treatments.

For more information visit:
www.ultramet.com
www.cytomatrix.com
www.zimmer.com



The World in 1986 ... The Space Shuttle Challenger disintegrates during launch, killing its six crew members and a schoolteacher. The Soviet Union launches the Mir space station. Levi Strauss & Co. introduces Dockers pants.

At SDIO in 1986 ... The Brilliant Pebbles idea of small, smart interceptors is conceived. Theater missile defense architectural study begins.



Nanofibers Before Nano Was Cool

Applied Sciences, Inc.'s vapor-grown carbon nanofiber, when added to a polymer, makes better composites than traditional carbon fibers.

Missile Defense Needs. Electromagnetic railguns were seriously considered during the 1980s as a possible alternative to conventional solid- and liquid-fueled rockets and missiles, both as a weapon system and for launching projectiles into orbit.

Powered by electricity, a railgun would work, in theory, like a huge slingshot, rapidly accelerating a small projectile (or payload) to hypersonic velocities. The advantage as a weapon system would be accuracy, range, and high repetition rate; the advantage as a launch system would be efficiency and low recurring cost. But in the 1980s there was no easy way to provide the enormous power surge that a railgun

demanded, and more to the point, there were no materials that could withstand the rigors of repeated use.

Technology Solutions. Therefore, as early as 1987, Applied Sciences, Inc. (Cedarville, OH), received SDIO funding to demonstrate the feasibility of cost-effective fabrication of composite materials using vapor-grown carbon fibers (VGCF) for use in the critical components of electromagnetic railguns.

When carbon fiber (or carbon black) is added to a polymer, it converts it from an insulating material into an electrically conductive material. However, VGCF is a "nanofiber" that takes up less volume than its competitors and has less of an effect on other polymer properties. A

composite with carbon nanofiber can be tailored to have electrical resistivities anywhere from 1 to 1010 ohms per centimeter. If thermal conductivity is the desired property, it conducts between 1,950 and 2,000 Watts per meter-Kelvin, or close to five times the thermal conductivity of copper.

Cashing In. Applied Sciences proved that VGCFs could be produced in a low-cost, high-volume production process and not just in the laboratory. Through a manufacturing subsidiary created in 1996, Pyrograf Products, Inc., the company built a pilot plant to produce 35 tons per year of carbon nanofiber called Pyrograf®-III. In fact, since 2002 the company has had the potential to build and

1987

SDIO funds
Applied Sciences, Inc.

1980

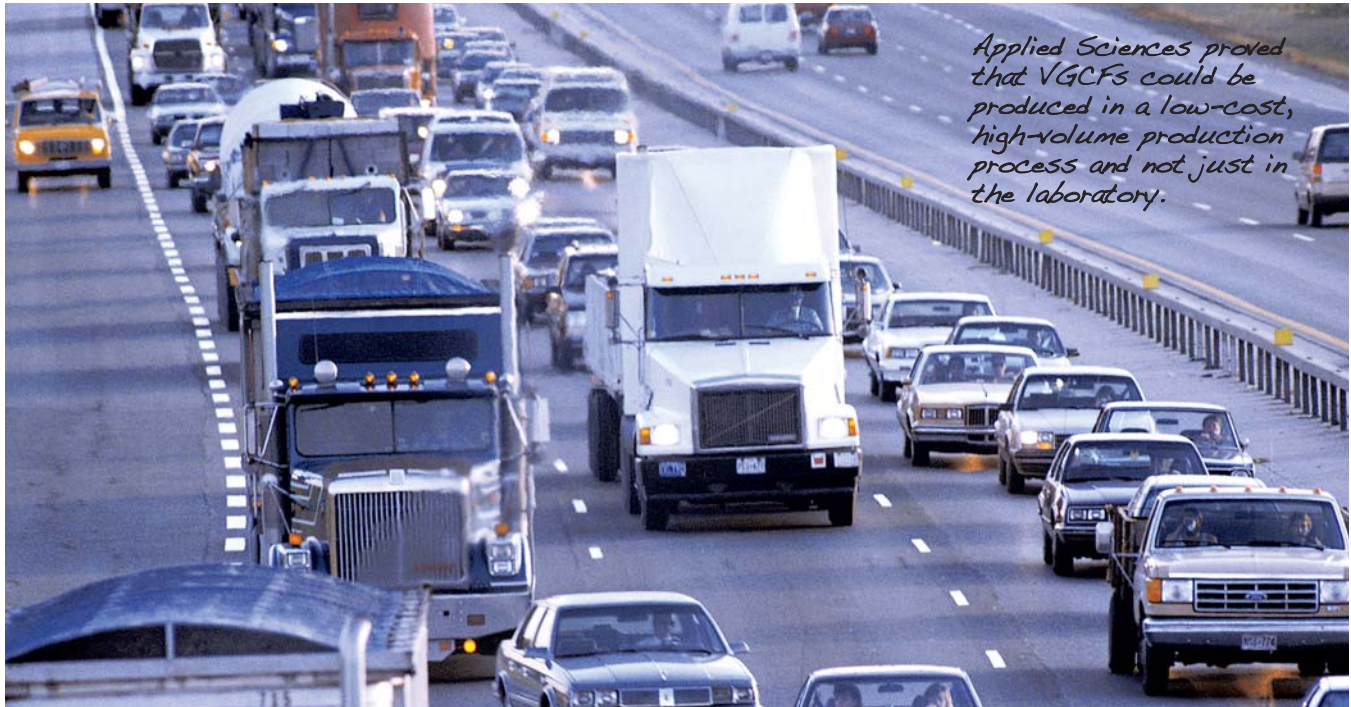
1985

1990

1995

2000

2005



Applied Sciences proved that VGCFs could be produced in a low-cost, high-volume production process and not just in the laboratory.

operate a facility that could produce up to 1,500 tons per year. The process uses inexpensive precursors such as metal catalysts and industrial gases. The cost of the material, however, depends on customer demand: at \$85 per pound, carbon nanofiber remains an expensive "exotic" material. With more orders and higher production rates, the price might drop to \$10 per pound or less, at which point demand might also increase as new applications become economically feasible.

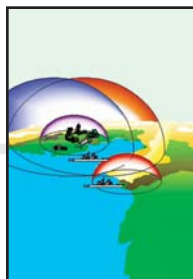
With funding from the Department of Energy and the U.S. Air Force, Applied Sciences began to look at commercial applications for nanofibers. Potential products from enhanced materials

include longer-wearing automotive tires, electrically conductive body panels, aircraft polymers with improved lightning-strike protection, and high-performance fuel cells. Applied Sciences joined forces with General Motors and licensed all of GM's intellectual property on VGCF. In 1996 Applied Sciences, GM, Goodyear Tire & Rubber Co., and other organizations joined in a cooperative research agreement and received funding from the National Institute of Standards and Technology's Advanced Technology Program.

Applied Sciences continues to upgrade its production and sell more and more Pyrograf-III carbon nanofibers. "Production operations have been

'cash-positive' for the past three years, and sales are increasing each month," said Max Lake, founder and president of the company. "The future looks bright for this material, and the support from MDA in establishing the materials property beachhead as well as low-cost manufacturing technology has been a critical contribution."

For more information visit:
www.apsci.com



The World in 1987 ... The first heart-lung transplant occurs. NASA awards contracts for construction of the International Space Station.

At SDIO in 1987 ... The Defense Acquisition Board conducts its first review of SDIO, and six components of SDI are authorized to enter the demonstration and validation stage.



Safely Making Semiconductors

Advanced Technology Materials, Inc.'s gas storage system has made semiconductor manufacturer safer and less expensive.

Missile Defense Needs. SDIO funding for research into semiconductors was not simply for academic reasons; it was to enable the next generation of radar and communications systems. Electronics needed to be developed into working components and also needed to be reliably and safely manufactured. However, making semiconductors often requires the use of some very dangerous chemicals, which increases costs and creates potentially dangerous conditions. For example, production of gallium arsenide semiconductors requires the use of arsine gas (AsH_3), which is highly flammable and toxic.

The semiconductor industry's dependence on dangerous gases did not end

with gallium arsenide. To make a modern n- or p-type semiconductor, as many as 35 ion-implantation steps are necessary. Each step, sometimes called doping, uses gases such as arsenic pentafluoride, boron trifluoride, and phosphine gas—all of which are flammable and poisonous like arsine gas. Having a safer method of storing and transporting these gases would reduce overall costs and increase personal safety when manufacturing cutting-edge semiconductor materials.

Therefore, in 1987 SDIO funded Advanced Technology Materials, Inc. (ATMI; Danbury, CT), to develop a method of safely delivering gases for semiconductor fabrication.

Technology Solutions. The idea behind the technology is to store a gas by absorbing it with some solid material rather than pressurizing it in a tank or cylinder. To achieve this goal ATMI developed a zeolyte (a material with an extremely high surface area) that could absorb these gases. Although a pressurized tank can leak, a gas absorbed into this zeolyte can remain safely stored even under normal atmospheric conditions. Dean Hamilton, marketing director for ATMI explained, "It's like a Velcro® for gas."

Cashing In. As a result of SDIO's funding, ATMI introduced the Safe Delivery Source, now called the Safe Delivery System (SDS). In 1995, ATMI partnered with Matheson Tri-Gas to manufacture

1987

SDIO funds
Advanced Technology Materials, Inc.

1980

1985

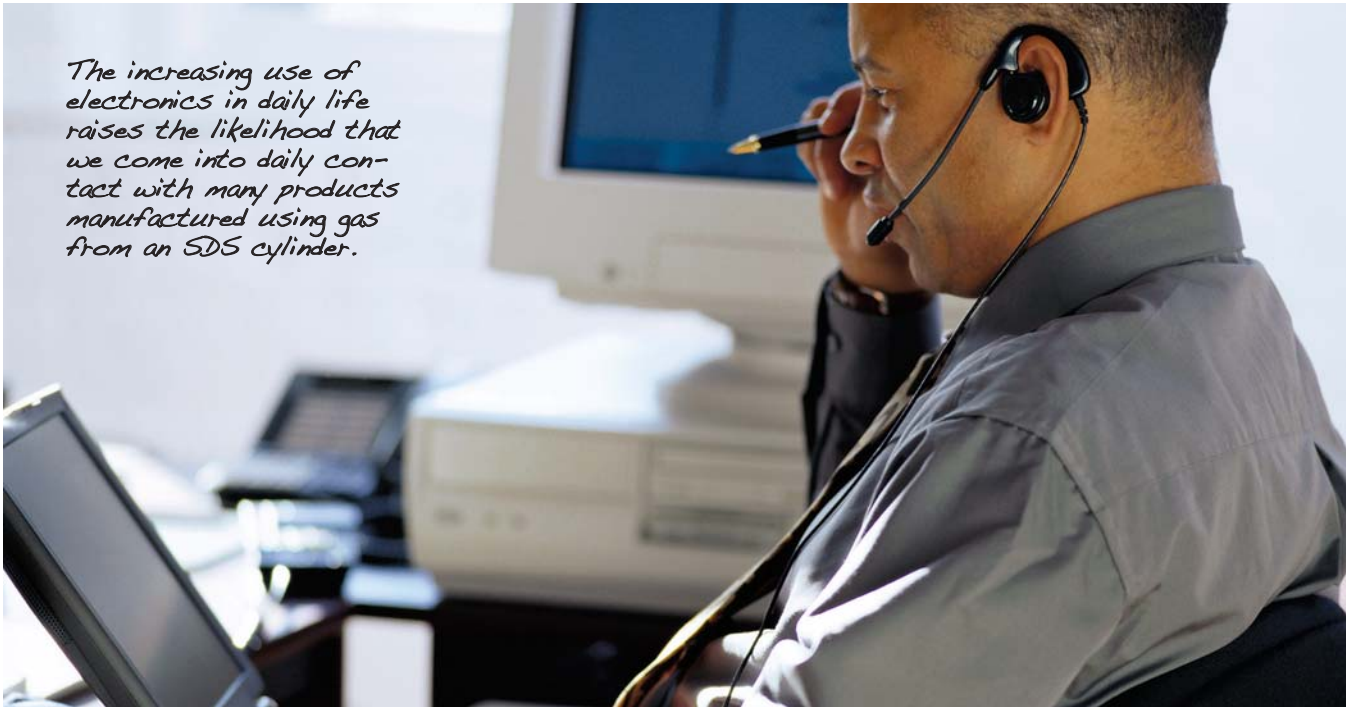
1990

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The increasing use of electronics in daily life raises the likelihood that we come into daily contact with many products manufactured using gas from an SDS cylinder.



and distribute the finished product of ATMI's labor. SDS was quickly adopted as the method of choice for supplying ion implementation gases to semiconductor fabrication facilities around the world, and it remains the only sub-atmospheric (meaning "not under pressure") gas storage system available for semiconductor process gases. SDS has saved money for semiconductor developers and manufacturers and has probably saved lives.

The increasing use of electronics in daily life raises the likelihood that we come into daily contact with many products manufactured using gas from an SDS cylinder. ATMI's SDS product generated tens of millions of dollars a

year and allowed the company to survive the semiconductor industry downturn in the late 1990s when almost all other semiconductor companies had losses.

Today, ATMI and Matheson Tri-Gas have introduced the third generation of SDS, which now uses a high-density, monolithic carbon absorbent that can hold more than twice as much gas as the second-generation SDS holds. In terms of conventional cylinders, the third-generation unit can hold the equivalent of 10 to 20 dilute high-pressure gas cylinders in the same amount of floor space. By storing so much gas, fabricators can operate production lines longer while still maintaining a greater margin of safety. According to Volker Heilmann,

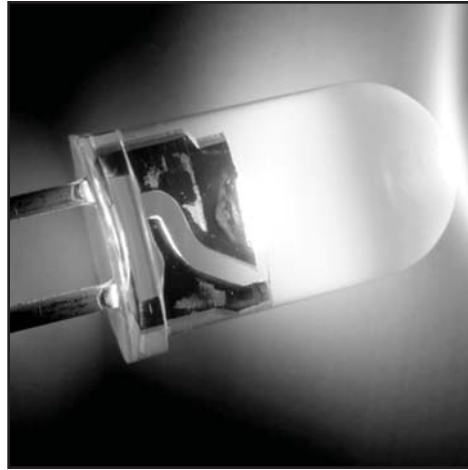
vice president for sub-atmospheric gas products at Matheson Tri-Gas, "Since we joined forces with ATMI more than 10 years ago, Matheson Tri-Gas and ATMI have shipped over 75,000 SDS cylinders without any significant gas-release incidents."

For more information visit:
www.atmi.com



The World in 1987 ... The USS Stark is struck by Iraqi missiles during Iran-Iraq war, killing 37 and injuring 21. The Macintosh II is introduced with a color monitor and 16-MHz processor. IBM introduces the PS/2.

At SDIO in 1987 ... The Brilliant Pebbles interceptor concept is introduced to Lt. Gen. James Abrahamson (USAF).



Workable Wide-Bandgap Wafers

Cree creates viable commercial SiC products, including light-emitting diodes (LEDs), wafers, power devices, materials for gemstones, and radio- and microwave-frequency transistors.

Missile Defense Needs. The interest in wide-bandgap semiconductors surfaced from the theory that these materials could allow integrated circuits to operate with microwave frequencies (improving radar and communications), higher power (for power electronics), and to emit longer wavelengths of light (blue, green and UV diodes and laser diodes). One wide-bandgap material of interest—silicon carbide (SiC)—was known to withstand very high temperatures and had been used to coat drill bits and other machinery, but in the mid-1980s there was no commercially viable process to fabricate low-defect SiC wafers.

Technology Solutions. A team of researchers led by Dr. Robert Davis at North Carolina State University developed a process to fabricate SiC wafers. In 1987, a group of students from the university licensed 10 SiC-related patents and spun out a small company called Cree Research, Inc. (Durham, NC), focusing on SiC wafer development.

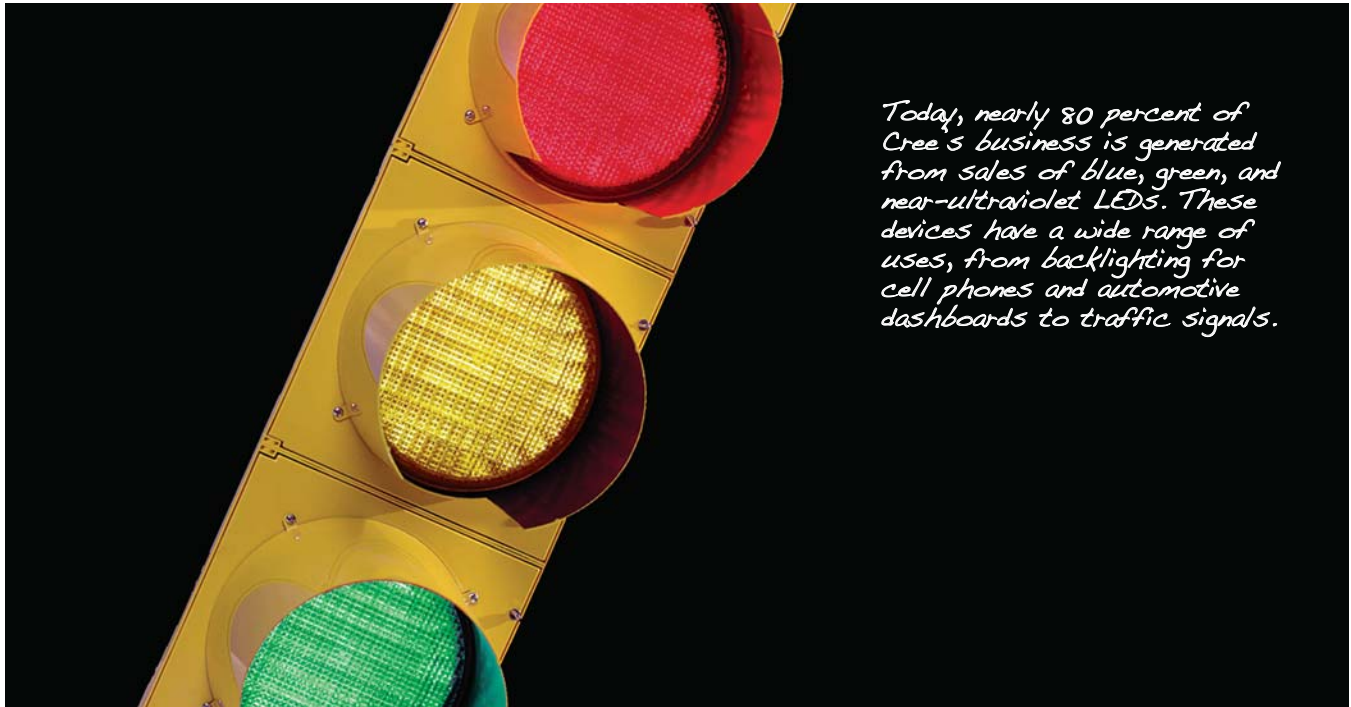
Cree Research, whose name was later shortened to “Cree”, received startup funding from SDIO’s SBIR and Innovative Science and Technology programs as well as a round of venture capital. With the SBIR program alone, SDIO funded more than \$4 million,

about \$2.5 million of which was funded during Cree’s first year. Between 1987 and 2004, SDIO and its successors, BMDO and MDA, awarded Cree more than 24 SBIR projects to investigate and/or develop various SiC electronic devices. Many of these projects, as well as some funded by the Defense Advanced Research Projects Agency and the National Institute of Standards and Technology, helped Cree to create viable commercial SiC products, including light-emitting diodes (LEDs), wafers, power devices, materials for gemstones, and radio- and microwave-frequency transistors.

1987

SDIO funds
Cree Research, Inc.

1980 1985 1990 1995 2000 2005



Today, nearly 80 percent of Cree's business is generated from sales of blue, green, and near-ultraviolet LEDs. These devices have a wide range of uses, from backlighting for cell phones and automotive dashboards to traffic signals.

Cashing In. Today, nearly 80 percent of Cree's business is generated from sales of blue, green, and near-ultraviolet LEDs. These devices have a wide range of uses, from backlighting for cell phones and automotive dashboards to traffic signals. LED devices are available in different brightness levels: standard; UltraBright® and SuperBright™ mid-brightness; and MegaBright®, XBright®, and XThin™ high-brightness. In 2005 Cree received the largest single order for LEDs—\$200 million—from its Japanese distributor, a division of Sumitomo Corporation.

Cree also generates significant revenue from selling SiC materials. The company

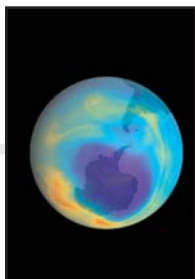
manufactures two-inch and three-inch SiC wafers for manufacturers to use in fabricating optoelectronic and power-device electronics. Corporate customers, government agencies, and universities also buy these wafers for research and development purposes. In addition, Cree manufactures near-colorless SiC crystals and sells them exclusively to Charles & Colvard, Ltd., which turns them into diamond-like moissanite jewelry.

Other SiC-based products sold by Cree include power devices, such as 300-volt, 600-volt, and 1,200-volt Schottky diodes. Applications for these devices include computer power supplies and

power conditioning and switching equipment. Cree offers a 10-watt SiC metal-semiconductor field-effect transistor (MESFET) product; a 60-watt SiC MESFET is currently being sampled by select customers. The company also develops and sells products based on gallium nitride, another semiconductor material, and silicon.

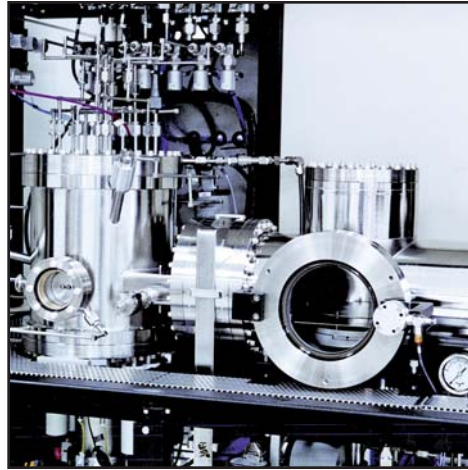
In 2004 Cree earned approximately \$307 million in revenue. It currently employs more than 1,000 people.

For more information visit:
<http://www.cree.com>



The World in 1987 ... Countries begin signing the Montreal Protocol to control damage to the Earth's ozone layer. Nancy Reagan treated for breast cancer.

At SDIO in 1987 ... A PAC-2 successfully destroyed another Patriot that was simulating an SS-23 ballistic missile.



Tools to Build the Future

EMCORE's technology for depositing thin layers of material on semiconductor wafers is now being used across the semiconductor industry.

Missile Defense Needs. In the 1980s SDIO saw the need for advanced semiconductor technology, especially devices based on wide-bandgap materials. However, devices based on these materials remained laboratory experiments; there was no method to make them in the volume needed for military or commercial use.

To tackle this challenge, SDIO funded the then-57-employee EMCORE Corporation in 1988 and 1989 to develop a process for making larger volumes of higher-quality compound semiconductors using atomic layer epitaxy in a rotating-disk reactor.

Technology Solutions. EMCORE's TurboDisc® technology enables cost-

effective metal-organic chemical vapor deposition (MOCVD) systems for producing commercial volumes of compound semiconductor wafers and devices. The MOCVD process adds ultrathin layers of materials on a substrate wafer by reacting gases together in a steel vacuum chamber. However, the reacting gases may deposit a thicker layer on part of the disc, causing manufacturing problems later on. TurboDisc ingeniously solves this by spinning the substrate wafer at high speeds, ensuring a uniform layer is deposited.

TurboDisc not only ensures uniformity of deposition across the wafer to increase yields, it also allows users to scale-up easily from research to com-

mercial volumes. TurboDisc tools can deposit semiconductor films, such as GaAs, AlGaAs, InP, InGaAlP, InGaN, AlGaIn, SiC, and GaN onto a substrate from 2 inches to 14 inches in diameter.

Layers grown by TurboDisc allow circuits and devices that are faster and denser, have photonic capabilities, and possess properties superior to those manufactured using traditional techniques.

Cashing In. In 1997 a majority of EMCORE's \$47.8 million in revenues resulted from TurboDisc technology, and an initial public offering raised more than \$20 million most of which was used to expand its manufacturing facility. In 2000, Shuji Nakamura, who in 1993 developed the first high-brightness

1988

SDIO funds
EMCORE Corporation

1980

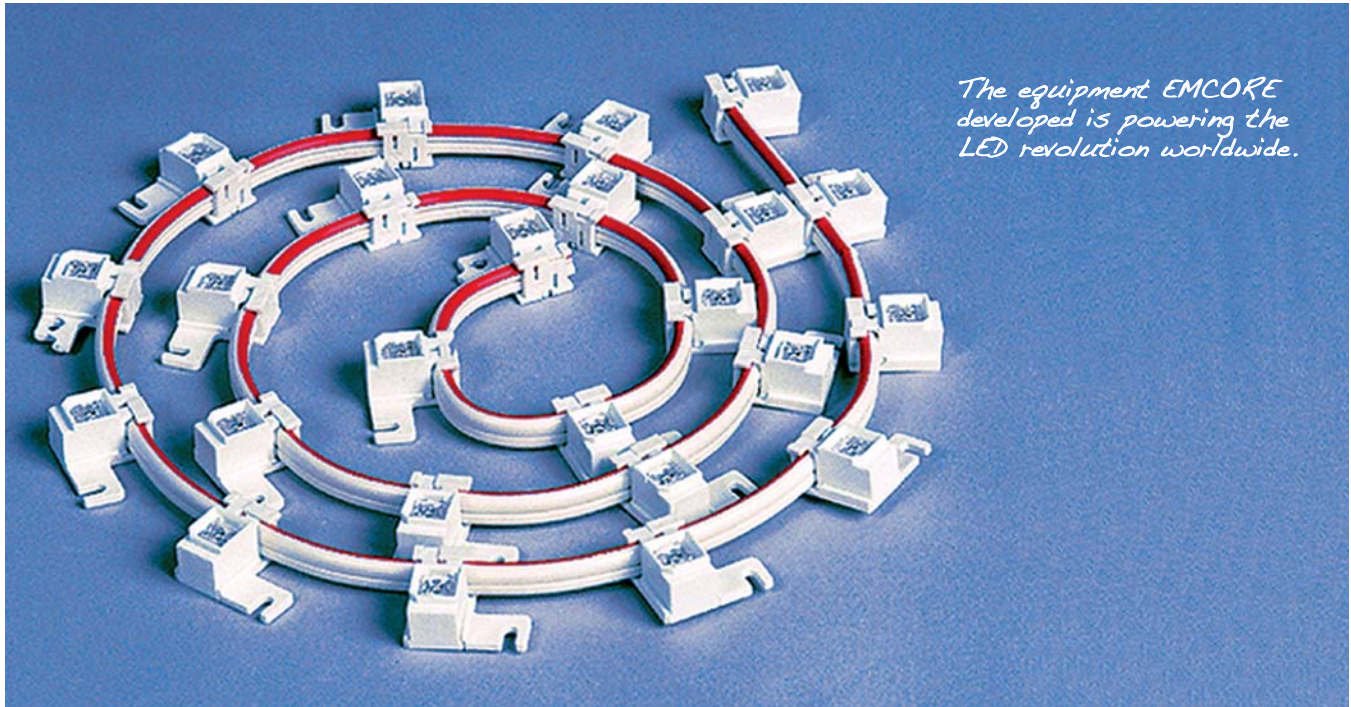
1985

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blue LED capable of being mass-produced, ordered an EMCORE MOCVD system to research new GaN devices with his new colleagues at the University of California at Santa Barbara.

EMCORE introduced another MOCVD system, called GaNzilla, to focus specifically on the production of GaN high-brightness LEDs. TurboDisc and GaNzilla systems are being used by some of the world's leading semiconductor companies, including LG, Lumileds, Osram, and Samsung, along with communications manufacturers such as Motorola and Sumitomo Electric.

On November 3, 2003, EMCORE sold its MOCVD division to Veeco Instruments, a leading instrument maker in the semi-

conductor manufacturing industry, for approximately \$80 million. According to the company, this will allow EMCORE to focus on its communications product lines and its joint venture with GE (GELcore, which makes high-brightness LED lighting). Since Veeco's purchase of the MOCVD division from EMCORE, it has signed two deals worth more than \$10 million with Lumileds in San Jose, CA, and Fujian Quanzhou Sanan Group Ltd., in China's Fujian Province, as well as supplied five GaNzilla MOCVD units to South Epitaxy Corporation in Taiwan.

EMCORE's production technology has become one of the most widely used methods for making wide-bandgap semiconductors, feeding an industry

that will keep growing. The equipment EMCORE developed, with the help of SDIO funding, is powering the LED revolution worldwide.

For more information visit:
www.emcore.com
www.veeco.com



The World in 1988 ... Oliver North and John Poindexter are indicted in the Iran-Contra affair. A Pan Am 747 is destroyed by Libyan terrorists over Lockerbie, Scotland, killing 270.

At SDIO in 1988 ... The National Test Facility is activated in temporary facilities at Falcon Air Force Base near Colorado Springs.



Section Two

**Changing Times
1990 - 1999**



Changing Times

Introduction

"Mr. Gorbachev, open this gate! Mr. Gorbachev, tear down this wall!" This emphatic statement in President Reagan's famous 1987 speech in Berlin, West Germany, foretells some of the events in 1990 and 1991. A year after the speech, Gorbachev allowed the Eastern European countries to decide their own affairs, leading to a reunited Germany. In 1989 the last remaining Soviet troops withdrew from Afghanistan. In this new decade, the United States would fight a war that not many saw coming, and the Cold War would end. There would be no massive nuclear war, no shots fired between East and West. These events would profoundly alter U.S. foreign policy, military objectives, and the goals of the ballistic missile defense program.

The Gulf War

A long-running border dispute between Iraq and Kuwait, along with other factors, led Iraq to invade Kuwait on August 20, 1990. Following worldwide condemnation, the United Nations sent an ultimatum for Iraq to withdraw, and troops from 34 countries prepared to liberate Kuwait by force if Iraq did not comply. The U.S. military led this coalition. However, the Iraqis possessed a threat that U.S. forces had not seen in action since World War II: regional ballistic missiles. In fact, Iraq's ballistic missiles, commonly called Scuds, were descendants of the German V2 rockets used during World War II (the last time American troops faced ballistic missiles in a hot war).

However, American troops were being defended by a new antiballistic missile weapon, the Patriot Advanced Capability (PAC) system. A day after coalition forces launched an air campaign against Iraqi forces (January 17, 1991), Iraq launched Scud missiles at both Israel and Saudi Arabia. One missile bound for Dhahran, Saudi Arabia, was successfully intercepted by a Patriot antiballistic missile. This marked the first time in history that a ballistic missile had been intercepted in combat.

Following Iraq's missile retaliation, President George H.W. Bush changed the goals for the missile defense program in his State of the Union speech, saying:

"I have directed that the Strategic Defense Initiative program be refocused on providing protection from limited ballistic missile strikes, whatever their source. Let us pursue an SDI program that can deal with any future threat to the United States, to our forces overseas, and to our friends and allies."

On February 25, 1991, soldiers stationed in Dhahran were not so fortunate. A software problem caused the Patriot to miss an incoming Scud, which killed 28 American personnel at a barracks. The era of missile defense had arrived, and the president outlined the new goals of the missile defense program. But these new goals were also supported by other events in 1991, which freed the United States from facing an imminent ballistic missile attack from the Soviet Union.

1991

Iraq uses ballistic
missiles in the Gulf War.



1993

SDIO is
renamed BMDO.



1990 1991 1992 1993 1994 1995 1996 1997 1998 1999

Back in the U.S.S.R.

After the events of the late 1980s—the fall of the Iron Curtain, the withdrawal of Soviet forces from Afghanistan, and the liberalization of the Soviet economy—Mikhail Gorbachev (the first president of the Soviet Union) now faced a coup in August 1991. Although the coup failed, the power had irreversibly shifted from the centralized U.S.S.R. government to the leaders of the republics, such as Russian President Boris Yeltsin. Massive protests forced the Soviets to recognize the independence of the Baltic republics and even Ukraine declared independence on December 1, 1991, after 90 percent of voters chose independence. As a result, the Soviet Union was officially dissolved on December 25, 1991. There was no going back to a large, anti-American, Soviet empire.

The military implications of the political changes in, and leading up to, 1991 were much less clear. The United States and the Soviet Union completed the Strategic Arms Reduction Treaty (START) to reduce the number of nuclear weapons in each other's arsenals. President Bush, upon signing the treaty, said, "Mr. President [Gorbachev], by reducing arms, we reverse a half-century of steadily growing strategic arsenals. But more than that, we take a significant step forward in dispelling a half-century of mistrust. By building trust, we pave a path to peace."

The Mid-1990s and Regional Conflict

In 1992, initial changes were made to SDIO so that it could follow its new direction toward a goal, what President Bush

called Global Protection Against Limited Strikes (GPALS). "It defends us and our allies from accidental launches or from the missile attacks of international renegades," he said. "While the Patriot worked well in the Gulf, we must prepare for the missiles more likely to be used by future aggressors." In 1993 SDIO was renamed Ballistic Missile Defense Organization (BMDO) by the new administration of President William Jefferson Clinton.

The new focus on regional missile defense was clearly supported by events during the 1990s. In 1993 North Korea test-launched a Scud variant over Japanese territory. In 1994 a Scud was used in the Yemeni civil war, killing as many as 25 people. In 1996 China launched missiles in the vicinity of Taiwan. In 1998 both Pakistan and Iran tested ballistic missiles with expected ranges of more than 800 miles. And "North Korea surprised us in 1998 with the launch of the Taepo-Dong 1 [a new long-range missile]," said Lt. Gen. Henry A. "Trey" Obering III (USAF), director of the current Missile Defense Agency, in opening remarks to the Multinational BMD Conference in Berlin, Germany, July 19, 2004. "We should expect to be surprised again."

Technology

But what, technologically speaking, did all these events mean? It meant that the new aim of BMDO was to develop and help field a theater missile defense system. Priority was placed on projects that fit this new goal, and projects like space-based lasers were now less likely to be funded as urgently. However, research on space platforms did not stop;



BMDO still wanted eyes in space to detect missile launches and needed communications capabilities to connect distant command centers. And, even though system integration and acquisition had begun on systems like Theater High Altitude Area Defense (THAAD) and the Aegis Standard Missile 3 (SM3), research was still vital. In a 1996 report to Congress, Lt. Gen. Malcolm O’Neill (USA), then-director of BMDO said:

“Today’s acquisition programs are possible only because significant past investments in BMD technology made them possible ... That includes infrared detectors, cryogenic coolers, optical hardware and radiation-hardened microelectronics ... Nowhere else in the [Defense] Department are the basic or component BMD technology programs funded. Therefore, to ensure the continued flow of new solutions to meet evolving ballistic missile defense requirements and technology needs, I encourage the Congress to consider the BMD advanced technology program as a strategic investment.”

Technology Applications Program

During the 1990s the Office of Technology Applications, now called the Technology Applications program, was very successful in promoting the commercialization of many technologies that BMDO had invested in through its Small Business Innovation Research (SBIR), Small Business Technology Transfer (STTR), and Innovative Science and Technology (IS&T) programs, as well as other programs.

Technology Applications (TA) Reviews, started in the mid-1980s, played a large role in helping researchers develop a business perspective on how best to grow their companies and ballistic missile defense technology.

Another way of helping promote SDI-funded technology research came through publications developed by the TA program’s outreach program. In 1991 a new publication called the *SDI High Technology Update* was launched to help get the word out about SDI-funded technologies. The publication grew and today has more than 9,000 subscribers, who range from media outlets and news organizations to major corporations looking to invest in or acquire new technologies. In addition, out of this publication effort grew the production of yearly reports, such as this *Technology Applications Report* that highlights commercial successes that have come from MDA research funding.

The 1990s saw the world moving to the Internet and the World Wide Web as a way to share information, and the TA program embraced these media as a way to leverage its technology transfer charter. From the restrictive, modem-accessible Technology Applications Information System (TAIS) electronic database started during the mid- to late-1980s, the TA program moved to open access of its unclassified technology information via two Web sites. The first site was the official government site, www.bmdolink.org, which is now www.mda.mil/mdalink. The other web site, www.mdat-

1991

The U.S.S.R dissolves.

1996

The TA program begins helping Phase I companies.

1990 1991 1992 1993 1994 1995 1996 1997 1998 1999

technology.net, was on a dedicated Internet server holding not only technology information but also a complete range of outreach materials, technology information, and commercialization information.

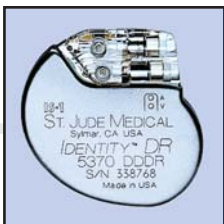
TA Reviews also continued, still organized by application areas such as optics, electronic materials, and other related groupings. However, it was evident that to participate in these end-use application discussions, ballistic missile defense technologists needed to be at a fairly advanced stage of development. Maturity of technology was an important factor in helping companies determine which business model and target market was best for them. Yet many companies needing help from the TA program were not yet at this level of maturity, but still needed to focus on future business opportunities even at their early stage of development.

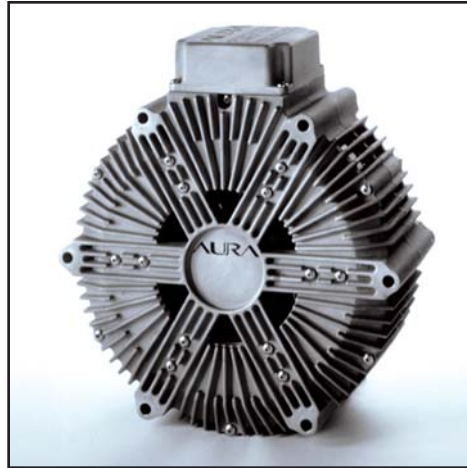
A large subgroup of researchers fell into this early stage of development. They were the winners of SBIR Phase I awards. In 1996 the TA program started a specific effort, called Business Focus Workshops (BFW), for these SBIR Phase I companies. Instead of subjecting them to the TA Review's large "board of advisors," whose advice and comments would be premature for early-stage development, BFWs paired each Phase I company with an astute business consultant. This one-on-one workshop encouraged the technologist to think like a business person, with the goal of developing a business case as a starting point.

"What we are trying to do is instill in these early-stage companies that you have to start thinking ahead about how you are going to grow your technology into a business," said Duane Zieg, director of the National Technology Transfer Center's Washington Operations (which works on MDA's Technology Applications program). This early effort is important because many researchers are scientists and have little business experience. But commercial funding could get their idea to mature and could eventually feed back into the missile defense program. Even if it is never used in missile defense, it can contribute to the American economy.

Successes

The following section highlights several companies that have had significant commercial success with technologies that BMDO or SDIO helped fund between 1991 and 1999. For example, technology developed to make a new type of radiation-hardened computer memory being developed by NVE, is being used to make better pacemakers and hearing aids. Laser communications, which may be applied to sending missile tracking data at high speed, is being marketed to companies by a division of Trex Communications to save the time and expense of burying fiber-optic lines to connect nearby buildings. Broadband communication to ships in or near harbors can benefit as well. These technologies, along with improvements in infrared imaging, camera stabilization, and laser radar have found commercial uses in addition to possible use by MDA.





Actuators into Generators

Aura Systems, Inc., turned actuator technology developed for the SDIO into a unique electrical generator for automobiles.

Missile Defense Needs. Missile interceptors need to adjust their flight so they can hit another missile. SDIO's Lightweight Exo-Atmospheric Projectile (LEAP) program was no different and needed highly responsive thrusters to steer the projectile into an incoming ballistic missile. In developing these thrusters, SDIO saw a need for high-fidelity actuators, which are very similar to actuators in audio speakers. The need was filled by a technology developed by Aura Systems, Inc. (El Segundo, CA).

Technology Solutions. Actuators and voice coils use electromagnetic principles to cause movement. When electrical

current flows through a coil of wire, a magnetic field is produced. In a speaker, the coil is attached to the speaker cone, and the coil's magnetic field interacts with a large permanent magnet behind the speaker. As the current changes, the speaker moves different distances away from the permanent magnet, and the listener hears sound.

Aura's patented design uses 90 percent of the magnetic flux within the coil, whereas traditional devices utilize only about 40 percent of the available magnetic flux. The result: the new actuator provides as much force as typical hydraulic or pneumatic actuators but

operates at the higher speed and precision of voice coil actuators.

Aura has now applied this knowledge to generating electricity under the hoods of automobiles. The company has developed a patented rotary device called the AuraGen™ that provides up to 8.5 kilowatts of continuous 60 hertz (Hz) AC power. Full power is generated slightly above engine-idle speeds and is more stable than home electricity.

AuraGen consumes less fuel, has reduced component wear, is much lighter and quieter, and produces nearly six times as much power per pound of equip-

1990

SDIO funds
Aura Systems, Inc.

1980

1985

1990

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2005



In 2004 the U.S. Army ordered a military version of the AuraGen for a brigade and a regiment that were being deployed to Afghanistan and Iraq.

ment than standard power generators and alternators. Typically, continuous alternators generate only 1.8 kilowatts, and can only produce 60 Hz electricity with the engine running at 3,600 revolutions per minute (rpm), much higher than idling rpm. In addition, AuraGen draws power from the engine proportional to its energy demand. Therefore, when there is no load, the generator draws no power from the engine.

Cashing In. As a result of the AuraGen's high efficiency and other advantages, the company has sold more than 4,000 of its AuraGen units as of August 2005. Aura has adapted the system to more

than 90 different engine models, including all Ford and GM models. Users include the Department of Health and Human Services' Office of Emergency Preparedness, the Federal Bureau of Investigation, police and fire departments across the country, and the U.S. military. In fact, in 2004 the U.S. Army ordered a military version of the AuraGen for a brigade and a regiment that were being deployed to Afghanistan and Iraq.

In addition to government uses, AuraGen could be used by construction companies, farms, emergency services, private residences, recreational vehicles, and

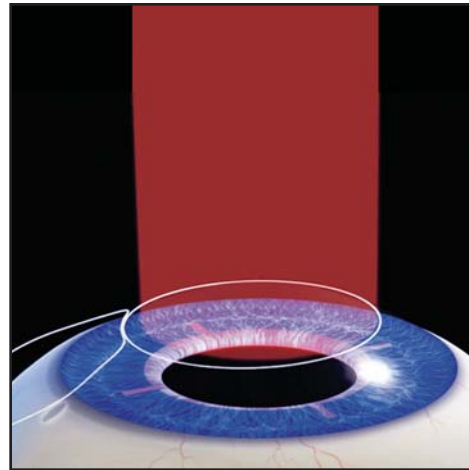
the military—virtually any application requiring power that cannot be accessed from the grid.

For more information visit:
www.aurasystems.com



The World in 1990 ... The Berlin Wall comes down; Germany unites. Nelson Mandela is released from prison in South Africa.

At SDIO in 1990 ... Ambassador Henry F. Cooper endorses the concept of Brilliant Pebbles and spells out the concept that became the system for Global Protection Against Limited Strikes (GPALS).



Tracking Missiles and Eyes?

Autonomous Technologies Corporation's LADAR technology is being used in an unexpected place, as part of vision correction laser surgery.

Missile Defense Needs. Part of SDIO's mission is to detect the launch of ballistic missiles and track them throughout their trajectory. Radar, generally understood to mean radio detection and ranging, is essential, but radio waves, and even microwaves are not the only parts of the electromagnetic spectrum that can be used to detect and track objects. Researchers are exploring a new technology using lasers called LADAR. One potential benefit seen for LADAR is that it could possibly provide more information about whether objects are decoys or actually warheads. As a result, in 1990 and 1991, SDIO funded Autonomous Technologies Corporation (ATC, Orlando, FL) to develop LADAR systems for tracking ballistic missiles.

Technology Solutions. Autonomous' research focused on increasing system speed and decreasing signal noise while reducing overall system size, weight, and complexity. Meanwhile, with NASA funding, the company also investigated LADAR's potential for use in autonomous rendezvous and docking of space vehicles. While conducting both SDIO- and NASA-sponsored research, Autonomous' president, Randy Frey, discussed with medical professionals the possibility of modifying his LADAR technology for laser vision correction. Frey's bright idea to commercialize the technology was later validated when he presented it to a panel of business experts at the SDIO Medical Technology Applications Review in 1992.

A person's eyes are always moving. Even when people think they are keeping them perfectly still, the eyes make small, involuntary movements (called saccadic movements). During laser vision correction, saccadic movements can cause laser pulses to impact the wrong location on the cornea, decreasing the accuracy of the procedure. Frey believed Autonomous' LADAR technology could track and compensate for these involuntary motions.

Cashing In. Frey's idea has grown into a very successful medical treatment used by hundreds of doctors in the United States. In 1993, ATC introduced the LADARTracker™ eye tracker. The patented device made 4,000 readings

1990

SDIO funds
Autonomous Technologies Corporation



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The U.S. Food and Drug Administration granted Autonomous approval to market LADARVision for the correction of nearsightedness, farsightedness, and astigmatism.

of the eye per second—effectively eliminating all eye movement errors. The eye tracker was combined with a unique, small-beam laser to create an automated laser vision correction system called T-PRK®. The new device, later renamed LADARVision™, became Autonomous' sole commercial product.

A turning point in product commercialization came in 1997 when the U.S. Food and Drug Administration granted Autonomous approval to market LADARVision for the correction of nearsightedness, farsightedness, and astigmatism. One year later, Autonomous merged with Summit Technology, Inc.,

which was then acquired by Alcon, Inc., a global eye-care products manufacturer in 2000.

Alcon currently offers the LADARVision 4000® system for laser vision correction, including laser-assisted in situ keratomileusis, or LASIK, surgery. According to Alcon, 396 LADARVision lasers have been installed worldwide. In 2002 Alcon received approval to marketing a new laser eye surgery procedure called LADARVision CustomCornea®, which pushes vision correction beyond 20/20. The new procedure uses wavefront technology to create a 3D map of the optical properties of the eye, enabling

surgeons to correct defects unique to the patient's eye.

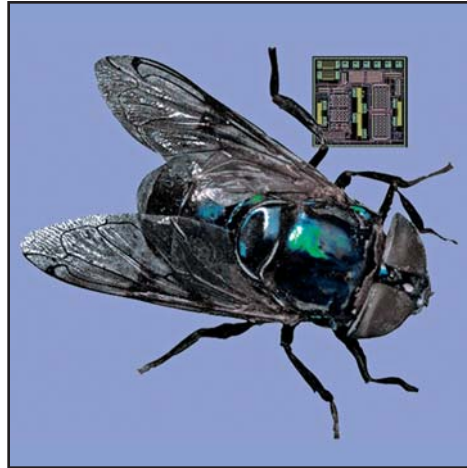
Overall, the laser vision correction market is significant. According to the Vision Council of America, approximately 157 million American adults, more than 70% of the population, wore eyewear such as eyeglasses, contacts, or reading glasses in 2005.

For more information visit:
www.ladarvision.com



The World in 1990 ... Iraq invades Kuwait, leading to the first Gulf War. The crew of the Space Shuttle Discovery deploys the Hubble Space Telescope.

At SDIO in 1990 ... The House calls for a centrally managed theater missile defense program that asks the Secretary of Defense to submit a plan for its development and fielding.



Chips for Hearts, Ears, and Satellites

NVE Corp.'s investigation into magnetic computer memory has led to sensors enabling the next generation of pacemakers and hearing aids.

Missile Defense Needs. The radiation in space is not kind to electronics, therefore in 1992 SDIO began funding NVE Corporation (Eden Prairie, MN), to investigate a new kind of computer memory, called magnetoresistive random access memory (MRAM), that might withstand radiation. Although MRAM would combine the advantages of existing types of memory, it is still being developed. However, devices needed for MRAM are being used to improve medical products.

Technology Solutions. MRAM uses magnetic fields to record information, but unlike tape recorders and VCRs in which a short section of tape holds magnetic information, these fields are

held in extremely small spaces—basically by one electron. With information stored in this way, extremely sensitive sensors are required to read the information. That role is played by giant magnetoresistive (GMR) sensors.

When conventional magnetic sensors pass over a magnetic surface, like a tape, an electrical current is induced in the sensor and is measured. In magnetoresistance, the magnetic field causes a change in resistance, or the flow of current, instead of inducing a current. In 1988 French scientists discovered the GMR phenomenon by using a unique arrangement of new materials to make an extremely sensitive sensor. Most

hard drives use this to read data and NVE has developed several GMR technologies in its push toward MRAM.

Cashing In. Some of the most useful applications of GMR sensors have been in medicine. New hearing aids being manufactured by Starkey Laboratories use NVE's GMR-based components to automatically detect whether a telephone headset or headphones are being used. Conventional hearing aids must be manually switched or incorporate a bulky mechanical coil sensor, so that they can amplify the sounds being produced by the telephone or speaker correctly. Now, Starkey produces very small hearing aids that can automatically

1992

SDIO funds
NVE Corporation



1980

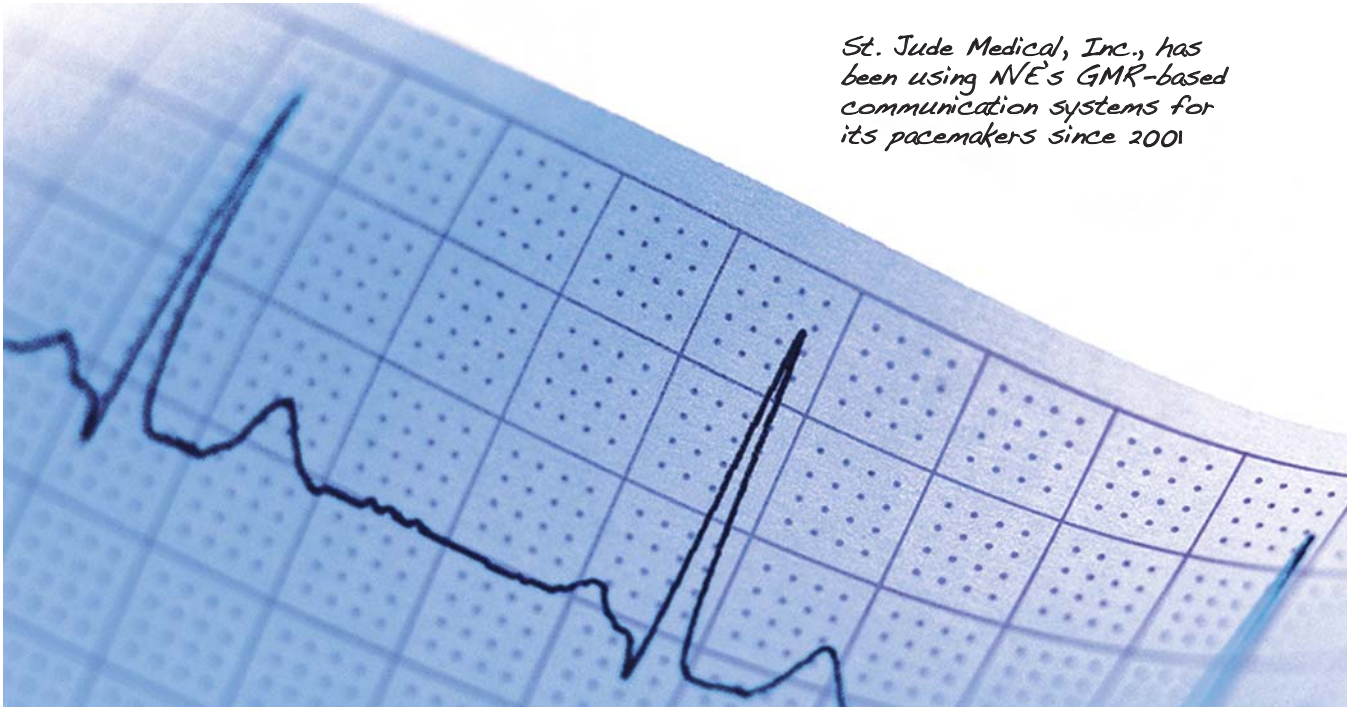
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St. Jude Medical, Inc., has been using NVE's GMR-based communication systems for its pacemakers since 2001

adjust—something that could not be done without a GMR sensor.

GMR sensors are used in hard drives to sense magnetic fields and read information, but NVE has developed a series of components for short distance wireless magnetic communication. The components use small coils as transmitters and GMR sensors as receivers, and they are being used in an important medical device: the pacemaker.

The Cardiac Rhythm Management Division of St. Jude Medical, Inc., has been using NVE's GMR-based communication systems for its pacemakers since 2001 when it placed an order for

more than \$200,000 of these systems—an order that grew to \$1.2 million in 2003. The GMR components allow the pacemaker to communicate information about heart function and receive new instructions faster and more reliably while still in the chest of the patient.

NVE is now developing on a nanoscale biological sensor that uses GMR sensors to detect and track molecules, such as DNA and proteins, that have been attached to nanosized magnetic beads.

One company is using NVE GMR sensors for a more pedestrian use, vehicle traffic sensors. Nu-Metrics, Inc. makes a line of compact automobile traffic sensors that

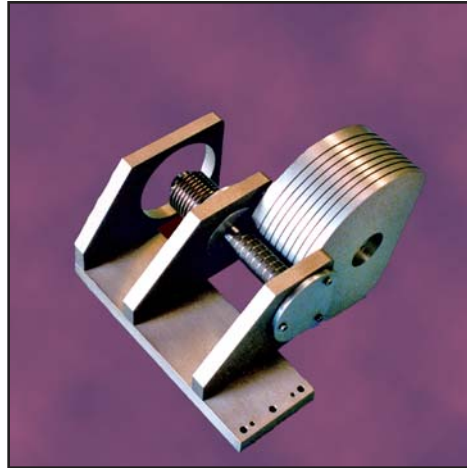
can be embedded in roadways to detect cars, trigger traffic lights, and record traffic volume. Conventional wire loops (rectangles cut into pavement at intersections) work well but are labor-intensive, interrupt traffic, and difficult to repair.

For more information visit:
www.nve.com



The World in 1992 ... Iraq refuses to abide by UN resolutions after the Gulf War. William Jefferson Clinton is elected president.

At SDIO in 1992 ... Ambassador Henry Cooper completes a memorandum of understanding with the branches of the armed services describing how the services would work with SDIO on missile defense systems.



Holding Steady

Sagebrush Technology, Inc.'s Roto-Lok technology enables stable and accurate positioning of tools from cameras in photography studios to needles for biopsies.

Missile Defense Needs. As anyone who has made home movies knows, stability is key for not making your audience sick to their stomachs. Stability and precise positioning of sensors, lasers, and antenna for missile defense systems present a similar problem. With help from the BMDO, Sagebrush Technology, Inc. (Albuquerque, NM), has developed a rotary drive system to precisely position instruments. This system, called Roto-Lok®, has been used on communications systems, and it controlled a telescope on BMDO's High Altitude Balloon Experiment. The system has found a wide range of uses and might even be at your local shopping mall.

Technology Solutions. To deliver high-precision positioning without the backlash and vibration normally produced by gears, the company's technology uses cables that are wrapped around a cylinder and a capstan in a figure-eight pattern and then attached using tensioning springs. When the capstan turns, friction between the cables and the cylinder provides smooth rotation of the drum and instruments mounted to it. The tensioned cables provide high torsional stiffness without backlash—a design problem in precision gears that reduces pointing accuracy and transmission efficiency. Also, because the cables do not slide on

the drum or capstan, there is virtually no wear, which decreases maintenance cost and extends the life of the system relative to competing technology. In addition, any imperfections on a single cable or on the drum are averaged over multiple cables, providing an extremely smooth and accurate drive.

Cashing In. Sagebrush's technology has had a wide range of commercial successes from holding cameras to holding needles. In the late 1990s, the company began building the first production units of its Roto-Lok pan-and-tilt gimbal for a chain of shopping-mall photography studios. The gimbal allowed studio photographers to quickly rotate their cameras from

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SDIO funds
Sagebrush Technology, Inc.



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In the late 1990s, Sagebrush began building the first production units of its Roto-Lok pan-and-tilt gimbal for a chain of shopping-mall photography studios.

landscape-mode to portrait-mode photographs. Photographers can remotely control and position the camera, then shoot and immediately display the picture on the monitor for the customer.

Sagebrush and Current Corp. of Port Moody, BC, Canada, have collaborated to develop a marine night-navigation system that incorporates Current's night-vision technology with Sagebrush's Model 30 positioner in both stabilized and unstabilized configurations. Current Corp. sells the night-navigation system and offers several configurations in which the Sagebrush Model 30 can be mounted on coastal patrol boats, high-end pleasure craft, or large ships

to identify potential marine hazards as well as to perform search operations from long distances.

Fischer Imaging (Denver, CO) uses Roto-Lok technology to improve the accuracy of its needle Mammothest® biopsy guidance system. Used with an x-ray imager, the system precisely positions the needle for breast tissue biopsy. Sagebrush began supplying parts for the needle positioner in 1998, and in 2002 Sagebrush began providing Fischer with the entire needle positioner as a turnkey product.

Sagebrush cited the Technology Applications program's TA Review process as well as exposure in TA

Program outreach publications as a "big stimulus" for Sagebrush's growth. For example, a panel member at a TA Review in 1993 provided Sagebrush with a contact at Fischer Imaging.

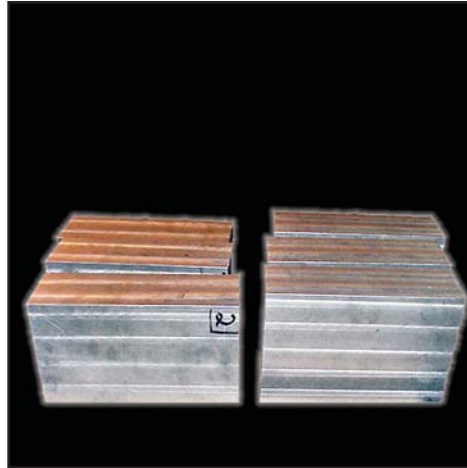
In 2005 Sagebrush leased an additional 5,000 square feet of space to handle production of new products, to satisfy increased demand from the security and defense industries, and to fulfill a continued manufacturing agreement with Fischer Imaging for needle-biopsy guidance systems.

For more information visit:
www.sagebrushtech.com



The World in 1993 ... The World Trade Center in New York City is bombed by terrorists. Palestinian and Israeli leaders sign a peace accord in Washington, DC.

At SDIO in 1993 ... The Strategic Defense Initiative Organization (SDIO) is redesignated the Ballistic Missile Defense Organization (BMDO) by the Clinton administration.



(Heat) Sinks in Space

Metal Matrix Cast Composites, Inc.'s graphite metal composite is orbiting the earth, cooling the electronics aboard an advanced DIRECTV satellite.

Missile Defense Needs. Thermal-management problems are endemic to missile defense by the very nature of the machines themselves. Both rocket motors and electronic equipment produce heat, and with no way to remove or withstand that heat, computer processors and rockets will fail. BMDO funded research to reduce the cost of manufacturing advanced thermal-management materials and to make them more capable, enabling short- and long-range payoff for both industry and for the U.S. military.

In the early 1990s, BMDO funded MIT researcher Dr. James Cornie through its Innovative Science and Technology program to investigate a new process of casting metal alloys. Cornie acquired an exclusive worldwide, all-fields-of-application license from MIT for the process and related tooling materials, and in 1993 he started Metal Matrix Cast Composites, Inc. (MMCC; Waltham, MA), to commercialize the technology.

Technology Solutions. The process came to be called Advanced Pressure Infiltration Casting (APIC™). As the name

implies, APIC uses pressure to fuse elements together inside a mold and then cools the alloy in a very precise and controlled way. The net result is a cast part that provides desirable characteristics of strength, thermal conductivity, thermal expansion, porosity, and density—at enviable rates of production under strict quality-control requirements. In a BMDO SBIR Phase II contract funded between 1994 and 1996, MMCC demonstrated this low-cost manufacturing aspect of the process and produced, as a test case, brake calipers.

1993

SDIO funds
Metal Matrix Cast Composites, Inc.

1980 1985 1990 1995 2000 2005



Boeing ordered MetGraf™ aluminum graphite composite material (made with the APIC™ process) to improve microwave communications on Spaceway, a new satellite communications system now being used in next-generation DIRECTV satellites.

Cashing In. The new material was applied quickly for missile defense. In a \$500,000 contract with the Raytheon Company, MMCC supplied low-density, high-stiffness parts for upper-stage housings used in the U.S. Navy-based Theater Wide Standard Missile-3.

BMDO further funded MMCC to create low-cost, graphite-fiber-reinforced copper and aluminum alloys for electronic thermal management. The idea was relatively simple: to create a heat sink that had a coefficient of thermal expansion similar to the device and substrate to which it was attached. Chips could

operate at higher efficiencies because heat would be whisked away more efficiently and the MMCC process made packaging less expensive. MMCC expanded its production facilities to fulfill customer orders from Ixion Technologies, an advanced electronics packaging company.

The success of APIC continued into 2004, when Boeing ordered MetGraf™ aluminum graphite composite material (made with the APIC process) to improve microwave communications on Spaceway, a new satellite communications system now being used in next-

generation DIRECTV satellites. MetGraf, with its low density, enabled a reduction in antenna mass and, thus, improvements in total satellite system design. The company, while continuing to market MetGraf, is working on a new class of materials that can conduct even more heat away from sensitive electronics. MMCC has also developed a graphite composite that can replace costly beryllium in structural components for spacecraft.

For more information visit:
www.mmccinc.com



The World in 1993 ... The Space Shuttle Endeavour crew corrects an optical flaw in the Hubble Space Telescope. The Mississippi and Missouri rivers flood portions of the Midwest.

At SDIO in 1993 ... The Extended Range Interceptor successfully collides with a STORM target warhead at the White Sands Missile Range in New Mexico.



Clear Voices Through the Fog

ThermoTrex's development of millimeter wavelength imaging has enabled a new technique for free space broadband communications that is not hindered by weather conditions.

Missile Defense Needs. Missile defense systems produce vast amounts of data that need to be transmitted, whether between satellites, to the ground from space, or from one equipment trailer to another. Ideally, fiber-optic cables could be easily strung everywhere, but practically they cannot. Therefore, in the early 1990s, BMDO began funding research investigating using lasers, without optical fibers, to transmit information.

Beginning in 1995 the Army Research Laboratory funded ThermoTrex Corporation (San Diego, CA) to develop imaging technology using passive millimeter-wave imaging in the frequency range of 70-100 gigahertz. Millimeter-

wave imaging occupies a middle ground between infrared imaging (at a shorter wavelength) and shortwave radio imaging (at the longer wavelength). Researchers at ThermoTrex soon realized that these millimeter-wave wavelengths could also be used to communicate.

Technology Solutions. Advanced millimeter-wave communications work much like free-space optical communications, but with one important difference: This wavelength travels uninterrupted through clouds and fog. Lasers are very good for high-speed communications, but they have a drawback: Laser beams are scattered by dust,

atmospheric disturbances, mist, fog, and clouds.

The advanced millimeter-wave radio technology had advanced to the point that Trex designers thought it could serve as a mainstay and not merely a backup. The millimeter-wave radio signals would not be scattered by clouds or heavy fog, and above frequencies of 60 gigahertz, the transmissions are not absorbed by oxygen in the atmosphere. And advanced millimeter-wave radios could be used for any broadband communications network requiring rapid deployment, redundancy, or mobility—characteristics typical of free-space optical equipment. These uses include point-to-

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BMDO funds
ThermoTrex Corporation

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The added advantage was that millimeter-wave radio signals would not be scattered by clouds or heavy fog.

point high-speed data transmission for locations such as islands, oil-drilling platforms, and ships.

Cashing In. In 2000 employees of the research and development division of ThermoTrex decided to spin off as an independent company called Trex Enterprises headquartered in San Diego. They also decided to concentrate on advanced millimeter-wave communications. In May 2001 Loea Corporation, a spinoff from Trex Enterprises, was formed to commercialize this technology.

In January 2004 the FCC formalized its rules on the millimeter-wave spectrum, and licensed the bands of 71 to 76 gigahertz and 81 to 86 gigahertz.

Loea has installed more than a half-dozen working systems for U.S. government customers such as the Coast Guard as well as with commercial partners such as Electronic Data Systems and customers such as the Hawaii Institute for Marine Biology.

The typical Loea transceiver has an antenna dish that measures anywhere from 2 to 4 feet wide, uses about 40 watts of power requiring only a standard 110-volt AC input power source, and connects with a standard telecommunications network. It costs far less than installing fiber-optic cable—costing about \$60,000 for a pair of transceivers, with an additional \$20,000 to \$40,000 in installation costs.

Another intriguing application is real-time airborne surveillance. The Office of Domestic Preparedness funded Trex, in partnership with Earthdata and Raytheon Company, to investigate using a wireless link to relay high-quality infrared images in real time to the ground for analysis. The feasibility of such a link was demonstrated in February 2005.

For more information visit:
www.trexenterprises.com



The World in 1994 ... The English Channel Tunnel is completed between the United Kingdom and France. O.J. Simpson is arrested for the killing of his wife and Ronald Goldman.

At BMDO in 1994 ... The Army selects the Extended Range Interceptor over the Patriot multimode missile for the Patriot Advanced Capability-3 theater missile defense program.



Seeing the Wind

Coherent Technologies, Inc.'s lidar technology may make air travel safer and help protect important locations from chemical or biological attack.

Missile Defense Needs. It is almost impossible to imagine a modern missile defense program without lasers for use as weapons, for communications, and for light detection and ranging (lidar). Lasers can obtain different information than radio- or microwave-frequency radar and, for missile defense systems, they might be able to discriminate at long range, between real and decoy ballistic missiles. If a lidar system is quick and sensitive enough, it can obtain data about a target and relay that data in time for a strategic defense decision to be made.

In 1995 BMDO began funding Coherent Technologies, Inc. (CTI; Boulder, CO), to develop tunable, high-power diode-pumped lasers for lidar.

Technology Solutions. CTI's high-power diode-pumped lasers produced 0.5 to 1.0 joule-per-pulse energies at pulse-repetition frequencies of about 40 hertz. CTI prototyped several different designs operating in the 1- to 2-micron wavelength range, which is considered to be eye-safe.

Cashing In. As it happens, lidar can also detect invisible air currents known as

wake vortices, which are disturbances in air caused by the passing of an aircraft. By measuring a vortex's circulation strength and by tracking its speed and direction, CTI's lidar device can determine when a disturbance dissipates. Such technology found immediate use for airport and aircraft safety—a fact not lost on the U.S. Air Force, NASA, or the FAA, all of which moved quickly to fund CTI as well.

In 1996 CTI created a commercial products division, CLR Photonics, Inc., to market its lidar technology as WindTracer®, which has many other

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BMDO funds
Coherent Technologies, Inc.



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Lidar can also detect invisible air currents known as wake vortices, which are disturbances in air caused by the passing of an aircraft.

applications including meteorological research, air pollution monitoring, and firefighting. But it is the airport and aircraft safety application that may be the biggest dividend to the U.S. taxpayer. WindTracer has been installed at the Aspen, CO, airport, St. Louis International Airport, Hong Kong International Airport, and McCarran International Airport in Las Vegas, and the FAA continues to study the wake vortex phenomenon.

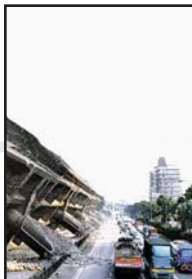
The U.S. military has used WindTracer to detect wake vortices; the military is also exploring its use in defending against chemical and biological attack. In this

application, lidar can detect and track plumes of bio-aerosols and chemical weapons. In May 2004 WindTracer, along with an army of other instruments, provided important wind and airflow data on conditions surrounding the Pentagon while a simulated chemical or biological agent was released to see how a such an attack would affect the base. Today, WindTracer continues to watch over the Pentagon.

In fall 2005 Lockheed Martin purchased CTI and announced that the organization would be called Lockheed Martin Coherent Technologies and be man-

aged by Lockheed Martin Space Systems. CTI's founder and chairman, R. Milton Huffaker, said, "Through this combination, Coherent Technologies will extend its reach by becoming the center of excellence for Laser Radar within Lockheed Martin, providing its customers access to new technological advancements, while our employees will have access to a broader array of professional opportunities. This is truly a win-win combination."

For more information visit:
www.ctilidar.com



The World in 1995 ... The Federal Building in Oklahoma City is bombed by Timothy McVeigh and Terry Nichols. A magnitude 7.2 earthquake strikes Kobe, Japan, killing 6,000.

At BMDO in 1995 ... President Clinton vetoes a \$265 billion defense bill, saying it would waste money on an unneeded missile defense system.



Strong and Bright Polymers

Maxdem, Inc., has taken polymers to new heights, making self reinforced polymers for structural applications as well as light emitting polymers.

Missile Defense Needs. BMDO began funding Maxdem, Inc. (San Dimas, CA), with an SBIR Phase II award in 1991 for a project on thermally stable, low-dielectric polymers for advanced electronics. Throughout the 1990s and into the current decade, the agency continued to fund Maxdem with SBIR awards for projects involving polymers, resins, and other materials. The Maxdem-developed tough polymers have been envisioned for a host of missile defense applications: in composites for missile components, on printed circuit-board

substrates, and even in scratch-proof windows or displays.

Technology Solutions. Maxdem created an entirely new family of rigid-rod polymers that are many times stiffer than conventional plastic materials. The structure of the polymers, called Parmax® Self-Reinforced Polymers (SRPs), contains a rigid-rod “backbone” that imparts exceptional strength and stiffness while also giving the polymers their processibility. For instance, the materials have been compared to several structural metals including forms of

aluminum and stainless steel, but they can be fabricated using more versatile and cheaper polymer manufacturing methods such as injection molding and extrusion.

For structural applications, manufacturers often reinforce conventional plastics with fibers, but Parmax plastics have enough strength due to their rigid-rod backbone that they do not need added fibers. According to Maxdem officials, the self-reinforced polymers are two to four times the stiffness of and two to three times the strength of any other

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BMDO funds
Maxdem, Inc.



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Organic light-emitting diodes are already being used in vivid color displays on some cell phones, but P-OLEDs will add the strength advantages of polymers to these displays and expand their potential applications.



thermoplastic. As a result, these polymers could replace steel or metal in applications such as ammunition cases, lightening the load for military transport aircraft.

Cashing In. According to Maxdem, pound for pound, Parmax SRPs could rival aluminum or titanium alloys in aerospace applications. To meet the demand for these materials, Maxdem spun off a company to produce them in quantity. Mississippi Polymer Technologies, Inc. (MPT), began operating in January 2000 and in the spring of

2002 opened a 20,000-square-foot research and processing pilot plant in the Port Bienville Industrial Park in Pearlington, MS.

Maxdem's materials also are serving as a foundation for research into other applications and could lead to a future with brighter and cheaper video displays. Maxdem is tailoring the polymers from the Parmax line for use in polymer organic light-emitting diodes (P-OLEDs). Such technology research opens up creative possibilities, such as pizza box tops that display video advertisements,

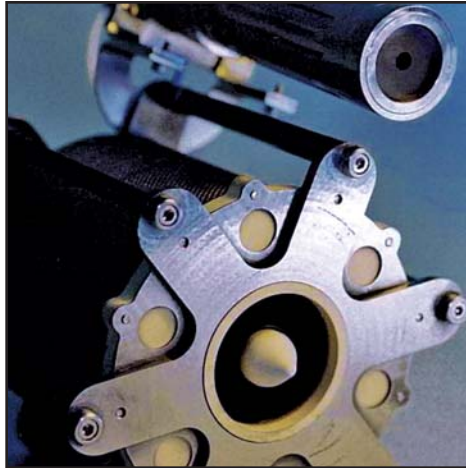
video store signs, and room lighting panels that could be applied like wallpaper. Organic light-emitting diodes are already being used in vivid color displays on some cell phones, but P-OLEDs will add the strength advantages of polymers to these displays and expand their potential applications. In 2004 Maxdem licensed its light-emitting polymer technology to an undisclosed multinational chemical company.

For more information visit:
www.maxdem.com



The World in 1996 ... The United Kingdom announces that mad cow disease may have caused the death of 10 people; mayhem ensues. Dolly, the first cloned animal, is born in Scotland.

At BMDO in 1996 ... The SDIO Clementine space experiment detects the presence of substantial amounts of ice near the south pole of the moon.



What Goes Around Comes Around!

Space Power, Inc., and other organizations have been advancing the development of Hall-effect thrusters which can maneuver spacecraft more efficiently.

Missile Defense Needs. Satellites use small onboard propulsion systems to help maintain and adjust their orbits. In the case of the ballistic missile defense application, BMDO was interested in keeping a sensor satellite in a precise high-altitude orbit looking over the same area of interest for a long periods of time. However, conventional thrusters are basically small rockets, and they contribute significant weight for their limited thrust and lifetime. Therefore, BMDO and NASA funded Space Power, Inc. (SPI; San Jose, CA), to develop Hall-effect thrusters.

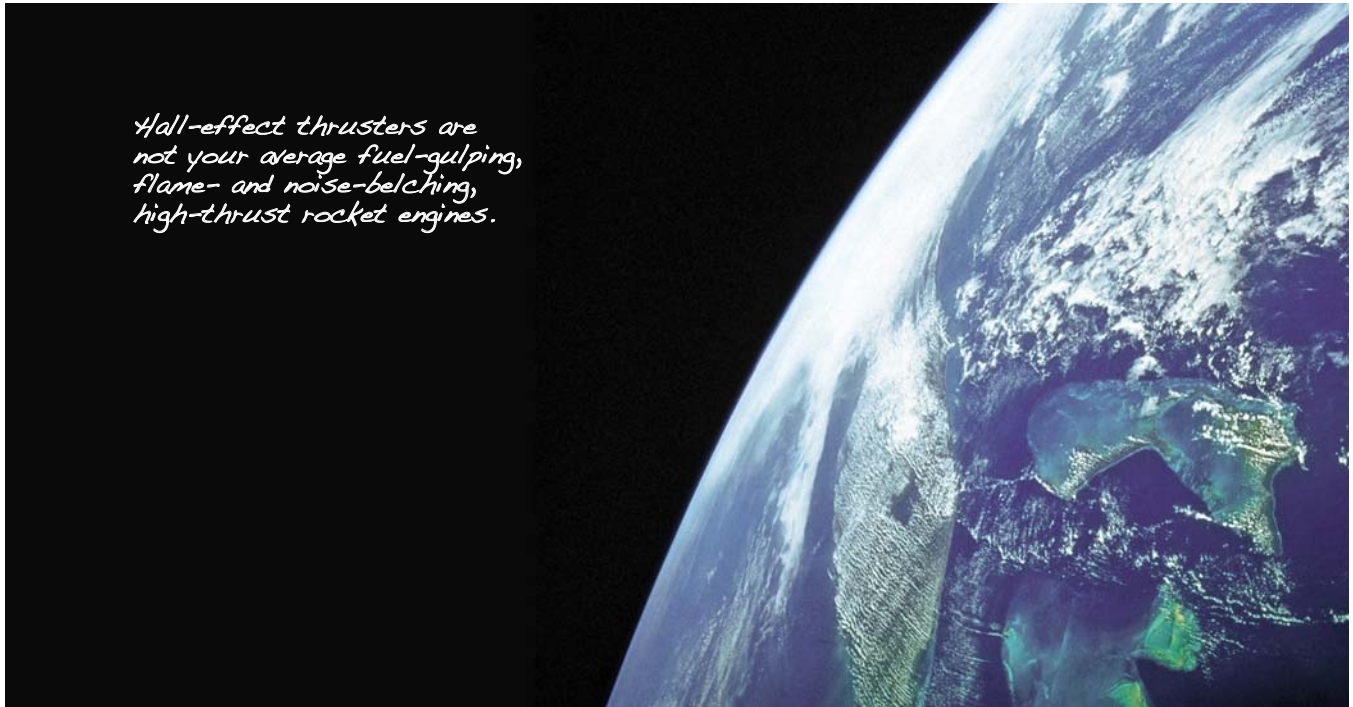
Although this type of thruster was originally conceived in the United States and some development work occurred in the 1960s, it was first fully developed and used in the Soviet Union in the 1970s. In fact, the Soviet Union flew many vehicles using the principle starting in 1972, and with the end of the Cold War, the United States learned of the Soviets' success. These thrusters could provide reliable, long-term, on-orbit propulsion systems to maintain satellites in their proper orbit, or to move them (gradually) into new orbits.

Technology Solutions. Hall-effect thrusters are not your average fuel-gulping, flame- and noise-belching, high-thrust rocket engines. Instead, they provide a source of very small but very long-lived thrust using a propellant that produces a very high thrust-to-weight measured as "specific impulse." Specific impulse is the ratio of thrust to the time-related amount (mass) of fuel required to produce that thrust, both measured in the same units (e.g., pounds of thrust divided by pounds of fuel per second to produce that thrust, measured in seconds).

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BMDO funds
SpacePower, Inc.

1980 1985 1990 1995 2000 2005



Hall-effect thrusters are not your average fuel-gulping, flame- and noise-belching, high-thrust rocket engines.

The technology itself uses a powerful magnetic field to accelerate a low-density plasma (usually a plasma of xenon gas)—the Hall effect. That acceleration of a very small mass results in the opposite and equal reaction against the thruster engine, producing thrust. Specific impulses of Hall-effect thrusters can range from 1,500 to 4,000 seconds, compared with 300 to 400 seconds for the fire-breathing monsters, but produce only milli-Newtons (mN) of thrust compared with their bigger million-pound thrust brethren. However, that miniature thrust can be maintained for

many thousands of hours and the fuel supply lasts for many years, which is exactly what is needed to keep satellites in orbit.

In the 1990s SPI had access to the Russian technology and in 1997 BMDO and NASA jointly funded a U.S./Russian Hall-effect thruster testing program, with NASA providing the ground-based test chambers as well as part of the \$10 million development funding, and SPI doing the actual development. Testing commenced in 1999 and met or exceeded specifications.

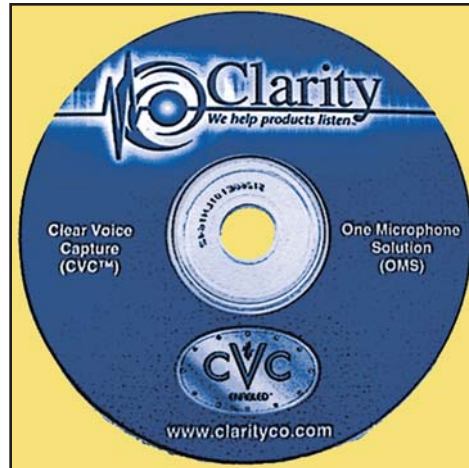
Cashing In. Other companies, large and small, have gone on to develop and use Hall-effect thrusters for space applications. SPI itself, perhaps due to its earlier BMDO- and NASA- funded success, was purchased by Pratt & Whitney, which produces a series of Hall-effect thrusters of varying thrust.

For more information visit:
www.pratt-whitney.com/prod_space_eprop.asp



The World in 1997 ... Japanese scientists control the motions of cockroaches by implanting microrobotic backpacks. The Green Bay Packers win their first Super Bowl in 29 years.

At BMDO in 1997 ... A modified SM-2 Block IVA destroys another missile at White Sands Missile Range. The SM-2 transitions from radar to infrared guidance before the intercept.



Listen Up

IC Tech, Inc.'s speech recognition systems improve computer based speech-recognition and are being used in mobile phone Bluetooth headsets.

Missile Defense Needs. Battle management, command, control, and communications are extremely important when military leaders are faced with decisions that must be made in minutes or even seconds. In 1997 BMDO funded IC Tech, Inc. (Okemos, MI), with an SBIR Phase II project to develop a microphone technology to assist battle management and other important functions for both Theater Missile Defense and National Missile Defense. And in 2002 BMDO funded IC Tech with an SBIR Phase I and then later with a Phase II to develop an audio-visual speech recognition engine using hidden Markov models, which are methods for recognizing sequences of information. Hidden Markov models can be used to recognize sequences of

missile data, which may help in distinguishing missiles from missile decoys.

Technology Solutions. The microphone system, called Clear Voice Capture (CVC)™, uses two microphones and advanced algorithms to mimic the human ear and brain. The algorithms extract signals and measure their frequency, direction, and time of arrival and then exploit statistical properties of distinct sound sources to isolate the voice signal of interest from background noise. The end result is speech that can be better understood in a noisy background, without the need for headsets that tether and encumber the user.

The process performs significantly better than conventional speech recognition microphones since it works by extracting the voice signal of interest from a mixture of sounds rather than suppressing noise, which can sometimes result in a suppressed signal as well. Demonstrated in an automobile in a variety of conditions, the system improved the accuracy of speech recognition by 35 to 40 percent, compared with conventional systems.

IC Tech's other BMDO-funded technology, the audiovisual speech-recognition "lip-reading" technology, is based on the premise that people recognize speech better when they see a speaker move his or her lips. IC Tech used hidden

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BMDO funds
IC Tech, Inc.

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In 2005 Clarity was acquired for \$17.1 million in cash by Cambridge Silicon Radio (CSR) of Cambridge, UK, a wireless solutions provider and supplier of Bluetooth technology.



Markov models to design and implement the visual object-recognition modules. Hidden Markov models are flexible and able to solve two problems at once: segmentation and recognition.

For instance, when audiovisual speech recognition is used to authenticate a user, a random phrase is issued as a challenge to the user who must speak it back. The voice print is matched with conventional software, but the video of the user is analyzed as well to make sure the lip shapes match what is expected. This prevents recorded voice prints from being used to gain illicit entrance.

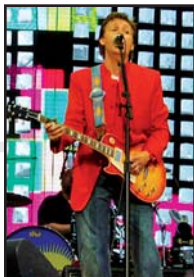
Audiovisual speech-recognition software also will significantly improve the

accuracy of existing speech-recognition engines for applications such as noise-immune voice command and control, whisper-level commands for enhanced privacy in public places, and automotive voice control.

Cashing In. In an effort to drive technologies toward commercialization, partners of IC Tech, Inc., formed a corporation called Clarity, LLC (later, Clarity Technologies, Inc.), to manufacture and market Clear Voice Capture (CVC)[™] noise-cancellation communications systems. Clarity released its first product in Summer 2000, focusing primarily on enhancing speed signals for PC speech recognition. And in September 2000, it established its first commercial contract

with a leading industrial design firm to provide signal processing software to a consumer electronics company. Clarity Technologies also funded 50 percent of the audiovisual speech-recognition development in exchange for transfer of the technology. In 2005 Clarity was acquired for \$17.1 million in cash by Cambridge Silicon Radio (CSR) of Cambridge, UK, a wireless solutions provider and supplier of Bluetooth technology.

For more information visit:
www.ic-tech.com



The World in 1997 ... The ashes of Gene Roddenberry, Star Trek creator, are launched into space. Paul McCartney is knighted by Queen Elizabeth II.

At BMDO in 1997 ... A PAC-3 missile launches successfully; no intercept had been planned.



120 Volts AC Under the Hood!

Raven Technology, LLC, has developed an under the hood electrical generator to provide power wherever it is needed.

Missile Defense Needs. Theater missile defense requires missile batteries as well as radar systems to be deployed in areas that might become targets of ballistic missiles. One essential component for mobile equipment is a reliable electrical supply, normally supplied by stand-alone generators. But in 1997 Raven Technology, LLC (New Brunswick, MA), received funding to develop a small, lightweight, under-the-hood generator to supply 5 kilowatts (kW) of instant-on, single-phase, 120-volt,

60-hertz AC power at any engine shaft speed. With no need for towing a generator, any vehicle could become an instant supplier of electricity for communications systems, detection equipment, or cooling systems.

Technology Solutions. The secret to Raven's patented AC-Direct™ system is what company designers call "soft commutation", a way of modulating an alternator's electromagnetic field to control the output voltage. It means no inverter

is required. No inverter means no bulky control-electronics package and less equipment to worry about, as well as less weight to carry. Raven named its 5 kW generator unit the Blackbird™ and subsequently created "install kits" for a variety of commercially available vehicles.

Cashing In. Instant-on power has both commercial and military applications. In January 2004 Raven Technology reached a joint marketing agreement with a leading manufacturer of mast

1997

BMD0 funds
Raven Technology LLC

1980 1985 1990 1995 2000 2005



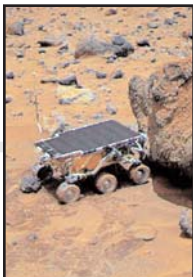
The secret to Raven's patented AC-Direct™ system is what company designers call "soft commutation".

and lighting products used by fire departments and other emergency services. And in May 2004 the Marine Corps Systems Command announced that it would include Raven's Blackbird generator as part of a comprehensive testing program to evaluate under-hood power for its multipurpose HMMWV ("Hummer") tactical vehicle.

In the commercial world, Raven currently offers kits that can be installed on 10 commercially available trucks, including several Ford Powerstroke

F-series trucks and Excursion SUVs and Chevy Duramax- and Vortec-powered trucks and SUVs. Raven is also introducing a power take-off driven unit (commonly called a PTO) that can be mounted on any larger diesel vehicle with a standard 1:1 hot shift PTO available. It will produce power much more efficiently than existing hydraulic systems and cost significantly less.

For more information visit:
www.raventechpower.com



The World in 1997 ... The Mars Pathfinder lands, and the Sojourner Rover records images and scientific data. Diana, Princess of Wales, dies.

At BMDO in 1997 ... Rep. Curt Weldon (R-PA) introduces legislation calling for more PAC-3, THAAD, NTW, and Israeli Arrow technology to counter Iran's development of mid-range ballistic missiles.



Seeing the Heat

Pacific Advanced Technology's infrared image correction technology can detect leaking gases at refineries, utilities, and other important sites.

Missile Defense Needs. Missile exhaust leaves trails that can be seen by infrared cameras. From the earliest inception of SDI, there has been continuous missile defense program interest in developing highly accurate infrared sensors to help detect missile launches.

Technology Solutions. Beginning in 1998 BMDO funded Pacific Advanced Technology (PAT; Santa Ynez, CA) to develop nonuniformity-correction technology that would attach directly to a focal plane array. PAT built a complete "smart" system including nonuniformity

correction, image stabilization, and two-color ratios directly on a focal plane array chip. The electronics PAT developed were uniquely low-noise and highly accurate.

The technology, in addition to identifying hot gases leaving a rocket, can detect any gases that absorb infrared radiation either in the mid-wave range (3 to 5 microns) or long-wave range (8 to 12 microns) in a more terrestrial setting. The correction technology could improve detection of leaking methane, propane, and many other gases by

comparing their spectral signatures (infrared absorption against a normal background).

Cashing In. Those electronics found a new life in a patented gas-leak-detection camera called the Sherlock®. The device is a combination of an image spectrometer, a cooled "sensor engine" (supplied by Indigo Systems Corp.), and a viewer. The system allows real-time detection of the presence of methane, propane, or other gas leaks. In addition, Sherlock is compact and battery-operated, making it portable enough for

1998

BMDO funds
Pacific Advanced Technology

1980

1985

1990

1995

2000

2005



The system allows real-time detection of the presence of methane, propane, or other gas leaks. In addition, Sherlock is compact and battery-operated, making it portable enough for handheld use or mounting on aircraft.

handheld use or mounting on aircraft. These abilities piqued the interest of petroleum companies, such as British Petroleum, which worked in tandem with the Gas Technology Institute to provide funding and facilities for testing the equipment and tested the device in 2003. Shell Petroleum, N.V., and a corporation in Sweden have also expressed interest in this technology.

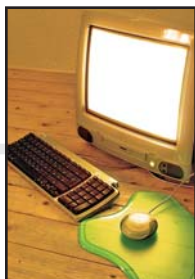
In November 2004 PAT formed a wholly owned subsidiary, Gas Imaging Technology, for the purpose of entering a potential multibillion-dollar gas imaging

market. If the U.S. Environmental Protection Agency were to accept spectral surveys in lieu of the current Method 21 (involving a painstaking method of physically applying solutions to facility components to find leaks), the market demand for gas-detection cameras would significantly and rapidly increase.

In addition, as concern about global warming increases, this technology may be used to detect leaks of greenhouse gases such as sulfur hexafluoride, which is used as an insulator in electrical

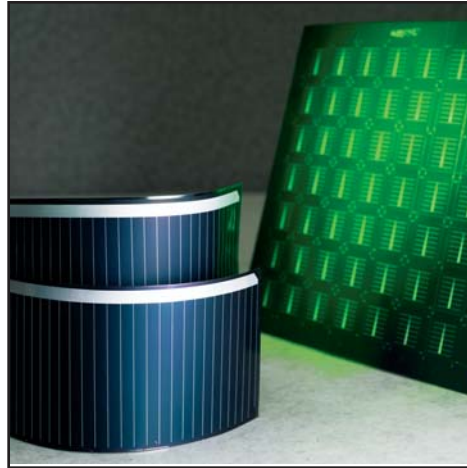
transformers at large utilities. The technology could also be applied to detect chemical and biological warfare agents, and PAT has introduced a camera system called Warlock for homeland security and military customers.

For more information visit:
www.patinc.com



The World in 1998 ... Daimler-Benz and Chrysler merge; Apple Computer introduces the iMac; Google is founded. The Int'l Space Station's first module is launched, and John Glenn is the oldest man to travel into space.

At BMDO in 1998 ... The National Missile Defense (NMD) Integrated Test Flight-2 (IFT-2) is carried out successfully.



Solar Cells—Foil-ed

Daystar Technologies, Inc.'s solar cells are flexible and lighter weight than traditional solar cells. And they may soon appear on a house near you.

Missile Defense Needs. Solar energy is essential for satellites and for the MDA's high altitude airship project. High performance solar cells for satellites are made in small batches, and MDA wanted to see if a previously developed mass-production technique could be modified to produce lightweight solar cells to power high-altitude airships.

Dr. John Tuttle and partners co-founded DayStar Technologies, Inc., in 1996, then located in Grass Valley, CA. Prior to founding DayStar, Tuttle held the position of senior scientist at the National

Renewable Energy Laboratory (NREL), where he was responsible for technology development relating to thin-film copper-indium-gallium-diselenide (CIGS)-based solar cells.

Technology Solutions. The DayStar Technologies innovation was twofold: a sandwiching of a 2.5-micron-thin CIGS layer between a transparent zinc oxide window on the top and a stainless steel foil on the bottom; and continuous in-line processing of the same, providing the economy of scale inherent in mass-production techniques.

In 1999 and 2000, MDA-predecessor BMDO funded DayStar Technologies to see if specialty lighter-weight foils could be substituted for steel, and whether the same reduced manufacturing costs could be achieved via similar high-volume production. This line of research continues today under a Phase II SBIR from the Department of Defense, administered by NASA's Glenn Research Center in Cleveland, OH.

The result was a product announced in March 2005 called LightFoil™ for high specific power applications such as

1999

BMDO funds
DayStar Technologies, Inc.

1980 1985 1990 1995 2000 2005



LightFoil is flexible. The product molds to curved surfaces, and can be trimmed to conform to complex geometric requirements.

high-altitude airships and winged unmanned aerial vehicles. DayStar claims that LightFoil provides a specific power level of 1,440 W/kg in the laboratory; realistically, DayStar engineers are aiming for a specific power target that will exceed 1000 W/kg with samples available in 2005. Even at the lower figures, it represents a significant improvement in power output-to-weight over existing thin-film solar technology. And there is another advantage: LightFoil is flexible. The product molds to curved surfaces, and can be trimmed to conform to complex geometric requirements.

Cashing In. In February 2004 DayStar Technologies announced an initial public offering and began trading on the NASDAQ stock exchange under the symbol DSTI. Shortly thereafter, the company moved to take advantage of a package of incentives offered by the state of New York. This included an award of a \$1 million grant to DayStar to scale up facilities for the commercial manufacture of low-cost solar cells for consumers in the state. The New York State Energy Research and Development Authority awarded the grant, which will be paid in phases as production milestones are

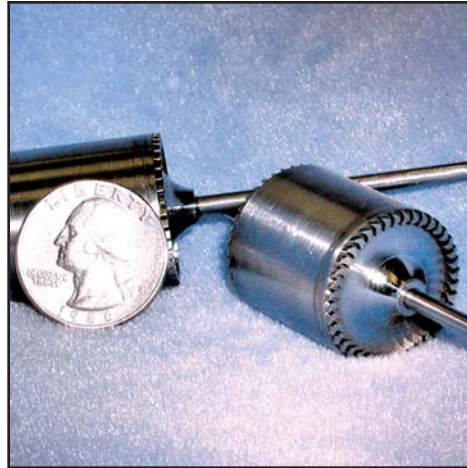
met at DayStar's Halfmoon, NY, manufacturing facility and at a new plant to be built at the Saratoga Technology & Energy Park. In 2005 DayStar won Frost and Sullivan's 2005 Technology Innovation of the Year Award for the development of the LightFoil technology.

For more information visit:
www.daystartech.com



The World in 1999 ... Companies and individuals prepare for computer problems stemming from Y2K. Nothing catastrophic happens. The euro currency is introduced in the European Union.

At BMDO in 1999 ... During a test, the PAC-3 missile system detects, tracks, and closes on a target missile, and intercepts the missile.



Going Up: Rockets and Ropes

Quoin International, Inc., developed a stabilization technology for rockets, but has turned it into a method of rapidly propelling people or objects up ropes.

Missile Defense Needs. On occasion, missile defense research produces a technology with a use that is quite unexpected and unanticipated—the equivalent of prospecting for silver and finding gold. One of the best examples was the research performed by Quoin International, Inc. (Carson City, NV), beginning in 1999. BMDO faced a challenge; a heat-seeking missile cannot afford to produce exhaust that fouls up its own guidance system. So BMDO was interested in any innovation that might help reduce contaminants from

the gas generator (rocket fuel). In 1999 BMDO awarded Quoin International an SBIR Phase I contract to study various filtration strategies.

Quoin engineers concluded that it was easier to just shut down the gas generator than to try and scrub the exhaust of contaminants. They turned the problem upside down: power the divert and attitude control thrusters via the gas generator indirectly by means of storing energy in, and then using, micro-flywheels. BMDO agreed and in 2000

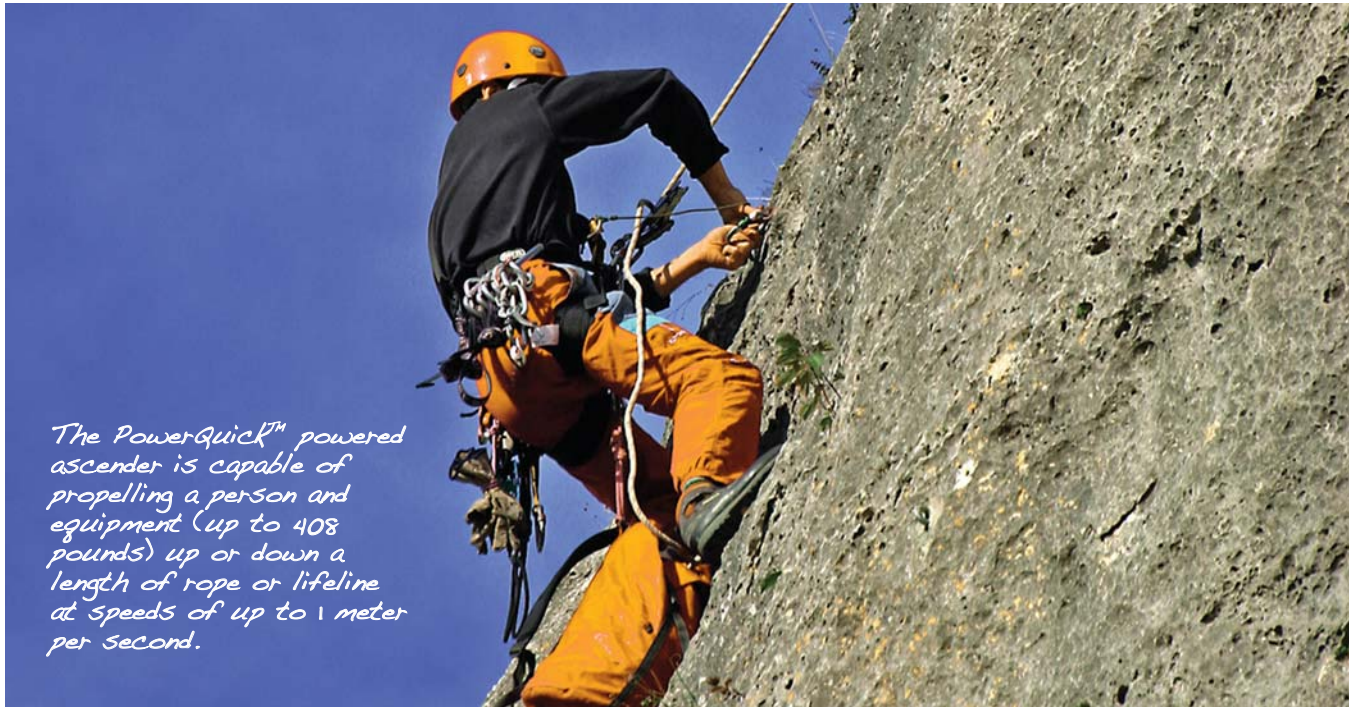
redirected the Phase II follow-on effort to focus on developing a flywheel-based attitude control system.

Technology Solutions. The result was a miniature turbine device, spinning an array of small flywheels at more than 100,000 revolutions per minute, that was estimated to be 70 percent lighter and 80 percent cheaper than conventional technology used to control pitch, yaw, and roll. This alone would have been a handsome return on investment, but there was more to the story. The

1999

BMDO funds
Quoin International, Inc.

1980 1985 1990 1995 2000 2005



Defense Advanced Research Projects Agency (DARPA) then funded Quoin to develop “ascender technology” based on the same concept of heated (or compressed, then released) gas spinning a turbine, but powering a device attached to a rope or cable.

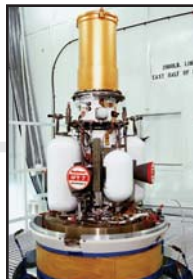
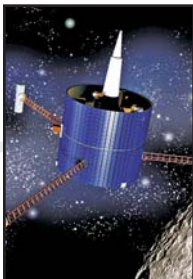
Cashing In. Quoin named the product that resulted the PowerQuick™ powered ascender, a lifting technology capable of propelling a person and equipment (up to 408 pounds) up or down a length of rope or lifeline at speeds of up

to 1 meter per second. The device itself weighs only about 7 pounds and could be used for a variety of both commercial and military applications, including emergency rescue, construction of skyscrapers, repair on bridges, and rapidly scaling walls, structures, cliffs, or ship hulls. It sells for approximately \$5,000.

Aside from ascenders, Quoin's miniature turbine could one day give a whole new meaning to the term “hybrid”, as it could be used to supplement existing internal-combustion engine technology. An

engine could use propane, butane, or diesel fuel to produce a continuous stream of highly pressurized air that spins a turbine. Flywheels and actuators could be connected to an engine's drive train to generate electrical power and mechanical energy, with energy conversion efficiency on the order of 60 to 70 percent.

For more information visit:
www.quointech.com



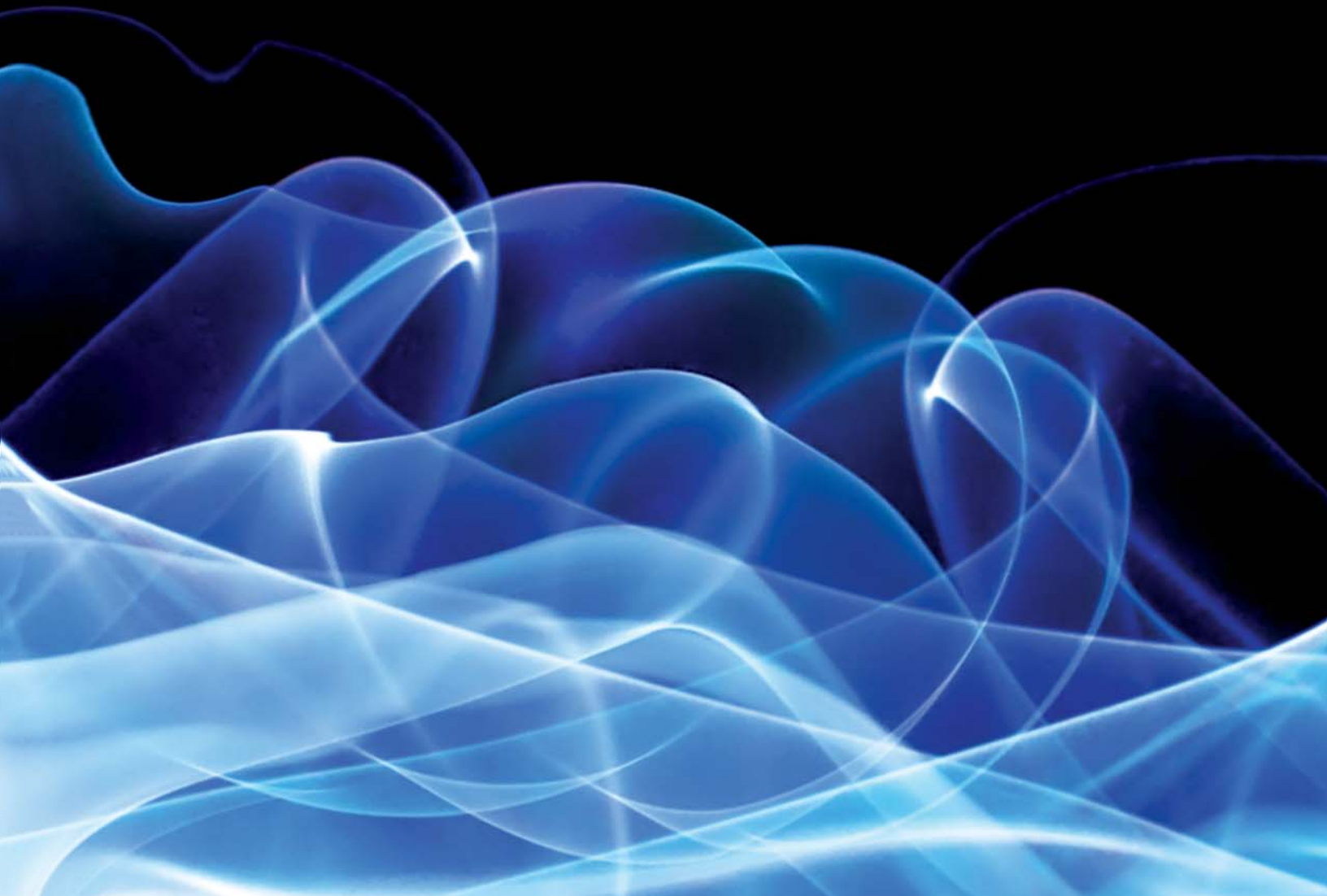
The World in 1999 ... China launches its first Shenzhou space craft. Antiglobalization protests in Seattle, WA, disrupt the World Trade Organization meeting.

At BMDO in 1999 ... A prototype NMD interceptor, carrying an exoatmospheric kill vehicle, is launched from the Kwajalein Atoll and successfully intercepts a Minuteman ICBM.



Section Three

**The Modern Era
1999 - 2005 and Beyond**



The Modern Era

Introduction

On March 16, 1999, the U.S. Senate, followed the next day by the House of Representatives, voted to deploy a national missile defense (NMD) system to defend the United States from a limited ballistic missile attack, “as soon as technologically possible,” launching a new era of missile defense. This was enabled by the successful development and acquisition of theater defense systems, such as Terminal High Altitude Area Defense (THAAD), the Standard Missile program, Patriot Advanced Capability (PAC), and continued research and development on hundreds of other systems including advanced radar, command and control systems, communications, and satellite-based sensors.

Nullifying the ABM Treaty

With this call to arms, one political problem remained: the 1972 Anti-Ballistic Missile Treaty. The treaty was brokered to prevent further build-up of nuclear weapons, which would be needed for the United States or the Soviet Union to overwhelm each other’s ballistic missile defenses. However, nuclear arms were now being cut by both sides and diplomacy ruled instead of the fear of nuclear retaliation. Throughout the first half of 1999, the U.S. administration, under President William Jefferson Clinton, attempted to negotiate with Russia to modify the Anti-Ballistic Missile Treaty, but each time negotiations were unsuccessful.

With the election of U.S. President George W. Bush, and Russian President Vladimir Putin in 2000, the situation changed. When the Russian Parliament ratified the Strategic Arms Reduction Treaty (START) II on April 14, 2000, Putin said that if the United States forced changes to the ABM treaty, Russia would withdraw from all conventional and nuclear treaties.

Bush was firmly behind deploying national missile defense despite Putin’s statements. In May of 2001, Bush said, “This is still a dangerous world, a less certain, a less predictable one ... Some already have developed the ballistic missile technology that would allow them to deliver weapons of mass destruction at long distances and at incredible speeds. And a number of these countries are spreading these technologies around the world.”

A Brave New World

It was an unpredictable world indeed, as the events of September 11, 2001, changed everything. The terrorist attacks on the World Trade Center in New York City, the Pentagon in Arlington, VA, and the crashing of an airliner in rural Pennsylvania changed the outlook for every American and the Bush administration. The United States invaded Afghanistan in October 2001 to remove support for the ter-

2001

2002

Terrorists attack
the U.S. on 9/11.

U.S. withdraws
from the ABM Treaty.

1999

2000

2001

2002

2003

2004

2005

rorists who had planned the attacks. And, although none of the groups in Afghanistan had ballistic missiles, due to the proliferation of intermediate-range ballistic missile technology, it was conceivable that terrorists could one day obtain these missiles and launch strikes against the United States or our allies.

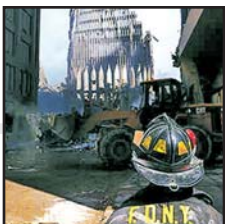
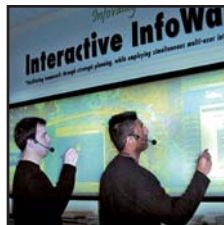
On December 13, 2001, the administration announced the United States' unilateral withdrawal from the Anti-Ballistic Missile Treaty, effective June 13, 2002, citing "new threats" to national security including "weapons of mass destruction and their delivery means wielded by terrorists and rogue states." The United States announced its withdrawal from the treaty in response to "the emergence of these new threats to our national security and the imperative of defending against them."

In 2002 it became clear that BMDO's mission of putting functional interceptors into service was essential to the security of the United States. The organization was renamed the Missile Defense Agency (MDA) to reflect that the mission had changed. Missile defense was no longer a bargaining chip with the Soviet Union; it was a defense against those who spread terror or sought ways to strike the United States

During 2003 the United States again faced a war in Iraq and, although the Iraqis were prohibited from having ballistic missiles, they may have had illegal weapons. Several missiles were fired at Kuwait and were intercepted by Patriot antiballistic missiles. However, on March 24, 2003, a Patriot missile battery mistakenly locked onto a British fighter plane, destroying it and killing its two crew members.

Ballistic Missile Defense Deployment

Construction of a national missile defense system began in 2003. Radars are being built or upgraded in several places around the world, and a missile defense site has been built at Fort Greely, AK, where, as of December 2005, eight ground-based midcourse missiles are in their silos ready to be fired at ballistic missiles launched against the United States; two additional missiles are located in California. More are to be delivered. However development is not over, and this is not the only system being deployed. "Our deployment strategy for missile defense is to add layers over time," said Lieutenant General Henry "Trey" Obering, MDA's director, in a report to Congress. "The more layers there are, the more shot opportunities we can have. And the more shot opportunities we have, the more potent our defenses."



In addition, technology development will remain essential to the MDA. "We are not in a traditional development, test, and production mode ... we will always be testing and improving this system," said Lt. Gen. Obering.

Technology Applications

During the past five years the Technology Applications (TA) program has helped many MDA researchers through its Technology Applications Reviews, Business Focus Workshops (BFW), and Outreach publications such as the *MDA TechUpdate* newsletter. And the program's dedicated staff has continued to improve upon these services.

The very popular TA Review was revamped so that meetings no longer focused on a single technology area. Although subject matter seminars seemed to make sense, there were often other circumstances involved. For instance, Jeff Reynolds, NTTC's manager of Technology Assessment and Engineering, said, "We would have a materials meeting in the fall and we'd get a range of some really good materials companies that were ready to commercialize, and then you'd get some that weren't quite ready." He added, "Or we would find a materials company that would need help in the spring, and have to say, 'sorry, that materials meeting is not until the fall.'"

Since the core advice offered to companies attending a TA Review has always been focused on business advice rather than technology advice, it makes more sense for companies who need timely business help to be invited to these meetings, no matter the technology area. Even with this change, ongoing efforts have been made to include at least one or two experts familiar with the companies' technology areas at every Review. Planning became more involved, and the Reviews became even more valuable.

Technology

Although MDA leadership placed emphasis on the incorporation of mature technology into ballistic missile defense system designs that could be built and deployed rapidly, the agency nevertheless maintained its interest in looking ahead to the future evolution of ballistic missile defense. And with systems being deployed, the agency continues to look for evolutionary improvements in performance and reliability. For instance, companies such as Acellent Technologies, Inc., and Morgan Research Corporation are developing equipment that may let missiles and other hardware determine if they are structurally healthy and ready to perform.



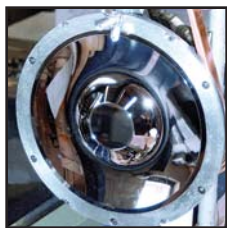
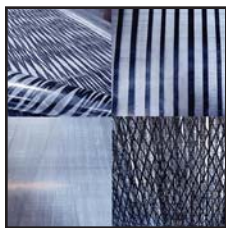
In addition to the search for novel approaches to challenges facing the task of missile defense, there is an increased emphasis on improving manufacturing technologies to reduce costs and allow new materials, once developed, to be used. This is due in part to the maturation of MDA technology, but is also due to a change in priority for the Small Business Innovation Research (SBIR) program. On February 26, 2004, Executive Order (EO) 13329, "Manufacturing in America," was signed by President George W. Bush requiring agencies to give high priority within the SBIR programs to manufacturing-related research and development. MDA's focus on manufacturing captured the spirit of this order even before it was issued.

Successes

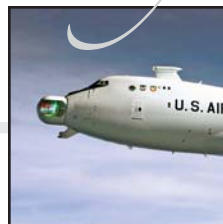
The new focus on manufacturing can be seen in some of the companies highlighted in the following pages. Companies such as Intrinsic Semiconductor are working on methods to deliver higher quality raw materials for wide-bandgap semiconductor fabrication. Advanced Optical Systems is working with MDA to cut costs in producing mirrors and optical components, and Oxazogen, Inc., has developed a new, high-temperature alloy and a special manufacturing process to cut the cost of missile parts.

During the first part of this new century, the TA program has assisted numerous companies in commercializing their technology to ultimately benefit the MDA and the citizens of the United States. The TA Review meetings continue to have panels of experts who volunteer their time to advise many fledgling companies. The Business Focus Workshops also have steered principal investigators to develop better business plans and presentations, giving business advice to the science-minded.

Many more innovations are on their way in this new century. In the following pages, many companies are introduced that have recently been covered in the quarterly *MDA TechUpdate*. Unlike the companies and technologies described in previous chapters, these technologies are much younger, only being funded in the last five years. Therefore, these companies have either just become commercially successful or are on their way to commercial success. In addition, many other companies currently being tracked by the TA program have the potential to succeed in the marketplace, bringing innovation and jobs to our nation and providing a means to reduce MDA's costs and providing a pool of technology for future defense applications.



and beyond ...





Ouch! Materials That Feel

Acellent Technologies, Inc., has developed a material that can detect damage, impact or fatigue in important structures.

A decade from now, airplanes, missiles, and even cars might inform technicians when the machines are sick or injured thanks to intelligent composites.

Missile Defense Needs. MDA started funding Acellent Technologies, Inc. (Sunnyvale, CA), in 2000 to put the company's SMART Layer® technology into composite materials to create "intelligent composites." Composites containing a SMART Layer could help monitor the structural health of missiles and space assets.

Technology Solutions. In the SMART Layer, a thin dielectric film embedded with a network of sensors monitors structures for misuse, damage, impact, or fatigue. The film could also be used in the testing process, to determine faults of a planned structure before final production, or it could be used to monitor the ongoing health of an existing structure, according to Acellent.

Competing technologies use strain gauges or fiber optics, which can provide point measurements and monitor pas-

sively, only detecting changes. The SMART Layer works passively, too, but it also can actively excite a structure upon command to assess structural health or a composite.

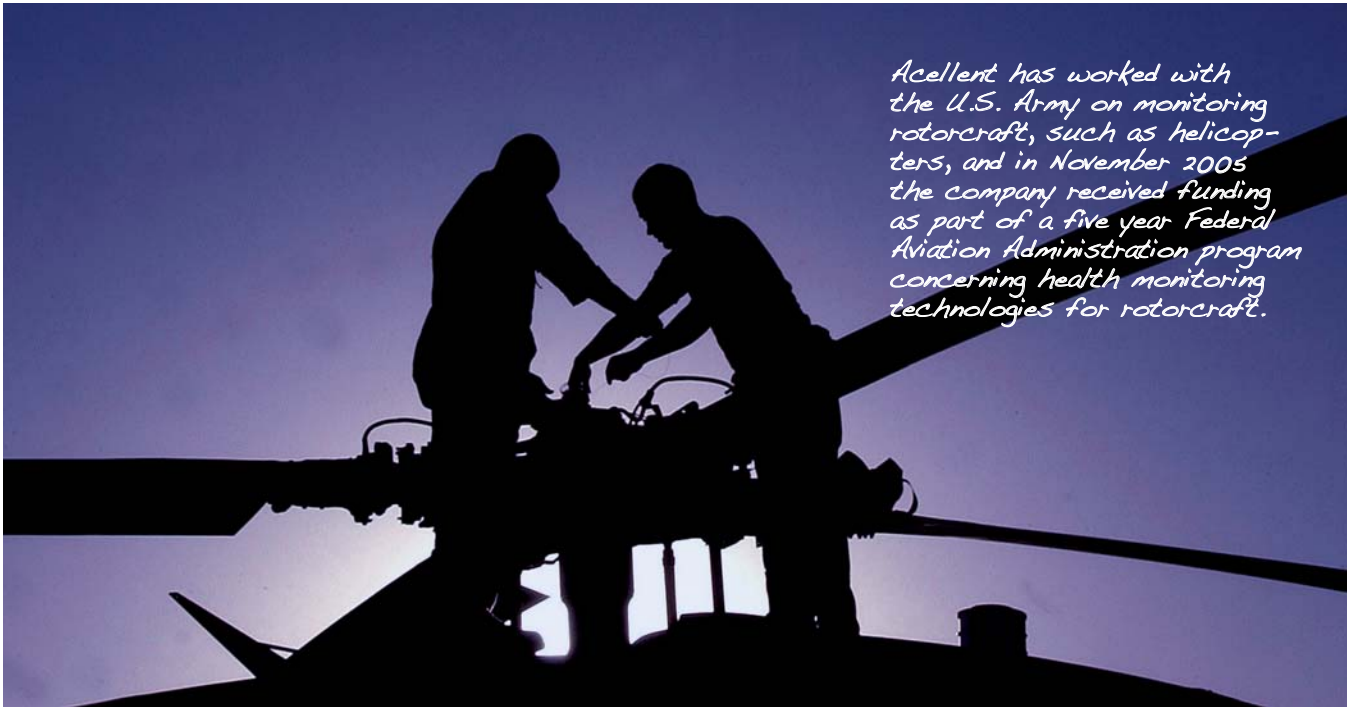
Cashing In. Since 2000 Acellent has worked with various aerospace and defense organizations as well as companies such as BMW and BP. The company has worked with the U.S. Army on monitoring rotorcraft, such as helicopters, and in November 2005 Acellent received funding as part of a five year Federal

2000

BMDO funds
Acellent Technologies, Inc.



1980 1985 1990 1995 2000 2005



Acellent has worked with the U.S. Army on monitoring rotorcraft, such as helicopters, and in November 2005 the company received funding as part of a five year Federal Aviation Administration program concerning health monitoring technologies for rotorcraft.

Aviation Administration program concerning health monitoring technologies for rotorcraft.

In 2004 and 2005 Acellent received funding from NASA and MDA (2005 Phase II SBIR) to further develop its structural health monitoring systems for rocket engine components. For the MDA project, Acellent is working in partnership with ATK-Thiokol.

Many other applications for Acellent's technology exist and the end result could be more reliable military hardware and safer planes, cars, bridges, refineries, and power plants.

For more information visit:
www.acellent.com



The World in 2000 ... A federal court rules that Microsoft violated antitrust laws. Pope John Paul II becomes the first Pope to visit Israel.

At BMDO in 2000 ... BMDO awards The Boeing Company the contract for continuing development of the National Missile Defense system.



Bulking-up on Silicon Carbide

Bandgap Technologies, Inc., and now INTRINSIC, are making larger and larger silicon carbide wafers, lowering costs for producers of communications and power electronics.

Fewer power plants, more robust electronics in airplanes and satellites, revolutionary wireless communications, all enabled by switching from silicon to silicon carbide electronics.

Missile Defense Needs. Beginning in June 2000, Bandgap Technologies, Inc. (Columbia, SC), received multiple MDA Phase I and Phase II SBIR contracts related to research on various aspects of bulk growth of silicon carbide (SiC) boules. INTRINSIC purchased Bandgap in 2004 and continued to receive MDA

SBIR awards for making semi-insulating high-resistivity SiC boules. The boules are sliced into wafers for making high-power and high-frequency integrated circuits for applications such as advanced radar systems and power amplifiers for cellular phone base stations. This research addresses the fact that SiC 4-inch-diameter wafers have proven difficult to produce in high yields with the desired electrical characteristics. Simpler production of such large wafers could reduce costs in the fabrication of integrated circuits.

Technology Solutions. The company developed a proprietary, high-temperature (2000°C) physical vapor transport (PVT) process that controls 50 to 100 variables during crystal growth. INTRINSIC engineers claim their PVT process has achieved nearly 100 percent polytype uniformity (a repeating pattern in subsequent layers of the crystal) and reduced micropipe densities (a type of imperfection) from above 100/cm² to below 20/cm² and often to 10/cm². Both improvements increase yield, thus reducing costs.

2000

BMDO funds
Bandgap Technologies, Inc.

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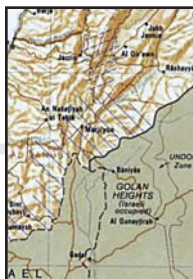


Larger wafers will allow producers of power and RF electronics to reduce costs and increase output simultaneously.

Cashing In. In June 2005 INTRINSIC introduced a commercially available line of 3-inch wafers including conducting SiC wafers, insulating SiC wafers, SiC epitaxy wafers, and GaN wafers. In September 2005, the company started producing 4-inch SiC wafers and introduced a new SiC wafer that has no micropipe defects. Larger wafers will allow producers of power and RF electronics to reduce costs and increase output simultaneously. Wafers with no

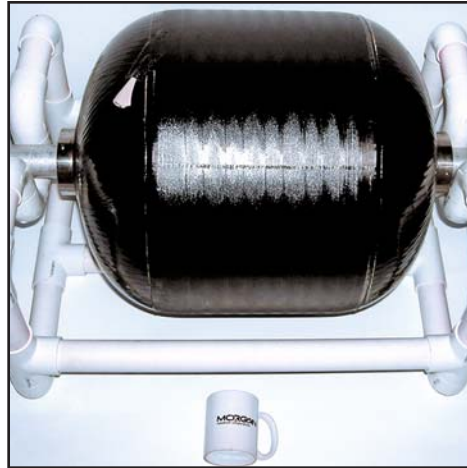
micropipe defects will increase yields and enable production of new products that could not be made because of defects. This is good news for all of us, from the military to cellular phone users.

For more information visit:
www.intrinsicsemi.com



The World in 2000 ... America Online buys Time Warner for \$162 billion. Israel withdraws troops from southern Lebanon.

AT BMD0 in 2000 ... A PAC-3 successfully intercepts a Hera target missile. The Army tests a PAC-2 launched from a PAC-3 launcher to collect reliability data.



A Check-up for Healthy Missiles

Morgan Research Corporation's inexpensive optical fiber method for detecting stress in materials may make it easier to identify damage in a wide range of objects.

Tedious and time-consuming damage inspection for rockets and potentially all types of structures—from car bodies to bridges—could become a thing of the past.

Missile Defense Needs. Missile interceptors will hopefully spend their lives inactive, but the military must ensure that, if needed, the missiles are not damaged. Current techniques for monitoring structural health can detect the possibility of damage in a rocket motor,

but pinpointing the “where,” “when,” and “how bad” is a difficult process. But a damage sensor for composite structures being developed by Morgan Research Corporation (Huntsville, AL) may provide vital information needed to make maintenance and repair decisions.

Technology Solutions. The optical fiber sensor allows a user to quickly interrogate a structure, locate potential problem areas, and employ more sophisticated systems to characterize

the damage. The system uses commercial off-the-shelf optical fibers that maintain polarization. Unlike Bragg gratings, which require insight into where damage is possible, the entire length of Morgan Research's optical fiber is a sensor. Damage is located by monitoring stress-induced changes in the local index of refraction.

Cashing In. The optical fibers used in Morgan Research's sensor costs \$10 to \$12 per meter and cause less distur-

2000

BMDO funds
Morgan Research Corporation

1980 1985 1990 1995 2000 2005

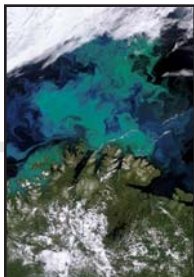


Morgan's acquisition could allow this technology to reach more customers, making missiles, rockets, and possibly bridges and car bodies more reliable and safer.

bance to the structure, whereas Bragg gratings typically cost \$200 to \$300 each and have to be dispersed throughout the structure. Morgan Research and ATK Thiokol have tested the damage sensor in composite rocket motor cases. The company has also received \$250,000 in matching funds for the MDA project from Edwards Air Force Base. In 2006 the company was acquired by Stanley Associates, Inc., an employee-owned government contrac-

tor. Morgan's acquisition could allow this technology to reach more customers, making missiles, rockets, and possibly bridges and car bodies more reliable and safer.

For more information visit:
www.morganres.com



The World in 2000 ... Voting disputes delay the outcome of the U.S. presidential election; Bush defeats VP Al Gore. The Russian nuclear submarine Kursk sinks, killing all 118 on board.

At BMDO in 2000 ... In a complex test, a PAC-3 targets and successfully intercepts a ballistic missile while, at the same time, a PAC-2 targets a drone plane.



Flexing Polymer Muscles

Composite Technology Development, Inc.'s polymer muscles could replace complicated and heavy motors and gears used to deploy solar arrays and antennas in space.

Gears, motors, and hydraulics in everything from toys to satellites could one day be replaced with muscles, but not just any muscles.

Missile Defense Needs. A satellite's large and delicate solar arrays and antennas are folded to make the journey into space and then unfurled once in orbit. Unfolding them may sound simple, but every ounce counts when launch costs are \$40,000 a pound. Composite Technology Development, Inc. (CTD; Lafayette, CO), has developed a new kind of elastic memory composite that

could be used to unfurl solar arrays and antennas without the need for motors and gears.

Technology Solutions. Shape memory materials can be bent and moved, but under certain conditions, whether temperature or electricity, the material returns to a predefined shape. CTD took a shape memory polymer and reinforced it with fiber, dramatically increasing stiffness and strength while accommodating much higher strain. The fiber-reinforced material is a thermally activated smart material meaning, it can be heated,

deformed, and then cooled to maintain a new shape. When reheated it recovers its original form.

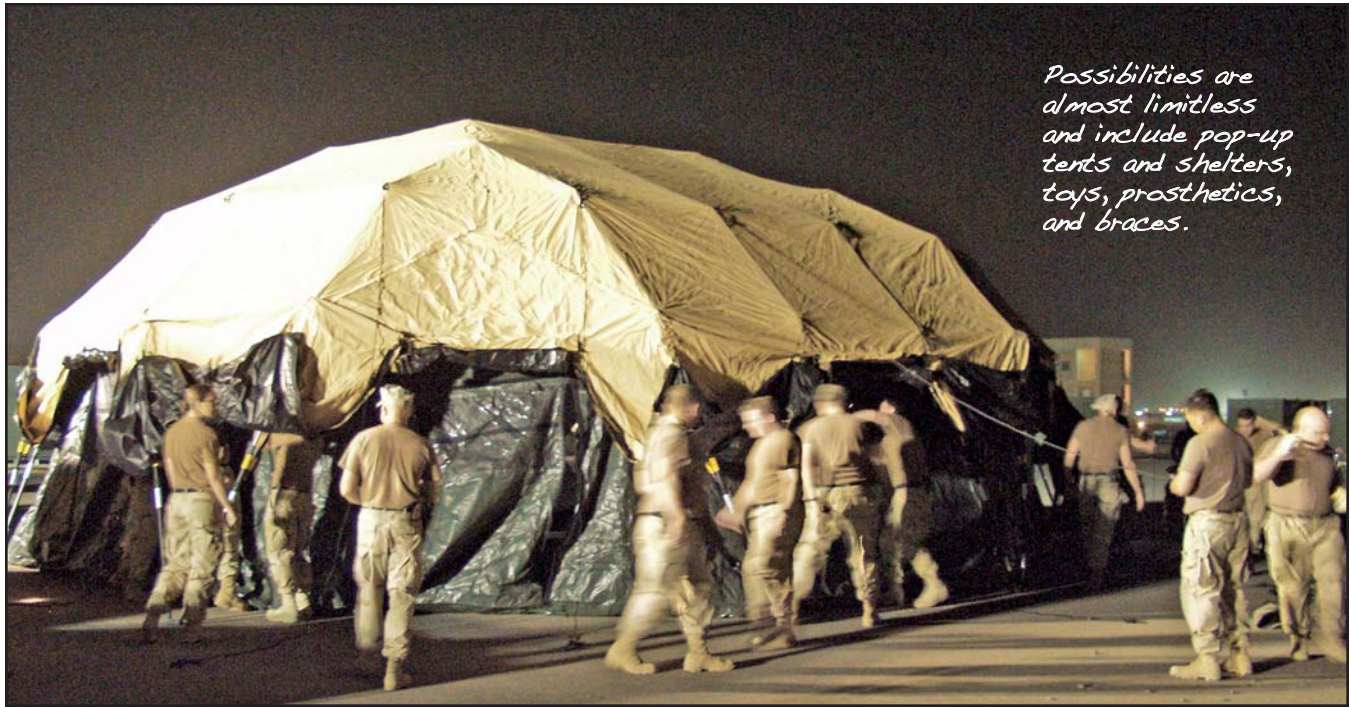
Shape memory metal alloys are well known, but CTD's polymer offers some key advantages. In tests it lifted the same mass as a metal alloy, but the polymer weighed half as much as the alloy. The polymer also changed shape more gradually than shape memory alloys, reducing the risk of damage to delicate equipment.

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BMD0 funds
Composite Technology Development, Inc.



1980 1985 1990 1995 2000 2005



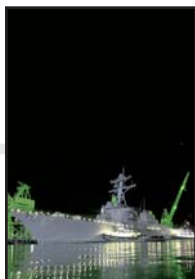
Possibilities are almost limitless and include pop-up tents and shelters, toys, prosthetics, and braces.

Future Applications. CTD tested some of its early elastic memory composite formulations onboard the International Space Station, and an experiment to validate the elastic memory composite hinge is scheduled for launch on the European Automated Transfer Vehicle, which is to be launched in 2007.

In space and on Earth, elastic memory composite could replace some components that currently apply force by means of motors, gears, and springs—all of which are subject to breakdown

or malfunction. One intriguing possibility is in fabricating pipe. If pipe were made with elastic memory composite, heated and spooled, it could be shipped in continuous lengths, but be unrolled to make 1,000 feet of straight, rigid, pipe with no seams. Possibilities are almost limitless and include pop-up tents and shelters, toys, prosthetics, and braces.

For more information visit:
www.ctd-materials.com



The World in 2000 ... Suicide bombers in Aden, Yemen, attack the USS Cole, killing 17 and wounding 39. President William Jefferson Clinton becomes the first sitting U.S. President to visit Vietnam.

At BMDO in 2000 ... Israel declares its Arrow missile defense system operational.



Here's Looking at You

Advanced Optical Systems, Inc.'s new mirror fabrication method can make better optical mirrors and make them less expensive.

Amateur astronomers make significant contributions to our understanding of the universe. What could we learn if we had even better, less expensive telescopes?

Missile Defense Needs. The standard technique for machining the high-quality aspheric mirrors MDA needs in its missile seekers is expensive and inconsistent. But Advanced Optical Systems, Inc. (Huntsville, AL), is developing a new process for the MDA that reliably fabricates high-quality mirrors for one-quarter the cost of the conventional single-point diamond turning.

Technology Solutions. Single-point diamond turning is a subtractive process that uses a diamond turning machine to hollow out a flat substrate into a mirror. Advanced Optical Systems's process—multigenerational electroforming—deposits materials such as nickel onto the negative (mandrel) of the desired shape of the product, and then removes the mandrel.

One advantage of the process is that thinner mirrors can be produced. The cost savings are produced by Advanced Optical Systems using the first set of mirrors made from the process as man-

drels for other mirrors. Mandrels degrade after about 20 uses, so by using this "generational" approach, the costs of producing new mandrels are reduced.

Future Applications. Advanced Optical Systems created a 4-inch, wildly aspheric mirror for MDA's Foveated Panoramic Seeker mock-up, which is designed to mimic the human eye. The mirror will provide the seeker with a wider field-of-view and will be paired with adaptive optics.

2001

BMD0 funds
Advanced Optical Systems, Inc.



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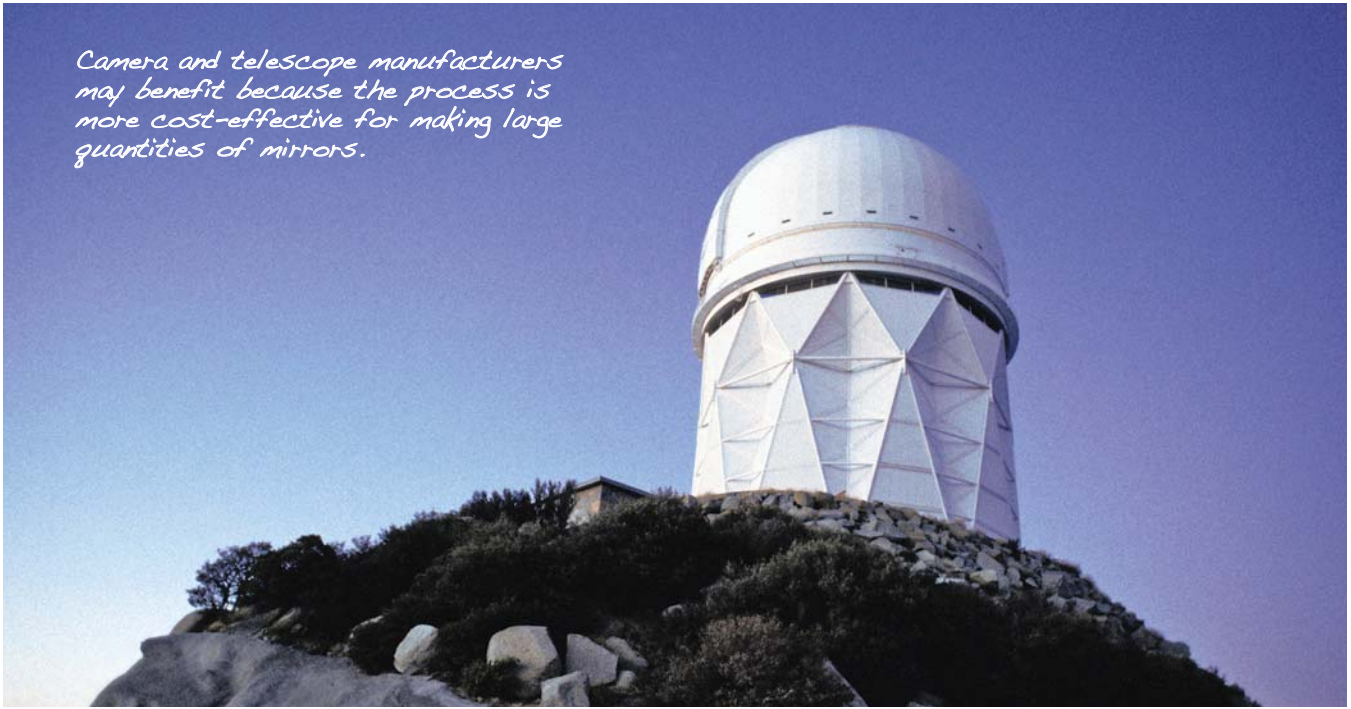
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Camera and telescope manufacturers may benefit because the process is more cost-effective for making large quantities of mirrors.



Camera and telescope manufacturers may benefit because the process is more cost-effective for making large quantities of mirrors. If a single mirror costs \$2,000 using a single-point diamond turning process, the cost of manufacturing 1,000 will be \$2 million. Using Advanced Optical Systems' process to make multiple mirrors from a single generation of mandrels, it can produce 1,000 mirrors for about \$500,000. And, as the quantity increases, so do the cost

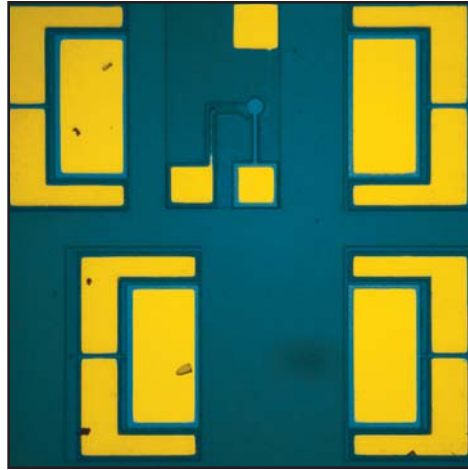
savings. In 2002 Advanced Optical Systems won a Tibbetts award for their SBIR work.

For more information visit:
www.aos-inc.com



The World in 2001 ... George W. Bush is sworn in as President. FBI agents arrest fellow agent Robert Hanssen for spying.

At BMDO in 2001 ... The Navy Standard Missile-3 successfully launches from an Aegis cruiser in the Pacific Ocean.



Converting Light to Electrons

Opel, Inc.'s photoreceiver could fill a void in electronics by providing a means to optically communicate on a computer chip.

Today's fiber-optic communications networks could be even more ubiquitous, reaching every home, and cost less due to a new, smaller and simpler device to convert light signals into electronic data.

Missile Defense Needs. MDA's use of optical communications necessitates that large amounts of data in the form of photons of light be converted into electronic data, but doing this cost-effectively is very difficult. The answer might lie in a thyristor-based photoreceiver being developed with MDA funding by Opel, Inc. (Mansfield, CT).

The device can act as an affordable bridge between optical and digital, ultimately helping drive down the cost of communications and networking equipment.

Technology Solutions. The company's approach combines optical and electronic components in the same epitaxial process using gallium arsenide (GaAs), providing components that are inherently compatible and easily fabricated. The photoreceiver, which includes a GaAs laser, requires only four components, whereas conventional devices

include as many as 50 components. The inclusion of a thyristor helps keep the device simple by serving as a switch and replacing the amplifier chain found in competing devices. It does this because the thyristor generates a voltage as it switches on and off, whereas diodes do not generate voltage and need amplification. The thyristor provides digital signal detection for the device by being switched on by light and off through the restoring force of transistors.

2001

BMDO funds
Opel, Inc.



1980 1985 1990 1995 2000 2005



Opel's thyristor may cut costs for connecting fiber optics to homes and businesses.

Future Applications. In addition to the advantages discussed above, the operating speed is limited only by the thyristors switching time, which could exceed 100 gigabits per second, making it on par with competing technology, but it will be smaller and simpler to manufacture. Opel's thyristor should cut costs for communications companies, not just for long distance fiber installation, and it may also reduce costs for connecting

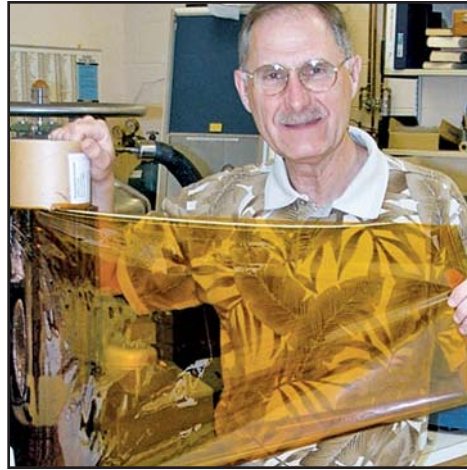
fiber optics to homes and businesses. Opel even suggests that the same technology could be used for solar power applications.

For more information visit:
www.opelinc.com



The World in 2001 ... The September 11 Al-Qaeda attacks kill almost 3,000 people in the U.S. The world is shocked. Letters containing anthrax arrive at network news offices and the National Enquirer.

At BMDO in 2001 ... BMDO collects optical and radar data in a test launching of multiple objects from Wake Island in the Pacific.



New Film Makes Better Boards

Oxazogen, Inc.'s film technology may allow denser circuitry on printed circuit boards enabling smaller and lighter electronics.

Tomorrow's even smaller laptops, cell phones, and PDAs, may be made possible because circuit boards can be made thinner, with denser circuitry, and at lower cost thanks to a new film technology.

Missile Defense Needs. MDA's electronic systems, from radars to communications, depend on printed circuit boards to connect components. An innovation being developed by Michigan Molecular Institute (MMI) and Oxazogen, Inc. (Midland, MI), may allow greater circuit density, offering size and weight advantages as well as improved reliability and lower costs.

Technology Solutions. The technology is based on a polyimide benzoxazole (PIBO) film invented by Dow Chemical Company and donated to MMI because it was not consistent with Dow's business focus. The film is self-reinforced, has a low dielectric constant, low coefficient of thermal expansion, and has a high level of thermal dimensional stability. These properties make it ideal for use as a dielectric layer in printed circuit boards, next-generation multilayer rigid printed wiring boards, and integrated circuit packaging. Dielectric layers in these devices isolate wires from each

other, preventing short circuiting, signal crosstalk, and other failures.

Competing dielectric layers made from ceramics are about one-quarter inch thick whereas the PIBO film would only be one one-thousandth of an inch thick, allowing more layers of circuitry to be stacked in a given space. The film's coefficient of thermal expansion matches that of silicon, making it easier to use as a packaging material because chips will not be strained or cracked by different rates of thermal expansion. This and other properties may also make electronics made with PIBO films

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BMDO funds
Oxazogen, Inc.



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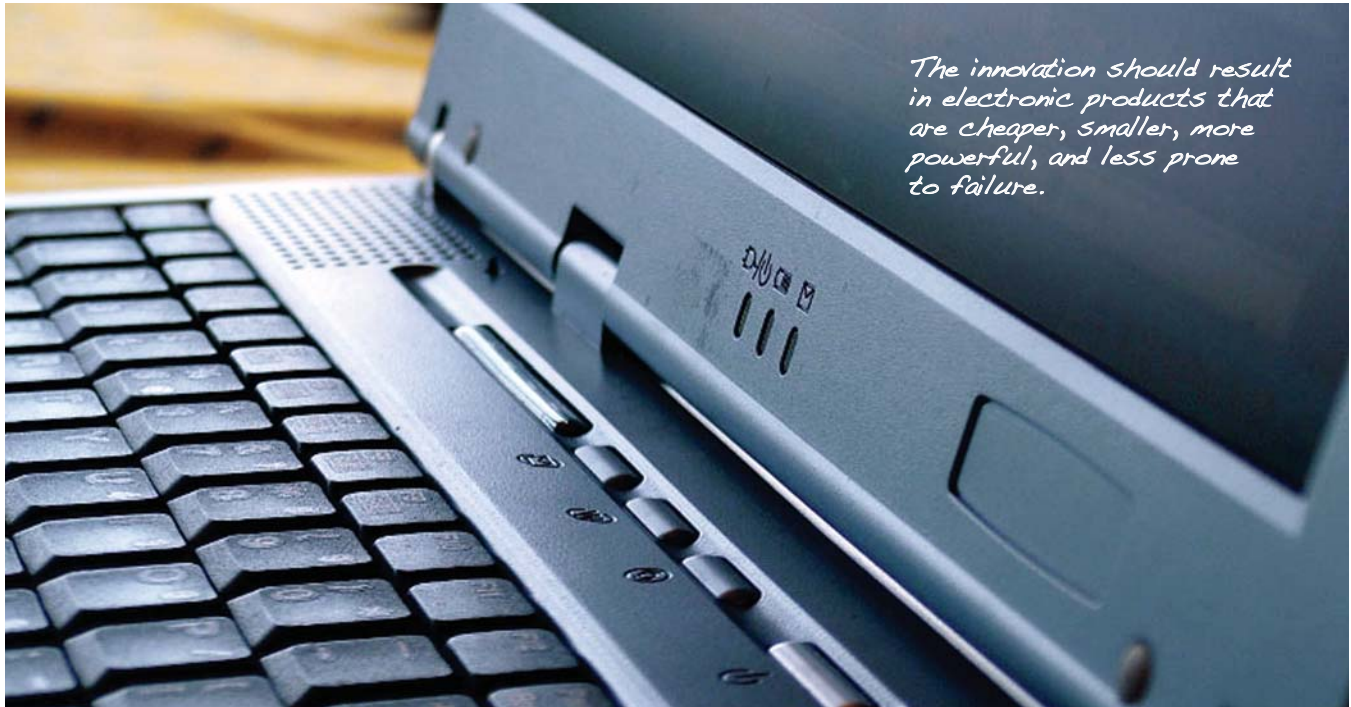
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more reliable. Oxazogen has made it compatible with roll-to-roll production.

Future Applications. The innovation should result in electronic products that are cheaper, smaller, more powerful, and less prone to failure. Having the copper lines closer together would mean that manufacturers in almost any electronics field could increase chip density, packing more circuits into an electronic product. And a more tightly packed design means that product makers can produce smaller, thinner, lighter devices or add functionality within the existing product footprint.

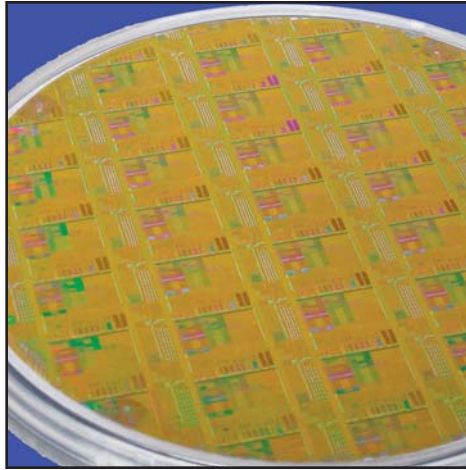
Oxazogen has licensed the technology to a Japanese film producer that is working on commercializing the product and has a pilot plant producing rolls of the film. Some of film being produced in Japan is being metallized by a U.S. company and may soon be used commercially to provide more compact and reliable electronics.

For more information visit:
www.oxazogen.com



The World in 2001 ... Enron collapses and files for bankruptcy. The *Lord of the Rings* is shown in theaters.

At BMDQ in 2001 ... President George W. Bush calls for a more appropriate sizing of America's nuclear forces and moving away from the Anti-Ballistic Missile Treaty; mutually assured destruction is not a useful strategy.



Transistors With a Short Gate

Spinnaker Semiconductor, Inc.'s Schottky barrier transistor could make electronics faster and radiation hardened for space use.

Faster electronics and better satellites may be coming soon, thanks to new transistors that are faster and more resistant to radiation than current designs.

Missile Defense Needs. Transistors are the workhorse of modern electronics, but transistors based on doped silicon are affected by radiation making their use in space electronics, such as military and civilian satellites, difficult. Now,

Spinnaker Semiconductor, Inc. (Eden Prairie, MN), working in partnership with MIT's Lincoln Labs with Air Force and MDA Small Business Innovation Research (SBIR) funding, has a solution.

Technology Solutions. Spinnaker has developed and demonstrated a short channel complimentary metal oxide semiconductor (CMOS) transistor with a gate length of 25 nanometers. This short gate length (conventional transis-

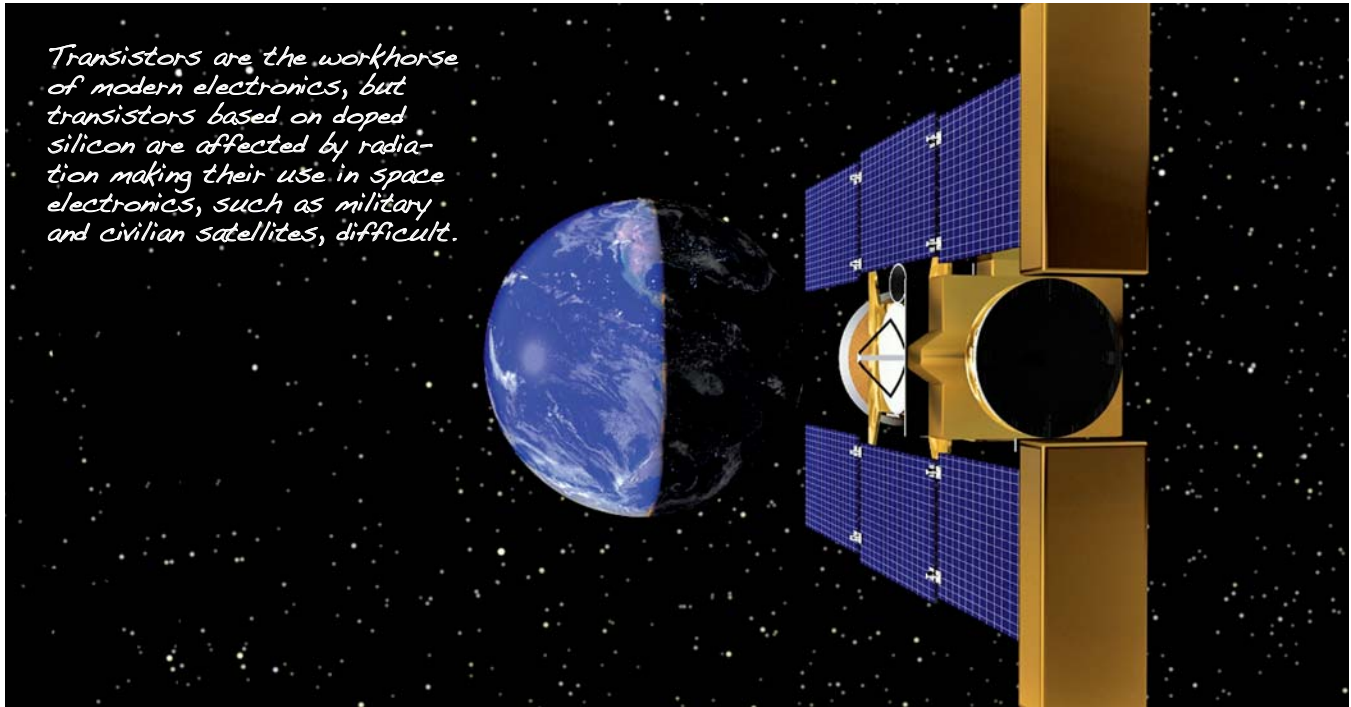
tors have 50-nm or larger gate lengths) promises an eightfold improvement in speed and power of circuitry and dramatically reduces the effects of radiation or charged particles.

The technique exploits the Schottky barrier phenomena, where the junction between a metal and a semiconductor creates an energy barrier. The use of metal silicides on a semiconductor material allows a shorter channel and

2001

BMDO funds
Spinnaker Semiconductor, Inc.

1980 1985 1990 1995 2000 2005



less channel doping and fabrication at lower temperatures, allowing other processes that can't withstand high temperatures to be completed on-chip.

Future Applications. Spinnaker has proven that Schottky barrier positive and negative CMOS devices can be created and manufactured. Working with commercial partner BAE Systems North America, the company intends

to prototype actual Schottky barrier CMOS-based circuitry. Spinnaker hopes to license the technology to existing manufacturers.

For more information visit:
www.spinnakersemi.com



The World in 2001 ... Richard Reid, the shoe bomber, is caught trying to bomb a flight by lighting his explosive-filled shoe. President George W. Bush creates the Department of Homeland Security.

At BMDO in 2001 ... The Army receives its first PAC-3 missiles.



Reach Out and Touch...A Wall?

InfoValley Corporation's interactive collaboration system enables colleagues to work together untethered to their computers.

Just as young students today are unfamiliar with typewriters and correction tape, tomorrow's students may seldom be seen crouching over each others computer screens or even working on blackboards.

Missile Defense Needs. In command and control environments personnel need to work together, but as computers are used on every desk, working together has meant huddling around monitors or tediously plugging computers into and out of projectors. InfoValley Corporation (King of Prussia, PA), with funding from MDA, has developed

computer interface technology that gives a team of workers simultaneous access to a large display wall that serves as a common computer screen.

Technology Solutions. A typical Interactive Info-Wall™ includes a rear-projection screen measuring roughly 3 by 12 feet, displaying a composite of three projected displays. This setup—which includes a special computer system called a “display controller,” networking, software, wireless microphones, and laser pointers—could cost between \$50,000 and \$100,000, depending on the level of service and

equipment the customer needs. The wall could be expanded to display a composite of as many as 44 or 128 projected displays, depending on the operating system.

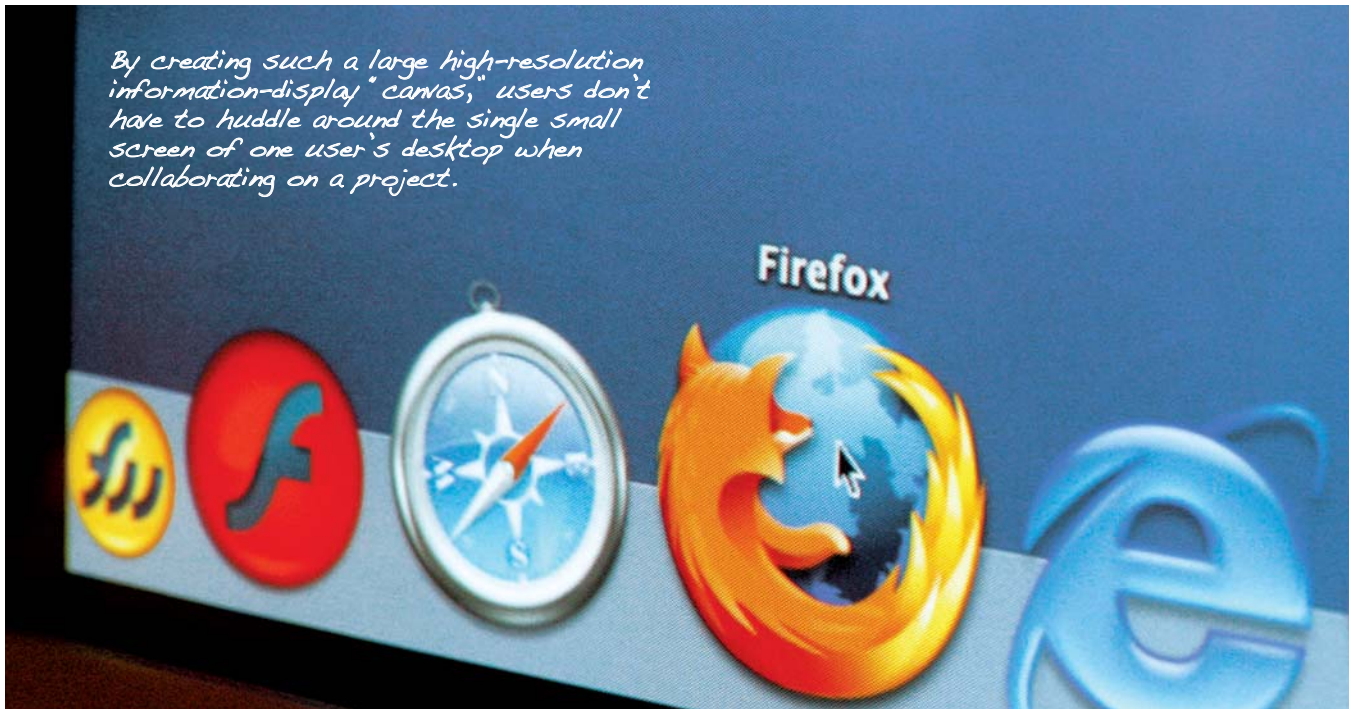
By creating such a large high-resolution information-display “canvas,” users don't have to huddle around the single small screen of one user's desktop when collaborating on a project. And users can see multiple information displays or computer applications running side by side, instead of toggling among applications on small computer screens.

2002

MDA funds
InfoValley Corporation



1980 1985 1990 1995 2000 2005



InfoValley's technology also offers "untethered" interaction. Users of the wall can navigate applications and access data using coordinated voice commands and a multifunction laser pointer instead of a mouse. These tools allow a user such as a lecturer to share information with a group without being confined to a desktop control panel.

Future Applications. InfoValley's technology holds promise for remote learning, as well as for meeting planners, office managers, and other users of today's teleconferencing equipment. As

of August 2005, InfoValley had sold 4 systems to the military, and in 2004 and 2005 it worked with the Office of Naval Research and the U.S. Navy Third Fleet's Cortex program to demonstrate the technology. And, of importance to new government customers, the company received 8(a) status in 2005. InfoValley has recently demonstrated the technology to the Defense Information Systems Agency Technology Insertion Panel.

The applications for Info-Wall are not restricted to government. This tool could

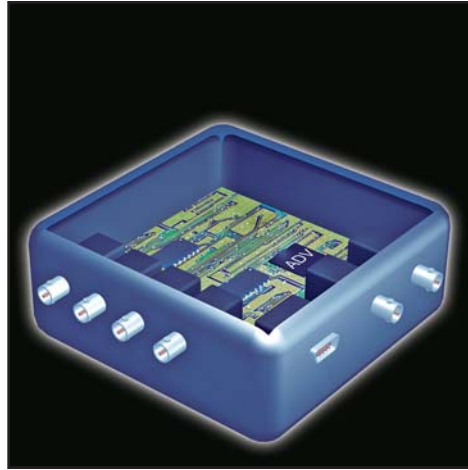
allow students to share their work instantly with an instructor and classmates, or it could allow an instructor to use several computer applications running side by side when teaching a class.

For more information visit:
www.infovalley.com



The World in 2002 ... Twelve EU countries begin using the new euro banknotes and coins. Months later, the countries completely switch to the euro. The U.S. Department of Justice begins investigating Enron.

At MDA in 2002 ... The Ballistic Missile Defense Organization (BMDO) is renamed the Missile Defense Agency (MDA).



Small and Fast Encryption

Asier Technology Corporation's compression and encryption enables fast and secure wireless communication.

Information is power, but communicating information brings risks of eavesdropping. One small box may be the answer for sending important data and video quickly and securely.

Missile Defense Needs. MDA programs need fast, extremely secure telemetry and video to be transmitted during missile interceptor tests. Asier Technology Corporation (Plano, TX), set out to integrate data compression and security algorithms. Such an integrated data compression/encryption device that enables fast, extremely secure wireless

transmission could be a boon to MDA, other military branches/government agencies, and the commercial sector.

Technology Solutions. The first prototype, with dimensions of 4 x 4 x 1.5 inches, compresses unencrypted data from synchronous (sensor and telemetry) and asynchronous (video) sources. The two data streams are combined into a single data stream that is encrypted by either using industry standard 256-bit key size software or by the company's proprietary algorithm using a 40,960-bit key size and transmitted. The propri-

etary algorithm can handle hundreds of megabits per second.

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

2002

MDA funds
Asier Technology Corporation

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In addition to MDA's interest, the Department of Homeland Security and the Office of Naval Research have worked with Asier on encryption projects, and the company has produced a software development kit for commercial and government customers.



Cashing In. In addition to MDA's interest, the Department of Homeland Security and the Office of Naval Research have worked with Asier on encryption projects. Asier has also produced a software development kit so the encryption algorithms can be built into other organizations' software more easily. Espre Solutions, Inc., a company specializing in video applications, used Asier's software development kit to add encryption to their eViewLink™ belt-mounted PDA system for technicians in less than a week. This system provides

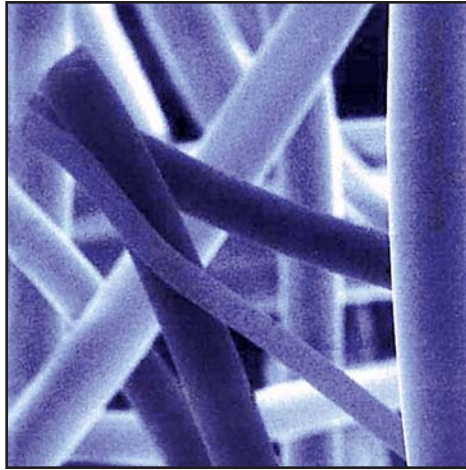
one-way video and two-way audio links to subject matter experts throughout the world using wireless Internet connections. Asier's software allowed encryption to be added without taxing the PDA's processor. Soon much more of our communications may be more secure thanks to this technology.

For more information visit:
www.asiertech.com



The World in 2002 ... Queen Elizabeth II gives Rudolph Giuliani, former New York City mayor, honorary knighthood. The Space Shuttle Columbia services the Hubble Space Telescope.

At MDA in 2002 ... The USS Lake Erie successfully tracks and fires a Standard Missile 3 at a ballistic missile target, which is successfully intercepted.



Not Just the Usual Suspects

MATECH Global Strategic Materials can now make lighter rocket engine part thanks to a new manufacturing technique using hafnium carbide.

Future space vehicles could be protected during launch and re-entry with parts made of hafnium carbide, which melts at an incredible 3890°C (7034°F).

Missile Defense Needs. Composite materials are very important to MDA and the military, and they have a wealth of current and potential uses. However the list of available composites has not changed since the early 1980s. But MATECH Global Strategic Materials (Westlake Village, CA), has introduced a new composite, by making the world's

first hafnium carbide (HfC) ceramic fiber mats and fabrics.

Technology Solutions. Hafnium carbide has the highest known melting temperature; therefore, in theory a part made with HfC fiber-matrix composite would survive temperatures that other refractory metal-metal alloys would not. In addition, HfC is about 60 percent less dense than other refractory metal alloys, resulting in lighter components. However, HfC chemistry was virtually unknown and no one had even made

HfC fibers from preceramic polymer, much less understood how the fibers could be manufactured and effectively used.

MATECH's equipment for making HfC fibers resembles a pasta machine. It uses solid pre-ceramic polymer that is made from raw materials, heats it, and forces it under pressure through an orifice, making a strand or filament that can be more than 30 kilometers long and wound on a spool.

2002

MDA funds
MATECH Global Strategic Materials



1980 1985 1990 1995 2000 2005



The composites could also be used in control systems on other rockets, as well as booster engines, and even space shuttle tiles.

Future Applications. MATECH has produced HfC composite mats and has successfully tested the material with a torch for use in rocket engines. In the company's ongoing Phase II work for MDA, it is evaluating several HfC composites prototypes and will test them in rocket engines in conjunction with aerospace contractor Aerojet. HfC composites could provide important benefits over existing materials used on Aerojet's divert attitude control system

that it provides for the U.S. Navy's Standard Missile-3 antiballistic missile. The composites could also be used in control systems on other rockets, as well as booster engines, and even space shuttle tiles.

For more information visit:
www.matechgsm.com



The World in 2002 ... Wall Street Journal reporter Daniel Pearl is kidnapped and killed in Pakistan. Pakistan arrests Ahmed Omar Saeed Sheikh and three others for his murder. Britain's Queen Elizabeth, "Queen Mother" dies.

At MDA in 2002 ... A GMD interceptor intercepts a modified Minuteman ballistic missile at an altitude in excess of 140 miles.



Shake It Up, Baby

Resodyn Corporation's unique mixing technology may make formulating rocket fuels easier and safer.

Rock and roll may not make the world go round, but acoustic energy may one day replace your kitchen blender.

Missile Defense Needs. MDA uses many rocket propellants for rocket engines and control thrusters, and is therefore very interested in manufacturing technology that could improve propellants. MDA funded Resodyn Corporation (Butte, MT), to develop a new technique for making gels, especially high-density, metallized gel propellants for divert and attitude control systems in the Theater

High Altitude Area Defense (THAAD) program. Rocket designers like gels because they are less likely to leak than liquid fuels.

Gels, like many materials, are made by mixing liquid, solid, and gaseous components, and this is typically done by using a stirring apparatus. But Resodyn has developed a method of mixing using no moving parts, just sound.

Technology Solutions. The new mixer uses a proprietary mechanical driver

that radiates an acoustic-energy field operating at approximately 50 to 100 hertz; this basically fluidizes the contents of the vessel. Because the vessel contains no moving parts, it has no spinning blades and requires less cleaning, both of which are important when handling hazardous chemicals. The technique reduces the potential of forming gas bubbles, which can degrade product quality. In addition, it can mix many substances faster than mechanical mixing. Using Resodyn's

2002

MDA funds
Resodyn Corporation



1980 1985 1990 1995 2000 2005



The mixer could be used to combine materials containing living cells that normal blenders would puree and kill.

machine, Dow Corning mixes a highly viscous material (100 million centipoises; water is 1 centipoise) in five minutes.

Future Applications. Resodyn is making a one-gallon bench-scale machine for MDA with the goal of making a production scale unit with up to a 50-gallon capacity. Resodyn is working with the National Science Foundation and the National Institutes of Health on using the mixing technology for pharmaceu-

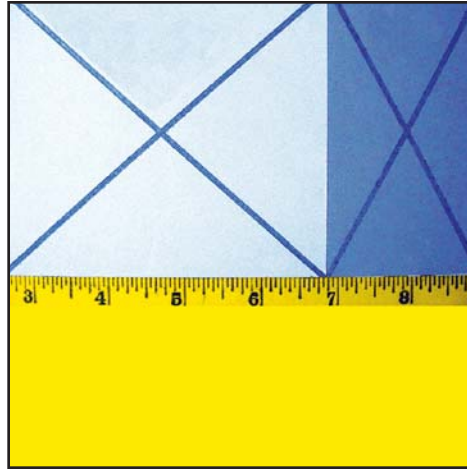
tical and biotech applications. The mixer could be used to combine materials containing living cells that normal blenders would puree and kill. More and more industries may find solutions to their mixing problems with Resodyn's new technology.

For more information visit:
www.resodyn.com



The World in 2002 ... Jimmy Carter is the first U.S. President to visit Cuba since Cuba's revolution in 1959. John Walker Lindh, pleads guilty to charges of supplying aid to the Taliban.

At MDA in 2002 ... The USS Lake Erie successfully tracks and fires a Standard Missile 3 at a ballistic missile target, which is intercepted above Earth's atmosphere.



Corrosion Resistance on Demand

TDA Research, Inc.'s chromate-free, corrosion-inhibiting coating could cut costs and increase safety when protecting metals from corrosive environments.

Corrosion costs billions and continues to sink ships and crash planes. But a new corrosion inhibitor, that is less toxic and less expensive than traditional inhibitors, may banish rust as easily as a coat of paint.

Missile Defense Needs. In 2002 MDA funded TDA Research, Inc. (TDA; Wheat Ridge, CO), to develop chromate-free, corrosion-inhibiting coatings, envisioning a pollution-free product that could protect equipment and buildings that are exposed to the corrosive salt air at

the agency's testing facilities located in Hawaii and the Kwajalein Atoll. Chromates, the most widely used and effective corrosion inhibitors, are toxic and tend to leach out of their coatings, taking their corrosion resistance with them.

Technology Solutions. TDA has subsequently developed a chromate-free, corrosion-inhibiting additive that stays put in its coating until needed. The coating is made by treating metal oxyhydroxide to modify its surface, reducing

its particle size to between 20 and 70 nanometers, and anchoring organic corrosion inhibitors on the outside surface of the particles. This process prevents the inhibitors from reacting with the polymer while curing, which limited previous organic coatings.

The company says that an organic coating using its corrosion-inhibiting additive is a viable replacement for chromate-based coatings used to protect high-strength aluminum alloys. In addition, chromate-free coatings can be manu-

2002

MDA funds
TDA Research, Inc.



1980 1985 1990 1995 2000 2005



Structures, from airframes and boats to gas and water pipelines, could benefit from these coatings by reducing their likelihood of failure due to corrosion. And applying the coatings may be as simple as painting.

factured more cheaply (\$2 to \$4 per pound) than chromate coatings (\$3 to \$5 per pound), and there are no additional costs for handling and disposal.

Future Applications. Structures, from airframes and boats to gas and water pipelines, could benefit from these coatings by reducing their likelihood of failure due to corrosion. And applying the coatings may be as simple as painting. TDA says that paint is one of the biggest commercial markets for its technology, and the company has been

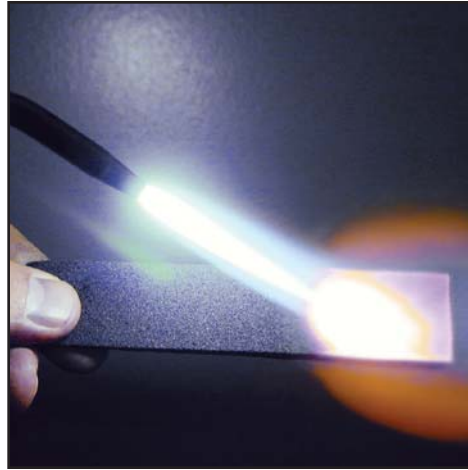
working with Sherwin Williams, the largest U.S. paint supplier, to bring the technology to market. Paint is easy to apply, and is already used in many industries to prevent exposure to the elements and corrosion.

For more information visit:
www.tda.com



The World in 2002 ... WorldCom files for bankruptcy, surpassing Enron as the largest bankruptcy in U.S. history. President George W. Bush challenges UN members to confront Iraq or stand aside as the U.S. and other nations act.

At MDA in 2002 ... The Airborne Laser makes its maiden flight over Kansas to test its flight characteristics after structural modifications.



Turning Coal into Foam

Touchstone Research Laboratory, Ltd.'s carbon foam is inexpensive and could be used in a wide range of products from ammunition cases to building materials.

We depend on coal for electricity but soon we may use coal for everything from industrial molds to building materials for ships and homes.

Missile Defense Needs. In 2002 MDA began funding research into CFOAM®, a carbon foam made from coal by an inexpensive, proprietary process invented by Touchstone Research Laboratory, Ltd. (TRL; Triadelphia, WV). CFOAM could provide inexpensive molds for casting composite materials that often required expensive molds made of metal alloys or graphite.

Technology Solutions. The source material for carbon foam—coal—is plentiful and inexpensive, but making carbon foam has been an expensive, multi-step process. TRL's proprietary process makes carbon foam cheaply and quickly. The properties of carbon foam depend upon three things: the length and width of the ligaments (which in turn determine the size of the cells); the chemical composition of the ligaments (how much carbon and additional trace elements); and how these cells are arranged (open or closed). Touchstone's carbon foam-making

process can vary the cell size, wall thickness, and the degree of openness of the cell structure. Similarly, the carbon foam density can be customized: it can be produced in a range between 0.08 and 0.80 g/cm³.

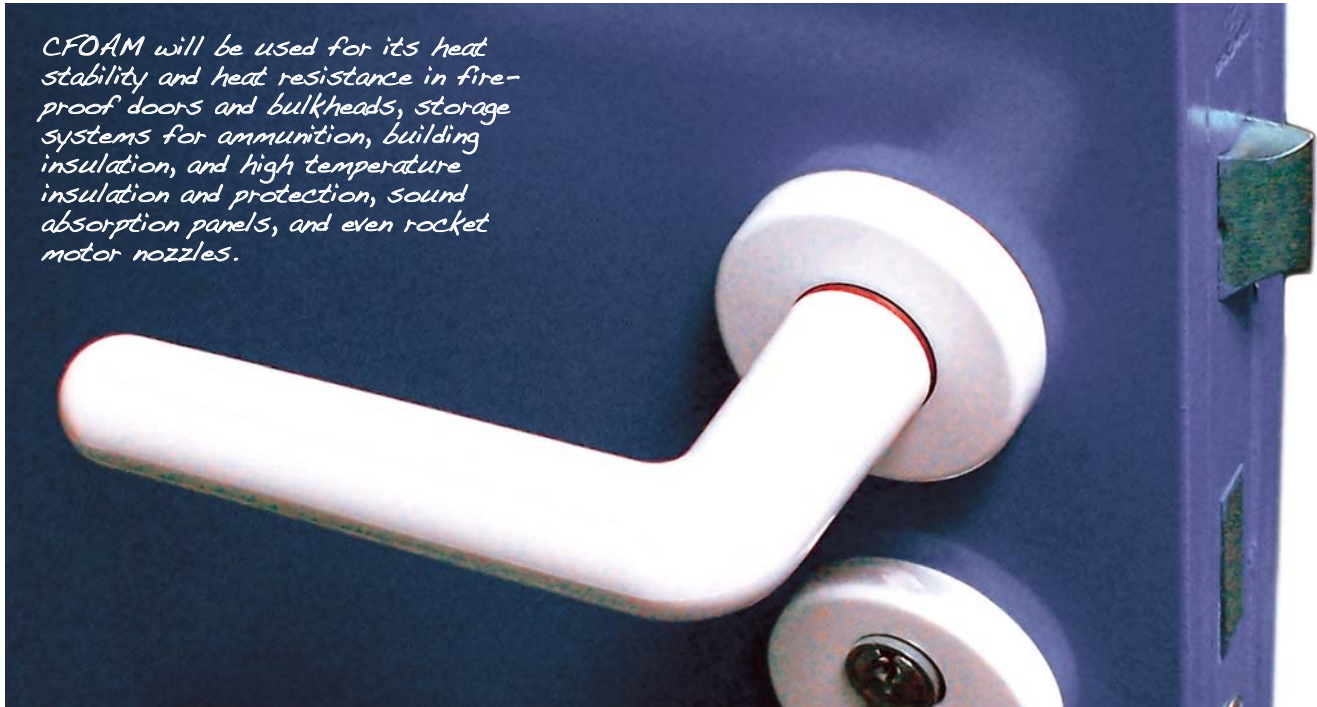
While carbon foam may be a valuable material in itself, it is fast becoming a useful mold material for casting composite parts. Carbon fiber composite parts expand at different rates from the metals typically used to make the molds, causing deformed parts in some situations. This can be solved inexpensively by

2002

MDA funds
Touchstone Research Laboratory, Ltd.

1980 1985 1990 1995 2000 2005

CFOAM will be used for its heat stability and heat resistance in fireproof doors and bulkheads, storage systems for ammunition, building insulation, and high temperature insulation and protection, sound absorption panels, and even rocket motor nozzles.



using carbon foam because its expansion rate can be adjusted to match that of the material being molded.

Cashing In. Touchstone has been producing CFOAM in its 12,000 square-ft. facility since 2001, but will soon open a new 43,000 square-ft. factory. CFOAM will be used for its heat stability and heat resistance in fireproof doors and bulkheads, storage systems for ammunition, building insulation, and high temperature insulation and protection, sound absorption panels, and even rocket motor nozzles. It can also shield

electromagnetic radiation, serve as vehicle armor, act as a filter, be used as an abrasive, or even be used as an electrode in fuel cells and batteries. CFOAM's impact could be immense, and in 2004 CFOAM was recognized by an independent judging panel and the editors of *R&D* magazine as one of the 100 most technologically significant products.

In 2005 Touchstone is developing a prototype heat shield for MDA's Terminal High Altitude Area Defense kill vehicle

and is also developing self-heating CFOAM molds for composites with MDA's assistance.

For more information visit:
www.trl.com



The World in 2002 ... A sniper terrorizes residents in and around the Washington, D.C., area. The U.S. Department of Homeland Security is officially formed.

At MDA in 2002 ... A GMD missile successfully intercepts a modified Minuteman ballistic missile target in the systems fifth successful test of seven tests since October 1999.



Quick Chips See Images

EUTECUS, Inc.'s visual processor technology mimics human sight to enable video to be analyzed more quickly.

One day, a child's toy may be able to recognize its owner thanks to an imaging chip inspired by human eyes.

Missile Defense Needs. Many of today's ballistic missiles carry decoys along with their warheads. MDA funded EUTECUS, Inc. (Austin, TX), to develop a video processor that could handle extremely high frame rates and recognize shapes and landmarks.

Technology Solutions. EUTECUS and two international companies—AnaLogic Computers, Ltd. (Budapest,

Hungary), and AnaFocus, Ltd. (Seville, Spain)—have developed a technique called cellular visual microprocessor technology and are using it to develop high-speed analog and digital imaging electronics. These chips mimic human visual sensing and thinking to increase processing speed.

The company is using both focal plane arrays and CMOS image sensors, but either system incorporates both image acquisition and processing, allowing more than 30,000 frames per second to be captured. Additional analysis of

images can be handled on digital signal processors that can use standard software or EUTECUS' line of algorithms called InstantVision software libraries. In addition to standard image analysis, InstantVision can perform multi-target tracking and feature classification.

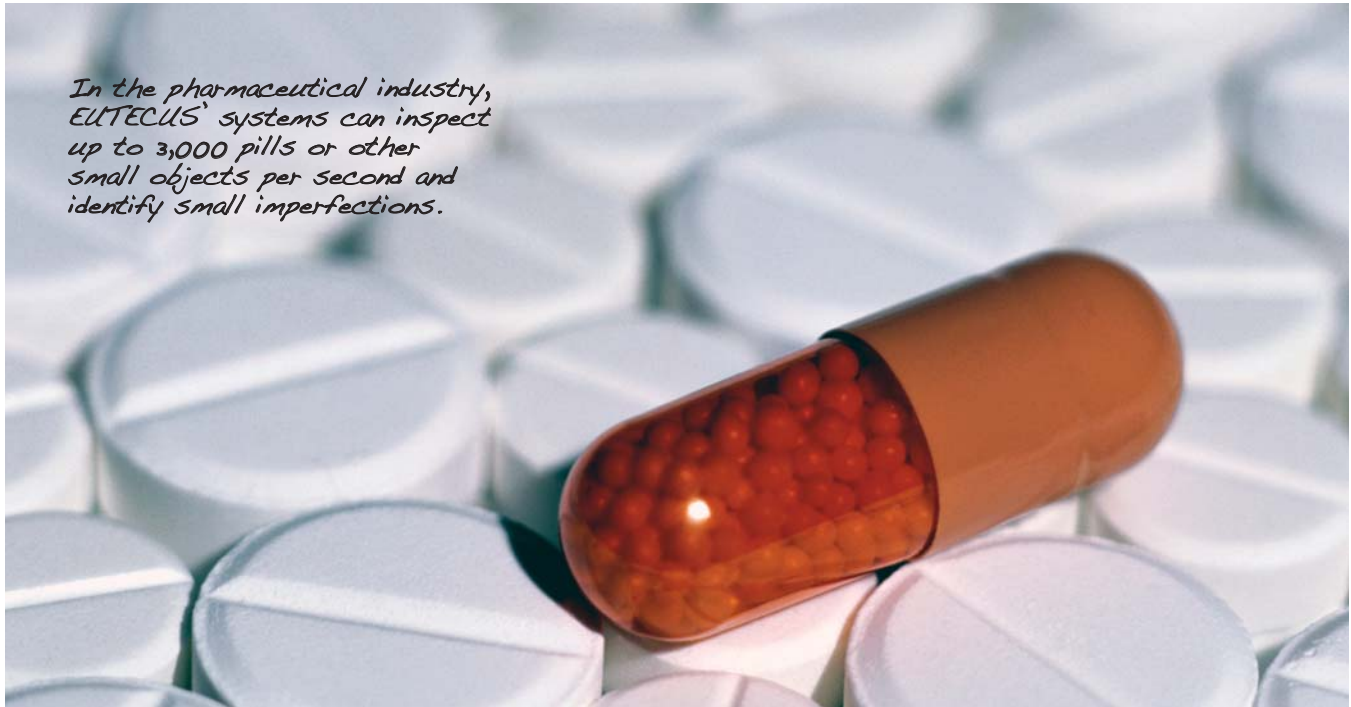
Future Applications. The company's Bi-I imaging system won the Product of the Year award at the Vision 2003 Conference, a notable machine vision exhibition in Europe. The system has been used with a label-manufacturing machine to inspect the finished labels

2003

MDA funds
EUTECUS, Inc.



1980 1985 1990 1995 2000 2005



In the pharmaceutical industry, EUTECUS' systems can inspect up to 3,000 pills or other small objects per second and identify small imperfections.

traveling at 4 meters per second for weaving errors, dirt, and oil spots. In the pharmaceutical industry, EUTECUS' systems can inspect up to 3,000 pills or other small objects per second and identify small imperfections. Other potential applications exist, from analyzing traffic to identifying cars going slower or faster than the average speed, identifying intruders, and even providing eyes for unmanned aerial vehicles (UAVs). In this application, EUTECUS' system can learn to recognize landmarks

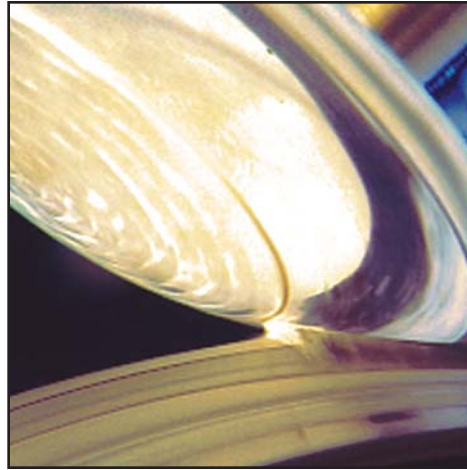
or geographic structures. EUTECUS is currently working on a new groundbreaking imaging system using nano-antennas.

For more information visit:
www.eutecus.com



The World in 2003 ... The SS Columbia disintegrates when re-entering Earth's atmosphere, killing all seven crew members. The SEC sues Martha Stewart for insider trading.

At MDA in 2003 ... MDA selects Adak, AK, as the primary support base for the Sea-Based X-Band radar for the Ground-based Midcourse Defense system.



Is it Solid? Is it Liquid?

QED Technologies, Inc.'s technique for polishing mirror uses a fluid that turns solid when an electromagnetic field is applied.

The legendary repair of the Hubble Space Telescope's mirror may never be repeated on future satellites or earth-based telescopes. A new polishing method makes quick work of making light mirrors.

Missile Defense Needs. Mirrors are essential to missile defense, from satellites that monitor for missile launches to interceptors that have optics to track and intercept missiles. Therefore, MDA funded QED Technologies, Inc. (Rochester, NY), to develop a new way to polish

large, lightweight optics faster and more precisely.

Technology Solutions. The high-precision technique that QED is developing will enable large, lightweight optics such as mirrors for space-based telescopes to be made thinner and lighter. Lightweight optics are inherently weak or fragile, making them difficult to polish without deformation or damage.

The instrument that QED has developed circulates a special liquid known as a

magnetorheological fluid in a closed-loop filtered system. This fluid, with about the viscosity of mineral oil, travels from a nozzle toward a motion-controlled arm that holds the optic and that rests above a strong electromagnetic field. As the fluid enters the field, it almost instantly transforms into a solid state, polishing the optic. The slurry-like solid maintains a clay-like viscosity while exposed to the field. After leaving the field, it returns to a liquid state. Because the system polishes on a tangent to the

2003

MDA funds
QED Technologies, Inc.



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The method may prove even more useful for satellite designers, as the company expects to be able to process optics that weigh less than 10 kg per square meter, whereas lightweight is considered to be under 50 kg per square meter.

optic rather than by a normal direct force, the system is less likely to create defects in the mirror surface.

In addition, polishing is controlled automatically, using interferometry and customized software to analyze optics before polishing and to guide the polishing instrument. This cuts polishing time from the months needed for manual methods to only days or weeks. The automated approach also offers the ability to measure and correct for the print-through effect—the quilted or

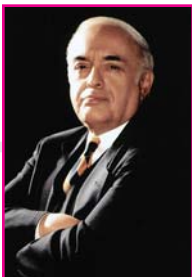
ridged pattern that sometimes bleeds through from the back of an optic when making it lightweight.

Future Applications. QED now sells a polishing machine that can polish spherical, aspherical, or flat optics up to 400 millimeters in diameter and custom instruments to process lightweight optics up to 1 meter in diameter. In addition, the method may prove even more useful for satellite designers, as the company expects to be able to process optics that weigh less than 10

kg per square meter, whereas lightweight is considered to be under 50 kg per square meter.

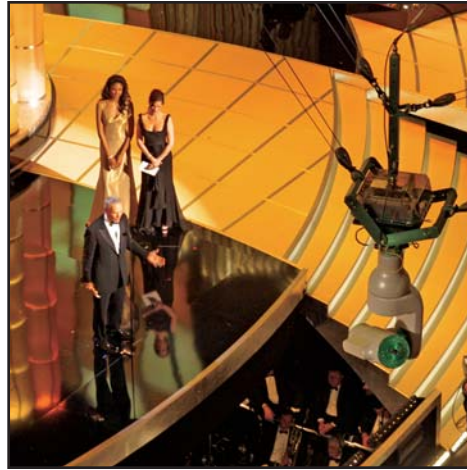
Company officials also see application of their technology in the production of silicon or compound semiconductor wafers, which must be flat with as few defects as possible.

For more information visit:
www.qedmrf.com



The World in 2003 ... Robert Novak publishes the name of an undercover CIA agent, beginning the CIA leak scandal. An outbreak of mad cow disease in Washington state causes several countries to ban the importation of U.S. beef.

At MDA in 2003 ... The U.S. Army activates a 90-soldier Ground-based Midcourse Defense Brigade for command and control of the system.



Shooting Missiles or Film

Sequoia Technologies, Inc.'s gimbal system is not just for missile defense, it is keeping cameras steady at major sports events.

Being in the huddle during a major football game is no longer an experience reserved for professional athletes. Now fans have a chance to be there, if only from the comfort of their living rooms.

Missile Defense Needs. In 2004 MDA awarded three Small Business Innovation Research (SBIR) awards to Sequoia Technologies, Inc. (Bellingham, WA), to develop a precision motion control and stabilization, or gimbal, system for the Airborne Laser program. But, with the

help of commercial investments, this technology has surprisingly given better game coverage to football fans reclining in their SuperBowl sweatshirts.

Technology Solutions. Sequoia's ground-up approach for designing, developing, and packaging the gimbal system using high-strength, high-stiffness, and lightweight composites maximizes performance at costs below competing systems. For the commercial application, this resulted in a gimbal architecture with composite packaging that offers

greater dynamic performance, lower mass, and better disturbance rejection (jitter reduction) at a lower cost and with better delivery schedules than competing systems. Sequoia can easily modify the system for varying customer requirements and produce a gimbal of the correct performance with very short development cycles.

Cashing In. The gimbal system is now being used by CableCam International as part of its CableCam™ capability for televising sporting and other events.

2004

MDA funds
Sequoia Technologies, Inc.



1980

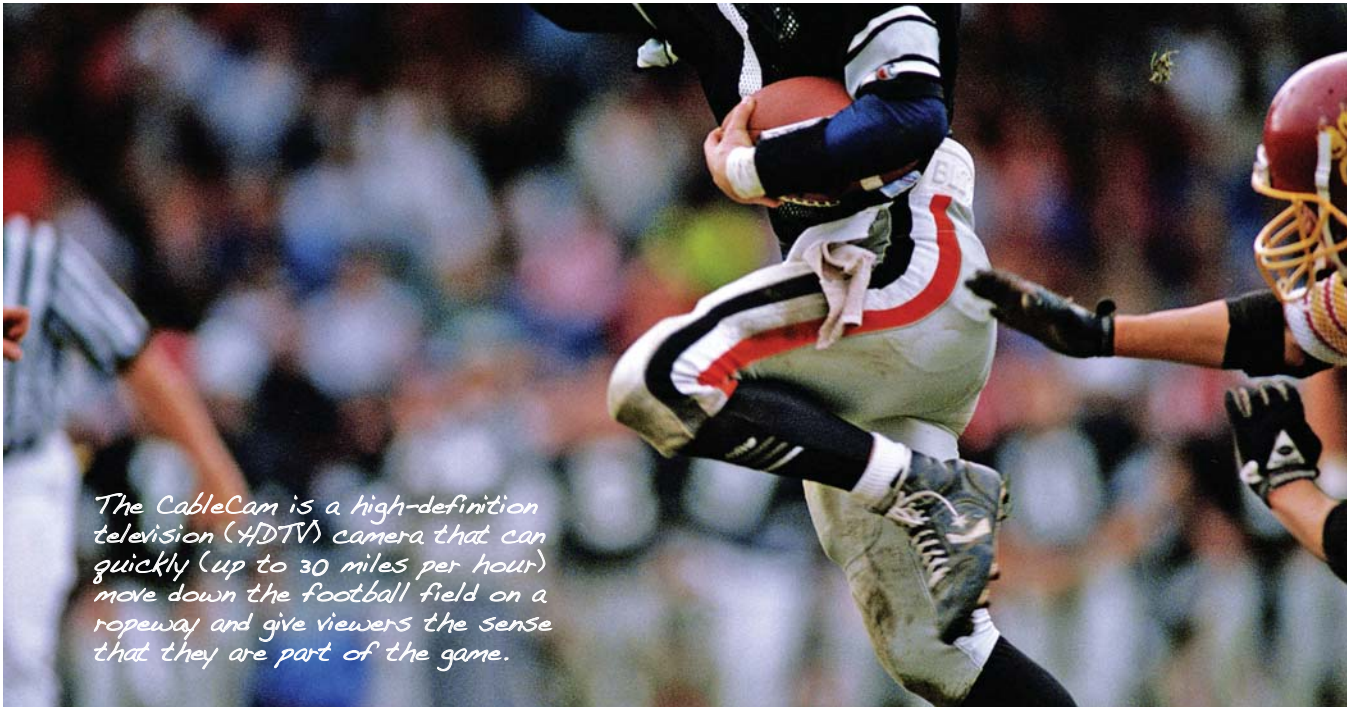
1985

1990

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2000

2005



The CableCam is a high-definition television (HDTV) camera that can quickly (up to 30 miles per hour) move down the football field on a ropeway and give viewers the sense that they are part of the game.

The CableCam is a high-definition television (HDTV) camera that can quickly (up to 30 miles per hour) move down the football field on a ropeway and give viewers the sense that they are part of the game. Without Sequoia's gimbal, a large helicopter turret camera would need to be used on the CableCam so that jitter would not distort the image.

In 2005 CableCam systems, with gimbals from Sequoia, were used at the Academy

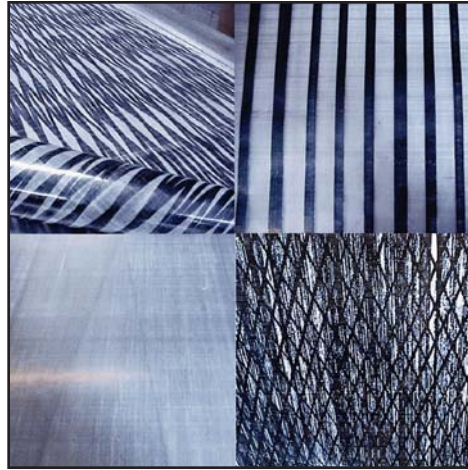
Awards and throughout the 2005 NFL, NBA, and PGA seasons. Whether military or commercial, most Americans will see something from Sequoia.

For more information visit:
www.sequoia-tech.com



The World in 2004 ... The NASA rovers, Spirit and Opportunity, land on Mars. Bulgaria, Estonia, Latvia, Lithuania, Romania, Slovakia, and Slovenia join NATO.

At MDA in 2004 ... The integrated flight test 13B of a Ground-based Midcourse Defense three-stage booster and interceptor is successfully tested.



Fabric of the Future

Cuben Fiber Corporation's high tech fiber materials may enable next generation military airships as well as parachutes, sails, kites, and more.

Airships could one day provide telecommunications, traffic cameras, weather forecasting, and other services to cities around the globe. These airships could be made of Cuben Fiber.

Missile Defense Needs. MDA awarded Cuben Fiber Corporation (Mesa, AZ), a SBIR Phase I contract to enhance the company's pre-existing material (also called Cuben Fiber) to meet specifications for the agency's High Altitude Airship (HAA) program. The program proposes to put in place unmanned, untethered, lighter-than-air high-altitude airships

that can be used in ballistic missile defense. Any materials used in the airship would have to meet rigorous demands to withstand the extremes of high altitude. So in tailoring the material for MDA's application, Cuben Fiber has had to meet unique structural demands. For example, the project has special requirements for temperature, strength, creep, optical properties, gas diffusion, and helium permeability.

Technology Solutions. The company's core patented product consists of a flexible material that is also structural,

load-carrying material. The material effectively splits the difference between a fabric and a structural composite material and can serve as a stronger and lighter replacement for any application that traditionally uses lightweight nylon or polyester material, according to the company.

Cuben Fiber is made from high-strength, high-modulus engineered fibers such as Spectra®, Kevlar®, or carbon fiber. The manufacturing process involves using extruded lightweight unidirectional "tapes" of material. In

2004

MDA funds
Cuben Fiber Corporation



1980 1985 1990 1995 2000 2005



Cuben Fiber originally made its name in the sailing industry, having been used for sails on the 1992 America's Cup winner, America³—hence the name "Cuben."

effect, fibers are converted from little threads into a very thin and uniform film of fibers in a resin matrix. Cuben's approach produces a flexible composite membrane by orienting the fiber material as needed. The process allows for local thickening and reduction as layers of material are placed down, with the all the layers being laminated together into a final piece. A final product made with Cuben Fiber, therefore, is more of an integrated whole rather than a sewn-together quilt made up of assorted pieces.

Cuben Fiber originally made its name in the sailing industry, having been used for sails on the 1992 America's Cup winner, America³—hence the name "Cuben." The material also has been used in artificial ligaments and ultra-lightweight heart valves.

Future Applications. Work on the HAA project is pushing the company into a more complex realm—development of larger and more intricate structures with highly detailed specifications. The project also could help move Cuben

Fiber Corporation toward manufacturing product at less cost on a greater scale. The company vision is one in which it could more quickly and more affordably churn out new generations of recreational balloons, military parachutes, airships, bulletproof clothing, and even giant kites for kiteboarding—making them all incredibly lightweight, too.

For more information visit:
www.cubenfiber.com



The World in 2004 ... Ronald Reagan dies. Lance Armstrong wins his 6th consecutive Tour de France.

At MDA in 2004 ... THAAD's meaning is changed from "Theater" to "Terminal" High Altitude Defense System to be in line with other systems such as the Ground-based Midcourse Defense system.

Conclusion

The year 2005 found the Missile Defense Agency fully focused on its capability to deploy a National Missile Defense System, and to reach the advanced stages of development for programs such as the Airborne Laser and theater missile defense systems. Because of this progress, MDA Small Business Innovation Research (SBIR) awards and other technology development programs were no longer focused on pioneering unique technologies from scratch. Technology developments now included projects to enhance the capabilities of current and near-term systems for missile defense and to find manufacturing techniques that could reduce costs.

The U.S. missile defense system will continue to evolve by incorporating improved technology and adapting to new threats. "That is why our research and development activities remain the heart of our program," said Lt. Gen. Obering. "Our aggressive research and development program reminds us that the missile defense system will evolve over time and become increasingly capable of protecting the United States, our troops, and our allies and friends."

At publication time, the 21st century is only in its sixth year, and technology transfer and commercialization remain a valuable complement to missile defense research efforts. Commercialization helps technology developers grow their businesses and it helps nourish and improve the technologies that await insertion into the current missile defense system, or a future one. These technologies may one day prove to be essential technologies for defense and other industries. Commercialization also encourages technology developers to pursue their dreams by providing them with vital financial support and resources to take their innovations to industry as well.

In the years ahead, be sure to watch for commercial successes from Missile Defense Agency research. If the past 25 years of technology development and commercial success are an example, great advances are in store for our country and its citizens.

Acronyms

ABM	Anti-Ballistic Missile
ABM Treaty	Anti-Ballistic Missile Treaty of 1972
BFW	Business Focus Workshop, part of the MDA Technology Applications program
BMDO	Ballistic Missile Defense Organization A predecessor to the Missile Defense Agency
GMD	Ground-based Midcourse Defense
GPALS	Global Protection Against Limited Strikes
HOE	Homing Overlay Experiment
ICBM	Intercontinental Ballistic Missile
IS&T	Innovative Science and Technology
JPL	Jet Propulsion Laboratory, Pasadena, CA
LEAP	Lightweight Exoatmospheric Projectile
LED	Light Emitting Diode
MDA	Missile Defense Agency
MOCVD	Metal-Organic Chemical Vapor Deposition
NASA	National Aeronautics and Space Administration, Washington, DC
NMD	National Missile Defense, a term no longer used

NTTC	National Technology Transfer Center
NTW	Navy Theater-Wide. Now referred to as the Sea-Based Midcourse Segment of the Ballistic Missile Defense System
PAC	PATRIOT Advanced Capability
PAC-2	PATRIOT Advanced Capability-2
PAC-3	PATRIOT Advanced Capability-3
SBIR	Small Business Innovation Research
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization. A predecessor to the Missile Defense Agency
SM-2	Standard Missile-2
SM-3	Standard Missile-3
START	Strategic Arms Reduction Treaty
STTR	Small Business Technology Transfer
TA	Technology Applications program
TA Review	Technology Applications Review, a service of the Technology Applications program
THAAD	Terminal High Altitude Area Defense System Formerly called Theater High Altitude Area Defense System

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*"I call upon the scientific community in our country,
those who gave us nuclear weapons,
to turn their great talents now to the cause of mankind and world peace,
to give us the means of rendering these nuclear weapons impotent and obsolete."*

President Ronald Reagan, 1983

Missile Defense Agency
Advanced Technology (MDA/DV)
Technology Applications Program



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