1997

TECHNOLOGY APPLICATIONS REPORT

BALLISTIC MISSILE
DEFENSE ORGANIZATION

FOREWORD

During the Cold War, there was much concern in the United States about the threat of ballistic missiles carrying weapons of mass destruction. To control this threat, the U.S. Department of Defense formed the Strategic Defense Initiative Organization (SDIO), a research program designed to look into defensive technologies and related systems that could destroy ballistic missiles and warheads in flight. Although the Soviet Union has collapsed and the Cold War is over, a growing number of hostile nations have invested heavily in ballistic missiles, prompting a change in U.S. defense policy. As a result of this change, SDIO became the Ballistic Missile Defense Organization (BMDO), which is now working to provide active defenses against ballistic missile attacks and to build a technical base that will support these defenses.

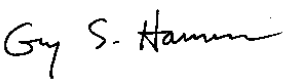
SDIO and BMDO have supported research on new technologies and provided options for improvement to existing systems. These new ideas—such as the kinetic energy interceptor, advanced tracking and surveillance sensors, and directed energy systems—are essential to strengthen our defenses and keep ahead of the increasingly sophisticated global missile threat. Investing in these and other missile defense systems also has provided enormous amounts of technology with many commercial applications outside their intended defense use. Leading-edge technology in lasers, optics, and computer algorithms, for example, may help doctors diagnose and treat cancer faster and more effectively, potentially saving many lives.

Recognizing the importance of transferring this technology to U.S. companies and its benefits to the U.S. economy, BMDO created the BMDO Technology Applications program. As its major thrust, this program facilitates the use of technology developed for BMDO in the non-defense public and private sectors, resulting in numerous technology transfers of leading-edge missile defense technology. For example, the program is establishing cooperative programs with industry to illustrate the uses of BMDO-funded communications, imaging, and computer technology in education. Applying new technologies to meet growing distance education needs could provide enormous benefits for rural and remote communities, in the United States and throughout the world.

The *1997 Technology Applications Report* highlights some of the most innovative and commercially oriented technology emerging from BMDO-funded research and development projects. What's more, many of these technologies are already finding homes in such myriad commercial markets as communications, displays, medicine, manufacturing, optics, and sensors—just to name a few. This report also discusses the program's integrated efforts to support BMDO-funded technologies at various stages of development through the following approaches:

- Making industry aware of BMDO-funded innovations.
- Guiding BMDO-funded researchers in the commercialization process.
- Leveraging cooperative relationships.
- Testing innovative, new models to commercialize BMDO-funded technology.

I invite you to sample the many BMDO-funded technologies featured in the report. And, as you read this publication, keep in mind that a staff of technology transfer specialists is only a phone call away at (703) 518-8800, ext. 500. They will be happy to answer any questions about a specific technology in this report or any other services of the Technology Applications program.

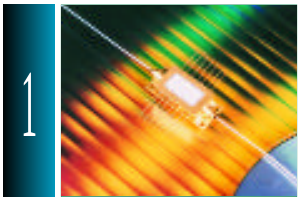


Guy S. Hammer
Director, BMDO Technology Applications

TABLE OF CONTENTS

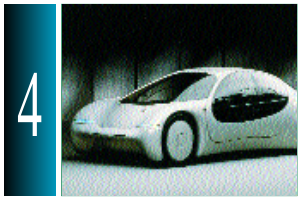
INTRODUCTION

COMMUNICATIONS AND DISPLAYS



COMPUTER HARDWARE AND SOFTWARE

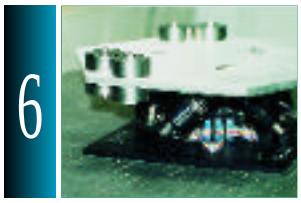
MANUFACTURING



MATERIALS

MEDICINE

MISCELLANEOUS

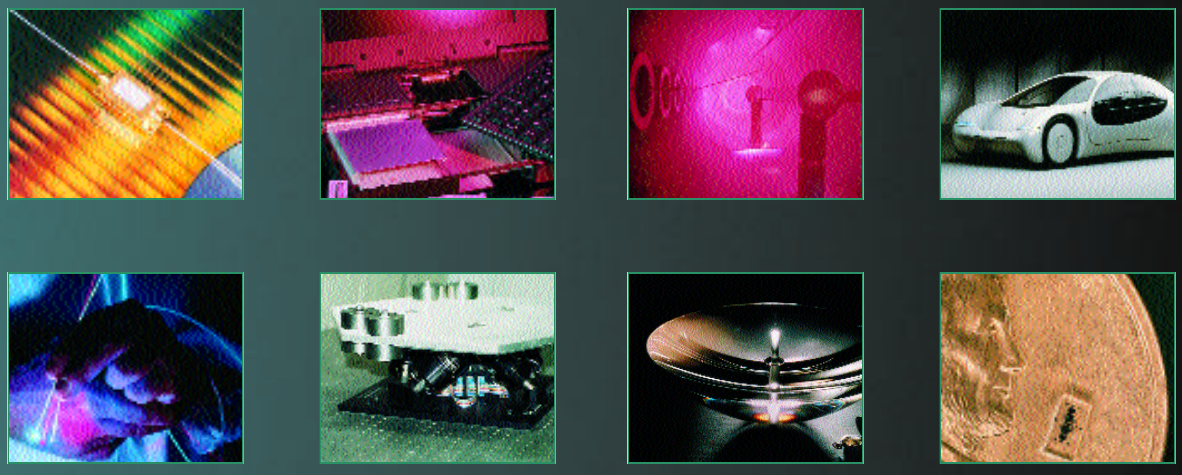


OPTICS

SENSORS AND RELATED TECHNOLOGY

LISTING OF FEATURED COMPANIES AND INDEX OF SUBJECTS

INTRODUCTION



America's strong support of world-class technologies has created a culture of innovation that will help our Nation remain competitive in the 21st century. We all can take pride in this support because innovation is key to producing technology breakthroughs that boost industrial and economic performance. However, we must also realize that such breakthroughs often have lengthy incubation periods; they can take years to mature into commercial products that become part of the fabric of everyday life. Some of today's most popular and useful technologies took more than a decade to go through the development process, mature, and find their markets, as shown in the table below.

HOW LONG DOES AN IDEA TAKE?

ITEM	CONCEPT	COMMERCIALIZATION	TIME GAP
Transistor	1940	1950	10 Years
TV	1907	1936	29 Years
Helicopter	1904	1936	32 Years
Zipper	1891	1923	32 Years
Diesel Locomotive	1895	1934	39 Years
Radar	1887	1933	46 Years
Ball Point Pen	1888	1938	50 Years
Fluorescent Light	1852	1934	82 Years

MAKING BALLISTIC MISSILE DEFENSE A REALITY

The Ballistic Missile Defense Organization (BMDO) is working to provide active defenses against ballistic missile attacks and a technical base that will allow the Department of Defense to protect against increasingly sophisticated missiles around the world. These efforts are carried out through three broad program areas: theater missile defense, national missile defense, and technology readiness.

THEATER MISSILE DEFENSE

BMDO's theater missile defense (TMD) aims to protect U.S. forces, allies, and other countries from theater missile attacks. Three core TMD programs represent the bulk of BMDO's research, development, testing, and evaluation budget for fiscal year (FY) 1996.

- PATRIOT[1] Advanced Capability-3. The PATRIOT Advanced Capability-3 (PAC-3)—a hit-to-kill, single-stage interceptor—is designed to provide a missile defense for our troops and fixed assets as quickly as possible. It will help destroy short- and medium-range ballistic missiles and other threats in the atmosphere.

  All PAC systems have four basic components; a radar set, an engagement control station, a launching station, and interceptors. Three increasingly sophisticated versions of PAC-3 will be built, with the final configuration projected to reach the field in 1999.

- Navy Area Defense. The U.S. Navy and BMDO have been working in partnership to develop a sea-based area defense capability that builds on the existing AEGIS[2]/Standard Missile air defense system. This system is based on AEGIS-class cruisers and destroyers, which already form the backbone of the U.S. fleet. AEGIS ships provide all elements of short- to medium-range missile defense and are particularly suited to protect forces moving inland from the sea.

  A user operational evaluation system (UOES) will be developed in several phases. The UOES computer program will be completed in FY 1998. The UOES missile is projected to be available in FY 2000. Actual deployment may begin as early as 2002.

- Theater High-Altitude Area Defense System. BMDO's Theater High-Altitude Area Defense (THAAD) system will form the largest umbrella of missile protection in a theater, arching over all other missile defense systems. To accomplish this mission, THAAD will have long-range and high-altitude intercept capabilities to engage the entire spectrum of theater ballistic missiles. These capabilities will give U.S. forces the earliest opportunity to shoot down incoming missiles and the best chance to destroy them far enough away that falling debris will not endanger friendly forces.

  The THAAD system consists of four major parts: truck-mounted launchers, interceptors, the THAAD radar systems, and the THAAD battle management (command, control, communications, and intelligence) system. Initial flight tests are under way. Beginning in late 1998, a prototype THAAD system will be available so that soldiers can comment on system design and conduct early operational assessments.

Courtesy of Raytheon Electronic Systems.

■ BMDO is upgrading the PATRIOT, which will help destroy short- and medium-range ballistic missiles and other threats in the atmosphere.

[1]PATRIOT is an acronym for Phased Array Tracking Radar Intercept on Target.

[2]In Greek mythology, AEGIS is the name of the shield owned by Athena, goddess of wisdom and war, who loaned the shield to Perseus to block the gaze of Medusa.

NATIONAL MISSILE DEFENSE

BMDO's national missile defense (NMD) is concerned with the possibility of a limited ballistic missile strike against the U.S. homeland. The current NMD program works toward building, if necessary, a ground-based antiballistic missile system to effectively defend all 50 states against a small number of threatening warheads from rogue nations.

NMD's key components under development include a ground-based interceptor, ground-based radar, upgraded early-warning radar, a battle management system, and sensor technology. Over the next few years, flight tests are planned at the national test range in the Pacific to demonstrate these elements, individually and together as a system. If successful, these tests will indicate that an effective and affordable NMD system can be built if needed.

TECHNOLOGY READINESS

BMDO depends on advanced technology of all kinds to invigorate its ability to defend against increasingly sophisticated ballistic missile threats. Therefore, the continued availability of such technology has become a vital part of the BMDO mission. The BMDO Deputy of Technology Readiness is responsible for fostering advanced research and development of new BMDO technology.

The Science and Technology Directorate is a part of BMDO's technology readiness effort. This group manages four BMDO programs:

- Innovative Science and Technology (IS&T). The IS&T program pursues speculative, high-risk technologies that could spur a revolutionary leap in capability. Specific goals include quickening the pace of technology development and decreasing the time required to transform scientific breakthroughs into actual applications.
- Small Business Innovation Research (SBIR). The SBIR program funds small businesses to develop far-reaching technology innovations. Projects are funded in two competitive phases. In Phase I, the researcher demonstrates feasibility and develops a design concept; in Phase II, a prototype is built.
- Small Business Technology Transfer (STTR). The STTR encourages cooperative joint research between businesses and nonprofit research institutions. It is structured like the SBIR program and operated by the same BMDO personnel.
- Technology Applications Program. Recognizing the potential economic value of its leading-edge research and development, BMDO created a Technology Applications program. Guided by BMDO's Office of Technology Applications, this program seeks to promote the commercialization and interagency sharing of BMDO-funded technologies. It sponsors this report and manages all technology transfer efforts involving BMDO-funded technology.

TECHNOLOGY APPLICATIONS PROGRAM

■ As the logo for the Technology Applications program, the linked chain signifies our ongoing commitment to link BMDO technology developers with other organizations that promote the technology's commercialization.

COMMERCIALIZING BMDO TECHNOLOGY

In its support of BMDO research and development (R&D), the Technology Applications program recognizes the importance of world-class technologies and their potential to influence the U.S. economy. The same technology that can protect the United States from ballistic missile attacks can also help U.S. businesses become more economically competitive. By creating new products with commercially promising BMDO technology, these companies can seize opportunities for profit and create new jobs. However, technology developers sometimes need help to convert their innovations into marketable products. To assist these developers, the Technology Applications program has established innovative, diverse, and proactive approaches that can be applied at various stages of the technology's development. The following sections discuss the program's approaches in more detail. The final section introduces new initiatives coming in 1997.

MAKING INDUSTRY AWARE OF BMDO-FUNDED INNOVATIONS

The Technology Applications program publishes many types of documents, raising industry awareness of BMDO-funded innovations. These documents are unique in the technology transfer community because their focus on technology areas is quite flexible. For example, one issue of our newsletter may highlight BMDO innovations having potential commercial applications in computers, manufacturing, and transportation; another issue may feature similar innovations in materials, sensors, and electronics. In another example, our special reports may explore BMDO innovations having potential commercial applications in only one industry—for example, medicine. Using both types of publications, our program spreads the word about BMDO-funded technology with high commercialization potential. The following describes our newsletter and special reports in more detail.

The *Update* Newsletter

To reach those who want to use BMDO technology, the Technology Applications program publishes a 12-page quarterly newsletter called the *Update*. The newsletter has been a major component of BMDO's technology push efforts, featuring BMDO innovations that already are being commercialized or that have potential commercial applications. By presenting technical solutions for which industry has a need or market, it also facilitates our market pull objectives. With more than 20 issues and 300 stories published since 1991, the *Update* has received and responded to over 13,500 requests for information. In fact, it has processed more than 7,600 requests in the past two years alone.


Fall 1996

THE UPDATE

Linking American Businesses to Ballistic Missile Defense Technology

Ballistic Missile Defense Organization

The Art of Display

IN THIS ISSUE

The Art of Display Page 1

Program Funds Research Leveled In Less Likely Places Page 3

Horizons Page 9-10

Bulletins Page 11

A Quarterly Publication of the Ballistic Missile Defense Organization Technology Applications Program

■ The *Update* newsletter, pictured above, is a tool for informing industry about technology-rich developments from BMDO R&D. It is a major component of BMDO's comprehensive outreach program.

The *Update* can produce marketing contacts that lead to important business deals, as illustrated by QM Technologies (Albuquerque, NM). This company, mentioned in the Spring 1996 issue, received a substantial amount of visibility, which in turn resulted in discussions, negotiations, and eventually contracts with such major corporations as Caterpillar, Gillette, and Rockwell. Under these contracts, QM Technologies will demonstrate its material-improvement technology on manufactured goods, which may lead to more opportunities.

The Trymer Company (Leander, TX), mentioned in the Fall 1995 issue, also benefited from marketing contacts generated by the *Update*. "After the *Update* article ran, we were inundated with calls, both near and far away," explains Jon Schroeder, Trymer's president. "This tells us we have a viable commercial product that could sell anywhere in the world. Also, by talking with potential end-users, we were able to design a new unit cooled differently from the existing product." In addition to its water-cooled unit, Trymer now offers an air-cooled version for dry, remote regions.

What's in the *Update*? The 1996 newsletters included feature stories highlighting ophthalmology, electric power generation, nanoscale materials, and flat-panel displays. A new "Bulletins" section highlighted items of interest to BMDO technology developers and the technology transfer community. In presenting BMDO innovations, the *Update* has an award-winning approach. It won a merit award from the Society for Technical Communication, Washington, D.C., Chapter, in early 1997.

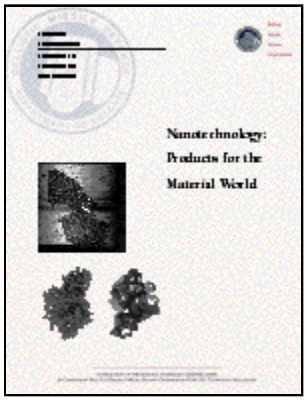
Sometimes, there is so much information for a feature story that a separate, supplemental publication is developed. This document covers more technologies on the same subject and their commercial applications, giving readers a more complete picture of what BMDO-funded technology has to offer. Published supplements include the following:

- *Nanotechnology: Products for the Material World.* Nanotechnology—including materials and the manipulation of materials below 100 nanometers—is an emerging scientific field with enormous potential in the commercial sector. This 15-page supplement identifies 22 BMDO-funded technologies directly involved in nanotechnology areas, including electronic devices, lithography, and materials. It also discusses BMDO-funded advances in technology areas that support primary nanotechnology research.

- *Law Enforcement Technology.* For the fight against crime, law enforcement agencies are investigating new tools in many areas. This 15-page supplement highlights 19 companies with BMDO-funded technologies that have potential applications in law enforcement areas, including communications, information management, surveillance, weapons detection, and investigative tools.

- *Adaptive Optics Technology.* BMDO, interested in destroying enemy missiles with laser weapons, funded the development of adaptive optics (AO) technology to see clearly through the atmosphere. As a result, astronomers now can see faint stars more clearly. In addition, AO technology may have new applications in medicine and manufacturing. This eight-page supplement highlights activities of eight BMDO-funded organizations pursuing commercial uses for their AO technologies.

- *Intelligent Transportation Technology.* BMDO has funded a wealth of technologies—such as sensors, controls, displays, and communications—that can be used to improve the movement of people and goods in America. For example, many of the technologies used to guide missile interceptors at 20,000 miles per hour can help with navigation of cars traveling at 65 miles per hour. This 10-page supplement identifies 20 companies moving BMDO-funded technology into intelligent transportation markets.



■ Separate, supplemental publications cover more technologies than can be included in *Update* feature stories. Published supplements have focused on nanotechnology (pictured above), law enforcement technology, adaptive optics, and intelligent transportation technology.

Applications Reports

The Technology Applications program focuses on areas where BMDO-funded technologies have high commercialization potential or could significantly improve our economy and quality of life. As a result of these ongoing efforts, the Technology Applications program produces detailed reports highlighting these areas and technologies. The reports are designed to make industry aware of BMDO-funded technologies that exist now or are on the horizon. The following reports are available:

■ This report speaks to the important ways our Nation's investment in ballistic missile defense is having a direct and supplemental bearing on medicine. The fruits of BMDO's technological advances are being seen in new techniques in the biomedical research laboratory, at the clinical bedside, and in the operating room.

- *BMDO Technology and the Electric Utility Industry.* Players in the electric utility industry are becoming ever more challenged by the dynamics of a more competitive economy. Advanced technology, in many areas, may lead this industry to higher performance and, often, higher returns. BMDO has funded advanced technologies in a wide range of areas that may help electric utilities meet these challenges. This report identified four areas where BMDO-funded technology can benefit utilities: power transmission and distribution, fossil-fuel power generation, environmental compliance, and load management. It highlights more than 40 technologies.

- *BMDO Technology Applications in Biomedicine.* The technical expertise used to solve the complex needs of missile defense has another fortunate spillover. It is enabling new biomedical technologies—some 10 years ahead of conventional equipment—that are beginning to make some diseases easier to detect and simpler to manage. This 96-page report highlights more than 60 technologies, in three major sections, that have resulted from or been improved through BMDO-funded research. The first section deals with existing technology, such as x-ray mammography and its conversion from a film-based to a digital technique. The second section explores emerging technologies, such as infrared detection of blood glucose and computer-aided diagnosis. Last, a section on enabling technologies discusses progress in data transmission and electronic storage, as well as high-temperature superconductors. The report can be found at http://www.acq.osd.mil/bmdo/bmdolink/html/transfer.html on the World Wide Web. In 1997, a follow-on to the first report will cover 35 new technology transfer stories.

Other applications reports available from the Technology Applications program include the following:

- *Energy Storage Technology.* Interested in power technology for satellites and power supplies for weapons, BMDO has funded many energy research projects, including new battery technologies. Building a better battery is not easy, and many research efforts are looking for new advances to help meet industry demand. With most of its content focusing on batteries, this 39-page report highlights the research efforts of 23 BMDO-funded organizations. Other energy sources—such as capacitors, flywheels, and fuel cells—are also described.

- *The Diamond Technology Initiative.* In the world of missile defense, diamond coatings promise more durable optics and mechanical parts; more efficient thermal management for electronics; and faster, more resilient semiconductors. With the opportunity for such a far-reaching payoff, the BMDO IS&T program created the Diamond Technology Initiative in 1986. Today, BMDO's investment in wide-bandgap semiconductor technology has played a major role in helping several U.S. companies introduce diamond-coated products to the marketplace. This 56-page report—our most requested publication—describes 25 projects funded by BMDO's Diamond Technology Initiative.

In addition, the Technology Applications program publishes yearly reports that review the top 50 commercial success stories emerging from BMDO technology transfer efforts. The following reports are available:

- *1995 Technology Applications Report.* This report highlights 50 1995 BMDO-funded technologies being commercialized in such areas as communications and multimedia, law enforcement, manufacturing, satellites, and transportation. It can be found at http://www.acq.osd.mil/bmdo/bmdolink/html/transfer.html on the World Wide Web and is also available in printed form.

- *1994 Technology Applications Report.* The report, available in hard copy, features 50 1994 BMDO-funded technologies moving toward the marketplace. Areas in which technology is highlighted include the environment, sensors, energy, software, microelectronics, superconductors, and the information superhighway.

Technology Applications Information System

The Technology Applications Information System (TAIS) contains hundreds of innovation highlights that describe BMDO-funded technologies either being commercialized or on the horizon. The database system is designed to suit those looking for new technologies for their specific needs. It also contains an extensive set of reference and assistance information, including a detailed listing of state and Federal technology transfer agencies.

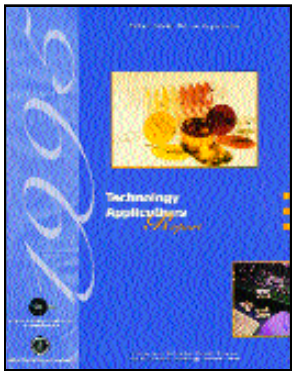
The TAIS can be a valuable tool for American businesses because they can find new technology that may give them an edge in today's competitive environment. *Any* American can use the service for up to three 30-minute blocks every day. New users can register online the first time they log on and will receive a database password within a few days. The system offers full-text searching and can handle modem transmission speeds up to 28,800 bits per second. Registration information can be obtained by calling (703) 604-3855.

In 1997, TAIS information will be moving to the information superhighway. The Technology Applications program is quickly building an on-line presence on the Internet and the World Wide Web. In fact, some BMDO technology information is already there, and can be accessed through the BMDO official home page, BMDOLink, at http://www.acq.osd.mil/bmdo/bmdolink/html. This web site includes downloadable files containing information from our *1995 Technology Applications Report*, as well as the *BMDO Technology Applications in Biomedicine* report. In the near future, the Technology Applications program plans to have its own World Wide Web site. Announcements will be made in upcoming issues of the *Update* newsletter.

Media Coverage

The Technology Applications program works with the media to leverage information that we disseminate through our publications. In most cases, our program staff respond to media queries by providing background information and organization contacts for a particular BMDO innovation. The media use this information to create new material, which is then published.

Sometimes, the newly published material can stimulate greater visibility for BMDO technology developers. For example, the Spring 1996 *Update* cover story, which featured four BMDO-funded technologies being transferred to ophthalmology, prompted a call from a *Wall Street Journal* editor. After speaking with our program staff, the editor wrote an article on three of the four technologies, which later appeared on the front page of the paper. A Maryland Public Television program, *TechnoPolitics*, also contacted us for more information about the ophthalmic technologies mentioned in the *Update* article. As a result, Guy Hammer, BMDO's Director of Technology Applications, appeared on this nationally broadcast show to discuss these technologies.



■ This report was released in April 1996. It features 50 stories on new ideas, new products, and new companies resulting from BMDO technology.

In 1996, our program successfully worked with the press on at least 100 occasions, resulting in articles about technology commercialization and the program itself. Articles were printed in such daily publications as the *San Diego Union-Tribune*, the *Tampa Tribune*, *USA Today*, the *Wall Street Journal*, the *Washington Post*, and the *Washington Times*. Weekly publications—including *Aviation Week & Space Technology*, *Business Week*, and *Industry Week*—also printed articles. In addition, articles were published by such trade publications as *Advanced Materials & Processes*, *BioPhotonics International*, *Design News*, *Diagnostic Imaging*, *Federal Technology Report*, *Futurist*, *Industry.Net*, *Journal of Metals*, *Laser Focus World*, *Mechanical Engineering*, *Medical Laser Report*, *R&D Magazine*, *Sensors*, and *Traffic World*.

GUIDING BMDO-FUNDED RESEARCHERS IN THE COMMERCIALIZATION PROCESS

One of the most important tasks performed by the Technology Applications program is guiding BMDO-funded researchers in the commercialization process. Our technology transfer specialists have designed innovative approaches to support BMDO-funded innovations at two levels of maturity. For technology in the early stages of development, the program holds planning meetings to help developers identify potential market niches for their research products. For technology in the final stages of development, it holds application reviews to help technology developers fine-tune their commercialization strategies. Each approach is further described below.

Planning Meetings for Early-Stage Research

In 1996, the Technology Applications program introduced a trial series of planning meetings for first-time winners of Phase I contracts from BMDO's SBIR program. Called "Business Focus Workshops," these meetings are designed to provide a framework and expert contacts for innovative business development. The workshops are key to helping companies establish commercial interest in their BMDO-funded innovations early in the development process.

■ The Technology Applications program convenes advisory panels for BMDO technology developers in early-stage research. Previous attendees have commented that some of the best advice comes from one-on-one conversations during breaks and at lunch.

More than 20 BMDO Phase I companies participated in the initial set of workshops. In each workshop, a research representative from the SBIR-awarded company was teamed with a technology transfer agent and a business adviser to form a collaborative team. This team assessed the technology and produced a brief business case highlighting five components: a company introduction, the business opportunity, the technical edge, company resource requirements, and a preliminary development plan. Later, the researchers presented the business cases to a panel of commercialization specialists to get feedback on their plans and advice on their commercialization strategy. These sessions helped spotlight company development issues that needed critical attention before they grew into real problems.

The workshop response was positive. Several participating companies told the Technology Applications program of modifications or developments in their company structure, new proposals, partners, and intellectual property action that resulted from their participation in a Business Focus Workshop. One company responded: "Your team gave us a template for evaluating our business strategy. . . . As a result, we are now working with [a] law firm . . . and are negotiating a partnership with a . . . worldwide leader [in the field]." With regard to the technical aptitude of consultant panelists, one research representative from an SBIR-awarded company was "particularly delighted to find that two of the outside advisers were highly knowledgeable in the . . . field." Based on the first-round successes, the Technology Applications program is planning to implement a full-scale workshop program for new SBIR Phase I winners in 1997.

Reviews for Final-Stage Research

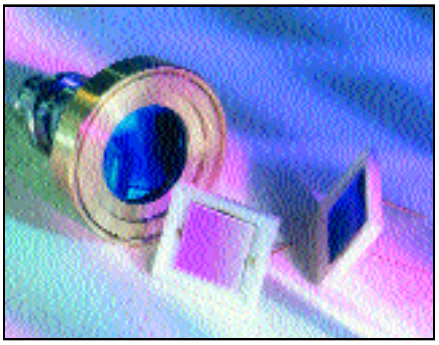
Technology Applications Reviews use a forum approach to provide commercialization advice and information to researchers with technology nearing the market. In these reviews, a panel of experts assesses and advises researchers on their commercialization process. The panel reflects the diversity required to make a business successful, with a wide range of expertise in such areas as venture capital, intellectual property, business formation, marketing, and strategic partnerships—all with focuses in different application areas.

BMDO-funded researchers use this expert advice to refine their business plans, with the goal of making their businesses more profit oriented and commercially driven. The reviews have been instrumental in the commercial success of dozens of small and large companies. As a result of these forums, many companies have revised business and commercialization plans, focused on new application areas, developed new industry contacts, and fostered new business relationships.

Since 1989, more than 200 inventors from industry and nonprofit organizations, 50 researchers from universities, and 40 researchers from the Government have presented their commercialization strategies in more than 40 Technology Applications Reviews. In 1996, the review process focused on such areas as biomedicine, commercial space, and nanotechnology. Some of the 1997 reviews are targeting power electronics, information networks, and industrial energy.

LEVERAGING COOPERATIVE RELATIONSHIPS

The Technology Applications program facilitates the transition of BMDO technologies to the commercial sector by leveraging cooperative relationships with a cross-section of professional societies, trade associations, and Federal agencies. Representative organizations include the Technology Transfer Society, Economic Development Administration, Bureau of Export Administration, Small Business Administration, Department of Commerce, and Department of Health and Human Services. The Technology Applications program has supported conferences and meetings with some of these groups, as highlighted below.



■ Advanced Photonix's avalanche photodiodes (pictured above) are one of six BMDO-funded technologies selected for further consideration by a multi-agency consortium on imaging technologies to improve women's health.

Meeting to Promote Innovative Technology for Women's Health

BMDO is involved in efforts to identify advanced technology for improving women's health. In late 1994, Dr. Dwight Duston, then BMDO's Director of Science and Technology, testified before a committee of the U.S. House of Representatives that several BMDO-funded technologies could improve the early detection of breast cancer.[1] As part of a 1996 follow-up to this testimony, BMDO joined the Federal Multi-Agency Consortium on Imaging Technologies to Improve Women's Health. In this collaboration, a technology transfer subcommittee reviewed innovative technologies for improving women's health from an inventory of 297 Federal agencies and laboratories. Of the 82 technologies given serious review, 6 of 14 selected for funding consideration were sponsored by BMDO: large-format digital sensors, avalanche photodiodes, acousto-optic tunable filters, active vibration isolation systems, uncooled infrared cameras, and polarization imaging and fluorescence spectroscopy devices.

[1]Testifying before the Research and Technology Subcommittee of the U.S. House of Representatives' Committee on Armed Services at the Hearing on the Uses of Military Technology and Information in the War Against Breast Cancer.

Conference on Technology Transfer Measurement and Evaluation

In early 1996, BMDO supported a first-of-its-kind working conference on technology transfer measurement and evaluation in Santa Fe, New Mexico, with the Technology Transfer Society and the Engineering Foundation. The conference's aim was to bring together various technology transfer communities so that they could learn from each other's experiences in performance measurement and evaluation.

Conference Series for Small and Medium-Size Businesses

During 1996, BMDO participated in the U.S. Department of Commerce and U.S. Small Business Administration nationwide conference series called "Commercialization of Defense Technology." These conferences were designed to acquaint small and medium-size businesses with Federal assistance in moving technology to market. For example, the Charleston, South Carolina, conference focused on construction, energy, and environmental remediation technologies, while the Austin, Texas, conference centered on biomedical, computer, and semiconductor technologies.

TESTING INNOVATIVE, NEW MODELS TO COMMERCIALIZE BMDO-FUNDED TECHNOLOGY

Working with industry, academia, and other Government agencies, the Technology Applications program is finding new ways to jump-start the commercialization process by formulating and validating technology transfer models, two of which are described below.

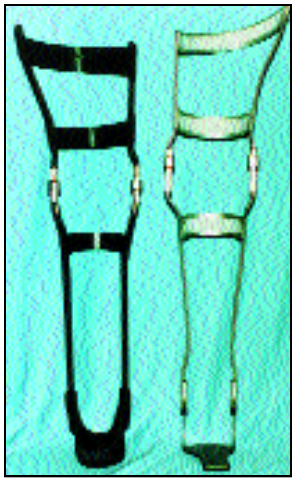
Leveraging the Expertise of State and Local Development Groups

The Technology Applications program successfully demonstrated a new model for technology transfer, bringing together the Los Angeles Regional Technology Alliance (LARTA), the National Association of State Development Agencies, and 14 companies—7 of them funded by BMDO to develop antimissile defense technology. This innovative model was designed to leverage the business, financial, and marketing expertise of state and local economic development groups in southern California, reasoning that the groups' expertise may be useful to the commercial plans of the participating companies.

LARTA will use the information from the presentations to assess each company's needs and match them with organizations from its mentoring network. Companies with promising technology and a keen eye for commercialization will be invited to attend LARTA's Southern Venture Forum, a premiere event in which venture capitalists pay to meet with representatives looking for new capital sources.

Encouraging the Use of Innovative Technology to Help the Disabled

As early as 1989, the Technology Applications program encouraged that a strong, lightweight composite material designed for missile structures be used in medical applications to help the disabled. One of the most promising developments was a leg brace, made of composite parts, that was much stronger, lighter, more durable, and easier to form than conventional aluminum braces worn by paraplegics today. In a current demonstration program, BMDO is funding one of the leaders in composite research, SPARTA, Inc. (San Diego, CA), to develop a method of manufacturing long-fiber composite parts to be used as spinal implants and spinal braces.



■ BMDO funded SPARTA's structural materials research for a ground-based missile interceptor. This research has enabled the development of a new leg brace (pictured on left) that is much stronger, lighter, and easier to form than the conventional brace worn by paraplegics today (pictured on right).

BMDO's interest in this project is proving that long carbon fibers (up to 1/2 inch, compared with the conventional fiber length of 1/16 inch) can be molded into shapes and sizes that can be implanted or affixed to the human skeleton. A group of biomedical professionals has formed around this initial attempt. This model of cooperation, critical for medical certification and acceptance, can be used by others if the application proves successful.

FINE-TUNING SPECIAL PROJECTS TO DEBUT IN 1997

The Technology Applications program is developing several special projects relating to BMDO technology transfer that are to be implemented in 1997 and 1998. The following project descriptions provide a sneak peak at what is in store:

- BMDO Technology Applications CD-ROM. This project will develop a compact disc read-only memory (CD-ROM) product to promote interest in the commercialization of BMDO-funded technologies in a wide variety of commercial applications. Primarily aimed at American industry, the CD-ROM will feature stories of companies successfully commercializing BMDO-funded technology, resources for high technology small business start-ups, and BMDO technologies available for licensing and their potential applications.

- Educational Technology Initiative. This effort will explore the potential of transferring BMDO-funded technology to the distance education market. In October 1996, BMDO participated in a Global Summit on Distance Education to obtain data on requirements.

- Medical Diagnostic and Telecommunications Project. This project will examine the possibilities of transferring BMDO innovations into medical imaging, diagnostics, procedures, and telecommunications. Involving other programs, such as National Aeronautics and Space Administration's (NASA's) Classroom of the Future and the U.S. Army's Battlefield Intensive Care Unit, the project could provide win-win situations for technology developers and the military.

- Missiles to Mammograms Program. This program will support the development of medical imaging technology to leapfrog the capabilities currently available and to achieve high quality and reliable mammography for combating breast cancer. This effort will initially focus on an interagency collaboration with NASA, the Public Health Service Office on Women's Health, and the National Cancer Institute.

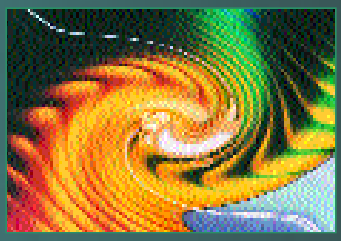
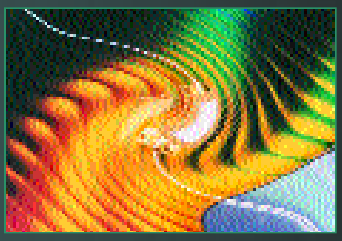
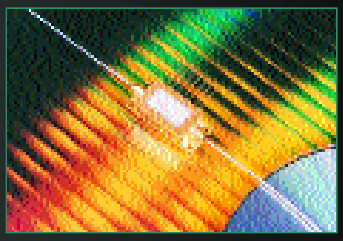
The following sections of this report highlight the top 50 BMDO-funded commercial success stories for 1997. Many of these products that companies, universities, and laboratories are developing are currently on the market, while some products are just entering their commercialization phase.

Courtesy of Trex Medical Corporation.

■ Mammography is critical for improving early detection of breast cancer. Through the Missiles to Mammograms program, BMDO will support the development of advanced imaging devices with the potential to reduce the mortality associated with breast cancer.

For copies of any program publication mentioned in this section, contact the National Technology Transfer Center, Washington Operations at the address listed on the inside back cover of this report.

COMMUNICATIONS AND DISPLAYS

With the rapid growth of fiber optics and the introduction of smaller displays, people are communicating faster and more efficiently. Fiber-optic cables and networks are rapidly encircling our Nation, increasing the bandwidth to handle a dizzying array of new interactive communications services. Miniature displays are enabling smaller personal communications devices—such as beepers, cellular phones, and personal digital assistants—allowing Americans to stay in touch while on the move.

Advanced technology offers much in these areas, allowing, for example, the elimination of unwanted light reflections in fiber-optic cables to improve signal quality. It can also enable displays that are lighter, smaller, more colorful, and more energy-efficient than previously available. These displays will find homes in such diverse markets as advertising, laptop computers, medical devices, video games, and even sport fishing.

Today's Market

The United States is the world leader in fiber-optic cable installations, accounting for one-third of the total worldwide market. As the number of fiber-optic cable installations rises, so does the demand for fiber-optic interconnect products. The North American market for these products was about $200 million in 1994 and could climb to $440 million by 2001.[1] The United States is a major player in the worldwide flat-panel display market, which is expected to climb from $8.6 billion in 1995 to about $15.8 billion by the year 2000.[2]

Tomorrow's Opportunity

BMDO has funded numerous photonics, electronics, computer-related, and even power technologies for tracking and destroying ballistic missiles that lend themselves to the communications and display industries. The following section highlights six of these technologies and the companies that are commercializing them.

---

[1]Kotelly, George. 1996. The communications future is fiber. Lightwave, December, 4.

[2]Electronic Trend Publications. 1996. Worldwide flat panel display markets and trends. March. World Wide Web at http://www.electronictrendpubs.com/fpd.htm.

Can You Imagine . . .

. . . a user-configurable transceiver that brings gigabit-per-second data transmission to computing applications.

VIXEL MEETS DEMAND FOR HIGH-CAPACITY INTERCONNECT DEVICES

As the global network grows in size and complexity, user-friendliness and flexibility will become the key criteria. Data transmission between older copper wire and new optical networks can link communication nodes without retooling the entire information infrastructure. This capability is crucial when extending new communication methods to traditionally underserved areas, such as developing countries and the rural United States.

To help interweave the various threads of the communications network, Vixel Corporation (Broomfield, CO) acquired a leading information management company, Western Digital (Lynwood, WA). The move cements an alliance that brings gigabit-per-second data transmission to computing applications. Through this alliance, Vixel introduced a new product, the IntraLink 1000™ Fibre Channel hub.

USING BMDO-FUNDED LASER TECHNOLOGY, VIXEL HAS MOVED AGGRESSIVELY INTO THE HIGH-SPEED COMMUNICATIONS MARKET.

The device, a user-configurable transceiver that allows communication between optical and copper wire topologies, offers gigabit-per-second data rate performance and can be reconfigured for different media, including fiber optics and copper. Server and storage array manufacturers intend to deploy this product for distributed database applications. EMF Associates, a technology and marketing group, estimates that Fibre Channel Arbitrary Loop hub sales will top $500 million by the year 2000.

The agencies that funded Vixel's research in optical data transmission and storage included BMDO; the U.S. Army, Air Force, and Navy; NASA; the National Institutes of Health; and the National Science Foundation. This research led to the development of vertical cavity surface-emitting lasers (VCSELs). VCSELs are small, high-powered lasers that operate at high efficiency and are the foundation of Vixel's LASE-ARRAY™ products. LASE-ARRAYs are responsible for the fast optical switching and high-bandwidth characteristics of its new Intralink product.

■ Vixel has supplied samples of its IntraLink 1000™ Fibre Channel hub to Sun MicroSystems and Compaq Systems Division.

To expand LASE-ARRAY manufacturing, Vixel acquired the assets and technology of Bandgap Technology Corporation. This acquisition includes a 5,000-square-foot cleanroom, with machines tailored for producing the semiconductor material for VCSELs. This move allows Vixel to consider new application areas, such as optical interconnects for computers and workstations, detector arrays, multifiber optical ribbon, and machine vision components. Other possibilities include optical data storage and medical instrumentation.

ABOUT THE TECHNOLOGY

VCSELs facilitate optical data transmission. Unlike other diode lasers, which emit light from their edges, VCSELs emit laser beams perpendicular to their surface. This design creates the ideal geometry for stacking VCSELs side-by-side in 1- and 2-D arrays. It also allows VCSELs to be 20 to 50 times smaller than edge-emitting diode lasers. Edge-emitting lasers produce elliptical beams whose high divergence makes focusing difficult; VCSELs produce nearly circular beams that diverge considerably less than the elliptical beams and thus require less sophisticated optics to focus the beam.

Compared with traditional lasers, VCSELs have been relatively inefficient. However, Vixel modified the VCSEL design to approach the efficiency of edge-emitting lasers. Wall-plug efficiencies of its VCSELs are now measured at about 10 percent, resulting in smaller, higher power lasers with extremely fast switching speeds. Also, Vixel's LASE-ARRAYs can operate in wavelengths ranging from 750 to 1,050 nanometers.

OPTICAL ISOLATOR REDUCES NOISE IN FIBER OPTICS

Can You Imagine . . .

. . . an isolator that improves the way optical amplifiers manipulate light to enhance signal quality in fiber optics.

The booming telecommunications market heavily supports fiber-optic technologies, leading to increased development of optical switching, multiplexing, and long-line transmission of the optical signals. Contributing to this technological advancement, E-TEK Dynamics, Inc. (San Jose, CA), developed a new fiber-optic device that reduces the electronic-to-optics transitions in the network.

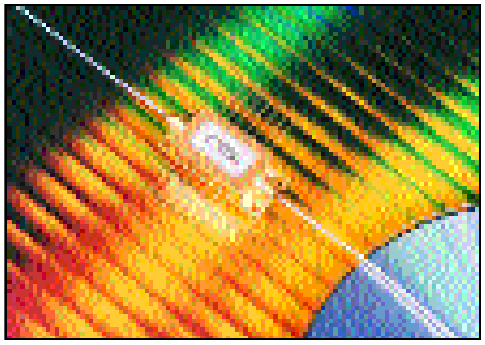
E-TEK's device, called the polarization insensitive fiber isolator (PIFI), eliminates unwanted light reflections in fiber-optic cables. These reflections cause noise, which greatly reduces signal quality. The BMDO SBIR program funded the development of the PIFI for a fiber-optic sensor system to track ballistic missiles. The technology is now finding a role in new fiber-optic systems.

For example, the PIFI is an essential component in advanced fiber-optic communications components, such as the erbium-doped fiber amplifier (EDFA). EDFAs are increasingly replacing repeaters to amplify lightwave signals in long-distance fiber-optic telecommunications (including transoceanic), cable television distribution, and long-distance soliton (isolated wave) transmission. Unlike repeaters, EDFAs do not convert an optical signal into an electric signal to boost it, resulting in lower operating costs, better transmission quality, and more compact systems.

E-TEK'S FIBER-OPTIC TECHNOLOGY IS BEING USED BY SUCH TELECOMMUNICATIONS GIANTS AS AT&T, SPRINT, AND MCI.

E-TEK supplies PIFIs to all of the major EDFA manufacturers that provide optical amplifiers to such telecommunications giants as AT&T, Sprint, MCI, and British Telecommunications. One of E-TEK's main product lines, the PIFI accounts for nearly 50 percent of the company's revenue. According to J.J. Pan, E-TEK's chairman and chief scientist, the company employed about 40 people and had an annual revenue of $1 million when it began the transition to volume production of the isolators in 1990. Today, the company employs 250 people and has annual sales of over $40 million.

The hermetically sealed semiconductor optical amplifier, another E-TEK product, also stems from BMDO-funded research. This device uses a diode laser and a temperature stabilizer to provide low-power optical amplification. Sold primarily for laboratory research, it may also be useful for small fiber-optic networks because of its compact packaging and lower cost than EDFAs.



■ E-TEK's optical amplifier, pictured above, may be ideal for small fiber-optic networks because of its compact packaging and low cost.

ABOUT THE TECHNOLOGY

Fiber isolators prevent one system from disturbing another while transmitting signals between them. E-TEK's PIFI minimizes back-scattering and back-reflection of optical signals, thus maintaining a high signal-to-noise ratio. Mismatching polarization in fiber-optic components causes high insertion loss, so polarization-insensitive fiber isolators are key to amplifier performance. The highly reliable PIFI Classic features 40 decibel (dB) of isolation, with a 0.3 dB insertion loss and 0.2 picosecond polarization mode dispersion. The multistage PIFI Ultimate has 70 dB of isolation, with 0.7 dB insertion loss and 0.5 picosecond polarization mode dispersion.

Can You Imagine . . .

. . . a drive mechanism that precisely aims and holds in position antennas used for satellite transmissions.

ROTARY DRIVE POSITIONS ANTENNAS FOR SATELLITE NEWS GATHERING

SAGEBRUSH'S COMMERCIALIZATION OF ROTO-LOK® DRIVES HAS SPREAD INTO SATELLITE NEWS GATHERING, VIDEO CONFERENCING, AND MEDICAL MARKETS.

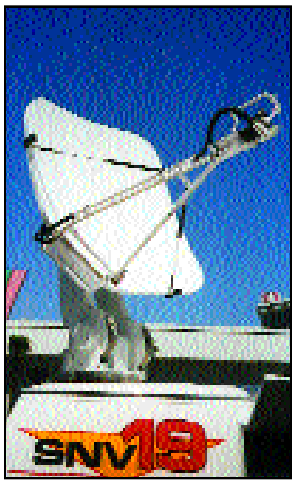
The booming business of satellite news gathering (SNG) uses mobile trucks equipped with portable satellite antennas. Many antenna systems, however, use a linear actuator (motorized rod-and-screw design) that makes it harder to point antennas in the right direction. This design also makes it difficult for the antenna to hold its position in windy conditions and to accommodate truck and satellite movements. Such problems interfere with transmission of sound and image data to television stations or other reception sites.

Responding to this problem, Sagebrush Technology, Inc. (Albuquerque, NM), now sells its Roto-Lok® rotary drive to designers of SNG antenna systems. Using an innovative motorized cable-drive system, Roto-Lok precisely positions and holds these antennas, even in windy conditions. The drive's zero-backlash, virtually perfect smoothness, and high torsional stiffness make it possible to position satellite antennas with greater reliability and accuracy than previous technology provided.

One of Sagebrush's newest customers—Andrew Corporation, a global supplier of communications systems equipment and services—recently introduced a compact, lightweight antenna for SNG trucks. Instead of the typical rod-and-screw design, a Roto-Lok drive precisely points the antenna. "Andrew selected the Roto-Lok drive because it is a very precise pointing system and is virtually maintenance free," says Bob Fitzgerald, Andrew's manager of earth-station antennas.

Electrospace Systems, Inc., also a supplier of communications systems and a Sagebrush customer, recently purchased many Roto-Lok drives to install on mobile satellite antenna systems for military vehicles. Roto-Lok's ruggedness and reliability allow operation in harsh environments, impressing the military. U.S. troops on a peacekeeping mission in Bosnia-Herzegovina used eight drives connected to satellite antennas. According to Don Carson, Sagebrush's vice president of marketing and sales, "These drives survived the coldest winter in European history and didn't lose a minute in downtime."

Sagebrush is supplying 250 Roto-Lok drives to a company that sells videoconferencing equipment to schools and colleges. In addition, the company is using Roto-Lok drives for precision positioning in medical and military equipment. The BMDO Laser Communications program provided key support to develop the Roto-Lok drive into a high-visibility product. In this program, the drive controlled the precision angular alignment of laser beam transmitters and receivers in a communications network.



■ This antenna system uses a Sagebrush Roto-Lok® rotary drive for precise positioning in satellite news gathering.

ABOUT THE TECHNOLOGY

In the Roto-Lok drive, tensioned cables wrap a figure-eight pattern around two closely spaced wheels. Friction carries torque from a powered wheel (capstan) to a driven wheel (drum). The drive maintains precision by employing many cables working in parallel. Sharing the load, the cables average the rotation rate so that any imperfections, dirt, or other slight irregularities on the drum or cables do not affect the drive rate. Because the cables do not slide on the drum or capstan, there is virtually no wear.

The Roto-Lok drive also maintains much higher stiffness than drives that use chains and drive belts because it has springs at the end of each cable, which provide tension throughout the cable. Spring-loaded cables also reduce backlash, a design problem that affects pointing accuracy and transmission efficiency. Roto-Lok positions the drum and the cylinder connected to the drum to within 50 millionths of one degree. It also transmits rotation at efficiency rates greater than 98 percent and runs quietly.

SOLID-STATE AMPLIFIER MAY COMPETE WITH MICROWAVE VACUUM TUBES

Can You Imagine . . .

. . . a solid-state alternative to vacuum tubes for generating and amplifying radio frequency and microwave power.

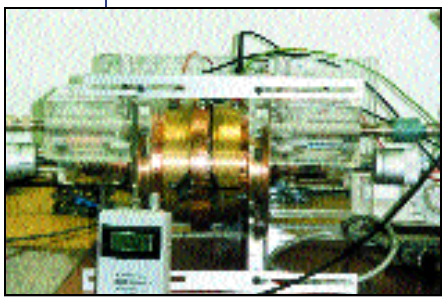
Solid-state devices, such as transistors and integrated circuits, have replaced most vacuum tubes. However, microwave vacuum tubes are an important exception and are still used in such diverse applications as radar, space communications, and television broadcasting equipment. Because solid-state devices cannot handle high-power loads at microwave radio frequencies, microwave vacuum tubes remain the chosen technology to amplify high power.

Aria Microwave Systems, Inc. (AMS; Englewood, NJ), developed a new active radio frequency (RF) cavity concept and prototype that can replace vacuum tubes with solid-state technology. This concept integrates low-power solid-state transmitters into the walls of a resonant cavity, forming a single, high-power structure called the active RF cavity amplifier (ARFCA). With this design, the amplifier handles high-power loads at radio and microwave frequencies with efficiencies approaching those of intrinsic solid-state devices.

With this unique capability, the ARFCA provides an alternative to vacuum tubes for generating and amplifying RF and microwave power. With voltage requirements 1,000 times less than conventional vacuum electron tubes and a cheaper power supply, the amplifier will use smaller, less expensive power conditioning equipment. This rugged and repairable device requires no vacuum, magnets, or complex electrodes, and it can be easily fabricated.

ARIA MICROWAVE IS NOW BUILDING PROTOTYPES FOR EXISTING AND EMERGING COMMERCIAL APPLICATIONS.

Under BMDO SBIR funding, AMS has proved the concept with a device that combines the output of six RF transistors at 1.8 gigahertz. The company is currently building two more prototypes for existing and emerging commercial applications. One will use 60 transistors to achieve an output of 1.8 kilowatts (kW) of ultrahigh frequency (UHF) power at 915 megahertz (mHz). This technology could eventually be used in commercial transmitters such as television, radar, satellite, and cellular communications, all of which are currently dominated by vacuum tubes.



■ Pictured above is Aria Microwave's active radio frequency cavity prototype. It requires no vacuum, magnets, or complex electrodes, and can be easily fabricated.

The second prototype, designed to serve the industrial heating market, contains 20 transistors to produce 1 kW of UHF power at 915 mHz. This ARFCA could replace magnetrons, which produce heat via microwaves for pharmaceutical and petroleum processing. Its reduced power consumption, longer lifetime, and gradual failure rate would make the amplifier cost-competitive with magnetrons. Furthermore, the amplifier would be safer than its high-voltage competitor; for example, magnetrons usually fail catastrophically, which could spark an explosion in chemical plants. The ARFCA's gradual failure mechanism would protect such volatile environments.

ABOUT THE TECHNOLOGY

The ARFCA combines the output from many low-power, solid-state devices into a single high-power device or structure. In the ARFCA, the cavity simultaneously acts as the power combiner, matching transformer, and heat sink. A waveguide or coaxial cable guides the RF and microwave power out of the ARFCA. Dr. Bernard Cheo, inventor of the ARFCA, states that only the number of transistors that can physically fit around the cavity limits the maximum output power. The first prototype produced a combining efficiency exceeding 90 percent.

Can You Imagine . . .

. . . a miniature display, the size of a quarter, that matches the viewing performance of a 21-inch color computer monitor.

BMDO-FUNDED R&D ENABLES SMALLER DISPLAYS, BIGGER IMAGES

From switchable color filters to miniature displays, devices developed by Displaytech, Inc. (Boulder, CO), use ferroelectric liquid crystal (FLC) technology funded through the BMDO SBIR program. Displaytech's innovative research and promising display products led to the company's successful initial public offering in 1996, which raised $2.2 million. Today, Displaytech is commercializing BMDO-funded technology in two areas.

IN 1996, DISPLAYTECH'S INITIAL PUBLIC OFFERING RAISED $2.2 MILLION.

First, Displaytech found a way to shrink color displays based on cathode ray tube (CRT) technology. Applying its patented FLC technology, the company used BMDO funding to develop an electrically switchable red-green-blue (RGB) color filter. The company's FLC-based RGB FASTFilter™, which won *Photonics Spectra*'s Circle of Excellence award in 1995, turns the black-and-white images on a miniature television tube into full-color pictures. Current technology cannot manufacture miniature color television tubes.

Used with a CRT or a charge-coupled device display, the RGB FASTFilter could help produce new head-mounted color displays. In addition, the same filter may help develop color, palm-held computers and 3-D displays for flight simulation and entertainment.

■ Displaytech's ChronoColor™ Miniature Display, pictured above, measures less than one inch diagonally.

In the second area, Displaytech applied BMDO-funded FLC technology to produce a color, high-resolution, video-capable electronic miniature display. The FLC-based ChronoColor™ Miniature Display demonstrates an image that, when magnified, compares favorably with the highest resolution 21-inch color monitors. The miniature display quality is also comparable to that of active-matrix liquid crystal displays used in laptops, but the smaller product features lower production costs and greater compatibility with standard integrated circuit components.

Measuring less than one inch diagonally, the miniature display can be used in a wide range of products, including laptop and notebook computers, wireless communications devices, medical devices, and video games. Displaytech has already built a 1,280 x 1,024 pixel miniature display for demonstration purposes and expects to offer a display with 256 x 256 pixel resolution to selected end-product manufacturers in early 1997.

ABOUT THE TECHNOLOGY

Developed for BMDO optical computing and space-based applications, Displaytech's FLCs switch 100 times faster than conventional liquid crystal displays. Thinly layered on a silicon chip, they construct dense arrays of very small pixels. Standard fabrication technology for complimentary metal oxide semiconductor memory allows cost-effective production of FLCs. The Department of Commerce awarded Displaytech a $1.7 million Advanced Technology Program contract in 1994 to develop low-cost volume manufacturing technology.

NEW DIFFUSERS HOOK DISPLAY MARKETS

Can You Imagine . . .

. . . a light-shaping diffuser that brightens the display of a depth finder used in sport fishing.

Marketing its novel Light Shaping Diffusers™ (LSDs), Physical Optics Corporation (POC; Torrance, CA) hooked several new display markets. Based on holographic technology, POC's LSDs offer unusually efficient light-shaping and transmission capabilities that make displays brighter and easier to see. These devices homogenize the light, smoothing out such irregularities as glare and hot spots.

POC's LSDs are used in many unusual display applications, such as the Humminbird® Jimmy Houston Pro Flasher™ depth finder. Techsonic Industries manufactures the depth finder that helps anglers "see" underwater to find fish, grass, brush, and drop-offs in a stream or lake. An LSD provides uniform illumination on the device's display, which uses a spinning disk to present a visual representation of the water depth. Adding the LSD to the depth finder results in a brighter and easier-to-read high-resolution display than previous light-emitting diode (LED) designs.

Originally developed for BMDO space-based sensor applications, the LSD allows designers to shape light, putting it precisely where they need it most. This capability opens up new commercial applications for the optical elements, for example, brightening and giving high contrast to movie screens, flat-panel displays, and high-definition television screens. In addition, the LSDs allow the reading of documents and can improve the illumination capability of spectroscopy, robotic vision, endoscopy, and LED displays. For beam-enhancing applications related to displays, LSDs come as metal-back reflectors, molded lenses, or thin sheets.

AMONG OTHER APPLICATIONS, POC'S TECHNOLOGY HAS FOUND USES IN MACHINE VISION SYSTEMS AND AIRCRAFT INSPECTION TOOLS.

Manufactured as a display screen, a POC LSD widens the angle of overhead slides. This ability allows nearly everyone, no matter where they sit, to see the information projected on the screen. POC developed two LSD products for this area: the front-projection Lights-On Reflection Screen™ and the rear-projection Light Shaper Viewing Screen™.

■ Pictured above is the Humminbird® Jimmy Houston Pro Flasher™ depth finder. POC's technology provides uniform illumination in the finder's display, making it brighter and easier to read.

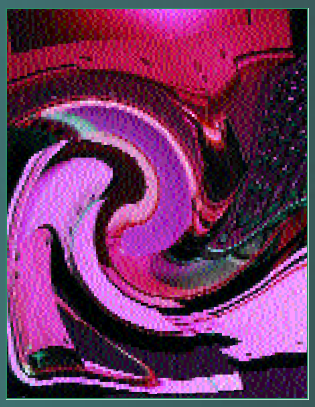
In addition to display applications, POC's LSDs have appeared in machine vision and aircraft inspection. Kulicke & Soffa Industries, a producer of semiconductor manufacturing equipment, incorporated an LSD assembly in the machine vision system of a wire bonder. Improving brightness and light uniformity, the LSD helps the bonder locate reference points on the die pad during semiconductor manufacture. In aircraft inspection, POC's LSDs offer a simple, low-cost improvement adaptable to most commercial flashlights. Providing even illumination with more than 90 percent of the light transmitted to the subject, this technology improves inspection efficiency and accuracy.

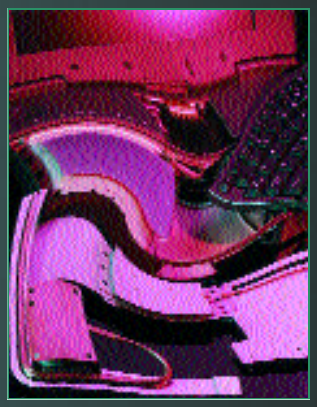
ABOUT THE TECHNOLOGY

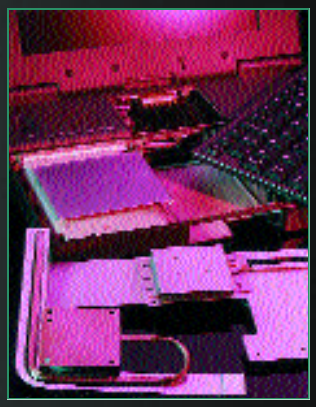
LSDs are surface-relief holograms that can be mass-produced inexpensively. An LSD is like a refractive negative lens in that it bends light, but its surface acts as various-sized, randomly distributed microlenses to produce the desired refraction angle.

LSDs shape light in two ways. First, they homogenize the light beam, eliminating variations in brightness caused by the structure of the light source. Second, they control light energy distribution along both the horizontal and vertical axes to match the light source with the area requiring illumination. An LSD produces a diffusion effect based on refraction rather than scattering, allowing more than 90 percent of the light striking the LSD to be transmitted to the target. The inherently antireflective nature of the holographic microstructure results in the high transmission efficiency.

COMPUTER HARDWARE AND SOFTWARE







Computer hardware and software have become an essential part of America's way of doing business. For example, corporate presentations are now routinely developed on personal computers and recorded on data storage drives, and proprietary information on company networks is protected from hackers and hostile insiders by information security software. Many types of advanced technology, such as electronics and optics, can improve the speed of computers and capacity of data storage drives. New software technology can also protect computer networks against industrial spies accessing company information from the Internet.

Today's Market

Millions of personal computers (PCs) are reaching international markets. PC shipments surged 25 percent worldwide in 1995 from the previous year, with over 59 million units shipped. In the United States, PC shipments increased by a rate of 21 percent from the 1994 level.[1] Software is becoming a hot industry, too, with more than 8,000 companies developing software products. In 1996, the software industry's estimated total revenue reached well into the tens of billions of dollars; it is expected to grow at a rate of 27 percent.[2]

Tomorrow's Opportunity

BMDO has funded technology for ballistic missile defense that can also provide the computer and software industries with innovative solutions to help the United States maintain a strong presence in these ever-growing world markets. Much of this technology covers such emerging areas as optics, electronics, neural networks, and information security. The following section describes six of these technologies.

---

[1]Carlton, Jim. 1996. PC shipments surged 25 percent worldwide in 1995. Computer News, 31 January. World Wide Web at http://www.newstimes.com/archive/jan3196/cpa.htm.

[2]Software Publishers Association. 1997. General issues: SPA to host congressional breakfast series. Washington Connections Monthly. January. World Wide Web at http//www.spa.org/gvmnt/Wash2_0.htm#anchor1251453.

Can You Imagine . . .

. . . a new and fundamentally more expressive "language" for designing digital electronics.

PARADIGM SHIFT IN DIGITAL CIRCUIT DESIGN ELIMINATES THE CLOCK

Widely accepted as the fundamental design paradigm in the computer industry today, Boolean logic has serious shortfalls in how it provides and moves information through digital circuits. Its circuit topology (the layout of transistors and their connection) is specifically designed for data processing, inherently preventing data movement from one processing step to the next. Therefore, "clocks" must regulate the movement of information packets.

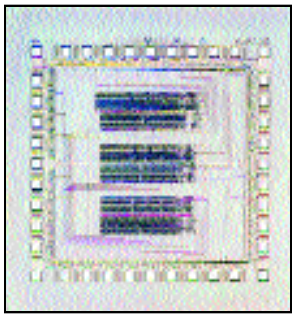
Not only is this design approach inefficient (the need for and use of input and output data may not match a particular clock cycle), but clocks account for up to 50 percent of the design cost, up to 25 percent of the manufacturing cost, and 40 percent of the power consumed in operation. More important, clocks present a potentially intractable barrier to faster, denser chip design. Denser circuit designs place more features on a chip, making the design and distribution of clock signals increasingly difficult.

To overcome this problem, Theseus Research, Inc. (Minneapolis, MN), formed Theseus Logic, Inc. (St. Paul, MN), to develop a patented chip technology called NULL Convention Logic™ (NCL). Representing a fundamental paradigm shift in the computer industry, this technology eliminates the need for clocks, allowing faster, more efficient, and better integrated internal computer systems. Fully compatible with existing fabrication processes and with existing clocked systems, NCL yields clockless circuits and systems that are straightforward to design and easy to test. Multichip integration is essentially "plug and play" as chips in a system inherently coordinate themselves regardless of their varying throughput rates.

TO ACCELERATE PRODUCT DEVELOPMENT, THESEUS IS FORMING STRATEGIC ALLIANCES WITH MAJOR ELECTRONICS CORPORATIONS.

Supporting the company's business strategy of licensing NCL throughout the industry, Theseus recently signed a five-year deal with Sanders, a Lockheed Martin Company. This strategic alliance provides Theseus with an established partner that can help insert the technology into system applications. As part of this alliance, Sanders and Theseus have started working on a $2.3 million Defense Advanced Research Projects Agency program, with an additional investment from Lockheed. The program aims to develop NCL-based Digital Signal Processors for system validation in the F-22 Advanced Tactical Fighter test bed.

In 1996, Theseus raised $1.9 million in a private stock offering, and the company is preparing another stock offering in 1997 to augment ongoing development funding from government agencies and private corporations.



■ Pictured above is a layout of one of Theseus' prototype chips. It contains no detailed timing analysis.

ABOUT THE TECHNOLOGY

All-digital electronic operations are based on two data values, usually represented as binary mathematics employing the digits 0 and 1. NCL employs a third value, the null, which indicates that no input or output value is present. Using the null value, NCL circuits can perform binary data processing functions without needing a clock circuit to synchronize data inputs and outputs. Each combinatorial circuit inherently "knows" when it has completed processing a data set, when it is reset, and when it is ready to process another data set. All communication is local and asynchronous.

NCL allows high-performance asynchronous chips without any detailed timing analysis. In a BMDO SBIR project, Theseus developed seven proof-of-concept asynchronous chips. In tests, these chips "worked perfectly on the first pass" said Ken Wagner, president of Theseus Logic. Tests also showed that the chips can operate at extremely wide temperature and voltage levels. Theseus demonstrated that input supply voltage on NCL-based chips can be varied during run time from as low as 0.5 volts to over 9 volts, allowing smooth control of speed and power consumption.

HIGH-DENSITY OPTICAL MEMORY RESULTS IN LICENSING AGREEMENTS

Can You Imagine . . .

. . . a high-density optical memory that could hold 18,000 sets of the Encyclopedia Britannica on a single 12-inch optical disk.

High-density data storage systems, essential to the survival of today's information-oriented companies, are some of the hottest items in the $20 billion computer storage device market.[1] Magnetic floppy disks and optical compact discs temporarily meet some of this demand, but companies still search for higher density technologies to store the flood of data that drives their business processes.

Researchers at Oak Ridge National Laboratory (ORNL; Oak Ridge, TN) developed a high-density optical memory with about 100 times more storage capacity than previous technology. Called surface-enhanced Raman optical data storage (SERODS), this technology offers benefits for virtually any application requiring vast data storage, such as optical archive storage for libraries or insurance companies or data banks for financial institutions. Two companies are now commercializing the high-density optical memory through licensing agreements with ORNL and its operator, Lockheed Martin Corporation.

TWO COMPANIES, WORLD LIBRARY, INC., AND PHOTRONIX, INC., HAVE ACQUIRED LICENSES FOR SERODS TECHNOLOGY.

The first licensee, World Library, Inc., created a new company called SEROTECH, Inc., to develop compact disc read-only memory (CD-ROM) and read/write CD products based on SERODS. World Library specializes in publishing text-based, interactive CD-ROM products and expects SERODS to increase the storage capacity of its products by 1,500 percent. The second licensee, Photronix, Inc., also spun off a new company, called CDEX® Corporation, to market its future SERODS products, such as a rewritable CD-ROM called CDE®, a video cube, and a digital still camera with optical card.

Current CD-ROMs have a storage capacity of up to 600 megabytes (600 million bytes), or the equivalent of 270,000 pages of typewritten text. However, a 12-inch CD using SERODS technology contains roughly 100 times more storage. This capacity could store 18,000 sets of the Encyclopedia Britannica, the name of every taxpayer registered with the Internal Revenue Service, or all the records on a U.S. Navy ship. With further development, SERODS could store as much as 1,000 times more information than fits on today's disks.

■ Dr. Tuan Vo-Dinh of ORNL operates the SERODS optical data storage system, which offers about 100 times greater storage capacity than previous technology.

BMDO originally funded SERODS research to develop an alternative technique for optically storing massive amounts of computer data. Although designed as write-once, read-many-times (WORM) technology, SERODS writes, reads, and deletes. Layered SERODS disks could allow 3-D data storage. This unique feature would permit simultaneous scanning of multiple tracks or layers, leading to improved data transfer rates.

ABOUT THE TECHNOLOGY

SERODS is based on the principle that the surface-enhanced Raman scattering (SERS) properties of certain molecules embedded in an optical medium can be altered to store information. The SERODS system uses a writing laser, a reading laser, a photometric detector, and an optical disk or a 3-D multilayer optical storage medium. The writing laser encodes bit information by altering the light-emitting properties of specific clusters of molecules on the disk, while leaving other molecules intact. The reading laser excites all the molecules in the disk's optical layer, including specific microregions of the disk, to produce altered and unaltered SERS light signals that correspond with "one" bits and "zero" bits, respectively. The photometric detector tuned to the frequency of the Raman emissions retrieves the stored information.

[1]Marketplace Information Holdings, Inc. 1996. Market analysis report: Computer storage devices. World Wide Web at http://www.imarketinc.com/anly/reports/rpt3572.htm.

Can You Imagine . . .

. . . porous metal wicks that cool heat-generating Pentium® micro-processors in portable computers.

HEAT PIPES KEEP CHIPS FROM BLOWING THEIR COOL

Manufacturers of portable computers deal with a hot issue when it comes to chip cooling. To prevent chip damage, heat-pipe technology helps them redirect away the heat that the microprocessor generates. But this technology does not work well when users tip and turn their computers.

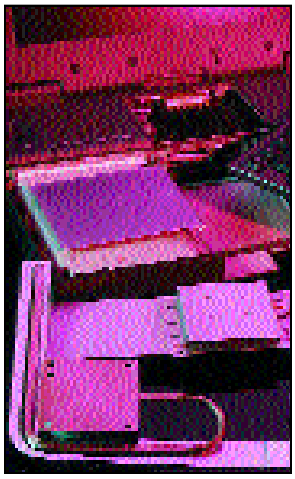
Thermacore, Inc. (Lancaster, PA), developed heat pipes that, unlike traditional heat pipes, allow users to tip and turn portable computers without degrading performance. These devices use porous metal wicks, the key to their capabilities. Thermacore developed the heat pipes through SBIR contracts—including several from BMDO—to cool laser mirrors, electronic devices, and batteries.

THERMACORE PRODUCES 7,000 HEAT PIPES PER DAY FOR PENTIUM® CHIP-BASED PORTABLE COMPUTERS.

Thermacore's heat pipes help the Pentium® chip (which has greater cooling requirements because it has over 3 million transistors[1]) find relief from the heat inside portable computers. For example, the company supplies devices to manufacturers for installation in 120- and 133-megahertz Pentium chip-based computers to prevent overheating. Alternative methods of cooling, such as electrically powered fans, are large and have high energy requirements that make them impractical for portable computers. Thermacore's compact, lightweight heat pipes do not interfere with the computer's portability. Also, since they use no electricity, the heat pipes conserve the precious energy essential for battery-powered portables.

To meet market demand, Thermacore enhanced the capabilities of its manufacturing division, Thermal Products. This division now produces 7,000 heat pipes per day (a rate based on existing and expected orders) to cool high-end Pentium-based portable computers. According to Yale Eastman, chairman of DTX, Thermacore's parent company, "In 1997, Thermacore expects to manufacture over 2 million heat pipes for this thermal management application."

Developing prototypes for desktop and workstation computer markets, Thermacore's heat pipe technologies provide the cooling improvement needed for increased computer speeds. "Faster chip speeds and microprocessor-intensive software create higher levels of heat in desktop and workstation computers," adds Eastman. "Our heat pipes are more reliable than other technologies and could provide all the cooling necessary to prevent chip damage."



■ Thermacore's heat pipes cool today's high-end processors in portable computers without using fans or extremely large or heavy heat sinks.

ABOUT THE TECHNOLOGY

Thermacore's passive heat pipes use porous metal wicks that move the heat-transfer liquid quickly and efficiently, using capillary action. Like kerosene in lantern wicks, the heat-pipe liquid moves against the force of gravity, making these devices ideal for any cooling need where the system moves. Other heat pipes lose their effectiveness when turned upside down because their wicks will not work against gravity.

Heating one end of the pipe causes evaporation of a liquid inside, absorbing heat. The vapor then flows to the opposite end of the pipe. At this cooler end, it condenses back into a liquid, thereby releasing heat. To repeat the cycle, the wick absorbs the condensed liquid and transports it back to the hot end. Capillary action, the same action that pulls kerosene through the wick in a kerosene lantern, moves the liquid along the wick.

[1]Intel Microprocessor Quick Reference Guide. 1996. World Wide Web at http://www.intel.com/pressroom/quickref.htm.

HOLOGRAPHIC MEMORY SPEEDS ACCESS

Can You Imagine . . .

. . . a holographic memory system that combines quick access speed with dense storage.

Today's specialized computer applications demand extraordinary data storage capacity and quick access. Despite the recent capacity and performance improvements of magnetic and optical disks, these emerging applications still require more—a fundamentally different approach that combines a quantum increase in storage with faster access. Holography provides such an approach.

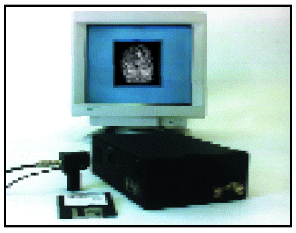
Aided by a BMDO SBIR contract, Holoplex, Inc. (Pasadena, CA), has developed a holographic memory system that combines quick access with dense storage. The system, dubbed HM-100, can store up to 1,000 gray-level images, each with 1,000 x 1,000 8-bit pixels, for a total of 1 gigabyte of storage. The HM-100 has a very fast internal image processing rate, so that many images can be compared quickly. The entire database of 1,000 images can be scanned in one second.

Applying the data storage technology for security applications, Holoplex recently delivered its first HM-100 to Hamamatsu K.K. in Japan for real-time fingerprint identification. This system functions as a holographic "lock" that can store up to 1,000 fingerprints as holograms. To gain entry to a room, one places a finger on a glass plate. The fingerprint must match one of the holograms in the system's memory. The fast memory of the HM-100 minimizes the delay while the system searches for a match.

In addition to fingerprint identification, the HM-100 offers a compact and low-cost alternative to the large, expensive CD-ROM "jukeboxes" that now store data for hospitals, libraries, and banks. Holoplex's system could save businesses both time and money, replacing their systems with a single 3-D holographic disk. Other uses for this technology include archival storage, government systems, military intelligence networks, and the ever-popular video game. Holoplex aims to capture a significant portion of the holography market, which it estimates at $20 billion worldwide.

HOLOPLEX AIMS TO CAPTURE A SIGNIFICANT PORTION OF THE HOLOGRAPHY MARKET, ESTIMATED AT $20 BILLION WORLDWIDE.

On a futuristic note, Holoplex's holographic memory may someday steer vehicles. One of the company's founders, Demetri Psaltis, used the holographic memory to drive a small car through the corridors of the California Institute of Technology. Psaltis is now designing a different vehicle with enough memory to travel around the campus.



■ Holoplex's HM-100 module, pictured above, is being used by one company as a holographic "lock" to store up to 1,000 fingerprints as holograms.

ABOUT THE TECHNOLOGY

The HM-100 module writes once, but reads many times and holds information in the form of 3-D holograms. Viewing the cube from various angles with the probe laser allows access to the image data stored as 2-D pages. The memory of the HM-100 module includes a temperature-controlled laser diode operating at 680 nanometers, a prerecorded holographic medium (a DuPont photopolymer) mounted on a motor, a two-beam steering mirror, and a tracking mechanism.

The data are converted into a pattern of clear and opaque squares on a liquid crystal display screen, then imprinted on the device. Then, lenses focus a blue-green laser beam shining through this crossword-puzzle-like pattern, or page, to create a signal beam. Next, a second beam, the reference beam, meets the signal beam, creating a hologram of the page of data in a photosensitive medium. Illuminating the hologram with the reference beam used to record it retrieves any stored page. Charge-coupled devices, which produce a current in response to light, read the reconstructed page.

Can You Imagine . . .

. . . a hybrid computer that will learn ten times faster than conventional neural networks.

HYBRID COMPUTER TO SIMPLIFY CONTROL SYSTEM DESIGN

WORKING WITH LOCKHEED MARTIN, IAI IS USING FUZZY CMAC TECHNOLOGY TO DEVELOP A SYSTEM THAT CANCELS MACHINE VIBRATIONS.

Design difficulties limit the use of neural networks for real-time control. For example, designers require complex models to account for many system variables. Furthermore, these variables change constantly, testing the neural network's limited ability to adapt to changing conditions.

To solve this problem, Intelligent Automation, Inc. (IAI; Rockville, MD), is developing the Fuzzy Cerebellar Model Arithmetic Computer (CMAC) with funding from BMDO's SBIR program. IAI's technology will learn ten times faster than conventional neural networks. It could simplify the design of real-time control systems and improve the speed and precision of pattern recognition systems.

Using its Fuzzy CMAC technology, IAI is working with Lockheed Martin to build a system that cancels machine vibrations, enabling machine tools to cut faster and more accurately. It is also developing a scanning-probe microscope that learns the characteristics of the sample as its scans, allowing faster and more accurate images. In a test, Fuzzy CMAC detected abnormal traffic patterns on a highway with 99 percent accuracy. Fuzzy CMAC has also tested successfully as a nonlinear adaptive signal filter.

Applying its innovative technology to law enforcement, IAI will use Fuzzy CMAC to further automate RotoScan™, a patented device for analyzing scratches (or striations) on a bullet, also known as ballistics testing. Useful as evidence in court, these scratches are the "fingerprint" of a particular gun on a spent bullet. A computer stores the bullet images on a disk, enabling investigators to identify and match the bullets. IAI and Mnemonic Systems, Inc., experts in forensic technology, are currently building RotoScan devices for law enforcement agencies.

■ RotoScan™, pictured above, is a ballistics testing device whose automation may be enhanced with IAI's Fuzzy CMAC technology.

Another potential application for Fuzzy CMAC is in flight control systems. For example, the ability to predict maneuverability and to accommodate uncertainties makes flight control systems more reliable and adaptive. When pilots input certain control parameters, they expect the aircraft to respond accordingly. But a full or near-empty gas tank may cause the response to differ from their expectations. IAI's technology could adjust for this difference in real time. In another application, Fuzzy CMAC could help weapons systems lock on to targets quickly and accurately.

ABOUT THE TECHNOLOGY

Fuzzy CMAC combines the ease of coding and the flexibility of fuzzy logic controllers with the self-learning ability of neural networks. These technologies enable the system to learn and to generate output faster than other learning control mechanisms. IAI expects Fuzzy CMAC to be easier to install in system hardware than conventional neural networks. For example, one test verified the possibility of easy and affordable customization of the device as a multiple-digital signal processor for an active-vibration isolation system, executing operations at close to a gigaflop rate.

NETWORK SOFTWARE PROTECTS AGAINST CYBERTHREAT

Can You Imagine . . .

. . . software that can protect a company's computer networks against hackers and hostile insiders.

Information security is an increasingly important issue for both private companies and the Federal Government. Information thieves are hacking into more company networks, stealing, modifying, or destroying confidential data. Some, interested only in causing chaos, shut down or crash entire computer systems and networks, costing companies thousands of dollars to assess and repair the damages. Also, Internet access allows an increased number of attacks on the U.S. military; it has been estimated that as many as 250,000 hacker attacks occur on the U.S. Department of Defense each year.[1]

In an important step toward helping nondefense companies protect their computerized assets, Gemini Computers, Inc. (Carmel, CA), adapted its BMDO-funded information security technology to an electronic bank loan pilot project at the Small Business Administration (SBA) Service Center in Fresno, California. BMDO's Science and Technology office and the SBA jointly sponsored this defense conversion.

Gemini's software, based on a network-level product, features integrated encryption and Department of Defense certification at its highest security level. In the SBA pilot project, this technology protects sensitive information for electronic bank loan operations among three SBA offices: SBA Headquarters in Washington, D.C.; the SBA Operation Finance Center in Denver, Colorado; and the SBA District Office and Service Center in Fresno, California.

The Gemini trusted network processor (GTNP) provides high-level security that helps protect information from such outside threats as computer hackers. It also controls damage from often-overlooked internal threats, such as hostile insiders and computer viruses. Providing companies with this security requires affordable products that minimally affect the performance of the existing network.

GEMINI'S TECHNOLOGY COULD CONTRIBUTE TO EMERGING MARKETS SUCH AS SECURE ELECTRONIC COMMERCE AND HEALTH CARE INFORMATION SYSTEMS.

Bringing the mandatory security controls of the military to commercial systems, Gemini could contribute to emerging markets such as secure electronic commerce, health care information systems, teleconferencing, and protection of industrial trade secrets. Increased security not only prevents companies from losing valuable information to competitors, but for such areas as electronic commerce and health care information systems, it increases the trust of customers.

■ Pictured above is a defense installation whose networks can be secured against cyberthreats using Gemini's technology. Nondefense networks can also be protected.

ABOUT THE TECHNOLOGY

The GTNP provides multilevel security, encryption, and concurrent processing. Gemini designed the GTNP to support integration with other technologies and products in order to build a variety of secure network interconnections and secure data-sharing components for multilevel, secure distributed information systems. GTNP's open architecture does not restrict its use to a single application or suite of protocols. Instead, applications and protocols can be developed to run on top of the GNTP-structured computing base to support the specific network requirements. The Gemini Multiprocessing Secure Operating System Security Kernel runs the GTNP. This software implements real-time, priority-based scheduling to provide multiprogramming and multiprocessing to support concurrent computing, including parallel and pipeline processing.

[1]United States Government Accounting Office. 1996. Information security: Computer attacks at Department of Defense pose increasing risks. No. GAO/AIMD-96-84, 22 May. GAO Reports and Testimony: May 1996. Washington, DC.

MANUFACTURING



Over the past decade, American manufacturing has made tremendous progress in improving the quality of products and services. The most successful U.S. manufacturers have realized that it is not what they produce but how well they produce it that determines customer satisfaction, sustained profitability, and long-term global competitiveness.

Advanced technology allows U.S. manufacturers to improve their techniques and processes and, in some cases, to reduce the environmental impact of manufacturing. For example, real-time computer software can help plant managers monitor and control processes remotely from multiple terminals, rather than limiting them to a single computer center at the plant site. In another example, new lead-free solder technology will enable manufacturers to produce stronger, more environmentally friendly printed circuit boards, which are used in nearly all electronic products.

Today's Market

Manufacturing is key to U.S. economic stability. Its share of the gross domestic product has remained remarkably stable, at 20 percent to 23 percent, for more than 45 years. Manufacturers employ 18.3 million people throughout the country. Thirty-seven states showed an increase in manufacturing jobs from 1993 to 1994. The United States is the world's largest industrial exporter. U.S. exports from 1985 to 1993 grew much faster than those of its two chief competitors, Japan and Germany.[1]

Tomorrow's Opportunity

BMDO has funded the development of advanced technology in pulsed power, control software, optical processing, and materials. While improving the Nation's defense, much of this technology also offers strategic benefits to the American manufacturing community, helping companies significantly improve their manufacturing capabilities. The following section describes seven of these innovations.

---

[1]The Manufacturing Institute. The facts about modern manufacturing. World Wide Web at http://www.nam.org/Modern/FactsMan/summary.html.

Can You Imagine . . .

. . . a process that may be able to harden synthetic knee joints to make them last longer inside the body.

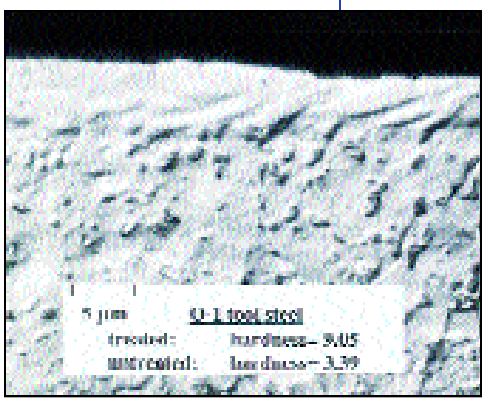
MATERIAL HARDENING PROCESS REDUCES TOOL-AND-DIE WEAR

For years, tool-and-die makers toughened their products using such processes as heat treatment and flame hardening. While these processes were highly effective, the growing demand for extreme precision in manufacturing new products made assembly lines and small precision fabrication shops much less tolerant of tool wear.

Spinning off technology from Sandia National Laboratories (Albuquerque, NM), QM Technologies, Inc. (same location), licensed and markets a material-improvement technology called IBEST[SM], or ion beam surface treatment. IBEST, an environmentally friendly pulsed ion beam process, can provide longer lasting, more wear- and corrosion-resistant materials for the tool-and-die industry, which the Association for Manufacturing Technology and the U.S. Department of Commerce estimated at $4.5 billion in 1994. BMDO-funded research in pulsed power technology enabled IBEST's development.

IBEST's benefits extend far beyond tools and dies. "Materials and surfaces are where everybody's problems are . . . everybody is up against the limit," comments Regan Stinnett of QM Technologies. Other industries, such as automotive and medical manufacturers, can also use IBEST for hardening materials. In the future, biomedical manufacturers may be able to use IBEST to treat synthetic knee joints (typically composed of a metal ball inside a plastic socket), which now have limited lifetimes inside the body. Treated knee joints would wear out less quickly, drastically reducing or eliminating replacement surgeries, which now typically occur every 7 to 10 years. QM Technologies is working with more than a dozen companies to validate industry applications of the technology.

QM TECHNOLOGIES IS WORKING WITH MORE THAN A DOZEN COMPANIES TO VALIDATE INDUSTRY APPLICATIONS FOR IBEST[SM] TECHNOLOGY.



■ This cross-sectional view of a steel tool sample shows the effects of rapid surface melting and cooling using IBEST[SM] technology.

QM Technologies obtained the exclusive worldwide rights to the patented IBEST technology from Sandia National Laboratories. Through a Cooperative Research and Development Agreement with Sandia and ongoing relationships with Cornell University and Applied Pulsed Power, the company continues to develop IBEST technology. In addition, the Technology Venture Corporation, a nonprofit organization for commercializing technology from national laboratories and research universities in New Mexico, helped QM Technologies obtain over $4 million in venture capital from Rainbow Technologies Inc.

ABOUT THE TECHNOLOGY

IBEST uses high-energy, pulsed (typically less than 500 nanoseconds) ion beams to heat the surfaces of a material. Because of the pulsed nature of these beams and the rapid cooling rates of the surface-heated material, only very thin surface layers (2 to 20 microns) of the material are rapidly melted and cooled; this process helps form amorphous and nanocrystalline grain layers without altering the atomic composition of the material.

The Repetitive High-Energy Pulsed Power (RHEPP) accelerators deliver the unique combination of high average power and short-duration electrical pulses required for high-efficiency IBEST systems. A magnetically confined anode plasma (MAP) diode generates the short pulse of ions using the RHEPP accelerator power pulse. The electrical pulse, applied to a preionized gas in the MAP diode, extracts ions from the plasma. The ions then travel through a vacuum to the material surface. The IBEST ion beam cover areas up to 200 cm^2 with each pulse. The RHEPP I accelerator was initially developed for the Department of Energy's inertial confinement fusion experiments and BMDO's free-electron laser weapons system.

REAL-TIME SOFTWARE CONTROLS INDUSTRIAL PROCESSES

Can You Imagine . . .

. . . a software-based system that can monitor and control plant processes remotely from multiple terminals.

In light of environmental regulations and growing populations, upgrading or expanding waste and drinking water treatment plants has become a priority for many municipalities. Officials are plunging into several relatively high technology improvements, including more advanced computerized automation systems. Called supervisory control and data acquisition systems (SCADAs), this technology allows technicians and managers to monitor and control the newer, more sophisticated plant processes remotely from multiple terminals, rather than being limited to a single computer center at the plant site.

A notable example of this trend is the upgrade of a water treatment facility for the growing population of Las Vegas, Nevada. In this project, officials installed an advanced automation and control system called TIS 4000® derived from software used to control a BMDO-funded particle beam accelerator. Developed by Tate Integrated Systems (Owings Mills, MD), the software-based system combines the features of SCADAs with distributed control systems, so that plant technicians can monitor and control the various parameters of their water treatment systems in real time through graphical tools. For example, users can link a graphic of a water pump with a parameter such as flow, and then control that process.

TATE HAS FOUND SEVERAL MARKETS FOR ITS TIS 4000®, WITH $10 MILLION IN SALES SLATED FOR 1996 ALONE.

The TIS 4000's open architecture allows its use with a wide range of hardware. Through graphics, trend windows, and text, users see—and control—what is happening in their processes in real time. The system also features alarms that direct an operator to areas where problems occur.

Tate licensed the technology three years ago from both Los Alamos and Argonne National Laboratories (Livermore, CA, and Argonne, IL, respectively), tailoring it for municipal and industrial processes. The company found many uses for the product and expected $10 million in sales in 1996 alone. For example, Tate has installed TIS 4000 in Libby Owens Ford's new glass plant to automate and control the annealing stage of glass production. The company also sold the software for petrochemical uses for offshore oil production in the Arabian Gulf. The St. Louis County Water Authority uses TIS 4000 for its drinking water treatment facility, and Baltimore Gas and Electric uses it for its liquid natural gas terminal.

■ One of Tate's many applications for its TIS 4000® product is to automate and control oil production and distribution systems.

In addition to pursuing domestic markets, Tate sells its system abroad in such areas as Russia and South America. The company has established a joint venture in Malaysia to capture Southeast Asian markets.

Tate notes that the system can handle energy management in buildings. The product can control a building's heating, ventilating, and air conditioning systems to optimize and control energy usage and environmental conditions.

ABOUT THE TECHNOLOGY

TIS 4000 operates on a wide range of client hardware or on off-the-shelf equipment supplied by Tate and is simultaneously connected to both a local area network (LAN) and a wide area network. The standard system runs on commercially available workstations and bridges to networks of personal computers with minimal software modifications. A basic TIS 4000 system requires only a few building blocks (workstations, a LAN gateway, and remote terminal units or a process control unit), although larger systems are possible.

Can You Imagine . . .

. . . stronger, more fatigue-resistant solder technology that will help electronics manufacturers make miniature cellular phones and remote controls.

NEW SOLDER TECHNOLOGY WILL ENABLE SMALLER ELECTRONICS

The demand for miniature electronic devices grows year by year, and with it comes the need for smaller printed circuit boards (PCBs). These tiny PCBs have less space for solder connections, which must maintain the highest level of reliability.

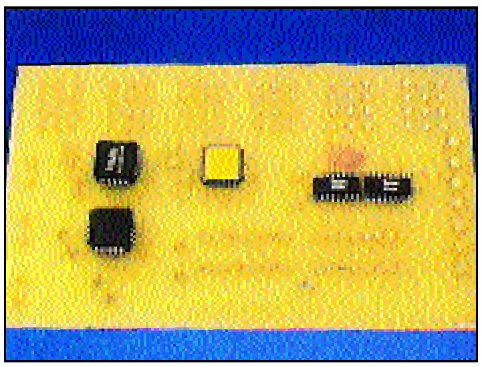
To avoid reliability problems, the BMDO SBIR program funded Toranaga Technologies, Inc. (Carlsbad, CA), to develop stronger, more fatigue-resistant solder technology for PCB manufacturing. Toranaga's proprietary combination of key metal alloys will make this grouping stronger than conventional lead-tin solders, allowing smaller, denser, and more rugged multilayer PCBs. BMDO needs more rugged PCBs for radar, missile interceptors, and other electronic equipment.

In addition, Toranaga's lead-free solder technology could alleviate growing environmental concerns over the disposal of lead-bearing PCBs, which can contaminate groundwater near landfills. Several European countries—including Germany, France, Sweden, and the United Kingdom—recently implemented mandatory recycling legislation for electronic components. These laws place the responsibility for proper disposal of lead-containing products squarely with the manufacturers. The adoption of similar waste disposal regulations in the United States would increase the domestic demand for lead-free solder technology.

TORANAGA EXPECTS TO OFFER LICENSES FOR ITS LEAD-FREE ATTACHMENT TECHNOLOGY.

Toranaga expects to license its solder to companies interested in creating lead-free attachment technology for their own electronic component assemblies. Its marketing department currently places the solder market at $350 million and growing 20 to 30 percent annually.

The company, formed to develop an organometallic conductive ink for creating wire traces on PCBs, entered into a licensing agreement with Kester Solder Company, a division of Litton Systems, to manufacture and market Ormet® ink. Kester provides royalty payments to Toranaga for transferring this technology to it.



■ This printed circuit board includes three types of components mounted with Toranaga's lead-free attachment technology.

ABOUT THE TECHNOLOGY

Investigating two solder products, Toranaga expects to meet the future demands of PCB assemblers using its atomized, lead-free alloy powders. The first product, a solder paste, will form stronger component joints than traditional lead-tin alloys. Because this formation will occur at a reflow temperature below 210°C, it represents a new solder option for PCB assembly. Most lead-free solder pastes require higher reflow temperatures, which can melt the plastic material of the PCB.

The second product combines a solder paste and a conductive adhesive. Designed to replace traditional solder pastes that lose mechanical bond strength because of accelerated aging, but similar to conventional solder, the hybrid will form strong intermetallic bonds with the contact pads. It will also form a metal matrix to stabilize electrical conduction within the joints, using a process called transient liquid-phase sintering. Finally, polymers in the hybrid will strengthen the joints. Toranaga expects the hybrid solder processing temperatures will be compatible with PCB manufacturing. Preliminary results from reliability testing show that the hybrid solder performs better than most commercially available conductive adhesives.

ENGINE PARTS GET BETTER COATINGS

Can You Imagine . . .

. . . a chemical vapor deposition process that coats objects, such as engine parts, that are generally difficult to place inside a traditional coating chamber.

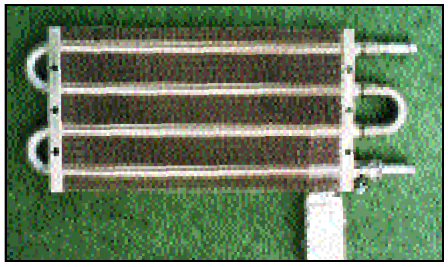
Manufacturers seek quick and affordable methods to apply thin-film coatings on large or irregular surfaces. Typical coating methods, such as physical vapor deposition and thermal spray, deposit films unevenly on assembled parts because of the difficulty placing the parts inside a traditional coating chamber. In addition, thin films are costly for large surface areas in large-scale industrial settings. These barriers have been especially noticed in the high-volume U.S. automotive industry, which sold roughly 15 million motor vehicles in 1994 alone.[1]

Researchers at MicroCoating Technologies (Atlanta, GA) reduced the cost and increased the rate of thin-film deposition through a chamberless process called combustion chemical vapor deposition, or CCVD℠. Using this process, the researchers have been working with engine manufacturers to develop coatings for parts requiring catalytic surfaces as well as protection from heat, corrosion, and oxidation. They expect these efforts to improve engine performance and increase the lifetime and efficiency of automobiles.

SOME OF MICROCOATING TECHNOLOGIES' CUSTOMERS INCLUDE GENERAL MOTORS/DELPHI AUTOMOTIVE SYSTEMS, CATERPILLAR, AND ALLIEDSIGNAL.

CCVD is a flame-assisted process that deposits a wide spectrum of thin-film coatings in open atmosphere conditions. Unlike other low-cost deposition technologies, which produce low-quality coatings, this process can produce the same high-quality coatings as more expensive chemical and physical vapor deposition technologies. It also can coat objects that have large or irregular surfaces, such as engine parts, that are difficult to place inside a traditional coating chamber.

For example, CCVD deposits platinum, an excellent catalytic and corrosion-resistant element, evenly on the entire honeycomb structure of catalytic converters. Unlike other platinum-deposition methods, which may provide only partial coatings and require costly recoatings, CCVD would be a much more efficient alternative, saving car makers both time and money. The process can also deposit corrosion-resistant coatings onto many engine parts, including those used in automotive heating and cooling systems. Customers for these applications include General Motors/Delphi Automotive Systems, Caterpillar, and AlliedSignal.



■ Pictured above is an aluminum radiator coated with platinum using MicroCoating Technologies' CCVD℠ process.

Platinum CCVD coatings will soon be used for fiber-optic applications and are being considered for prototype fuel cell components. Funding from BMDO's SBIR program provided much of MicroCoating Technologies' startup capital and allowed the refinement of the CCVD process.

ABOUT THE TECHNOLOGY

In CCVD, a combustible liquid dissolves the chemical precursor. Then, combustion of the liquid atomizes the solution, forcing the reaction that results in deposition of the material on the substrate. Because the process is simple, deposition of multiple materials and complex compounds proceeds with few complications. CCVD also allows greater control of the physical structure of the coating.

Because the CCVD process takes place at ambient temperatures, without a costly reaction furnace or vacuum chamber, technicians can continuously feed materials into the deposition zone, providing significant cost advantages over traditional thin-film processes. CCVD also uses inexpensive chemical solutions, or precursors, costing up to 100 times less than the high-purity, high-vapor-pressure solutions used in conventional chemical vapor deposition chambers.

[1]Standard and Poor's. 1995. *Industry Surveys*. 27 April, A-82.

Can You Imagine . . .

. . . an optical processor that is at home on the factory floor and in the cell biology laboratory.

SMD'S HIGH-SPEED CCD-BASED CAMERA WON THE SBIR TECHNOLOGY OF THE YEAR AWARD AT THE 1995 NASA TECHNOLOGY 2005 CONFERENCE.

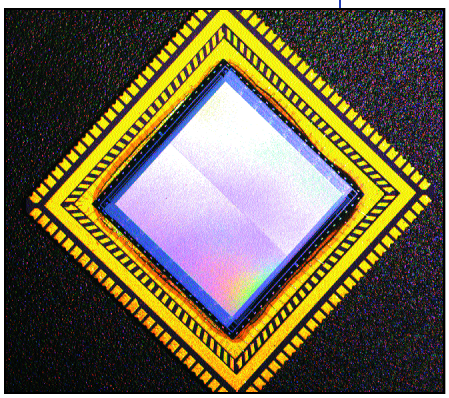
OPTICAL PROCESSOR LOOKS FOR PACKAGING FLAWS

A large food-processing company can suffer hundreds of thousands of dollars in losses each week, owing to such packaging problems as smudged ink on labels and unreadable price codes. Better inspection technology can identify a problem early in the production stage to prevent large batch losses, saving both money and time.

Silicon Mountain Design, Inc. (SMD; Colorado Springs, CO), designed an optical processor that can image products on the assembly line and determine package integrity. The company is working with Teledyne, Inc., to integrate this technology into an optical computing system for industrial inspection. This system can identify faulty packaging, enabling inspectors to remove defective products from the assembly line.

The technology grew from a BMDO-funded SBIR contract for rapid target recognition and missile detection. SMD's optical processor consists of a camera based on a charge-coupled device (CCD) and a spatial light modulator located on the same chip. This arrangement eliminates a data bottleneck and helps acquire images rapidly. For example, the optical processor can image products in various stages of completion and identify such manufacturing parameters as package integrity and visual appeal.

The optical processor can also be used for medical imaging in combination with computer-aided diagnosis. Historically, human inspection of Pap smears posted false negative results up to 30 percent of the time. SMD's technology can screen a microscope slide and identify the most atypical cells, saving technicians time and quickly routing suspicious slides to an experienced pathologist. This technology can also be used to examine radiographic images or to analyze live fluoroscopic images. SMD projects a prototype within a year.



■ SMD's optical processor, pictured above, consists of a CCD-based camera and a spatial light modulator located on the same chip.

The company is also working with the University of Colorado (Colorado Springs) to develop a solid-state miniaturized imager with a disposable imaging head. This device will give doctors a better view during endoscopic procedures, such as examining patients for esophageal cancer or performing surgery inside the body.

NASA singled out SMD for excellence at the October 1995 NASA Technology 2005 conference, held in Chicago, Illinois. The company received the SBIR Technology of the Year Award for its high-speed CCD-based camera, used for analyzing kinetic weapons and the flight dynamics of missiles.

ABOUT THE TECHNOLOGY

For pattern recognition, the two principal functions are digital image acquisition and image comparison. The first function can be performed by a pixel array detector or a digitizer. A hardware solution for the second function, a spatial light modulator (SLM), can produce a pixel-by-pixel comparison image from two digital inputs.

Parallel process architectures speed both image-processing steps dramatically. Under these conditions, however, the serial data transfer step between the detector and the SLM becomes a bottleneck. SMD used a combination of micromachining technology and ultrathin wafer processing to put a CCD and the SLM on the same chip. The resulting high-speed optical processor performs real-time screening or enhancement of any digital image database.

NEW TOOL PROMISES SMALLER, FASTER COMPUTER CHIPS

Can You Imagine . . .

. . . a chip-making tool that uses extreme ultraviolet light to print lines as small as 0.1 microns, shaving more than two-thirds off current minimum dimensions.

The semiconductor industry has targeted ever-smaller circuits in its drive toward faster computer chips that pack more memory into less space. But those miniaturization goals make integrated circuit (IC) manufacturers face a task equivalent to painting a thin line with a thick brush.

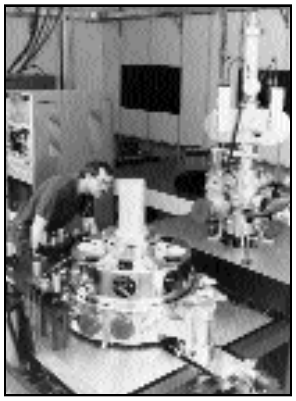
In a recent advance, Sandia National Laboratories (SNL; Livermore, CA) and AT&T Bell Laboratories developed a new research tool that produces chips with features below 0.1 microns—three times smaller than today's best feature sizes. IC manufacturers did not expect to achieve this precision until the year 2007. Smaller feature sizes will result in ICs with higher memory density, higher performance capabilities, and lower energy consumption rates.

SNL'S RESEARCH TOOL PRODUCES FEATURE SIZES BELOW 0.1 MICRONS, A FEAT OF PRECISION THAT IC MANUFACTURERS DID NOT EXPECT TO ACHIEVE UNTIL 2007.

In a recent test, Sandia printed the world's first working microelectronic device that uses extreme ultraviolet light lithography (EUVL). The device, a field-effect transistor and a common building block of all integrated circuits, features an electrical channel (or gate width) of 0.10 microns—one thousandth the width of a human hair. To further evaluate and develop EUVL technology, the researchers plan to create more complicated devices and circuits.

SNL researchers are also investigating the possibility of using the EUVL tool to print some of the world's smallest holograms. The nanometer-scale holograms could form the basis of a new security system that would use holographic "microtags" to brand everything from computer chips to currency to compact discs. The advantages of the microtag lie in both its size and complexity. Its sub-0.2 micron features make the microtag difficult to find and replicate, frustrating chip counterfeiters who bombard computer integrators with forgeries. Its physical orientation provides another security feature: Only read-out equipment that illuminates the microtag at the correct incidence angles can discover its true identity.

This technology grew out of a BMDO program in which SNL developed a laser plasma source of extreme ultraviolet radiation. BMDO needed this EUVL source, intended for classified studies of detector performance and material survivability at these wavelengths, as an alternative to synchrotrons, which were not approved for classified research.



■ Mechanical technician Yon Perras inspects the extreme ultraviolet light lithography tool, which etches fine patterns in silicon chips.

ABOUT THE TECHNOLOGY

Lithography transfers microscopic device patterns onto silicon wafers, level by level. Shrinking device dimensions continue to push traditional optical lithography systems to the limits of fine resolution between the circuit elements. An EUVL system, using shorter wavelength light than traditional systems, can overcome the optical resolution problems inherent when the device feature size approaches the wavelength of the light used.

SNL's EUVL source uses a laser striking a solid metal target to create a plasma of ions. When these ions lose their energy, they emit a broad spectrum of radiation centered in the extreme ultraviolet region. A monochrometer filters out unwanted light and helps choose the wavelength best suited for a particular application.

Can You Imagine . . .

. . . a new processing alternative that treats machine components, altering their surface layers to improve durability and resistance to corrosion.

NEW PROCESS ALTERNATIVE PROMISES HARDER MATERIALS

When manufacturing such heavy machinery as automobiles, hardness and durability are two qualities essential to satisfy quality-seeking consumers. The low-wear requirements of the machines that manufacture these products also make these qualities essential to manufacturers.

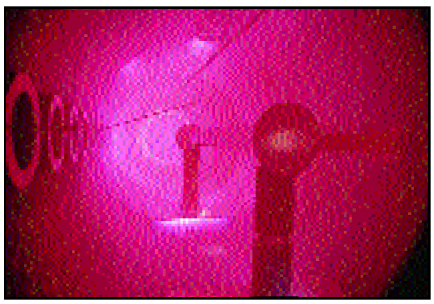
Through an Advanced Technology Program-sponsored project, a consortium of 14 participants is addressing these qualities, scaling up a technology called plasma source ion implantation (PSII). Rather than coating industrial parts, which must be toughened to survive severe environments, PSII actually changes the material surface, providing performance and environmental advantages over other hardening methods. It uses a power modulator derived from BMDO-funded work on the particle beam accelerator developed at Los Alamos National Laboratory (LANL; Los Alamos, NM).

GENERAL MOTORS IS INVESTIGATING PSII TO CHANGE THE SURFACES OF LIGHTWEIGHT ALUMINUM AND MAGNESIUM ALLOYS USED IN ENGINES.

This process can be used to harden components for automobiles, aircraft, power plants, and prosthetics. For example, General Motors is investigating PSII to change the surfaces of lightweight aluminum and magnesium alloys so they can withstand the high wear and harsh environment found in engines. Substituting these materials for steel and iron could result in a 10 percent decrease in the cost of making automotive power trains.

In addition, treating production machine parts themselves increases their service lives for manufacturing, thereby reducing associated costs and downtimes in manufacturing plants. In a study comparing the service lives of steel-tool punches, nitrogen-implanted punches using PSII lasted two times longer than chrome-only plated punches and five times longer than untreated punches. With further development, some dies and tools may last 10 times longer than their untreated counterparts.

The modulator used to control the voltage output from the power source came from the BMDO-funded Ground Test Accelerator project at LANL. Built as a follow-on to the Beam Experiment Aboard Rocket project, the Ground Test Accelerator, a cryogenically cooled device, was developed to provide a model of a space-based neutral particle beam weapon.



■ Rather than coating the material, PSII modifies its surface. Pictured above is a look inside the PSII chamber.

ABOUT THE TECHNOLOGY

In PSII, injecting a low-pressure gas, such as nitrogen, into a steel vacuum chamber hardens the material. The nitrogen ionizes into a plasma using oscillating radio frequency waves, and it strips electrons from the gas atoms. Then, exposing the material to short pulses of negative voltage causes positive-charged ions to accelerate toward the negative-charged material, bombarding it from all sides. The ions penetrate and modify layers of the material near the surface. This process can treat polymer surfaces as well as metals.

The process offers several advantages over other hardening methods. For example, since PSII is not a coating, adhesion and delamination are not concerns. Less expensive and with a higher average current (1.00 ampere versus 0.03 ampere) than line-of-sight implantation processes, it permits much faster implantation. Also, PSII does not require masking or expensive fixtures to manipulate nonplanar parts, and it evenly treats such odd-shaped items as power tools, door locks, and drive trains. An environmentally benign “dry” alternative to the wet chemical baths used in electroplating, the process does not produce effluent pollutants.

MATERIALS

Stronger, lighter, and better insulating materials—the United States has received tremendous benefits from materials developments, particularly in the automobile industry. For example, new materials have allowed the introduction of lighter, yet stronger, automobile bodies and longer-lasting tires and batteries.

In a new era of miniaturization, researchers working at the atomic level have constructed a new class of advanced materials with properties far superior to those of conventional materials. These "nanophase" materials, which offer such characteristics as increased hardness, wear resistance, adhesion, and slipperiness, are useful in applications as diverse as microelectronics, automotive components, business machines, and even personal care products.

Today's Market

Advanced materials offer benefits to diverse and growing markets, such as the automotive and nanotechnology industries. Stronger, lighter, and more affordable materials will help make the U.S. automotive industry more competitive. The chairmen of Chrysler, Ford, and General Motors each have stated that they expect 1997 U.S. vehicle sales to reach or exceed 15 million units.[1] Nanotechnology is here, and it is a multibillion-dollar worldwide industry with almost unlimited potential for growth. In particular, the nanophase materials market is expected to grow from $300 million today to $1.5 billion by 2001.[2]

Tomorrow's Opportunity

BMDO research and development in materials has produced many innovations for ballistic missile defense systems. These innovations have been incorporated into new technologies that can help industry develop lighter automobile and satellite components, improve the thermal protection for aircraft flight data recorders, build higher-performance microelectronic devices, and produce smoother semiconductor polishes. The following section describes six such examples.

---

[1]American Automobile Manufacturers Association. 1996. Automotive Forecasts. World Wide Web at http://www.aama.com/data/autofore.html.

[2]British Parliament's Office of Science and Technology. World Wide Web at http://www.nanothinc.com/NanoVentures/NanoMarkets_frames/nanomarketsframes.html.

Can You Imagine . . .

. . . a process that could help create automobile tires that provide better fuel efficiency, traction, and wear resistance.

APPLIED SCIENCES COLLABORATED WITH GENERAL MOTORS, GOODYEAR, AND OTHERS TO DEVELOP THEIR INNOVATIVE PROCESS.

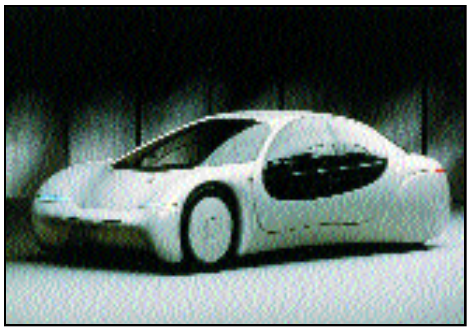
LOW-COST STRUCTURAL COMPOSITES MAY SOON HIT THE HIGHWAY

Composite materials are essential to the automotive industry's drive toward cars that are lighter, stronger, and more fuel efficient than their predecessors. Perhaps the most promising of these materials are carbon fiber composites. Stronger than steel, stiffer than titanium, and lighter than aluminum, carbon fibers could be added to a range of automobile components, giving them exceptional mechanical properties while significantly reducing their weight.

These enhanced properties come at a cost, however. Carbon fiber material costs much more than competing fibers and requires complex manufacturing processes. Such roadblocks have slammed the brakes on the use of carbon fiber composites in the automotive industry.

In a collaboration with General Motors Corporation, the Goodyear Tire & Rubber Company, and others, Applied Sciences, Inc. (Cedarville, OH), introduced a low-cost, high-volume process to produce vapor-grown carbon fibers (VGCFs). Developed with the help of BMDO SBIR contracts, VGCFs' range of properties—including high strength and light weight—make them an attractive fiber reinforcement in advanced composites. According to a survey conducted for Applied Sciences, VGCFs could cost less than $5 per pound when produced at capacities greater than 10 million pounds per year. Competing fiber reinforcements cost $100 per pound.

The National Institute of Standards and Technology's Advanced Technology Program recently awarded matching funds to the new development program, which also includes the Gas Research Institute, EMTEC, and GM Delphi Chassis Systems. The program will develop VGCF composites for automotive applications and address the technical hurdles associated with scaling the process to high-volume production.



■ The GM Ultralite, pictured above, epitomizes the objectives of Applied Sciences' work with GM and Goodyear. This 1,400-pound vehicle's fuel economy (100 miles per gallon) is achieved using carbon fiber composites combined with efficient powertrain and chassis systems.

One potential automotive application is in tires that provide better fuel efficiency, traction, and wear resistance. Economical production of VGCF composites could also help car makers reduce vehicle weight up to 132 pounds. Members of the venture also seek to develop VGCF anodes for lithium-ion batteries, which are attractive for all-electric vehicles because they can provide high specific power, high specific energy, and long cycle lifetimes.

Applied Sciences has also explored other applications for VGCFs; their high thermal and electrical conductivity make them attractive as battery electrodes, microelectronic substrates, electromagnetic shielding, and static reduction composites. The company currently markets four products, and two more are nearly ready.

The BMDO SBIR program funded early development of Applied Science's VGCF technology in six projects, two of which received Phase II funding. These programs focused on developing VGCFs for electromagnetic railguns and for other structural, thermal, and electronic applications.

ABOUT THE TECHNOLOGY

Introducing gas-phase catalysts into a heated hydrocarbon atmosphere produces VGCFs. The resulting fibers derive many of their attractive properties from the high degree of graphite crystalline phase that is produced. Individual fibers range in size from 100 microns (µm) to several centimeters long, and from 0.2 µm to 30 µm in diameter. These size differences, along with the ability to combine fibers in several bulk shapes (from a cottonball-shaped tangle to a paper-like sheet), allow Applied Sciences to tailor the fibers' properties for many uses. The ability to coat the fibers with other materials provides further flexibility.

Can You Imagine . . .

. . . a thermal storage material that protects aircraft flight recorders from destructive heat in plane crashes.

MATERIAL STORES HEAT TO PROTECT FLIGHT RECORDERS

Recent plane crashes have highlighted the importance of flight recorders, devices contained in so-called "black boxes" that help officials determine the cause of airplane accidents. These boxes must withstand the destructive heat of a crash, protecting the recorders from serious damage. The Federal Aviation Administration (FAA) recently doubled the performance requirements of these black boxes, raising their required time of heat protection from 30 to 60 minutes.

Hayes & Associates (San Diego, CA) has developed new material for black boxes to protect flight recorders from thermal damage. Previous boxes manufactured and distributed by Smiths Industries used alloy-based heat sinks to absorb heat. Hayes' new technology replaced these expensive, toxic heat sinks with smaller, cheaper, and less toxic material. In this application, the new heat sink improves cooling effects up to 400 percent and reduces manufacturing costs by 83 percent. After acquiring a license, Smiths Industries incorporated Hayes' material into its Voice and Data Recorder™ product line, which consists of Cockpit Voice Recorders, Flight Data Recorders, and combined recorders for commercial and military aircraft.

This thermal storage technology, called Composite Fabric Endothermic Material, can easily be retrofitted in current black-box designs. This flexibility can reduce or eliminate the airline industry's reengineering costs to address black-box requirements. Currently, Smiths Industries is working with Hayes to enhance the material's thermal performance to meet the FAA's 60-minute requirement. Hayes originally developed the material for BMDO's Laser Shield project for temperature control in aerospace vehicles.

Hayes & Associates' multilayer material also can be tailored to do the opposite—first store and then slowly release heat over a prolonged period. For example, in a licensing deal with Pepsico, Hayes has developed a material for Pizza Hut to heat carts that sell pizza away from the stores, delivering the food at 140˚F to 180˚F, even after the food has sat in the cart for hours. Pizza Hut uses the material in thermal plates heated with the pizza in the oven; carts bearing the thermal plates warm the pizza until delivery to factories, sporting events, and cafeterias.

Rigid or flexible, Hayes' material molds into cups, plates, and panels. It could even be applied to clothing; when people go out in the snow, they could first zap their gloves in the microwave, so the gloves—and the wearers' hands—will stay warm.

HAYES' NEW MATERIAL IS FINDING HOT MARKETS IN FLIGHT RECORDER PROTECTION AND FOOD DELIVERY OPERATIONS.

■ Smiths Industries' Voice and Data Recorder™ products, pictured above, are more resilient to heat using Hayes' thermal storage material.

ABOUT THE TECHNOLOGY

The multilayer materials consist of an inner region of thermally active material sandwiched between protective outer layers of plastic or metal. The inner section may contain a polymer that undergoes a thermochemical reaction or phase change to absorb and release heat at a critical temperature. The key aspects of Hayes' patented technology include (1) active materials that retain large amounts of heat and (2) the ability to tailor the material to temperature and time-at-temperature requirements.

When heated, the temperature of the composite material increases to the critical point; the material holds this temperature while continuing to absorb heat until saturation. At that point, the temperature may still increase further. On cooling, the reverse trend occurs, with the temperature falling rapidly to the critical point and remaining there for an extended period until the internal thermochemical processes are exhausted.

Can You Imagine . . .

. . . a carbon composite that will provide better heat control for high-power electronic equipment on satellites.

HEAT-CONDUCTING COMPOSITE PROTECTS SATELLITE COMPONENTS

Engineers designing satellites and high-performance aircraft face the conflict of requiring more while needing less. They require more in that they must continuously increase the performance of their vehicles, using high-powered electronics to meet military and commercial missions. At the same time, they require less in that they must find ways to reduce or maintain the vehicle weight, despite increased capabilities. They also require less in that new technology must be relatively low cost to meet mission budgets.

Research Opportunities, Inc. (ROI; Torrance, CA), developed a process that tailors the thermal properties of specially prepared carbon composite structures to meet the stringent packaging requirements for high-power electronic modules. The processed materials have a much higher thermal efficiency than conventional metal components at lower cost than advanced high-thermal conductivity materials, such as diamond. ROI also designs thermal management interfaces that match the material characteristics of attached electronic devices. This matching ability prevents failures of solder joints and adhesive bond lines caused by differences in thermal expansion between the device and its enclosure.

ROI IS FOCUSING ON SPACE APPLICATIONS FOR THE NEAR TERM, BUT PLANS TO PURSUE OTHER MARKETS.

BMDO-funded research at ROI led to lay-up, machining, and cure techniques for the composite structures. The materials have twice the thermal conductivity of copper (850 watts per meter Kelvin) at one-fifth the density. Their light weight and high strength make them especially useful in thermal management applications. Some examples of applications include thermal doublers, radiators, and equipment shelves for satellites. In aircraft, the materials can be used for electrical component cooling and thermal dissipation at hot spots. They also can serve as heat spreaders for gallium arsenide-based microelectronics.

ROI offers full-scale thermal measurement services and maintains an electronic database of over 10,000 measured properties of high thermal conductivity composites. The company plans to pursue other markets as the price of the material decreases, while focusing on space applications for the near term.

■ ROI's carbon composite structures are ideal for satellite applications where light weight and high strength are important.

ABOUT THE TECHNOLOGY

To fabricate the carbon composite structures, ROI uses a self-reinforced graphite (SRG) called ThermalGraph®, produced by Amoco Performance Products Division. ROI machines the SRG "brick" into a wafer design, cross-plying it in alternating right angles and then sandwiching it with metal such as aluminum. Laminate thickness ranges from about two micrometers up to one centimeter. The thermal expansion properties of the heat source and sink materials determine the relative thicknesses of the SRG and the aluminum.

Tailoring SRG to thermal management applications involves innovative processing and machining techniques developed with BMDO funding. Special resin impregnation and curing techniques produce dense SRG with a graphite volume fraction of 90 percent. Carefully selected adhesive materials for laminating metals to the impregnated SRG allow minimal stress in the SRG while preventing adhesive shear failure, or separation along the grain, over a broad range of operating temperatures.

PURE AND LOOSE, NANO-SIZED PARTICLES MAKE BETTER MATERIALS

Can You Imagine . . .

. . . a process that can produce nanopowders to make smoother semiconductor polishes and stronger sun-blocking lotions.

As the feature sizes of electronics shrink below the wavelengths of visible light, semiconductor manufacturers will require nanopowder-based optical polishes for smoothing the surfaces of silicon wafers. To be effective, powder particles must have uniform sizes and must resist the tendency to clump together, or agglomerate. Larger-than-average particles or particle clusters can create defects on the surfaces of wafers, which can cost up to $50,000 to replace.

Under BMDO SBIR funding, Structured Materials Industries, Inc. (SMI; Piscataway, NJ), developed a nanopowder production process that may produce the next generation of ultrasmooth polishing compounds. The company can produce nonagglomerated nanoparticles with narrow size distributions for a variety of materials, including metals, oxides, and nonoxides.

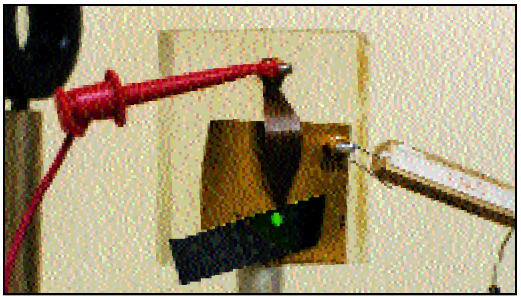
SMI formed a new division called Nanopowder Enterprises, Inc. (NEI; Piscataway, NJ), to manufacture and sell the nanoparticles to industry. NEI has already received orders from the semiconductor manufacturing industry for sample quantities of Nanomyte™ nanopowder abrasives. In addition, the company is making a titanium dioxide sun-blocking agent. Titanium dioxide particles in sun-blocking lotions tend to clump together, weakening their ability to deflect the sun's harmful rays. NEI's nonagglomerated nanoparticles eliminate this clumping effect, improving the lotion's sun-blocking properties.

TO MANUFACTURE AND SELL NANOPARTICLES TO INDUSTRY, SMI FORMED A NEW DIVISION CALLED NANOPOWDER ENTERPRISES, INC.

The company also sells a low-cost tool for producing nanoparticles. The Nanomyte One™ produces a wide variety of nanopowders in the 3- to 50-nanometer range. It features several modules that enable different processes to fabricate the nanoparticles.

SMI and Rutgers University originally developed the nanopowder production process to make silicon and germanium light-emitting nanocrystals for BMDO displays. The company continued the original research and recently demonstrated that silicon emits white light (full-color, including ultraviolet, visible, and infrared light) when electrically stimulated. More recently, SMI developed a line of transparent conductive oxides and electroluminescent and cathodoluminescent oxides.

With these initial successes in hand, SMI has already planned the first product for its films, a green electroluminescent flat-panel display. The NanoChrome Display could be an economical alternative to liquid crystal displays.



■ BMDO-funded research is helping SMI develop the first product for its film, a green electroluminescent flat-panel display

ABOUT THE TECHNOLOGY

SMI developed a dry, chemical vapor condensation process that produces nonagglomerated nanoparticles. In the process, reactant chemicals ride an inert carrier gas and pass through a reaction chamber. This chamber can be an evaporation chamber, a hot wall chamber, a combustion flame, or a plasma source, any of which will force condensation. During condensation, by-products dissipate as vapors. The remaining products are dry, nonagglomerated nanoparticles.

The nonagglomerated nanoparticles have a narrow size distribution, because the residence time for the reactant chemicals equals that of the carrier gas for all gas streams as they move through the chamber. Selecting an oxidizing, reducing, carbonizing, or nitridizing atmosphere controls the particular compound chemistry, as required. Multiple chemical reactant sources form multicomponent, multiphasic particles. This process controllably produces nanopowders from 3 to 50 nanometers in size.

Can You Imagine . . .

. . . silicon transistors that promise impressive performance advantages over today's microelectronic devices.

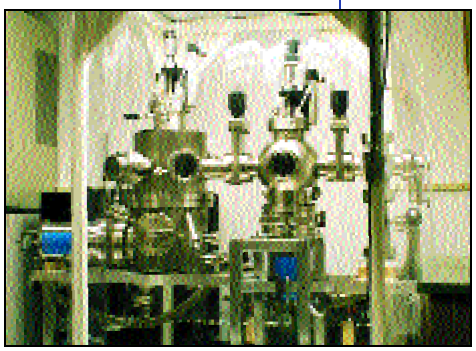
SILICON MAKES A QUANTUM LEAP IN MICROELECTRONICS

NANODYNAMICS HAS TEAMED WITH INFINITE TECHNOLOGIES, INC., TO PRODUCE WORKING PROTOTYPES.

Conventional silicon transistors have enjoyed spectacular success over the past three decades, but size limitations of the technology threaten future progress. If transistors shrink much below 0.1 microns, the barriers that control switching functions will no longer operate properly. Also, as the devices shrink, the amount of heat within a chip builds up, requiring costly thermal management solutions.

To address these problems, NanoDynamics, Inc. (New York, NY), is building silicon-based superlattice devices called quantum transistors. These devices will use semiconductor heterostructures with thicknesses approaching those of an atom to overcome the heat build up common in integrated circuits. The razor-thin layers will allow the current to flow according to the rules of quantum tunneling without electron scattering, which causes heat. BMDO is funding this research through an SBIR Phase II contract for smaller, faster, and cooler electronics.

The most innovative aspect of this project is the use of silicon. Combining the low cost of silicon-processing technology and the high performance of column III-V semiconductor superlattices, this technology is an attractive replacement for many microelectronic devices. Because the technology also permits optical transitions in silicon, it ideally suits all light-using applications of solid-state devices, including lamps, light-emitting diodes, flat-panel displays, optoelectronics circuits, and photon detectors.



■ Pictured above is Nanodynamics' newly built fabrication chamber, which can control the fabrication process accurately down to fractions of an atomic layer.

NanoDynamics built the working diodes based on its BMDO-funded technology. Its next step connects the diodes in a working transistor. Toward this end, the company teamed with Infinite Technologies, Inc., to produce linear transistor prototypes. NanoDynamics and Infinite Technologies are jointly creating a new company, Dallas Linear Devices, with the goal of gaining 1 to 2 percent of the semiconductor market within five years. NanoDynamics currently estimates this market at $150 billion, possibly reaching $300 billion in the next six years.

ABOUT THE TECHNOLOGY

To deposit the superlattice, NanoDynamics alternates layers of silicon and partial layers of silicon oxide. The structural differences between the two layer types produce localized strain regions in the semiconducting medium. These regions form quantum wells for the electrons in the medium. Applying voltages to the electrons in the wells enables such electronic functions as transistor amplification, diode current control, and switching. Theoretically, the quantum wells can be packed in high densities, allowing smaller transistors.

RIGID PLASTIC FLEXES ITS MUSCLES FOR STRUCTURAL APPLICATIONS

Can You Imagine . . .

. . . rigid-rod polymers, over four times stiffer than conventional plastic materials, that could compete with some types of metals.

Cheap and durable, plastic has an amazing track record in replacing a wide range of metals. However, it falls short in applications requiring a combination of high strength and stiffness. For example, under heavy loads plastic without enough stiffness bends. To compensate for this problem, material processors often add glass and carbon fibers—an expensive, additional manufacturing step—to stiffen plastic.

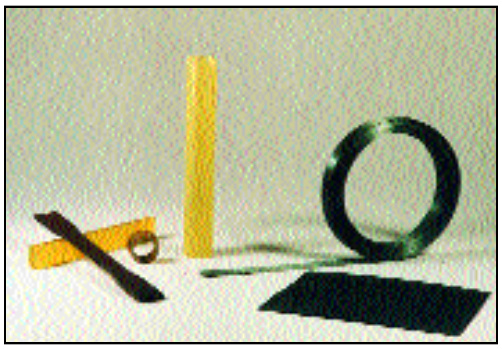
With BMDO SBIR funding, Maxdem, Inc. (San Dimas, CA), developed a new family of rigid-rod polymers that are more than four times stiffer than conventional plastic materials. Called Poly-X™ Self-Reinforced Polymers (SRPs), these inexpensive, durable materials could replace structural materials—including certain types of aluminum and stainless steel—particularly in automotive, aerospace, and defense applications. They also could substitute for expensive fiber-reinforced composites.

For example, the company is working to develop a Poly-X SRP resin to replace the fiberglass sheet molding compound (SMC) used in automotive body panels. Unfilled Poly-X plastics could decrease vehicle weight and facilitate recycling, impossible with current SMCs because of their high fiberglass content.

In another application, Poly-X SRPs could work in laminate form for printed circuit boards and electronics connectors. These harder, more abrasion-resistant polymers could also make highly scratch-resistant windows for automobiles, airplanes, machinery, and windows. The polymers might also be used for brakes, clutches, and other parts.

MAXDEM SUPPLIES BATCHES OF POLY-X™ SRPs TO COMPANIES THAT MAY DEVELOP NEW APPLICATIONS.

Funding from the BMDO SBIR program is helping Maxdem to scale up the Poly-X SRP production process, to bring Poly-X SRPs to market. Currently, Maxdem's small-scale production facility regularly produces 22-pound batches of the polymers. It supplies these batches to companies that may develop new applications. According to Maxdem's projections, Poly-X SRPs will cost $10 to $12 per pound when production achieves 5 million pounds per year.



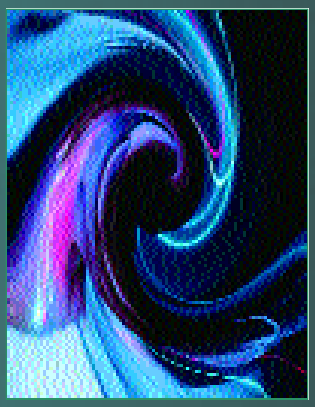
■ Maxdem's Poly-X™ SRPs can be fashioned into molded parts and composites, as shown above. They also can be made as resins, pellets, films, and solutions.

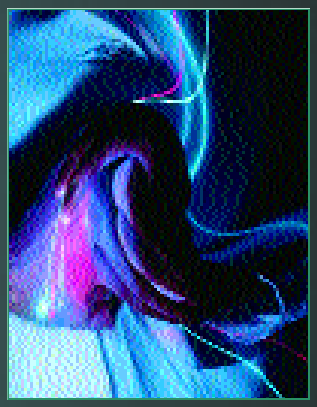
ABOUT THE TECHNOLOGY

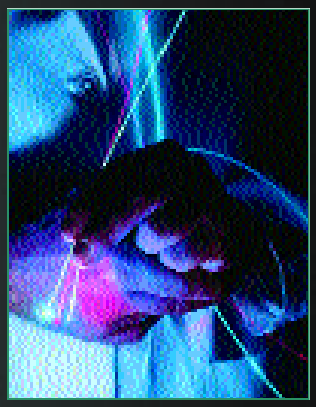
Poly-X SRPs are rigid-rod polymers with exceptional strength and stiffness. For example, the elastic modulus, or stiffness, of Poly-X SRPs ranges from 1 to 2.5 million pounds per square inch (psi). In contrast, the modulus of conventional engineering resins ranges between 300,000 to 600,000 psi. Unlike liquid crystal polymers, whose strength lies in one direction, Maxdem's rigid-rod materials are equally strong in all directions.

Poly-X SRPs are unique thermoplastic resins based on amorphous rigid-rod polymers. These polymers possess carefully chosen pendant side chains (the flexible component) to impart tractability to the rigid-rod polyparaphenylene backbone. Maxdem's proprietary production process ensures the isometric integrity of the rigid-rod structure. Therefore, homopolymers (the repetition of a similar molecular chain) and copolymers (the repetition of two or more molecular chains) can readily be prepared.

MEDICINE







Americans are concerned about improving the quality and efficiency of health care in the United States. Innovations in medical technology can address this concern, revolutionizing many medical procedures and enhancing the quality of medical products and services. For example, newly developed laser techniques are being used to selectively kill viruses or cancers, replacing traditional radiation and chemical treatments that are toxic to the human body. Sophisticated technology will offer physicians better, more accurate diagnostic and surgical tools, potentially saving lives and improving patient care. Also, such technologies often reduce or eliminate the need for hospital care, thereby reducing associated costs.

Today's Market

The United States produces more than half the world's medical technology, employing about 301,000 people and exporting about $11.4 billion in products. In 1995, the United States produced $56.7 billion in medical devices and diagnostic products; production is projected to grow to $70.9 billion by 1998.[1] Innovative medical technologies are needed to help reduce the rising costs associated with today's health care. According to a recent report by the U.S. Department of Health and Human Services, the Nation's total spending for health care in 1995 increased 5.5 percent to nearly $1 trillion, an estimated average of $3,621 per person.[2]

Tomorrow's Opportunity

The technical expertise used to solve the complex needs of ballistic missile defense has a fortunate spillover. It has resulted in new medical technologies some 10 years ahead of the medical curve that are beginning to make diseases easier to detect and simpler to manage. Many organizations are applying these technologies, making new breakthroughs in treating breast, cervical, and esophageal cancer, among other ailments. The following section describes eight of these innovations.

---

[1]Industry figures are cited from the Health Industry Manufacturers Association's U.S. Medical Technology Industry Fact Sheet.

[2]U.S. Department of Health and Human Services. 1997. National health expenditures for 1995. Press release, 27 January. World Wide Web at http://www.os.dhhs.gov/news/press.

Can You Imagine . . .

. . . breakthroughs in laser medicine that help specialists provide better care to skin, kidney, and burn patients.

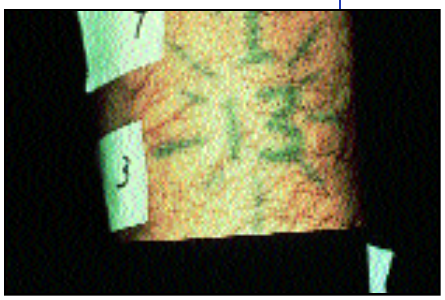
LASER R&D PROMISES NEW MEDICAL THERAPIES

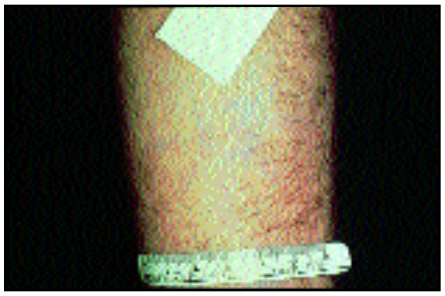
In the early years of medical laser research, doctors used single-wavelength lasers with limited dynamic properties. When the free-electron laser (FEL) was developed, it offered short pulses, high peak power, and a greater range of wavelengths. Not surprisingly, this innovation yielded a host of insights in the medical field; the Wellman Laboratories of Photomedicine (Boston, MA) is a nexus of these advances.

From 1986 to 1991, BMDO provided support to the Wellman Laboratories of Photomedicine at Massachusetts General Hospital (MGH) through the Medical Free-Electron Laser (MFEL) program. The U.S. Congress conceived the MFEL program as a means to transfer technology from military laser research to medicine. Now part of the MGH's Laser Center, Wellman Laboratories built a stellar reputation and a long list of successes in laser medicine. Their laser-related successes follow.

THROUGH ITS MFEL PROGRAM, WELLMAN LABORATORIES' RESEARCH AND TECHNOLOGY TRANSFER RESULTED IN OVER $250 MILLION IN SALES OF LASER EQUIPMENT, BOTH DOMESTICALLY AND INTERNATIONALLY.

■ **Assessing and treating burns.** In burn therapy, an infrared laser system optically determines the depth of the burn and uses a carbon dioxide laser to remove the injured tissue quickly and precisely in preparation for skin grafts. This method reduces blood loss and the imprecision of physical debridement (cutting or scraping away the tissue with surgical instruments). Wellman patented the optical diagnostic component of this technology; Sandia National Laboratories (Albuquerque, NM) and MGH are developing a therapeutic device through a Cooperative Research and Development Agreement (CRADA).





■ Laser treatment selectively and safely removes pigment from tattoos, revealing normal skin color.

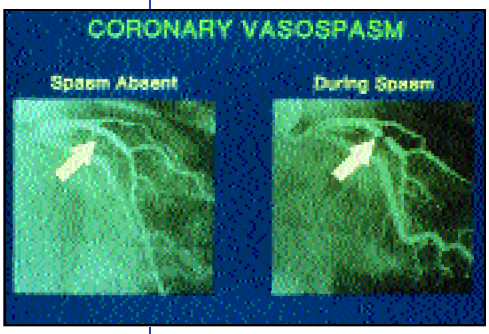
■ **Eliminating kidney stones.** The laboratory developed a laser-based lithotripsy method to eliminate kidney stones nonsurgically. Kidney stones afflict 400,000 people each year. Instead of sound waves, this method uses an intense light beam to create a shock wave in the fluid medium surrounding the stones, causing the stones to shatter. Excretion of the fragments takes place with little or no pain. Wellman Laboratories holds three patents that arose from a collaboration with a major laser company that licensed the invention, generating over $100 million in revenues.

■ **Removing undesirable skin features.** Wellman Laboratories introduced laser treatments for nonscarring removal of tattoos, portwine stain birthmarks, pigmented moles, and vascular lesions of the skin. Before this type of laser therapy, there was no effective way to achieve satisfactory outcomes with these conditions. Wellman Laboratories continues to work on the system, optimizing and reducing costs of laser delivery systems and applying selective treatments to other organs besides the skin. A Wellman Laboratories' report estimates that 300,000 patients have been treated with this therapy, generating $250 million in business revenues. In cosmetic surgery, for example, laser removal of "spider veins" on the face and legs is growing in popularity. MGH filed a patent application in 1991 for laser removal of skin lesions and tattoos and licensed the technology. Laser products for dermatologic use are on the market and MGH receives royalties.

■ **Shining new light on cancer and arthritis.** Wellman Laboratories also studied and advanced photodynamic therapy (PDT) of various cancers. Rheumatoid arthritis (RA) may also be amenable to treatment by PDT. Degenerative changes associated with RA are treated by injecting photoactive drugs into the synovial fluid that surrounds an RA-affected joint, then irradiating it with a low-powered laser source. For PDT of cancers, MGH filed a total of eight patent applications. A CRADA with Lawrence Livermore National Laboratory (Livermore, CA) resulted from these studies. Two patents that cover the device and method of use have been awarded for PDT of dysfunctional uterine bleeding. Wellman Laboratories

licensed the inventions to a medical start-up company. Wellman Laboratories is collaborating with two companies to establish research programs for drug development for this application. These treatments are in development, and Wellman Laboratories is also working with a recent FDA-approved compound for the treatment of late-stage esophageal cancer.

■ Reducing brain damage. In hemorrhagic stroke or head injuries, arteries in the brain respond to bleeding by contracting (vasospasm), thereby shutting off the blood supply to areas in the brain. This protective mechanism causes even more damage by depriving the injured brain of needed oxygen. A short-lived, low-powered laser pulse instantly reverses vasospasm, re-establishing blood flow to the stroke-affected area and possibly reducing brain damage. Wellman Laboratories estimates that 800,000 persons each year are impaired by head trauma and brain hemorrhage. Wellman Laboratories designed a laser catheter system that threads into cerebral arteries to deliver laser light. Undergoing testing, this system may be in clinical use within the next one to two years. A Wellman Laboratories' report estimates the cost benefit of early intervention and effective therapy of early stroke at about $3 billion, in terms of lifetime dependency.



■ A short pulse of laser light can instantly reverse arterial spasm, restoring critical blood flow to the heart muscle.

For laser-induced vasodilation of cerebral arteries, MGH filed two patents and is in licensing negotiations. For preventing coronary artery narrowing with a PDT agent (such as chloroaluminum phthalocyanine) MGH filed two additional patents and is negotiating a license. This treatment is not yet clinically available.

According to Lynn Osborn at MGH and market analysis by Arthur D. Little and Co. in Cambridge, Massachusetts, the MFEL program's research and technology transfer resulted in over $250 million in sales of laser equipment, both domestically and internationally. This figure does not include the cost savings resulting from decreased hospital stays or from more rapid patient recovery and return to work.

ABOUT THE TECHNOLOGY

The FEL employs high-frequency electromagnetic fields to control and accelerate bursts of electrons, causing the particles to emit coherent light. Because the characteristic wavelength of the emitted light depends on the properties of the excitation fields, rather than on the intrinsic properties of the medium being excited, FEL emissions are continuously tunable over some range of operation. This behavior contrasts with other lasing mechanisms, which produce one of several discrete wavelengths available for that particular laser material. The continuously variable wavelength feature makes the FEL extremely valuable as a research tool to explore the effect of wavelength on any laser-based process or effect.

During BMDO development of FELs for high-power applications, interest arose in applying these advancements to the then-new field of photonics in medicine. Laser treatments had already shown promise for several skin therapies, surgical cutting, and selective tumor ablation. BMDO established the MFEL program to research and refine these processes and to explore new medical applications, such as PDT. The program's intent was not to develop FELs for medical uses, but to find the best laser operating conditions (wavelength, pulse shape, intensity) for a given therapeutic outcome, and then to use that knowledge to determine the best laser source for the application.

Can You Imagine . . .

. . . 3-D imaging equipment that makes delicate surgery safer and helps train new doctors.

REAL IMAGES OFFER REAL BENEFITS TO MEDICINE

Performing surgery through the eye of a lens, whether endoscopically or microscopically, takes time and training to perfect. As difficult as hand-eye coordination is in procedures like laparoscopic abdominal surgery and microvessel suturing, adding cameras and specialized tools makes it even more complicated. Surgical tools that function as naturally as possible can minimize the impact these tools have on hand-eye coordination.

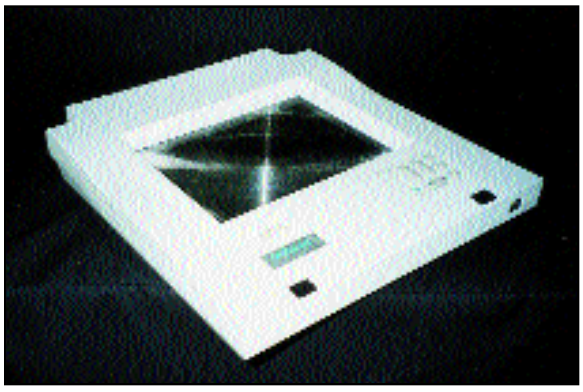
To this end, VRex, Inc., a marketing arm of Reveo, Inc. (Hawthorne, NY), now offers real-time 3-D imaging equipment for medical education and surgeries. The company's µPol™ system works with microscopes and endoscopes to give physicians an accurate 3-D view of the surgical field. The surgeon looks through normal eyepieces, manipulates tools, and performs procedures, while observers use passive glasses to view the procedure on an output display. Students at remote sites could also view the operation on a display.

VREX DEMONSTRATED STEREO ENDOSCOPY WITH THE µPOL™ SYSTEM AT NUMEROUS MEDICAL CONVENTIONS.

In demonstrations of stereo endoscopy with the VRex system at numerous medical conventions, surgeons acknowledged the advantages of the 3-D capability. It restores depth perception, reduces operating time, and allows surgical execution to a precise depth. These advantages are crucial in such procedures as nasal sinus endoscopy, which poses a risk of damage to the brain, optic nerve, and carotid arteries.

The company's award-winning 3-D stereoscopic notebook computer—CyberBook™—also uses the µPol system. Along with CyberBook, VRex introduced a Microsoft Windows™ and Apple Macintosh™ compatible SMUX™ software program. SMUX enables users to create 3-D stereoscopic images and display them on the CyberBook. CyberBook sells for as little as $3,500 and SMUX costs between $300 and $400.

Other 3-D stereoscopic products include the VR-1000™ and CAM-3000™. VR-1000, a compact liquid crystal display projection panel, displays flickerless video and computer graphics on large screens from a conventional overhead projector; CAM-3000 is a compact 3-D stereoscopic video camera.



■ Reveo has recently introduced the world's first 3-D stereoscopic overhead projection system, pictured above, which uses polarization encoding to project two digital images simultaneously.

Reveo received BMDO SBIR contracts to build a stereo printer, display, and camera for viewing missiles, decoys, and other battlefield situations in 3-D. The company developed micropolarized viewing hardware, a polarization encoding system, and spatial multiplexing methods to enhance its displays.

ABOUT THE TECHNOLOGY

The system's µPol array uses polarization encoding to project two digital images simultaneously. The system uses spatially multiplexed imaging (SMI) to arrange the left and right images of a stereo pair by position in space instead of by time. It transforms incoming unpolarized light into two perpendicular polarized states, each of which passes one of the stereo pairs of images. Passive polarized glasses decode the polarized (or encoded) images, passing the appropriate image from the stereo pair to the appropriate eye. Processing the images spatially eliminates flicker, so SMI can be used for video and television. In addition to producing 3-D images for all VRex display devices, SMI can generate 3-D transparencies.

Can You Imagine . . .

. . . a strong, lightweight surgical tubing that offers low-cost advantages to physicians and hospitals.

RIGID TUBING FINDS MEDICAL MARKET IN OPERATING ROOMS

Using surgical equipment presents risks. The most obvious ones concern the patient, but the surgeon must also be wary. For example, the high-voltage surgical cautery knife minimizes bleeding during incision-making, yet poses both an electrical hazard and a source of sparking. Metal-to-metal contacts, such as when the knife grazes a surgical clamp, can cause unpleasant shocks; they also can produce sparks that, in the presence of volatile anesthetic gases and high-concentration oxygen in the operating room, may ignite small fires and, rarely, explosions.

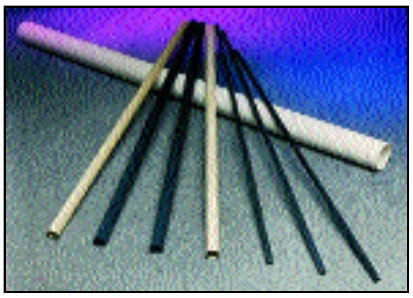
Foster-Miller, Inc. (Waltham, MA), developed strong, lightweight medical tubing that electrically shields devices for endoscopic and laparoscopic procedures, minimally invasive techniques that help to reduce both the length of hospital stays and risks associated with major surgery. Made from an innovative polymer developed for BMDO satellite applications, the surgical tubing minimizes electrical hazards through superior insulation properties. The material costs 30 percent less than fiber-reinforced composite tubing, and it resists delamination under the high pressures and temperatures required for medical sterilization.

The company formed a subsidiary called Superex Polymer, Inc. (Waltham, MA), to commercialize this tubing. Superex Polymer then entered into an agreement with ACT Medical, Inc. (Waltham, MA), a manufacturer and vendor of specialized materials, to produce and sell its liquid crystal polymer (LCP) to medical device manufacturers. For example, ACT uses the LCP tubing for cannulae, the tubes through which doctors insert cameras and surgical instruments into the body. LCP tubing could find a substantial market in the field of minimally invasive surgery; the industry projects nearly 4 million such procedures in the United States in 1996.[1]

FOSTER-MILLER'S SUBSIDIARY, SUPEREX POLYMER, HAS FORMED AN AGREEMENT WITH ACT MEDICAL, WHICH WILL PRODUCE AND SELL LCP TO MEDICAL DEVICE MANUFACTURERS.

Pursuing other R&D efforts that may bring LCP technology to the market, Superex is developing LCP thin films for printed circuit boards (PCBs). Manufacturers of PCBs use epoxy to laminate copper on layers of fiberglass, a high-cost, time-consuming, multistage process. However, most polymer alternatives expand and contract with temperature fluctuations, limiting their application. Superex's thin films will tolerate temperature differences, leading to lower production costs. The company is building a thin-film process facility and expects production to begin in late 1996. Superex teamed with Brampton Engineering, a Canadian company, to market LCP films and laminates to electronics manufacturers.

LCP technology could also solve the flatness and contamination problems that have caused the beer industry to shun plastic bottles until now. Superex is working with five companies from Europe, Japan, and the United States to develop a multilayered LCP bottle for beer. Superex expects to license its technology, slated for completion by July 1997, to these five companies.



■ Among other applications, Superex's LCP tubing is used as cannulae, tubes through which doctors insert cameras and surgical instruments into the body.

ABOUT THE TECHNOLOGY

Superex's material property improvements turn on advanced die technology. The die simultaneously orients polymer molecules perpendicular to each other and at an angle to the length of the tubing. This orientation solves the problem of poor transverse strength that, until now, made LCP virtually useless in many applications because of its tendency to split or thin unevenly when stressed in the nonmachine direction. In 1995, Foster-Miller's LCP extrusion process won an R&D 100 award from *R&D Magazine* as one of the year's 100 most significant innovations.

[1]Global Industry Analysts, Inc. 1995. Medical industry market research reports: Endoscopy equipment. World Wide Web at http://www.globind.com/315.htm.

Can You Imagine . . .

. . . a neural network technology that helps doctors double-check Pap smears for suspicious cells, increasing the reliability of tests for cervical cancer.

PAPNET IMPROVES SCREENING EFFICACY FOR CERVICAL CANCER

Cervical cancer strikes about 65,000 U.S. women per year, accounting for 5,000 deaths annually.[1] However, during the past 30 years a screening test called the Pap smear accounted for a 63 percent decrease in the death rate from this disease.[2] Curable if caught early enough, cervical cancer is one of the few human malignancies strongly associated with the human papilloma virus (HPV). A Pap smear helps reveal the presence of HPV and helps a patient discover her risk factor for cervical cancer.

Laboratories perform over 50 million Pap tests in the United States every year.[2] Due to the large volume and fast turnover of test slides in a typical histology laboratory, positive test results are sometimes overlooked. When this occurs, a potentially curable carcinoma-in-situ can progress to an invasive cancer. In late 1995, Neuromedical Systems, Inc., received FDA approval for a neural net–based screening method that greatly increases the odds of detecting a suspicious Pap smear, helping to save women's lives. This computerized system owes part of its existence to BMDO funding through HNC Software Inc. (San Diego, CA).

IN ADDITION TO DETECTING CERVICAL CANCER, HNC MAY APPLY ITS NEURAL NETWORK TECHNOLOGY TO SCREEN FOR LUNG CANCER.

HNC developed avalanche neural network computer architectures and systems for BMDO to detect ballistic missiles. HNC's network technology now forms the basis of Neuromedical Systems' PAPNET® Testing System. This system uses fast, powerful neural network algorithms to quickly identify the signs of malignancy in cell clusters. With the PAPNET test, cytology labs increase the total detection of abnormalities up to 30 percent. The FDA approved the system in November 1995, and more than 40 U.S. clinics and 15 countries now use it.

Neuromedical Systems, which acquired its software development tool for neural networks from HNC, holds a patent for applying neural networks to cell analysis. The company may apply the technology to develop automated systems for lung cancer screening, urinalysis, and other cell analyses.

■ PAPNET® uses HNC's neural network technology to detect potentially missed abnormal cells on a woman's Pap smear.

ABOUT THE TECHNOLOGY

Showing the system a variety of images representing both benign and malignant cervical cells trains the computer to read Pap smears. The computer examines the images and learns the most salient characteristics of each type of cell or cell cluster. For example, large and misshapen nuclei can signify cancer. After the network is trained, it can be used in an automated system to quickly scan slides and flag abnormalities.

PAPNET uses two separate neural networks, one trained to recognize suspicious single cells, and the other trained to recognize abnormal cell clusters. The system selects and records color images of the 128 most suspicious cell images on a smear, and allows the cytologist to scrutinize them. In unassisted visual screening, the error rate (classifying abnormal smears as normal) can be as high as one in three. In a test of 1,247 Pap smears, the PAPNET system identified 517 of 534 abnormal smears, for a 97 percent accuracy rate. Note, however, that PAPNET is a supplemental screening method: A qualified pathologist makes the final diagnosis.

[1]University of Pennsylvania Cancer Center. 1996. Clinical trials news: New treatment options for cervical cancer. World Wide Web at http://oncolink.upenn.edu/upcc/clin_trials/fall94/RUBIN.html.

[2]U.S. News Online. 1995. Health: Digital help to spot cervical cancer. World Wide Web at http://www.usnews.com/usnews/nycu/cervical.htm.

DRUG-SCREENING SOFTWARE GOES COMMERCIAL

Can You Imagine . . .

. . . an algorithm that promises to transform new drug research by rapidly suggesting candidate molecules.

MOLDYN'S COMMERCIAL PLANS FOR ITS COMPUTER ALGORITHM INCLUDE PARTERNERING WITH LEADING PHARMACEUTICAL COMPANIES AND A COMPUTATIONAL CHEMISTRY SOFTWARE FIRM.

Advances in the pharmaceutical industry can be painfully slow and costly. Typically, it takes an average of 15 years and nearly $500 million to bring just one new drug from the laboratory bench to the pharmacy shelf.[1]

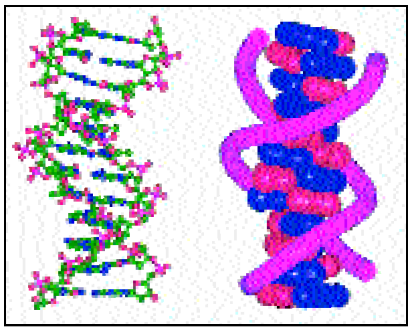
In an effort to expedite drug development, researchers have turned to computational chemistry, a branch of theoretical science that uses digital computers to model systems of chemical interest. But even this computerized technique is time consuming. For example, a full all-atom simulation of just two interlocking molecules can consume hundreds of hours of computer time, even on supercomputers.

Moldyn, Inc. (Arlington, VA), developed a computer algorithm that reduces the time needed to model the dynamics of large molecular systems. The company's algorithm, MBO(N)D[2], promises to transform new drug research, helping find new cures faster. Moldyn, a subsidiary of Photon Research Associates, Inc. (San Diego, CA), developed this technology using BMDO-funded modeling methods designed to simulate the dynamics of large space-based structures.

Because it increases computational speed, MBO(N)D will make the discovery of new drugs and the development of new materials through computational techniques more practical. Tests of the algorithm show that it simulates the dynamics of large molecules (10,000 atoms) up to 50 times faster than conventional all-atom modeling techniques. With further refinements, the algorithm could even be applied to even larger molecules (10,000 to 100,000 atoms) at speeds 100 to 1,000 times faster than all-atom approaches.

Moldyn received an Advanced Technology Program award from the National Institute of Standards and Technology to help bring this technology to the pharmaceutical industry. In this project, the company and its partners will refine the algorithm for commercial use. Moldyn's partners in the project include leading pharmaceutical companies, a computational chemistry software firm, and leading academics in the field of computational chemistry.

The company plans to market the MBO(N)D algorithm as a stand-alone software package and as an interface module link to software already on the market. The stand-alone package targets developers of new drugs and materials, while the interface module targets software firms.



■ Moldyn's algorithm can simulate DNA (pictured above right) 50 times faster than all-atom modeling techniques (pictured above left).

ABOUT THE TECHNOLOGY

MBO(N)D accelerates computational speed without affecting chemical and physical realism through a technique known as substructuring, which combines atoms into interacting groups of rigid and flexible bodies. The algorithm also filters out small-scale motions that do not affect the overall behavior of the molecule. These two innovations reduce the number of system variables and allow the simulation to be computed over a smaller number of time steps.

[1]Pharmaceutical Research and Manufacturers Association. 1996. The drug development and approval process. World Wide Web at http://www. phrma.org/charts/approval.html.

[2]MBO(N)D stands for multibody order(n) dynamics. Multibody refers to the method of combining the molecules in a series of substructures; order(n) refers to the number of variables in the model. In conventional simulations, the number of variables equals the number of objects squared (n^2). MBO(N)D reduces the number of variables to the number of objects (n).

Can You Imagine . . .

. . . a breast ultrasound instrument that could examine breast abnormalities not readily apparent with x-ray mammography.

BREAST ULTRASOUND MAY SAVE WOMEN'S LIVES

An important addition to mammographic screening in recent years, breast ultrasound helps doctors decide whether a suspicious area on a mammogram is a benign cyst or a malignant tumor. Investigators found new ways to use hand-held ultrasound wands for this task. Manufacturers of ultrasound equipment also responded to the needs of clinicians, developing specialized units for breast ultrasound.

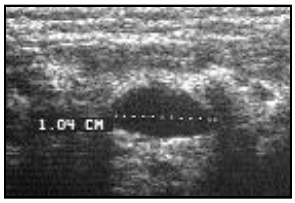
Demonstrating its proactive corporate strategy of continual innovations in breast imaging, ThermoTrex Corporation (San Diego, CA) transferred some of its BMDO-funded advanced imaging technology into the growing field of breast ultrasound. ThermoTrex is also developing digital mammography techniques.

SONIC CT™ IS UNDERGOING LIMITED TRIALS AT THE HILLCREST CENTER FOR WOMEN'S HEALTH IN SAN DIEGO, CALIFORNIA.

In its unique approach, ThermoTrex incorporated computed tomography (CT) techniques into breast imaging with ultrasound. Sonic CT™ images the breast in a slice-like fashion using high-frequency sound waves. This method yields an image relatively free from overlying tissue interference, helping doctors to see features not always apparent with x-ray mammography. Radiation exposure is not a concern with this method, because Sonic CT uses ultrasound instead of x-rays to form a breast image. Also, this technology does not require painful compression of the breast.

Sonic CT can spot breast abnormalities not associated with microcalcifications. Thus, it could assess such conditions as fibrocystic breast disease (also called "lumpy" breast disease). It also could help reduce the number of breast biopsies, 80 percent of which turn out negative. Currently, Sonic CT is undergoing limited trials at the Hillcrest Center for Women's Health in San Diego, California.

ThermoTrex is developing Doppler CT, an imaging technology related to Sonic CT. This device uses ultrasound to assess blood vessels for blockages. Specifically, it will detect blood flow speed and image vessels in three dimensions, providing useful information for examining coronary and carotid arteries to assess the risk of heart attack and stroke, respectively. Doppler CT also can image the peripheral blood vessels of the legs, an important capability for detecting blood clots in elderly patients after surgery and during prolonged periods of bed rest.



Courtesy of New South Wales Breast Cancer Institute.

■ Ultrasound can help confirm the presence of a malignant lesion, as pictured above.

ABOUT THE TECHNOLOGY

Both Sonic and Doppler CT devices convert ultrasound signals into digital images of anatomical features and electronically process and store them, just as x-ray images are manipulated in "conventional" CT. Sonic CT uses low-frequency ultrasound to produce cross-sectional slices of the breast, acquiring images in near-real time. Doppler CT will measure the velocity of blood coursing through vessels. Blood flows at a higher speed through a passage narrowed by plaque or scar tissue than through an unobstructed blood vessel with a wider diameter. Therefore, comparing the speed of blood flow in adjoining areas of an artery allows detection of blockages in that artery.

PHOTODYNAMIC THERAPY EMERGES IN WAR ON CANCER

Can You Imagine . . .

. . . techniques in which photoactive dyes kill viruses or cancers when irradiated with laser light.

Esophageal cancer leaves many of its victims unable to swallow, and nearly always results in death. The American Cancer Society projects diagnosis of 12,300 people in the United States with esophageal cancer in 1996 and 11,200 deaths from it.[1] Doctors have limited treatment options.

Now there is a new treatment for esophageal cancer, based on a method that holds great promise for other cancers, as well as for noncancerous conditions. The FDA-approved Photofrin® captures light energy and uses it to selectively destroy diseased cells. It is the first drug ever approved for the photodynamic therapy (PDT) of cancer.

Photofrin was originally developed by Dr. Thomas Dougherty as an anticancer agent at the Roswell Park Cancer Institute (Buffalo, NY). The Medical Free Electron Laser (MFEL) program at Baylor Research Institute (Dallas, TX) studied it as a blood purifier. BMDO's MFEL program, established by Congress to transfer BMDO-sponsored free-electron laser (FEL) technology to medical and other spinoff applications, initially funded some of this laser research.

Using laser light of a specific wavelength, Photofrin produces an oxygen radical that kills cells in its immediate vicinity. Abnormal tissues selectively absorb the drug, which laser light then activates, making it a well-controlled therapy that avoids harm to normal cells. In late-stage esophageal cancers that obstruct breathing and swallowing, PDT is a kinder alternative to surgery, which causes pain and forms scar tissue.

Baylor eventually licensed Photofrin to QLT Phototherapeutics, Inc., which submitted the drug for FDA approval. QLT awaits FDA approval to use Photofrin in the treatment of bladder and some lung cancers. The company is conducting extensive research in PDT for treatment of a wide variety of cancers and for noncancerous disorders such as psoriasis, rheumatoid arthritis, and cardiovascular disease.

Many exciting clinical advances resulted from Baylor's MFEL-related research, including unique photoactive drugs for collagen repair in the knee joint and improved methods for treating eye disease. Baylor has developed a photochemical to isolate stem cells from blood in order to restore the marrow of chemotherapy patients and other immunocompromised individuals. Baylor also developed a photochemical, now available in Taiwan and Egypt, that can reverse drug resistance in malaria sufferers.

QLT PHOTOTHERAPEUTICS, INC., HAS ACQUIRED A LICENSE FOR PHOTORIN, WHICH AWAITS FDA APPROVAL FOR USE IN THE TREATMENT OF BLADDER AND SOME LUNG CANCERS.

Courtesy of Beckman Laser Institute.

■ Fiber optics can deliver light energy through endoscopes and catheters in PDT for cancer.

ABOUT THE TECHNOLOGY

PDT involves techniques in which photoactive dyes kill viruses or cancers when irradiated with laser light. The dyes selectively attach to a number of enveloped viruses, such as HIV, hepatitis, Epstein-Barr, cytomegalovirus, and herpes, as well as many cancerous cells. When light of a specific wavelength and intensity shines on the dye, a chemical reaction begins that gives off a toxic oxygen radical, called singlet oxygen, that exists for a short distance and for a fraction of a second. The oxygen radical breaks down the viral sheath and kills the virus.

Because these dyes produce this radical when they absorb laser light of a specific wavelength, Baylor used an FEL and other lasers to deliver the correct wavelength. Before FELs, doctors used continuous-wave lasers, which could not produce the variety of wavelengths and very short pulses of FELs. The FELs produce more precise and varied wavelengths, enabling researchers to study discrete interactions of light and matter.

[1]Cancer facts and figures. 1996. American Cancer Society. 1-800-4-CANCER.

Can You Imagine . . .

. . . an imaging technology that offers medical researchers a less destructive way to look at samples under a microscope.

NEW METHOD ELIMINATES FIXING IN BIOLOGICAL ANALYSES

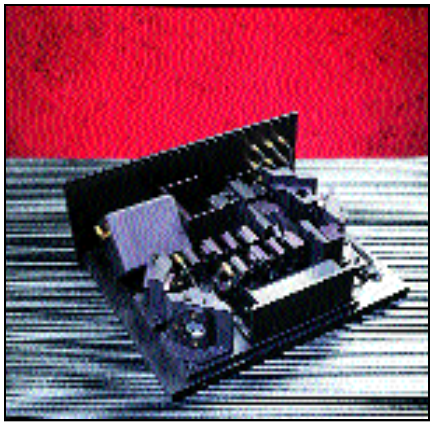
To look at some of life's smallest building blocks, many light-based imaging methods require physical alteration of the biological material before viewing. Preparing a sample for viewing often means stabilizing the cell with special chemicals and removing all the water, potentially distorting the image of the cell and its contents. Newer techniques can eliminate some fixative steps, but may also cause photo-bleaching, a phenomenon that can ruin parts of the image.

A new imaging method offers a less destructive means of biological analysis and of examining industrial and semiconductor materials. Essex Corporation (Columbia, MD) developed a synthetic aperture microscope (SAM), based on synthetic aperture radar. The device produces high-resolution, 3-D, complex-valued representations in a few seconds, with reduced alteration of the specimen. It also allows specimen viewing from a greater distance than many light-based imaging methods. Applications of the SAM include both macroscopic and microscopic imaging.

ESSEX'S TECHNOLOGY HAS SUCCESSFULLY IMAGED A VARIETY OF BIOLOGICAL SPECIMENS AND SEMICONDUCTOR MATERIALS.

The SAM, a coherent-light microscope, can resolve images as small as one-quarter the device's operating wavelength. Thus, using ultraviolet light (280 nanometers) allows visualization of sample features as small as 70 nanometers. Working with Dr. Lee Peachey, a biology professor at the University of Pennsylvania, Essex discovered that this resolution gives a sharp view of the complex eyes of fruit flies and the intricate exoskeletons of diatoms (microscopic algae). It also produces detailed images of carbon fibers and diffraction gratings.

Essex's device can operate at wavelengths from ultraviolet to visible and infrared. Independent of working distance, the device resolves very small features from several inches away. By changing the focal lens of the SAM, Essex expects to increase this distance to four to six inches or even more.



■ Essex's microscope works in tandem with ImSyn™ (pictured above), Essex's high-speed optical processor which forms images from a wide range of sensor inputs.

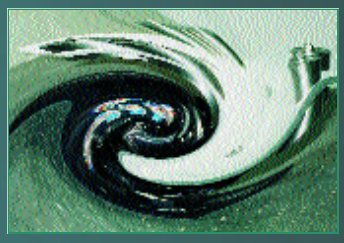
The SAM works in tandem with ImSyn™, Essex's high-speed optical processor which is capable of forming images from a wide range of sensor inputs. An outgrowth of BMDO-sponsored research in rapid optoelectronic processing of radar signals, the ImSyn processor significantly cuts data processing time in magnetic resonance imaging (MRI), ultrasound, and other diagnostic examinations. For example, the optoelectronic processor allows physicians to see a target tumor or other anatomical feature in real time, and its high speed increases the resolution of images and prevents blurring.

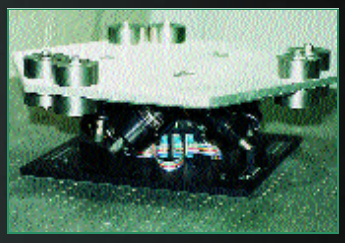
Dr. Peachey notes that when used to collect data digitally, the SAM may mimic different types of microscopes. Thus, a biological sample would be subjected to only one data collection event because the digital data could continually be rearranged to produce images in different formats. The SAM also could generate full phase and amplitude information for 3-D holographic imaging, allowing the viewing of images from different angles. Today's microscopes that use film or charge-coupled devices record only amplitude information.

ABOUT THE TECHNOLOGY

SAM's key, the ImSyn processor, takes data directly from any sensor, such as an MRI coil, and sends real-time imaging to the workstation for display. Standard workstation software performs image enhancement and manipulation, if desired. The system, a 2-D real-time Fourier transform processor with high-speed input and output, uses optoelectronic technology for speed and flexibility. The processor transforms the received data into images and then forwards those images to the image analysis workstation. The complex correlation with an appropriate pattern in a database forms the pattern recognition option.

MISCELLANEOUS





Nineteen ninety-five was a banner year for innovation in the United States. That year, the U.S. Patent and Trademark Office received the largest number of applications for patents and designs to date, according to the 1995 Commissioners' Annual Report. As a result of these applications, 64,562 residents of the United States received patents in such diverse areas as mechanical, electrical, and chemical engineering.[1]

Innovations in these areas offer significant improvements to the transportation, utility, semiconductor, and space industries. Breakthroughs in electrical engineering can facilitate the development of high-speed trains to reduce traffic congestion between major cities. They can also enable superefficient power-control devices to double power line capacity. Innovations in chemical engineering can lead to better materials for vibration suppression in semiconductor manufacturing equipment and can help in deploying inflatable space structures.

Today's Market

Electric utilities and semiconductor manufacturers can benefit greatly from technological innovations. Deregulation is forcing more competitiveness in the electric power industry, which accounted for $208 billion in revenues from retail sales to ultimate customers in 1995.[2] New technologies can help electric utilities establish a competitive advantage, improve efficiency, and trim costs. Reducing production costs is a primary concern for computer chipmakers, whose sales are estimated to reach $197.6 billion in 1999, up from $101.8 billion in 1994.[3] Innovative technologies can suppress vibrations in manufacturing equipment, reducing errors that add to production costs.

Tomorrow's Opportunity

BMDO has funded various technologies for ballistic missile defense that can also provide companies with innovative solutions to help the United States build a stronger economy. The following section describes five examples.

---

[1]U.S. Patent and Trademark Office. 1995. Setting the course for our future, a Patent and Trademark Office review, Fiscal Year 1995. World Wide Web at http://www.uspto.gov/web/offices/com/annual/annual.html.

[2]Energy Information Agency. 1996. Electric Power Annual 1995, Vol. 1, Chapt. 1. World Wide Web at http://www.eia. doe.gov/cneaf/pubs_html/epa_1995/volume1/chapter1.html.

[3]Semiconductor Industry Association. 1995. Semiconductor forecast summary 1995–1998. World Wide Web at http://www.semichips.org.indstats.htm.

Can You Imagine . . .

. . . a power control device that will help electric utilities reduce power outages and double the capacity of transmission lines.

ELECTRICITY-SAVING CIRCUITS HELP UTILITIES UPGRADE POWER GRIDS

Investigating a flexible alternating current transmission system (FACTS), the Electric Power Research Institute (EPRI) and other groups expect to improve the switching capabilities, capacity, and security of electric utility transmission lines. FACTS controllers also prevent power outages that cascade throughout the distribution system. These devices require highly advanced power electronics to control the flow of current over the transmission lines.

One of the nearest term technologies for FACTS controllers is a high-powered variable switch marketed by Harris Semiconductor Corporation (Melbourne, FL), called the metal oxide semiconductor–controlled thyristor (MCT). Originally funded as a power control device for BMDO's directed energy weapons, MCTs will instantly reroute power to avoid outages and double the capacity of transmission lines. These rugged, reliable, efficient thyristors can operate at higher temperatures and permit faster switching speeds than such conventional thyristors as the silicon-controlled rectifier, the insulated gate bipolar transistor, and the gate-turnoff device.

HARRIS FOCUSES ITS MARKETING EFFORTS FOR THE MCT ON AUTOMOTIVE, ELECTRIC UTILITY, AND MANUFACTURING APPLICATIONS.

Harris launched its first line of MCTs (a 600-volt p-type MCT) in September 1992 and added three more MCT devices, including one 1,000-volt, 65-ampere p-type MCT and two 35-ampere devices (one with and one without a built-in diode). The company soon expects to release a 600-volt, 75-ampere device in a second generation of MCTs. This device will offer a fourfold improvement in switching speed over current generation devices. Harris primarily focuses its marketing efforts for the MCT on automotive, electric utility, and manufacturing applications.

In September 1995, Harris announced plans to invest $250 million in its power semiconductor operation to construct a metal oxide semiconductor (MOS) eight-inch wafer fabrication facility in Mountain Top, Pennsylvania, for MCTs, MOS field effect transistors, and insulated gate bipolar transistors. When fully operational (scheduled for 1997), the facility should create about 120 new highly skilled manufacturing jobs for the community.

Through U.S. Navy funding and a project sponsored by the Defense Advanced Research Projects Agency, Harris and EPRI continue to address further development and packaging requirements for high-power MCTs. Forming much smaller and more powerful power electronic building blocks (PEBBs), the team plans to package MCTs with semiconductor rectifiers and high-performance gate-driver integrated circuits. With such smart power devices as PEBBS, utilities could save $6 billion compared to the cost of adding the same capacity with new lines.[1]

■ Harris' MOS-controlled thyristor may be one solution for upgrading utilities' transmission and distribution systems.

ABOUT THE TECHNOLOGY

Serving as variable-gain switches, thyristors regulate current flow with a technique known as phase control. A significant advance in high-powered electronics, Harris' MOS-controlled thyristors switch much faster, operate at higher power levels, and withstand higher temperatures than conventional thyristors, such as silicon-controlled rectifiers. They handle up to 1,000 volts at more than 100 amperes. Further development could lead to individual devices that handle 2,500 to 4,500 volts at comparable currents. In addition, Harris expects these silicon-based devices to be more easily manufactured than competing power semiconductors.

[1]Hingorani, N. and Karl Stahlkopf. 1993. High-power electronics. *Scientific American*. November, 78–84.

INFLATABLE SPACE STRUCTURES COME OF AGE

Can You Imagine . . .

. . . an inflatable space antenna that is 100 times cheaper than an equivalent mechanically deployed system.

Upon reaching orbit, satellites typically use complex mechanical systems to unfold large communications antennas stowed onboard. Unfortunately, these bulky systems increase the cost and mass of satellites. Also, if rocket launch vibrations exceed upper limits, the antennas could become damaged so that they cannot be fully deployed. L'Garde, Inc. (Tustin, CA), addressed these problems using BMDO-funded technology that inflates structures like a balloon.

L'Garde pioneered the use of inflatable space structures, which can reduce the cost and mass of future spacecraft. This inflatable technology is 10 to 100 times less expensive than mechanically deployed systems, because of its much smaller mass and stowed volume. Also, because an inflatable structure incorporates no moving parts, excessive launch vibrations may not damage it.

The company tested its most complex and precise inflatable space structure in an experiment carried onboard the space shuttle *Endeavor*. L'Garde built the inflatable antenna experiment (IAE) under a $9-million contract from NASA's In-Space Technology Experiment Program. Goddard Space Flight Center integrated IAE into its Spartan 207 spacecraft. *Endeavor*'s astronauts used a robotic arm to release Spartan into free flight, which set the stage for deploying the IAE.

L'GARDE RECENTLY TESTED ITS MOST COMPLEX AND PRECISE INFLATABLE SPACE STRUCTURE IN A SPACE SHUTTLE experiment.

The IAE achieved its proper configuration, and pictures taken from *Endeavor* gave ground control personnel a spectacular sight. However, before L'Garde considers the IAE operational, it must resolve some apparent glitches in the deployment and conduct further testing. Despite these problems, the IAE demonstrated many advantages of inflatable structures. The antenna stowed away in a 7 x 3 x 1.5 foot box, but inflated to the size of a tennis court; the whole deployment system weighed only about 132 pounds; and it cost 100 times less than an equivalent mechanically deployed system.

The IAE is just one example of the many space structures that could benefit from L'Garde's inflatable technology. Other possible inflatable structures include solar arrays, solar concentrators, support struts, and sunshades. The Defense Advanced Research Project Agency funded L'Garde to develop and test the first inflatable solar array with an output of 200 Watts and power density of 90 to 100 Watts per kilogram.

Having worked with space inflatables since 1971, L'Garde has tested more than 100 inflatable structures for government clients. The company developed much of the basic technology that underlies all of its inflatable systems in several BMDO projects to build decoys of ballistic missiles for sensor and interceptor studies.

ABOUT THE TECHNOLOGY

L'Garde's inflatable systems can be packaged in compact containers; a gas inflates the clear or metallic structural film. Inflatable structures do not need the mechanical parts that conventional systems do—an important feature on a spacecraft, where any mechanical difficulty can ruin a mission. When required, structures can be made rigid through several methods, including the use of ultraviolet (UV) light-sensitive epoxy upon inflation. When exposed to plentiful UV rays in space, the epoxy hardens. Once hardened, the support struts act as one solid structure, holding the structure fast without the need to maintain inflation pressure.

■ The IAE experiment, shown here following its deployment from the space shuttle *Endeavor*, will lay the groundwork for future technology development in inflatable space structures.

Can You Imagine . . .

. . . a vibration isolator that can provide a stable environment for precision lithography equipment and can control vibrations in medical imaging devices.

BMDO SPACE R&D RESULTS IN ULTRAQUIET EQUIPMENT

Advances in lithography have enabled the miniaturization of computer chips. Shrinking the circuit elements on these chips has resulted in tighter acceptable alignment tolerances for lithographic equipment, making the lithography process even more sensitive to vibration. Thus, chip makers are searching for new ways to keep their equipment isolated from excessive vibrations that can lead to flawed products. In a $151-billion industry that grew 37 percent in 1995,[1] throwing away even a small percentage of those chips is costly.

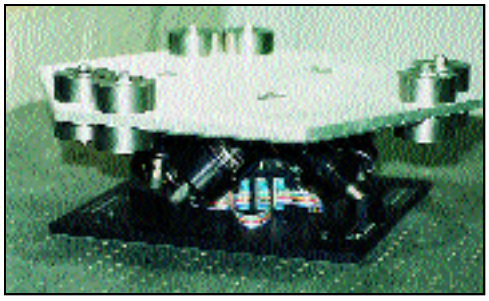
CSA Engineering, Inc. (Palo Alto, CA), developed an electromechanical control system that can control vibrations in precision lithography equipment. The system can also be used in other applications, such as cellular base station receivers and airborne sensors. It was derived from CSA's UltraQuiet Platform (UQP), a six-axis vibration isolation system for space-based sensors originally developed with BMDO SBIR funding.

The UQP system uses a novel combination of passive and active vibration suppression devices connected serially within each of six struts. This passive-active combination allows the use of high-force, short-stroke actuators, giving the UQP system superior performance over passive-only, active-only, or parallel passive-active systems. It also makes the control system less sensitive to vibrational modes of the isolated instrument or machine.

LEVERAGING ITS EXPERTISE IN ACTIVE AND PASSIVE VIBRATION SUPPRESSION, CSA FORMED A STRATEGIC ALLIANCE WITH NEWPORT CORPORATION.

Leveraging its expertise in vibration suppression, CSA formed a strategic alliance with Newport Corporation, which sells precision optical equipment. This alliance, which has already resulted in several small product-development projects, could grow significantly during the next few years. For example, the team may invest a large amount of time and capital in developing the next generation of active vibration-suppression equipment for the precision lithography machinery used in manufacturing semiconductors.

CSA has investigated excessive vibrations in the cooling system of a newly developed magnetic resonance imaging machine and created several technology fixes for it. The company is currently developing vibration isolation technology for the cryocoolers used to cool superconducting switches and junction boxes in base stations for cellular communications.



■ CSA Engineering's UQP system, pictured above, uses a novel combination of passive and active devices connected serially to suppress vibration.

ABOUT THE TECHNOLOGY

The UQP system uses a novel combination of passive and active vibration-suppression devices connected serially. This six-legged, spider-shaped flexure provides the passive isolation to an intermediate stage. The system measures the damped motion of this stage and feeds it to the control circuitry for a base-mounted actuator that serves as an active isolator. The intermediate stage and the serial mounting reduce the amount of displacement the actuator must counter, making the system more efficient than either passive-only, active-only, or parallel passive-active systems. It also does a better job of canceling vibrational modes that arise in flexible payload structures.

The UQP system works optimally for stroke displacements of 25 to 50 microns (1 to 2 mils), frequencies greater than 5 Hz, and payloads of up to 100 pounds. It integrates all of the mechanical actuators, dampers, and electrical control components into a platform less than six inches high. A version of the UQP system designed for payloads up to 15,000 pounds would double the height.

[1]Singer, Peter H. 1996. Dataquest revises 1996 chip forecast sharply downward. *Semiconductor International*, June.

NEW TRANSISTOR TAKES THE HEAT

Can You Imagine . . .

. . . a new transistor that operates at temperatures over 500˚C.

Car makers would like to put electronics deeper into engines to keep a closer watch on control and exhaust functions. However, the silicon transistors used in these systems cannot operate above 150˚C, and their performance may start dropping off at around 80˚C. New transistors that operate above 500˚C would allow car makers to move electronic control systems closer to engines.

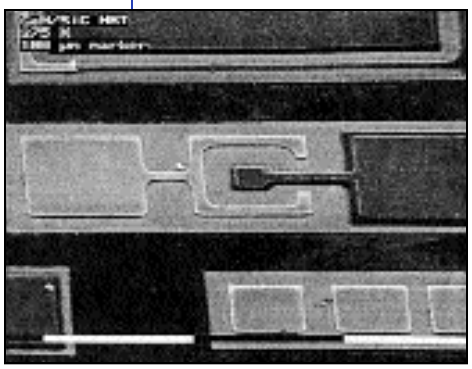
Researchers at Astralux, Inc. (Boulder, CO), have tested a new transistor up to 535˚C, as high as their equipment permitted. The transistor's much higher temperature range results from its materials: silicon carbide (SiC) and gallium nitride (GaN), two semiconductor materials particularly suited to operation at high temperatures. The BMDO SBIR program funded the research and development of this technology, which could provide high-temperature electronics for missile defense control systems.

The new transistor will have important uses in a growing number of high-temperature environments in the automotive and aerospace industries. For example, Astralux says the technology may control the power delivered to motors in future electric cars, replace hydraulic systems with electric motors, and eliminate the need for heavy, expensive cooling systems in space electronics. Future innovations, such as fabricating several transistors on a single chip, may allow high-temperature digital circuits.

The same characteristics that allow the new transistor to operate at high temperatures will also allow it to operate at high frequencies and high powers. Astralux began to address these capabilities in two recently awarded SBIR Phase I contracts. The company is also looking at high-frequency possibilities for the device.

Astralux plans to sell various high-temperature transistors when it resolves several packaging issues, the first quarter of 1997. Meanwhile, the company welcomes strategic partners or licensees to help market the device.

ASTRALUX WELCOMES STRATEGIC PARTNERS OR LICENSEES TO HELP MARKET THE DEVICE.



■ The high-temperature transistor has construction similar to silicon bipolar transistors, except that it is made of large-bandgap materials.

ABOUT THE TECHNOLOGY

The high-temperature capabilities of Astralux's heterojunction bipolar transistor (HBT) come from the materials used as the heterojunction. Generally, a material's band gap limits the transistor's operating temperature range. Silicon's band gap of 1.1 electron volts (eV) translates into a maximum operating temperature of around 180˚C. SiC and GaN, with band gaps of 2.9 eV and 3.4 eV, respectively, allow transistors to work at much higher temperatures.

The HBT uses SiC for the base and collector; GaN may also be used for the collector. Because GaN's band gap is wider than SiC's, a barrier blocks hole current flow from the base to the emitter, increasing the electron injection efficiency in the transistor. Higher emitter efficiency results in higher current gain. At room temperature, the HBTs have a current gain of over 10 million, while at 535˚C the gain is still around 100.

Can You Imagine . . .

. . . a high-speed train that would cost far less than a magnetically levitated train.

BMDO-FUNDED R&D MAY GET FAST TRAINS BACK ON TRACK

For years, magnetically levitated (maglev) trains fostered high expectations of state and Federal transportation planners, because the trains could reach speeds up to 300 mph. Zipping along new tracks, maglev trains could relieve increasing airport and highway congestion between major cities 200 to 600 miles apart. In 1994, air passengers traveled 170 billion miles more than they did in 1970—an increase of 87 percent. Automobile use overshadows all other transportation modes, growing by over 900 billion passenger-miles in the last 24 years.[1]

However, obtaining rights-of-way to lay new track and laying the track itself may cost tens of millions of dollars per mile, pushing this technology out of reach for cash-starved governments. For example, Florida's Department of Transportation derailed a proposed maglev train to transport tourists from the Orlando International Airport to Walt Disney World Amusement Park in 1994 when the price reached $1 billion.

Sandia National Laboratories (Albuquerque, NM) has proposed a new high-speed train that runs on today's rail lines for a fraction of the cost of maglev systems. A segmented-rail phased-induction motor, called Seraphim for short, is the keystone of Sandia's proposal. The motor provides the electromagnetic induction required to propel the new train on conventional wheels and rail. Sandia developed this technology as part of a BMDO electromagnetic "gun" for launching projectiles into space at speeds around one kilometer per second.

TO TEST THEIR IDEAS, SANDIA RESEARCHERS BUILT AND TESTED A MODEL THAT REACHED A SPEED OF 34 MPH IN JUST 12 FEET.

■ Pictured above is an artist's concept of Sandia's high-speed train, which could easily reach 300 mph on today's rail lines.

Construction and maintenance costs comprise a large portion of the maglev train's price tag, because it must run on electrified tracks. Sandia projects that its approach, which combines existing track with inexpensive aluminum plates mounted alongside or between the rails, would cost 75 percent less than a maglev system. This approach also allows old-style and new-style trains to travel on the same tracks. In the Seraphim scheme, electromagnets on the locomotive generate accelerating forces between the track plates and the vehicle, pushing the train to 200 mph. With new precision rails, the train could easily reach 300 mph—just as fast as maglev trains.

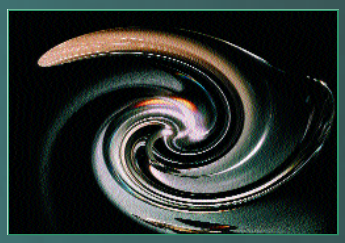
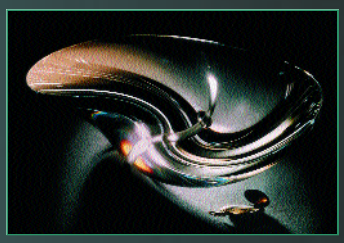
To test their ideas, the Sandia researchers built and tested a crude model that reached a speed of 34 mph in just 12 feet. To get out of the lab and onto the rails for real-world experiments, Dr. Barry Marder, the physicist heading the project, expects to raise $1 million from private investors and other organizations.

ABOUT THE TECHNOLOGY

In the Seraphim train concept, a segmented aluminum rail mounted alongside or between the rails interacts with powered coils on the train, causing acceleration. Pulsing the current through the coils as they cross the edges of the rail induces surface currents that repel them. The pulse through the coils must occur in synchronization with the relative movement over the rail segments. Sense-and-fire optical circuits, controlling the pulsing of the power modulators, provide this synchronization. The repulsion between the rail segments and magnets propels the train forward. This electromagnetic propulsion technology allows the train to achieve high speeds in relatively short distances. Reversing the phasing of the coil pulsing provides efficient braking.

[1]Lakshmanan, T.R. 1996. Statement of T.R. Lakshmanan, Ph.D., Director, Bureau of Transportation Statistics, Department of Transportation before the Subcommittee on Surface Transportation Committee on Transportation and Infrastructure, U.S. House of Representatives, Washington, DC, 28 March.

OPTICS


What role do optics play in America's economy? Some important and useful devices depend on optics to produce, control, and detect light in special ways. For millions of Americans who see life as a blur, eyeglasses and contact lenses use optics to focus light so that images can be seen with more clarity. Medical systems see inside the body through precision optical components. And electric utilities are experimenting with optical panels to develop more efficient solar energy collectors, bringing affordable power to many territories.

More sophisticated optics can improve many of these technologies. For ophthalmic equipment, a set of optical mirrors can increase the resolution of retinal cameras, helping researchers identify the biological causes of several eye diseases that can lead to blindness. For electric utilities, new optics panels can improve the efficiency of solar energy conversion, ultimately reducing the cost of electricity for consumers. Unusually shaped optics, called aspheres, offer benefits to a wide range of optical systems, from small image-projection and videography systems to large astronomical telescopes and space surveillance sensors.

Today's Market

U.S. optics companies see signs that the market is growing, so many are adding new employees to explore new opportunities. A recent survey by CorpTech of 88 small U.S. optics companies (fewer than 1,000 employees) reveals that 39 percent of them plan to expand their workforce in 1997; the average anticipated increase is 15.1 percent. The companies expect to create 361 new jobs and generate sales opportunities for their suppliers. More than one company in nine projects growth of more than 25 percent. The highest growth is expected in the Southwest and Eastern Lakes regions, with average increases of 26.6 and 14.8 percent, respectively.[1]

Tomorrow's Opportunity

BMDO has funded the development of precision optics for imaging systems and high-powered lasers that can track and destroy ballistic missiles. Some of the most notable achievements of BMDO technology developers include reducing the cost of optics manufacturing and producing smaller, more sophisticated optical components. These developers, in turn, have found new markets for their optical technologies in such industries as astronomy, holography, and spectrography. The following section highlights six technologies and the companies that are commercializing them.

[1]CorpTech. 1997. Technology spotlight in future employment trends: Photonics-optics and related equipment report. February. World Wide Web at http://www.corptech.com/emptrends/ppho-op.htm.

Can You Imagine . . .

. . . full-color display holograms that add flair to promotional applications.

HOLOGRAPHIC TECHNOLOGY BRIGHTENS A TOWN'S FUTURE

GEARING UP FOR MASS PRODUCTION OF FULL-COLOR DISPLAY HOLOGRAMS, HOLOS OFFERS HOPE FOR A TOWN'S REVITALIZATION.

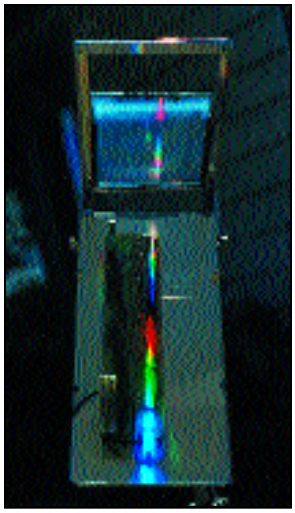
When a producer of medical instruments in Fitzwilliam, New Hampshire, shut its doors in 1994, more than 300 high-tech workers lost their jobs and the entire town felt the repercussions. Then a new manufacturer of holograms, the HOLOS Corporation, set up shop, offering new hope for the town's revitalization. Commercializing BMDO-funded work conducted at Northeast Photosciences (Hollis, NH), HOLOS built on holographic photovoltaics work originally developed to produce solar electricity in space. This work led to HOLOS' production of full-color display holograms.

Often associated with images on credit cards and packaging, holograms represent a growing market. *Holography News*, an international business newsletter of the industry, estimates this market at $200 million in 1995 for embossing alone.[1] However, holography applications extend beyond advertising, packaging, and artistic use into the areas of energy production and conservation. HOLOS currently sells customized full-color displays for promotional applications and expects mass production of full-color displays to begin in mid-1997. The company expects to create at least 60 high-technology jobs in Fitzwilliam within one year of beginning mass production; that number should double as production shifts into high gear.

In some of its more novel applications for its facilities, HOLOS plans to produce holographic films for daylighting. These films will bend sunlight into darkened rooms, allowing building engineers to track and control the amount of sunlight that enters offices. Many expect holographic-coated windows to reduce the need for lighting and air conditioning enough to pay their cost to the consumer in less than a year. A holographic awning, another product in the planning stage, will use treated glass to refract sunlight, brightening the area under it.

HOLOS also plans to produce holographic photovoltaics for terrestrial uses. The holographic device originally developed at Northeast Photosciences greatly improves the efficiency of solar energy conversion, with net conversion efficiencies of up to 30 percent. Arizona Public Service has agreed to host a massive hologram test site for utility-scale power generation. A cost analysis of this technology shows that if one includes environmental cleanup costs with the initial cost of nuclear and fossil fuels, holographic photovoltaic costs are comparable. Holograms could allow solar cells to produce electricity for just five to six cents per kilowatt-hour.

HOLOS has had discussions with a venture capital investor interested in improving the performance of solar cells. The Naval Air Warfare Center at China Lake, California, is interested in using the hologram in SELENE, a program to beam power to a satellite solar power system using a free-electron laser.



■ HOLOS' spectrally sensitive photovoltaic technology, pictured above, greatly improves the efficiency of solar energy conversion.

ABOUT THE TECHNOLOGY

HOLOS' single-element hologram spectrally separates light and focuses it perpendicular to the hologram in a thin concentrated line. Spectrally separating the light, the hologram lets two or more different solar cells absorb only those wavelengths each cell most efficiently converts to electrical power. Only light of high visibility (active radiation) is diffracted to the solar cell, while the undesired infrared radiation totally bypasses the cells, thereby reducing cooling requirements. In addition, the technology's side-by-side design (or side focus) replaces the difficult-to-cool stacked design and improves solar cell efficiency, eliminating shadow effects.

[1]1995: The year holo packaging took off. 1995. *Holography News*. December/January. World Wide Web at http://www.hmt.com/holography/hnews/decjan.htm.

THUMB-SIZED OPTICAL SPECTROMETER COULD BE A HANDY GADGET

Can You Imagine . . .

. . . a micro-optical spectrometer that will allow fiber-optics telecommunications systems to transmit higher data rates efficiently and affordably.

Successful implementation of high-speed fiber-optic data highways depends on the development of state-of-the-art optical devices at reasonable cost. Wavelength division multiplexing (WDM) systems, for example, can transmit multiple wavelength data channels on a single optical fiber. However, WDM systems require expensive technology to sort these wavelengths, spaced as close as 1.6 nanometers apart, for routing purposes.

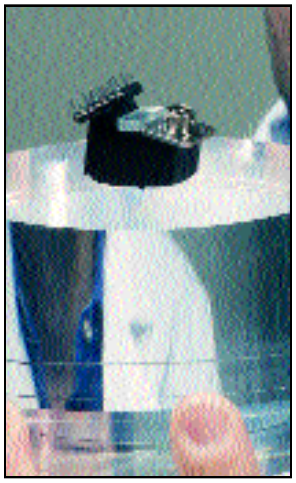
Oak Ridge National Laboratory (ORNL; Oak Ridge, TN) developed a thumb-sized optical spectrometer that offers an affordable solution for WDM and provides optical solutions for many other industries as well. The low-cost microspectrometer can sort light according to wavelengths, allowing fiber-optic telecommunications systems to route multiple data streams easily and efficiently. In a different configuration, the device can detect the presence of a variety of chemicals. These two capabilities open the door to many other applications, such as industrial process control, noninvasive blood chemistry analysis, and environmental and aircraft corrosion monitoring.

The microspectrometer is 6 cm^3 compared with today's television-sized laboratory spectrometers, which can be 20,000 cm^3. In addition, users can tune the rugged device for specific sensing applications. For example, when tuned as a gasoline octane analyzer, it could help alert motorists if any contaminated fuel enters the gas tank. Since it is fully aligned during fabrication (unlike conventional spectrometers), ORNL's device does not require periodic re-alignment. A novel fabrication technique of the microspectrometer lowers its cost. This technique uses specialized diamond-turning equipment originally developed for BMDO through ORNL's Manufacturing Operations Development and Integration Laboratory.

Sensiv, Inc., a manufacturer of infrared optical transmitter probes and remote process monitoring sensors, is the first company to receive a license for the microspectrometer. The company plans to use this technology in a second-generation product for monitoring chemical compositions during materials and pharmaceuticals manufacturing. Company officials project first-generation product availability in early 1997, and expect the microspectrometer's low cost to make the monitoring system more cost-competitive than other systems.

Lockheed Martin, ORNL's operator, now offers nonexclusive licenses in the near-infrared wavelength range of 0.7 to 5.0 microns. It may grant an exclusive license for a specialized application other than general process control and analysis.

SENSIV HAS ACQUIRED THE FIRST LICENSE FOR ORNL'S MICROSPECTROMETER.



■ The 6 cm^3 microspectrometer, pictured above, is much smaller than today's television-sized laboratory spectrometers, which can be 20,000 cm^3.

ABOUT THE TECHNOLOGY

The microspectrometer's design is a modified Czerny-Turner configuration that contains five precision surfaces encapsulated in a single structure. At the entrance surface, the optical fiber collects light and directs it to the collimating surface. The collimating surface redirects the light toward the grating surface. The grating surface disperses the incident light toward the focusing surface, which intercepts the diverging cone of light and focuses it onto the image surface. A detection array attached to the image surface interprets the light wavelengths.

Can You Imagine . . .

. . . a deformable mirror that can help astronomers obtain Hubble Space Telescope–quality imaging with a ground-based telescope.

ADAPTIVE OPTICS BRING SHARPER IMAGES TO ASTRONOMY AND MEDICINE

XINETICS' TECHNOLOGY WON A *PHOTONICS SPECTRA* CIRCLE OF EXCELLENCE AWARD AS ONE OF THE 25 MOST INNOVATIVE PRODUCTS IN 1995.

The atmosphere's turbulent mix of hot and cold air distorts starlight, making it difficult for astronomers to see faint stars through telescopes on earth. Finding a way to compensate for turbulence effects has been a top priority for many in the astronomical community.

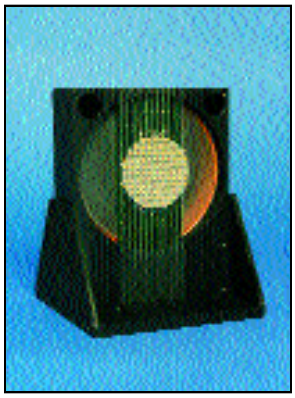
Xinetics, Inc. (Littleton, MA), developed adaptive optics (AO) technology that can help ground-based telescopes probe the mysteries of the universe with 20/20 vision. This technology is based on a deformable mirror system that, with additional AO components, performs real-time compensation for distortions in the optical path. It achieves this compensation through a series of actuators that deform the mirror into different shapes. In 1995, Xinetics' technology won a *Photonics Spectra* Circle of Excellence Award as one of the 25 most innovative products of the year.

AO technology is particularly attractive to astronomers trying to obtain Hubble Space Telescope–quality images with a ground-based telescope. For example, Xinetics' 37-actuator deformable mirror maintained its optical figure (flatness) at 0°C on the mountaintop site of the Keck Observatory in Hawaii. A 349-actuator mirror is also in development for Keck. Under a Hughes Danbury Optical Systems subcontract, Xinetics has built a 941-actuator mirror for the U.S. Air Force's Starfire Optical Range, and is building a similar mirror for the Advanced Electro-Optical System observatory, also located on Mount Haleakula, Hawaii.

In addition to astronomical telescopes, Xinetics uses its AO technology to enhance the image quality of medical and photonics equipment. For example, the company teamed with researchers at the University of Rochester to improve the resolution of a retinal camera. The camera, which analyzes laser light reflected out of the eye, could help the researchers better understand the biological causes of macular degeneration and retinitis pigmentosa, two common eye diseases that can lead to blindness. Researchers integrated a Xinetics' mirror into the AO system, which corrects light distortions coming from the eye.

In another collaboration, Xinetics is developing a distortion-control device for laser film recorders to improve high accuracy scanning, clearing up aberrations from thermal effects. The company expects this teaming effort to produce filmless x-ray technology for medical uses. Working with a leading producer of industrial bar-code scanners, Xinetics is also building an optical corrector that allows scanners to read any size bar code on both small and large packages.

BMDO's ground-based laser program required advanced optics to view space objects clearly and funded much of Xinetics' AO technology to meet this need. Recently, Xinetics has been supported by two new BMDO SBIR Phase I contracts: one for developing a monolithic multilayer actuator module, and the other for developing an adaptive pumping technology for laser mirrors.



■ Xinetics' deformable mirror, pictured above, performs real-time compensation for distortions in the optical path.

ABOUT THE TECHNOLOGY

Key elements of Xinetics' AO technology—piezoelectric or electrostrictive actuators made with lead magnesium niobate (PMN) crystals—expand and contract during application of an electric field, pushing and pulling the mirror into different shapes. Historically used as the preferred piezoelectric material, lead zirconate titanate (PZT) exhibits large hysteresis (cyclical energy lost because the process is not totally reversible), creep, and aging effects. PMN, originally developed at Pennsylvania State University in the late 1970s, overcomes the deficiencies of PZT, making it attractive for adaptive mirrors because of its high stiffness, negligible hysteresis, and excellent stability.

SPACE OPTICS FIND DOWN-TO-EARTH APPLICATIONS

Can You Imagine . . .

. . . automated techniques that reduce the manufacturing cost of precision aspheric optics.

The famous repair of the Hubble Space Telescope illustrates the utility of precision optical components. The National Aeronautics and Space Administration built the telescope, designed to reveal the outer reaches of the universe, at a cost of $1.5 billion and launched it in 1991. In orbit, however, the telescope's flawed primary optics greatly impaired its vision. Correcting Hubble's optics required fabricating and installing several nonspherical optical components called aspheres. With these components, Hubble's enormous telescopic power achieved its designed capacity.

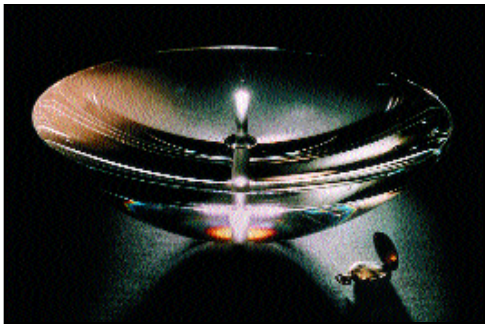
Other fields also demand precision aspheres. The asphere, whose surface can be tuned to a specific application, opens up many advantages to the optical designer, among them reduced weight and size and improved light throughput. However, the aspheres' high cost and the difficulty of making them have limited their widespread use in commercial applications. With the help of BMDO funding, Tinsley Laboratories, Inc. (Richmond, CA), developed sophisticated automated manufacturing techniques to make aspheres more efficiently.

Grinding and polishing tools and the accuracy of measurement tools previously limited the fabrication and testing of aspheres. Tinsley's techniques combine high-speed equipment with computerized control to automate these processes, saving one-third of the time needed to build and test aspheres and making new applications economically feasible. Applications for Tinsley aspheres range from tiny lenses for image projection and videography to large optics for astronomy and space surveillance sensors.

Tinsley expects its collaboration with Lawrence Livermore National Laboratory (Livermore, CA) to result in new ultraprecision aspherical optics for microlithographic and laser fusion applications. The team will be developing new technology for the precision optics required for the next generation of "steppers," machines used to manufacture computer chips. In another project, Tinsley is developing aspheric focus lenses for the laboratory's experiments in inertial confinement fusion.

TINSLEY HAS INTRODUCED A WIDE-ANGLE ASPHERE AS A COMPACT, LIGHTWEIGHT ACCESSORY TO VIDEO-CAMERA LENSES.

Through its recent acquisition of Century Precision, Tinsley supplies advanced optical products, including aspheres, for cinematography, the professional video market, and gyrostabilized video cameras for television news and sports coverage. The company has already introduced a wide-angle adaptor consisting of a single-element, two-sided asphere as an accessory to video-camera lenses. The asphere provides a wide-angle image without adding to the distortion of the camera, and videographers appreciate its compact, lightweight design.



■ This oddly shaped lens was designed to concentrate light for a laser-fusion project.

ABOUT THE TECHNOLOGY

Developed in the BMDO-sponsored Aspheric Surfacing Technology (AST) program, Tinsley's techniques include computer-controlled optical surfacing, high-speed profilometry, and phase-measuring interferometry. BMDO's plan to develop a fleet of missile-tracking satellites required precision optical components for sensor-based surveillance systems.

The computer-generated hologram (CGH) risk-reduction experiment provided a key to the AST program. In the past, combinations of spherical and cylindrical optics canceled out the aberrations normally produced by the aspheric optic. CGH technology, long viewed as an attractive alternative to multiple optics, proved difficult to implement in the manufacture of complex aspherics. However, Tinsley's AST-funded CGH successfully demonstrated the feasibility of using a CGH as a null corrector to test aspheric optics for defects.

Can You Imagine . . .

. . . a tracking system that can tell in what direction and at what depth the eye is focusing.

3-D EYE TRACKING TO AID VIRTUAL ENVIRONMENTS TECHNOLOGY

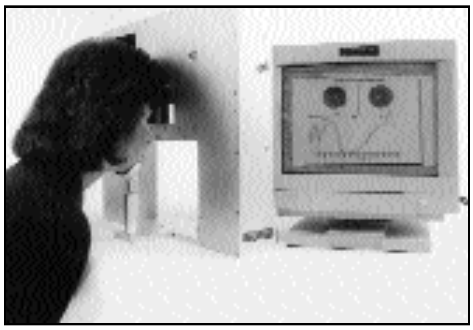
Projecting images where the user's eyes look, and not just where the head points, creates a more realistic virtual environment for flight simulators, virtual reality (VR) displays, and helmet-mounted displays. This function requires new technology to track the eyes' movements and focusing distances in real time. The new ocular information would enable computers to precisely locate where the user looks. It also would allow the computers to project low-resolution images in areas where the user's eyes are not focused, saving valuable computer time.

Applied Modern Technologies Corporation (AMT; Huntington Beach, CA) developed a real-time device that tracks critical eye movements and measures important physical characteristics of the eye. The next generation of VR displays and telemedicine systems could incorporate this device, which is called OVAS® (short for ocular vergence and accommodation sensor). OVAS is derived from BMDO-funded research and development in adaptive optics.

AMT MARKETS A VERSION OF OVAS® SUITABLE FOR USE IN AN OFFICE OR LABORATORY.

AMT's technology could significantly improve VR displays. Feeding viewer sight information to image generators, OVAS could reduce the cost of VR displays, since computer resources will not be spent generating images in areas outside the viewer's focus. Because it can help image generators to precisely position the virtual scene before the viewer's eyes, OVAS could also increase the sophistication of VR displays.

AMT markets a version of OVAS for VR suitable for use in an office or laboratory. Currently housed in a box that fits on a tabletop, OVAS weighs approximately 10 pounds. It could be miniaturized to 20 grams per eye, with a size approximately 1 x 6 inches for helmet-mounted displays or goggle applications. Because OVAS takes readings from up to four feet away from the subject, AMT envisions application in VR theaters, rides, or games.



■ AMT's OVAS® projects near-infrared light on the retinas to tell where the eyes are focused.

As part of a telemedicine system, OVAS could help doctors diagnose ophthalmic conditions in patients located miles away. AMT plans to build a telemedicine system that incorporates OVAS technology under a proposal to the U.S. Army Medical Research and Material Command. Other research participants include Multimedia Medical Systems, the University of Washington, and the University of Southern California's School of Ophthalmology. In addition, AMT has obtained a two-year grant from the American Health Foundation to apply OVAS in the diagnosis of Alzheimer's disease. Other applications may include ophthalmic research and corneal surgery. AMT will soon seek FDA approval for OVAS.

ABOUT THE TECHNOLOGY

OVAS measures the ocular foci and vergence—or inward pointing of the eyes—faster than the eyes can respond. It also measures pupil size in real time. Using two low-power, near-infrared lasers operating at a wavelength of 840 nanometers, OVAS bounces light off the retina of each eye and through a set of optics. The spectral reflection provides wavefronts of very short spatial coherence length. A wavefront-sensing technique originally developed for BMDO-funded adaptive optics research characterizes the wavefronts. A desktop computer processes this information to extract the refractive power of the ocular system from the wavefronts. OVAS currently operates at data rates between 0.5 and 10 Hertz.

LASER BEACON SHARPENS IMAGES OF EARTH-BOUND ASTRONOMY

Can You Imagine . . .

. . . a laser guide that helps astronomers see the universe with greater clarity from retrofitted terrestrial telescopes.

The science of adaptive optics (AO) is at least as old as the speculations of Sir Isaac Newton on the nature of light scatter. He once observed that good astronomical viewing required a "serene and quiet Air," and for centuries stargazers sought high ground to escape the influence of the earth's atmosphere. Some of the world's most powerful telescopes were built on mountaintops to get a clearer look at the universe and the Hubble Space Telescope represents the latest extension of this quest for clear vision.

In recent years, as defense technology yielded its secrets to the astronomy community at large, the undulations of the air seem more manageable. AO, originally conceived to get a clear view of missile threats and spaceborne weaponry, now provides astronomers with a conjurer's bag of tricks. Shape-changing mirrors, fast digital processors, and powerful lasers help to gather and focus errant light waves. Once indistinct, or even hidden, stars and galaxies will soon be seen with greater clarity from retrofitted terrestrial telescopes.

Lawrence Livermore National Laboratory (LLNL; Livermore, CA) testfired a new sodium laser guide star at Mount Hamilton's Lick Observatory. The guide star is part of an AO system that enables astronomers to sharpen ground-based celestial images to resolutions approaching the quality of Hubble. The LLNL project aims to retrofit some of the world's largest telescopes, including the Keck II telescope on Mauna Kea, Hawaii, with new eyes to see the universe. Its sister, Keck I, has already made significant discoveries about the cosmos. Many expect Keck II to outperform Keck I once it has the high-technology equivalent of corrective lenses.

The U.S. Department of Energy at LLNL originally sponsored the Atomic Vapor Laser Isotope Separation program, whose technology led to the evolution of the high-powered laser. However, BMDO and the U.S. Air Force's pioneering AO research marks the AO system surrounding the laser. Dr. Claire Max, principal investigator, worked on the original concept of laser guide stars in a BMDO-supported AO project in the early 1980s.

A number of AO experts contributed to LLNL's technology development. These experts came from companies such as Xinetics, Inc., Itek, Adaptive Optics Associates, and MIT's Lincoln Laboratory.

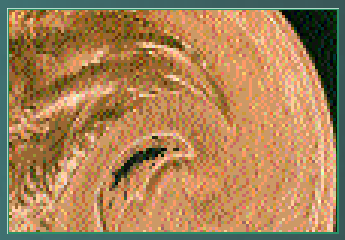
A NUMBER OF ADAPTIVE OPTICS EXPERTS CONTRIBUTED TO LLNL'S TECHNOLOGY DEVELOPMENT.

■ A laser guide star is beamed out of the open dome of Lick Observatory. It sharpens ground-based celestial images.

ABOUT THE TECHNOLOGY

The laser guide beams up to a focal point 95 kilometers above the earth. This soldium-rich region of the upper atmosphere fluoresces when the laser beam illuminates it. Knowing the properties of the exciting laser and of the returning sodium light, researchers can map the atmospheric distortions in the signal and compensate for those distortions with AO elements.

SENSORS AND RELATED TECHNOLOGY



Sensors are becoming essential for today's commercial products, which must have increasingly sophisticated capabilities. Automobiles need crash sensors to detect a car's deceleration and deploy the air bag long before the driver and passenger move toward the dashboard. Videocameras rely on motion sensors to help reduce jitter and stabilize picturetaking. And in security cameras, infrared sensors allow the detection of heat patterns given off by the human body in nighttime conditions. Advanced sensor technology has allowed U.S. companies to develop new commercial products that can make a significant contribution to our Nation's economy.

Today's Market

The 1993 U.S. sensor market reached $4 billion, and it is expected to grow significantly by the year 2000. The worldwide sensor market was $7 billion in 1993 and, like the U.S. sensor market, will grow substantially by the year 2000, possibly reaching $12.7 billion. One of the largest segments of the worldwide sensor market is passenger car sensors, whose share has grown from $2.63 billion in 1991 to $4.7 billion in 1996. In 1997, 47 million sensors are expected to be installed worldwide, with a large portion in the United States.[1]

Tomorrow's Opportunity

BMDO has funded some of the most innovative sensor research and development for its ballistic missile defense systems. As one of the first programs to be implemented by BMDO, sensor activities have focused on improving sensor materials and developing innovative approaches to track multiple targets with multiple sensors in a noisy environment. Developers, in turn, have converted their BMDO sensor products to such commercial uses as astronomic, automotive, and environmental applications. The following section describes a few examples of the commercialization activities of BMDO-funded companies.

---

[1]All marketing figures cited from the staff of *Sensors*.

Can You Imagine . . .

. . . a low-cost, digital accelerometer that improves the performance of triggering devices for automobile air bags.

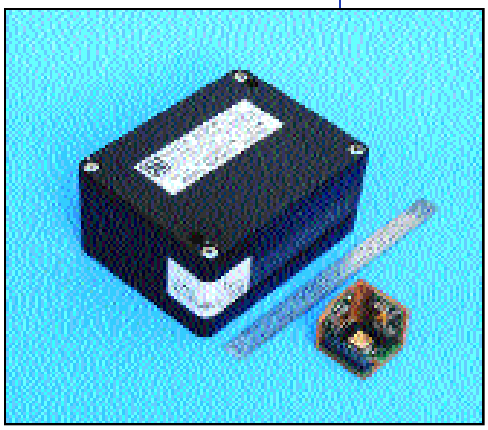
ACCELEROMETERS FIND A HOME IN AUTO AIR BAGS

CHRYSLER USES THESE ACCELEROMETERS FOR AIR BAG TRIGGERS IN FIVE CAR MODELS.

Although the seat belt is the first line of defense in a car accident, air bag systems offer additional protection during frontal impacts of sufficient force. As an integral part of car safety, air bags continually undergo improvements to provide state-of-the-art protection for drivers and passengers.

Until about two years ago, "ball-and-tube" devices triggered most air bags. A collision jolted a ball that traveled down a tube to activate an electrical signal, triggering the air bag. However, a light-impact collision sometimes caused the device's mechanics to inflate unnecessarily or prevented the air bag from working later in a high-impact collision.

A low-cost digital accelerometer from Silicon Designs, Inc. (Issaquah, WA), overcomes these problems. This miniature accelerometer forms the basis of a crash sensor that is superior to the mechanical devices found in previous air bag designs. It rejects certain patterns of vibration, reducing the chance of unnecessary inflation or system malfunction. Silicon Designs has signed a licensing agreement with TRW, Inc., which sells the accelerometers to a large percentage of the automotive industry. Today, Chrysler uses these accelerometers in five car models.



■ Silicon Designs' data acquisition system, pictured above, uses several miniature accelerometers, and has been used in automotive suspension testing.

The accelerometer's other uses include motion detection, active suspension, and aircraft flight control. For example, some racing cars use it to monitor acceleration and cornering, and General Motors Corporation used it in an automotive suspension monitoring system at its proving ground. It may also prove useful in aircraft flight control, because an autopilot system needs an accelerometer to sense changes in the direction (right and left movement) and altitude (up and down movement) of the aircraft.

The radiation-hardened accelerometer was developed with BMDO funding for research in kinetic energy vehicles. Because of its ability to measure changes in velocity, it is well suited to navigate and guide these vehicles, as well as act as the fuzing. In addition, the accelerometer is being put to work in the safe-and-aim device for the BMDO-funded PAC-3, an extension of the Patriot missile family. It costs half as much as current designs for contact fuzes used in the high-speed missiles.

ABOUT THE TECHNOLOGY

The digital accelerometer consists of two chips assembled in a single integrated circuit package: a sensory chip and an integrated electronics chip. The sensory chip contains two micromachined, capacitive sense elements that change their capacitance in response to acceleration. The integrated electronics chip measures the change in capacitance and converts it to a digital pulse output stream. Overall, the accelerometer is low-power (1.0 milliamps at five volts direct current) and operates over a wide temperature range (–55 to +125˚C). It has been designed for high-volume production at low cost.

INFRARED CAMERA SURVEYS FIRE SCENE

Can You Imagine . . .

. . . a highly sensitive, hand-held camera that could help firefighters pinpoint hot spots after forest fires.

Even after a forest fire subsides, firefighters remain alert for hot spots, areas where wood still smolders. These spots can ignite almost instantly if a gust of wind fans them, even slightly. Because they burn with little smoke and no flame, hot spots are difficult to locate.

The Jet Propulsion Laboratory (JPL; Pasadena, CA), in partnership with Amber, developed a highly sensitive, handheld camera that could help firefighters pinpoint hot spots after forest fires. The camera features quantum-well infrared photodetectors (QWIPs) that cover an essential long-wavelength portion of the infrared spectrum. This capability allows the camera to see through smoke and detect lingering hot spots that appear innocuous to the eye. It works effectively in both daytime and nighttime conditions.

Built on gallium arsenide (GaAs) substrates, QWIPs are tiny structures that are extremely sensitive to heat radiation. GaAs-based QWIPs are easier to manufacture than conventional mercury long-wavelength infrared detectors, which can have low yields and high costs. The QWIP cameras' cost should drop below that of competing infrared cameras as the technology matures.

In its debut as a fire-observing device, JPL's camera helped a news crew from KCAL-TV in Los Angeles cover the dramatic Malibu fires in October 1996. The camera hopped a flight on the station's news helicopter, allowing the crew and television audience to get a unique perspective on the fires. It enabled the station to transmit live images of the hot spots by detecting their infrared heat patterns.

JPL'S CAMERA HELPED A LOS ANGELES TELEVISION NEWS CREW GET A UNIQUE PERSPECTIVE ON FIRES THAT RACED THROUGH MALIBU, CALIFORNIA.

Other potential applications of the technology range from the prosaic to the provocative. In the medical arena, by sensing a change in the heat pattern of the patient's blood, the camera could enable doctors to detect tumors close to a patient's skin. By providing a visual image of airport runways in bad weather conditions, it could help pilots to make more precise landings. Pollution monitoring, weather detection, law enforcement, and search-and-rescue operations may also benefit from JPL's technology.

■ Pictured above is the first portable QWIP camera, which uses a 256 x 256 focal plane array tuned to detect infrared radiation in the 8- to 9-micron wavelength range.

NASA- and BMDO-sponsored programs funded JPL's QWIP research. NASA may use the technology for observation satellites, while BMDO will use it to study the phenomenology of missile plumes. In a recent proposal to BMDO, Amber has proposed to build and sell 15 QWIP-based infrared cameras to explore potential research opportunities. In addition, a QWIP-based camera is being considered for use on a second Clementine satellite mission.

ABOUT THE TECHNOLOGY

A quantum well is a microscopic "trap" for an electron inside a transparent solid medium. When exposed to radiation of the appropriate wavelength, the electron can be liberated, producing an electric current. Many quantum wells in a pixel can be used to detect infrared light with a total current proportional to the amount of light hitting the pixel.

The QWIP camera uses a 256 x 256 focal plane array tuned to detect infrared radiation in the 8- to 9-micron wavelength range. It contains a Stirling cooler, a closed-cycle refrigerator about the size of a fist. The small motor circulates a gas to cool the array from room temperature to very low temperatures, about –343˚F, in 10 minutes. The camera weighs just 10 pounds, and it measures about 4.5 inches wide, 10.5 inches deep, and 7 inches high. The camera's current prototype plugs into a 110-volt wall socket for power, although battery power can make it portable.

Can You Imagine . . .

. . . a calibration-free thermometer that may help fossil-fuel power plants protect boiler tubes and other costly equipment from overheating.

NEW SENSOR TAKES THE HEAT IN UTILITY APPLICATIONS

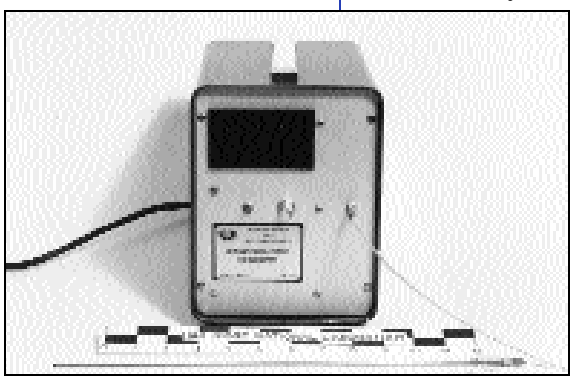
THE COMMERCIALIZATION OF THE JOHNSON NOISE THERMOMETER IS CURRENTLY IN NEGOTIATIONS.

Sensors are perhaps some of the oldest equipment in today's fossil-fuel power plants. As a result, they do not accurately provide the data required for either efficient plant operation or early detection of equipment failure. In power plant boiler tubes, for example, the reliability of resistance temperature detectors (RTDs) decreases when steam temperatures rise above 500˚C. At these temperatures, boiler tubes may explode, requiring costly repairs and plant downtime.

To prevent boiler tubes from overheating, plant personnel need a better way to verify RTD temperature readings. In cooperation with the Electric Power Research Institute (EPRI; Palo Alto, CA), researchers at Oak Ridge National Laboratory (ORNL; Oak Ridge, TN) developed a simple device called the Johnson Noise Thermometer (JNT). Originally developed to monitor coolant temperatures up to 1,100˚C, the JNT was intended for use on a space-based nuclear reactor jointly funded by BMDO, NASA, and the U.S. Department of Energy.

The JNT can measure temperatures up to 1,100˚C over long periods with an accuracy of about 1 percent. Because the JNT can maintain this level of accuracy indefinitely, it eliminates the need for expensive recalibration or replacement of conventional thermometers. Other thermometers, susceptible to drift, provide less accurate temperature measurements at high temperatures.

The JNT's accuracy over long periods at high temperatures makes it attractive for verifying the accuracy of RTDs in fossil-fuel and nuclear power plants. To demonstrate this technology, ORNL tested several JNT prototypes at the Tennessee Valley Authority's Kingston steam plant. In these tests, the devices successfully identified when existing RTDs drifted.



■ Pictured above is an industrial prototype of the JNT. In a demonstration at a fossil-fuel utility plant, this device monitored furnace temperature.

EPRI, which funded the tests, is negotiating the commercialization of JNT technology, but must still address shielding material and packaging requirements, among other issues. It has already found one utility to support this research and continues to look for others.

Power plants could also use the JNT to generate power more cost-effectively. Higher temperatures and pressures increase the efficiency of a plant's turbines, and the JNT can help plant personnel monitor such temperatures. Other uses for the technology may include unattended temperature recording and monitoring, as well as controlling chemical, ceramic, metallurgy, and petroleum processes.

ABOUT THE TECHNOLOGY

The JNT operates on the principle that any electrical conductor (metal, semiconductor, or resistor) produces random electrical signal oscillations because of thermal vibrations in the material structure. For alternating current signals in the 10 kHz range and higher, Johnson noise predominates as the internally generated noise component, varying proportionally with the total resistance of the circuit element and its temperature. Therefore, temperature measurement is possible as long as the resistance is known. Unlike other RTDs, however, the JNT does not require the relationship between temperature and resistance, because it works regardless of the material. It is particularly attractive for applications where long-term stability and calibration-free operation are critical.

VIBRATION SENSOR CROSSES THE BRIDGE TO STRUCTURAL APPLICATIONS

Can You Imagine . . .

. . . a vibration sensor that can help transportation authorities determine when highway bridges need maintenance.

Along with heavy traffic and bad weather conditions, infrequent maintenance takes its toll on America's highway bridges. According to the Federal Highway Administration, one-third of the Nation's bridges are structurally unsound or otherwise deficient, and the monetary backlog for repairs—from deck replacements to complete reconstruction—hovers at about $78 billion.[1]

Squeezed by decreasing Federal funds for bridge maintenance, states and localities sorely need innovative technology that lowers costs and streamlines maintenance and repair of structural problems. With BMDO funding, ERG Systems, Inc. (St. James, NY), has developed a rugged, reliable, low-cost vibration sensor that may advance the technology for monitoring the safety of bridges, a time-consuming and costly job.

The sensor, a fiber-optic light-emitting diode (FO/LED), can measure the vibration of a free-standing structure or of a structure in which it is embedded. Detecting movement photoelectrically through light reflected from a curved or flat surface would allow the sensor to detect problems before severe hazards develop. Continuous monitoring using the sensor and a system to alert transportation officials to schedule preventive maintenance could reduce future repair costs. The extremely compact, lightweight FO/LED can withstand harsh environments—such as the one found on New York City's heavily traveled George Washington Bridge—better than other laser-based vibrometers.

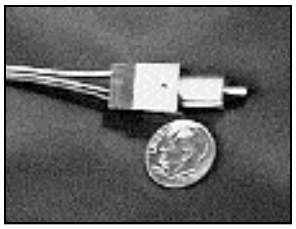
The FO/LED can monitor the structural integrity of aircraft, commercial machinery, building construction, and other types of heavy industry. It also can measure microdisplacements such as those found in engine camshafts of automobiles. In this automotive application, the device could help reduce component wear and improve fuel efficiency.

ERG Systems actually reduced the BMDO SBIR funding it originally requested, thanks to private sector capital and New York State funds. The company's cost-effective sensor, if manufactured in volume, could sell for $40 per unit. Optical Research Associates, a leading distributor for optical equipment and accessories, now provides marketing and sales support for the FO/LED.

OPTICAL RESEARCH ASSOCIATES, A LEADING DISTRIBUTOR FOR OPTICAL EQUIPMENT AND ACCESSORIES, PROVIDES MARKETING AND SALES SUPPORT FOR THE FO/LED TECHNOLOGY.

ABOUT THE TECHNOLOGY

The FO/LED's sealed monolithic housing, with a dual fiber-optic probe, measures less than 3 cm long and less than 2 cm^2. The LED fiber-optic channel produces a constant light output that the external (vibrating) surface reflects into a photodiode input channel. The amount of light the photodiode receives depends on the relative displacement of the external surface. The device senses vibrations through oscillation of the photodiode's output signal voltage.



■ ERG's fiber-optic light-emitting diode, pictured above, can measure the vibration of a free-standing structure or of a structure in which it is embedded.

[1]American Public Works Association. Transportation is America's way of life. World Wide Web at http://www.pubworks.org/roads.html.

Can You Imagine . . .

. . . a family of low-cost, high-volume, production-rate inertial sensors for the automotive industry.

NEW SENSORS TO ENHANCE VEHICLE OPERATION

ROCKWELL AND DRAPER LABORATORY EXPECT THE MINIATURE SENSORS TO PLAY MAJOR ROLES IN AUTOMOTIVE PASSENGER SAFETY AND INTELLIGENT NAVIGATION.

Previously ancillary, but now essential, sensors are involved in nearly every aspect of vehicle operation. Today's sensors keep a close watch on exhaust gas to minimize emissions, on deceleration to deploy air bags quickly in accidents, and on wheel motion to improve the reliability of antilock braking systems. In recent years, the number of sensors per automobile has quadrupled: In 1980, automobiles incorporated 10 to 30 sensors; in 1990, they contained 50 to 100 sensors.[1]

Car makers need new sensor technologies for future vehicle designs. Inertial sensors, for example, play major roles in passenger safety, vehicle dynamic control, and intelligent navigation systems. However, their cost—even when produced in large batches—limits their widespread use in the automotive industry.

Rockwell International (Anaheim, CA) joined forces with researchers at The Charles Stark Draper Laboratory, Inc. (Cambridge, MA), to develop a family of low-cost, high-volume, production-rate inertial sensors for the automotive industry. These sensors will owe much of their existence to Draper Laboratory's work for BMDO, which involved building miniature inertial sensor units to guide ballistic missile interceptors.

Inertial sensors measure rotation and linear acceleration and, in large systems, help guide moving objects or detect unwanted motion. Rockwell and Draper Laboratory see many uses for smaller, low-cost versions of these sensors in the automotive industry. A lateral skid detector, for example, requires sensing uncontrolled sideways movement to trigger a system to re-establish control. Such a device does not exist today, simply because no low-cost instrument accurately measures the kind of angular rate triggered by a skidding or sliding car.

The Silicon Micromachined Angular Rate Sensor, the first product being developed, provides single-axis angular rate data such as yaw, pitch, and roll. It can be used in sensing dynamic vehicle motion to help make antilock brakes safer, increase steering responsiveness, and improve driving comfort. The Rockwell/Draper Laboratory team plans to develop several other products, including gyroscopes and accelerometers for four-wheel steering, automatic braking, skid detection, and collision avoidance. Ultimately, the companies expect to develop a product that provides intelligent control, diagnostic, and navigation functions in a single package.

■ The Silicon Micromachined Angular Rate Sensor, pictured above, provides single-axis angular rate data, such as yaw, pitch, and roll.

ABOUT THE TECHNOLOGY

Rockwell and Draper Laboratory are developing low-cost, miniaturized inertial systems that contain accelerometers, gyroscopes, and information processors in dedicated units. These systems will measure 2 x 2 x 0.05 cm, require less than one milliwatt of power, and be accurate up to 100 degrees per hour. Further development could lead to devices with accuracies as high as 10 degrees per hour, while still keeping costs under $100 per unit. In general, inertial systems tend to drift. For inertial sensing applications, lower drift rates increase unit precision.

Draper will fabricate the sensors using an innovative micromachining process that employs a controlled isotropic chemical etch of silicon to form up to 10,000 devices on a single silicon wafer. This mass production keeps the device portion of the inertial sensor's total cost minimal.

[1]Abachi, Raida. 1996. An overview of automotive sensors. *Sensors*. April, 82–85.

BMDO-FUNDED ALGORITHM ENHANCES ENVIRONMENTAL FORECASTS

Can You Imagine . . .

. . . an algorithm that simplifies data from computers and sensors so the paths of groundwater contaminants can be predicted.

Predicting environmental contamination is important today because groundwater contaminants can leach into the earth's aquifers and then appear in drinking water. At weapons facilities, highly toxic materials for weapons manufacturing and chlorinated hydrocarbons for equipment cleaning pose costly cleanup questions for environmental engineers: Where will contaminants end up next? To what extent is the environment at risk? The answers to such questions can help engineers determine the extent of contamination and the best strategy for effective remediation.

Coleman Research Corporation (Columbia, MD) developed a technology that can predict the paths of groundwater contaminants. The company's technology, Data Fusion Modeling (DFM), helps scientists assess the environmental impact in at-risk sites. Like modern weather-prediction techniques, DFM analyzes vast amounts of computer and sensor inputs, information that normally requires a supercomputer to process. But an algorithm developed for BMDO simplifies the data so that a Unix-based system or high-end personal computer can process them.

CRC'S TECHNOLOGY HAS ALREADY HELPED SCIENTISTS ASSESS THE ENVIRONMENTAL IMPACT IN AT-RISK SITES.

CRC successfully applied its DFM software and services to several hydrogeological projects, such as site characterization and remediation at the Hanford and Savannah River weapons facilities. At the Savannah River weapons site, the software accurately predicted the movement of tritium leaching from a hazardous materials burial ground into the groundwater.

Fossil-fuel power plants can also use aspects of this technology for nonlinear model predictive control (NMPC), a system that predicts the plant's response to control actuators. Simulation results at two of Southern California Edison's El Segundo units demonstrated many of its benefits. For example, the system changed the power output of the simulated plant about six times faster than conventional means, and it produced higher performance and better fuel efficiency. In particular, thermal efficiency improved almost 1 percent, saving the plant roughly $480,000 each year.

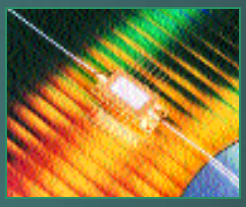
■ In addition to its environmental uses, CRC's technology can be used to control plant processes.

In addition to environmental applications, DFM can be used with medical imaging to track electrical activity in the brain. This application of the technology could lead to better treatments for patients with epilepsy. DFM also could apply to spacecraft guidance and control. CRC originally developed the algorithm for a BMDO missile defense system to help computers and sensors track targets and decoys.

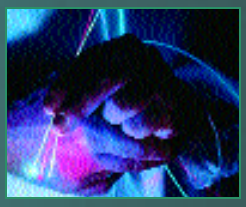
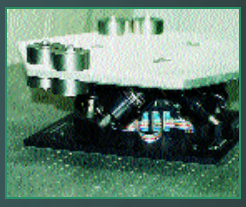
ABOUT THE TECHNOLOGY

The CRC algorithm optimizes computer and sensor resources, combining redundant data and reducing the number of calculations that a processing system must handle. Most automated prediction and control systems receive information from many sensors and compare the data from each sensor. This process eliminates faulty data that result from sensor misalignment and random signal variations; however, it produces redundant data that tie up a computer. The CRC algorithm eliminates these redundant data, thus lowering the computational demands on the predictive control system. As a result, a system that previously required supercomputer monitoring can now use a Unix-based workstation or high-end personal computer.

LISTING OF FEATURED COMPANIES
AND INDEX OF SUBJECTS





LISTING OF FEATURED COMPANIES

Would you like to learn more about any of the BMDO-funded technologies mentioned in this report? If so, contact the organization's representative by telephone, facsimile, or e-mail. The following list contains representatives at all the organizations featured in the report. This list is organized alphabetically by organization name.

■ Applied Modern Technologies Corporation (page 78)
Mr. Larry Horwitz, Founder
5500 Bolsa Avenue, Suite 155
Huntington Beach, CA 92649
Telephone: (714) 379-2870
Facsimile: (714) 379-2873
E-mail: ish-amt@primenet.com

■ Applied Sciences, Inc. (page 46)
Mr. Max Lake, President
141 West Xenia Avenue
Cedarville, OH 45314-0579
Telephone: (513) 766-2020
Facsimile: (513) 766-5886

■ Aria Microwave Systems, Inc. (page 23)
Dr. Bernard R. Cheo, President
291 South Van Brunt Street
Englewood, NJ 07631
Telephone: (201) 569-6221
Facsimile: (201) 569-5258
E-mail: amsinc@chelsea.ios.com

■ Astralux, Inc. (page 69)
Dr. Jacques Pankove, Vice President for Research and Development
2500 Central Avenue
Boulder, CO 80301-2845
Telephone: (303) 492-5470 or (303) 494-0670
Facsimile: (303) 494-7414 or (303) 492-2758

■ Baylor Research Institute (page 61)
Dr. Les Matthews, Principal Investigator
P.O. Box 710699
3812 Elm Street
Dallas, TX 75226
Telephone: (214) 820-4951
Facsimile: (214) 820-4952

■ Coleman Research Corporation (page 87)
Dr. Thomas Lightner, Vice President
9891 Broken Land Parkway, Suite 200
Columbia, MD 21046
Telephone: (301) 621-8600
Facsimile: (410) 312-5600

■ CSA Engineering, Inc. (page 68)
Dr. Eric Anderson, Principal Investigator
CSA Engineering, Inc.
2850 West Bayshore Road
Palo Alto, CA 94303-3842
Telephone: (415) 494-7351
Facsimile: (415) 494-8749
E-mail: eric@csaengr.com

■ Displaytech, Inc. (page 24)
Mr. Mark Handshey, President
2200 Central Avenue
Boulder, CO 80301
Telephone: (303) 449-8933
Facsimile: (303) 449-8934

■ Electric Power Research Institute (page 84)
Mr. Joseph M. Weiss, Marketing
3412 Hillview Avenue
Palo Alto, CA 94303
Telephone: (415) 855-2751
Facsimile: (415) 855-8759

■ ERG Systems, Inc. (page 85)
Dr. John L. Remo, Principal Investigator
Brackenwood Path
Head of the Harbor
St. James, NY 11780
Telephone: (516) 584-5540
Facsimile: (516) 584-4213

■ Essex Corporation (page 62)
Mr. Terry Turpin, Principal Investigator
9150 Guilford Road
Columbia, MD 21046-1891
Telephone: (301) 953-8765
Facsimile: (301) 953-7880

■ E-TEK Dynamics, Inc. (page 21)
Mr. Jack Brouhard, Marketing Manager
1885 Lundy Avenue
San Jose, CA 95131
Telephone: (408) 432-6300
Facsimile: (408) 432-8550

■ Gemini Computers, Inc. (page 33)
Dr. Tien F. Tao, President
P.O. Box 222417
Carmel, CA 93922
Telephone: (408) 373-8500
Facsimile: (408) 649-7563

■ Harris Semiconductor Corporation (page 66)
Mr. John Allen, Public Affairs
Power Semiconductor Division
PO Box 883 MS 53-208
Melbourne, FL 32902
Telephone: (407) 729-4928
Facsimile: (407) 729-5312

■ Hayes & Associates (page 47)
Dr. Claude Hayes, President
3737 Third Avenue, Suite 308
San Diego, CA 92103
Telephone: (619) 299-2267
Facsimile: (619) 299-3449

■ HOLOS Corporation, The (page 74)
Mr. Ronald M. Visocchi, President
Route 12 North
Fitzwilliam, NH 03447
Telephone: (603) 585-3400 x221
Facsimile: (603) 585-6936

■ HNC Software, Inc. (page 58)
Ms. Patsy Campbell, Marketing
5930 Cornerstone Court West
San Diego, CA 92121
Telephone: (619) 546-8877
Facsimile: (619) 452-6524

■ Holoplex, Inc. (page 31)
Dr. Fai Mok, Founder
600 South Lake Avenue, Suite 102
Pasadena, CA 91106
Telephone: (818) 793-9616
Facsimile: (818) 793-9615

■ Intelligent Automation, Inc. (page 32)
Dr. Leonard Haynes, Founder
2 Research Place, Suite 202
Rockville, MD 20850
Telephone: (301) 590-3155
Facsimile: (301) 590-9414
E-mail: lhaynes@i-a-i.com

■ Jet Propulsion Laboratory (page 83)
Dr. Sarath D. Gunapala, Principal Investigator
Microdevices Technology Section, MS 302-306
4800 Oak Grove Drive
Pasadena, CA 91109-8009
Telephone: (818) 354-1880
Facsimile: (818) 393-4540
E-mail: sgunapala@vaxeb.jpl.nasa.gov

■ L'Garde, Inc. (page 67)
Dr. Constantine Cassapakis, Vice President
15181 Woodlawn Avenue
Tustin, CA 92680-6487
Telephone: (714) 259-0771
Facsimile: (714) 259-7822

■ Lawrence Livermore National Laboratory (page 79)
Dr. Claire E. Max, Principal Investigator
P.O. Box 808
Livermore, CA 94550
Telephone: (510) 422-5442
Facsimile: (510) 423-0238

■ Los Alamos National Laboratory (page 42)
Mr. Jim Danniskiold, Public Affairs
MS C177
Los Alamos, NM 87545
Telephone: (505) 667-1640
Facsimile: (505) 665-5552

■ Maxdem, Inc. (page 51)
Dr. Virgil J. Lee, Manager, Product R&D
140 East Arrow Highway
San Dimas, CA 91773-3336
Telephone: (909) 394-0644
Facsimile: (909) 394-0615
E-mail: maxdem@maxdem.com

■ MicroCoating Technologies (page 39)
Mr. Jeffrey C. Moore, Chief Operating Officer
430 Tenth Street NW, Suite N-108
Atlanta, GA 30318-5769
Telephone: (404) 249-7001
Facsimile: (404) 249-1719

■ Moldyn, Inc. (page 59)
Dr. Frank P. Billingsley, President and Chief Executive Officer
c/o Photon Research Associates, Washington Division
1911 North Fort Myer Drive, Suite 408
Arlington, VA 22209
Telephone: (703) 243-6613
Facsimile: (703) 243-6619

■ NanoDynamics, Inc. (page 50)
Dr. Chia-Gee Wang, President
510 East 73rd Street
New York, NY 10021
Telephone: (212) 249-2232
Facsimile: (212) 249-4021

■ Oak Ridge National Laboratory (page 29)
Dr. Tuan Vo-Dinh, Group Leader
P.O. Box 2008, MS 6101
Oak Ridge, TN 37831
Telephone: (615) 574-6249
Facsimile: (615) 576-7651

■ Oak Ridge National Laboratory (page 75)
Mr. Slo Rajic, Principal Investigator
Bearcreek Road
Oak Ridge, TN 37831-8039
Telephone: (423) 574-9416
Facsimile: (423) 574-9407
E-mail: urv@cosmaill.ctd.ornl.gov

■ Oak Ridge National Laboratory/University of Tennessee (page 84)
Dr. Robert Shepard, Principal Investigator
Electrical and Computer Engineering Dept.
Ferris Hall
Knoxville, TN 37996-2100
Telephone: (423) 974-0694
Facsimile: (423) 974-5483

■ Physical Optics Corporation (page 25)
Mr. Rick Shie, Director of Sales and Marketing
20600 Gramercy Place, Bldg. 100
Torrance, CA 90501-1821
Telephone: (310) 320-3088
Facsimile: (310) 320-8067

■ QM Technologies, Inc. (page 36)
Mr. Gene Neau, Vice President, Technology Development
2201 San Pedro Drive NE, Bldg 3, Suite 210
Albuquerque, NM 87110
Telephone: (505) 881-4121
Facsimile: (505) 880-0727
E-mail: elneau@qminc.com

■ Research Opportunities, Inc. (page 48)
Mr. William C. Riley, Principal Investigator
2200 Amapola Court, Suite 101
Torrance, CA 90501
Telephone: (310) 533-5149
Facsimile: (310) 533-1068

■ Reveo, Inc. (page 56)
Dr. Sadeg M. Faris, Principal Investigator
8 Skyline Drive
Hawthorne, NY 10532-2151
Telephone: (914) 345-9555
Facsimile: (914) 345-9558

■ Rockwell International (page 86)
Mr. Robert Christiansen, Principal Investigator
Mail Stop 031-CA30
3370 Miraloma Avenue
Anaheim, CA 92803-3105
Telephone: (714) 762-6173
Facsimile: (714) 762-2415

■ Sagebrush Technology, Inc. (page 22)
Mr. Donald G. Carson, Vice President of Marketing and Sales
10300A Constitution Avenue NE
Albuquerque, NM 87112
Telephone: (505) 299-6623
Facsimile: (505) 298-2072

■ Sandia National Laboratories (page 41)
Dr. Richard Stulen, Principal Investigator
P.O. Box 969
7011 East Avenue
Livermore, CA 94551
Telephone: (510) 294-2070
Facsimile: (510) 294-3231
E-mail: stulen@california.sandia.gov

■ Sandia National Laboratories (page 70)
Mr. Barry M. Marder, Principal Investigator
MS-1186
Albuquerque, NM 87185
Telephone: (505) 845-7274
Facsimile: (505) 845-7890

■ Silicon Designs, Inc. (page 82)
Mr. John C. Cole, Principal Investigator
1445 NW Mall Street
Issaquah, WA 98027
Telephone: (206) 391-8329
Facsimile: (206) 391-0446

■ Silicon Mountain Design, Inc. (page 40)
Mr. David Gardner, Principal Investigator
2864 South Circle Drive #900
Colorado Springs, CO 80906
Telephone: (719) 576-4800
Facsimile: (719) 599-7775

■ Structured Materials Industries, Inc. (page 49)
Dr. Gary S. Tompa, President
120 Centennial Avenue
Piscataway, NJ 08854
Telephone: (908) 885-5909
Facsimile: (908) 885-5910
E-mail: 75031.1321@compuserve.com

■ Superex Polymer, Inc. (page 57)
Mr. Richard W. Lusignea, President
350 Second Avenue
Waltham, MA 02154
Telephone: (617) 890-3200
Facsimile: (617) 890-4084

■ Tate Integrated Systems (page 37)
Dr. Tim Shaw
11431 Cronhill Drive, Suite J
Owings Mills, MD 21117
Telephone: (410) 581-0422
Facsimile: (410) 581-5738

■ The Charles Stark Draper Laboratory, Inc. (page 86)
Mr. John Elwell, Principal Investigator
555 Technology Square
Cambridge, MA 02139
Telephone: (617) 258-3832
Facsimile: (617) 258-3777

■ Thermacore, Inc. (page 30)
Ms. Irina S. Rozin, Marketing
780 Eden Road
Lancaster, PA 17601
Telephone: (717) 569-6551
Facsimile: (717) 569-4797

■ ThermoTrex Corporation (page 60)
Dr. Peter Martin, Principal Investigator
9550 Distribution Avenue
San Diego, CA 92121
Telephone: (619) 578-5885
Facsimile: (619) 578-1419

■ Theseus Research, Inc. (page 28)
Mr. Ken Wagner, President
4601 29th Avenue South
Minneapolis, MN 55406
Telephone: (612) 699-6388
Facsimile: (612) 699-6933
E-mail: kwagner@theseus.com

■ Tinsley Laboratories, Inc. (page 77)
Mr. Bob Johnson, Marketing
3900 Lakeside Drive
Richmond, CA 94806
Telephone: (510) 222-8110
Facsimile: (510) 223-4534

■ Toranaga Technologies, Inc. (page 38)
Dr. Goran Matijasevic, Senior Scientist
2236 Rutherford Road, Suite 123
Carlsbad, CA 92008
Telephone: (619) 931-7099
Facsimile: (619) 431-6971

■ Vixel Corporation (page 20)
Mr. Stan Swirhun, Chief Technology Officer
Mr. David Lewis, Marketing
325 Interlocken Parkway
Broomfield, CO 80021
Telephone: (303) 460-0700
Facsimile: (303) 466-0290

■ Wellman Laboratories of Photomedicine (page 54)
Ms. Lynn Osborn, Executive Director
MGH Laser Center
Massachusetts General Hospital
Bartlett Hall X630
Boston, MA 02114
Telephone: (617) 726-2327
Facsimile: (617) 726-4103

■ Xinetics, Inc. (page 76)
Mr. Mark Ealey, President
410 Great Road #A6
Littleton, MA 01460
Telephone: (508) 486-0181
Facsimile: (508) 486-0281

INDEX OF SUBJECTS

D E F

G H I

J K L

M N O

P Q R

S T U

V W X Y Z

This report was written and produced by the
National Technology Transfer Center, Washington Operations
for the Ballistic Missile Defense Organization.

- Writer/Editor — Pat Hartary
- Production manager/Editor — Lisa Hylton
- Contributing writers — Leslie Aitcheson, Joan Zimmermann, Arawana Hannon, Linda Voss
- Design and layout — Renan Kiper, Lan Crickman
- Advisors — Ralph Albano, Bob Dundervill, Jeff Reynolds, Sally Rood, Tom Tucker, Jean Zettler, Duane Zieg