ColorLink, Inc.

LCOS Technology Expands Potential of Color Imaging and Display

As computer and communication devices have miniaturized, a key problem has been capturing and displaying high-quality and high-resolution color images. In 1995, ColorLink, Inc., was created to develop a tunable optical filter technology that would be compatible with a decreased display size while increasing the brightness and clarity of the image. They believed that the next generation of consumer televisions, monitors, and business projectors would be based on liquid crystal on silicon (LCOS) technology. To further its research and development efforts and to demonstrate a proof of concept for tunable filters, ColorLink needed an injection of capital. The company was unable to attract any venture capital funding, however, because its proposed research was considered too high risk and too long term. ColorLink received an Advanced Technology Program (ATP) award in 1997 and by the end of its three-year ATP project, the company had developed several components that support image capture and display applications. Over the course of the project, ColorLink shifted focus from miniature displays to the more promising application of projection displays. As a result of the technology developed during this project, ColorLink has formed partnerships with a Japanese material supplier, to decrease manufacturing costs and improve its U.S. product line, and with Thomson RCA.

COMPOSITE PERFORMANCE SCORE

(based on a four star rating)

* * * *

Research and data for Status Report 96-01-0263 were collected during October - December 2001.

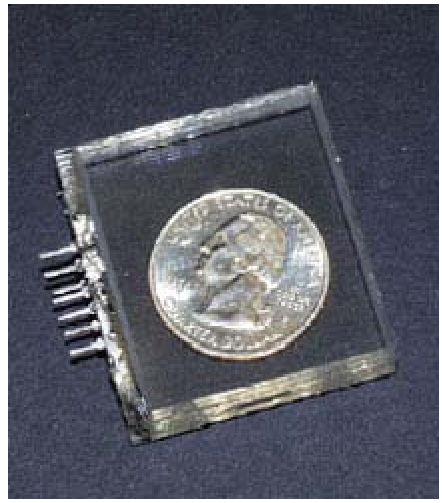
Existing Technologies Limit Evolution of Image Devices

Most digital color cameras and color displays capture or create the appearance of a color image by spatially separating the individual colors. In a typical color display, each color pixel (i.e., the basic unit of the composition of an image on a television screen, computer monitor, or similar display) is actually a combination of three monochrome pixels, each assigned a different primary color (red, green, or blue; commonly referred to as “RGB”). Although this technique has been effective for the last 30 years, it has become an inhibitor as display devices such as compact personal digital assistant (PDA) devices, web-enabled cellular phones, and compact flat-screen televisions become smaller and users demand higher resolutions.

ColorLink Proposes Color Sequential Imaging

In 1995, Dr. Kristina Johnson and Dr. Gary Sharp incorporated ColorLink with the goal of developing a tunable optical filter technology that would increase capture and projection display color quality. Previous approaches to color sequential imaging used RGB color wheels or inefficient color shutters to achieve color, but neither of these could achieve the desired size and resolution. The problem with color shutter technology at that time was its use of highly absorptive, poor-quality dye color polarizers. The key distinguishing feature of the ColorLink polarizer is that the separation of primary and complementary color is achieved through a loss-less transformation using a stack of optically transparent retarder films, known as a retarder stack.

ColorLink proposed, in its ATP application to introduce a new paradigm in high-resolution display and imaging by developing the underlying technologies for a high-efficiency, solid-state, electro-optic tunable filter for color sequential imaging. In color sequential imaging, which encodes color in time and not space, the complete color image is displayed as a rapidly changing sequence of primary RGB monochrome images. A switchable color filter selects which color is displayed in each image (red, green, or blue). Since every pixel in the display contributes to every primary image, a color sequential imaging display can have at least three times the resolution of an equivalent display that uses spatial separation. ColorLink's approach would employ color sequential imaging to capture or display information with the highest color quality, resolution, and brightness.



ColorLink's color switch uses color sequential imaging to capture or display information with the highest color quality, resolution, and brightness.

ColorLink's Innovation Has Potential Economic Benefits

If ColorLink's technology proved successful, it would advance the state-of-the-art in projection display and image capture from the pixilated, slow-moving color switches to smaller high-resolution displays with increased switching times. This could dramatically improve the quality in the highly competitive miniature display market and lead to a decrease in cost to consumers. Also, ColorLink's project had the potential to significantly impact the electronic display and digital imaging markets, which, according to the Optoelectronics Industry Development Association, were predicted to exceed $20 billion by 2001.

RGB technique has become an inhibitor as display devices become smaller and users demand higher resolutions.

ColorLink Forms Partnerships and Finds Funding

ColorLink partnered with Polaroid Corporation and Kent State University's Liquid Crystal Institute to assist in the development of the color sequential imaging technology; later in the project, the company also added MicroContinuum, Inc., as a subcontractor. ColorLink had also attracted the interest of the industry's largest players.

The company's early-stage funding from "friends and family" disappeared quickly, however, and as a small company, ColorLink did not have the financial resources to support the development of the technology on its own. Moreover, the proposed research was too long term to attract the interest of venture capitalists. In 1997, ColorLink received an award of approximately $1.8 million from ATP to pursue research and development of its color sequential imaging technology. Its proposed tunable color filter was highly innovative, but needed significant improvements before it would become commercially viable. At that time, Japan and other countries dominated flat-panel display technology overseas, with the United States' world market share at less than 5 percent. The proposed technological developments could give the United States a greater share in at least part of this important and growing market.

Goals Defined for Color Sequential Imaging Project

ColorLink pursued three major technical goals in the color sequential imaging project: 1) maximizing the filter optical efficiency, 2) developing a new class of fast-switching nematic liquid crystals with switching times below one millisecond, and 3) fabricating liquid crystal devices on plastic. The purpose of the company's first objective was to produce the very brightest color-filter technology for integration into direct views and displays. At the time, there was not a high-quality method to colorize monochrome display systems. Their second objective focused on developing a new class of fast-switching nematics (relating to a liquid crystal phase in which the molecules are oriented in loose parallel lines) to optimize the duty cycle of the filter. Their third objective was important in producing a lightweight, compact tunable filter technology for application in displays for portable computing and communication devices.

ColorLink Refocuses on Projection Displays

In order to serve the growing projection display market, ColorLink began to shift its focus from developing a core technology to developing components for applications and, eventually, to system development of projection displays and digital imagery.

Over the course of the project, ColorLink realized that the most promising application stemming from the system development efforts was in projection displays, rather than digital imaging. To expand into this market, ColorLink sought a partnership to enhance its manufacturing operations. In 2000, before the ATP project ended, the company used internal resources to complete a joint venture agreement with material supplier Arisawa of Japan to form ColorLink Japan, Ltd.

To serve the growing projection display market, ColorLink began to shift its focus to system development of projection displays and digital imagery.

ColorLink believed that the next generation of consumer televisions, monitors, and business projectors would be based on liquid crystal on silicon (LCOS) technology. These displays are liquid crystal films that are sandwiched between an integrated circuit chip and a transparent window.

At the time, there were inefficiencies in the technology and widespread acceptance had been slow. One challenge with the LCOS technology involved a lack of color management, as poor color brightness and contrast were evident. ColorLink felt that it could modify its filter technology to further the development of LCOS technology and thus began a testbed program.

The goal of the program was to optimize the component technology and the color management architecture until the company was able to achieve the required performance on a system level. The feedback from the testbed produced many changes to the retarder stack designs and architecture, ultimately allowing ColorLink to identify the best use of its technology.

Subcontractors Provide Insight and Expertise

Polaroid and Kent State, the primary subcontractors, offered technical expertise, technological validation, and valuable industry insight. Polaroid was responsible for thinning and decreasing the weight of the color switch by using plastic cells. Early samples were achieved by the end of the second year of the ATP project, but Polaroid dropped out due to internal financial issues that were unrelated to this project. Although the project failed to reduce filter thickness and weight, reductions in thickness proved to be unnecessary because ColorLink focused on more viable opportunities in the projection display market instead of miniature displays.

Kent State worked primarily in liquid crystal development, in particular trying to increase the switching speed of the liquid crystal devices. One solution they developed involved adding a small amount of polymer to stabilize a particular liquid crystal state, which resulted in a faster relaxation rate. Kent State performed a number of experiments in this area, but results were not promising enough to proceed further. Kent State also assisted ColorLink in other relevant areas, including field-of-view compensation, the design of compound-element liquid crystal switches for improved speed, and the development of diagnostic hardware.

ColorLink also awarded a small subcontract to MicroContinuum, Inc., to assist in the solvent-welding process. MicroContinuum was instrumental in proving the viability of the process, identifying a class of solvents, and developing hardware for generating stacks using solvent welding.

Technical Success in Image Capture and Display

By the end of its three-year ATP project, ColorLink had developed several components that support image capture and display applications. These components have enabled the company to achieve good color quality with filter transmission exceeding 90 percent, something that was previously not possible. In addition, ColorLink produced a five-cell color switch that provides average turn-on and turn-off times of under 0.2 milliseconds, times that are significantly faster than previous color-switching technologies.

ColorLink's Target Shifts to HDTVs and Monitors

Over the course of the project, ColorLink realized that the most promising application was in projection displays, rather than digital imaging. Consumer demand for thin, large-area monitors was high, but so was the cost. For example, a 21-inch flat-panel liquid crystal display (LCD) monitor was over $3,000 and a high-definition television (HDTV) plasma display cost $10,000. However, ColorLink's revolutionary color management components enable a new lower cost class of computer monitors and digital televisions. These new monitors and digital TVs offer larger screens in a slimmer profile with resolution, color, contrast, and brightness that are superior to existing products.

LCOS microdisplay-based TVs with ColorLink technology are emerging as the best solution in this potentially exploding market. LCOS microdisplay-based systems with ColorLink technology can provide a high-quality, greater-than-24-inch screen with enhanced resolution in a 6-inch-deep monitor for about $1,000. The future in projection systems includes computer monitors and digital TVs, a multibillion-dollar market with annual growth rates in excess of 15 percent. The demand for computer monitors and projection devices that utilize LCOS is estimated at 10 million units per year by 2004.

Commercialization

ColorLink has formed partnerships to commercialize this technology. To decrease manufacturing costs and expand into new projection display markets, ColorLink sought a partnership to expand its international operations. In 2000, before the ATP project ended, the company completed a joint venture agreement with material supplier Arisawa of Japan to form ColorLink Japan, Ltd. This partnership would greatly increase ColorLink's investment in research and development as well as decreasing its manufacturing costs and improving its product line for U.S customers. ColorLink and Thomson RCA have recently entered into a partnership and plan to explore various applications for the ATP-funded technology.

ColorLink's revolutionary color management components enable a new lower cost class of computer monitors and digital televisions.

Conclusion

With ATP's funding support, ColorLink obtained the resources necessary to explore the potential of color sequential imaging. Based on its ATP project, the company was able to commercialize its LCOS technology. In the earliest stages of the technology development effort, when prototypes were unproven and the technology was untested, ColorLink parlayed the ATP-supported research into the nascent LCOS microdisplay and HDTV markets. This successful transition to a new color imaging and display technology has made ColorLink's vision a reality and has led to successful commercialization of its products.

PROJECT HIGHLIGHTS
ColorLink, Inc.

Project Title: LCOS Technology Expands Potential of Color Imaging and Display (Color Sequential Imaging)

Project: To introduce a new paradigm in high-resolution display and imaging by developing the underlying technologies for a high-efficiency, solid-state, electro-optic tunable filter for color sequential imaging.

Duration: 5/1/1997-4/30/2000
ATP Number: 96-01-0263

Funding (in thousands):

ATP Final Cost	$ 1,790	84%
Participant Final Cost	340	16%
Total	$2,130	

Accomplishments: With ATP's support, ColorLink developed an innovative technology that decreased the cost and size of projection displays, while simultaneously allowing improvements in display resolution and brightness. Utilizing its ATP-funded project as a springboard, ColorLink successfully developed and refined several technologies that are presently being commercialized in the television and monitor display industries. Highlights of the technology include:

- Development of a custom lamination technology that provides a low-cost product with little optical loss and high optical power handling
- Refinement of retarder-stack technology

ColorLink has received a number of patents associated with the technology developed during the ATP project, including the following:

- "Retarder stacks for polarizing a first color spectrum along a first axis and a second color spectrum along a second axis"
  (No. 5,953,083: filed May 8, 1997; granted September 14, 1999)
- "Retarder stack for preconditioning light for a modulator having modulation and isotropic states of polarization"
  (No. 5,929,946: filed May 9, 1997; granted July 27, 1999)
- "Color selective light modulators employing birefringent stacks"
  (No. 5,990,996: filed May 9, 1997; granted November 23, 1999)
- "Optical retarder stack pair for transforming input light into polarization states having saturated color spectra"
  (No. 5,999,240: filed May 9, 1997; granted December 7, 1999)
- "Polarization manipulating device modulator with retarder stack which preconditions light for modulation and isotropic states"
  (No. 6,049,367: filed May 9, 1997; granted April 11, 2000)
- "Optical system for producing a modulated color image"
  (No. 6,417,892: filed July 30, 1998; granted July 9, 2002)
- "Color imaging systems and methods"
  (No. 6,183,091: filed May 14, 1999; granted February 6, 2001)
- "Display architecture using electronically controlled filters"
  (No. 6,273,571: filed October 1, 1999; granted August 14, 2001)

Commercialization Status: ColorLink is continuing development of the liquid crystal tunable filter for one-, two-, and three-panel systems. Since the completion of the ATP-funded project, ColorLink has entered into a partnership with Thomson RCA.

Outlook: ColorLink has formed partnerships with Arisawa Manufacturing and Thomson RCA, has established relationships with original equipment manufacturers, and has the funding and market demand to remain a market innovation leader. ColorLink's technology developed through the ATP project has received considerable attention and has facilitated additional fundraising opportunities. Finally, ColorLink holds the rights to more than 30 patents (8 that resulted from the ATP-funded research). The funding, partnerships, intellectual property, and market opportunities bode well for the future of the technology that ColorLink developed during this ATP-funded project.

Composite Performance Score: * * * *

Number of Employees: Five employees at project start, 65 as of December 2001

Company:

ColorLink, Inc.
2425 55th Street
Suite 250
Boulder, CO 80301

Contact: Gary Leslie, CEO
Phone: (303) 545-5843

Subcontractors:

Kent State University, Liquid Crystal Institute
Polaroid Corporation
MicroContinuum, Inc.

Research and data for Status Report 96-01-0263 were collected during October - December 2001.

Digital Optics Corporation

IMOS Technology Improves Scalability and Lowers Cost

Founded in 1991, Digital Optics Corporation began as a micro-optics developer and is now a leading supplier of diffractive and micro-optical components. In the late 1990s, Digital Optics recognized that the labor-intensive integration and packaging of its components in the optoelectronic industry was driving customer costs higher and was leading manufacturers to seek inexpensive, overseas labor to produce these components. In 1998, Digital Optics identified an innovative technology that had the potential to change the telecommunications, data storage, and scanner industries in many of the ways that the integrated circuit has changed computer electronics since 1959. The technology, called integrated micro-optical systems (IMOS), uses many of the same processes of reflective manufacturing to make miniature optoelectronic systems.

Potential benefits from Digital Optics's IMOS technology were threefold: it would decrease costs, reduce component size and reduce the need for offshore labor production of the components. Digital Optics would develop an infrastructure that could easily transition to the prototyping and pilot production of IMOS; but first, the company would need sufficient resources from an investor that would assume the high risk factor. To complete the early infrastructure development of IMOS, in 1998 Digital Optics applied for and was awarded cost-shared funding from the Advanced Technology Program's (ATP) Focused Program for Photonics Manufacturing. After completion of the project in late 2000, Digital Optics successfully brought to market the IMOS technology, branded as the Photonic Chip™, and is now experiencing commercial growth despite a slowing economy and inventory gluts in the telecommunications and data communications industries. The IMOS project broke through industry barriers of size, reliability, and high-volume replication in the optical component market to open new markets of competition and development. Spillovers from these new markets will affect manufacturers and consumers alike in many of the ways that the integrated circuit has affected the microelectronics industry.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * *

Research and data for Status Report 98-02-0034 were collected during October - December 2001.

Digital Optics Identifies Need to Integrate Micro-optic Components

As the optoelectronic industry flourished during the technological boom of the late 1990s, the need to more efficiently integrate and package optical components increased. Originally operating as a micro-optics firm, Digital Optics identified the future potential of subassemblies and integrated optical components. The company refocused its research and development (R&D) activities to move ahead of the competition in the evolving optoelectronic marketplace.

Historically, discrete components were purchased and integrated into assemblies through labor-intensive processes, which were typically outsourced to developing countries where labor costs were lower than in the United States. To address this market-driven need to decrease both production cost and component size, and to curb the exportation of production, Digital Optics sought to develop the key processes and infrastructure necessary to use wafer-scale integration of these components in integrated micro-optical systems (IMOS).

IMOS Technology Lowers Fabrication Costs

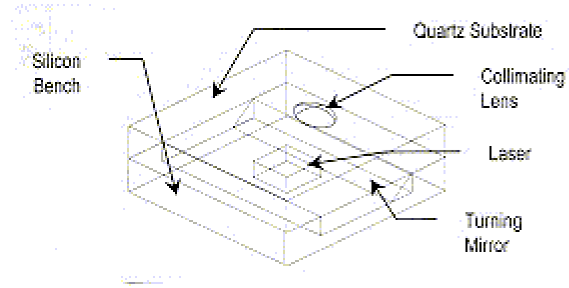
IMOS modules are compact (typically a few millimeters on a side), integrated optoelectronic systems comprising micro-optics, lasers, detectors, and interfacing electronics. IMOS technology does not consist of a single type of component. Rather, it is a new, functional paradigm in which the fabrication, integration, and packaging of micro-optics and electronics are all considered from the very beginning of the design process. Furthermore, IMOS fabrication makes use of wafer-like manufacturing techniques similar to those used in the microelectronics industry for producing integrated circuits. With IMOS, components are aligned and assembled at the wafer level, allowing the production of complex, three-dimensional optical systems on a chip. This integrated approach allows the inexpensive fabrication of miniaturized, high-performance optoelectronic modules and subsystems.

Benefits of IMOS Devices

IMOS takes many elements (e.g., micro-optics, lasers, detectors, and interfacing electronics) and creates an optical system that is a single, discrete unit. These low-cost devices have broad applications, including incorporation into bar code scanners, telecommunications equipment, miniature sensors for the environment, medical sensors, and precision encoders. The IMOS technology has the potential to enter and dominate markets such as compact disk/digital versatile disc (CD/DVD) systems, magneto-optical disk drives, and optical tracking for floppy disks.

Strong Parallels Exist Between IMOS and Integrated Circuits

There are many parallels between the introduction of the integrated circuit in 1959 and the IMOS technology that Digital Optics sought to develop. Whereas integrated circuit technology made it possible to "shrink" large systems of transistors into much smaller elements, the IMOS process "shrinks" an expensive, macroscopic optical system into an inexpensive, compact optical system. Before the invention of the integrated circuit, the production of computers and other electronic systems involved slow hand-assembly



With IMOS, components are aligned and assembled at the wafer level, allowing the production of complex, three-dimensional optical systems on a chip.

of discrete components and resulted in low yields. In the optoelectronic industry, laborious assembly of individual components with high failure rates has been the norm. The development of semiconductor manufacturing techniques allowed for the efficient production of high-quality integrated circuits; some of these same manufacturing techniques can be used to manufacture less expensive, high-quality integrated micro-optical systems. Automated design, layout, and production tools for integrated circuits are now commonplace (Digital Optics proposed to develop analogous design, layout, and production tools for photonics).

Digital Optics Identifies High-Risk Optical Integration Opportunity

The marketplace and the investors considered Digital Optics' IMOS technology too risky and cutting edge to support a significant investment. Therefore, the company turned to ATP's Focused Program for Photonics Manufacturing for R&D support for this innovative technology. The ATP funding would serve as a catalyst for U.S. industrial investment into IMOS technology by overcoming the basic technological hurdles and by accelerating the development of a sufficient prototyping and manufacturing foundation from which future applied projects would be viable. Macroeconomic benefits could then be realized from products based on the technology, to include a decrease in labor outsourcing and the potential to revolutionize the optical industry with smaller, faster, and less expensive components.

Development Objectives Defined for IMOS

The ATP-funded project for IMOS development simulated and designed IMOS devices using integrated software modules for optical, mechanical, thermal, and electromagnetic analysis.

The IMOS technology has the potential to enter and dominate markets such as CD/DVD systems, magneto-optical disk drives, and optical tracking for floppy disks.

The development objectives for the IMOS devices were fabrication at the wafer level and then integration and testing. The project focused primarily on infrastructure development while maintaining alignment with photonics industry requirements.

Digital Optics and Its Partners Solve Technological Barriers

At the project's outset, Digital Optics identified several technological barriers to achieving the project's goals. The primary barriers were a lack of systems-level design and fabrication engineering capability; incompatibility across multiple vendors; low yields for both fabrication and assembly processes; and lack of testing mechanisms, particularly at the wafer level, for both components and finished modules.

Digital Optics has identified the $20 billion data storage industry as a potential early adopter of the IMOS technology.

To meet the challenges of these technical barriers, Digital Optics developed integrated design tools, used lithographic techniques to manufacture high-precision diffractive and refractive micro-optics at the wafer level, and integrated and tested optics and optoelectronic components at the wafer level. The final barrier of component testing was solved with the help of two strategic partners (Agilent Technologies, Inc. and MicroE Corporation).

Partners Help Expand Project Scope

Agilent, a market leader in communications and life science innovation, had worked previously with Digital Optics on other research initiatives. Following the ATP award, the scope of the project expanded to include the development of a demonstrator module by Agilent for use in transmitter/receiver communications applications in support of the infrastructure development of IMOS technology. The Digital Optics-Agilent partnership continued after the end of the project and still is a mutually beneficial relationship.

Digital Optics formed a second partnership with a previous customer, MicroE. Similar to the Agilent work, MicroE created a technology demonstrator during the ATP project. Although no product development directly resulted from the partnership with MicroE, the knowledge spillover positively benefited both companies, and their relationship continued beyond the project's completion.

Digital Optics Meets Project Objectives

As a result of the ATP-funded IMOS project, Digital Optics can now quickly produce miniaturized components with higher performance and lower cost than conventional optoelectronic approaches. As an ISO 9001-certified manufacturer, Digital Optics maintains the highest level of quality to meet the market demands of the photonics industry. The modular, wafer-level nature of IMOS manufacturing enables reductions in manufacturing risk, delivery time, and cost through the use of common, modular components.

Photonic Chip™ Completed as a Result of ATP Funding

In early 2001, after the project's completion in October 2000, Digital Optics officially launched the IMOS technology under the brand name Photonic Chip™. The optical subassembly (OSA) of a Photonic Chip™ is based on wafer-fabricated micro-optics. Passive optical functions, such as collimation, focusing, splitting, and reflection, are fabricated with photolithographic techniques. Standard die-bonding equipment then attaches active components such as lasers and detectors. A key benefit of the Photonic Chip™ OSA integration platform is the ability to accomplish at the wafer level as many of the critical alignment steps and assembly steps as possible. This, in turn, enables high-volume capacity, tight alignment tolerance, and lower cost OSAs.

The Photonic Chip™ developed for the project platform simplifies and enhances optical integration within fiber-optic transmission systems. Potential applications include integrated OSAs for dense wavelength division multiplexing, coarse wavelength division multiplexing, terabit routers, all-optical switches, optical interconnects, and many other telecommunications and data communications applications.

Future of Photonic Chips and Integrated Optical Components

Digital Optics has secured the intellectual property rights to the technologies supporting the Photonic Chip™ technology and brand to ensure a return on its investment. Since the ATP project, Digital Optics has applied for 42 U.S. patents either directly or through licensing agreements with research universities. Before the ATP funding, Digital Optics held or controlled 28 patents. Digital Optics has identified the $20 billion data storage industry as a potential early adopter of the IMOS technology.

The data storage industry is affected by optics in three ways. First, CDs and DVDs are becoming more prevalent as a form of business data storage and commercial entertainment. Second, magneto-optical disk drives have the potential to replace conventional magnetic hard drives. Third, optically tracked floppy disk drives have the potential to replace conventional floppy drives. IMOS can become a key technology in expanding storage density, volumes, and retrieval times in these three large markets. In addition, Digital Optics has targeted the telecommunications and data communications markets, which would profit from the improved scalability and miniaturization aspects of IMOS, as well as the elimination of the excessive manual labor required to produce conventional optoelectronic subassemblies.

Conclusion

The technological boom of the late 1990s generated inflated demands on industries such as optoelectronics. During this time of accelerated growth, Digital Optics, with the support of ATP funding, successfully developed new IMOS technology, which led to its launch of the patented Photonic Chip™. When the telecommunications market contracted in early 2001 and developed a surplus of optical components, the demand for the Digital Optics' Photonic Chip™ decreased. Despite the negative market conditions, Digital Optics continued to grow and outpace its competitors through its new R&D initiatives and aggressive promotion of its products. The potential remains positive for the Photonic Chip™, as well as the IMOS technology that supports it and the infrastructure developed as a result of the ATP funding. Once the markets recover and inventories diminish, IMOS technology will be positioned to serve new customers and lead the next paradigm in optical integration.

PROJECT HIGHLIGHTS
Digital Optics Corporation

Project Title: IMOS Technology Improves Scalability and Lowers Cost (IMOS Infrastructure for Photonics Manufacturing)

Project: To develop an integrated optical infrastructure that can easily be transitioned to prototyping and pilot production of low- and mid-volume optoelectronic devices and can serve as the foundation for efficient production in higher volumes in later years.

Duration: 11/1/1998-10/31/2000
ATP Number: 98-02-0034

Funding (in thousands):

ATP Final Cost	$ 1,700	59%
Participant Final Cost	1,200	41%
Total	$ 2,900	

Accomplishments: This project accomplished the intended goal of developing an infrastructure for the IMOS technology. Additionally, Digital Optics has successfully commercialized the Photonic Chip™. The ATP funding gave Digital Optics the ability to anticipate market trends and to become the leader in integrated optical modules. Digital Optics has applied for 42 patents since the ATP project.

Commercialization Status: Digital Optics has fully commercialized the IMOS technology under the brand name Photonic Chip™. The company continues to refine, redesign, and customize the Photonic Chip™ to meet the needs of various customers, as well as pursuing potential future markets, such as the huge data storage industry and the telecommunications and data communications markets.

Outlook: Digital Optics has weathered the recent contraction in the telecommunications and data communications markets and is well-positioned to ramp-up operations when the market returns to positive growth. Digital Optics's technology is highly regarded in the marketplace and is poised to become the primary production method for integrated OSAs.

Composite Performance Score: * * *

Number of Employees: 35 employees at project start, 130 as of December 2001

Focused Program: Photonics Manufacturing, 1998

Company:
Digital Optics Corporation
9815 David Taylor Drive
Charlotte, NC 28262

Contact: Mike Feldman
Phone: (704) 887-3100

Subcontractors:
Agilent Technologies, Inc.
MicroE Corporation

Research and data for Status Report 98-02-0034 were collected during October - December 2001.

Displaytech, Inc.

Mass-Producing Display Chips that Will Improve Image Quality, Extend Product Lifetime, and Reduce Costs

A news article in 2000 asserted that, "For many years, the Holy Grail of the display community has been the enabling of both very large-screen and very small-screen high-resolution displays with optimal clarity, field of view, and performance."[(1)] Excessive size and the cost of existing liquid crystal displays (LCDs) prevented having convergent devices such as personal organizers, laptop computers, and portable phones in one unit. In the search for faster, smaller, cheaper, and better displays, scientists turned to a new type of liquid crystal—the ferroelectric liquid crystal (FLC). Displaytech of Longmont, CO, could produce FLC chips, but it only could produce them one at a time. With funding from the Advanced Technology Program (ATP), however, Displaytech successfully developed technology to mass-produce FLC display chips. This achievement increased image quality by 600 percent, expanded product lifetime by 100 percent, and cut per-unit costs from $6,000 to $160. The technology is now integrated into Samsung projection TVs and JVC camcorder displays and will be commercialized in several other products shortly. Displaytech's success has encouraged more than two dozen U.S. firms to enter the Japanese-dominated display market.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
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Research and data for Status Report 94-01-0402 were collected during January – March 2001.

Existing LCDs Were Costly and Limited in Range

In 1994, LCD technology used in televisions and computer monitors was not keeping pace with the needs of emerging applications, such as high-definition televisions (HDTVs), head-mounted virtual displays, and videophone wristwatches. At that time, the manufacturing process was too expensive, and the LCDs were incapable of handling extremely small or large displays. These chips, manufactured one at a time, took an engineer several hours to build and carried massive overhead costs that priced the equipment well out of the range of the average consumer.

The process involved implanting liquid crystals onto individual silicon chips, inserting circuitry to control the "on-and-off" states of the liquid crystal, and then coating the chip with glass for durability. Moreover, as screens became larger, traditional LCDs could not pack enough pixels into displays to meet the detail requirements of extremely large displays. Overcoming the magnification problem was prohibitively expensive, as each increase in screen size cost manufacturers approximately $1 billion in development costs. Those costs could not be passed on to the average consumer because of price sensitivity.[(2)] And, for converged personal digital assistant/laptop/cell phones, the displays needed to be small, lightweight, detailed, and inexpensive. Smaller

1. Ajluni, Cheryl. "Stamp-Sized Ferroelectric LCD Can Power 50-in. TV Screens." ASAP. March 20, 2000.
2. Lieberman, David. "Displaytech Makes Big Waves in Miniature Displays." Electrical Engineering Times. May 18, 1998.

screens needed small, plentiful pixels that are viewable at any angle from the compressed display, a task that was impossible with traditional LCDs because of the pixel requirement and the need to bounce light off a triad of red, green, and blue light generators in order to show colors.

Ferroelectric Liquid Crystals Held Potential to Solve Problems

A new generation of LCDs, displays using FLCs, had the potential to be manufactured in mass quantities at affordable prices by placing the FLCs on an entire silicon wafer and then cutting the wafer into individual chips at the end of the process. This process could reduce costs by spreading direct labor costs over hundreds of units rather than just one. Before Displaytech's ATP-funded project began, projections suggested that using FLCs could reduce the price of an LCD chip from thousands of dollars to a much more affordable $100.

These chips consist of a fast light-modulating layer of FLCs that sits directly atop a silicon very-large-scale integrated (VLSI) circuit active matrix device. FLC/VLSI devices are smaller, faster, use less power, and can be magnified to extremely large sizes without image degradation. FLC images begin with electric current sent through the silicon circuitry. Silicon circuitry routes the energy to the appropriate aluminum pixel pads

The FLC display can produce detailed images as small as the silicon chip (about the size of a postage stamp) more quickly than do existing LCDs.

sitting atop the silicon. The pixel pad fires individual pixels made of FLC. Whereas traditional LCDs could only enable a matrix of large pixels separated by relatively large distances of circuitry, FLC displays operate with smaller pixels situated much closer to one another. Therefore, the FLC display can produce detailed images as small as the silicon chip (about the size of a postage stamp) more quickly than do existing LCDs. Moreover, when magnified, the images are still sharp at sizes needed by HDTV technology.

ATP Funds New Production Method for FLCs

In 1994, Displaytech invented and first demonstrated FLC displays that were compatible with large and small screens and were also faster than traditional LCDs. Displaytech's FLCs displayed color without bouncing light off the traditional red, green, and blue triads and turned pixels on and off faster than did traditional liquid crystal pixels. This development resulted in even higher image quality and even faster image change speed. Although the FLC images were fast, the one-at-a-time manufacturing process was still too slow. Displaytech devised a technically sound strategy for a new manufacturing process that could reduce the net cost per unit by 99 percent and increase the daily yield from 4 to 500 units per operator. The company approached both private investors and the United States Army for funding. The Army recognized the potential of Displaytech's manufacturing process, but made no funds available for the project. Private sources of capital were reluctant to fund the project because of the risks involved with investing in a proposed method without a demonstrated manufacturing process in place.

An FLC display chip, sitting atop a silicon wafer, is smaller, faster, uses less power, and can be magnified to extrememly large sizes without image degradation.

To get past the technical hurdles that discouraged potential private investors, Displaytech submitted a single-company proposal to ATP's 1994 general competition to develop its new manufacturing process technology. In ATP's peer review, potential economic benefits appeared solid and the engineering plan was judged sound. In 1995, ATP awarded Displaytech $1.748 million for a two-year project. The award attracted $1.503 million in matching funds from Century Partners, an established venture capital firm that focused on new technologies, and a private investor affiliated with Century.

Displaytech Solves Technical Problems

The first major technical barrier that Displaytech overcame was developing the FLC array on a "dummy" silicon wafer to test the manufacturing process. Silicon substrates are fairly expensive. Consequently, development costs would have been prohibitive if Displaytech had used real silicon wafers as it sought to develop a new manufacturing process. The company was unable to find a source for FLC materials to be mounted on "dummy" silicon, so it developed its own FLC materials.

Final image quality increased 600 percent, product lifetime increased 100 percent, and costs declined from $6,000 per unit before ATP funding to $160 per unit after funding.

These materials resulted in higher conductivity and higher speeds than FLCs produced from commercially available materials.Displaytech overcame a second major technical barrier by developing an affordable mass-manufacturing process for the FLC display chips. The company developed a process that yielded 35 percent usable FLC chips from the dummy silicon wafer and then incrementally increased the yield from there. Ultimately, the process was improved to the point where final image quality increased 600 percent, product lifetime increased 100 percent, and costs declined from $6,000 per unit before ATP funding to $160 per unit after funding.

The best-case scenario without ATP funding had been projected at $1,200 per unit. Although the $160 per-unit cost ultimately achieved in the project did not meet the pre-project estimate of $100 per chip, costs are projected to decline further as plant capacity increases. The company's third task was to develop approaches for ramping-up the manufacturing process to produce high volumes of FLC displays. As of early 2000, implementation of manufacturing improvements had increased Displaytech's production capabilities to 100,000 displays per month.

Displaytech's FLCs Are Changing Entire Industries

The postage-stamp-sized FLC chip, together with projection lens technology also developed by Displaytech, is capable of displaying images as small as the chip itself and as large as the industry demands, without image degradation. In short, Displaytech appears to have found "the Holy Grail of the display community."

The trade press lauded FLC displays as technology that will completely replace cathode ray tubes and change the way the world uses visual images.(3) According to the press, the lighter, faster, better, and cheaper technology may completely change the market price for flat-panel HDTVs, enable full convergence of smaller machines, and spawn a new line of eyeglass-frame-mounted personal displays. The FLC technology also has shown promise in the development of optical memory systems that are faster, use less power, and are smaller than current computer-based memory systems.

Alliances with Hewlett Packard and Miyota Result in Diversified Products

The manufacturing process for FLCs appeared so promising that in 1995 Hewlett Packard (HP) approached Displaytech about forming a joint venture. The result was the birth of LightCaster, a product series of Video Graphics Array, eXtended Graphics Array, and Super-eXtended Graphics Array postage-stamp-sized panels for the personal, projector, and high-resolution markets.

Displaytech manufactures the FLC, HP manufactures the silicon chip, and Miyota mass-produces the actual displays. These displays are then shipped to original equipment manufacturers such as JVC, Samsung, and Minolta. Samsung installs LightCaster into its Tantus line of projection HDTVs. These HDTVs include both 43-inch and 50-inch screens and are one-third the weight of other HDTVs.

3. Ibid.

Each HDTV fits onto an 18-inch-deep shelf and features 2.76 million pixels with 16.77 million color shades.

The success of this ATP-funded project encouraged a major manufacturer of displays to develop FLC technology, helped U.S.-owned technology find its way into display equipment shipped by a number of companies worldwide, and encouraged more than 24 U.S. firms to enter the display market.

Other companies also are applying Displaytech's FLC technology:

- JVC installs Displaytech LightView monochrome FLC video display modules into its digital camcorders. These microdisplays are much better than traditional display options.
- Concord and Minolta will each begin using LightView viewfinders in their high-quality digital still cameras in the near future.
- Densitron Technologies, a global supplier of industrial electronics and computers in Denmark, France, Germany, Sweden, and the United Kingdom, signed an exclusive distribution agreement with Displaytech. This gives Displaytech a sound footing in Europe that solidifies its global presence. [(4)]

Conclusion

Before Displaytech's ATP-funded project, the Japanese maintained 90 percent of the global market share for LCDs. [(5)] Today, although the Japanese still have a strong presence in the LCD market, Displaytech's success has shown that U.S. competition can succeed in this market. [(6)] More than 24 U.S.-based firms are now in the display market.

In addition to licensing partnerships, Displaytech is actively marketing its FLC display's potential for multiple uses. The company is in discussions with suppliers and potential partners to develop the following in-house and licensed products: wearable computers, technical document viewers, fax pagers, cellular phone fax receivers, fingerprint recognition mechanisms, machine vision equipment, image search and retrieval devices, and optical memory capabilities.

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4. "Displaytech's First-Half of 2001 Very Bright." PR Newswire. June 5, 2001.
5. DeJule, Ruth. "Flat Panel Technologies." Semiconductor International. January 1997.
6. Ibid.

PROJECT HIGHLIGHTS
Displaytech, Inc.

Project Title: Mass-Producing Display Chips That Will Improve Image Quality, Extend Product Lifetime, and Reduce Costs (FLC/VLSI High-Definition Image Generators Produce Affordable, Improved Displays)

Project: To develop a new FLC-based image-generation technology and mass-manufacturing process for advanced display, printing, and computing applications that uses a silicon chip with circuitry densely patterned into a miniaturized, high-resolution pixel array with individually controllable pixels and high reliability.

Duration: 2/15/95-2/15/97
ATP Number: 94-01-0402

Funding (in thousands):

ATP Final Cost	$1,748	54%
Participant Final Cost	$1,503	46%
Total	$3,251	

Accomplishments: ATP funding allowed the development of a manufacturing process for the mass production of FLCs for displays. Without this funding, the best-case scenario was a cost reduction of 80 percent. The new process resulted in the following achievements for projection displays:

- 600-percent quality improvement
- 100-percent product lifetime improvement
- 97.4-percent reduction in cost, bringing the displays within the appropriate cost range for commercialization.

The success of this ATP-funded project encouraged a major manufacturer of displays to develop FLC technology, helped U.S. owned technology find its way into display equipment shipped by a number of companies worldwide, and encouraged more than 24 U.S. firms to enter the display market. [(7)]

Displaytech received three core patents stemming from the ATP-funded project:

- "Optics arrangement including a compensator cell and static wave plate for use in continuously viewable, reflection mode, ferroelectric liquid crystal spatial light modulating system"
  (No. 6,016,173: filed February 18, 1998, granted January 18, 2000)
- "Continuously viewable, DC-field balanced, reflective, ferroelectric liquid crystal image generator"
  (No. 6,075,577: filed September 4, 1999, granted June 13, 2000)
- "Continuously viewable, DC-field balanced, reflective ferroelectric liquid crystal image generator"
  (No. 6,144,421: filed February 19, 2000, granted November 7, 2000)

Commercialization Status: Starting in 1995, Displaytech announced several joint ventures and partnerships with Hewlett Packard, Miyota, Motorola, Samsung, JVC, Concord, and Densitron Technology to pursue commercialization of its technology. There now is a network of worldwide licensees of Displaytech's core FLC technology, and more are planned. The technology is integrated into Samsung projection TVs and JVC camcorder displays and will be commercialized in several other products shortly.

Outlook: The FLC manufacturing process has the potential for extremely broad application across the electronics industry. Inexpensive FLCs have the potential to improve displays in most electronic equipment. Moreover, the technology could potentially spawn entirely new products through convergence of old products and the development of eyeglass-mounted computers and personal video displays. The outlook is excellent for continued market success of existing products and commercialization of entirely new products.

Composite Performance Score: * * *

Number of Employees: Twenty employees at project start, 150 upon completion of status report

Company:
Displaytech, Inc.
2602 Clover Basin Drive
Longmont, CO 80503

Contact: George Clough
Phone: (303) 449-8933

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7. Lieberman. "Displaytech Makes Big Waves."

Research and data for Status Report 94-01-0402 were collected during January – March 2001.

Eagle-Picher Research Laboratory

Brighter, Longer Lasting Blue and Green Lasers and LEDs

In the early 1990s, true green or blue light-emitting diodes (LEDs) with enough intensity for commercial applications were not available. Eagle-Picher and North Carolina State University (NCSU) had achieved groundbreaking developments in creating zinc selenide blue and green lasers and LEDs, but needed financial assistance to continue the research and development. With funding from the Advanced Technology Program (ATP), Eagle-Picher and NCSU (a subcontractor) partnered to develop blue LEDs that were approximately 40 times brighter than those commercially available and green LEDs that were 50 times brighter than those commercially available. Near the end of the project, however, a Japanese company released a blue LED with a longer life span. In response, Eagle-Picher redirected its research into zinc oxide-based lasers and LEDs.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)

No Stars

Research and data for Status Report 92-01-0109 were collected during October - December 2001.

Short-Wavelength Lasers Impeded by Crystal Degradation

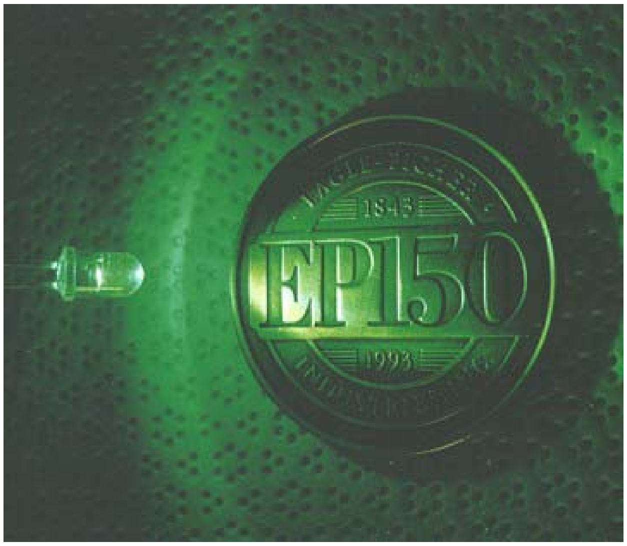
In the early 1990s, the laser industry was using zinc selenide (ZnSe) and gallium arsenide (GaAs) to produce various types of lasers. These two compounds have different thermal coefficients of expansion, however, and they expand and contract at different rates and by different amounts. Consequently, when ZnSe and GaAs are joined together, the bonds between them fail and degradation problems are frequently encountered, resulting in substantial limitations of the capabilities of various laser products.

Furthermore, when this ATP project began in 1993, no one in the industry had been able to develop true green or blue light-emitting diodes (LEDs) that lasted more than a few seconds before the crystal structures became riddled with light-quenching defects. In addition, LEDs marketed as "green" lacked intensity and were actually a disappointing hue of yellow green.

Eagle-Picher Research Laboratory and North Carolina State University (NCSU) had achieved groundbreaking developments in this field of research. Their funding was limited, however, so additional financing was required in order to continue with the research and development of this breakthrough technology. Consequently, they approached ATP for financial assistance to jump-start the development of commercially viable ZnSe blue and green lasers as well as LEDs.

Multiple Industries Expected to Benefit from New Technology

The proposed technology was expected to benefit multiple industries and end users. The shorter wavelength blue/green lasers resulting from this technology could store more information than the red lasers that were at the heart of optical communications. Moreover, the shorter wavelengths could lead to data recording and storage systems with much greater capacities than offered by the lasers in use at the time.



Eagle Picher's green LEDs were 50 times brighter than existing GaP green LEDs.

It was anticipated that the following markets would be affected by this technology:

- Flat panel displays
- Automotive displays
- Information storage
- Color printing
- Optical communications
- Medical lasers
- Optical computing

Partnership Overcomes Obstacles

The goal of this ATP project was to develop high-efficiency, long-lifetime blue/green lasers and LEDs using homoepitaxy of ZnSe-based structures on ZnSe substrates. (Homoepitaxy refers to the growth of a crystalline substance (ZnSe) on a crystalline substrate of the same material.) To achieve this goal, the project objectives included development of substrate and device fabrication. Eagle-Picher planned to complete the substrate development; NCSU, under subcontract, would focus on device fabrication.

Eagle-Picher believed that its patented seeded physical vapor transport (SPVT) bulk crystal growth method provided a solid base for this project because it was capable of growing ZnSe crystals large enough for commercial purposes, whereas other methods were incapable of growing these larger crystals.

Growing crystals was just one step in the complex development cycle. The next step, which plagued developers for some time, involved depositing ZnSe layers onto GaAs layers. This process was difficult because the respective spacing between the atoms of the two layers did not match, which led to weaknesses within the crystal substructures. Fortunately, NCSU's molecular beam epitaxy (MBE) process addressed this issue by allowing the building and varying of crystal structures, atomic layer by atomic layer.

When this ATP project began in 1993, no one in the industry had been able to develop true green or blue light-emitting diodes (LEDs) that lasted more than a few seconds.

At the start of this project, only semi-insulating ZnSe substrates were available, so the device structures were designed to utilize them. However, conductive substrates were essential to the successful development of efficient short-wavelength blue and green lasers, as well as diodes. As conductive substrates became available, the developers created device structures to use those substrates as the back contact.

Researching the Parameters of Bulk Crystal Growth

Initially, four furnaces were used to grow crystals for this project. One of these furnaces supplied state-of-the-art substrates to NCSU. The remaining three furnaces were used in studies to improve the growth conditions. Through a series of designed experiments, researchers investigated growth temperature, seed type, seed preparation, growth pressure, cooling conditions, and growth rate. As improvements were identified, they were incorporated into the procedures for the production furnace. Initial efforts at NCSU were directed at MBE growth of ZnSe and related alloys on three different orientations of ZnSe substrates. All substrates supplied to NCSU were fully characterized by Eagle-Picher.

SPVT Method Proves Successful in Bulk Crystal Growth

By the end of the ATP project in 1996, the yield, size, and crystalline quality of the ZnSe crystals grown by the SPVT method had notably improved. Yields approaching 100 percent were achieved in production-scale runs. Three-inch-diameter crystals with quality similar to two-inch-diameter crystals were produced. Moreover, growth of conductive crystals for injection laser fabrication was remarkably successful. Net carrier concentrations as high as 2 X $1018/cm^3$ were achieved, with mobilities similar to those of MBE films of the same net carrier concentration. These significant milestones aided in the development of short-wavelength blue and green lasers.

In addition to production improvements in the SPVT method, developers made significant strides in understanding the ZnSe SPVT crystal growth process. At the onset of the project, control of the ZnSe SPVT process was good, but the parameters used for crystal growth were empirically determined. To develop a true production-scale manufacturing facility that was capable of producing extremely high yields at a low cost, it was essential to understand the actual control mechanisms for the SPVT method. By the conclusion of this project, models of the control mechanisms permitted the determination of optimum operating parameters based on desired product specifications. The models also could identify equipment problems at an early stage to avoid the expense of making long crystal growth runs with poor yields. Without these models, it was necessary to wait as long as two weeks to determine the yield of the crystal growth runs.

By the end of the ATP project in 1996, the yield, size, and crystalline quality of the ZnSe crystals grown by the SPVT method had improved notably.

Although these accomplishments were impressive, Eagle-Picher believed that the most significant result of the crystal growth optimization study was the dramatic improvement in the crystalline quality of the undoped, semi-insulating ZnSe being grown. Multiple test results verified that the world's best crystalline quality, large-area ZnSe wafers were being routinely produced.

Another first achieved during this project was the doping (that is, the introduction of an element that alters the conductivity) of the bulk crystals to achieve n-type, or positive, conductivity. This doping was necessary for the production of short-wavelength blue and green lasers. In fact, as the level of doping is increased, so is the intensity of the light emitted by lasers and LEDs. According to Eagle-Picher, at the conclusion of the project it had achieved the highest n-type doping concentration ever obtained in large-area ZnSe crystals with high crystalline quality. This achievement enabled the production of the first practical, short-wavelength injection lasers.

Prototype LEDs Are Brighter than Existing Commercial LEDs

The project's second objective, the device fabrication, also met with technical success. NCSU was able to develop functional blue and green LEDs from the improved wafers created at Eagle-Picher. The blue LEDS were approximately 40 times brighter than commercial silicon carbonide (SiC) LEDs, and the green LEDs were 50 times brighter than gallium phosphide (GaP) green LEDs. In addition to being brighter, the light emitted by these LEDs was purer than that available from the commercial blue and green LEDs available at the time.

Although the development of the lasers using homoepitaxy of ZnSe on ZnSe substrates was slower than expected, the first homoepitaxial ZnSe injection laser was accomplished before the end of the project. At the time, the laser operated in pulse mode only.

Prototypes Fail to Achieve Life-Span Objectives

With the development of prototypes that incorporated the new technology, scale-up and commercialization were almost within sight. Unfortunately, as the project neared its conclusion, a Japanese firm, Nichia, successfully completed the development of gallium nitride (GaN) blue LEDs that took the industry by storm.

Nichia's LEDs and lasers were more appealing because their operating life spans exceeded 10,000 hours, whereas the prototypes that Eagle-Picher and NCSU had developed were only capable of operating up to 8,000 hours. This difference in laser and LED operating life spans prompted Eagle-Picher to abandon its original plan of developing and commercializing ZnSe-based blue and green lasers and LEDs.

The most significant result of the crystal growth optimization study was the dramatic improvement in the crystalline quality.

Conclusion

After the conclusion of the ATP project, Eagle-Picher used the knowledge it had gained from the project to focus its efforts on developing zinc oxide (ZnO)-based lasers and LEDs. ZnO has the potential to produce lasers and LEDs that are stronger than those based on ZnSe.

PROJECT HIGHLIGHTS
Eagle-Picher Research Laboratory

Project Title: Brighter, Longer Lasting Blue and Green Lasers and LEDs (Development of Blue/Green Emitters Using Homoepitaxial Zinc Selenide (ZnSe)-Based Heterostructures)

Project: To apply newly developed production technologies to the fabrication of high-efficiency, long-lived blue/green lasers and LEDs.

Duration: 3/1/1993-2/28/1996
ATP Number: 92-01-0109

Funding (in thousands):

ATP Final Cost	$ 1,759	59%
Participant Final Cost	1,200	41%
Total	$ 2,959	

Accomplishments: Eagle-Picher was unable to achieve its goal of LED life spans of 10,000 hours; instead the life spans reached approximately 5,000 to 8,000 hours. However, the project achieved successes in substrate development, laser and LED output power, and substrate quality. Eagle-Picher and NCSU developed blue and green prototype lasers and LEDs that exhibited superior output capabilities. The blue LEDs were approximately 40 times brighter than commercial SiC LEDs, and the green LEDs were 50 times brighter than GaP green LEDs. In addition to being brighter, the light emitted by these LEDs was purer than the light from the commercially available blue and green LEDs. Eagle-Picher developed three-inch-diameter crystals with superior quality characteristics. At the conclusion of the project, the company had developed crystals capable of achieving n-type conductivity. This achievement was the highest n-type doping concentration ever obtained in large-area ZnSe crystals with high crystalline quality.

Commercialization Status: Eagle-Picher's laser and LED prototypes had life spans of approximately 5,000 to 8,000 hours; however, Nichia, a Japanese firm, successfully developed a GaN blue LED with a life span in excess of 10,000 hours. Because of its inability to meet the 10,000-hour product life-span, Eagle-Picher suspended further research and development of ZnSe-based lasers and LEDs in order to pursue other alternatives.

Outlook: Because of difficulties associated with the life spans of ZnSe-based lasers and LEDs and competition from abroad, the outlook for this technology is poor. Eagle-Picher has redirected its focus to ZnO-based lasers and LEDs.

Composite Performance Score: **No stars**

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Contact: Gene Cantwell
Phone: (918) 542-1801

Subcontractors:
North Carolina State University

Research and data for Status Report 92-01-0109 were collected during October - December 2001.

Elsicon (formerly Alliant Techsystems, Inc., and Hercules)

Optical Alignment Technique To Improve LCD Quality and Price

Liquid crystal displays (LCDs) are incorporated into myriad technologies ranging from automated teller machines (ATMs) and computers to kitchen appliances and automotive dashboards. Although American businesses and consumers spend billions each year on these types of equipment, LCD brightness and clarity problems persist, and the high costs associated with LCDs remain. For years, the Asian marketplace has dominated LCD manufacturing, while the United States has been eager to establish a stronger position in the industry. Recognizing the potential growth of LCD technology and the need to find better ways to mass-produce LCDs, Hercules, a global manufacturer of chemical specialty products for a variety of markets, conceived of an optical production technique that had the potential to enhance LCD quality and improve the economies of scale in LCD production. At the time, however, Hercules was a small company without a sizeable research budget. The risk involved in developing a generic new technology for LCDs was too high for Hercules to bear alone; therefore, the company applied to the Advanced Technology Program (ATP) for research funds in 1993 and received an award in February 1994. Through this ATP-funded project, the company developed processes and materials that have been applied to several prototype LCDs. Elsicon acquired the optical technology in 1997 and now markets products and services for the optical alignment of LCDs.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* *

Research and data for Status Report 93-01-0091 were collected during October - December 2001.

Production Technology Is Complicated, Expensive, and Error-Prone

The growth in the demand for liquid crystal displays (LCDs) and monitors in the early 1990s was accompanied by an increasing need to improve manufacturing processes for these products to reduce cost and improve quality. To ensure the clarity and brightness of LCDs, manufacturers must precisely align the crystals within them. Older, less expensive LCDs were often fuzzy and unclear because of improper alignment. Existing LCD technology exhibited high sensitivity to dust, requiring expensive isolation rooms to minimize errors. The industry tried to solve these problems through mechanical buffing, an alignment process that used a polymer film adjoined to the display to align the crystals. Although this process improved the clarity of the LCDs, it produced less-than-perfect results, was expensive, and led to defects in the displays.

Static electricity, for example, caused a problem when the mechanical buffing film touched the liquid crystal medium, thereby creating "dead" crystals. Although LCDs consist of many small crystals, just a few dead crystals can substantially reduce display image quality, forcing the manufacturer to scrap the product. This problem occurred frequently with products that contained a large number of crystals, such as larger laptop monitors, desktop flat-screen displays, and flat-screen televisions. An innovation that could align crystals without making contact with the liquid crystal medium would minimize the risk of damaging the displays. The resultant benefits of this innovation would include reduced scrap waste, tremendous cost savings to the users of LCDs, and greater overall quality of the product.

Before this ATP project, alignment techniques for LCD production relied on a process that created "alignment masters" that had limited reuse capabilities. Attempts to increase the number of times a master could be reused proved unsuccessful. Consequently, despite large-scale production of LCDs, the production costs remained high. If an alignment process could be created that eliminated the need for these expensive masters, manufacturers could reduce production costs and improve LCD quality.

ATP Funding Crucial to Enabling Generic LCD Technology

Hercules proposed a sound research plan that they would follow to create a new generic LCD manufacturing technology. However, as a small company, it could not take on the risks of this endeavor alone. Therefore, Hercules submitted a proposal to ATP in 1993 and in 1994 was awarded $1.67 million to conduct its proposed research.

New Technology Promises Lower Costs and Higher Quality

The goal of this ATP project was to develop an optical alignment technique to be used in the production of LCDs that would incorporate a noncontact process to eliminate the static electricity problem associated with the existing mechanical buffing process and to improve display quality. The company projected that the use of an optical alignment technique would be less expensive, less prone to display errors, and more suitable for mass production than the existing buffing process. Optical alignment equipment is much smaller and less expensive to transport. Moreover, the use of this noncontact technique would also eliminate the need for expensive isolation rooms. In addition, the optical alignment technique would provide cost savings by eliminating the need for expensive masters, thereby reducing overhead costs.

Researchers Achieve Technical Innovations

During the project, the researchers achieved their technical goals and successfully developed the materials and processes required for the optical alignment of LCDs. Technical accomplishments that resulted from this project included the following:

- Creation of a colorless optical alignment material
- Introduction of an optical alignment material with pre-tilts for both homogeneous and homeotropic alignment configurations
- Development of materials with good dielectric properties measured by voltage-holding ratio and residual DC voltage
- Demonstration of thermal and optical stability
- Development of a process to use an ultraviolet lamp as a light source with acceptable throughput
- Establishment of testing capabilities to characterize electrical, optical, and electro-optical properties of optical alignment materials and liquid crystal test cells
- Fabrication of liquid crystal test cells with nonrubbing optical alignment technology

Hercules conceived of an optical production technique that had the potential to enhance LCD quality and improve the economies of scale in LCD production.

The company continued to search for new applications that could benefit from this technique. Toward the end of the project, they performed research to develop technology solutions for the most important new modes of flat displays with wide viewing angles.

Hercules Evolves from Research to Product Development

In 1995, partway through the ATP project, Alliant Techsystems (a U.S. aerospace and defense company) acquired the aerospace portion of Hercules, including its LCD-related technology. Although the LCD products fell outside the scope of Alliant's strategic focus, the company recognized the business potential of the ATP-funded project and helped to form a separate business unit to focus on the project's goals. As the ATP project came to a close in 1997, the optical technology developed at Hercules and Alliant Techsystems was divested and sold to privately held Elsicon. Elsicon has continued to develop the ATP-funded technologies, including a pre-tilt analysis system for LCDs, which reduces the risk of defects in the orientation of the liquid crystals, and a research and development tool that enables identification of the process parameters for the optical alignment of LCDs and devices. Elsicon also sells a measurement system for the voltage-holding ratio, a critical electrical parameter for LCDs. Finally, the company offers the materials that support the optical alignment of LCDs. Elsicon sells and markets these products through a Japanese partner, Japan Storage Battery Company, because LCD manufacturers are located predominantly in East Asia. Today, Elsicon generates revenue from contracts, licenses, and consulting assignments that are related to the technology developed during the ATP project.

Project Benefits Elsicon and Creates Economic Spillover

In June 1997, Elsicon received a $1.65 million contract to develop new materials and processes for optical alignment from the U.S. Display Consortium (USDC), a public-private partnership based in San Jose, CA, which aims to establish a U.S. infrastructure to support high-definition display manufacturing.

The USDC, which has 130 corporate members and also receives support from the Defense Advanced Research Projects Agency in the U.S. Department of Defense, paid 50 percent of the $3.3 million cost to develop a scaled-up manufacturing process, with Elsicon funding the other half. According to Dr. Robert Pinnel, the Chief Technical Officer of USDC, Elsicon "...built upon a strong foundation of intellectual property in patents and know-how that were developed under a prior grant in the NIST-ATP program. The research and proof of feasibility developed under the ATP grant will now be supported toward practical realization in fulfillment of the USDC mission."

The alignment process has appeared in several prototype LCDs from various global manufacturers, but none of these manufacturers has brought its prototype into mass production. LCD manufacturers worldwide are evaluating the products commercialized from this project. Although the products have not yet been fully incorporated into manufacturing processes for mass production and large-scale sales, initial results from the products are positive.

Elsicon continues to sell and seek licensing for the products and processes developed during the ATP project, creating a sound foundation for its future. Benefits for Elsicon, however, represent only a fraction of the broader economic benefits that may be provided by optical alignment LCD technology. Current and future benefits include more efficient manufacturing processes, higher quality displays, lower cost to users, and a larger knowledge base for the development of future technologies. In 2000, the LCD market was $20 billion worldwide for laptops, personal digital assistants, and other technologies that rely on flat displays. With the demand for these products increasing rapidly, the high cost of LCD monitors represents a burden on the economy as well as on consumers. As the enhanced production technology spreads in the industry, the cost advantages are expected to translate into lower prices for the displays, benefiting American businesses and consumers.

ATP Award Sustained the Project and Ensured a Short Development Life Cycle

Had the project not received support and funding from ATP, Alliant Techsystems would likely have abandoned the development of the optical alignment technique because of the lack of funding, preventing the important innovations that occurred as a result of the project. The LCD technologies fell outside the scope of Alliant's strategic focus, and the project could not rely on additional internal funding. Thus, external funding was critical in ensuring the timely completion of the project.

Conclusion

Elsicon is in the process of evaluating its optical alignment technology, known as OptiAlign™, in the liquid crystal display (LCD) manufacturing industry. The company has formed strategic partnerships and alliances that provide feedback, allowing researchers to further refine the technology and facilitate its implementation. An evaluation of OptiAlign™ is currently under way by a number of manufacturers in East Asia, Europe, and North America. The results have been very promising and suggest that the technologies may lead to new and improved flat displays.

PROJECT HIGHLIGHTS
Elsicon (formerly Alliant Techsystems, Inc., and Hercules)

Project Title: Optical Alignment Technique To Improve LCD Quality and Price (Optically Controlled Alignment Materials for Liquid Crystal Displays)

Project: To reduce the cost and improve the yield of liquid crystal displays (LCD) manufacturing by developing optically controlled alignment materials and processes to replace the mechanical buffing process, thereby expanding the LCD applications base in optical data storage and signal processing.

Duration: 2/1/1994-1/31/1997
ATP Number: 93-01-0091

Funding (in thousands):

ATP Final Cost	$1,670	55%
Participant Final Cost	1,370	45%
Total	$3,040	

Accomplishments: During the project, the researchers achieved their technical goals and successfully developed the materials and processes required for the optical alignment of LCDs. The project led to the development of successful technologies as well as marketable products.

The U.S. Patent and Trademark Office granted the following patents that stemmed directly from the research conducted during the ATP project. These patents, which Elsicon purchased from Alliant, serve to disseminate the knowledge created by the project.

- "Liquid crystal optical storage medium with gray scale"
  (No. 5,846,452: filed April 6, 1995, granted December 8, 1998)
- "Process and materials for inducing pre-tilt in liquid crystals and liquid crystal displays"
  (No. 5,731,405: filed March 29, 1996, granted March 24, 1998)
- "Process and materials for aligning liquid crystals and liquid crystal optical elements"
  (No. 5,807,498: filed March 29, 1996, granted September 15, 1998)
- "Process and materials for inducing pre-tilt in liquid crystals and liquid crystal displays"
  (No. 5,817,743: filed May 14, 1996, granted October 6, 1998)
- "Process and materials for inducing pre-tilt in liquid crystals and liquid crystal displays"
  (No. 5,856,430: filed March 31, 1997, granted January 5, 1999)
- "Fluorinated amine products"
  (No. 5,929,201: filed May 20, 1997, granted July 27, 1999)
- "Polarizable amines and polyimides for optical alignment of liquid crystals"
  (No. 6,084,057: filed May 20, 1997, granted July 4, 2000)·
- "Materials for aligning liquid crystals"
  (No. 5,965,691: filed July 1, 1997, granted October 12, 1999)
- "Process and materials for inducing pre-tilt in liquid crystals and liquid crystal displays"
  (No. 5,856,431: filed November 7, 1997, granted January 5, 1999)
- "Polarizable amines and polyimides for optical alignment of liquid crystals"
  (No. 6,043,337: filed May 18, 1998, granted March 28, 2000)
- "Process for materials for aligning liquid crystals and liquid crystal optical elements"
  (No. 6,200,655: filed January 25, 1999, granted March 13, 2001)
- "Polymides for optical alignment of liquid crystal displays"
  (No. 6,451,960: filed February 4, 2000, granted September 17, 2002)

Commercialization Status: The ATP project resulted in the development and patenting of several new technologies, which now provide a platform for the commercialization of a series of products and services related to the optical alignment of LCDs at Elsicon.

The alignment process has appeared in several prototype LCDs from various global manufacturers. None of these manufacturers has brought its prototype into mass production, and until that happens, Elsicon will not pursue upfront licensing fees when entering into agreements with manufacturers, opting instead for a percentage of total sales. Elsicon views this as the strategy that will both generate the most revenue and distribute the technology to the largest number of manufacturers. LCD manufacturers around the globe are evaluating the products commercialized from this project. Although the products have not yet been fully incorporated into manufacturing processes for mass production and large-scale sales, initial results from the products are positive.

Outlook: Elsicon is in the process of implementing its optical alignment technology, known as OptiAlign^{TM}, in the LCD manufacturing industry. For the longer term, the company is developing similar technologies related to optical data storage and optical signal processing. Those products include liquid crystal-based storage media, liquid crystal diffractive and holographic elements, phase and polarization devices, document security, and fast optical communication devices. By conducting research in optical signal processing, used in the optical networking industry, the company is working to develop a foundation for additional successful technologies.

Composite Performance Score: * *

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Research and data for Status Report 93-01-0091 were collected during October - December 2001.

Information Storage Industry Consortium (INSIC)
[formerly National Storage Industry Consortium (NSIC)]

Cooperative Effort Leads to Magnetic Recording Innovation

One key technology driving the explosive growth of the computer industry in the late 1980s was magnetic storage technology that recorded data as a pattern of magnetic domains on a disk. As of early 1991, the best commercial disk drives could store less than 100 million bits of information per square inch. Memory-hungry applications, such as graphics, video images, and visually oriented user interfaces, demanded that increasingly more data be packed even more densely onto disks. The problem was that traditional inductive recording heads were rapidly approaching their technological limitations and could not expand enough to handle the new applications. In 1991, IBM introduced disk-drive products containing magnetoresistive (MR) recording heads, which enabled greater recording densities than the industry-standard thin-film inductive head.

The National Storage Industry Consortium (NSIC) proposed to vastly improve the potential for MR head technology through an award from the Advanced Technology Program (ATP). NSIC's goal was for industry members to work together on head technologies and, within five years, to demonstrate in the laboratory magnetic recording at 10 gigabits per square inch. NSIC aimed to accomplish its dramatic goal by providing a forum for industry competitors to work together, using ATP funds on early-stage research and then to take the research back to their labs for separate product development efforts. When the ATP project ended in 1997, the U.S.-based magnetic recording industry had removed the major technical barriers to achieving recording densities of 10 gigabits per square inch. The resulting giant magnetoresistive (GMR) heads were quickly adopted by the magnetic recording industry. By early 2000, 100 percent of new personal computers used GMR head technology.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * *

Research and data for Status Report 91-01-0016 were collected during October - December 2001.

Inductive Head Magnetic Recording Improves Slowly

By 1991, the rate of improvement in magnetic recording, typically occurring at less than 30 percent per year (or by a factor of 10 in 10 years), was not keeping up with advances in computer software capabilities. The read-write head technology that sustained the hard-disk-drive industry was based on inductive voltage produced when a permanent magnet (the disk) moves past a wire-wrapped magnetic core (the head). Early recording heads were fabricated by wrapping wire around a laminated iron core, analogous to the horseshoe-shaped electromagnets found in elementary school science classes. Market acceptance of hard drives, coupled with increasing memory-density requirements, fueled steady advances in inductive recording heads. This progression culminated in advanced thin-film, inductive read-write heads that were fabricated using semiconductor-style processes in volumes large enough (greater than 500 million heads per year) to meet the data storage demands of the computer industry. Even though advances in inductive read-write head technology were able to keep pace with increasing data storage density requirements, the cost-effective manufacture of these heads was projected to approach its natural limit by 1995. The biggest problem limiting further advances in inductive head technology was the structure of the recording head itself. The structure required the head to alternate between writing data on the disk and retrieving previously written data, which required compromises in head design to serve both functions. Industry recognized that a new recording head technology would be needed to fuel continued growth in capacity and performance.

Magnetoresistive Heads Promise Continued Recording Improvements

In 1991, IBM introduced the industry's first disk-drive product to use a magnetoresistive (MR) head, which separated the write and read functions into two physically distinct portions of a combined head. An inductive head, optimized for writing information, was integrated with an MR head, which was optimized for reading. This technology represented a breakthrough for the magnetic recording industry and was quickly incorporated into products.

Industry-Wide Effort Required to Resolve Remaining Risks

The National Storage Industry Consortium (NSIC) proposed to vastly improve the potential for MR head technology with the help of an ATP award. NSIC's goal was for industry members to work together on head technologies and, within five years, to demonstrate in the laboratory magnetic recording at 10 gigabits per square inch.

Achieving this desired performance required a revolutionary approach to the design and fabrication of magnetic heads that no one company could afford to explore alone.

Achieving NSIC's goals for such increases in storage density so quickly was no small task. Ten gigabits per square inch of data storage required each recorded bit to occupy an unusually small area on the recording medium.

The energy in the magnetization of that small area on the disk would have to be of similar scale. The need, therefore, was to develop heads that could accurately detect these tiny magnetizations. The heads would need to provide sufficient signal-to-noise detection capabilities so that data could be recorded and read with error rates low enough to enable system performance of not more than one error in 10^{14} bits. Achieving this desired performance required a revolutionary approach to the design and fabrication of magnetic heads that no one company could afford to explore alone. Paradigm shifts in design, materials, and fabrication technologies were required. NSIC's ATP project was predicated on creating and optimizing these shifts, then allowing the recording industry to use the resulting series of innovations in product development.

Much of the U.S.-based magnetic recording industry and many universities joined NSIC to work on this project. Eight companies joined the project at the start (Applied Magnetics, Digital Equipment, Eastman Kodak, Hewlett-Packard, IBM, Maxtor, Quantum, and Read-Rite), along with seven university centers (Data Storage Systems Center at Carnegie Mellon University, the Center for Magnetic Recording Research at University of California-San Diego, the Center for Materials for Information Technology at the University of Alabama, the Center for Micromagnetics for Information Technology at the University of Minnesota, the Center for Information Storage Materials at Stanford University, the Institute for Magnetics Research at George Washington University, and the Magnetic Information Storage Center at Washington University in St. Louis). Seagate and Censtor joined the project after it started, and Maxtor left the project when it temporarily became foreign owned. Digital Equipment sold its data storage business to Quantum. Several national laboratories also participated in the collaborative effort.

NSIC Foresees Sizeable Benefits to U.S. Economy

If NSIC succeeded in significantly accelerating magnetic recording density progress, the results for the industry, for computing applications, and for the U.S. economy would be staggering. Given the projected 14-percent annual growth rate in the disk storage market from 1997 to 2001, one additional percentage point in market share could have a billion-dollar impact. Moreover, a substantial improvement could enable entirely new computing applications, with spillovers across the computer industry and every industry that uses magnetic recording to store data. Finally, even if the project failed, NSIC's efforts could significantly reduce duplicative research across the industry.

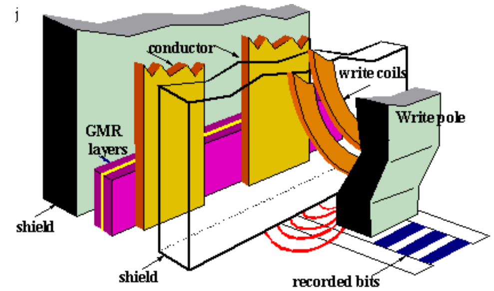
The capital and personnel demands for NSIC's project were too daunting for any single, private firm to meet. In the words of Jim Brug, a researcher at Hewlett-Packard Laboratories who served as project leader for NSIC, "…[giant MR] recording heads take hundreds of people to make."[1] There are so many materials to test, methods to explore, and processes to improve that it would take years and millions of dollars for individual companies to explore them all separately. In the magnetic recording business, that kind of time and money is prohibitive for individual companies. It took NSIC's ATP award to galvanize the industry to work toward a common goal even though the individual firms (much less the entire industry) would not capture all of the economic benefits of the project.

Paraphrasing the words of Dr. Brug, the ATP project gave participants the knowledge to be able to improve the heads well beyond what was imaginable in 1991.[2]

NSIC Solves Technical Issues Relating to GMR Heads

The consortium started from scratch with recently introduced MR heads, working with completely new design concepts. The consortium members faced issues that fell into technical and organizational/logistical categories.

The technical issues were remarkably daunting. Projecting out two years from project start, MR technology would require material layers of a thinness unheard of in the magnetic recording industry. The industry would need to make 800 million heads with MR read heads made up of layers of materials, some of which were only a few atoms thick. Finding materials that kept their useful properties when cut into several atoms' width was difficult enough. Creating processes for mass-producing such materials was considered nearly impossible. Through the project's first three years, NSIC members modeled and tested a variety of different types of MR heads that could be used to read and write information at high densities, providing the requisite research to develop GMR read-head technology. Similarly, NSIC researchers accomplished pioneering work in write-head materials and fabrication processes that also demonstrated the capability to write



A cutaway schematic of a GMR Head device developed during the ATP project.

data at 10 gigabits per square inch onto the magnetic disk-a necessary complement to the GMR read-head research.

Because of the variety of interacting magnetic layers in the head structures, the design of the heads was critical given the extremely small dimensions required for this project. One misstep could throw off the magnetization or could cause the read head to fail to read information properly. To ensure the tightest tolerances, NSIC members developed and used advanced micromagnetic models to study whether conventional longitudinal recording (magnetization in the plane of the media) was capable of achieving the desired recording density of 10 gigabits per square inch. This was a significant question in the industry because Japanese companies had long advocated perpendicular recording (magnetization perpendicular to the media) as capable of achieving higher data densities. After extensive modeling, NSIC's project showed that longitudinal recording would produce the desired effect with the fewest technical issues.

In terms of organizational/logistics, representatives from all the companies and universities had too many different ideas on head design, materials choice, and fabrication techniques for any one company to make these decisions. NSIC's project participants therefore took it upon themselves as a group to determine which materials worked best. This task required thousands of research hours, conducted in parallel, at each of the participating institutions and hundreds more hours compiling the data and discussing which method worked best. This cooperation was a remarkable aspect of the ATP project; companies that were trying to drive each other out of business in the marketplace were actually cooperating with one another on precompetitive

1. Email conversation with Jim Brug, August 10, 2001.
2. Ibid.

competitive research to come up with the best possible materials and methodologies for GMR heads.

Using GMR Head Technology Leads to Product Introductions

After the initial research, multiple companies integrated GMR head technology into a variety of products that resulted in truly remarkable capabilities. The first product to hit the market using GMR technology was IBM's Deskstar 16GP™.

The product was announced in the last quarter of 1997 (less than six months after the end of the NSIC ATP project) and shipped in volume starting in the first quarter of 1998. GMR technology also enabled a 73-gigabyte hard drive, IBM's Ultrastar 72ZX™, which at the time was the largest hard drive ever made. The hard drive, used for transaction processing and digital documentation, could store seven billion data bits per square inch. Roughly the size of a paperback novel, it could hold as much information as a floor of books at the New York Public Library (with room to spare).

In the highly competitive magnetic recording industry, companies are known to rapidly outpace one another. For example, less than six months after IBM introduced the Ultrastar model, Seagate announced the demonstration of technology that could store 20.8 billion bits (gigabits) per square inch. IBM followed by announcing a 20.3-gigabit laboratory demonstration in May 1999 and another 35.3-gigabit demonstration in October 1999, nearly doubling demonstrated density within six months! By mid-2002, laboratory demonstrations using GMR heads had achieved the astounding level of 103 gigabits per square inch.

These developments in GMR head technology have enabled the U.S. industry to deliver hard-drive products that serve a multitude of application environments. Examples include:

- Drives with extremely high capacity, such as the Barracuda 180 drive from Seagate (with a total capacity of 181.6 gigabytes) and Western Digital's 200-gigabyte Caviar® "Drivezilla" drive
- Drives with rotational speeds as great as 15,000 revolutions per minute to provide very-high-speed access and transfer of data (such as the high-performance models of IBM's Ultrastar and Seagate's Cheetah drive families)
- Drives designed with a single disk platter to permit low product cost while providing astonishing capacities of 60 to 80 gigabytes from Maxtor, Seagate, Western Digital, and others
- Small, form-factor, mechanically robust drives with capacities as great as 60 gigabytes (IBM's Travelstar 60GH product) to serve the mobile computer market
- The miniaturized IBM Microdrive that provides one gigabyte of storage in a package weighing less than 16 grams for use in digital cameras and other handheld consumer electronics

NSIC Changes Magnetic Recording in Record Time

The GMR head technology that resulted from the ATP project changed the magnetic recording industry. Once it was apparent that GMR heads improved data storage density nearly hundredfold, industry moved quickly to adopt the technology. By the last quarter of 2000, the new technology had been fully adopted by the U.S. industry: all hard drives manufactured by U.S.-based companies used GMR heads. In other words, GMR heads achieved a 100-percent market penetration in three years. In comparison, thin-film inductive heads took 15 years to be adopted as the industry standard, and conventional MR heads took 5 years.

GMR head technology also has the potential to further change the magnetic tape recording industry via two distinct scenarios. First, as future generations of tape recording technology evolve toward much higher track densities and thinner magnetic media, GMR heads, because of their ability to provide the required additional signal-detection sensitivity, will probably replace conventional MR heads.

At the same time, continuing improvements in hard-disk technology afforded by the use of GMR heads are providing disk storage arrays with newly emerging opportunities in applications that have traditionally been served by tape. These include backup and restore functions in computer environments ranging from large enterprises to small businesses.

GMR heads achieved a 100-percent market penetration in three years.

This wave of new products contributed to an increase of eight percent in the U.S. market share of global magnetic recording devices. At the start of the ATP project, U.S.-based companies held a 62-percent global market share. As of the last quarter of 2000, when GMR heads completely penetrated the industry, U.S.-based companies held 70 percent of the global market share, with Japanese companies holding the next largest portion. Japanese firms have recently formed their own NSIC-like consortium to try to compete with U.S.-based firms. NSIC was later renamed the Information Storage Industry Consortium, or (INSIC).

Conclusion

ATP funded the efforts of NSIC to coordinate an extensive research and development process designed to significantly advance MR head technology. As a result of comprehensive materials testing and modeling, GMR head technologies enabled an extensive set of new data storage products. Although a completely integrated magnetic recording demonstration at a density of 10 billion bits per square inch was not carried out within the timeframe of the ATP project, the resulting technology represented such a significant advancement over earlier technology that, within three years after the ATP project ended, 100 percent of all hard drives produced used GMR technology.

PROJECT HIGHLIGHTS
Information Storage Industry Consortium (INSIC)
[formerly National Storage Industry Consortium]

Project Title: Cooperative Effort Leads to Magnetic Recording Innovation (Ultra-High-Density Magnetic Recording Heads)

Project: To develop technology for new data recording heads capable of writing and reading 10 gigabits per square inch; a hundredfold improvement over the best commercial devices available when the project began.

Duration: 8/1/1992-7/31/1997
ATP Number: 91-01-0016

Funding (in thousands):

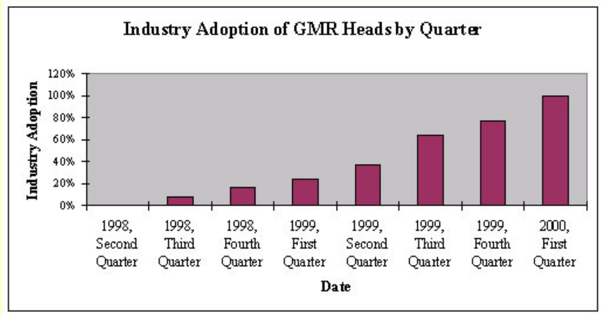
ATP Final Cost	$ 5,457	48%
Participant Final Cost	5,984	52%
Total	$11,441	

Accomplishments: This ATP-funded project was remarkably successful. The research and development process helped to create giant magnetoresistive (GMR) heads that could record nearly 100 times more information per square inch of recording medium than the heads that were commercially available at the time. The successes of the ATP project included:

- Coordinating hundreds of researchers across the country on a single project
- Achieving a technological breakthrough that industry experts initially believed was impossible
- Combining films of existing materials to create new devices that, at just a few atoms' thickness, exhibited the required magnetic properties
- Creating read and write heads so exact that errors occurred no more than once in every 10^{14} bits
- Developing a technology that 100 percent of the industry adopted within three years
- Enabling an additional eight-percent global market share for U.S.-based companies

NSIC coordinated efforts among hundreds of researchers to set an industry standard for the very best magnetic recording heads possible. Subsequent related products pushed the envelope of magnetic recording farther and faster than ever.

Commercialization Status: Before the ATP project, GMR head technology did not exist, and magnetic inductive head technology was rapidly reaching its technological zenith. During the ATP project, researchers settled on the GMR head design and on specific materials to use in its fabrication. After the ATP project ended, GMR head technology received such broad and fast industry adoption that it became the industry standard in record time, as shown in the chart (source: Morgan Stanley Dean Witter Disk Drive Industry Update, June 15, 2001).



The previous two generations of magnetic recording head technology took 15 and 5 years, respectively, to become the standards. GMR heads took less than three years to achieve total market domination. Until the next generation of technology replaces GMR heads, companies will continue to use the technology in every hard drive they produce.

Outlook: The GMR head technology that benefited from the ATP project changed the face of magnetic recording. When GMR heads enabled a nearly hundredfold improvement, the industry moved as fast as it could to adopt the technology. GMR technology currently dominates the marketplace. Industry competitors are still rushing to improve the technology as quickly as possible to surpass their competitors. This dynamic should continue for the foreseeable future; the outlook for GMR head technology is outstanding within the magnetic recording industry.

Composite Performance Score: * * *

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Research and data for Status Report 91-01-0016 were collected during October - December 2001.

Laser Power Corporation

Commercializing Red-Green-Blue Microlaser Technology to Revolutionize Projection Displays

Increased demand for bigger, brighter, and higher resolution large-screen, high-definition televisions and projection displays prompted a joint venture between Laser Power Corporation and Proxima Corporation to explore the use of laser technology to meet this demand. As relatively early-stage companies, the joint venture partners lacked sufficient internal funds for research and development, while other more established firms considered the use of lasers in projection displays as too risky to meet the required rate of return for private funding. In short, the joint venture had the necessary expertise and vision, but it lacked the funds to develop projection displays that could be purchased or manufactured through licensing and placed in a variety of products. Co-funding from the Advanced Technology Program (ATP) allowed the companies to pursue the development of a high-resolution multimedia laser projection display. The joint venture successfully developed red-green-blue microlasers and prototyped a projector display unit. Although commercialization of the display unit was not cost effective, the microlasers were applied to a wide variety of other displays. Laser Power Corporation sold the microlaser technology to Melles Griot, which continues to develop it.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* *

Research and data for Status Report 94-01-0133 were collected during Ocober – December 2001.

Projection Displays Viewed as the Wave of the Future

Difficulty in manufacturing large-screen, direct-view liquid crystal displays and cathode ray tubes (CRTs) led many developers to believe that projection displays would be the wave of the future for large-screen, high-definition television (HDTV). Furthermore, developers thought projection displays would penetrate the existing market for direct-view, CRT-based television.

At the time this project was proposed, the idea of using a laser to project high-resolution images was groundbreaking.

Therefore, Laser Power Corporation (LPC) entered into a joint venture with Proxima Corporation to develop a high-resolution, multimedia laser projection display and to then pursue a higher risk, higher payoff technology that addressed super-resolution HDTV requirements for large-screen applications. The success of this project hinged on commercializing LPC's red-green-blue (RGB) microlaser technology, which, if successful, would revolutionize the projection display market. At the time this project was proposed, the idea of using a laser to project high-resolution images was groundbreaking. As promising as the idea was, however, a joint venture involving two relatively early-stage companies could not attract a source of funds to enable the necessary research.

More established firms, for example, considered the research and development expense of using lasers as too high to generate required rates of return on either internal or other sources of private funding.

In 1995, the joint venture submitted a proposal to ATP for cost-shared funds to conduct its research and development. The project's goal was to achieve a 1,000-lumen, 10-lumens-per-watt projection display on a screen that is approximately 90 inches diagonal and combines HDTV resolution with 24-bit color. At the project’s conclusion in 1997, LPC had successfully developed RGB diode-pumped, solid-state microlasers to produce full-color images that had extremely high resolution and brightness. Of all the project's achievements, the microlaser development was the most impressive.

LPC Overcomes Technical Risks in Microlaser Development

Development of the blue microlaser source had the highest technical risk. When the project first started, LPC could generate no more than 10 milliwatts (mW).Through the ATP project, the company overcame many technical challenges to develop what was referred to at the time as the most powerful commercially available blue microlaser, exceeding 780 mW at 457 nanometers (nm). At the end of the program, LPC was focused on improving the operating life of the blue microlaser unit.

One of the most significant outcomes of the ATP project was the advancement of the microlaser technology and the positive impact on a variety of other laser-based display initiatives.

Although the blue microlaser was the most noteworthy of the three microlasers developed, the output levels of the green and red microlasers were also increased significantly. Initially, LPC was unable to produce more than 300 mW of green microlaser power. By the end of the project, it had developed its most powerful laser, which could produce 4.4 W at 532 nm. This achievement represented a 15-fold improvement in power for the green laser, without an alteration in the quality of the green light. In addition, by the end of the project, LPC had improved red microlaser production from an initial output of 90 mW to 1.6 W at 656 nm.

Although LPC attained the desired level of output for the red microlaser, it was unstable and unreliable at that power level. LPC had to temporarily lower output power and change power sources to make the red microlaser more stable. Despite the problems, the company still views the development of the red microlaser as a significant achievement.

ATP Project Spurs Additional Industry Benefits

The successful development of these three diode-pumped, solid-state microlasers enabled LPC to continue its research and development initiatives. The company incorporated the microlasers into various display units with Proxima Corporation and with other companies seeking to benefit from the resulting increase in resolution. Moreover, both LPC and Proxima successfully completed several other planned objectives.

As a result of the ATP project, LPC's other contributions included light-shaping development, beamlet formation, polycrystalline lanthanum-modified lead zirconate titanate modulator development, scanner development, and optical system design. Proxima's contributions included modulator driver development, video electronics development, and color gamut transformation.

LPC's Research and Development Efforts Span Public and Private Sectors

One of the most significant outcomes of the ATP project was the advancement of the microlaser technology and the positive impact on a variety of other laser-based display initiatives. For example, shortly after the start of the ATP project, LPC was awarded funds to develop a 1280 by 1024 resolution (color pixel) system for Armstrong Laboratories, research that ran concurrently with the ATP-funded research.

Based on the results of both the ATP project and the Armstrong Laboratories research, Armstrong awarded LPC an additional contract that focused on developing an even higher resolution projector. This new projector was to be used in a flight simulator and needed a resolution of 5000 by 4000 (compared with the resolution of standard broadcast television, which is 480 by 640).

Following the conclusion of the ATP project, LPC continued to pursue other initiatives with both Armstrong Laboratories and other private-sector and government entities. For example, under the sponsorship of the Defense Advanced Research Projects Agency, LPC began developing a digital-color version of the direct-write projector and head-mounted displays.

Further leveraging its established industry relationships, LPC developed a full-color, laser projection display test bed, which was based on highly efficient RGB microlasers. These high-power, high-efficiency microlasers have repeatedly proved to be the critical component in high-resolution, high-brightness, laser projection displays. The microlasers also have been applied to multiple backlight laser projectors and multiple direct-write displays.

LPC Addresses Safety Concerns with Lasers

LPC also conducted eye safety evaluations to ensure that the new products are safe for commercialization. The company hired Dr. Myron Wolbarsht, the author of *Safety with Lasers and Other Optical Sources* and a recognized legal expert in the field of laser safety.

Laser products are classified on a scale of I to IV, based on the degree of hazard posed by the output beams. After careful analysis, Dr. Wolbarsht determined that LPC's projector could be manufactured to conform to a Class II laser classification, rather than the higher power, more dangerous Class III level. Class II lasers are low power (less than 1 mW) and are visible-light lasers that can possibly cause damage to one's eyes. Some examples of the use of Class II lasers are laser pointers, aiming devices, and range-finding equipment.

LPC Sells Microlaser Business Unit

After the conclusion of the ATP-funded project, LPC began marketing green and blue microlaser products to medical and other customers. The company manufactured these products in a low-volume fabrication facility. LPC planned to expand its capabilities by building a new production facility; however, this effort was slow to progress, and LPC eventually sold its microlaser business unit to Melles Griot, Inc., a member of Barlow Scientific Group, Ltd. The sales agreement provided for initial payments for the purchase of most of the assets of LPC’s microlaser operations and for future royalty payments of up to $2.7 million, based on sales of products that incorporate microlaser technology.

LPC's products allow Melles Griot to sell microlasers that offer 3 W of output power at 532 nm, shorter wavelengths at 457 nm, and a robust, solid-state technology. In addition, LPC's microlaser products were transferred to the Melles Griot Laser Group's new and wholly dedicated 100,000-square-foot laser-manufacturing facility in Carlsbad, California.

New Technology Benefits Many Industries

Proxima Corporation incorporated the microlaser technology into its display units. The company developed working prototypes of projector display units that incorporated the RGB microlaser technology. After further research, however, Proxima determined that it was not economically feasible to pursue commercialization initiatives. Proxima's studies revealed that, although the new technology was very effective in both brightness and resolution, competing products were more cost effective.

Although Proxima did not pursue this project beyond the development stage, the company gained a significant understanding of the new technology. This knowledge helped Proxima to apply the microlaser technology to other projection-display products, as well as in other technology areas that rely on modulated light information transmission. The primary benefit of this new technology to both directly and indirectly related applications was a significant increase in viewing resolution. In the projection market alone, some of the applications that benefited from the increase in resolution include:

- Helmet-mounted displays
- Virtual-reality viewers
- Flight simulators
- Advanced aircraft-cockpit displays
- Home entertainment systems
- Medical/surgical training aids

Although the initial objective to incorporate the RGB microlaser technology into high-resolution multimedia laser projection display units was not accomplished, a significant level of spillover was achieved in otherproducts and industries. Furthermore, the knowledge base resulting from this project continues to be valuable to both the companies involved and to others.

Conclusion

Although LPC sold its microlaser business unit to Melles Griot, the outlook for the RGB technology and its associated benefits is excellent. Melles Griot, with its strong revenue stream and solid customer base, is well positioned to further advance the RGB microlaser technology. Moreover, the United States is positioned to profit from this technology through its stronger presence in the microcrolaser projector and microlaser markets.

Although Proxima did not pursue commercialization of the high-resolution multimedia laser projection displays, the company gained a significant understanding of the new technology, which led to the granting of several patents. In June 2000, Proxima Corporation and Infocus Corporation completed a merger agreement. The new company kept the name InFocus Corporation and is now the world's largest developer, manufacturer, and marketer of multimedia projection systems and services.

PROJECT HIGHLIGHTS
Laser Power Corporation

Project Title: Commercializing Red-Green-Blue Microlaser Technology To Revolutionize Projection Displays (High-Resolution Multimedia Laser Projection Display)

Project: To research and develop methods of production for RGB laser technology to meet projected demands for large-area, HDTV, and multimedia displays.

Duration: 1/15/1995-1/14/1997
ATP Number: 94-01-0133

Funding (in thousands):

ATP Final Cost	$ 1,695	48%
Participant Final Cost	1,800	52%
Total	$ 3,495	

Accomplishments: Laser Power Corporation achieved several technical successes through its collaboration with ATP, including the following:

- LPC increased the blue microlaser's output power from 10 mW to greater than 750 mW.
- LPC increased the green microlaser's output power from 300 mW to 4.4 W.
- LPC continues to improve the red microlaser's output power along with the other microlasers.
- Furthermore, Proxima developed working prototypes of display units that incorporate the RGB microlaser technology.

LPC received the following patents for technologies resulting from this ATP project:

- "Efficient frequency - converted laser" (No. 5,761,227: filed December 5, 1996, granted June 2, 1998)
- "High resolution image projection system and method employing lasers" (No. 5,990,983: filed June 23, 1997, granted November 23, 1999)

Proxima received the following patent for technologies resulting from this project:

- "Laser illuminated image producing system and method of using same" (No. 5,704,700: filed July 24, 1995, granted January 6, 1998)

Commercialization Status: Melles Griot is continuing the research, development, and commercialization of red-green-blue microlaser technology. InFocus Corporation, the result of the merger between Proxima Corporation and InFocus Corporation, is now the world's largest developer, manufacturer, and marketer of multimedia projection systems and services. InFocus Corporation continues to benefit from the RGB microlaser technologies developed during the ATP project.

Although the original companies involved in developing this breakthrough technology are not actively pursuing the RGB microlaser display technology, they have benefited from this joint program. LPC, which was the lead participant in this project, sold its microlaser business unit to a company that could properly support the continuation of the technology. In addition to the undisclosed dollar amount for the sale of the unit, LPC arranged for $2.7 million in future royalty payments to aid in the company's expected technology research and development endeavors in its core competencies of optics and thin film coatings.

Outlook: The multimedia projection systems and services market is expected to grow substantially because of high demand. Therefore, the potential for diffusion of the ATP-funded technology through Melles Griot and InFocus Corporation is promising.

Composite Performance Score: * *

Number of Employees: Eighty-five employees at project start, 85 upon completion of status report

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Research and data for Status Report 94-01-0133 were collected during October – December 2001.

MicroFab Technologies, Inc.

Using Solder-Jet Technology to Attach Semiconductor Chips to Circuit Boards

High-density chips require high-density soldering methods to solder leads to circuit board contacts. Continuing advances in electronics miniaturization spurred manufacturers to seek cheaper and faster methods for packing greater functionality into less space, without using toxic chemicals during the tooling process. They sought new methods that lacked the complexity, expense, tooling-intensiveness, and time-consuming steps of the existing methods. One technology that emerged is liquid solder-jetting, a process that uses the printing industry's ink-jetting methods to "write" molten solder directly onto electronic components such as circuit boards, surface mount packages, and chips.

COMPOSITE PERFORMANCE SCORE

(based on a four star rating)

* * *

Research and data for Status Report 93-01-0183 were collected during October - December 2001.

Ink-Jet Printing Technology To Connect Microelectronic Components

MicroFab Technologies, Inc., a small company based in Plano, Texas, was founded in 1984 by an expert in ink-jet printing technology. In 1994, the company received $1.6 million in funding from the Advanced Technology Program (ATP) to apply its ink-jetting methods in a novel way to disperse molten metal solder drops to attach semiconductor chips to circuit boards. The resulting technology can produce droplets as small as 40 microns across (about half the width of a human hair). No other technique had been able to establish sizes this small. The size of the droplets allows more information to be packed into less space, with far more control over the process. In addition, jet-based solder equipment can produce and place molten solder droplets at rates up to 2,000 droplets per second.

MicroFab's method "writes" the solder patterns on circuit boards at high temperatures using an ink-jet printer. The technique is unique in its ability to write solder lines and achieve line density four times that of traditional lithography methods.

MicroFab Explores Two Methods To Generate Solder Streams

During the ATP project, MicroFab explored continuous and drop-on-demand methods for generating solder streams. In the continuous method, the liquid solder goes through a charging electrode system that creates pressure oscillations of constant frequency that break up the solder stream into uniform droplets and can produce thousands of solder droplets per second. A disadvantage of this method is that unused drops are produced that must be recycled or discarded, which raises an environmental concern.

The drop-on-demand solder method uses a reservoir of fluid that is acted on by a force, which causes it to eject droplets in a discrete volume. It is a slower process that has the advantage of generating no excess droplets that must be discarded. MicroFab selected the drop-on-demand method for its ink-jet soldering because this method avoided the environmental concerns of the continuous method. Ink-jet solder deposition is a low-cost alternative to traditional soldering methods because no masks or screens are required.

It is flexible because images are formed and stored digitally, and it is highly repeatable at differing resolutions. It lends itself to customization and reworking. Because ink-jet soldering is driven by computer-assisted design, it provides more flexibility in the types of patterns that can be created and the variety of applications for which it can be used.

The solder-jet technology can produce droplets as small as 40 microns across (about half the width of a human hair). No other technique has been able to establish sizes this small.

Real-time process control is possible because the depositions can be inspected immediately after the process, thus reducing prototyping and development time. This represents a major improvement over other less flexible methods.

Consortium Formed to Test Prototypes

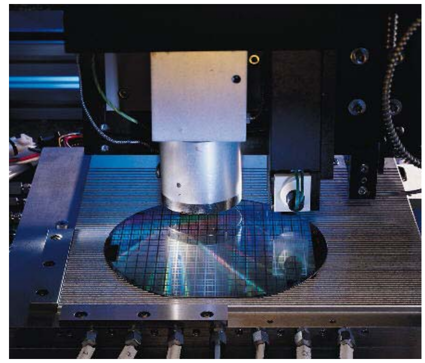
During the time that MicroFab collaborated with ATP, the company also entered into a consortium with high-end original equipment manufacturers, which represented the potential end users of this technology. These manufacturers, including Motorola, Delco, Texas Instruments, Kodak, and AMP, received prototype machines that used the solder-jet technology, tested them, and provided feedback to MicroFab as development proceeded.

The ATP award helped MicroFab to collaborate with and attract additional funding from a consortium of five major electronics manufacturers to further develop its technology.

Accordingly, the requirements of the technology were more quickly and accurately defined, and MicroFab was able to more easily and accurately configure the machines to implement the technology. These relationships also had the potential to improve the ultimate diffusion of the technology.

MicroFab Leverages Solder Jet Technology

The development of solder jet technology enabled MicroFab to create other viable technologies as well. In



Liquid solder-jetting uses the printing industry's ink-jetting methods to "write" molten solder directly onto electronic components such as circuit boards, surface mount packages, and chips.

its own production, it applies the drop-on-demand process it developed during the project. MicroFab uses the solder jet technology in its its Jetlab® platform, which has a selling price of approximately $200,000. The Jetlab® platform is a tool for a variety of industries—including microelectronics, photonics, medical diagnostics, and drug delivery—to identify jetting processes and fluids that best meet their specific needs. In addition, MicroFab sells fluids designed for micro-optic and microelectronic applications. It also supplies printhead subsystems using the ATP funded technology.

Conclusion

Many were skeptical of MicroFab's proposed process. In fact, major players in the industry said that it could not be done. Such skepticism reflected the highly risky nature of the venture. Private capital was unavailable to the company in order to pursue development of the technology. Without ATP's help, MicroFab would have had great difficulty in proceeding with its concept. In the words of MicroFab's research director David Wallace, "We'd done some preliminary technical work and feasibility studies to show our concept's viability, but it was at a stage where it was far too risky to get venture capital or investments from large end-user companies that would be beneficiaries of the technology."

ATP's backing also gave other major players in the industry the confidence to test the new process. The ATP award helped MicroFab to collaborate with and attract additional funding from a consortium of five major electronics manufacturers to further develop its technology. MicroFab continues to work with these manufacturers and other end users to develop and refine the technology.

PROJECT HIGHLIGHTS
MicroFab Technologies, Inc.

Project Title: Using Solder-Jet Technology to Attach Semiconductor Chips to Circuit Boards

Project: To develop a fast, accurate, and flexible process for "writing" solder droplets onto electronic circuit boards by applying the concepts of ink-jet printing.

Duration: 1/1/1994-12/31/1996
ATP Number: 93-01-0183

Funding (in thousands):

ATP Final Cost	$1,639	70%
Participant Final Cost	695	30%
Total	$2,334	

Accomplishments: MicroFab, with ATP funding, developed a prototype process to demonstrate the dispensing of 40-micron to 120-micron spheres of molten solders onto high-density electronic components at temperatures up to 220 °C, on demand, and at rates up to 2,000 per second.

MicroFab received the following five patents for technologies resulting from its ATP-funded project:

- "Method of making solder interconnection arrays"
  (No. 5,377,902: filed January 14, 1994; granted January 3, 1995)
- "Solder compositions and methods of making same"
  (No. 5,411,602: filed February 17, 1994; granted May 2, 1995)
- "Process for manufacturing metal ball electrodes for a semiconductor device"
  (No. 5,861,323: filed June 6, 1994; granted January 19, 1999)
- "Methods and apparatus for forming microdroplets of liquids at elevated temperatures"
  (No. 5,415,679: filed June 20, 1994; granted May 16, 1995)
- "Printhead for liquid metals and method of use"
  (No. 5,772,106: filed December 29, 1995; granted June 30, 1998)

MicroFab published several papers and gave several presentations regarding the ATP-funded technology. Toward the end of the project, the company attracted funding from the Defense Advanced Research Projects Agency (DARPA) to test the dispensing of high-lead solders at even higher temperatures (325 °C), with partial success.

Commercialization Status: MicroFab has progressed to the point of commercializing its ATP- funded technology. At the time the information for this report was being collected, the company was in the process of launching an outsourcing business to provide its soldering techniques to customers. In the fall of 2001, MicroFab also licensed its technologies for use in solder balls. MPM, a division of the Cookson Group, PLC, invested more than $5 million in the development of this technology.

Outlook: MicroFab continues to test the solder-jet technology pioneered under the ATP-funded project for additional applications in microelectronics and other industries. One technical issue that still remains is achieving reliability in the yield of the solder droplets that are produced. MicroFab is continuing research and development efforts to explore ways of improving reliability.

Composite Performance Score: * * *

Number of Employees: 18 employees at project start, 30 employees as of December 2001. A new micro-optics division consisting of five employees was created as a result of the project.

Company:
MicroFab Technologies, Inc.
1104 Summit Avenue
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Plano, TX 75074

Contact: David B. Wallace
Phone: (972) 578-8076

Collaborating Consortium Members:
Motorola, Delco, Texas Instruments, AMP, and Kodak

Research and data for Status Report 93-01-0183 were collected during October - December 2001.

Micron Optics, Inc.

Faster, More Accurate Filters for All-Optical Networks

The increased need for speed and precision in a variety of communication networks has spurred the quest to develop high-speed, high-capacity, packet-switched, all-optical fiber networks. Networks face bottlenecks, among them the slowness of electronic switches. In a project that started in 1994, Micron Optics, Inc., a small company from Atlanta, GA, was awarded funds by the Advanced Technology Program (ATP) to develop the technology to increase the speed and accuracy of fiber Fabry-Perot tunable filters (FFP-TF) using ferroelectric liquid crystals. Although Micron Optics was unable to accomplish this goal, the company was able to miniaturize the FFP-TF, and this improved device is currently being used in the mechanical sensing, optical performance, and test equipment markets.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* *

Research and data for Status Report 93-01-0027 were collected during October-December 2001.

Telecommunication Networks Require High-Speed Capacity

Advances in telecommunications occur at a rapid pace, but technological advances are sometimes uneven. This was the case when the use of fiber optics for transporting telecommunication signals began to expand rapidly within the industry in the early 1990s.

Increased bandwidth demands could not be met with electronic networks.

Prior to the start of this ATP project, millions of miles of fiber that carried long-range and local communications were already in place in the United States. However, there was a bottleneck problem in the electronic systems that were used to detect and switch signals at both ends of the fibers. Furthermore, increased bandwidth demands could not be met with electronic networks. It was anticipated that the use of all-optical networks would solve this problem. Networks were increasingly using a technique called wavelength division multiplexing (WDM), which uses optical rather than electronic systems. WDM involves using multiple laser wavelengths to carry many signals simultaneously simultaneously. In the end, a machine is used that can translate the light back into binary signals if necessary.

Century-Old Technology Updated for Optical-Fiber Networks

As fiber-optic applications technology continued to develop, it became clear that the direct optical processing of signals without conversion to electronic signals was required to sustain the speed necessary to keep up with the volume that was building in these systems. A fiber Fabry-Perot (FFP) interferometric filter is one component that can handle such an application.

Direct optical processing of signals without conversion to electronic signals was required to sustain the speed necessary to keep up with the volume.

The Fabry-Perot was first described by C. Fabry and A. Perot in 1897. Fabry-Perot filters are constructed of bulk lenses, mirrors, and beam optics along with geared positioning stages. For more than 100 years, designs based on these original optical configurations have provided the highest known optical wavelength

A miniaturized Fabry-Perot tunable filter (FFP-TF).

resolution. Other filter and tunable laser technologies offered the speed, but lacked either the tuning range or the resolution that was needed. Micron Optics added a single segment of fiber within the original Fabry-Perot device and patented the fiber Fabry-Perot tunable filter (FFP-TF). The FFP-TF is a simpler design, since it does not require complex optics and lenses; yet FFP-TFs are more robust and field-worthy than traditional Fabry-Perot interferometers. Since the early 1990s, Micron Optics has been the only supplier in the world of FFP components, including optical filters used as switches in optical-fiber networks.

However, as progress was made in telecommunication networks and their usage grew, it became apparent that the packet-switching, all-optical networks planned for the future would require far more capability than what Micron Optics could produce in the early 1990s. The electromechanical (piezoelectric)-tuned FFP filters commercially available in the early 1990s had wide wavelength-tuning ranges, but their tuning speed was limited to the 1- to 10-millisecond range. This was 1,000 times too slow for packet-switching. [(1)] In addition, these filters were limited in capacity to between 50 and 100 channels, whereas a capacity approaching 1,000 channels was needed.

Each filter cost thousands of dollars; however, widespread use could only be achieved if the cost was approximately $100. Therefore, to keep up with the capability of optical networks, it would be necessary to improve the tuning speed by a factor of 1,000, channel capacity by a factor of 10, and cost by a factor of 10.

Micron Optics Designs a Faster Fiber Fabry-Perot Tunable Filter

Micron Optics envisioned a highly optimized version of its FFP-TF that would be faster and could reach more channels by replacing the present piezoelectric-tuning mechanism with a ferroelectric liquid crystal (FLC) cavity capable of tuning the filter to the desired wavelength without requiring moving parts. The company sought to develop an FFP-TF with quicker tuning speeds and channel capacities approaching 1,000, (reaching a finesse, i.e., measure of sharpness, approaching 2,000) while costing only several hundred dollars per filter. This was an ambitious endeavor because the required improvement in performance was significant. Micron Optics wanted to develop an FFP-TF that used FLCs to tune the path length electro-optically in hopes that it would achieve packet-switching speeds that were three orders of magnitude faster than the piezoelectric device that was used for channel switching.

The company sought to develop an FFP-TF with quicker tuning speeds and channel capacities approaching 1,000 while costing only several hundred dollars per filter.

With $1.895 million in co-funding from ATP, Micron Optics teamed with subcontractors, IBM and University of Colorado, in a three-year research program to achieve these performance and cost goals. The University of Colorado focused on the FLCs, and IBM provided a testbed for evaluating the new filters. The research program centered on evaluating the following:

- High-performance FFP-TFs that included high finesse, low-insertion loss, dual-band functionality, device miniaturization, and stable thermal and mechanical characteristics
- High-speed FLC-based FFP-TFs

1. Packet-switching is a method whereby messages are divided into packets before they are sent. Each packet is then transmitted individually and can even follow different routes to its destination. Once all the packets forming a message arrive at the destination, they are recompiled into the original message.

Through its collaboration with ATP, the company was able to miniaturize the FFP-TFs. Micron Optics developed a prototype that demonstrated high-speed performance and low-cost fabrication. The new fabrication technique was an improvement over Micron Optics' previous technique, which required constant realignment. These improved FFP-TFs had higher finesses (>2,000), lower loss, lower mass and smaller size, good thermal and mechanical stability, and the potential for low-cost, high-volume production.

Unfortunately, research into the high-speed FFP filters using FLCs resulted in minimal success. While these FFPs provided moderate improvements in wavelength tuning range, switching time, finesse, and total insertion loss, the device fell short of Micron Optics' originally proposed goals of quicker tuning speeds and increased channel capacities.

With ATP support for research and development, Micron Optics responded to the needs of the market at the right time by decreasing the cost of FFP-TF manufacturing by 99 percent.

For these reasons, at the conclusion of the ATP project in 1996, the company decided to focus its future development efforts on improving FFP-TFs that used piezoelectric-tuning mechanisms, and they spent no more effort utilizing FLCs.

Strategic Alliances Result from ATP Funding

Advances made during its ATP project allowed Micron Optics to form pivotal collaborative alliances in the post-project period with equipment and system developers for further development of optical filter technologies. The company formed a joint effort with Photo Kinetics, Inc., to develop optical channel analyzers for WDM applications based on high-performance FFP-TFs.

Further, Micron Optics worked with the Massachusetts Institute of Technology Lincoln Labs on optical coherence tomography, an alternative to ultrasound imaging that can be used in sensor networks.

Conclusion

With ATP support for research and development, Micron Optics responded to the needs of the market at the right time by decreasing the cost of FFP-TF manufacturing by 99 percent.

The prototypes built by Micron Optics helped the firm strengthen its position in the telecommunications market as well as expanding into new markets. Shortly after the project ended, the company began introducing its FFP-TF technology into the mechanical-sensing market through prototype-based marketing in early 1997. More recently, it has expanded into the optical performance and test equipment areas.

PROJECT HIGHLIGHTS
Micron Optics, Inc.

Project Title: Faster, More Accurate Filters for All-Optical Networks (Fiber Fabry-Perot Tunable Filters for All-Optical Networks)

Project: To combine FLCs as the tuning element in fiber Fabry-Perot optical filters suitable for a high-speed, high-capacity, packet-switched, all-optical fiber communications network with switching speeds of 1 to 10 microseconds and capacities approaching 1,000 channels.

Duration: 1/1/1994-12/31/1996
ATP Number: 93-01-0027

Funding (in thousands):

ATP Final Cost	$1,895	58%
Participant Final Cost	1,354	42%
Total	$3,249	

Accomplishments: Through ATP's funding support for research and development, Micron Optics developed a prototype of a tunable high-speed FFP, which was a significant technical development. Moreover, the company experienced a 100-percent increase in sales, a 50-percent increase in research and development funding, and a sevenfold increase in the number of its employees. They gave several presentations and published 25 articles on its project-related research.

Micron Optics received the following patents for technologies resulting from this successful ATP project:

- "Temperature compensated fiber Fabry-Perot filters"
(No. 5,509,093: filed August 9, 1994, granted April 16, 1996)

- "Temperature compensated fiber Fabry-Perot filters"
(No. 5,563,973: filed May 30, 1995, granted October 8, 1996)

- "Reference system for optical devices including optical scanners and spectrum analyzers"
(No. 5,838,437: filed April 9, 1997, granted November 17, 1998)

- "Fabry Perot/fiber Bragg grating multi-wavelength reference"
(No. 5,892,582: filed July 21, 1997, granted April 6, 1999)

- Temperature compensated fiber Bragg gratings”
(No. 6,044,189: filed December 3, 1997, granted March 28, 2000

- "Fabry-Perot Fiber Bragg Grating Multiwavelength Reference"
(No. 6,115,122: filed April 5, 1999, granted September 5, 2000)

- "Fabry-Perot/Fiber Bragg Grating Multiwavelength Reference"
(No. 6,327,036: filed September 5, 2000, granted December 4, 2001)

Commercialization Status: Although Micron Optics did not develop an FFP-TF using FLCs, by 1995 the company had improved its original FFP-TF by developing a prototype that incorporated the results of its ATP-funded project. These results yielded advances over the earlier filter in terms of high-speed performance and low-cost fabrication. The prototype has since been commercialized, and companies in multiple industries use the technology in various components.

Outlook: Micron Optics was able to improve its FFP-TFs; however, the outlook for FLC-based FFPs is poor because the company was unable to meet its technical goals. Since the conclusion of the project, the company has redirected its attention on continuing to improve piezoelectric transducer-based FFPs.

Composite Performance Score: * *

Number of Employees: 10 employees at project start, 74 employees upon completion of status report

Company:
Micron Optics, Inc.
1900 Century Place, Suite 200
Atlanta, GA 30345

Contact: Calvin Miller
Phone: (404) 325-0005

Subcontractors:
IBM
University of Colorado

Research and data for Status Report 93-01-0027 were collected during October-December 2001.

Physical Optics Corporation

Holographic Diffusers Can Efficiently and Cost Effectively Distribute Light

Many industries use some kind of light source in their products. For instance, industries that make laptop computers, flashlights, or projection-display screens need a dependable light source. Conventional light diffusers, such as frosted glass or plastic, tend to spread light inefficiently, which wastes energy and money. Physical Optics Corporation (POC) invented a new type of diffuser screen, but the time required to complete development and to bring the technology to market was still too long to attract private capital. In 1994, the company applied for and was awarded cost shared funding from the Advanced Technology Program (ATP) for a two-year project. With ATP funding, POC was able to overcome the technical barriers to cost-effective use of its technology, and develop a diffuser screen that could provide an intense, evenly distributed beam of light that was more than twice as efficient as previous diffusers. Moreover, the screen lowers the power consumption of computer displays up to 10 times, significantly increasing battery life for laptop computers. Through this innovation, POC also has been able to increase its market share both in the United States and abroad.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * *

Research and data for Status Report 93-01-0205 were collected during October - December 2001 and January - March 2002.

Inventing a New Light Source is a Long-Term Project

Historically, overhead lighting, flashlights, liquid crystal displays (LCDs), projection displays, and even movie screens have been inefficient. Conventional frosted glass or plastic light diffusers scatter light equally in all directions, instead of directing light where it is needed.

Physical Optics Corporation tried to correct the problem of nondirectional light by developing new light-diffusion devices.

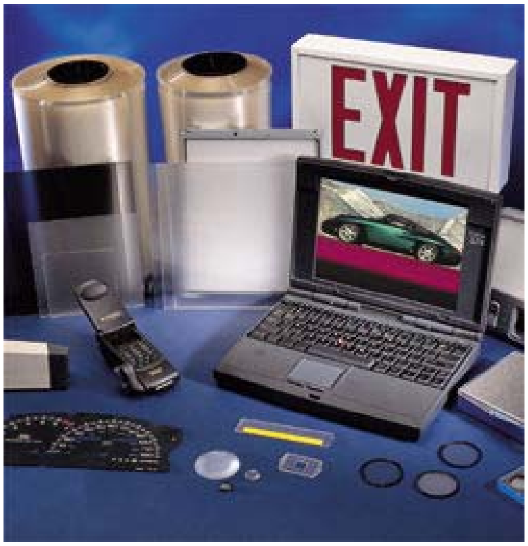
They also produce strong backscattering, so much of the light energy is scattered backward and is essentially lost. Over the years, plastics companies have attempted to create new and improved diffusers; however, on the whole, the new diffusers have remained inefficient and costly.

Physical Optics Corporation (POC) tried to correct the problem of nondirectional light by developing new light-diffusion devices, but the company lacked the funds to complete the necessary research and development (R&D). Traditional sources of capital were not interested in a high-risk project that would involve years of R&D before showing a profit.

ATP and POC's Partnership Changes Lighting

"None of this would have ever happened without ATP," said Rick Shie of POC. Mr. Shie was referring to POC's opportunity to pursue its idea that although the development of holographic technology was important, incorporating the improvements into useful devices was key. With ATP funding, POC honed the exacting science of holographic diffusers and made it reliable.

Holographic diffusers can increase the brightness of any traditional light source and greatly enhance the brightness and contrast of optical images. This effect is accomplished by using proprietary holographic



Laptop computers, flashlights, or projection-display screens are among the products that utilize holographic diffuser technology.

technology to produce screens and filters that sculpt beams of light by distributing most of the light into the desired direction. Beam shaping controls the vertical and horizontal intensity distributions of the beam, leading to directed light intensities. Holographic diffusers also can "homogenize" light beams, which can be described as restructuring light beams into a uniformly diffused beam without internal structure or "hot spots," regardless of the source (e.g., filament, lamp, and LCD backlighting).

With ATP funding, POC honed the exacting science of holographic diffusers and made it reliable. Holographic diffusers can increase the brightness of any traditional light source and greatly enhance the brightness and contrast of optical images.

POC also developed high-resolution screens in a variety of sizes, shapes, and properties for a range of applications. The company developed projection (or reflection) screens capable of providing intense and directed light beams onto a surface and transmission screens that greatly enhance what was once a dull image.

POC Ensures Mass Production and Opens New Markets

Early versions of holographic diffusers were difficult to mass-produce because they were small and were based on volume scattering. Epoxy diffuser replicas were durable, but delicate and hard to mass-produce. Even with proper handling, cleaning, and storage in a clean environment, only a limited number of diffusers could be made from a single master.

POC's innovation has spawned new markets.

POC's surface-relief holographic scatterers, however, eliminated the painstaking process of producing optical holograms one by one, making mass-production possible. Being able to translate theory into practice was the next challenging step. POC persevered and developed two processes that would ensure mass-production capabilities:

(1) high-pressure molding for smaller products, and

(2) web production for larger applications.

As a result, POC's innovation has spawned new markets, such as flashlights for aircraft inspections, enhanced blood analyzers, heat-resistant directed lighting, automotive dashboard display panels, semiconductor mask homogenizers, credit card security products, and data-storage technology.

Holographic Technology Doubles Diffuser Efficiency

Successful development of a new type of diffuser screen with holographic technology resulted in an intense, evenly distributed beam of light. This innovation has allowed POC to develop light diffusers that are more than twice as efficient as previous diffusers. In addition, the diffusers can lower the power consumption of a computer display by up to 10 times, compared with typical cathode ray tube displays that use approximately 110 watts of energy.

POC has expanded its initial business strategy. It has formed alliances with various original equipment manufacturers (OEMs) and has agreed to license its technology to specific application providers. POC also established a dedicated production facility for holographic diffusers that currently produces 100,000 parts per month.

Conclusion

In May 1996, Physical Optics Corporation (POC) created a subsidiary, Farlight Inc. (which was sold to Farlight LLC in 2000), to commercialize the holographic diffuser technology for industrial and residential lighting applications. POC is actively pursuing potential new applications for the technology, such as the next generation of display screens (reflection and transmission), large screens for high-definition television, computer displays in a variety of sizes, cockpit and car dashboard screens, and ATM displays.

During the course of the ATP project, POC evolved from a low-revenue research and development business into a manufacturing and marketing company with $20 million in annual revenues. Through contracts with large automotive companies, such as Ford Motor, as well as with computer component providers, POC will continue to improve the efficiency of lighting sources.

PROJECT HIGHLIGHTS
Physical Optics Corporation

Project Title: Holographic Diffusers Can Efficiently and Cost Effectively Distribute Light (Holographic Graded Index Non-Lambertian Scattering Screens and Components with Light-Shaping Capability)

Project: To develop innovative techniques and manufacturing processes for holographic scattering screens and diffusers capable of controlling, distributing, and efficiently using light from a variety of sources for flashlights, LCDs, projection displays, laptop computers, and other applications in which tailored lighting is required.

Duration: 2/1/1994-1/31/1996
ATP Number: 93-01-0205

Funding (in thousands):

ATP Final Cost	$ 850	49%
Participant Final Cost	870	51%
Total	$1,720	

Accomplishments: During this ATP-funded project, Physical Optics Corporation (POC) perfected new holographic systems for recording diffusers with desired scattering distributions. The company also developed the technology for surface-relief holographic diffusers, substantially improved coating and processing techniques for deep-surface structures, and refined fabrication techniques for high-resolution diffusion masters.

A number of trade press and journal articles were written about this technology. The following is a sample of articles related to the ATP project:

- Lerner, J. M., R. L. Shie, and Joel Peterson. "Holographic Light Shaping Diffusers." The Aerospace Lighting Institute, Advanced Seminar. Los Angeles, CA. Feb. 1994.
- Shagam, R. N. "Diffusers Simplify Aircraft Inspection." Photonic Spectra. Nov. 1994.
- "Light Shaping Diffusers Improve Aircraft Inspection." Fiberoptic Product News. 11.2. Feb. 1995: p.13
- Kreifeldt, Erik. "Fish Fear New Diffusers." Optics & Photonics News. 6.9. Sept. 1995: p.8.

POC received the following patents for technologies related to the ATP project:

- "Viewing screen formed using coherent light" (No. 5,609,939: filed December 14, 1994, granted March 11, 1997)
- "Homogenizer formed using coherent light and holographic diffuser" (No. 5,534,386: filed February 23, 1995, granted July 9, 1996)
- "Illuminated display with light source destructing" (No. 5,956,106: filed February 1, 1996, granted September 21, 1996)

Commercialization Status: Since the conclusion of the ATP project in 1996, POC has pursued several commercialization channels, such as in-house manufacturing and marketing, strategic alliances with various original equipment manufacturers (OEMs), and licensing agreements with specific application providers. Furthermore, POC established a dedicated production facility for the holographic diffuser that currently produces 100,000 parts per month. Significant demand prompted POC to create a subsidiary, Farlight Inc. (now Farlight LLC), to commercialize the holographic diffuser technology for lighting applications. As a result, POC now has annual revenues in excess of $20 million.

Outlook: The outlook for this technology is excellent. After POC introduced its holographic diffusers into the marketplace in the late 1990s, the technology has been adopted for new applications, and industry continues to recognize its benefits. Some of the promising new markets are fiber-optic telecommunications products, high-resolution imaging in homes, and security-control products. As POC moves into the data-storage security area, in addition to its diffuser applications, the company is poised to expand into additional domestic and international markets.

Composite Performance Score: * * *

Number of Employees: Eighty-five employees at project start, 170 (including subsidiaries) as of May 2002.

Company:
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Torrance, CA 90501-1821

Contact: Rick Shie
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Research and data for Status Report 93-01-0205 were collected during October - December 2001 and January - March 2002.

X-Ray Optical Systems, Inc.

Innovative Optics Technology to Focus X-Rays and Neutrons

When X-Ray Optical Systems, Inc., (XOS) proposed its project to the Advanced Technology Program (ATP), the company was an early-stage venture with an unproven technology and little potential for attracting private investors. Now the company is a leader in x-ray focusing optics, and, as a niche technology business, XOS collaborates with numerous sectors of the U.S. economy. XOS continues to develop the next generation of x-ray technologies that promises to have significant social, economic, and scientific impact in medical imaging and materials research. The three-year ATP project, which ended in 1995, laid the groundwork for several follow-on contracts from other Federal agencies and enabled the company to pursue diverse applications that began to offer broad-based benefits in early 2000. As of summer 2002, XOS had developed six partnerships with businesses that sell machines specifically designed for use with XOS lenses.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * * *

Research and data for Status Report 91-01-0112 were collected during July - September 2002.

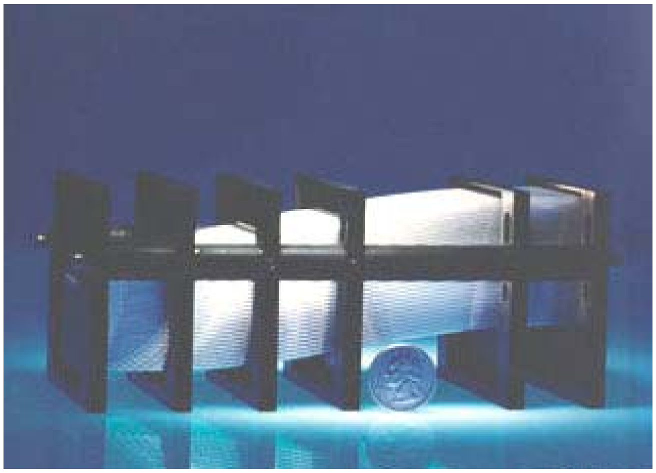
ATP Funds New Technology to Focus X-Rays and Neutrons

"At the time we started with ATP, there had never been a useful example of this technology anywhere in the world," stated David Gibson, chief executive officer of X-Ray Optical Systems (XOS). He was referring to a new method for focusing x-rays and neutrons. Mr. Gibson tried to attract investors to his start-up company; however, with no proven product, he was unable to find seed money.

Polycapillary optics may facilitate new x-ray and neutron applications for medical therapy, x-ray fluorescence, mammography, lithography, and protein crystallography.

Then, in 1990, Mr. Gibson read about ATP in an industry magazine and was immediately intrigued by ATP's unique willingness to fund high-risk technologies in need of incubation. He proposed his idea to ATP and received an award in 1992. With ATP co-funding, XOS successfully developed, tested, and perfected a new technology for focusing x-rays and neutrons by reflecting them in orchestrated arrays through thousands of tiny, curved glass optic tubes capable of controlling radiation from a divergent beam.

Multifiber polycapillary optics, which were developed through this project, are an enabling technology geared toward providing high-end x-ray and neutron components to analytical instrument original equipment manufacturers (OEMs) to increase their efficiency, mobility, and cost effectiveness. Polycapillary optics may be integrated with other components to facilitate new x-ray and neutron applications for medical therapy, x-ray fluorescence, mammography, lithography, and protein crystallography. With XOS's optics, a significant portion of the x-rays or neutrons emitted from a point source can be controlled to produce a collimated beam of radiation, enabling the acquisition of more detailed images at a lower radiation dosage. These tiny collimating optics continue to be a revolutionary factor in many types of diffraction applications. Primitive versions of polycapillary optics, which were developed in the late 1970s, were wholly unreliable and, therefore, were not widely adopted. During the time XOS was working to refine its manufacturing techniques,



Polycapillary optics focuses x-rays and neutrons by reflecting them in orchestrated arrays through thousands of tiny, curved glass optic tubes capable of controlling radiation from a divergent beam.

Russian, Chinese, and Japanese labs were attempting to refine polycapillary optics models, but they met with lackluster results.

XOS Focuses on Polycapillary Optics

XOS's research and development (R&D) efforts focused on two types of optics:

1) multifiber polycapillary collimating and focusing optics and

2) monolithic polycapillary optics. The second type emerged as a derivative of the first type during the ATP project.

Multifiber polycapillary optics are perfect for use with high-power x-ray sources and large-diameter beam applications. Glass fibers are threaded individually through a series of thin screens set up with hole patterns controlled at the micrometer level. A series of frames support the screens and maintain alignment. Each optic is composed of thousands of such fibers.

The major obstacle was getting thousands of string-like hollow glass tubes to bend at a precise, uniform, and reliably proper arc.

Monolithic polycapillary optics involve a different process. Individual capillaries are fused together, eliminating the need for tiny framed screens and frame supports. The monolithic optics vary in length, yet are smaller and more compact than multifiber polycapillary lenses. Moreover, they have the ability to form tighter beams for collimating purposes and smaller spot sizes for focusing purposes.

Overcoming Technical Problems of Capillary Arrays

Polycapillary optics are based on arrays of microscopic glass tubes that direct beams toward a desired focal point or to a parallel beam. Because x-rays have such high energy, however, they pass through most materials without interacting with them. XOS found that if the curvature of the capillary is kept below a certain critical limit, the x-rays reflect off the inside surfaces of the capillary, skipping like a rock across a pond. Capillary arrays can capture convergent, as well as parallel, x-ray beams and can focus or redirect their energy, thus reducing measurement times, improving spatial resolution, and increasing sensitivity.

Lab experimentation early in the development of this new technology showed that capillary arrays could focus high-energy x-rays. The lingering problem was how to make it happen consistently and without having to face recurring technical imperfections. The major obstacle was getting thousands of string-like hollow glass tubes to bend at a precise, uniform, and reliably proper arc. XOS faced another obstacle in that all existing polycapillary optics were made outside the United States. No component manufacturer was able to reliably and consistently mass-produce polycapillary collimators that were able to focus x-rays with any legitimate control.

Finding Alternative Materials that Withstand Wear and Tear

XOS conducted a thorough materials analysis to discover which materials could withstand relatively intense x-ray and neutron beam irradiation over long periods. Over time, most types of materials deteriorate from continued contact with neutrons and x-rays. Through the ATP-funded project, XOS successfully identified and developed new glass-type materials that are less susceptible to x-ray degradation.

Medical Imaging Applications

Polycapillary optics able to scan large areas have applications in soft-tissue imaging, specifically mammography and angiography. The effectiveness of this type of medical imaging depends on image contrast and resolution. Once the technology evolves and allows larger scans, polycapillary optics are expected to enhance image quality in mammographic systems by serving as a scatter-control component. Polycapillary optics can also help medical technicians and researchers detect tumors that are smaller than those currently detected, and this capability will improve as scanning areas increase. Because only relatively small areas of a sample can be imaged at one time, polycapillary optics are currently more suited for research than for use in doctors' offices. Therefore, only university hospitals and laboratories have been the early purchasers of XOS equipment.

ATP's Contribution Advances Technology by a Decade

"Without the ATP project, XOS would be at least a decade behind where it is today," Mr. Gibson stated. "And any commercial success from these new technologies most likely would not have originated in the U.S." The ATP-funded project helped to build up a small start-up company, attracted strategic partnerships with private investors and collaborators, and, most importantly, dramatically accelerated the pace of technology development. Currently, two of XOS's customers are OEMs that use the technology for high-resolution imaging of small areas.

Conclusion

After receiving the ATP award, XOS further developed the technology and attracted the interest of private investors. In addition, the ATP project laid the groundwork for several follow-on contracts with other government agencies that enabled the company to pursue different applications of the technology. This effort resulted in two new, improved lenses and imaging methods for use in high-resolution imaging machines. Moreover, the company has received several industry recognition awards as well as seven patents.

PROJECT HIGHLIGHTS
X-Ray Optical Systems, Inc.

Project Title: Innovative Optics Technology to Focus X-Rays and Neutrons (New Optics Enhance X-Ray and Neutron Focusing)

Project: To establish the capability to manufacture reliable polycapillary x-ray optics technology, which is needed for medical imaging and materials research, and to explore and experiment with design, alternative materials, and productivity models.

Duration: 6/1/1992-5/31/1996
ATP Number: 91-01-0112

Funding (in thousands):

ATP Final Cost	$1,949	84%
Participant Final Cost	371	16%
Total	$2,320	

Accomplishments: Through its collaboration with ATP, X-Ray Optical Systems (XOS) achieved a number of accomplishments, including winning the 1996 Photonics Circle of Excellence Award presented by Photonics Spectra Magazine and being listed among the R&D top 100 from R&D Magazine in 1995. XOS received the following patents for technologies resulting from this ATP-funded project:

- "Polychannel multiple-total-external reflection neutron radiography"
(No. 5,553,105: filed October 31, 1994, granted September 3, 1996)
- "Use of a Kumakhov lens in analytic instruments"
(No. 5,497,008: filed February 1, 1995, granted March 5, 1996)
- "High intensity, small diameter x-ray beam, capillary optic system"
(No. 5,570,408: filed February 28, 1995, granted October 29, 1996)
- "Multiple-channel, total-reflection optic with controllable divergence"
(No. 5,604,353: filed June 12, 1995, granted February 18, 1997)
- "Radiation focusing monocapillary with constant inner dimension region and varying inner dimension region"
(No. 5,747,821: filed August 4, 1995, granted May 5, 1998)
- "Multiple channel optic"
(No. 5,745,547: filed August 2, 1996, granted April 28, 1998)
- "Microcalorimeter x-ray detectors with x-ray lens"
(No. 5,880,467: filed March 5, 1997, granted March 9, 1999)

Commercialization Status: XOS commercialized its optics technology and was working on improving the optic components' ability to scan larger areas by 2002. Furthermore, the ATP award enabled XOS to develop its technology to a level that made possible further collaboration with private and public entities for a variety of research and commercial endeavors. XOS assisted the National Aeronautics and Space Administration in determining the structure of proteins, which will have a wide impact on the study of diseases, including the possibility of preventing a rare children's disease. XOS also collaborated with the Department of Energy and with research organizations such as the Los Alamos and the Oak Ridge National Laboratories. In the private sector, XOS started numerous joint development projects with companies such as VECCO, EDAX, Roentgenanalytik, Shimadzu, Bede Scientific, Inc., and Thermo Electron. The partnerships with Shimadzu and Bede Scientific, Inc., resulted in commercialized machines that use the ATP-funded technology, while the other projects were still in the R&D stage. Although the market size for polycapillary optic lenses and collimators is small, it is growing. The lens is revolutionary because, for the first time, researchers are able to investigate materials at a level of detail once thought impossible. This technology should open new markets in the materials research and protein crystallography sectors.

Outlook: Prospective applications and benefits from this new optics technology were just beginning to be identified. Polycapillary optics were only starting to make inroads within the economy. For example, one area of future interest is in microelectronic lithography, where x-ray lenses can be used to make finer microchip features. Furthermore, polycapillary optics are useful for materials research, medical imaging, and long-wavelength x-ray applications. X-ray diffraction, for example, is useful for government, commercial, and scientific applications aimed at studying molecular structures within materials. As a component provider for customized optics, XOS is beginning to expand on this role and enter into new territory.

Composite Performance Score: * * * *

Number of Employees: One employee at project start, 22 as of September 2002.

Company:
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30 Corporate Circle
Albany, NY 12203

Contact: David Gibson
Phone: (518) 464-3334

Research and data for Status Report 91-01-0112 were collected during July - September 2002.