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ABSTRACT

Recent and projected advances in and commercial applications of lasers and laser technology were examined in order to assist vocational planners in responding to skill needs that will be created by lasers in the next few years. Until recently, most laser applications were in research and development settings; however, in the last several years lasers have gained widespread acceptance in such commercial settings as the manufacturing, medical, entertainment, printing, and communications industries. For the remainder of the decade, it is expected that commercial laser sales will average a 20 to 25 percent growth rate. The increasingly widespread application of lasers suggests that postsecondary schools may wish to begin programs to train laser electro-optics technicians (LEOTs). Those planning such programs should be sure to identify employer demand for LEOTs, attain a strong financial commitment for equipment and facilities, and recruit qualified faculty. (MN)

LASER APPLICATIONS: IMPLICATIONS FOR VOCATIONAL EDUCATION

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- Developing educational programs and products
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- Providing information for national planning and policy
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- Operating information systems and services
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TABLE OF CONTENTS

LIST OF EXHIBITS

FOREWORD

If vocational education is to prepare citizens to adapt and respond to changes in the skills required to maintain employment, vocational educators must understand current changes and anticipate possible and probable future developments. The information assembled and presented in this report represents one effort by the National Center to help vocational education planners prepare for a world of changing technologies.

This report examines present and anticipated future applications of lasers and discusses implications for program offerings in vocational education. The information presented is directed to individuals responsible for program planning in vocational education at the National and State levels. The report addresses the need of vocational educators who are trying to decide whether or not to implement a program in laser technology.

This report was produced in the Evaluation and Policy Division under the direction of N. L. McCaslin, Associate Director, with funding from the Office of Vocational and Adult Education, U.S. Department of Education. The research for this report was conducted during the previous contract year in the Personnel Development and Field Services Division under the direction of Lucille Campbell-Thrane, Associate Director. The project staff includes Jeannette Fraser, the author; Jay Smink, the project director; Morgan V. Lewis, Senior Research Scientist; Robyn A. Murry, Graduate Research Associate; and Paul V. Unger, Graduate Research Associate. Sherri Trayser served as project secretary and Mary Beth Dauner served as the word processor operator for this report. National Center staff William Ashley, Research Specialist, and Connie Faddis, Program Assistant, conducted internal reviews of the report and Judy Balogh provided the editorial review.

The project also benefited from the participation of others who are not on the National Center staff. These include the following individuals who participated in the convening at the National Center: Glenn McCartney, Vice-President for Operations, Litton International Laser Systems, Orlando, Florida; Haynes Lee, General Manager, Laser Institute of America, Toledo, Ohio; Jay Staley, Head of the Laser Department, Orlando Vocational-Technical Center, Orlando, Florida; Barbara Akerley, Business Editor, Laser Focus, Littleton, Massachusetts; and Marvin Bausman, Jr., High Technology Coordinator, North Central Technical Institute, Wausau, Wisconsin. Daniel Hull, President, Center for Occupational Research and Development, Waco, Texas, and C. Breck Hitz, a contributing editor to Lasers and Applications, Torrance, California, provided external reviews of the report. Technical sections of the report were also reviewed by

Stuart Collins, Jr., Professor of Electrical Engineering and Welding Engineering at The Ohio State University, and by Marvin Bausman, Jr.

On behalf of the National Center, I wish to express our appreciation to all of these individuals for their interest and involvement.

Robert E. Taylor
Executive Director
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in Vocational Education

EXECUTIVE SUMMARY

As our country's economy changes from manufacturing based to information based, the role of technological innovation and diffusion has become increasingly important to the Nation's economy and its people. This increased importance has heightened awareness throughout society of the potential impact of technological advances on all aspects of our lives. Particularly, many are worried that the skills they have acquired will be obsolete in this new economy.

Under its contract with the Office of Vocational and Adult Education, U.S. Department of Education, the National Center conducts yearly studies of selected occupational areas with an emphasis on those requiring a high degree of technical training in high-demand occupations. This report is directed to individuals responsible for program planning in vocational education at the National and State levels. This review and synthesis of technological developments in laser technology describes the potential demand for skills and the skills training that will be required to respond to this technology in the next 3-5 years.

First developed in the early 1960s, laser technology is currently experiencing wide diffusion in the commercial marketplace. Until recently, most laser applications were in research and development settings; however, in the last several years lasers have gained widespread acceptance in a variety of commercial settings. For instance, lasers are now widely used in the manufacturing, medical, entertainment, printing, and communications industries. This rapid proliferation of laser applications and the resulting growth in the laser marketplace have led to the selection of laser technology for study in this report.

The general research procedure consisted of assembling relevant information that could be identified and integrated and supplementing this information with input from knowledgeable individuals. A special effort was made to identify any indicators of future directions, such as sales projections or technical innovations. When the assembled information was summarized, industry and training representatives were brought together to review the material. These representatives were asked to assess the accuracy and comprehensiveness of the material and to help assess implications for vocational education.

Growth averaging between 20 and 25 percent is expected in commercial laser system sales for the remainder of the decade. Government-sponsored, defense-related research and sales are expected to continue. New applications continue to be developed. This constant identification of new uses portends additional growth of laser applications. For many applications, the laser is the only technology available to perform the task.

Laser electro-optics technicians (LEOTs) are used in the research, development, manufacture, sale, installation, repair, and maintenance of laser devices and systems. In the past, the employment of LEOTs has been in research and development settings or with original equipment manufacturers in four areas of the country (Florida, Texas, California, and the Boston-Washington, D.C. corridor). As the industry matures, more employment will be available in laser system companies and at the application site. Hence, the employment for LEOTs is moving from a regional to a National focus.

The increasingly widespread application of lasers suggests that postsecondary schools may wish to begin LEOT programs. The decision process and subsequent program planning should follow the same planning process used to establish any high-technology program. Of particular concern for LEOT training programs is the identification of employer demand for LEOTs, a strong financial commitment from the institution for equipment and facilities, and the recruitment of qualified faculty.

CHAPTER 1

INTRODUCTION

Technology is affecting society at a pace never before witnessed. The very nature of work is changing because of this impact. As the nature of work changes, the nature of training must also change. Hence, it is important for vocational education to anticipate the implications of changing technologies on the demand for skills training. Under its contract with the Office of Vocational and Adult Education, U.S. Department of Education, the National Center conducts studies of high-demand occupational areas that require a high degree of technical training.

All technologies follow a process of innovation; the laser is no exception (Lewis, Fraser, and Unger 1984). Laser principles were identified as early as 1917 but were not developed into a technically feasible product until 1960, when the first working laser was demonstrated. In the early 1960s, commercially feasible products were developed and applications began in various industries in the late 1960s. The 1970s were a time of extensive research and development efforts, resulting in improved laser devices and systems. The decade of the 1980s marks the beginning of widespread diffusion of lasers into the marketplace. This review and synthesis of technological developments in the laser industry describes the potential demand for skills and the skills training that will be required to respond in the next 3-5 years to the diffusion of laser technology.

Selection of Laser Technology for Study

Although the range of technologies for study was so extensive, laser technology was selected as the one best meeting the following criteria:

- The occupations affected by these technologies must require a high level of technical training.

- There must appear to be a potential for high demand for individuals trained in this area.

- Training must be provided below the baccalaureate level.

- The impact of this technology must be felt within 3-5 years.

- Preference should be given to discrete technologies: those where the impact can be identified separately from other improvements in processes and products. (Fraser, Unger, and Lewis 1984, p. 2)

Project staff collected information from diverse sources about the impact of technologies. Laser technology was selected for examination because the laser has moved from the research and development stage to widespread diffusion throughout various industries and settings. In many applications, the laser stands alone as the only possible technology to complete the necessary task. The increased range of applications for which the laser is becoming a viable option to other processes portends an anticipated growth in the application of lasers in the next 10 years.

Procedures

Once laser technology was selected for study, project staff (1) assembled information describing laser technology, its current usage patterns, and projections of usage for the remainder of this decade; (2) described skills required to use this technology; and (3) identified the demand for laser skills in the next 3-5 years. Implications for vocational education were then developed. Information was assembled and a packet of background materials was prepared.

To validate the completeness and the accuracy of the information assembled, industry representatives were convened. The convening included a representative from an original equipment manufacturer, a representative from the relevant professional organization, a representative from a laser industry publication, and representatives from two postsecondary institutions. A listing of the convening participants and their affiliations appears in the appendix.

Convening participants were asked to respond to the accuracy of the materials presented and to identify any gaps in the information base assembled. Participants also assisted in developing the implications of these findings for vocational education. Specifically, they aided in identifying the skills requirements for the individuals using these technologies and in identifying concerns that postsecondary administrators should consider when planning a laser electro-optics program.

Transcripts of the convenings were produced, and the information obtained is synthesized in this report. Project staff also further investigated new information provided by convening participants. Published sources were identified to verify the conclusions drawn from the convening. A technical discussion of laser principles was prepared and reviewed by experts to ensure its accuracy.

CHAPTER 2

LASER PRINCIPLES, APPLICATIONS, AND THE MARKETPLACE

Based on concepts first identified by Einstein in 1917, lasers were developed almost simultaneously by several physicists in the United States in the early 1960s. The first working laser was demonstrated in 1960 by Theodore H. Maiman, a physicist from Hughes Aircraft Company.

Laser Principles

The light produced by a laser has several important characteristics that differ from other light. Ordinary light is a mixture of various wavelengths that travels in all directions. Light produced by a specific laser usually has only one specific wavelength or one frequency and hence only one very pure color. The medium and optics used to produce the laser light determine the wavelength or frequency. The coherent light produced by a laser is very directional.

The laser is a complex device that can be constructed in a variety of ways. All lasers function, however, on the same set of principles. Atoms are raised to an excited state by pumping energy into a medium. This pumping of energy can be achieved using an electrical power supply, a powerful flash lamp, another laser, a chemical reaction, or even nuclear radiation. The medium used usually consists of a gas, a liquid, or a crystal, although other mediums have also been successfully used. Some of the excited atoms return to their natural state emitting particles of light (called photons) in a process called "spontaneous emission." (Spontaneous emission is the process that creates the light from light bulbs that we deal with everyday.) If one of the emitted photons passes near an excited atom, it can cause that atom to release its stored energy in the form of a photon that is identical in all respects to the original photon. This process is called "stimulated emission."

Light energy can be amplified to make it stronger and more useful by oscillating it in a medium where stimulated emission can occur. In a laser, oscillation is accomplished by the use of two reflective surfaces. The stimulated photons of light travel the length of the laser, bouncing back and forth in the laser cavity or resonator between the reflective surfaces. One surface is fully reflective, whereas the other is only partially reflective. As the photons bounce back and forth, they stimulate the emission of additional coherent photons. On every path through the medium, a certain number of photons exit through the partially reflective surface, producing a beam of coherent light.

Laser light has several desirable properties that contribute to the laser's wide range of applications. Laser light is directional and can be focused to very small spots. Directional and focusing characteristics allow the light to be projected over great distances with very little spreading (i.e., little loss of intensity, and to be controlled to very exact tolerances and very specific locations. The power output can be a minute fraction of a watt in a low-powered laser or can be a trillion watts of power for a pulsed laser (Townes 1984).

When a laser device is produced, several parameters influence the limits of performance; the spectral characteristics, efficiency, and power scalability. The spectral characteristics of the laser medium are investigated to determine the output wavelength and its tunability, for example, the extent to which the wavelength can be varied. Greater tunability increases the number of potential applications of the device (Christensen 1984).

The ratio of average optical output power to average input power is the measure of laser efficiency. In many instances, an efficient laser will output less than 1 percent of the input power. With a carbon dioxide laser, the most efficient laser available, an output of up to 30 percent of the input power is possible. A laser's efficiency strongly influences the ultimate size, weight, capital cost, and operating cost of the device.

Power scalability is the ability to scale a laser dimensionally to achieve high power levels. Whereas all lasers can be scaled to high power levels, some devices are much more easily scaled upward than others.

There are primarily four types of lasers: solid state, semiconductor, gas, or liquid. Their light-amplifying substance may be a crystal, glass, or semiconductor. Crystal lasers are made of a solid rod of crystalline material such as ruby or yttrium aluminum garnet (YAG). The light amplification comes from impurities such as chromium or neodymium added to the crystalline materials; the impurity atoms can be stimulated to emit coherent photons. The ends of the crystalline rod are polished to serve as reflective surfaces and the rod itself serves as the resonant chamber. The pumping action is achieved by a high-intensity flash lamp that is wrapped around the crystal rod. A common flash lamp might be filled with the gas xenon and discharged by electricity. Glass lasers use glass instead of crystal, with impurity atoms still acting as the light-amplifying substance. They operate in much the same way as crystal lasers. Most ruby and glass lasers produce single bursts of light, whereas a Nd:YAG laser can be made to produce a continuous beam.

A semiconductor conducts electricity, but not as well as true conductors such as iron or copper. A semiconductor laser consists of two layers of materials that have different electrical charges. A common material used is gallium arsenide. An electric current passes through the layers, producing coherent light along the junction between the two layers. The light exits through the polished faces.

Gas lasers use a gas or a mixture of gases as the light-amplifying source. The gas is contained in a glass or quartz tube. Chemical reactions, electric current, electron beams, and ultraviolet rays are possible power sources. Most gas lasers produce a continuous beam of light and can produce beams of higher average power than can solid lasers. Gas lasers include the powerful, continuous beam CO_2 laser, the workhorse of the laser field, which is used when relatively efficient power is needed. Argon lasers used in surgery and helium-neon (HeNe) lasers used for point-of-sale scanning and alignment purposes are also gas lasers.

Liquid lasers produce both bursts of light and continuous beams. The light-amplifying substance in most liquid lasers is a dye mixed into methanol or a similar liquid. Flash lamps provide the power for lasers producing bursts of light, whereas continuous beam liquid lasers are pumped by gas lasers. A liquid laser has a wide range of tunability and can be finely tuned.

The wide number of applications of lasers is a reflection of the extreme variation in the types and powers of the lasers available for application. The next section describes some of the applications in current usage.

Applications

When lasers were first developed, they were considered "a solution in search of a problem." Today, the list of problems for which lasers are the best and sometimes only solution is impressive and continues to grow. Lasers are used in materials processing, agriculture, construction, measurement, inspection, research and development, printing, communications, medicine, defense, and entertainment.

Lasers are faster, cleaner, and often produce a higher quality result than traditional methods (Krauskopf 1984). For some applications, particularly in the medical field, the laser is the only solution. For example, no other noninvasive technique exists that can penetrate the outer eye and weld a detached retina into place in the inner eye without cutting the outer eye, nor can any other method burn out artery blockage in heart patients. Experts contend that the next major medical application will be the use of lasers to activate certain body chemicals and ingested drugs (Johnson 1984).

One of the newest advances is the merging of the laser with the robot. "The laser has been hampered in its expansion by the lack of a motion device capable of operating in all degrees of freedom. And the robot has lacked a process that was as flexible as itself" (Kehoe 1984, p. 63). Lasers can perform two roles when linked with a robot. Lasers can be used as sensing devices or as working tools. Virtually every automated manufacturing system of the future is going to employ a sensing mechanism; many of these mechanisms could potentially employ a laser. As a working tool, the laser improves upon traditional methods by allowing noncontact machining: cutting, scribing, and hole making. Fewer tool changes, decreased total tool wear and cost, increased cutting speed, and decreased waste increase uptime and productivity (Krauskopf 1984; Kehoe 1984). Hence, the marriage of the robot and the laser will result in a proliferation of lasers in industrial settings that will tend to improve product quality and productivity levels while removing workers from hazardous situations.

Exhibit 1 presents a sampling of the applications for which the laser is currently used. The list reflects both generic applications such as drilling or welding and some very specific applications such as the disconnection of redundant integrated circuit components.

Many of the applications listed in exhibit 1 are an outgrowth of government-sponsored research, even though they are applied in commercial settings. Almost all basic research and development of lasers is funded by the Federal Government; hence, almost all technological innovation can be traced directly or indirectly to federally funded research projects. The U.S. Department of Defense is the major funding agency. The U.S. Department of Energy also funds basic research in the area of nuclear fusion. Other less significant funding comes from the National Institutes of Health, NASA, and the National Science Foundation. The Department of Defense is in an unusual position in that not only does it fund the research and development costs of many laser systems, but the department is also a major purchaser of equipment from these companies.

One technique of anticipating the rate of technological change in the laser field is to examine the level of funding from the Federal Government for defense and energy projects. Currently, the Federal Government is engaged in developing a space-based laser defense system: the Strategic Defense Initiative. Announced by President Reagan in March 1983 and approved by the National Security Council in December 1983, this system would employ lasers to destroy ballistic missiles while they are above the atmosphere. The 5-year, $21 billion plan began the development of this defense system. Much of the money in this effort is being spent for the development and testing of chemical lasers. Short wavelength lasers, about 5-7 years behind the chemical

EXHIBIT 1

A SAMPLING OF LASER APPLICATIONS
IN CURRENT USE

Materials Processing

Metals, plastics, and textiles cutting
Plastics and metals drilling
Plastics and metals welding
Transformation hardening of metals
Seam, spot, and fusion welding
Laser marking (numbers, barcodes, logo)
Laser machining
Hole making
Parts sizing
Hermetic package sealing
Ceramic substrates scribing
Trimming
Soldering
Redundant integrated circuit components disconnection
Deburring
Scarfing
Wood engraving
Baby bottle nipple and cigarette paper perforation

Agriculture/Construction

Laying of straight sewer lines
Distance measuring systems
Leveling of ceilings
Depth-of-excavation measurement
Bulldozer control

Metrology and Inspection

Lumber alignment in sawmills
Industrial alignments
Laboratory optical alignment
Industrial and warehouse barcoding
Doppler velocimetry
Remote sensing
Forsensic applications
Inspection of printed circuit boards
Inspection of currency
Inspection of glass bottles and vials
Holographic inspection of solid objects for stress
Nondestructive testing with holograms

EXHIBIT 1--Continued

Research and Development

Processes or applications considered to be experimental
Laser-induced chemistry

Point-of-Sale Scanning

Supermarket scanning
Department store scanning
Other barcoding/scanning applications

Printing

Nonimpact printing
Typesetting

Platemaking and Film Exposure

Fabrication of printed circuit boards
Printing plates
Flexographic printing plates
Analysis of color for color graphics reproduction
Development of color negatives for printing

Communications

Optical space communication systems
Light source for fiber optic communication links

Medical

Cell sorting
Patient alignment
Vaporizing of diseased or disabled tissue
Cauterizing of vessels
Surgery: optical, gastrointestinal tract
Dermatology
Cosmetic surgery
Photoradiation therapy

EXHIBIT 1--Continued

Entertainment and Display

Light shows
Artistic holography
Laser displays
Video disc players

Tactical Military

Rangefinders
Target designators
Small arms aiming devices
Battlefield simulation
Gyroscopes

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lasers in development, are also being targeted for use in this defense initiative. The current funding level certainly implies that, in the near future, the rate of innovation and application in the commercial area will continue to grow robustly; the defense budget continues to enjoy healthy growth in the funding of laser-related projects.

Laser Use: The Commercial Laser Industry

The worldwide laser marketplace experienced robust health during 1984 and is expected to experience continued growth throughout the decade. Estimates of laser device sales--sales of the laser device only, not the entire system--vary from $363 million ("Annual Economic Review and Outlook" 1985) to $416 million (Hitz 1985) for 1984 and is expected to grow at an annual rate of 20-25 percent until the end of the decade. By then, sales of laser devices are expected to top $1.4 billion annually (1984 constant dollars).

Sales of laser systems--the laser device plus all of the ancillary equipment needed to deliver the laser beam to the application--are estimated to have reached $4.4 billion in 1984 (Hitz 1985). No estimates are made of the actual number of laser devices or laser systems sold. Since prices of laser devices and systems can vary greatly ($200-$2 million), sales figures cannot easily be translated into the number of devices or systems sold. Laser system sales are expected to grow 10-15 percent until the end of the decade.

Based on interviews with U.S. and European laser companies and supplemented with mail surveys and published data from the government and independent consultants, Laser Report estimates the growth by application area in 1985 ("Annual Economic Review and Outlook" 1985). Communication applications will grow the fastest with a 50 percent increase in sales of laser devices. Sales of laser devices for material processing, medical, and information processing applications are expected to grow at 35 percent, whereas scientific R&D, graphic arts, alignment, measurement, and control sales should experience a growth of approximately 15-17 percent. Entertainment applications are expected to grow by 9 percent.

In 1985, over one-half of the expected $465 million sales of laser devices will be for materials processing and scientific R&D applications ($139 and $100 million, respectively). Expected sales for medical and graphic arts applications each comprise another 14 percent. Expected sales for communications, information processing, alignment, measurement and control, and entertainment applications comprise 10 percent, 6 percent, 5 percent, and 1 percent, respectively, of the total laser device sales market.

Annual growth in the entire laser industry will average between 20 and 25 percent over the remainder of the decade ("Annual Economic Review and Outlook" 1985; "Annual Economic Review and Outlook Predicts Growth" 1984; Hitz 1985).

The laser industry consists of approximately 450 laser companies. Included in this count are original equipment manufactures and companies that design, build, and install complete laser systems. Laser companies tend to be located in four areas of the United States--Florida, Texas, California, and the Boston-Washington, D.C. corridor. User companies, however, are located in all areas of the United States.

There tend to be few midsized laser companies. The large companies can afford to invest in laser R&D. Most of the large laser companies, because of exorbitant R&D costs and the need to use middle-to-high skilled labor to build actual laser devices and laser systems, operate on very low profit margins. A 1 percent profit is not unusual although profits almost never go any higher than 5 percent. The low profitability of original equipment manufacturing firms is a continuing pressure on the laser marketplace. With such low profit margins, there is little room for error ("Annual Economic Review and Outlook Predicts Growth" 1984).

The other segment of the laser industry consists of small firms that primarily develop, build, and install the ancillary equipment necessary to deliver the laser beam in the fashion required by the application. The number of these firms continues to grow.

A growing segment of the laser industry is the laser job shop. Manufacturing firms cannot justify the purchase of a $70,000 laser system to manufacture 100 parts. Hence, a growing number of laser job shops are coming into existence. These job shops specialize in machining or welding operations, usually employing a single CO_2 laser. Often, a manufacturing company has only a short-term need for a laser application and can employ a job shop more cheaply than acquiring the equipment themselves.

Influences on Usage

In most projections, a number of the factors that influence the laser marketplace are assumed to remain constant over time. The factors discussed in this section are some of the variables that may change. If these factors change, then the projections discussed earlier might also change.

The marketplace for the laser industry is worldwide. Japan and Europe both produce laser devices and systems that compete with U.S. firms. Government regulation in the United States somewhat impedes the sale of American laser products overseas. Generally, 15 percent of the U.S. industry's sales are affected by export controls. Industry experts believe that at least a 10 percent increase in sales would result from removing the current export controls (Hitz 1985).

As is the case with all overseas activities, the continuing strength of the dollar has left our international sales in an unfavorable position. The strength of the dollar makes our products overpriced compared to products produced in other countries. One technique to counteract this strength is the overseas production of lasers by U.S. companies. Only the largest and most profitable companies will be able to try this approach. Spectra-Physics, the industry leader in sales, will be manufacturing lasers in Europe beginning in 1985. Coherent, Inc., already has overseas manufacturing facilities in Japan and Europe.

Producers of lasers for medical applications respond to an additional level of Government controls. The Federal Drug Administration (FDA) has to provide clearance for any medical procedure, and until it does, the procedure is considered experimental. Insurance companies do not necessarily provide coverage for experimental procedures. FDA approval may take as long as 3 years. Tests and other information generated in other countries are not considered by the FDA in their approval procedures.

Finally, the low profitability of many companies has restricted the proliferation of new techniques and applications. A number of factors contribute to this low-profitability. First, the production of a laser is a very labor-intensive activity. Many hours of skilled labor are required to manufacture a laser device. In fact, few unskilled and semiskilled workers are employed by manufacturers, which results in a high wage scale. In 1983, the industrywide average revenue per worker was $65,000 ("Annual Economic Review and Outlook Predicts Growth" 1984). Employees' salaries constitute a significant proportion of that revenue. A second factor is the high level of research and development costs necessary to get a laser to market. For instance, in defense-related firms, it might cost $5 million to produce the first 5 lasers of a defense contract. In commercial firms, to maintain the competitive edge, firms spend between 10 and 15 percent of their revenues on research and development. Third, because the laser industry is relatively new, most of the management personnel of laser firms have strong technical backgrounds but are relatively inexperienced as managers. Until a more experienced group of managers is available, some laser firms will continue to suffer. Finally, customer-related services are also expensive. Customer education and support networks are costly as are the warranties for scientific products. All of these factors contribute to the low profitability of many laser companies.

CHAPTER 3

LASER TRAINING IMPLICATIONS

The laser industry employs persons with less than a baccalaureate degree to assist in the manufacture, sales, installation, repair, and maintenance of laser devices and systems. They are trained in electrical, electronic, mechanical, optical, fluid, and thermal equipment principles, procedures, and techniques. These persons usually are retrained electronics technicians or have completed a 2-year laser electro-optics technician (LEOT) program.

The Demand for LEOTs

With the laser industry projected to experience continued growth throughout the decade, it is likely that the demand for LEOTs will also continue to grow. There is little information available about the number of LEOTs currently employed. A sample of 50 potential laser employers was surveyed in 1983 to estimate the number of LEOTs currently employed. This survey updated a more comprehensive survey conducted in 1980. The average number of technicians reported by the companies in the 1983 sample was multiplied by 1,641 LEO employers in the surveyed population. In 1983, there were an estimated 19,364 persons employed in LEOT positions in the United States (Moore and Hull 1984). Employment of LEOTs has more than doubled since 1980. However, as of 1985, approximately 3,000 LEOTs have graduated from LEOT postsecondary programs. The remaining LEOTs employed are probably electronics technicians who have received on-the-job training in laser electro-optics. The same survey estimates projected employment of LEOTs to approach 30,000 by 1990.*

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*Another viewpoint offered by C. Breck Hitz, a contributing editor for Lasers & Applications and a reviewer of this report, is that the estimates of LEOT demand are too large by a factor of 5 or 10.

In fact, Hitz believes that the basic assumption that manufacturers of laser systems and the users of laser systems will need highly trained LEOTs is invalid. Because the different parts of the "laser market" have very little in common, no single LEOT training program can meet the needs of all parts of the market.

The skills required for employment in the medical laser field, for example, are vastly different than those required in the industrial laser field. He concludes that rather than establishing dedicated LEOT programs, postsecondary schools might be encouraged to integrate some practical LEOT technology instruction into existing programs, particularly, electronics technician programs.

At present, postsecondary schools graduating LEOTs have experienced no problems in placing their graduates. The major problem is the location of the jobs available: some are not in the training program's local labor market.

Location of Employment

As the laser industry ages, the location of employment for LEOTs changes. Originally, most employment was in research and development settings. As the industry matured, employment of LEOTs moved to the original equipment manufacturing firms and eventually to the manufacturers of laser systems. Current growth in employment for LEOTs is found in laser systems firms and in applications settings. For example, a hospital that has several laser systems may employ a LEOT to check the laser before using it in surgery. A manufacturing firm that uses lasers to drill and weld may employ a LEOT to maintain and repair that equipment. Employment in user firms is found primarily in larger companies that have purchased several lasers. It is unlikely that LEOTs will be employed by firms owning only one or two lasers. These firms use service contract arrangements to install, test, repair, and maintain their laser devices and systems. As the number of user firms with several lasers grows, so should employment opportunities for LEOTs.

The advantage of employment being based in the large user firms is that the demand for LEOTs is moving from being regional in nature to existing in all major population centers and manufacturing locations. Laser technician employment was previously found in the four primary locations where laser manufacturers were based.

Skills

LEOTs are required to have a variety of skills. Exhibit 2 is a comprehensive listing of competencies and tasks for which a LEOT may need to be trained. This list, developed by the Center for Occupational Research and Development (CORD) in Waco, Texas, serves as a shopping list for program planners. The actual competencies and tasks that any specific program should address are determined by the needs of the local labor market. These needs are identified by the program's advisory committee or from a needs assessment of the employers likely to hire program graduates.

Implications for Vocational Education

Although all indications are that the demand for well-trained LEOTs will continue throughout the decade, this does not mean that every postsecondary institution should incorporate a

EXHIBIT 2

LASER ELECTRO-OPTICS TECHNICIAN COMPETENCY/TASK LISTING

Noble Gas Lasers

Operate helium-neon lasers
- Install HeNe lasers
- Measure output characteristics

Maintain helium-neon lasers
- Clean optics
- Align cavity mirrors
- Adjust for optimum output
- Install, align, and calibrate wavelength selector
- Install, align, and adjust electro-optic intracavity modulators
- Test and repair power supply
- Install, align, and adjust acousto-optic beam deflectors

Set up/modify helium-neon lasers for analytical, alignment, distance measurement, product identification, entertainment, and R&D laboratory use
- Modify laser output altering cavity mirrors
- Modify laser output altering power supply
- Modify laser output adjusting or replacing modulators
- Modify laser output externally
- Integrate helium-neon lasers with other equipment

Ion Lasers

Operate argon lasers
- Install argon lasers
- Measure output characteristics

Maintain argon lasers
- Clean optics
- Align cavity mirrors
- Adjust for optimum output
- Install, align, and calibrate wavelength selector
- Install, align, and adjust electro-optic intracavity modulators
- Test and repair power supply
- Test and repair cooling system
- Install, align, and adjust acousto-optic beam deflectors

Set up/modify argon lasers for manufacturing, medical, graphic applications and R&D laboratory use
- Modify laser output altering cavity mirrors
- Modify laser output altering power supply
- Modify laser output adjusting or replacing modulators
- Modify laser output externally
- Integrate argon lasers with other equipment

Molecular Lasers

Operate CO_2 molecular lasers
- Install CO_2 molecular lasers
- Measure output characteristics

Maintain CO_2 molecular lasers
- Clean optics
- Align cavity mirrors
- Adjust for optimum output
- Install, align, and calibrate wavelength selector
- Adjust flowing gas mixtures
- Test and repair power supply
- Test and repair cooling system

Set up/modify CO_2 molecular lasers for manufacturing, medical, and R&D laboratory use
- Modify laser output altering cavity mirrrors
- Modify laser output altering power supply
- Modify laser output adjusting or replacing modulators
- Modify laser output externally
- Integrate CO_2 molecular lasers with other equipment

Semiconductor Lasers

Install and maintain laser and light-emitting diodes
- Install diodes into electronic circuits
- Measure output characteristics
- Adjust for optimum output
- Test and repair power supply
- Install, test, and repair cooling system

Set up lasers for use as transmitters
- Set up lasers for free space transmission
- Set up lasers for fiber-optic transmission

Set up lasers for controlling data
- Set up lasers for recording data
- Set up lasers for manipulating data
- Set up lasers for displaying data

Optically Pumped, Solid Lasers

Operate Nd:YAG, glass, and ruby lasers
- Install Nd:YAG, glass, and ruby lasers
- Measure output characteristics

Maintain Nd:YAG, glass, and ruby lasers
- Clean optics
- Align cavity mirrors
- Test and replace lamps
- Maintain laser heads (optical pumping cavity)
- Adjust for optimum output

Install, align, and calibrate wavelength selector
Install, align, and adjust electro-optic intracavity modulators
Test and repair power supply
Test and repair cooling system
Install, align, and adjust acousto-optic beam deflectors
Install, align, adjust, and repair Q-switching and mode-locking devices

Set up/modify Nd:YAG lasers for manufacturing, medical, angle and distance measuring, and R&D laboratory use
Modify laser output altering cavity mirrors
Modify laser output altering power supply and capacitor discharge system
Modify laser output adjusting or replacing modulators
Modify laser output externally

Dye Lasers

Operate dye lasers
Install dye lasers
Measure output characteristics

Maintain dye lasers
Clean optics
Align cavity mirrors
Test and replace lamps
Maintain laser heads (optical pumping cavity)
Prepare and replace dye solution
Install and maintain ion laser for optical pumping
Install, align, and calibrate wavelength selector
Adjust for optimum output
Install, align, and adjust electro-optic intracavity modulators
Install, align, and calibrate wavelength selector
Test and repair cooling system
Install, align, and adjust acousto-optic beam deflectors
Test and repair cooling system

Set up/modify dye lasers for medical spectrographic, photochemical, and graphic applications, and R&D laboratory use
Modify laser output altering cavity mirrors
Modify laser output altering power supply and capacitor discharge system
Modify laser output adjusting or replacing modulators
Modify laser output by selecting wavelength
Modify laser output externally

Related Optical Systems

Measure characteristics of geometric optical components
Measure deflection of light by a prism
Measure lens focal length
Measure spherical aberration of a lens
Measure chromatic aberration of a lens

Measure lens resolution
Measure radii of curvature of a lens
Measure radii of curvature of mirrors
Measure spherical aberration of a mirror
Measure magnification and image position of a lens
Measure magnification and image position of a mirror
Measure the index of refraction of a liquid
Measure the index of refraction of glass samples
Measure transmission characteristics of optical fibers and connectors

Select geometric optical components
Select lenses
Select mirrors
Select prisms
Select windows

Measure characteristics of wave optic controlling devices
Measure precent reflection/transmission of light
Measure wavelength of light
Measure absorption coefficient
Measure scattering pattern of light from small particles
Measure extinction ratio of polarizers
Measure spectral characteristics of light sources

Select wave optic controlling devices
Select filters
Select beam splitters
Select gratings
Select polarizers
Select frequency doublers
Select wave retarders
Select total internal reflectors (TIR)
Select Brewster angle reflectors
Select Brewster windows
Select spatial filters
Select optical isolators
Select bleachable absorbers
Select antireflecting (AR) coatings
Select high-reflectance (HS) coatings

Build a predesigned optical system
Select optical mounts and holders
Align an optical bench collimator
Align components using an autocollimator

Draw optical systems
Determine location of optical components
Measure characteristics of optical components
Make physical drawing

Design, test, and draw an optical system
- Sketch optical system
- Select optical components
- Assemble optical system
- Test optical system
- Draw optical system

Design, test, and draw a holograph system
- Make a hologram
- Display a hologram

Related Light Measurement

Measure spectral emission of light sources
- Measure ultraviolet spectral emission
- Measure infrared spectral emission
- Measure visible-light spectral emission

Measure absorption, transmission, and reflection properties of materials
- Measure ultraviolet response
- Measure infrared response
- Measure visible-light response

Measure optical quality of solids, liquids, and gases
- Measure mechanical strain in solids
- Measure irregularities in optical surfaces
- Measure flatness of optical surfaces
- Measure index of refraction inhomogeneities in solids and gases

Measure laser output characteristics
- Measure laser power
- Measure laser pulse energy
- Measure laser pulse shape
- Measure laser pulse repetition rate
- Measure laser linewidth
- Measure laser coherence length
- Measure laser beam divergence
- Measure laser beam diameter
- Measure laser polarization
- Measure laser transverse electromagnetic mode pattern
- Measure laser spatial intensity distribution
- Measure laser longitudinal mode

Related Electrical/Electronics

Related Vacuum Systems

Operate a high-vacuum system

Clean surfaces for vacuum coating

EXHIBIT 2--Continued

Related Mechanical Systems

Fluid power

Heating and cooling

Mechanical devices

Other Related Competencies

Math

Physics

Properties of materials

Prepare laboratory reports
- Prepare written reports
- Prepare oral reports
- Maintain laboratory notebooks

Purchase laser systems and components
- Write specifications
- Select vendor
- Order and receive

Sketch and dimension parts, schematics, and flowcharts

Write up a model shop work order

Interpret blueprints

Interpret schematics

Interpret flowcharts

SOURCE: Center for Occupational Research and Development (1985, p. 26).

LEOT curriculum into their program offerings. Like all postsecondary programs, a careful assessment of the local labor market is an essential component of this programming decision. If a program is begun without an identified local demand for LEOTs, students must be carefully counseled that the obtaining of training-related employment will necessitate relocation.

If an institution decides to consider offering a LEOT program, there are a number of concerns that need to be addressed. If this is the institution's first experience with high-technology programs, careful plans must be developed and followed to ensure successful development and implementation. High-technology programs are somewhat unique and require that leaders in education and industry collaborate to achieve outcomes benefiting both parties.

Abram et al. (1980) developed a guide for planning and implementing programs in high-technology fields, identifying a 30-step process with the do's and don'ts for each step. CORD (1985) provides specific guidelines for developing LEOT programs. That guide clearly defines probable equipment needs and some budget options for developing an LEOT program as well as staffing and facility concerns. The information that follows presents a synthesis of the two planning documents. Readers are advised to seek out these reports if they are considering beginning a LEOT program.

The Abram et al. (1980) guide leads the planner through five major phases of program establishment: long-range planning, program planning, program development, program implementation, and evaluation and refinement. Long-range planning activities include the initial linkages with local industry through the establishment of a high-technology advisory committee and the actual development of a 5-year plan. These planning activities are global in nature and should include all high technology programs, not just the LEOT program.

Once probable programs have been identified, the program planning phase begins. During this phase, the development of program performance goals to determine what skills and knowledge should be emphasized in the proposed program and a first draft of program requirements is completed. CORD (1985) identifies possible competencies and job tasks for LEOTs. This list, exhibit 2, can serve as a guide to developing a list of specific competencies needed by the local labor market. Other program planning activities are the establishment of a LEOT advisory committee representing local industry and potential employers and the identification of relevant faculty who will support and develop the LEOT program. Typically, linkages must be made with electronics and physics faculty. Faculties who provide instruction in drafting, instrumentation, fabrication, English, mathematics, communication, and mechanics need to be included in these linkage activities also.

Finally, the cost-effectiveness of the program must be evaluated, including alternative equipment and facility arrangements. At the end of this phase, the institution may decide to continue with development of the LEOT program, slow down the program development process to fit budgetary and planning considerations, or discontinue the development altogether. Once the decision has been made to continue with the LEOT program development activity, phase three, the actual development of the program, begins.

In the program development phase, the LEOT program advisory committee participates actively in the final decisions concerning curriculum, in the identification of necessary equipment and facilities, and in the assessment of employer and student needs. CORD, the Center for Occupational Research and Development, has developed curriculum for LEOT training. Schools should explore this curriculum as a starting point. Most schools currently offering LEOT training began with this curriculum and modified its sequencing and emphasis to fit their needs as defined by the local labor market.

CORD has also developed an advanced technology core curriculum approach based on engineering principles that can be used for all high-technology programs. The basic skills core includes topics in mathematics, science, communications, computer literacy, and socioeconomics. The technical core consists of electricity, electronics, mechanics, electromechanics materials, fluids, thermics, graphics, controls, and computer concepts and principles. Students also select a specialty area usually incorporating five or six courses such as laser electro-optics, robotics, microelectronics, or instrumention and control. The goal of this curriculum design is to prepare technicians with a systems orientation, a combination of interdisciplinary skills, and a strong technical base (Hull 1985).

A needs assessment instrument is sent to employers to identify demand for LEOTs and for the retraining of current employees. Another instrument is sent to students to identify their probable enrollment interest. CORD (1985) provides a model needs assessment form that can be adapted for use. Once the results of the employer and student needs assessments have been analyzed, the institution must again decide if offering a LEOT program is a realistic goal.

The development of final equipment lists with specifications for bids and potential suppliers now occurs, as well as final specifications for facility construction or renovation. CORD (1985) provides lists of equipment and some guidelines for facility specifications. These guidelines should be reviewed by program developers and the advisory committee to evaluate options for equipment purchase and facilities construction. The advisory committee may be able to identify potential donors of equipment for the program.

The program and courses need institutional review and approval. Funding or grant applications also need to be submitted to potential funding agencies.

Once facilities have been developed, equipment identified, and institutional approval granted, phase four, program implementation, begins. Program implementation entails the ordering of equipment and materials, the professional development or hiring of LEOT faculty, the orientation of faculty, the counseling of students, and the development of course syllabi.

Most LEOT programs currently begin with the instructional modules available from CORD. As discussed earlier, most schools adapt these materials to fit into their sequencing of the program and their program focus. CORD updates these materials yearly, using a convening of current users to identify weakness in the modules and to modify them to maintain their relevance to the developing laser field. Other curriculum guides are available from the regional curriculum coordination centers.

The securing of faculty can be approached by retraining current faculty in declining enrollment areas or hiring new faculty. These instructors need to have a strong background in lasers, applied optics, and electronics. If sufficient full-time faculty cannot be recruited, part-time faculty should be recruited from local industry. It might also be necessary to hire a student or a laboratory assistant to maintain the equipment and to aid in laboratory activities.

Counseling of perspective students must stress the rigor of the LEOT curriculum. Successful students in this program are often tested at the highest ability levels of all high-technology program students.

After the program has been implemented it should be evaluated and refined: phase five. High-technology programs require constant attention to changes in the technology, its applications, and its use in the local labor market. The program can gain from evaluating the performance of graduates on the job. Curricula, textbooks, equipment, and other instructional materials should be periodically evaluated to assess their fit with the current state of the art.

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