# The National Photonics Skill Standards for Technicians

**Third Edition**

OP-TEC
National Center for Optics and Photonics Education

This document was produced by OP-TEC: The National Center for Optics and Photonics Education, an NSF Advanced Technological Education (ATE) Center of Excellence (NSF award 0603275). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

For more information about OP-TEC, contact either of the following persons:

Dan Hull, PI, Director
CORD
P.O. Box 21689
Waco, TX 76702-1689
(245) 741-8338
(254) 399-6581 fax
hull@cord.org
www.op-tec.org

Dr. John Souders,
Director of Curriculum Materials
P.O. Box 21689
Waco, TX 76702-1689
(254) 772-8756 ext 393
(254) 772-8972 fax
souders@cord.org
www.op-tec.org

Published and distributed by

CORD
P.O. Box 21689
Waco, Texas 76702-1689
254-772-8756
800-972-2766
http://www.cord.org/

ISBN 978-157837-510-x

# Contents

# Executive Summary

## *Photonics and the need for photonics education*

*Photonics* is "the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon."* Photonics includes optics, lasers, fiber-optics, and other electro-optical devices. Photonics has many applications in manufacturing, medicine, communication, solid-state lighting, and other high-tech fields. Thus, it represents a broad, commercially viable area in which American employers require a steady supply of well-qualified technicians. At the same time, photonics offers people with appropriate technical education and training a wide variety of rewarding employment opportunities and great potential for personal advancement.

The demand for photonics technicians in the United States is great—over a thousand new openings a year—and that demand is growing faster than the pool of qualified candidates. The resulting shortfall cannot be met entirely through on-the-job training. Our public education institutions, particularly two-year colleges, must play a role. Since most of the skills needed by photonics workers at the technician level are obtainable via AAS degree programs, community and technical colleges provide the optimum environment for significantly increasing the number of qualified personnel available to U.S. employers in technical fields.

The need for new courses and programs falls into three broad categories, as determined by the three types of technicians the courses and programs would be designed to support:

> Photonics specialists—These technicians work in research and development laboratories; as team members for original equipment manufacturers in lasers, optics, and photonics; and as field service techs. They are typically graduates of AAS programs that focus specifically on optics, lasers, and photonics.
>
> Technicians in photonics-enabled fields—These technicians are typically graduates of technical education programs in fields in which photonics technology enables processes to be accomplished at higher efficiencies or with greater precision. (The use of lasers in manufacturing for cutting, welding, measuring, and aligning is an example of this "enabling" principle. The concept of photonics as an "enabler" is discussed more fully in the body of this document.)

---

**Photonics Spectra* (Laurin Publishing)

Incumbent workers who require continuing education—These technicians are already employed but require additional training to advance in their fields or to adapt to changes in the workplace.

In keeping with the three categories of technicians described above, we suggest that photonics education and training courses and programs should be of three general types:

Photonics AAS—Two-year postsecondary programs in which photonics is the primary focus

Infusion AAS—Two-year postsecondary programs in fields in which technicians learn how lasers and photonics are used in other technologies. This document provides information for infusing photonics as an "enabling technology" into those programs.

Advanced Certificate—Short duration programs lasting less than two-years in which incumbent workers receive customized education/training in specific photonics concepts or skills

## *What are skill standards and why are they needed?*

Skill standards are employer-driven statements of expectation as to what workers should know and be able to do on the job. Skills standards are employers' "specifications." They are the primary means by which employers communicate to educators their (the employers') requirements regarding the content of the courses and programs that will produce their future employees. Skill standards such as those contained in this document are necessary to ensure that technicians are well prepared for the challenges that await them in today's high-tech, globally engaged workplace.

## *The purpose of this document*

This document represents the consensus of a broad cross-section of U.S. employers regarding the technical and workplace skills required of entry-level photonics technicians. It is designed to give educators and employer advisory committees a solid foundation for generating courses and programs that will enable U.S. two-year colleges (and their feeder high schools) to produce globally competitive workers.

The document provides "critical work functions" and typical tasks for six photonics-enabled technologies: communication, lighting and illumination, medicine, manufacturing, optoelectronics, and imaging and remote sensing. The document also provides foundational knowledge components (both optics-intensive and general) for photonics technician programs, along with outlines for five secondary and ten postsecondary courses, two models for infusing photonics content into AAS programs, and an advanced certificate curriculum.

## ***How this edition expands upon the previous two***

The first edition of the *National Photonics Skills Standards* was published in 1995 by the Center for Occupational Research and Development (CORD), with funding provided by the U.S. Department of Education, Office of Vocational and Adult Education, and with the assistance of photonics industry representatives and educators. The 1995 standards provided task lists supporting cumulatively six photonics specialties—defense/public safety/aerospace, communication, medicine, environmental/energy/transportation, manufacturing, and computers*.* Included in that edition was a set of knowledge components derived from the task lists.

Development of the second edition (CORD 2003; ISBN 1-57837-357-3) was funded by the National Science Foundation (NSF) as part of CORD's STEP II project (NSF award 0202424; Scientific and Technological Education in Photonics). The second edition refined the first-edition standards via an online survey of photonics educators and employers. Two significant changes resulted. First, the areas of specialization were revised to align more closely with the latest trends in photonics. (The new areas were communication, lighting and illumination, medicine, manufacturing, optoelectronics, and imaging and remote sensing*.*) Second, the critical work functions and tasks were arranged by specialty area. The second edition also presented a sample 4+2 (secondary-postsecondary) course sequence and outlines of three secondary and eight postsecondary courses.

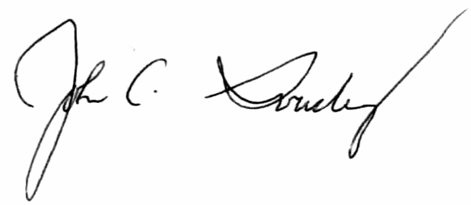
The third edition was developed by OP-TEC: The National Center for Optics and Photonics Education, an NSF Advanced Technological Education (ATE) Center of Excellence (NSF award 0603275). Like the second edition, the third reflects input gathered from the photonics community via an online survey. (The survey was "live" online for about a year.) Before being incorporated into the third edition, the survey results were reviewed by the advisory committees and/or technical experts at OP-TEC's partner colleges—Camden County College, Central Carolina Community College, Indiana University of Pennsylvania, Indian Hills Community College, Indian River Community College, and Texas State Technical College. The changes that resulted from the third-edition survey and its review are relatively minor, attesting to the comprehensiveness and thoroughness of the original standards and the review process used to generate the second edition. The majority of differences are found in the specialty area of medicine. The third edition also expands the optics-intensive knowledge components to include knowledge relevant to the use of lasers and electro-optical systems in making precision measurements and alignments.

The third edition includes three new curricula derived from research conducted by OP-TEC during its first two years of operation. The first is a 4+2 AAS photonics curriculum that can be used as a benchmark for existing AAS programs or for implementing new programs. The second presents two models for infusing photonics concepts into AAS programs in photonics-enabled technologies. The third is an advanced certificate curriculum designed to enhance and update the knowledge and skills of technicians already employed in photonics-enabled technologies. All three of the new curricula are standards-based.

The final section of the third edition lists the individuals and organizations that have contributed to the development of all three editions. The steady growth of this list since 1995 attests to CORD's and OP-TEC's determination to ensure that these standards serve the broadest possible cross-section of the photonics community and give American educators an essential tool in the production of world-class workers.

The OP-TEC staff invites you to review the standards and welcomes your recommendations for their improvement.

Daniel M. Hull
OP-TEC Director



John C. Souders Jr.
OP-TEC Director of Curriculum Materials

May 1, 2008

# Acknowledgments

Special thanks are gratefully acknowledged to the following persons and entities:

Mr. Darrell Hull, for the key role he played in the development of the first edition (1995) through a grant from the U.S. Department of Education, OVAE. Drs. Art Guenther (deceased) and Leno Pedrotti were also instrumental in that early work and have contributed to both phases of the STEP project.

NSF, for grants supporting both phases of the STEP project (NSF grants 9752092 [STEP I] and 0202424 [STEP II]) and for the creation of OP-TEC: The National Center for Optics and Photonics Education (0603275). Without these grants, this document and its supporting materials could not have been developed. The credibility gained through NSF's endorsement of the STEP project and OP-TEC has also proved to be an invaluable asset.

Dr. Chandra Roychoudhuri, the PI of the STEP I project, for the key role he played in directing a program of work that continues through the STEP II project

SPIE the International Society for Optics and Photonics (especially Dr. Eugene Arthurs, executive director, and Ms. Sheila Sandiford, education and membership director) for support, advocacy, and technical review by their members of the earlier editions of the standards

The Optical Society of America (especially Dr. Elizabeth Rogan, executive director, and Mr. Jason Briggs, educational specialist) for support, advocacy, and technical review by their members of earlier editions of the standards

The Texas Skill Standards Board (especially Pamela Rogers, director, and Lee Rector, former director and now deputy director of the Texas Council on Workforce and Economic Competitiveness) for guidance in ensuring that the tasks associated with the standards are appropriately *performance based*

The National Research Council for its contribution in defining "National Science Education Standards"; The American Association for the Advancement of Science for its identification of the "Benchmarks for Scientific Literacy" in Project 2061; and the National Council of Teachers of Mathematics for its delineation of the "Principles and Standards for School Mathematics"

OP-TEC partner colleges—Camden County College (Dr. Fred Seeber), Indiana University of Pennsylvania (Dr. Feng Zhou), Central Carolina Community College (Gary Beasley), Texas State Technical College (John Pedrotti), Indian Hills Community College (Greg Kepner), and Indian River Community College

(Dr. Chrysanthos Panayiotou)—for their work in organizing reviews of these standards through their respective advisory committees and for their own professional input into the review process

The almost 300 business and technical representatives who, by contributing their time and effort, have ensured that the standards and other information presented herein respond to the real needs of the working world

Participating educators, for accepting the responsibility of leading the way in shaping postsecondary photonics education in this country

Through the generosity and hard work of many persons, OP-TEC has taken significant strides—of which this document is only one—in relieving the critical shortage of photonics technicians in the United States.

## HOW TO USE *THE NATIONAL PHOTONICS SKILL STANDARDS FOR TECHNICIANS*

This document should be used as a guideline for developing and/or updating photonics education programs, especially at the two-year postsecondary level. (Information pertaining to articulated high school “feeder” programs is also provided.)

The document gives users a comprehensive view of what photonics technicians in certain broad specialty areas should know and be able to do—as determined by a consensus of practicing specialists in the field. Program developers (who should include both educators and employers) will find that the information provided eliminates the need for extensive research and thus gives them a head start on the development process.

The mission of every technical associate degree program should be to provide skills that accomplish three goals: (1) satisfy the needs of local employers but are also transportable to other locales, (2) prepare graduates for further education, and (3) give graduates mobility within the field and the ability to adapt as the field changes. To fulfill that mission, each program should represent a workable balance between the specificity desired by employers and the breadth desired by educators. This document will help educators and employers find that balance.

The information provided will also help school counselors gain an understanding of the photonics field that will enable them to describe the field’s rewards and demands to prospective photonics students. (Guidance counselors will also want to become familiar with the websites of the Optical Society of America [http://www.osa.org/] and SPIE the International Society for Optics and Photonics [http://www.spie.org/].)

And last, but not least, the information provided in this document will provide career-minded students with a bird’s-eye view of the laser/optics/photonics industry.

# Overview

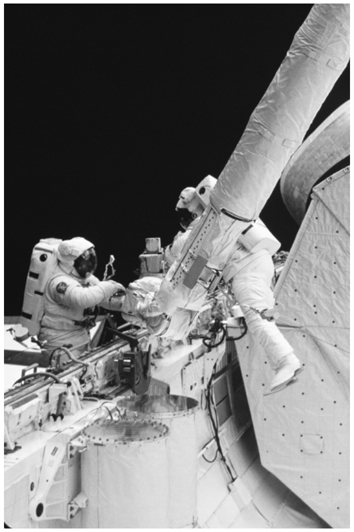
## Introduction

This edition (2008) of the *National Photonics Skill Standards for Technicians* was developed using a variety of sources for both content and validation of the information collected. The primary source, however, was the second edition, which was published in 2003. CORD developed both the 1995 and 2003 editions, first with funding from the U.S. Department of Education, Office of Vocational and Adult Education, and then with support from the National Science Foundation (NSF) (Award #0202424). The 2008 edition was developed by OP-TEC with funding, once again, coming from NSF. OP-TEC is an NSF/ATE National Center of Excellence (Award# 0603275) whose mission is to increase the nation's supply of skilled photonics technicians.

## A Brief History

This document is a result of work that started back in the early 1990s. In that time, the Center for Occupational Research and Development (CORD) realized the need for photonics standards and undertook a project to develop them. CORD elicited the help of photonics industry representatives and educators to help author a set of standards that would lay a foundation for developing curriculum for AAS photonics programs at two-year community and technical colleges. The authors of that work identified key areas of photonics specialization and what technicians in those areas are expected to know and be able to do. This work resulted in the first edition of the *National Photonics Skill Standards for Technicians* (CORD, 1995).

In 2000, CORD recognized the need to update the standards and embarked on a program designed to generate the second edition. The general structure for updating the 1995 standards originated with a broad organizational strategy based on constructs drawn heavily from the first edition and proposed by CORD to individuals in diverse areas of business and industry. Those individuals spent many hours responding to that general framework, making clarifications and refinements, and offering suggestions for additional technical skills that should be considered. The STEP II project investigators and project staff members (all of whom are optics and photonics scientists, engineers, and technicians with experience in education)



This document gives users a comprehensive view of what photonics technicians in certain broad specialty areas should know and be able to do—as determined by a consensus of practicing specialists in the field.

then formulated the business and industry representatives' comments as lists of tasks and skills. The business and industry contributors were then given an opportunity to review the skills and task lists prior to developing lists of knowledge requirements and other educationally relevant information.

When sufficient information had been gathered from the business and industry community, the process then involved educators from two-year colleges, i.e., the people who were responsible for producing the vast majority of technicians entering the optics/photonics workforce.[1] Those educators provided information that assisted the investigators and staff in compiling a list of foundational knowledge components based on the tasks and skills requested by business and industry representatives. The CORD staff reorganized those knowledge components into logical sequences that reflected a modular approach to presenting the material in the classroom. This work was captured in the second edition in the section headed "Foundational Knowledge Components for Two-Year Photonics Technician Programs," which has been retained in the third edition.

[1] Agustín Navarra, Darrell Hull, Arthur Guenther, and Leno S. Pedrotti, "Whence the Technicians?" *Photonics Spectra,* Vol. 35, Issue 4, April 2001.

In September 2006, the responsibility of maintaining these standards was passed from CORD to the newly established NSF/ATE National Center of Excellence, OP-TEC. OP-TEC reviewed the second edition of the standards and determined that another update was needed. This update started in January 2007.

## 3rd Edition Review Process

The third edition of the standards draws heavily on the organization and content of the 2003 standards. To determine where changes to the second edition were needed, OP-TEC staff created an online survey that presented all elements (critical work functions, tasks, employability and technical skills) contained in the 2003 standards. Survey participants (all of whom had experience as photonics engineers, scientists, or technicians) could review a particular element of the standard and decide whether it was to be retained, deleted, or altered. Participants who indicated that alteration was called for were given space for entering how the alteration should be made. The survey was kept active on the OP-TEC website for one year. During that year, the survey's purpose and existence were publicized at several major photonics and optical conferences. At the end of the year all recommended changes (deletions or alterations) from the survey were summarized.

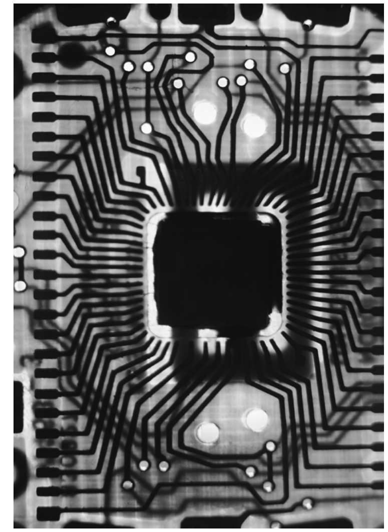
This summary was sent to the advisory committees at the OP-TEC partner colleges where it was reviewed. All recommended changes were voted on for approval or disapproval by the committees. If disagreement occurred between committees on their recommendations, a third-party photonics expert was consulted to resolve the disagreement. The changes that were approved were incorporated into the 2003 standards, thus creating the standards that appear in this document.

## Intent of the Standards

The standards presented in this document are intended to be useful to educators (including counselors) and employers of photonics technicians. However, their primary purpose is to help guide the development of comprehensive curricula that would help U.S. two-year colleges produce globally competitive workers in the optics and photonics industries and the industries that are enabled by photonics. These curricula must also be flexible enough to address the needs of undergraduate students and already employed technicians. Such curricula should be broad enough to address the wide diversity of skill needs experienced by employers across the country. Consequently, OP-TEC has completely revamped the second edition "Curriculum" section of the standards so as to present within the third edition not only a new benchmark 4+2 AAS photonics program, but also curriculum models for infusing photonics into technical programs where it is an enabler, and proposing templates for retraining employed technicians through advanced certificate programs.

At the same time, because the mission of most two-year colleges is to help meet *local* needs for qualified workers, the final result of the curricula recommendations offered in this document is modular so that colleges can select the portions that correspond to conditions in their regions. The envisioned curricula would provide ample opportunities for students to practice using the tools of their trade but would also stress fundamentals, thus maximizing student options.

The information provided will help community colleges partner with high schools in designing photonics career pathways that will lead their students through well-planned secondary course sequences and into articulated two-year postsecondary programs. ( As an example, see the benchmark 4+2 course sequence in the section headed "Curriculum.") Some students will conclude their formal education at that point, which is fine, given that a



Because it encompasses applications in numerous and diverse fields of technology, photonics offers technicians a wide variety of employment opportunities and great potential for personal advancement.

growing number of employment opportunities in photonics require no more than associate degrees. For students who want to continue their schooling, the standards presented in this document are rigorous enough to serve as the groundwork for curriculum materials suitable for most of the first two years of baccalaureate programs in engineering technology.

Two-year colleges should find the standards useful as a guide when working with their industry advisory committees to determine what courses they should offer. They should also find the standards useful when partnering with high schools or Tech Prep consortia that prepare students for entry into their programs, and with the four-year colleges to which their graduates transfer.

High school guidance counselors will find the standards useful in helping students decide whether to pursue careers in optics and photonics and alerting them to the demands of photonics training and performance in the workplace.

And students interested in careers in the general field of optics technology will find information outlined in the standards to be a useful description of tasks and skills expected of photonics technicians in today's industries.

As the optics/photonics industry continues to mature, and more and more research-based programs evolve into commercial enterprises, people in photonics-related businesses and industries should find the standards useful in identifying optimum technician-level qualifications for both new and existing employees. Human resource personnel should find the standards useful in selecting training programs that will help their employees keep pace with changes in industry. The standards can also be used to guide discussions between employers and community college faculty members as they attempt to identify, in industry-driven situations, critical skills for which short-term training is needed. See in the section headed "Curriculum" the advanced certificate curriculum for helping retrain already employed technicians.

## Photonics Technology

### *The Depth and Breadth of Photonics*

*Photonics* is defined by a leading industry trade publication, *Photonics Spectra,*[2] as:

> *The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon*

---

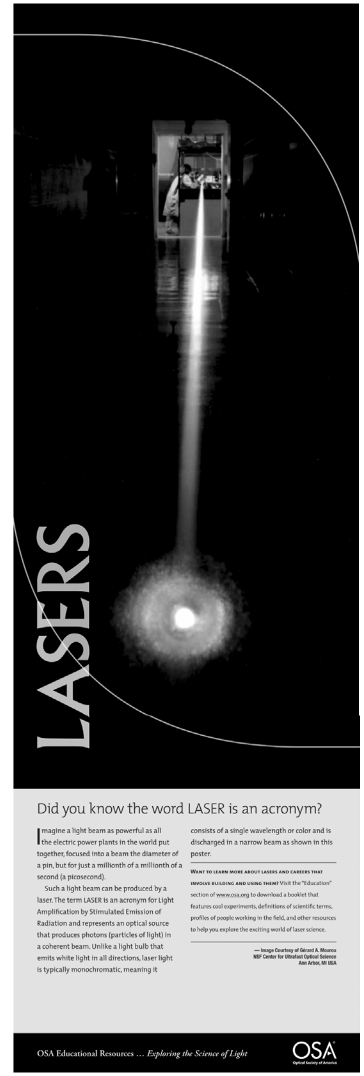
[2] A Laurin publication, Laurin Publishing Co., Inc., PO Box 4949, Pittsfield, MA 01202

*Photonics,* as defined, becomes at once an integral part of the broader discipline of *optical science and engineering* or simply *optics*. Because photonics encompasses applications in numerous and diverse fields of technology, it offers technicians a wide variety of employment opportunities and great potential for personal advancement.

Consider, for example, the following: Photonics technicians work in *information technology* and *telecommunication,* wherein information and data are transported, processed, stored, and displayed. They contribute to *medicine and healthcare* by supporting healthcare givers with minimally invasive laser therapy, micromanipulation techniques, and DNA analysis. They are involved in the *monitoring of our environment and atmosphere* through the use of optical sensors and advanced imaging systems. They contribute to *laser entertainment* through new illumination and lighting processes. They assist the country's *industrial manufacturing* arm by using light and lasers to perform and control diverse manufacturing processes and by helping to fabricate and produce special optical components and systems. And they help in national defense through the application of light and lasers to surveillance, night vision, communication, navigation, and homeland security.

These examples of the depth and breadth of photonics in optical technology provide us with a clear picture of the importance of photonics in helping fuel the economic engine of our country and of the challenging opportunities that the field of photonics offers learners in our schools. Still, we must admit that—outside of scientific and industrial circles—the word "photonics" does not create excitement and interest. We have work to do in associating the word "photonics" with the more readily understood word "light."

The professional societies have made large gains in bringing an understanding of light technology to the general public. The Optical Society of America (OSA) has produced an Optical Phenomena Poster Series and corresponding pamphlets featuring images and text about medical optics, fiber optics, lasers and spectroscopy. These posters and pamphlets are being provided to educational institutions around the world for use as instructional aides and motivational pieces for careers in optics. To request a copy of the poster series, visit the "Education" section of *www.OSA.org* or e-mail *opticseducation@osa.org*. Additionally, OSA hosts an in-depth website, *www.OpticsforKids.org*, encouraging kids of all ages to "Explore the Science of Light."




Photonics continues to move ahead, catalyzing and supporting new areas in technology and identifying trends for the near future and beyond.

Likewise, SPIE the International Society for Optics and Photonics has a large collection of Optics and Photonics Awareness posters covering topics such as biophotonics, nanotechnology, sensors, and more. To view SPIE's poster series and educational resources, visit the "Resources" section of *www.spie.org* and select "Resources for Educators."

Both of these organizations have extensive websites highlighting available teaching aids and resources such as posters, videos, and optics kits. In addition, SPIE, with support from OSA, produced a DVD titled *Optics: Light at Work* (available on both websites) that is geared for middle school students and encourages young people to explore optics and photonics. Promotional materials such as the SPIE and OSA posters and videos help clarify the meaning of photonics and create interest and excitement among students.

## *Trends in Photonics Technology*

The section headed "The Depth and Breadth of Photonics Technology" pointed to the already significant role that photonics is playing in such critically important fields as *national defense*, *remote sensing, healthcare and life sciences, industrial manufacturing*, *information technology and telecommunication*, *fabrication of optical components and systems*, *optical sensors and lighting*, and *transportation.*. Clearly, optics and photonics pervade our everyday lives and are strategic enablers in our world of technology.

What is more exciting, photonics continues to move ahead, catalyzing and supporting new areas in technology and identifying trends for the near future and beyond. For example, in the field of *biophotonics* we see the emergence of the "lab on a chip," where microoptics and microfluidics come together. In *nanoscience* and *nanotechnology*, we are learning how to assemble molecules one at a time in perfect lattice structures, thereby building materials with enormous strength and heretofore-unattainable physical properties. In the field of *atomic optics* we hear of such strange names as "quantum dots," "optical tweezers," and "atomic force microscopes." In *transportation*, the ubiquitous application of microprocessors moves ahead rapidly, changing everyday automobiles into marvels of technology that rival the fictitious Batmobile.

*Forensic science and analysis*, increasingly popularized in the recent wave of "who done it?" television dramas, look to optics and photonics for help in unraveling crime-scene puzzles. In research laboratories, especially those devoted to the fields of *genomics* and *proteomics,* there is a growing need for (and opportunity to develop) state-of-the-art *solid-*

*state laser-assisted analytical instrumentation*, such as the first generation of mobile, compact, and efficient high-end desktop flow cytometers. Optical science, engineering, and photonics also play a key role in *homeland security*—defending our nation against biological, chemical, and explosive threats—which became, and will continue to be, a matter of great urgency with the tragic events of September 11, 2001.

Photonics and photonics technologies are linchpins in many of our country's expanding industrial technologies and promise to continue fostering and supporting emerging technologies. It is no wonder, then, that photonics is an exciting, challenging, and rewarding field for our current and future photonics technicians.

Alongside scientists and engineers in our laboratories and industries, increasing numbers of photonics technicians are (and will continue to be) needed. They will serve primarily in the broad areas of *R&D* and *production*, providing support also in *sales* and *repair*.

Two-year community and technical colleges, which are the primary target audience for the information provided in this document, have become widely perceived as the optimum training ground for photonics technicians. Data collected in a national survey of 39 industries in late 2000 (i.e., before 9-11) indicated preference for graduates of two-year postsecondary technical schools over graduates of high schools and four-year colleges—by a factor of 22 to 5! The surveyed industries also reported hiring Asian and Hispanic photonics technicians at a ratio of roughly 3 to 1 over technicians with Anglo or African-American backgrounds.[3]

The emerging picture is that photonics is a wide-open arena in which technicians and technicians-in-the-making—regardless of gender or ethnicity—compete on a level playing field and have many opportunities to benefit financially and to grow both personally and professionally.

Two-year community and technical colleges—the primary target audience for the information provided in this document—have become widely perceived as the optimum training ground for photonics technicians.

### *Photonics as an Enabling Technology*

The examples in the previous section underscore the fact that photonics is a technology that enables other technologies. In the second edition of these standards, this enabling concept was explained. The third edition expands the presentation of curriculum from the previous edition by including several different models for infusing photonics into technical programs that are

[3] Navarra, Hull, Guenther, and Pedrotti, "Whence the Technicians?"

enabled by photonics. (See the section headed "Curriculum.") OP-TEC has added these models because the high demand for photonics technicians is not limited to graduates of AAS programs that focus specifically on photonics. Much of the demand is for technicians who have a basic understanding of photonics and are capable of using that understanding to monitor and troubleshoot the photonics subsystems that enable certain processes in their areas of specialization. For instance, a manufacturing technician does not need an in-depth understanding of lasers, but he or she must be able to recognize when lasers used in a manufacturing process (for cutting, welding, measuring or aligning) are causing problems. These technicians do not need to know how to repair or re-calibrate the laser, but they must be able to identify it as a cause of the problem. An infusion curriculum will provide an undergraduate manufacturing technician with the necessary skills and knowledge (as defined in this document) to perform this type of troubleshooting task. For technicians who are already employed in technical areas that are enabled by photonics but have no background in photonics, this edition provides a template for designing an advanced certificate that will provide the skills and knowledge needed to understand the role of lasers in processes they oversee.

## Organization of the Standards

This document divides the photonics skill standards into six major ***specialty areas***. The standards pertaining to each area are presented as a series of ***critical work functions***. The description of each critical work function is accompanied by lists of relevant ***tasks, technical skills,*** and ***employability skills***.

### *Specialty Areas*

Photonics technicians work in the following six broad areas of specialization (which are the organizing principle upon which this document is based).

- *Communication:* Fiber optics, transmitters, and sensors
- *Lighting and illumination:* Lighting, displays, and entertainment
- *Medicine:* Biomedical optics and medical imaging
- *Manufacturing:* Materials processing, alignment, metrology, and inspection
- *Optoelectronics:* Nanotechnology, microsystems, and semiconductors
- *Imaging and remote sensing:* Signal and image processing, environmental, and aerospace

The six specialty areas should not be thought of as airtight categories. Rather, they reflect general groupings of the types of photonics-related activities that take place within a broad cross-section of the optics/photonics industry; a certain amount of overlap is to be expected.

## *Critical Work Functions*

In each of the six specialty areas, technicians are responsible for performing 4–6 *critical work functions*. Each critical work function is broad and subsumes a number of lower-level tasks. For example, one of the critical work functions for photonics technicians in the area of *communication* is:

> *Assemble various fiber-optic components and modules into subsystems and understand their functions.*

## *Tasks*

Performing each critical work function involves performing one or more of 5–10 *tasks.* For example, appropriate tasks for the critical "assembly" work function identified above are:

> *Gather technical requirements for components/devices/materials to facilitate ordering and procurement*
>
> *Assemble components/modules according to manufacturing specifications*
>
> *Prepare component/module for final test*
>
> *Perform reliability test and/or burn-in tests according to manufacturing specifications*
>
> *Integrate fiber-optic components and modules into specified systems*

## *Technical and Employability Skills*

Performance of every task requires at least one *skill* (often several). In this document, the term *skill* refers to the basic abilities necessary to perform a given task. For any task, there may be significant overlap among the required skills. Further, there are two general classifications of skills:

- *Technical* (example: Measure noise equivalent power)
- *Employability* (example: Navigate the Internet to gather information)

The importance of employability skills—In 1990, the U.S. Secretary of Labor appointed a commission to identify the skills our young people need for success in the world of work. The commission's fundamental purpose was to support the development of a high-skill workforce for a high-performance, high-wage economy. Although the commission completed its work in 1992, its findings and recommendations continue to be a valuable source of information for individuals and organizations involved in education and workforce development, including

Alongside scientists and engineers in our laboratories and industries, increasing numbers of photonics technicians are (and will continue to be) needed.

development of the nation's photonics workforce (see below).

While the information presented in this document pertains primarily to the technical side of the commission's findings, many members of the photonics business and industry community have noted that employability skills are no less important than technical skills (and are generally lacking in the current workforce). Therefore, the skills listed for the six photonics areas include both technical and employability skills.

### Workplace Know-How

The know-how identified by SCANS is made up of five competencies and a three-part foundation of skills and personal qualities that are needed for solid job performances. These include:

Competencies—Effective workers can productively use:

- Resources—Allocating time, money, materials, space, and staff
- Interpersonal skills—Working on teams, teaching others, serving customers, leading, negotiating, and working well with people from culturally diverse backgrounds
- Information—Acquiring and evaluating data, organizing and maintaining files, interpreting and communicating, and using computers to process information
- Systems—Understanding social, organizational, and technological systems; monitoring and correcting performance; and designing or improving systems
- Technology—Selecting equipment and tools, applying technology to specific tasks, and maintaining and troubleshooting technologies

The Foundation—Competence requires:

- Basic skills—Reading, writing, arithmetic and mathematics, speaking, and listening
- Thinking skills—Thinking creatively, making decisions, solving problems, seeing things in the mind's eye, knowing how to learn, and reasoning

*From "What Work Requires of Schools: A SCANS Report for America 2000," The Secretary's Commission on Achieving Necessary Skills, U.S. Department of Labor, June 1991*

# The Standards

On the pages that follow, the photonics skill standards, which form the heart of this document, are grouped according to the six specialty areas identified in concert with major optics and photonics industries:

- Communication
- Lighting and illumination
- Medicine
- Manufacturing
- Optoelectronics
- Imaging and remote sensing

The reader will see that under each *specialty area* the standards are organized by *critical work functions,* i.e., general occupational activities. Outlined under each critical work function are the *tasks* it involves. The tasks are then followed by lists of relevant *technical* and *employability skills*.

At the head of each of the six sections a short introductory description identifies the types of industries and activities in which technicians in that specialty area are likely to be engaged.

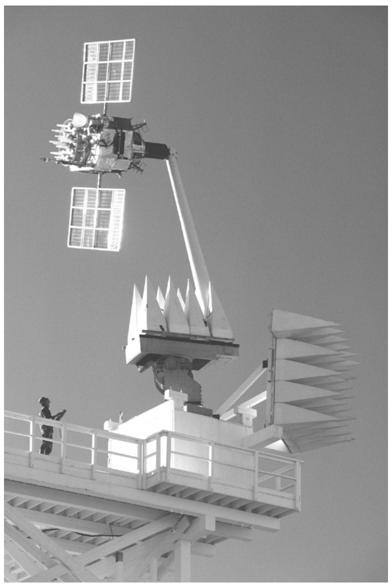
The standards are not intended to produce a curriculum to be uniformly adopted by community colleges across the country. Instead, the standards are meant to be a powerful tool that business representatives and educators can use to develop their own local curricula.

The critical work functions, tasks, and employability and technical skills specified for each specialty area represent a national consensus of what photonics technicians should know and be able to do. These statements are meant to be used locally to create or revise photonics curricula that make sense to educators and meet the standards of the industry. In general, the stated *workplace tasks* are *performance tasks*.

We recommend that local businesses select one or two photonics specialties from among the six provided, review the appropriate curriculum standards, propose revisions needed to meet the needs of the local environment, and validate the final standards. Educators then should align curriculum objectives with the validated standards and create or revise course sequences, syllabi, and instructional materials that meet the course objectives. The curricula provided in the section headed "Curriculum" can be used as a starting point for local curriculum development.

# Communication

## (Fiber optics, transmitters, and sensors)



Technicians working in communication may work for companies that use optical fiber capable of carrying telephone services (voice) across local, regional, and/or nationwide networks. They may work for corporations, banks, universities, and other entities that depend on private networks to transmit digital information (data). They may work for cable television and community antenna television companies (CATV) that use optical fiber systems for transmitting signals to subscribers (video). They may also work in a variety of high-tech industries that use lean manufacturing and just-in-time production methods in the manufacture of fiber-optic cables and fiber-optic components.

Communication technicians may work with fusion splicers, optical power meters, and laser sources and detectors, as well as optical spectrum analyzers and other electronic test equipment.

## Critical Work Functions and Tasks

### Critical Work Function

***Assemble a demonstration system for fiber-optic communication***

### Tasks

- Identify technical functions for customer requirements
- Analyze and convert customer requirements into technical specifications
- Convert supervisor's task statement into a statement of work
- Identify measurable parameters to match the statement-of-work specifics
- Understand how to identify/define technical tasks for supervisory designer reviews
- Recommend development, fabrication, or purchase of components necessary for a system that meets specs
- Generate functional schematics for the system configuration
- Prepare technical schematics and documentation for assigned tasks

### Critical Work Function

***Critically evaluate a fiber-optic systems installation process***

### Tasks

- Identify and interpret critical customer requirements
- Specify appropriate fiber-optic cable, transmitters/receivers, and components that match system requirements
- Develop assembly installation plan based on assigned system configuration
- Calculate acceptance values for power loss; correlate transmitter/receiver requirements to customer requirements
- Identify and resolve technical assembly/installation problems
- Perform bit error rate test
- Perform component and/or cable assembly/installation per job specifications
- Perform risetime and loss budget analysis to ensure adequate signal quality per job specifications
- Identify potential safety hazards and develop and implement safe operating procedures per company specifications
- Prepare technical schematics and documentation for assigned tasks
- Identify system performance parameters and measurement procedures per job specifications

### Critical Work Function

***Identify critical functions that maintain fiber-optic system operation***

#### Tasks

- Measure, analyze, and compare system performance to baseline specifications
- Troubleshoot and repair component and connectivity problems to system specifications
- Create and implement system maintenance plan
- Enhance system performance by properly cleaning components used to transmit, route, and test the fiber optics signal in the prescribed system
- Perform functional verification and system audit checks
- Follow safety requirements for equipment use
- Document maintenance activities per company procedure
- Develop upgrade plans for the assigned experiment and/or system maintenance

### Critical Work Function

***Identify fiber-optic cable manufacturing steps and understand them***

#### Tasks

- Fabricate fiber-optic cable according to specifications
- Generate technical documentation/reports of completed tasks
- Monitor fiber draw process
- Perform quality and performance inspections per company procedures
- Perform packaging and inventory control per company procedures

### Critical work function

***Assemble various fiber-optic components and modules into subsystems and understand their functions***

#### Tasks

- Gather technical requirements for components/ devices/materials to facilitate ordering and procurement
- Assemble components/modules according to manufacturing specifications
- Perform quality inspections per manufacturing specifications
- Support project management and cost control functions
- Prepare component/module for final test
- Ensure that manufacturing quality guidelines and documentation are followed
- Perform reliability test and/or burn-in tests according to manufacturing specifications
- Integrate fiber-optic components and modules into specified systems
- Use free space optics in specific telecommunication systems

## Employability and Technical Skills

### Employability Skills

- Work cooperatively with others
- Identify hazard potentials and follow laboratory safety rules and regulations
- Be punctual for work days, assignments, and tasks
- Navigate the Internet to gather task-related information
- Use appropriate word processing, database, and presentation software efficiently
- Maintain daily real-time laboratory notebooks
- Present technical information clearly and concisely in written and oral form
- Work responsibly with minimal supervision
- Be acquainted with vendors and equipment sources and know how to complete a purchase order
- Be able to interpret and evaluate graphical and tabular data
- Create and implement system-scheduled maintenance plan

### Technical Skills

- Measure and calculate coupler split ratio
- Identify troubleshooting parameters and measuring instruments to assess operational integrity of given fiber-optic systems
- Measure *power* and compare with *power budget* to assess performance of given fiber-optic systems
- Determine *dispersion characteristics* of optical fibers
- Calculate *insertion loss* in fiber-optic systems
- Measure power and determine system *signal gain and loss*
- Calculate *bandwidth* of a fiber-optic system
- Select *appropriate fibers* for various system operations
- Select *appropriate detectors* in accordance with system speed, response, rise time, wavelength, distance bandwidth product and sensitivity specifications—including PIN or APD detectors
- Select appropriate modulators for a given system
- Select appropriate connectors, couplers, and splicers for a given system
- Terminate fiber with appropriate fiber-optic connector using manufacturing specifications
- *Polish fibers* at connector insertion
- *Cleave* at correct length
- *Join fibers* at connectors
- Test and verify initial *source output* and *launch angles* at source/fiber interface
- Install appropriate laser diode, VCSEL diode array, or a non-laser light source for system assembly
- Characterize fiber-optic source using optical spectrum analyzer
- Interface diode laser with current drive and TE cooler
- Install and test wave-locking device

**TECHNICAL SKILLS (CONTINUED)**

- Align and terminate polarization maintaining (PM) fiber
- Interface laser to fiber with minimal insertion loss
- Measure fiber-optic cable parameters (i.e., circularity, concentricity, etc.)
- Measure optical modulator output parameters
- Perform eye-pattern test
- Check optical system alignment
- Determine optimal repeater location
- Use erbium-doped fiber amplifiers for signal regeneration
- Measure EDFA output spectral characteristics
- Use appropriate gain flattening filters
- Use fiber Bragg gratings
- Use fiber-optic circulators
- Measure signal amplitude at the transmitter and detector (receiver)
- Install and use electro-optic (EO) and acousto-optic (AO) devices
- Select, install, and use fiber-optic add/drop multiplexor
- Measure wavelength division multiplexing (WDM) and dense wavelength division multiplexing (DWDM) spectrum
- Use fusion splicer to join fibers
- Use mechanical splices to join fibers
- Use bit error rate (BER) tester
- Use fiber-optic fault locater

# Lighting and Illumination

## (Lighting, displays, and entertainment)

Technicians with a concentration in this specialty area deal with uses of light and lasers that impact our everyday lives at home, at work, and at play. This group of technicians comprises multidisciplinary individuals representing a variety of perspectives.

Display technology involves the use of light to project the images necessary for the operation of cell phones, cars, wristwatches, calculators, computers, TVs, and projection systems. Display technology includes technical analysis and diagnostic tools and equipment for jobs in medicine, electronics, aviation, navigation, and law enforcement—to name only a few. In display technology, the interface between a display and its parent device is critical and requires a multidisciplinary background to be fully understood.

Skilled technicians with multidisciplinary backgrounds are also required in the high-profile business of producing laser light shows. To be successful, these individuals—each a businessperson, artist, and laser/optics technician rolled into one—must know the entertainment business, have a keen sense of what will hold an audience's attention, and understand how to use the features of the technology to create the high-quality productions that will keep them in business.

Lighting designers and display technicians combine their knowledge of human nature, engineering, and construction with their knowledge of photonics to create environments and devices that make our everyday surroundings safer, more aesthetically pleasing, and more functional. These technicians must also understand and comply with regulatory criteria and procedures.

Lighting designers and display technicians represent an emerging type of photonics technician that requires a unique set of skills in spatial reasoning and design.

## Critical Work Functions and Tasks

### CRITICAL WORK FUNCTION

***Develop, set up, and operate lasers used in a range of activities, such as light shows, rastering lithography, and scanning for laser light shows***

#### TASKS

- Determine overall plan and effects of light show in conformance with user needs and specified safety standards
- Generate system requirements for light show
- Develop appropriate beam-path schematic for desired light show
- Select lasers for appropriate color effects and available laser show software
- Interface computer hardware with laser light show system to achieve optimum control
- Program scanning software for desired effect per customer specifications
- Operate laser light show system to meet customer needs
- Meet all safety regulations of the Center for Devices and Radiological Health and ANSI Z136 and other applicable standards

### CRITICAL WORK FUNCTION

***Determine lighting and associated imaging-optics requirements for specific applications***

#### TASKS

- Verify electrical source capacity and conditions
- Determine building conditions for the desired lighting or light show
- Verify eye-safety operation practices in accordance with OSHA and ANSI standards
- Verify factors affecting energy use (including heat energy) to minimize energy dissipation
- Evaluate human visualization factors to achieve customer needs and conform to ANSI safety standards

## Critical Work Function

***Develop lighting and associated optics design***

### Tasks

- Assess lighting system per customer requirements
- Establish design constraints (regulatory, project, and physical) per cost, space, and safety standards
- Establish lighting design criteria per customer needs
- Evaluate proposed lighting conditions
- Verify eye-safety operating practices per ANSI and OSHA standards
- Identify and evaluate human visual and other factors per performance and safety standards
- Develop schematic in conjunction with electrical engineering input for selected design
- Prepare cost projections for specific project
- Identify/evaluate/select lighting technology to best meet customer needs
- Develop construction documents (specifications) per given project

## Critical Work Function

***Operate and maintain lighting system***

### Tasks

- Develop and communicate maintenance documentation for given system
- Develop and communicate operation and maintenance procedures for given system
- Input and communicate to ensure regulatory compliance
- Verify eye-safety operating procedures in accordance with established safety standards
- Troubleshoot and communicate component/system problems for given system

### CRITICAL WORK FUNCTION

***Perform electro-optic display characterization and performance evaluation***

### TASKS

- Incorporate performance criteria for CRT, LCD, active matrix, plasma, and other displays
- Conduct performance evaluation measurements in accordance with industry standards on specific electro-optic display
- Troubleshoot and make repairs to circuit boards and interfaces as required for effective operation
- Understand schematic diagrams
- Assemble and test preproduction prototypes
- Conduct burn-in tests
- Establish accuracy of measurement results per specifications
- Maintain and ensure properly calibrated measurement equipment per company specifications
- Verify eye-safety operating practices per OSHA and ANSI standards

## Employability and Technical Skills

### EMPLOYABILITY SKILLS

- Work cooperatively with others
- Follow laboratory safety rules and regulations
- Be punctual for work days and assignments
- Navigate the Internet to gather information
- Use appropriate word processing, database, and presentation software
- Maintain daily real-time laboratory notebooks
- Present technical information clearly and concisely in written and oral form
- Work responsibly with minimal supervision
- Be acquainted with vendors and equipment sources and know how to complete a purchase order
- Be able to interpret and evaluate graphical and tabular data
- Maintain a personal work schedule with appointments
- Select vendors and optimum equipment sources
- Know characteristics of different light sources

## TECHNICAL SKILLS

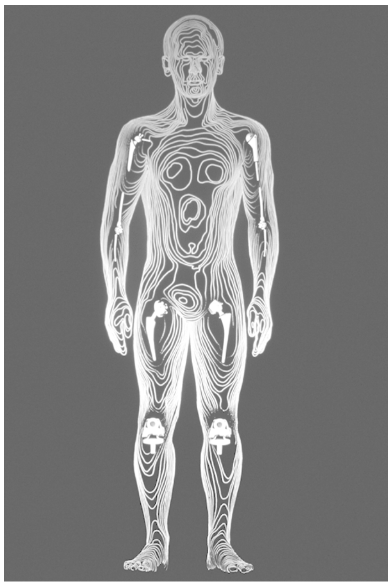
- Storyboard light show
- Identify continuous elements of show
- Select/acquire necessary lasers for show within budgetary constraints for maximum number of wavelengths available and necessary energy/power limitations
- Perform site inspection for display surfaces and to identify projection and control locations
- Determine max/min image dimensions at site and rig screens
- Program and validate software to control the projector
- Sequence animation effects
- Align and set up projector
- Perform a safety audit in conformance with OSHA and ANSI safety standards
- Preset site with projector and controls
- Perform run-through with artists
- Conduct preshow check
- Initiate and monitor projector and controls during show
- Construct or repair projection systems in accordance with ILDA standards
- Control ambient lighting
- Inspect panels
- Clean panels
- Surface treat panels with buffer layer
- Surface treat panels with electroluminescent polymer layer
- Measure luminance levels
- Assess day lighting characteristics
- Identify potential lighting, equipment, and electrical problems
- Install lighting controls including occupancy sensors, timer switches, and photocells
- Measure AC and DC voltage
- Determine proper wire size for current limits
- Install emergency power system per specified project
- Determine plug loads
- Identify and comply with established regulatory codes
- Identify project constraints (physical and budget)
- Evaluate electrical lighting load distribution
- Determine user need (i.e., visual performance, visual comfort)
- Specify lighting system and technology requirements
- Specify critical product criteria
- Perform preliminary cost calculations and estimates
- Develop plans and specifications
- Prepare lighting drawings and specifications
- Evaluate lighting performance versus design criteria
- Develop luminaire, lamp, and control schedules
- Develop relamping and cleaning schedule

**TECHNICAL SKILLS (CONTINUED)**

- Identify and document safety issues in accordance with ANSI and OSHA standards
- Troubleshoot and rectify premature component failure
- Troubleshoot and rectify flicker
- Troubleshoot and rectify color shift
- Troubleshoot and rectify control systems operating improperly
- Educate client per proper design operation and safety standards
- Measure spectrum of lighting
- Measure temporal properties of pulsed lighting
- Incorporate tolerances of fabrication method into design
- Measure compliance of fabricated parts to design
- Specify cooling systems when required
- Identify suitable sources for required task

# Medicine

## (Biomedical optics and medical imaging)



Photonics technicians working in this specialty area install, inspect, maintain, and repair complex equipment and instruments used in medical diagnosis and treatment. The equipment includes electronic devices, optical components, diagnostic scanners, ultrasound equipment, magnetic resonance imagery machines, and lasers.

Working in hospitals and research facilities, technicians in this field inspect and test equipment to make sure it complies with performance and safety standards. To ensure safe operation, technicians must have a thorough understanding of the regulations that govern grounding.

Technicians in this area handle equipment maintenance, which often involves heading off problems or identifying and solving small problems that have the potential to become serious. As circumstances dictate, technicians disassemble equipment to locate malfunctioning components, replace defective parts, and reassemble equipment, adjusting and calibrating it to ensure that it operates according to manufacturer specifications. Technicians who perform these activities are normally required to keep records of machine repairs and maintenance checks.

## Critical Work Functions and Tasks

### Critical Work Function

***Perform the set-up of medical laser systems and provide clinics and technical support***

### Tasks

- Set up required laser system in medical treatment areas
- Perform initial laser system diagnostics per specifications
- Monitor laser treatment parameters and operational safety during laser procedures
- Assist physician with laser operation as directed during specific medical procedures and research projects
- Clean, store, and secure laser system at conclusion of specific procedures

### Critical Work Function

***Align, operate, troubleshoot, repair, and maintain advanced medical lasers***

### Tasks

- Troubleshoot and diagnose medical laser system
- Calibrate and adjust beam output to include spatial and temporal beam characteristics of medical lasers
- Perform preventive maintenance, regularly scheduled service, and routine alignment/calibration on medical lasers
- Document and maintain testing results per specifications
- Exercise knowledge of all applicable regulatory guidelines and procedures
- Consult with medical laser manufacturer to solve problems that cannot be addressed in-house (including provider training or retraining program)
- Ensure that proper preventive maintenance procedures are followed for periodic certification of medical lasers
- Perform alignment of complex, rigid, microscopic, and fiber optics delivery systems

### Critical Work Function

***Maintain, operate, and verify laser delivery devices and related equipment***

#### Tasks

- Evaluate, clean, and test ancillary instrumentation (e.g., microscopes, smoke evacuators, fiber optics, beam delivery systems, etc.) per specifications
- Use and perform optical alignment of microscopes, fibers, handpieces, micromanipulators, endoscope couplers, and all related beam delivery devices.
- Evaluate, clean, test, and document, power and energy measurement meters
- Operate and maintain ancillary instrumentation
- Ensure that proper company and medical facility procedures are followed for recertification of medical lasers
- Understand fundamental laser/biological matter interactions

### Critical Work Function

***Perform medical laser safety officer duties for healthcare facilities in accordance with ANSI Z136(series) for safe use of lasers***

#### Tasks

- Implement S.O.P.s
- Conduct training for all employees/staff involved in laser operation during medical procedures
- Perform regularly scheduled audits
- Perform accident investigation and follow-up documentation
- Oversee medical surveillance of personnel
- Ensure that established laser control measures (engineering, administrative/procedural, eyewear) are met

## Employability and Technical Skills

### Employability Skills

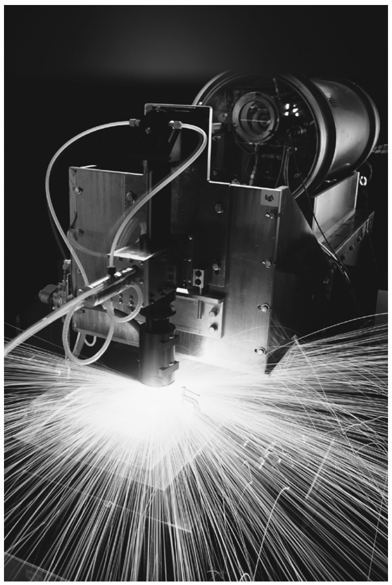
- Work cooperatively with others
- Follow laboratory safety rules and regulations
- Be punctual for work days, assignments, and tasks
- Navigate the Internet to gather information
- Use appropriate word processing, database, and presentation software
- Maintain daily real-time laboratory notebooks
- Present technical information clearly and concisely in written and oral form
- Work responsibly with minimal supervision
- Be acquainted with vendors and equipment sources and know how to complete a purchase order
- Be able to interpret and evaluate graphical and tabular data

## TECHNICAL SKILLS

- Align and clean laser beam delivery system according to required operating procedures
- Operate and troubleshoot gas lasers as required (i.e., $CO_2$, Argon, Krypton, excimer, HeNe, etc.)
- Operate and troubleshoot ion lasers as required
- Operate and troubleshoot solid-state lasers as required (ND:YAG, HO:YAG, alexandrite, erbium, ruby, etc.)
- Operate and troubleshoot liquid dye lasers as required
- Operate and troubleshoot excimer lasers as required
- Operate and troubleshoot diode lasers as required
- Monitor laser parameters during medical procedures
- Clean optics according to manufacturer's specifications
- Operate and maintain cooling systems for various laser light sources per specifications
- Maintain and troubleshoot laser microscope adapters and mircomanipulators
- Maintain and troubleshoot laser endoscope couplers and related laser delivery components
- Calibrate medical imaging devices and instrumentation according to manufacturer's specifications and regulation standards
- Ensure laser safety according to regulatory standards
- Maintain and troubleshoot ophthalmic systems as required by medical facilities
- Clean, align, calibrate and perform necessary troubleshooting and repair on electronic, optical, and cooling subsystems of gas, liquid, and solid-state lasers used in surgical, ophthalmic, and aesthetic procedures

# Manufacturing

## (Materials processing, alignment, metrology, and inspection)



The range of options for photonics technicians in the area of manufacturing is broad. Some technicians work for companies that design and build lasers for industrial, medical, and commercial applications. Some are involved in the construction, alignment, operation, and testing of highly sophisticated computer-controlled laser systems. Some work for companies that use lasers for materials processing applications such as cutting, drilling, welding, marking, and etching. Others work with customers to determine the most effective methods for processing materials such as metals, plastics, and ceramics. Still others work for companies that use lasers to perform extremely precise measurements and inspection applications. Those applications encompass the use of laser-based instruments to perform (a) submicron defect measurements in mechanical components, (b) surface quality measurements in optical components, (c) extremely precise dimensional tolerance measurements, and (d) other measurements that require accuracies on the order of the wavelength of light.

## Critical Work Functions and Tasks

### Critical Work Function

***Perform laser and optical system alignment***

### Tasks

- Set up and align a laser/optical system according to given manufacturing specifications
- Establish alignment using straight-line projection techniques
- Perform necessary troubleshooting and maintenance of laser/optic systems per company procedures
- Determine deviation of beam-on-target from desired result and recommend necessary changes
- Identify the correct optics for the intended application.
- Follow proper methods for optical inspection and cleaning.

### Critical Work Function

***Operate, qualify, maintain, and upgrade laser material processing systems***

### Tasks

- Set up a laser/optical system to perform a specific material processing requirement.
- Measure appropriate spatial and temporal beam parameters for final product quality and adjust the laser system if spatial or temporal beam parameters are outside acceptable values.
- Set up, align, and operate a material processing system in accordance with technical specifications
- Program laser material processing system
- Perform pre- and postprocessing of working materials and final product
- Perform laser cutting, welding, marking, etching, drilling, and profiling
- Identify laser safety hazards and apply necessary control measures per ANSI laser safety standards.
- Observe ANSI laser safety standards during operation
- Perform troubleshooting and required maintenance on material processing system
- Perform frequent spot checks to ensure proper laser safety procedures per ANSI standards

### Critical Work Function

***Conduct laser/optics-based industrial metrology measurements and inspections***

### Tasks

- Set up and perform interferometric and other surface-quality measurements per company specifications
- Set up and perform interferometric and other dimensional measurements per specifications
- Verify that manufacturing tolerances are within acceptable limits per specifications
- Ensure that company quality control procedures are understood and followed
- Set up and perform interferometric and other displacement measurements per company specifications
- Perform functional measurements per technical specifications of:
  - – Proper function/operation
  - – Threshold testing
- Inspect surfaces for imperfections of optical components, e.g., scratch/dig specs
- Specify how to differentiate between coated and uncoated optics using established inspection techniques.

## Employability and Technical Skills

### Employability Skills

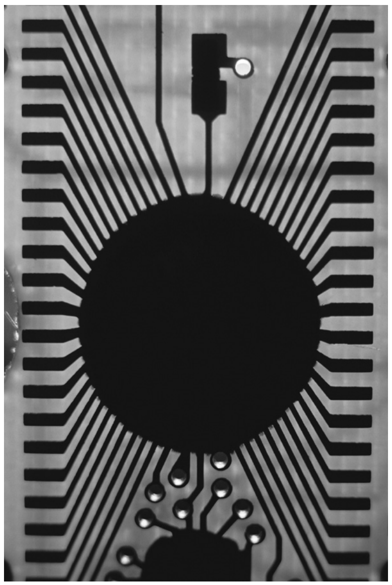
- Work cooperatively with others
- Follow laboratory safety rules and regulations
- Be punctual for work days, assignments, and tasks
- Navigate the Internet to gather information
- Use appropriate word processing, database, spreadsheet, and presentation software
- Maintain daily real-time laboratory notebooks
- Present technical information clearly and concisely in written and oral form
- Work responsibly with minimal supervision
- Be acquainted with vendors and equipment sources and know purchasing processes
- Be able to interpret and evaluate graphical and tabular data
- Perform statistical analysis of manufacturing data
- Document intellectual property concerns such as invention disclosures and maintain proper notebooks that include accurate records of procedures followed

## Technical Skills

- Determine focused beam spot size and location
- Calculate power density
- Determine laser beam quality factor
- Determine depth of focus (DOF)
- Determine required spatial and temporal laser beam characteristics for specified material processing application
- Determine assist gas requirements
- Use centering detector and beam targets to ensure that laser spot is on target
- Set up optical system according to specifications
- Use appropriate alignment techniques for application or characterization
- Measure deviation of laser spot from specified position
- Align laser and optical components in system per technical specifications
- Optimize system parameters
- Conduct laser safety checks per ANSI standards
- Perform laser heat treatment
- Perform laser welding per company specifications
- Perform laser drilling per company specifications
- Perform laser cutting per company specifications
- Perform laser marking and scribing per company specifications
- Perform preventive laser maintenance as required
- Perform laser surface hardening
- Clean optics to appropriate technical specification level
- Measure laser power output
- Follow laser safety practices in working area per ANSI standard
- Program CNC controller according to specifications
- Use an optical comparator
- Use an oscilloscope and related electronic equipment
- Use an optical alignment scope
- Set up and align common path (Fizeau) interferometers
- Set up and align Twyman-Green interferometers
- Set up and align Mach-Zehnder interferometers
- Set up and align Michelson interferometers
- Set up and align beam-modulation telemetry systems
- Demonstrate triangulation methods
- Demonstrate two-spot methods
- Set up and align a holographic interferometric system
- Demonstrate autocollimation methods
- Evaluate laser kerf
- Evaluate laser weld quality per company specifications
- Perform Rockwell Hardness Test
- Analyze and evaluate interferometric fringe pattern
- Generate peak-to-valley and RMS surface-quality data
- Perform scratch-and-dig test
- Perform Foucault test
- Perform null test using compensators
- Use phase-shifting interferometer
- Use contact and noncontact profilers
- Perform interferogram evaluation and wave front fitting
- Perform diffraction pattern analysis
- Perform surface-roughness test
- Use data-acquisition software

# Optoelectronics

## (Nanotechnology, microsystems, and semiconductors)



Photonics technicians in optoelectronics are involved in forging a new future for optics and photonics devices. That future springs in part from the invention of the transistor and the integrated circuit, which, taken together, launched the miniaturization of electronics. The coming years will see new, more powerful chip structures in which light and optics will enable chips to reason, sense, communicate, and act. In addition to processing data, the chips of tomorrow will process such things as chemicals, motions, light, and knowledge. This should have a profound effect on the quality of life.

Optoelectronic photonics technicians work alongside engineers in driving the miniaturization of these devices—making them less expensive, smaller, faster, lighter, and more precise. These technicians understand the fabrication process, which involves deposition and etching techniques as well as assembly, packaging, and testing. Not only do the devices themselves depend on optics and photonics technology, but the fabrication techniques involved are heavily optics-based. Optical microlithography is the primary technique used to fabricate these devices. Technicians in this specialty work in carefully controlled clean-room environments, are involved in optical pattern formation and imaging, apply photoresists, use high-vacuum systems to apply thin films, and employ various light sources and illumination systems to create intricate multiple-layer micro- and nanodevices. These processes require technicians who have patience, diligence, and an eye for detail.

## Critical Work Functions and Tasks

### CRITICAL WORK FUNCTION

***Perform initial testing and preparation for lithography processes (e.g., microfabrication)***

### TASKS

- Prepare component for characterization, including cleaning/dicing of material, electrical and optical connections, and control circuitry tailored for specific devices
- Establish patterns and images at the required resolution
- Characterize electrical, mechanical, thermal, and chemical performance per specifications
- Characterize optical performance with appropriately calibrated test equipment
- Characterize thermal performance with appropriately calibrated test equipment

### CRITICAL WORK FUNCTION

***Operate, maintain, and troubleshoot systems used to develop nanotechnology, microelectromechanical devices, and semiconductor devices***

### TASKS

- Form optical patterns with mask software and image
- Prepare, write, and ensure tolerance of masks
- Apply photoresists and thin films to specification
- Operate, maintain, and repair light sources for exposing material surfaces—following appropriate ANSI and OSHA safety procedures
- Set up, test, and maintain optical system to correct for image aberrations
- Program, install, and operate mechanical stepper and scanning devices per technical specifications
- Set up, test, operate, and maintain diffractometry systems to measure and evaluate product quality in situ per company specifications
- Align, calibrate, operate, and maintain scanning electron and atomic force (tunneling) microscopes for surface profiling
- Operate and maintain vacuum systems in support of physical vapor deposition and real-time residual gas analysis systems

### CRITICAL WORK FUNCTION

***Optimize performance of various devices that emit, detect, transmit, amplify, or attenuate light***

#### TASKS

- Understand physical processes that improve thermal transport
- Modify input optical pump parameters to maximize output-beam quality of a laser
- Develop and maintain database for theoretical numerical analysis
- Recommend material design processing improvements and operational improvements

### CRITICAL WORK FUNCTION

***Assist in the design and construction of prototype packaging***

#### TASKS

- Use computer-aided design and modeling tools to optimize layout for efficiency, compactness, and desired output characteristics per job specifications
- Assist in the design of an electronic control and power system per technical specifications
- Assist in the design and integration of prototype systems
- Assist in the design of an optical layout per technical specifications
- Interface with external suppliers as necessary
- Build, calibrate, and test systems and devices per technical specifications

## Employability and Technical Skills

### EMPLOYABILITY SKILLS

- Use appropriate personal protective equipment (gloves, gown, apron, face shield, safety glasses, etc.)
- Assess equipment functions using manufacturer's data books and spreadsheets
- Manage time schedules for fabrication runs
- Use materials and resources efficiently
- Identify and assimilate information from prior shifts to determine process status on parts
- Maintain effective tracking data on parts and support materials-distribution systems
- Establish effective working relationships with others involved in processing and fabrication of materials and parts
- Understand how component skills and tasks support the achievement of goals
- Apply principles of continuous quality improvement and teamwork concepts

## Technical Skills

- Read and interpret digital and analog circuit diagrams
- Generate and execute operation procedures
- Interpret laser, light source, and detector specifications to determine optimal functioning levels
- Install semiconductor detectors
- Use a wide range of semiconductor detectors
- Maintain semiconductor components and devices
- Interpret spectral characteristics specifications of semiconductor detectors
- Calculate detector frequency response required for specific applications
- Interpret frequency response specification
- Calculate and interpret detector noise equivalent power
- Interpret a manufacturer's datasheet to determine detector output per unit of input power
- Use manufacturer information to determine the relative response of the detector circuit as a function of wavelength for several wavelengths in the spectral region of interest
- Operate and calibrate signal generators
- Operate and calibrate multifunction digital multimeters
- Operate and calibrate digital and analog oscilloscopes
- Perform and identify quality and reliable soldering joints for both surface-mount and through-hole technologies
- Use a variety of soldering tools and materials
- Select, specify, purchase, and classify transformers for specific applications
- Select, specify, and purchase half-wave and full-wave voltage rectifiers for specific applications
- Remove insoluble contaminants from substrates
- Remove ionic and heavy metal contaminants
- Deposit polycrystalline thin films using a chemical vapor deposition system
- Perform thermal annealing
- Improve photoresist adhesion using silyation
- Etch and qualify patterns using a wet station
- Strip oxide from wafers using a wet system
- Ash photoresist using a plasma stripper
- Apply photoresist using a spindle rotator
- Align mask for exposure within specifications
- Bond wafers using fusion, thermocompression, or anodic bonding
- Develop photoresist using a wet station
- Spin nonstandard organic coatings (polymide, SU-8) onto wafer samples
- Apply sputter coatings using a sputter deposition system
- Deposit metal using an e-beam evaporative deposition system
- Deposit dielectric films using a chemical vapor deposition system
- Etch wafers using a radio frequency (RF) magnetically coupled etching system
- Etch wafers using an electron cyclotron resonance (ECR) reactive ion etcher

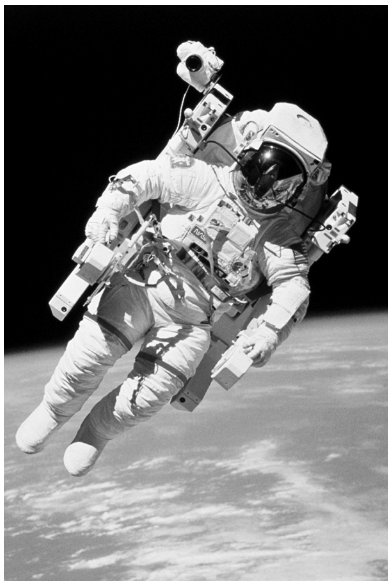
**TECHNICAL SKILLS (CONTINUED)**

- Measure sheet resistivity
- Measure thickness and index of thin films using an ellipsometer
- Measure vertical surface features using a profilometer
- Measure thin film thickness using an interferometer
- Section wafers using a dye saw
- Bond packaging
- Prepare emulsion-based transparencies to transfer features to masks
- Perform die bonding
- Specify line-regulation power supply requirements
- Measure line-regulation parameters
- Interpret line-regulation test data
- Interpret circuit schematics to determine the digital circuit operation
- Analyze digital circuits using probes, pulsers, logic analyzers, oscilloscopes, counters, and digital multimeters

# Imaging and Remote Sensing

**(Signal and image processing, environmental and aerospace)**

I



The work of a photonics technician in this specialty is critical to aerospace and national defense, since, unlike devices using conventional electronics, these photonics devices must be resistant to electromagnetic interference. A technician working in this specialty must understand the operation of forward-looking-infrared systems (FLIR), lidar, and image processing to be able to use devices to enhance logistics and control issues in a safe and reliable manner.

Photonics technicians in this area work with engineers and scientists in the construction, testing, operation, and maintenance of systems for all kinds of spacecraft and aerospace/national defense control systems. Their work may include the operation, installation, calibration, troubleshooting, and repairing of equipment. Typical tasks include collecting and recording data, operating test equipment, performing laboratory tests, devising tests to ensure quality control, modifying procedures to solve specific problems, laying out experimental circuits to test scientific theories, and evaluating data for practical applications.

# Critical Work Functions and Tasks

## Critical Work Function

***Review and understand optical systems and test specifications for remote sensing application***

### Tasks

- Develop optical system requirements for specific applications that include required laser power, detector bandwidth and sensitivity, and acceptable SNR
- Evaluate system requirements
- Determine image resolution requirements and/or limitations per technical specifications
- Determine physical and electrical requirements of a given power supply
- Ensure appropriate safety procedures (eye safety, burn safety, etc.) in accordance with ANSI and OSHA standards
- Compare alternative imaging and remote sensing techniques
- Use optical software to build a system model and predict expected performance

## Critical Work Function

***Build, troubleshoot, and test imaging and remote sensing systems***

### Tasks

- Prepare schematic drawings as needed
- Develop and document key features of test procedures and technical specifications
- Select appropriate optical components for system application
- Operate wavefront aberration measuring interferometer per technical specifications
- Perform quality testing related to production of parts, components, and system assemblies
- Perform optical system analysis as per manual instruction for a particular purpose
- Build and align a given prototype system per technical specifications
- Run system performance tests according to specifications
- Develop, set up, and perform calibration tests
- Identify appropriate interfacing between camera and computer platforms

### CRITICAL WORK FUNCTION

***Acquire, manipulate, record, and store data, signals, pictures, and images***

#### TASKS

- Identify and select images to be processed as live, print, picture, or copy
- Capture/obtain digital images/data of "experiment"
- Incorporate and set up selected data-acquisition method
- Edit digital images for color correction, size, crop, orientation, and other requirements using image processing software
- Organize and prepare digital files to be written to CD or DVD
- Prepare necessary electronic documentation that accompanies each CD or DVD
- Process/enhance remote sensing data/images according to requirements
- Prepare written documents and oral reports as needed

### CRITICAL WORK FUNCTION

***Produce and display data, signals, pictures, and images with appropriate software***

#### TASKS

- Determine quality and resolution of images to be displayed, recorded, or printed
- Specify and implement data-acquisition method for a given instrument
- Identify and specify appropriate image processing algorithms
- Specify how images are to be displayed depending on user requirements
- Select appropriate display technology
- Generate output images for viewing in accordance with specifications
- Perform color calibration and correction on display systems
- Identify components needed to acquire data

### CRITICAL WORK FUNCTION

***Analyze and document experimental data***

#### TASKS

- Use a computer to reduce and plot experimental data including necessary statistical measures
- Write technical reports per company policy
- Develop technical presentations
- Recommend additional experiments to resolve questions raised by data

# Employability and Technical Skills

## Employability Skills

- Work cooperatively with others
- Follow laboratory safety rules and regulations
- Be punctual for work days, assignments, and tasks
- Navigate the Internet to gather information
- Use appropriate word processing, database, and presentation software
- Maintain daily real-time laboratory notebooks
- Work responsibly with minimal supervision
- Present technical information clearly and concisely in written and oral form
- Be acquainted with vendors and equipment sources and know how to complete a purchase order
- Be able to interpret and evaluate graphical and tabular data
- Manage and maintain laboratory and equipment inventory
- Maintain calibration logs on equipment

## Technical Skills

- Interpret and implement general imaging requirements
- Set up an optical system according to specifications
- Use appropriate alignment techniques
- Align laser and optical components in system
- Focus beam on target surface
- Collimate a laser beam
- Optimize system parameters
- Conduct appropriate laser safety checks per ANSI standards
- Clean optics according to manufacturer's specifications
- Measure output power of laser or other light source
- Ensure correct laser safety practice in working area per OSHA and ANSI standards
- Use oscilloscope and related electronic equipment
- Use optical alignment scope
- Set up and align common path (Fizeau) interferometers
- Set up and align Mach-Zehnder interferometers
- Set up and align Michelson interferometers
- Set up and align a telemetry system employing beam modulation
- Align an optical system using a triangulation technique
- Set up and align a holographic interferometric system
- Align an optical system using an autocollimation technique
- Analyze and evaluate interferometric fringe patterns
- Plan, coordinate, and carry out conversion of survey/map data to digital form
- Create or read and understand CAD drawings
- Perform interferogram evaluation and wave front fitting using the software provided
- Perform diffraction pattern analysis
- Use data-acquisition software

**TECHNICAL SKILLS (CONTINUED)**

- Perform setup and calibration of FLIR systems
- Perform setup and calibration of LIDAR systems
- Perform setup and calibration of imaging systems
- Measure wavefront aberrations
- Verify wavefront correction using an adaptive optics optical system
- Perform radiometric and photometric measurements
- Design and test photodetector circuits
- Set up and calibrate focal plane arrays
- Set up and calibrate infrared detectors
- Perform digital image processing
- Read a mechanical/optical drawing for dimensions and tolerancing and data reference
- Read a basic wiring and optical layout schematic

# Foundational Knowledge Components for Photonics Technician Programs

As stated in the introduction, during the development of the second edition of these standards, selected educators from two-year colleges provided information that assisted the investigators and staff in compiling a list of foundational knowledge components based on the tasks and skills requested by employers. While updating of the first edition, staff reorganized the knowledge components into logical sequences that reflected a modular approach to presenting the material in the classroom. In creating the third edition, OP-TEC staff along with its partner colleges reviewed these foundational knowledge components and determined that they were relevant in developing AAS photonics curriculum, as well as infusion curricula for both undergraduate students and employed technicians. In effect, once educators and employers decide on the standards that must be met, the knowledge components associated with those standards can be used as building blocks to develop curriculum that will meet local employers' needs. These knowledge components differ from those in the second edition only by the inclusion of the new category "Optical and Electro-Optical Systems for Precision Measurements and Alignments."

We define *knowledge components* as intellectual functions that, in specific combinations, form the basis for understanding concepts in science, engineering, and technology. With respect to the standards outlined in the preceding sections of this document, it can be said that certain ***knowledge components*** are essential for behaviors that enable photonics technicians to perform ***tasks*** using ***skills*** to accomplish ***critical work functions****.* For example, an understanding of *Snell's law of refraction* enables a technician to match a particular light source to a particular fiber. The matching process is a *skill*, while the underlying principle (Snell's law) is a *knowledge component*. A good understanding of knowledge components enables technicians to apply principles and techniques to the design, fabrication, modification, and operation of optoelectronic devices and systems.

Listed here in the pages that follow are the *knowledge components* that, according to industry, are essential for learners in two-year photonics technician education programs. Some of the knowledge components will have been learned *before* students enter two-year postsecondary programs while many will be learned while students are *in* the programs. In either case, some knowledge components represent core principles that are *invariant;* that is, they do not change even though the technology and applications based on them do. On the other hand, some knowledge components deal with the operation of a particular *optical device* such as a Q-switch or a *tool* such as an optical power meter. In these cases, the knowledge is *variant,* since its relevance depends on the current state of technology, even though using the device or tool may also require knowledge of invariant laws, principles, or theories.

Comprehending the interplay between *invariant* knowledge (of laws, principles, and theories) and *variant* knowledge (of how to use the latest tools and devices) is one of the great challenges facing photonics students—and developers of skill standards such as those contained in this document. Yet educational institutions must strive to find the balance between the two if their students are to succeed both in the short and long term, that is, as soon as they exit their programs *and* throughout their careers as photonics technicians.

The following knowledge components include both variant and invariant knowledge. They are offered as a checklist of important basic principles, optical components, and operating devices that students in photonics technician programs should learn about. In total they constitute a useful foundation for future work in the changing fields of optics and photonics technology.

The knowledge components we consider to be *optics-intensive* have been divided according to easily recognized areas of optics and photonics applications—such as *principles of optics, types and characteristics of optical components, optical devices and principles of operation, optical support and positioning equipment, physics of lasers and laser operation, fibers and fiber optics, optics of imaging and display, materials processing systems,* and *holography*.

In addition we have included the more familiar *general* knowledge components—those that are derived from the basic disciplines of mathematics, physics, biology, and chemistry, as they are usually addressed in two-year technician-education programs.

## Optics-Intensive Knowledge Components

### Principles of Optics

*Nature of Light*

- Light described as a ray
- Light described as a wave
- Characteristics of photons—energy, momentum, frequency, and wavelength
- Characteristics of light waves—amplitude, frequency, period, wavelength, wavefronts, and propagation direction

- Reflection, scattering, and absorption of light in various media and at various interfaces

*Geometric Optics*

- Law of reflection
- Law of refraction (Snell's law)
- Index of refraction/speed of light
- Critical angle
- Total internal reflection
- Refraction of light by prisms
- Characteristics of electromagnetic spectra
- Optical and geometrical characteristics of convex and concave spherical mirrors
- Ray tracing to locate position, size, and orientation of images formed by spherical mirrors
- Use of mirror formulas to locate images
- Optical and geometrical characteristics of concave and convex thin lenses
- Ray tracing to locate position, size, and orientation of images formed by systems of thin lenses
- Use of thin-lens formulas to locate images

*Wave Optics*

- Principle of superposition and interference of light waves
- Standing waves (nodes and antinodes)
- Formation of interference fringes
- Diffraction of light waves through small openings and around sharp edges
- Single-slit and double-slit diffraction patterns
- Diffraction with gratings
- Diffraction-limited optics
- Randomly polarized, plane polarized, circularly polarized, and elliptically polarized light
- Producing polarized light
- Detecting polarized light
- Bragg's law
- Birefringence

## Type and Characteristics of Optical Components

- Front-surface mirrors
- Plane, spherical, and aspherical mirrors
- Retroreflectors
- Thin and thick lenses
- Beam collimators
- Coated optics
- Thin films
- HR/AR multilayer dielectric coatings
- Prisms
- Windows
- Filters
- Beamsplitters
- Gratings (transmission, reflection, and blazed)
- Wave plates/phase retarders

- AO/EO modulators
- Q-switches
- Infrared optics/components
- Ultraviolet optics/components
- Scratch/dig/hardness coating specifications
- Fibers
- Fiber connectors, splicers, and amplifiers

### Optical Devices and Principles of Operation

- Light sources (visible, IR, UV)
- Light detectors
- Power/energy meters
- Prism spectrometers
- Grating spectrometers
- Spectrum analyzers
- Monochromators
- Fabry-Perot cavities
- Interferometers
- Collimators
- Eyepieces
- Cameras
- Microscopes
- Telescopes
- Photoconductors
- Semiconductor detectors
- CCD/CID devices
- Electro-optical Q-switches
- Acousto-optical Q-switches
- Phase/polarization modulators
- Mechanical scanners and deflectors

### Optical Support and Positioning Equipment

- Breadboard tables with magnetic mounts
- Rails/benches
- Metric lab jacks
- Holders (post and component)
- Mounts (rotary, filter, prism, mirror, lens, gimbal, etc.)
- Translation stages (rotary, tilt, vertical, horizontal, and motorized)
- X-Y positioning stages
- Diaphragms, pinholes, and slits
- Micropositioners
- Vibration-isolation tables

### Physics of Lasers and Laser Operation

- Physics of laser operation (energy levels, half-lives, inverted population levels, and stimulated emission)
- Laser systems (cavity, mirrors, pump, and gain medium)
- Laser beams (pulse, CW, divergence, power, monochromaticity, TEM characteristics, and coherence)
- Laser resonators (gain, longitudinal/ transverse modes, stable, and unstable)

- Laser types and characteristics (type of pump, power, cooling, beam parameters, and efficiency)
  - Gas lasers (HeNe, Argon, $CO_2$, dye, and excimer)
  - Solid-state lasers (Nd:YAG, Nd:glass, solid-state, and diode)
  - Chemical lasers (gas dynamic and oxygen-iodine)
  - Free-electron lasers

### Fibers and Fiber Optics

- Fiber types and physical/optical characteristics
- Light sources and desirable wavelengths
- Maximum fiber acceptance angle, TIR and numerical apertures (NA)
- Core/cladding requirements
- GRIN and step-refraction indices
- Losses in single- and multimode fibers
- Transmission power losses and decibel signal attenuation
- Analog/digital signal distortion
- Information transmission capability (distance–bandwidth product, etc.)
- Pulse-code modulation
- Modal and material dispersion
- Fiber-optic system components (fibers, cables, detectors, connectors, couplers, repeaters, switches, transmitters, time-domain reflectometers, etc.)
- EIA/TIA standards

### Optics of Imaging and Display

- Principles of image processing (pixels, bandwidth, resolution, and spatial frequency)
- Phosphors and electroluminescence (absorption and emission characteristics)
- Types and characteristics of image processing equipment
- Cathode ray tubes (CRT)
- Liquid crystals (LCD)
- Light-emitting diodes (LED)
- Charge-coupled devices (CCD)
- Design and characteristics of flat-panel, liquid crystal displays (LCD)
- Cameras as imaging systems
- *f*-numbers and shutter speed
- Scanners (flying spot, flatbed, drum)
- Characteristics/operation of a vidicon, image intensifier, CCD camera
- Storage of digital images as computer files
- CD-ROM and DVD diskettes
- Flat-panel-electroluminescent displays (ELD)

### Materials Processing Systems

- Types of lasers (power, wavelength, and beam profile)
- Optics of beam-delivery systems

- Target material absorption characteristics (metal, fabric, wood, etc.)
- Laser welding systems and operation
- Laser drilling systems and operation
- Laser cutting systems and operation
- Laser scribing and marking systems and operation

### Optical and Electro-Optical Systems for Precision Measurements and Alignments

- Study the principles of laser measurements
- Describe the applications that utilize laser measurements and alignments
- Describe the types of lasers used in precision measurement and alignment
- Analyze beam quality necessary for precision measurement and alignment
- Build and test an optical system for performing precise laser measurements
- Build and test an optical system for performing precise laser alignments
- Demonstrate proper and safe operation of a laser measurement system to specific parameters
- Demonstrate proper and safe operation of a laser alignment system to specific parameters
- Perform advanced measurements on several runs of actual manufactured parts from industry and apply statistical analysis and process control on those parts

### Holography

- Principles of holography
- Optical system for recording holographic images
- Optical system for reconstructing holographic images
- Optics of holographic nondestructive testing (HNDT) systems

## General Knowledge Components

As mentioned earlier, we also list those general knowledge components associated with the mathematics, physics, biology, and chemistry required for entry into a postsecondary photonics program. Note that these knowledge components tend to emphasize the application of principles as much as they do the principles and processes themselves.

For each of the general disciplines listed below, we begin with a list of overarching standards and support these with more specific prescriptions. We are indebted to the National Council of Teachers of Mathematics, The National Research Council (Project 2061), and the American Association for the Advancement of Science for the overarching standards and expectations in mathematics and science for grades 9–12.

## Applied Mathematics

### *General Standards and Expectations*

- *Number sense and number theory:* Recognize, represent, model, and apply real numbers and authentic operations verbally, symbolically, and graphically
- *Estimation, measurement, and computation:* Apply appropriate tools and units of measurement; develop effective estimation and computation strategies for producing reasonable results; and calculate using appropriate tools such as mental mathematics, technology, manipulatives, and pencil and paper
- *Patterns, functions, and algebraic thinking:* Describe, extend, analyze, and create a variety of patterns and functions using appropriate materials and representations in real-world problem solving
- *Statistics and probability:* Collect, organize, represent, and interpret data; make inferences and predictions; and present and evaluate arguments based on data analysis
- *Spatial sense and geometric concepts:* Investigate, model, and apply geometric properties and relationships
- *Apply and adapt problem-solving techniques and strategies:* Apply the scientific method to general problem solving, to the design and collection of data in laboratory environments, and to the analysis and effective presentation of results and conclusions

### *Specific Mathematics Skills*

- Work with fractions, decimals, and percents
- Collect data; draw and interpret graphs to include bar graphs, pie charts, and line graphs
- Learn how to apply general problem-solving techniques to the solution of any problem
- Learn how to estimate answers and round off numbers
- Learn about lines and angles (parallel and perpendicular lines)
- Learn about perimeters and areas of rectangles, parallelograms, trapezoids, triangles, and circles
- Learn about surface areas and volumes of boxes, cones, cylinders, and spheres
- Use ratio and proportion
- Make and read scale drawings
- Learn about powers, roots, and scientific notation
- Learn about precision, accuracy, and tolerance in measurement
- Learn how to arrange equations to solve for specified unknowns
- Learn how to read and draw graphs for linear and nonlinear curves

- Learn how to use probability to predict outcomes
- Learn how to calculate mean, median, mode, and standard deviation for a set of numerical data; apply statistics
- Learn how to work with right triangles and use trigonometric functions
- Learn how to graph and solve quadratic equations
- Learn how to solve systems of two equations with two unknowns
- Learn how to solve problems that involve combinations of geometry, trigonometry, and algebra in workplace applications
- Use computers with spreadsheets and computer graphics
- Learn how to measure and control quality for a manufacturing process in a true-to-life situation

## Applied Physics

*General Standards and Expectations*

- Understand and apply Newton's three laws as they refer to systems with balanced and unbalanced forces, relationships between forces, mass and acceleration, and action-reaction forces
- Understand and calculate the motion of objects with and without acceleration, both in rectilinear and curvilinear systems of motion
- Understand and apply the inverse-square laws relating to gravitational forces between masses, electrical forces between charges, and electromagnetic forces between moving charges and magnets
- Understand and apply the conservation laws that govern mechanical energy, linear and angular momentum, and mass-energy equivalence
- Understand and apply the laws and rules that govern the change of energy between mechanical, fluid, electrical, and thermal systems, and the operation of devices and systems that bring about these changes
- Understand and apply the ray theory and wave theory of light as they govern the propagation, image-formation, interference, and diffraction of light in various applications
- Understand the basic atomic structure of matter involving electrons, neutrons, and protons and how energy levels in atoms are established

*Specific Skills in Applied Physics*

- Learn about forces in mechanical, fluid, and electrical systems
- Learn about movement of objects undergoing linear and rotational motions; learn about related distance, speed, acceleration, and time for each type of motion

- Learn about pressure and flow rates in fluid systems
- Learn about voltage, current, and resistance in electrical systems
- Learn about temperature and heat-flow rates in thermal systems
- Learn about mechanical resistance, friction, fluid resistance, electrical resistance, and thermal resistance (insulation)
- Learn about kinetic and potential energy in mechanical, fluid, and electrical systems
- Learn about power and efficiency of mechanical, fluid, electrical, and thermal systems
- Learn about electrical transformers
- Learn about linear momentum and angular momentum and their relation to linear and angular impulse
- Learn about transverse, longitudinal, and harmonic waves
- Learn how to damp out unwanted vibrations in a system
- Learn about energy converters that convert energy between mechanical, fluid, electrical, and thermal systems
- Measure energy in, energy out, and efficiency of different energy-conversion systems
- Describe characteristics of transducers that detect mechanical, fluid, electrical, and thermal signals
- Identify transducers that change mechanical signals into electrical signals
- Identify transducers that change electrical signals into mechanical signals
- Identify transducers that change thermal signals into mechanical, fluid, or electrical signals
- Describe characteristics of the following transducers: strain gage, piezoelectric, bourdon gage, barometer, flowmeter, anemometer, moving-electrical coil, galvanometer, electrostrictive, photoconductive, bimetallic strip, thermocouple, and thermistor
- Learn about electromagnetic and nuclear radiation
- Describe the electromagnetic spectrum from gamma rays to radio waves and give representative wavelength and frequency ranges for major parts of the spectrum
- Describe alpha, beta, and gamma nuclear radiations
- Describe the origin and production of X rays
- Describe how Einstein's mass-energy relationship is used to make calculations for fission and fusion reactions
- Describe the action of mirrors, lenses, and prisms on laser beams
- Describe interference and diffraction and how diffraction gratings and spectrometers disperse light

- Describe the components of simple gas and solid-state lasers
- Describe the characteristics of laser light
- Describe how the eye, cameras, beam-expanders, fiber optics, and laser systems work as optical systems

## Applied Biology/Chemistry

*General Standards and Expectations*

- Understand the relationships between different groups of elements in the periodic table and describe their similar and dissimilar properties
- Understand and describe how atoms and molecules bond to each other to form various gases, liquids, and solids
- Understand and describe how chemical reactions occur and which characteristics of the combining elements remain in balance before and after the reaction
- Understand and describe how chemical and nuclear reactions conserve energy and mass in the overall reaction
- Understand and describe how the individual cell can be considered as a system in itself, as part of larger systems, but always as part of an ecosystem
- Understand and describe how special parts of cells transport energy and materials, build proteins, dispose of waste, and provide information feedback and movement
- Understand and describe how the genetic information encoded in DNA molecules provides instructions for assembling protein molecules
- Understand and describe how ecosystems tend to fluctuate around a state of rough equilibrium, and how human beings, deliberately or inadvertently, can alter this equilibrium

*Specific Skills in Biology/Chemistry*

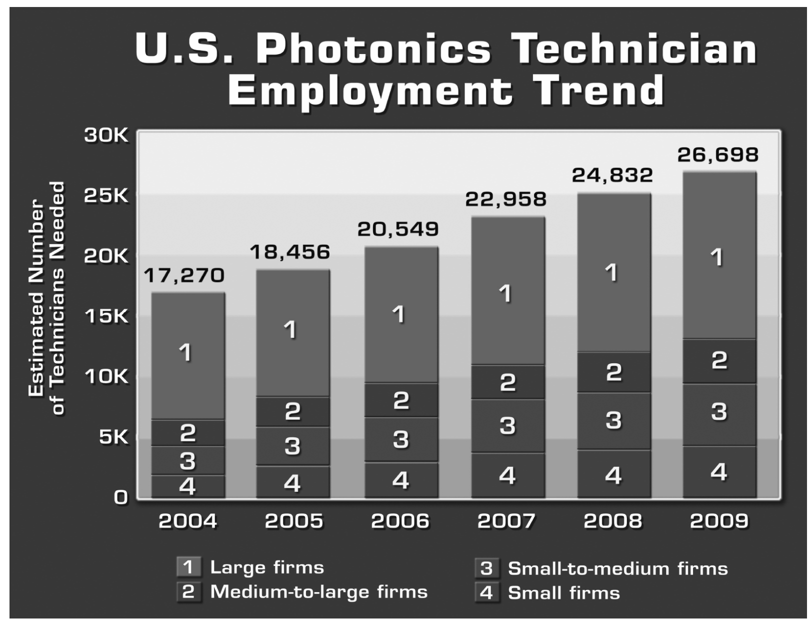
- Using appropriate resources, identify materials that have specific physical and chemical properties
- Relate different types of chemical bonding to material properties
- Relate the physical and chemical properties of metals and alloys to their uses
- Explain the properties of metals and alloys in terms of atomic, crystalline, and grain structure
- Distinguish ceramics from other materials such as metals and polymers on the basis of their chemical structure and properties
- Explain how the molecular structure of polymers affects their properties
- Analyze the effect on a composite’s performance of using different kinds of structural components
- Explain how the structure of a water molecule affects the way water behaves, especially the way water dissolves materials

- Give examples of the “like dissolves like” rule in the everyday use of solutions
- Determine the amounts of solute required for solutions of various concentrations, using three different types of units: molar, normal, and percent composition
- Calculate dilution to a desired concentration
- Make sketches of known crystals and compare them to a table of crystal systems
- Identify five types of chemical reactions that play a role in the formation of materials
- Predict the properties of steel based on the processes used to make it
- Relate the differences in structure between crystalline and glass ceramics to the differences in their properties
- Explain why high temperatures and atmospheric control are necessary for ceramic manufacturing processes
- Model the chemical bonding involved in a polymerization reaction
- Distinguish between structure of thermosetting and thermoplastic polymers and the properties and uses of each
- Explain how different types of stimuli—light, sound, pressure, etc.—are converted to impulses that can be carried by neurons
- Evaluate different types of hearing and vision corrective/safety devices according to their appropriate use, risks, comfort, and durability
- Identify the chemical elements that make up a living cell and how carbon atoms can bond in chains and rings to form large and complex molecules
- Describe how DNA molecules provide instructions for assembling protein molecules and how gene mutation in a cell can result in uncontrolled cell division, called cancer
- Explain how ecosystems depend on environmental forces within them, how they tend to operate around an equilibrium state, and how human activities can alter this equilibrium
- Describe how the amount of life any environment can support depends on the available energy, water, oxygen, and minerals, and on the ability of ecosystems to recycle the remains of dead organic materials
- Discuss the relationship between diversity of life and the equilibrium of various ecosystems

# Curriculum

## Overview

As mentioned earlier in this document, one of the primary purposes for developing skill standards is to support the curriculum development process. Skill standards are the foundation of this process and provide educators with the necessary information to determine the knowledge and rigor students will need to be successful in the workplace. Once educators have translated these standards into knowledge components (both variant and invariant) that support the learning of required skills, the process of arranging these components into courses and sequences of courses, i.e., curriculum, can begin. The three curriculum models presented in this section have evolved from such a process.




In this edition of the standards, OP-TEC presents three models designed to give two-year colleges maximum flexibility in meeting the demand for photonics technicians. The chart provided here was extracted from a report[4] that studied the demand for photonics technicians in the United States.

According to the chart, in the out-years U.S. photonics employers will need approximately 1800 new workers each year. If our country had to depend solely

[4] Hull and Navarro.

on the capacity of its AAS photonics programs, only about 10% of this demand would be met. However, a study of the trend represented by the chart has shown that the vast majority of these workers will be employed in industries that are *enabled* by photonics. This means that the bulk of the chart's indicated demand can be met by infusing photonics into technical programs that are enabled by this technology. An example of this "infusion" was previously presented in this document and focused on the need of manufacturing technicians to understand the basic concepts of photonics so they can isolate and troubleshoot problems related to the photonics subsystems used in their processes. These technicians do not need the in-depth knowledge of photonics that a graduate with an AAS degree in photonics would have. This concept of "infusion" can also be extended to the technicians who are already employed in photonics-enabled industries but did not have the opportunity while earning their degrees to learn basic photonics concepts. This group of technicians provides yet another resource for filling the chart's projected demand through advanced certificate programs that concentrate on teaching the basics of photonics. Thus, there are three basic pipelines for meeting the future demand for technicians: (1) AAS graduates of photonics programs, (2) AAS graduates who have learned basic photonics via infusion curricula, and (3) technicians who have been retrained through photonics-concentrated advanced certificate programs. The three curriculum models presented in this section provide educators a starting point for developing programs for each of these pipeline options.

## Benchmark 4+2 AAS Photonics Curriculum

The Benchmark 4+2 AAS Photonics Curriculum presented in this section was designed by OP-TEC to meet the standards presented in a previous section of this document. To ensure compliance with the standards, Dr. Fred Seeber, CoPI for OP-TEC, conducted a review of this curriculum with several two-year community and technical colleges that have established AAS photonics or AAS laser programs. These colleges included: Camden County College, Texas State Technical College, Cincinnati Technical College, Indian Hills Community College, and Central New Mexico Community College. Input received from these schools was incorporated into the benchmark curriculum; as a result of this review, OP-TEC is confident that the curriculum meets the third edition standards.

In developing this benchmark curriculum, OP-TEC has attempted to take a broad view of the educational process rather than focus exclusively on the two years required for associate degrees. Those two years are critical; for many photonics technicians, they mark the completion of formal education and the period of greatest concentration on the tools of the trade. But they are not likely to produce optimum results unless they are logically coordinated with the four years of high school that precede them.

For this reason, the curriculum recommendations offered for an AAS photonics program follow the 4+2 Tech Prep model. That model, which is supported by most community colleges across the nation, lays out career pathways that enable students to build a strong academic foundation while acquiring technical and employability skills relevant to the career clusters of their choice. The technical focus of the model is general at first and becomes increasingly specific as the student progresses from each grade to the next. The model not only gives high school students a sense of direction but provides the background in mathematics and science that will allow them to attain higher skill and knowledge levels during the first two years of postsecondary education and to pursue further education, if they so choose.

The courses specified in the 4+2 course sequence presented here are based on the employability and technical skills and on the foundational knowledge components listed in the preceding sections. The 4+2 course sequence provides a model educational pathway for students to follow in beginning their photonics studies in high school and, upon graduation, transitioning smoothly to cooperating community or technical colleges.

The courses specified indicate the technical content, scope, and sequence recommended for a broadly educated photonics technician. (Outlines for five high school courses—*Career Management Success, Computer/Software Applications, DC/AC Electricity, Digital Electronics,* and *Introduction to Photonics*—are provided.)

The technical courses to be offered in the college freshman and sophomore years are outlined in the section headed "Selected Postsecondary Courses." The two technical courses marked "Electives" could be offered in a selected photonics-enabled area, advanced digital electronics, or additional postsecondary math/science courses.

Supporting courses in mathematics, science, communication, and social studies may vary according to state and accreditation requirements.

## Explanation of Benchmark Curriculum

For those involved in the preparation of photonics technicians in AAS programs, or for those planning to begin such programs, the following 4+2 curricular integration of high school and the first two years of postsecondary may be helpful. The pathway we have outlined represents a comprehensive program ending in an AAS degree. It can be used more or less as it stands, or it can be used as a starting point that enables schools to add to, delete from, or otherwise modify the overall curriculum to suit individual needs dictated by school goals and local industries.

We start with this proposed 4+2 integration of high school and two-year postsecondary by presenting a curriculum that encompasses the contributions of both levels. This curriculum outline is sometimes referred to as an "egg-crate" because it consists of a matrix of rows and columns indicating grade levels and their corresponding courses.

Next we describe the five nontraditional high school courses that have been selected to facilitate articulation from high school to postsecondary and lay a foundation for the two-year postsecondary program. These courses are as follows:

Career Management Success
Computer/Software Applications
DC/AC Electronics
Digital Electronics
Introduction to Photonics

The section titled "Selected High School Courses" provides a short description and a list of topics for each course.

To conclude this explanation of the benchmark curriculum, we describe ten courses that one might call basic and photonics-specific. They are:

Introduction to Lasers
Geometric Optics
Light Sources and Wave Optics
Laser Electronics
Laser and Electro-optic Components
Laser Technology
Trouble-Shooting Photonics Systems
Laser Applications
Laser Electro-optic Devices
Laser Electro-optic Measurements

The section titled "Selected Postsecondary Courses" provides a short description and a list of topics for each course.

OP-TEC welcomes questions and comments from the national family of photonics educational programs and stands ready to serve as a clearinghouse for questions concerning this and similar 4+2 technician preparation programs.

## Benchmark 4+2 Photonics AAS Curriculum

| | 9th Grade | 10th Grade | 11th Grade | 12th Grade | 13th Year | | 14th Year | |
|---|---|---|---|---|---|---|---|---|
| Math | Algebra 1* | Geometry* | Algebra 2* | Precalculus | | Calculus or other adv. Math | | |
| Science | Biology/Life Sciences* | Chemistry* | Physics or Principles of Technology* | | College Physics | | Elective*** | |
| English | English I* | English II* | English III* | English IV* | English | Technical Communication / Writing | | |
| Technology | Career Management Success | Computer Applications | DC/AC Electricity | Digital Electronics | | Elective*** | | Photonics Troubleshooting |
| Technology | | | | Introduction to Photonics** | Introduction to Lasers | Light Sources and Wave Optics | Laser Electronics | Laser Applications |
| Technology | | | | | Geometric Optics | | Laser and Electro-Optics Components | Lasers/Electro-Optic Devices |
| Technology | | | | | | | Laser Technology | Laser Electro-Optic Measure-ments |
| | Social Sciences, Humanities, History, Government, and Health | | | | Humanities, Social Sciences | | | |

*Standard secondary school offerings determined by state educational agencies

**Could be offered as a dual credit or concurrent enrollment course that replaces a postsecondary technical elective

*** Could be a course in a selected photonics-enabled area, advanced digital electronics, or additional postsecondary math/science courses

## Career Management Success

### Course Description

*Career Management Success* is a one-year course for high school freshmen or sophomores who may be interested in careers in engineering and technology. In addition to helping students develop positive attitudes and behavior patterns necessary for success in the classroom, this course helps them acquire effective teamworking, communication, and job-seeking skills and provides them with a broad overview of the photonics industry. Because the course focuses broadly on selecting careers and developing effective personal and workplace skills, it should be of benefit to many students at the high school level.

### Course Topics

1. Develop positive attitudes for personal and academic success
   a. Examine and adapt learning styles and strategies
   b. Use time-management strategies to prioritize short- and long-term activities
   c. Improve study skills
   d. Develop techniques for managing stress
   e. Model attitudes that lead to personal success
2. Learn and demonstrate attitudes, skills, and strategies necessary for success in the workplace
   a. Analyze the importance of values and ethics in the workplace
   b. Analyze the value of diversity in the workplace
   c. Demonstrate workplace attitudes that lead to workplace success
3. Apply teamworking skills to accomplish team goals, solve problems, and resolve conflict
   a. Study the role and function of teams in the workplace
   b. Practice role-playing the various roles in effective teamwork
   c. Identify strategies and reducing conflicts within groups
   d. Provide and receive constructive criticism
4. Practice effective oral and written communication
   a. Understand the nature and importance of communication in the workplace
   b. Demonstrate effective, concise verbal communication

c. Demonstrate effective workplace written communication in various business formats
d. Develop listening and responding skills

5. Identify effective job-seeking skills and desirable employee characteristics
   a. Plan a job search interview
   b. List the personal and behavior characteristics that an employer looks for in a good worker
   c. Role-play interviewer and interviewee situations

6. Demonstrate leadership, teamwork, and good citizenship skills for success in the school, community, and workplace
   a. Identify and role-play good leadership skills in teamworking situations
   b. Identify and apply problem-solving and decision-making skills to problems arising in the school, community, or workplace
   c. Take part in Skills USA-VICA as an integral part of classroom learning

## Suggested Teaching Resource Materials

Bailey, Larry. *Working: Learning a Living.* Carbondale, Illinois: South-Western Educational Publishing, 1997.

Bingham, Mindy, and Sandy Stryker. *Career Choices Curriculum*. Santa Barbara, California: Academic Innovations.

CORD. *Assessing and Evaluating Information*. Waco, Texas: CORD Communications, 2000.

CORD. *Measuring Your Processes*. Waco, Texas: CORD Communications, 1999.

CORD. *Quality and Your Customer: A Systems Approach*. Waco, Texas: CORD Communications, 1999.

CORD. *Teams at Work*. Waco, Texas: CORD Communications, 1999.

CORD. *The Business*. Waco, Texas: CORD Communications, 2000.

International Technology Education Association. *Standards for Technological Literacy: Content for the Study of Technology.* Reston, Virginia, 2000.

Kimbrell, Grady, and Ben S. Vineyard. *Succeeding in the Work of Work.* New York: Glencoe/McGraw-Hill, 1998.

Levitt, Julie Griffin. *Your Career: How to Make it Happen*. Boise, Idaho: South-Western Educational Publishing, 2000.

## COMPUTER/SOFTWARE APPLICATIONS

### Course Description

*Computer/Software Applications* is a one-year course for high school sophomores or juniors that builds on standard keyboarding skills developed at the elementary school level. The principal goal of the course is to advance the student's computer skills and facility through the use of currently available software related to *word processing; spreadsheets; CAD; data collection, manipulation, and display;* and *making presentations*. The course enhances the student's computer skills both for personal use and for collection and display of quantitative data in the laboratory and workplace environments.

### Course Topics

1. Develop proficiency in the use of *Microsoft Word* or equivalent and communicate via E-mail
2. Develop proficiency in the organization and display of data via spreadsheets
3. Develop computer skills that make use of software designed for computer-aided drawings (CAD) systems
4. Identify available physical sensors in the fields of biology, chemistry, and physics that enable the user to measure physical quantities of interest
5. Use laboratory sensors in combination with dataloggers and computers to measure physical quantities (e.g., force, linear speed, angular speed, temperature, pressure, voltage, and current); to collect and organize data for tabular and/or graphical representation and display; and to use software specifically designed to enable one to proceed through sequences of calculations to arrive at desired results
6. Develop proficiency in preparing PowerPoint presentations involving data collection, organization, and display
7. Prerequisites: Keyboarding skills and a laboratory science course

### Suggested Teaching Resource Materials

"Data Collection for Computers and Handhelds." *Vernier 2003 Catalog*. Vernier Software and Technology. Beaverton, California 97005.

Dyszel, Bill, and Jim Walkenbach. *Microsoft Office 2000 9-in-1 for Dummies Desk Reference*. IDG Publishing, 1999.

French, Thomas E., Carl L. Svensen, Jay D. Helsel, and Byron Urbanick. *Mechanical Drawing, Twelfth Edition*. Glencoe McGraw-Hill, 1997. (Two chapters are devoted to AutoCAD and CADKEY. Updated and expanded end-of-chapter problems simulate real-world design and drafting problems.)

Habraken, Joe, and Joseph W. Habraken. *Microsoft Office 2000 8-in-1*. Que Publishing, 1999.

Probeware. PASCO, 10101 Foothills Blvd., Roseville, California 95746. http://www.pasco.com

Probeware. Team Labs Corporation. 6859 North Foothills Highway, Building D200, Boulder, Colorado 80302. http://www.teamlabs.com

Spencer, Henry Cecil, John Thomas Dygdon, and James E. Novak. *Basic Technical Drawing*. Glencoe McGraw-Hill, 2000. (Updated coverage of CAD provides a basic introduction to CAD hardware and software. Specific CAD applications appear throughout the text. New career information opens each chapter to help students learn how drafting principles and skills are applied on the job.)

Wahlers, Terry T. *Applying AutoCAD 2000: A Step-by-Step Appro*ach. Glencoe McGraw-Hill, 2000. (This reorganized, updated edition teaches students both the basic and advanced CAD skills used in industry. Text features help students to move from basic to advanced using real-world problems making learning more relevant to students.)

## DC/AC ELECTRICITY

### Course Description

*DC/AC Electricity* introduces the student to the basics of DC and AC electricity, covering current, voltage, resistance, capacitance, and inductance. In addition, the course introduces the student to Ohm's law and additional circuit laws that enable one to analyze the characteristics and operation of DC and AC circuits. The course ends with an introduction to semiconductor devices.

### Course Topics

1. Introduction to electricity
2. Direct current
3. Voltage
4. Resistance
5. Ohm's law
6. Electrical measurements—meters
7. Electrical power
8. DC circuits
9. Magnetics
10. Inductance
11. Capacitance
12. Alternative current
13. AC measurements

14. Resistive AC circuits
15. Capacitance AC circuits
16. Inductive AC circuits
17. Resonance circuits
18. Transformers
19. Semiconductor basics
20. Junction divider
21. Zener diodes
22. Bipolar transistors
23. Field-effect transistors
24. Thyristors
25. Integrated circuits
26. Optoelectric devices

### Suggested Teaching Resource Materials

Gates, E. D., *Introduction to Electronics, 4th Edition.* Delmar Thompson Learning (or equivalent).

## DIGITAL ELECTRONICS

### Course Description

*Digital Electronics* is a course in electronic theory and application focusing on binary systems. The student will gain experience in the design and construction of combinational logic circuits and devices and in the use of electronics equipment such as multimeters, power supplies, function generators, and oscilloscopes. The student will gain prototyping, bread boarding, and soldering skills.

### Course Topics

1. Introduction
    a. Safety and solder
    b. Basic electron theory
    c. Resistors, capacitors, inductors
    d. Circuit analysis laws
    e. Analog and digital wave forms
2. Number systems
3. Gates
4. Boolean algebra
5. Combinational circuit design
6. Adding
7. Flip-flops
8. Shift registers and counters
9. Logic families
10. Spec sheets

## Suggested Teaching Resource Materials

Gates, E. D., *Introduction to Electronics, 4th Edition.* Delmar Thompson Learning (or equivalent).

# INTRODUCTION TO PHOTONICS

## Course Description

*Introduction to Photonics* is a one-year course for high school juniors or seniors who are interested in careers in optical science and engineering and who plan to specialize in the fields of optics and photonics after high school, in either two-year or four-year colleges. *Introduction to Photonics* is also appropriate for high school students seeking a general introduction to the field of light and lasers.

The course begins with a basic study of the electromagnetic (EM) spectrum, covering the range from microwave radiation to X-radiation. The first part of the course concentrates on the region of the EM spectrum that includes visible light and ultraviolet and infrared radiation. The second part of the course deals with an elementary treatment of geometrical and physical optics (including the effect of mirrors, lenses, and prisms on the reflection and refraction of light energy) and closes with a general overview of the special characteristics of laser light and optical systems designed for specific purposes. The third (and largest) part of the course presents a more in-depth study of the basic parts of a laser and how laser light is generated, controlled, and detected.

## Course Topics

1. Overview of the photonics industry
    a. Communication (fiber optics, transmitters, and sensors)
    b. Lighting and illumination (lighting, displays, and entertainment)
    c. Medicine (biomedical optics and medical imaging)
    d. Manufacturing (materials processing, alignment, metrology, and inspection)
    e. Optoelectronics (nanotechnology, microsystems, and semiconductors)
    f. Imaging and remote sensing (signal and image processing, environmental concerns, and aerospace)
2. Radiation
    a. Electromagnetic radiation
    b. Electromagnetic spectrum
    c. Photon energy
    d. Visible light
    e. Infrared radiation
    f. Ultraviolet radiation
    g. Microwaves
    h. X rays
3. Light and optical systems

a. Ray optics: reflection and refraction
b. Wave optics: interference and diffraction
c. Laser light
d. Optical systems

4. Introduction to lasers
    a. Elements and operation of a laser
    b. Elements and operation of an optical power meter
    c. Introduction to laser safety
    d. Properties of light
    e. Emission and absorption of light
    f. Lasing action
    g. Optical cavities and modes of oscillation
    h. Temporal characteristics of lasers
    i. Spatial characteristics of lasers
    j. Helium-neon gas laser: a case study
    k. Laser classifications and characteristics

## Suggested Teaching Resources Materials

*Introduction to Lasers.* (Laser Electro-Optics Technology Series, Course 1.) Waco, Texas: CORD, 1986.

*Radiation*. (*Principles of Technology*, Unit 12, Second Edition.) Waco, Texas: CORD, 1993.

*Light and Optical Systems*. (*Principles of Technology*, Unit 13, Second Edition.) Waco, Texas: CORD, 1993.

# Selected Postsecondary Courses

## INTRODUCTION TO LASERS

### Course Description

This course presents the technical principles and equations needed to understand the operation of lasers and to modify their outputs. It builds on the *Introduction to Photonics* course and provides a more rigorous presentation of laser operations, control, and maintenance. The course emphasizes the basic physics underlying lasers and the procedures required to ensure their safe operations. Optical cavities are defined and their temporal and spatial characteristics presented. The course provides a capstone experience through a case study of the helium-neon gas laser.

### Course Topics

1. Elements and operation of a laser
2. Elements and operation of an optical power meter
3. Introduction to laser safety
4. Properties of light
5. Emission and absorption of light
6. Lasing action
7. Optical cavities and modes of operation
8. Temporal characteristics of lasers
9. Spatial characteristics of lasers
10. Helium-neon gas laser—a case study
11. Laser classification and characteristics

## GEOMETRICAL OPTICS

### Course Description

*Geometric Optics* provides the student with a mathematical procedure, an ability to employ the graphical ray tracing technique, and the experimental expertise to trace a ray of light thorough a system using any one of these techniques for a large variety of optical components systems. The course deals with ordinary reflection, refraction at plane and spherical surfaces, imaging with lenses, the use of apertures and stops to control the dimensions and brightness of a final image, and the use of materials to trace rays through an optical system. The course ends with an introduction to the physics of fiber optics.

### Course Topics

1. Reflection at plane and spherical surfaces
2. Refraction at plane surfaces
3. Refraction at spherical surfaces
4. Imaging with a single lens
5. Imaging with multiple lenses

6. F-stops and apertures
7. Optical systems
8. Matrix optics
9. Fundamentals of fiber optics

## Light Sources and Wave Optics

### Course Description

*Light Sources and Wave Optics* concentrates on describing sources of light and the behavior of light as a wave, and on presenting the technical principles and equations that are needed to understand the operation of lasers and to modify laser outputs. It considers the generation and measurement of light, including the fundamental origin of light, different types of light sources, spectral characteristics of light sources, and radiometry and photometry. The course addresses the wave nature of light and considers reflection, refraction, and propagation of light. It also presents the essential principles of interference, diffraction, and polarization. The course also addresses the applications of wave optics in the area of holography.

### Course Topics

1. Light sources and their characteristics
2. Radiometry and photometry
3. Wave nature of light
4. Reflection and refraction
5. Propagation
6. Interference
7. Diffraction
8. Polarization
9. Holography or other applications

## Laser Electronics

### Course Description

*Laser Electronics* consists of the technical principles and basic knowledge associated with the various electrical systems and circuits found in laser electro-optical systems. Its purpose is to provide laser technicians with the knowledge and skill to adapt and modify laser systems to ensure that they operate safely and reliably. The course considers the safety aspects of lasers and electro-optic devices. The course also presents gas and laser power supplies and ancillary equipment in laser systems that deal with electrical energy, input, and output.

### Course Topics

1. Electrical safety
2. Gas laser power supplies
3. Ion laser power supplies
4. Flashlamps for pulsed lasers and flashlamp power supplies

5. Arc-lamp power supplies
6. Diode laser power supplies
7. Electro-optic and acousto-optic devices
8. Optical detectors
9. Electro-optic instrumentation

## LASER AND ELECTRO-OPTIC COMPONENTS

### Course Description

*Laser and Electro-Optic Components* considers the family of optical components that are used in designing both simple and complex optical systems. Photonics technicians who design and modify those systems must be familiar with the array of components available to them, and how each component can serve their needs. This course will cover basic optical benches and the tools and methods used to locate and support components on benches. Additionally, the nature and use of windows, mirrors, filters, prisms, lasers, diffraction gratings, and polarizers in designing optical systems is presented. This course also examines nonlinear optical materials to generate phase-matched second harmonic light.

### Course Topics

1. Optical tables and benches
2. Component supports
3. Photographic recording mediums
4. Windows
5. Mirrors and etalons
6. Filters and beam splitters
7. Prisms
8. Lenses
9. Gratings
10. Polarizers
11. Nonlinear materials

## LASER TECHNOLOGY

### Course Description

*Laser Technology* presents the technical principles and equations that are needed to understand the operation of specific laser systems and to modify their outputs. The purpose of this course is to provide laser technicians the knowledge and skill to build, modify, install, operate, troubleshoot, and repair lasers. The course covers excitation sources for continuous-wave (CW) and pulsed lasers. Specific laser types—solid-state, ion, molecular, dye, and semiconductor—are explained. Additionally, the topics of Q-switching, measuring outputs, and safety are also addressed.

## Course Topics

1. Power sources for CW lasers
2. Pulsed Laser flashlamps and power supplies
3. Energy transfer in solid-state lasers
4. CW Nd: YAG laser systems
5. Pulsed solid-state laser systems
6. Energy transfer in ion lasers
7. Argon ion laser systems
8. Energy transfer in molecular lasers
9. $CO_2$ laser systems
10. Liquid dye lasers
11. Semiconductor lasers
12. Laser Q-switching—giant pulses
13. Measurement of laser outputs
14. Laser safety: hazards evaluation

# PHOTONICS TROUBLESHOOTING

## Course Description

*Photonics Troubleshooting* covers the identification and operation of a number of hand tools and measuring devices. Measurement techniques will be applied to various electronic circuits and optical equipment. The importance of equipment manual usage is emphasized. The course also covers problem analysis and maintenance and repair of photonics equipment.

## Course Topics

The following list of troubleshooting-enabling goals will be addressed in the course. Goals shown with an asterisk are considered *crucial* in the development of troubleshooting skills.

1. Identifying hand tools
2. *Operating hand tools
3. Reading equipment manuals
4. Utilizing equipment manuals
5. *Explaining measurement devices operation
6. *Operating measurement devices
7. *Utilizing standard measuring techniques
8. *Using optical device measurement techniques
9. *Identifying equipment components
10. Describing photonics equipment efficiency
11. Describing wavefront distortion-decreasing methods
12. Describing beam analysis techniques
13. *Using laser beam quality testing methods
14. Identifying flashtube-testing methods

15. Identifying current measuring methods
16. *Applying current testing methods
17. *Applying flashtube-testing methods
18. Listing photonics equipment troubleshooting techniques
19. *Demonstrating photonics equipment troubleshooting techniques
20. Identifying vacuum systems measurements
21. Troubleshooting vacuum systems

### Suggested Teaching Resource Materials

(Will vary widely with school and instructor)

## LASER APPLICATIONS

### Course Description

*Laser Applications* examines important ways in which lasers are used in industry and society—specifically in manufacturing, information handling, metrology, tracking and alignment, telecommunications, medicine, construction, and spectroscopy. The purpose of the course is to provide laser technicians insights into how lasers enable other technology areas.

### Course Topics

Topics will be chosen to coincide with students' interests and future places of employment.

1. Laser in manufacturing
2. Lasers in optoelectronics
3. Laser trackers and alignment systems
4. Laser/fiber-optic communication systems
5. Lasers in biomedicine
6. Lasers in forensic science and homeland security
7. Lasers in environmental monitoring
8. Lasers in distance measurements
9. Lasers in construction

## LASER ELECTRO-OPTIC DEVICES

### Course Description

*Laser Electro-Optic Devices* describes special devices used in photonics to modify the output signal in particular optical systems. Its purpose is to provide laser technicians the knowledge and skills to build, modify, install, operate, and troubleshoot the specialized laser electro-optic devices found in many laser/optical systems. The course covers nine specific devices—photo detectors, power/energy detectors, photo instrumentation equipment, collimators, auto collimators, beam expanders, spatial filters, isolators, and AO/EO modulators.

### Course Topics

1. Photodetector characteristics
2. Photodetector types
3. Laser power and energy detectors
4. Photoinstrumentation equipment
5. Holographic techniques and equipment
6. Collimators and autocollimators, beam expanders, and spatial filters
7. Isolators
8. Electro-optic (EO) modulators
9. Acousto-optic (AO) devices
10. Mode-locking

## LASER ELECTRO-OPTIC MEASUREMENTS

### Course Description

*Laser Electro-Optic Measurements* considers the standard instruments and measurement techniques in photonics technology that are important to the photonics technician. It treats optical instruments under the general names of spectrometers, monochromators, and spectrophotometers and explains their use in making spectral measurements of light sources to determine both wavelength and intensity distribution of the light. The course also discusses the various types of interferometers available to the technician and their many uses in making interferometric measurements on small thicknesses, surface irregularities, and wavelength determination. The spatial resolution of optical systems is also presented. The emphasis in this course is on optical measurements with optical instruments. In summary, it is the intent of the course to enable the student to obtain laboratory experience in carrying out laser electro-optic measurements with modern optical equipment.

### Course Topics

1. Spectrometers
2. Monochromators
3. Spectrophotometers
4. Michelson interferometers
5. Fabry-Perot interferometers
6. Twyman-Green interferometers
7. Mach-Zehnder interferometers
8. Spatial resolution of optical systems

# Infusion Curriculum Models

## The Need for Infusion Models

As explained earlier, photonics is an enabling/converging technology for technical areas such as manufacturing, healthcare, telecommunications, environmental monitoring, homeland security, aerospace, and optoelectronics. Within these areas, the cutting-edge uses of lasers, fiber optics, LEDs and electro-optic devices are integrated into production processes and final products. Technicians working in these areas do not need the intensive course of study outlined in the Benchmark 4+2 AAS Curriculum but instead need a basic understanding of photonics principles to allow them to troubleshoot problems and maintain the quality of these processes and products. Colleges can help their students gain this understanding by infusing photonics principles into the curricula of their AAS technical programs and advanced certificates.

## Infusion in AAS Programs: Two Models

*Model 1: Course-by-Course Content Substitution*—This document provides two infusion models for AAS degrees. The first model involves course-by-course review of a given AAS curriculum to determine where photonics acts as an enabling technology. Once these course elements have been identified, the photonics principles that support this enablement are infused into the flow of material being taught. In effect, the photonics principles are presented on a "just in time" basis, enabling students to understand how the principles support specific processes and procedures. The final product of this review and infusion process is an infusion curriculum that provides students insights into how photonics is embedded into their technical areas and what purposes it serves at the component and systems levels. This knowledge is essential for technicians to effectively meet their job responsibilities.

Manufacturing is a technical area that lends itself well to model 1. The manufacturing operations of cutting, welding, grinding, measuring, and aligning are enabled by photonics and are key topics covered in AAS manufacturing programs. Consequently, the courses that present these operations could be infused with photonics concepts that provide a foundation for understanding how this technology enables them.

As curriculum is modified one must pay close attention to maintaining state-mandated limits for total program hours. Thus, curriculum modification is typically a zero sum game. Since most technical program curricula are already at or very near state requirements, infusing new content requires some hard decisions. These decisions should be made on the basis of what best prepares future technicians. Content that is out-of-date can be removed with minimal impact to student preparation. Another way of introducing photonics concepts without expanding the overall content to the curriculum is to introduce photonics in the context of how it is used. For instance, in the cutting processes used in manufacturing, the thickness of the cut becomes an important parameter. When this parameter is presented in an AAS manufacturing program, it can be described in the context of the power and inherent characteristics of a laser's output beam. Thus, while addressing the concept of cutting thickness, the instructor also introduces laser fundamentals. This contextual approach to adding photonics is efficient and does not increase the amount of material to be covered by the curriculum.

*Model 2: Two-Course Substitution Model*—A second model for infusing photonics into a curriculum is to add courses. This may seem to contradict some of the statements in the previous section—that curriculum modification is "typically a zero sum game"—but it is a viable option for technical programs with built-in electives. Technical programs with electives are very common. For instance, Figure 1 is a generic AAS manufacturing curriculum framework that was generated from curricula used at several institutions around the country. Two electives were included since most of the programs surveyed had them.

| Grade | English | Mathematics | Science | Tech Courses | Tech Courses | Other |
|---|---|---|---|---|---|---|
| 13<br>Semester 1 | English Composition | College Algebra & Trig | Electronic Control Devices | Computer Applications Manufacturing | Principles of Machining I | Eng Design |
| 13<br>Semester 2 | Hum Elect | Precalculus or Math Models | Tech Elect | Advanced CAD | Materials & Manufacturing Processes | Hum Elect |
| 14<br>Semester 1 | Tech Writing | | Gen Phy I | Electromech Devices | Statistical Process & QC | Econ |
| 14<br>Semester 2 | | Tech Elect | Tech Elect | Metrology & QC | Automated Manufacturing Systems | Tech Elect |

**Figure 1. Generic Manufacturing Technology Curriculum Framework**

OP-TEC has developed two courses that can be used to infuse photonics concepts into technical programs. Table 1 outlines their content. Course 1, *Fundamentals of Light and Lasers*, covers basic concepts related to light, optics, and laser operations. Course 2, *Elements of Photonics*, builds on Course 1 and gives students an understanding of laser types and methods for determining their output characteristics. Course 2 also allows for concentration in technical areas that are enabled by photonics. This customization is shown in Table 2, where the last half of the course is devoted "specialization modules" whose focus would be determined by the overall focus of the program. For example, if the two courses are being added to an AAS program in manufacturing, the "specialization modules" for Course 2 would cover the use of lasers in cutting, grinding, welding, measuring, and alignment. OP-TEC has developed and is continuing to develop courseware that supports this customization in several technical areas. Figure 3 shows the currently available courseware.

**Table 1. Module Titles of OP-TEC Courses 1 and 2**

| 1. Fundamentals of Light and Lasers | 2. Elements of Photonics |
|---|---|
| Nature and Properties of Light | Operational Characteristics of Lasers |
| Optical Handling and Positioning | Specific Laser Types |
| Laser Safety | Optical Detectors and Human Vision |
| Basic Geometric Optics | Principles of Optical Fiber Communications |
| Basic Physical Optics | Photonics Devices for Imagining, Storage, and Display |
| Principles of Lasers | Basic Principles and Application of Holography |

**Table 2. Customization of *Elements of Photonics***

| |
|---|
| Operational Characteristics of Lasers |
| Specific Laser Types |
| Optical Detectors and Human Vision |
| Specialization Module 1 |
| Specialization Module 2 |
| Specialization Module 3 |

**Table 3. Specialization Modules Currently Available from OP-TEC**

| | | |
|---|---|---|
| **Manufacturing** | **Biomedicine** | **Forensic Science and Homeland Security** |
| Laser Welding and Surface Treatment | Lasers in Medicine and Surgery | Lasers in Forensic Science and Homeland Security |
| Laser Material Removal: Drilling, Cutting, and Marking | Therapeutic Applications of Lasers | Infrared Systems for Homeland Security |
| Lasers in Testing and Measurements: Alignment Profiling and Position Sensing | Diagnostic Applications of Lasers | Imagining System Performance for Homeland Security |
| Lasers in Testing: Interferometric Methods and Nondestructive Testing | **Environmental Monitoring** | **Optoelectronics** |
| | Basics of Spectroscopy | Photonics in Nanotechnology |
| | Spectroscopy and Remote Sensing | |
| | Spectroscopy and Pollution Monitoring | |

Again using manufacturing as an example, Figure 2 shows the modified curriculum that would result from using the two-course substitution model. The only difference between Figure 1 and Figure 2 is that in Figure 2 the technical electives have been replaced with OP-TEC Courses 1 and 2. Course 2 would contain the customization already mentioned for a manufacturing program. Using this modified curriculum, students pursuing an AAS in manufacturing will receive a solid grounding in photonics and have a solid understanding of how it enables manufacturing processes.

| Grade | English | Mathematics | Science | Technology | Technology | Other |
|---|---|---|---|---|---|---|
| 13 Semester 1 | English Composition | College Algebra & Trig | Electronic Control Devices | Computer Applications Manufacturing | Principles of Machining I | Eng Design |
| 13 Semester 2 | Hum Elect | Precalculus or Math Models | Gen Phy I | Advanced CAD | Materials & Manufacturing Processes | Hum Elect |
| 14 Semester 1 | Tech Writing | | **Fundamentals of Light and Lasers** | Electromech Devices | Statistical Process & QC | Econ |
| 14 Semester 2 | | Tech Elect | **Elements of Photonics + Manufacturing Modules** | Metrology & QC | Automated Manufacturing Systems | Tech Elect |

**Figure 2. Photonics Infused Manufacturing Technology Curriculum Framework**

## Advanced Certificate

The two infusion models described in the preceding section are specifically for preparation of new technicians in technical areas enabled by photonics. Many of the technicians who are already working in these areas did not have an opportunity to study photonics and its applications in their degree programs. The advanced certificate provides an opportunity for those technicians to build this knowledge base.

Figure 3 illustrates a generic two-semester, 12-credit-hour advanced certificate. Again Courses 1 and 2 are used; Course 2 has been customized to focus on the technical area in which the technician is working or has received his or her AAS degree. This certificate assumes that the technician already has an AAS degree in a technical area and does not need instruction in basic concepts within that area. This certificate is for refinement, not for laying a foundation. The electronics courses shown in Figure 3 are optional and can be substituted for other courses that provide knowledge in areas that are rapidly changing or have experienced significant technical growth. Through the addition of these courses, the advanced certificate serves a dual purpose: It provides a means for technicians to learn how photonics enables their areas of expertise and allows technicians to keep abreast of technological breakthroughs.

| | Technology | Technology |
|---|---|---|
| Semester 1 | Electronic Circuits for Photonics | Fundamentals of Light and Lasers |
| Semester 2 | Laser Electronics | Elements of Photonics + Specialty Modules |

**Figure 3. Example Advanced Certificate**

# Contributors

*The National Photonics Skill Standards for Technicians* is a living document. Since the inception of the standards in 1995, CORD and now OP-TEC have committed themselves to keeping them current and relevant. Accomplishing this requires the assistance of the educators; employers; professional societies; and practicing technicians, engineers, and scientists that make up the national photonics community.

Following is a list of those who have contributed their time and expertise in making these standards possible. The list is comprehensive: It encompasses the full contingent of professionals who were involved in developing the standards in 1995 and updating them in 2003 and 2008.

The list includes the organizations with which the contributors were affiliated at the time of their participation in the development and revisions processes. In compiling the list, we have not attempted to ascertain the contributors' current status or professional affiliations.

A major contributor to these standards is The National Science Foundation (NSF). NSF funds OP-TEC and the effort that led to the third edition of the standards. NSF's Advanced Technological Education (ATE) Program promotes improvement in technological education at the undergraduate and secondary school levels by supporting curriculum development; the preparation and professional development of college faculty and secondary school teachers; internships and field experiences for faculty, teachers, and students; and other activities. With an emphasis on two-year colleges, the program focuses on the education of technicians for the high-technology fields that drive our nation's economy. The program also promotes articulation between programs at two-year colleges and four-year colleges and universities—in particular, articulation between two-year and four-year programs for prospective teachers (with a focus on activities and disciplines that have a strong technological foundation) and between two-year and four-year programs in science, technology, engineering, and mathematics (also with a focus on disciplines that have a strong technological foundation). (Source: http://www.nsf.gov/search97cgi/vtopic)

# OP-TEC PIs and Staff

Daniel M. Hull, PI
Director, OP-TEC
P.O. Box 21689
Waco, TX 76710
254-772-8756 or 800-972-2766
Fax 254-772-8972
hull@cord.org

Fred Seeber, Co-PI
Camden County College
P.O. Box 200
Blackwood, NJ 08050
856-227-7200 x 4475
fseeber@camdencc.edu

Larry Grulick, Co-PI
Texas State Technical College
3801 Campus Drive
Waco, TX 76705
254-867-3901
Fax 254-867-3915
larry.grulick@systems.tstc.ed

Chrys Panayiotou, Co-PI
Indian River Community College
3209 Virginia Avenue
Ft. Pierce, FL 34981
772-462-7621
Fax 772-462-7797
cpanayio@ircc.edu

M. J. Soileau, Co-PI
University of Central Florida/CREOL
MH 243
4000 Central Florida Blvd.
Orlando, FL 32816
407-823-2000
Fax 407-823-3299
mj@creol.ucf.edu

John C. Souders Jr.
Director of Curriculum
P.O. Box 21689
Waco, TX 76710
254-772-8756 or 800-972-2766
Fax 254-772-8972
souders@cord.org

Julie Foreman
Associate Director of Communications
P.O. Box 21689
Waco, TX 76710
254-772-8756 or 800-972-2766
Fax 254-772-8972
jforeman@cord.org

Donna Flanery
Program Associate
P.O. Box 21689
Waco, TX 76710
254-772-8756 or 800-972-2766
Fax 254-772-8972
dflanery@cord.org

Sean Erickson
Webmaster
P.O. Box 21689
Waco, TX 76710
254-772-8756 or 800-972-2766
Fax 254-772-8972
serickson@cord.org

## Individual Contributors

Robert Ade, PhD
Kalkovan, Pettit & Levin Ventures, LLC

Jean-Yves Allard
Consensys Innovation

Bruce Allen
Newport Corporation

Ahmed Muhammed Almanasreh
The Hashemite University

Seung Ho Baek
Eastman Kodak

Leo Baldwin
Electro Scientific Industries

Lonson Barr
Michigan State University

Michael Bass
Bright View Technologies

Prem Batra
Cincinnati State CC

Brian Bauman
Lawrence Livermore National Laboratory

Cathy Bayer
CardioGenesis

Gary Beasley
Central Carolina CC

Carl Becker
Sandia Science and Technology Park

John Bellum
Sandia National Laboratories

Steve Benavides
Albuquerque TVI

Cody Benkelman
Positive Systems, Inc.

Karen Bergman
Columbia University

Mike Bethel
Northrop Grumman Space
Technology/Cutting Edge Optronics

Robert P. Breault
Breault Research Organization

Kenneth Brecher
Boston University

Bruce Brinson
Rice University

Osvaldo Buccafusca
Agilent Technologies

Jeff Bullington
Infinite Photonics

Kelley D. Burroughs
The University of Alabama at Birmingham

Rob Campbell
Lawrence Livermore National Laboratory

Milton Chang
Incubic, LLC

Curtis F. Chapman
Modesto Junior College

Steven Chiavoroli
Vacuum Process Technology

Sang-Yeon Cho
Georgia Institute of Technology

Carol A. Christian
STScI

James Clark
Corning Cable Systems

Joseph S. Coel
Laserage Technology Corp.

Thomas W. Collins
Northern Kentucky Technical College

Meagan Cooper
Texas State Technical College, Waco Campus

Simon C. Cowley
Avaya Corporation

Kevin Crane
Naval Research Laboratory

Ron Crocker
Vacuum Process Technology

Michael Crowley
WaveSplitter Technologies

Wayne Cullen
Transparent Networks

Michael Cusanovich
University of Arizona

David Cushing
Corning Precision Lens, Inc.

Steve Decker
Autoliv

Richard DeSalvo
JDS Uniphase

Sohail A. Dianat
Rochester Institute of Technology

Judith Donnelly
Three Rivers Community College

James Downing
Springfield Technical College

Martin Drexhage
Center for Advanced Fiber Optic Applications

Ranjan Dutta
Lucent Technologies

Mark Enright
Arcturus Engineering, Inc.

Michael Escuti
Technical University of Eindhoven

Shahab Etamad
Telcordia Technologies, Inc.

Shane Fazzio
Agilent Technologies

Matt Fetterman
Penn State Electro-Optics Center

Jim Florence
ELCAN

Dennis Ford
Lumenis

Edward J. Forrest
ITW-Chemtronics

Daniel Friedman
Howard Community College

Joshua Gibson
Raytheon

Michael K. Giles
New Mexico State University

Lee Ky Good
Research & Development Laboratories

William H. Graham
Mississauga Training Consultants

Bill Gray
Indian Hills Community College

John E. Greivenkamp
University of Arizona

Warren Grundfest
UCLA

Haisong GU
UNR

Arthur Guenther (deceased)
Center for High Technology Materials
University of New Mexico

Bob Guenther
Duke University

Solomon A. Gugsa
UNCC

Michael F. Gunther
Luna Innovations Incorporated

Eric J. Gustafson
BAE Systems

Richard Hackel
Lawrence Livermore Lab

David J. Hagan
University of Central Florida

David Hagan
Associate Director for Academic Programs
School of Optics CREOL

Grover Hall
Lockheed Martin

Tom Hammans
TSTC Harlingen

Lucian Hand
Altos Photonics, Inc

Thomas Happ
University of Wuerzburg

Jim Hayes
The Fiber Optic Association Inc.

Michael Head
Crane Aerospace, Hydro-Aire

Chris Heaton
Morgan Research Corporation

Donnie Heinrich
Rocky Mountain Instruments

Sammy W. Henderson
Coherent Technologies

John Highhouse
Lincoln Trail College

Peter Hill
Kadence Photonics

Keith Hinrichs
MicroE Systems

David Hirst
Afonics Fibreoptics Ltd.

Breck Hitz
LEOMA

Flora Ho
ASTRI

Tim Huebner
Newport Corporation

Darrell M. Hull
CORD

Boyd Hunter
Light Path Technologies

Dhiaa A. Hussen
The North Alberta Inst. of Technology

B H Ihde
Colorado Photonics Industry Association

Bill Janssen
LASERVISION USA

Robert Jensen
Pima Community College

Feng Jin
Brimrose Corporation of America

Shiefman Joe
Shiefman Consulting

Pearl John
Columbia Career Center

Anthony Johnson
New Jersey Institute of Technology

Larry Johnson
Light Brigade

W. D. Johnston
Multi-plex, Inc.

Bradley M. Jost
Goodrich Corporation

Shanalyn Kemme
Sandia National Laboratories

Greg Kepner
Indian Hills Community College

Danny Keswater
Raytheon Space and Airborne Systems / Operations

Robert Keys
Nortel Networks

Zhi M. Kiao
Lawrence Livermore National Laboratory

Dennis Killinger
Center for Laser Atmospheric Studies

Peter Kirkpatrick
Intel

Klaus Kleine
Guidant

Raman Kolluri
Camden County College

John Koshel
Breault Research Organization, Inc.

Dmitriy Krylov
Internet Photonics

Joseph Kulakofsky
JDSU

Silas Kung
Pemstar, Inc.

Peter Latham
Air Force Research Laboratory

Daniel E. Leaird
Purdue University

Wei-Ming Lee
New Focus, Inc.

Dong-cheol Lim
Lightron Fiber-Optic Devices, Inc.

Dennis Lockwood
Northrop Grumman

Ernie Longo
Precision Laser Specialist. Inc.

Janet W. Lou
SFA, Inc.

Tom Mahoney
CAPT Center

Jason Mangum
USEPA

Fabrice Manns
University of Miami

Nick Massa
Springfield Technical College

Laurel Mayhew
Lightpointe Communications

John McGeehan
University of Southern California

Jim McNally
InLight Solutions

Jim Menders
IPITEK

Sylvia Mioc
Datex-Ohmeda

Brian Motts
American Immuno Tech, LLC

Heinrich G. Muller
Corning Inc.

Daryl R. Myers
National Renewable Energy Laboratory

Luu Nguyen
National Semiconductor Corp

Matt Nixon
Boeing SVS

William D. Nothwang
U.S. Army Research Labs

Jean-Luc Nouges
LightPath Technologies

Glenn Oliver
DuPont

William R. Owens
Raytheon

Patrick Ozeene
Philips

Jeff Padgett
Zygo

Rajesh S. Patel
IMRA America Inc.

Gopalkrishna Y. Patro
ITerra Communications

Eric R. Pearson
Pearson Technologies Incorporated

John Pedrotti
Texas State Technical College

John T. Petrick
TWR Lighting, Inc.

Bob Pierson
Applied Technology Associates

Jason Podsednik
Sandia National Labs

Eric Potma
Harvard University

Denis Potvin
International Institute of Telecommunications

Sudhakar Prasad
University of New Mexico

Robert Pugliese
Trumpf Laser, Inc.

Gloria Putnam
Eastman Kodal

Steve Qualls
Optos, Inc.

Vicke Quinlyn
Digioto

Michael J. Ramsay
Aerotech

Jerry Reay
TSTC Waco

Frank Reed
Indian Hills Community College

Chris Remen
Cymer Inc., OMM Inc., Stanford University

Ryan Renfrew

Cymer Incorporated

Dirk Richter
Physical Electronics

Daniel G. Rippere
Thermo–Oriel Opticon Mirror Works

Dwight L. Ritums
DigiLens, Inc.

Michael Rivera
Sandia National Laboratories

Neil Roberts
Anritsu Company

Kevin J. Rodgers
Precision Laser Specialist, Inc

Chandra Roychoudhuri
University of Connecticut

Michael Ruane
Boston University

Robert Sanchez
Altus Medical

Gayle Schomberger
In-Phase Technologies

J. Thomas Schriempf
Penn State Applied Research Lab

John F. Schultz
Battelle

Andreas Schumacher
Infineon Technologies

Jelle Schuurmans
Philips Lighting BV
BG Lamps/CDL

James F. Shackelford
University of California–Davis

Adel Shamseldin
Gateway Consulting Networks

Richard A. Shanks
Columbia Career Center

Fatimah Shehadeh
Columbia Business School

Duncan Shields
Front Range Community College

Harry Shields
Northrop Grumman Space Technology

Barry Shoop, TLC
U.S. Naval War College

James P. Siepmann
LightTime

Dr. Philip Slator
Retired
Optical Sciences Center, University of Arizona

Larry Smith
Lawrence Livermore National Lab

Richard J. Smith
Richard Smith Computer Technologies

Bob Soales
CVI Laser Corporation

M.J. Soileau
University of Central Florida

Thomas R. Steele
Spectra-Physics

Karl Stengel
Boeing

John Sugrim
Jabil Circuit

Sydney Sukuta
San Jose City College

Margaret Sullivan
MKS Online Products Group

Matt Swass
Agere Systems

John Swienton
EXFO America

Greg Taft
KMLabs Inc.

Thomas E. Taylor
University of Georgia

Carlos G. Trevino-Palacios
INAOE

Jim Trice
Corning

Tom Tsao
Umachines

David Tyree
Vincennes University

Vien Van
University of Maryland

Bill Waggoner
Agilent Technologies

Lewis Wang
Corning

Ming Wang
Photonify Technologies, Inc.

Barbara Washburn
Springfield Technical Community College

H. Washburn
CoAdna Photonics

Sam Weaver
Network Photonics

Tim Weiland
Lawrence Livermore National Laboratory

Brian R. West
University of Arizona
Bright View Technologies, Inc.

Teresa West
Welch Allyn, Inc.

Peter Wigley
Corning, Inc.

Dominique Foley Wilson
Sandia National Laboratories

Ben Witham
Vectron International

Chongjin Xie
Lucent Technologies, Bell Labs

Yuhuan Xu
University of California, Los Angeles

Vlaislav Yakovlev
UWM

Perry P. Yaney
University of Dayton

Jae Chul Yong
Fiberpro

Gary Zacheri

Guangzhi Z. Zhang
New Focus, Inc.

Huanlin Zhang
University of Houston

Feng Zhou
Indiana University of Pennsylvania

## Professional Organizations Contributors

SPIE the International Society for Optics and Photonics

Optical Society of America (OSA)

Laser Institute of America (LIA)

Laser and Electro-Optics Society (LEOS) of the Institute of Electrical and Electronics Engineers (IEEE)

Coalition for Photonics and Optics

Laser and Electro-Optics Manufacturers Assn. (LEOMA)

New Mexico Optics Industrial Association