Photonics Systems Technician

Curriculum Guide

OPTICS AND PHOTONICS SERIES

National Center for Optics and Photonics Education

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PREFACE

In the last two decades photonics (optics, lasers and electro-optics) has grown from a specialized technology to an "enabling technology", which means that lasers, LEDs, electro-optical systems and optics are used in a wide variety of equipment, devices and processes: either as the critical (enabling) element, or to improve the performance of the equipment or process. As the nature of the technology has changed, so have the education and skill requirements for photonics technicians. Today there are three types of photonics-related technicians:

- **<u>Laser/Electro-Optical (LEO) Specialist Technicians</u>: for Research and Development Labs, and for Laser Original Equipment Manufacturers (OEMs)**

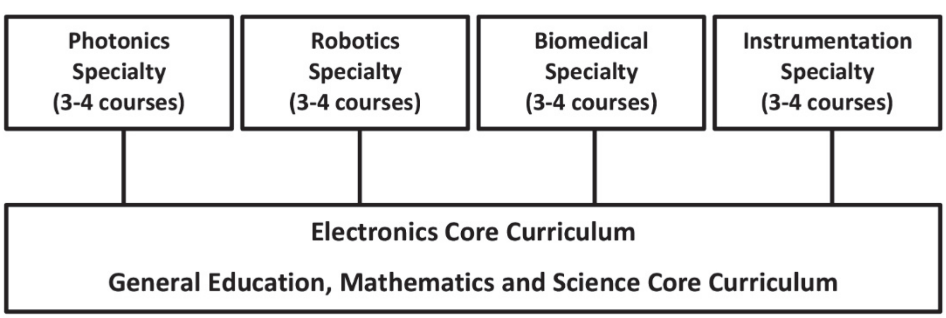
  Three decades ago, nearly all employers required photonics Specialist Technicians and all the AAS degree programs in the country (as many as 25) used LEO curricula that included eight to ten photonics courses in full AAS degree programs. Most of the colleges with LEO programs employed two or three LEO faculty and maintained over $2 million in lab equipment. In the 21st century, less than 20% of the photonics technician jobs require LEO Specialists and only three or four colleges are able to continue to offer full AAS degree programs.

- **<u>Application Technicians:</u> Technicians Educated and Trained in Other Fields Where Photonics is an Enabling Technology**

  These fields include manufacturing, materials processing, medical instrumentation and fiber optic/communications. Technicians in these fields typically operate lasers or other electro-optics devices, and benefit from completing an elective course in the *Fundamentals of Light and Lasers*. Colleges that prepare technicians in manufacturing, materials processing, medical instrumentation, etc., frequently include one or two elective courses in lasers, optics and specific applications of lasers/optics to the major field of study.

- **<u>Photonics Systems Techs (PSTs)</u>: Integrating and Using Photonics in Larger Systems**

  PSTs are in the greatest demand; they are qualified for over 80% of the photonics technician jobs in the U.S. Similarly, over 80% of the two-year colleges that offer education for photonics technicians are adopting the PST curriculum model. Most of these colleges are attempting to offer three or four photonics courses as a specialty in an AAS degree electronics program.



The purpose of this Guide is to support implementation and successful teaching of the PST program and courses. The Guide contains some information to help colleges plan new PST programs; but most importantly, the Guide provides assistance to faculty who will be developing laboratories and teaching the three courses in the PST curriculum. Detailed information is included to assist faculty on acquiring lab equipment, designing efficient (laser-safe) lab facilities, teachings maintenance/troubleshooting, lab book preparation and systems integrations. Solutions to problems and workplace scenarios that are embedded in the modules can only be accessed in a secure site by faculty using instructions and codes provided by OP-TEC staff.

This Guide, as well as the teaching materials, online faculty development courses and technical assistance are products and services of the National Center for Optics and Photonics Education (OP-TEC), an organization of the University of Central Florida, wholly supported by the National Science Foundation, Advanced Technological Education division.

Daniel Hull, PI and Executive Director   February 2018
OP-TEC

ACKNOWLEDGMENTS

The design and development of OP-TEC's Course 2 was an exemplary model for collaboration among organizations and professionals.

The need for an up-to-date, cost-effective and resource-efficient educational delivery system (curriculum) was expressed by numerous members of the OP-TEC Photonics College Network (OPCN) who were struggling with limited resources to provide quality, relevant photonics education programs to prepare technicians needed for the demanding, dynamic jobs by photonics employers in the colleges' service area. Employers from across the nation provided information and staff time responding to OP-TEC inquiries and served on focus groups that shaped and validated the Photonics Systems Technician (PST) curriculum specifications. Technical members of OP-TEC's National Visiting Committee also reviewed and supported the PST plan.

OP-TEC's faculty team from its five Partner Colleges met by teleconference, email and in person to create the design of the PST curriculum, and to identify the necessary teaching modules and laboratories. The members of this faculty team also designed the laboratories and specified equipment that could be effectively used for the vital "hands-on learning"—at minimum costs to the colleges. The following laser equipment suppliers graciously offer educational discounts to colleges who will be equipping the PST labs:

- Coherent
- Edmund Optics
- eLas Americas
- IPG Photonics
- Newport

The instructional modules were authored by Jack Ready, Jeff Hecht, and Dan Hull. Gary Beasley (CCCC) assisted in preparing the Workplace Scenarios, including solutions and faculty guidance. Technical advice was provided by Feng Zhou. Frank Reed (IHCC) provided information on laser maintenance, troubleshooting and lab equipment storage. John Chamberlain and William Hudson (TSTC) assisted OP-TEC staff member Todd Ewing in preparing lab videos to be used in faculty training. The development of this Guide was led by Bonnie Rinard and design and formatting by Rachel Haferkamp.

John Souders led the Course 2 development project, worked with the authors and editor, and technically reviewed and edited every module. John's valuable contributions assured that over 500 pages of high quality teaching materials were completed on a very tight timeline, and are now available to our colleges.

February 2018

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INTRODUCTION

Photonics Systems Technicians

Photonics systems technicians (PSTs) work in industries whose processes and operations require the extensive use of photonics devices to meet production or mission goals. PSTs frequently integrate photonics devices or subsystems into larger systems, where photonics is an enabling technology. PSTs have the responsibility of ensuring these photonic devices operate within prescribed specifications and are compatible and/or complementary with the entire integrated system.

These technicians must know how these photonic devices operate and interface with the equipment or systems in which they are embedded. They must also understand how photonics devices and subsystems enable equipment and systems to accomplish specific tasks.

Photonics systems technicians will have broad, working knowledge and skills of electronic and electromechanical devices/systems, combined with their specialty knowledge and skills in photonics to efficiently and effectively repair systems, and operate, maintain, and calibrate photonics subsystems, and integrate these subsystems into full systems.

Photonics Curriculum

The curriculum design for preparing PSTs is based on the 2018 National Skills Standard for Photonics Systems Technicians[1]. The design is also responsive to the limited capabilities and resources of two year colleges that offer technical courses.

Many colleges have historically offered AAS degree programs for electronics technicians. In recent years these electronics programs have evolved into "electronics-based" technologies, such as robotics, instrumentation, communications and medical instruments/equipment. Another evolution of electronics is *mechatronics,* which is an interdisciplinary field involving mechanical, instrumentation, electronics, robotics/automation, computer components and control systems. A model of an electronics core curriculum with several specialties, including PST, is shown in Figure 1.

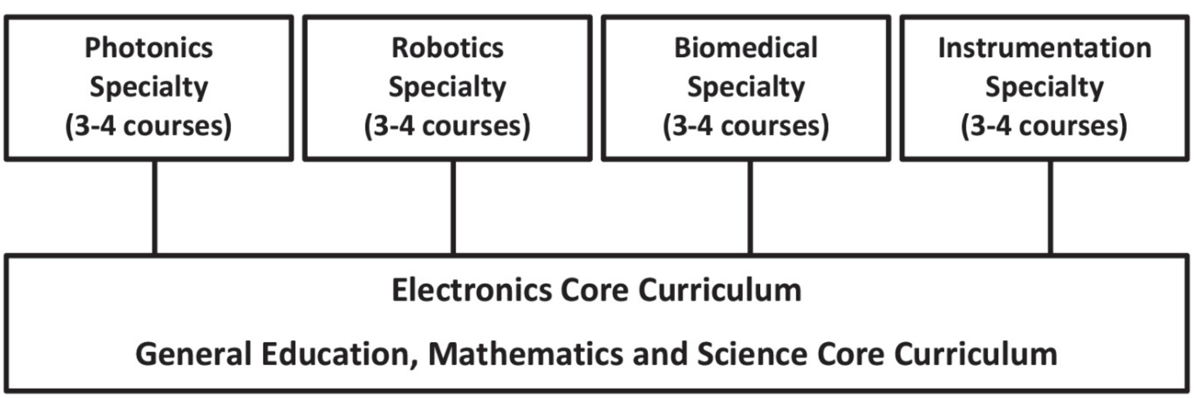

Figure 1 *Core curriculum model for supporting Photonics Systems Technician Specialty*

[1] Dan Hull, *The National Skill Standards for Photonics Systems Technicians*, (Waco, Texas: OP-TEC, 2018).

Completers of this curriculum typically receive an AAS degree in Electronics with a Certificate of Specialization in Photonics. Colleges offering this model of PST curriculum require only one photonics instructor and photonics lab equipment costing less than $200,000.00.

Adding a photonics specialty to an electronics core curriculum is not only technically sound, it offers a technical and cost-effective strategy that colleges can accommodate with a minimum of resources in new faculty and laboratories. Interested, experienced electronics instructors can be trained to teach each of the PST courses, using OP-TEC online professional development courses combined with 3-day capstone lab experiences at experienced OP-TEC Partner Colleges. Cost to the college for these faculty training courses is limited to time allocations for the instructor plus travel expenses for the instructor to attend the capstone.

Three semesters of photonics courses are required for this model.

- Course 1: *Fundamentals of Light and Lasers*
- Course 2, Semester 1: *Laser Systems and Applications*
- Course 2, Semester 2: *Laser Systems and Applications*

Each of these courses will require three, one-hour class periods and at least one, three hour lab per week. (Two lab sessions per week would be preferable for Course 2 Semester 1 and 2) Complete descriptions of the courses, labs, and equipment are provided in this Guide. In addition, solutions to the Problem Exercises and Questions (PE&Q) and to the Workplace Scenarios are provided online to instructors through a secure site.

Student learning materials for each course are available from OP-TEC. The text for Course 1 is also available in an eTextbook format. In addition, there are supplemental video tutorials for 11 required math topics, six technical concepts and lab tutorials. There are also 16 modules on Photonics Enabled Technologies (PET modules) in the following application areas:

- Manufacturing (4)
- Optoelectronics (Nanotechnology, Photovoltaics) (3)
- Biomedicine (3)
- Environmental Monitoring (3)
- Forensic Science and Homeland Security (3)

If a fourth photonics course is desired it can be constructed from combinations of other OP-TEC modules in subject areas such as:

- Fiber Optics Communication
- Optical Detectors, Lighting and Human Vision
- Holography
- Imaging, Storage and Display

OP-TEC teaching materials are available by request from the OP-TEC online store at www.optecstore.org.

CURRICULUM MATERIALS AND OTHER SUPPORT FOR PHOTONICS PROGRAMS

Essential Courses

The following courses are recommended for educating photonics systems technicians. The courses address the knowledge and skills identified as required in *The National Skill Standards for Photonics Systems Technicians*.

Course 1, *Fundamentals of Light and Lasers*

Course 1*, Fundamentals of Light and Lasers*, is a comprehensive study of photonics designed as a one-semester course. It provides the foundation required to prepare technicians in the areas of optics, electro-optics, lasers, and photonics. The course is designed for use as the introductory course in AAS programs in laser/electro-optics and photonics at two-year postsecondary community and technical colleges; as a specialty elective laser/electro-optics course in related fields such as biomedical equipment, manufacturing, defense and nanotechnology; as well as in programs to educate employed engineering technicians. The materials can also support dual-credit offerings for high school students in STEM career pathways.

Prerequisites: Students enrolling in Course 1, *Fundamentals of Light and Lasers* should have a math background that includes high school algebra, geometry, trigonometry, general scientific nomenclature, the scientific process, unit conversions, and basic concepts in elementary physics and chemistry. Each module in Course 1 lists specific prerequisites.

For students whose math skills need improvement, there are materials available from OP-TEC to help provide the needed skills including online math tutorials referenced in the text and a supplemental text, *Mathematics for Photonics Education*.

Content: *Fundamentals of Light and Lasers* consists of the six modules listed below with a brief description of their content:

- ***Module 1-1: Nature and Properties of Light*** covers the wave and particle properties of light, light interactions, and fundamentals of laboratory safety.
- ***Module 1-2: Optical Handling and Positioning*** covers bulk optical materials and their properties, optical coatings and methods of coating deposition, laboratory mountings, positioning equipment, surface quality of optical components, inspection methods and procedures, and the care and cleaning of optics.
- ***Module 1-3: Light Sources and Laser Safety*** covers important properties of non-laser and laser light sources, non-laser light sources, concepts of laser safety, and laser safety standards and safety classifications.
- ***Module 1-4: Basic Geometrical Optics*** covers the laws of reflection and refraction, image formation with mirrors, and image formation with lenses.
- ***Module 1-5: Basic Physical Optics*** covers light waves and their interaction with various objects in interference, diffraction, and polarization processes.

- ***Module 1-6: Principles of Lasers*** covers the generation of laser light, optical cavities and modes, laser beam characteristics, and a brief survey of different types of lasers.

Components and Features: Each module in the text contains the following features:

- The "Introduction" informs students what they will be studying in the module and may have information designed to catch their interest.
- "Prerequisites" lists what students should know and be able to learn the content included in the module.
- The "Objectives" lists what students should know and be able to do after they successfully complete the module. These objectives are designed to support *The National Skill Standards for Photonics Systems Technicians*.
- The "Scenario" provides a glimpse at what technicians do on the job in various industries.
- The "Basic Concepts" is the technical content of the module. It includes figures, tables, equations, as well as links to applets and videos provided on the OP-TEC website that support the content.
- "Laboratories" provide the hands-on learning opportunities to build technical skills in working with lasers and optical components. The following section of the guide provides more details on the laboratories and information on how to organize and run a lab. (NOTE: For high schools implementing Course 1, a separate *High School Photonics Lab Manual* is available that provides a less expensive option for laboratory equipment but an equally rigorous challenge in making measurements and collecting, organizing, and analyzing data.)
- The "Workplace Scenario" provides the background and assignment for a problem-based learning activity that requires students to do independent research of the type they might be assigned to do on the job. Further information on workplace scenarios is involved later in this Guide.
- The "Problem Exercises and Questions" are provided to check how well students understand the content of the module.
- "Meet a Technician" provides a biographical sketch of actual technicians with workforce experience in the photonics industry.
- The "References" section lists publications that provide additional information on the content of the module.

Online Features: In addition to the text features, the course provides the following support online. These materials are available at www.optecvideo.opteccrm.org.

- ***Math Videos*** – There are eleven math videos provided to assist students in performing mathematical operations required in the text. Each module of Course 1 includes a list of the math videos covering the topics required for that module. The videos include the following:

1. Scientific Notation
2. Unit Conversion
3. Introductory Algebra
4. Powers and Roots
5. Ratio and Proportion
6. Exponents and Logarithms
7. Graphing in Rectangular Coordinates
8. Geometry
9. Angle Measure in Two and Three Dimensions
10. Trigonometry
11. Special Graphs

- ***Lab Activity Videos*** – There are 23 videos that present safety issues, equipment use, data collection techniques, required calculations, and expected results related to the laboratory activities included in each module. Instructors can use these videos as pre-lab activities to familiarize students with the laboratory activities.
- ***Mini-Tutorial Videos*** – Mini-tutorial videos for each Module present instruction by experienced photonics faculty that give new insights into understanding an important, and sometimes difficult concept from the module that is designed to supplement the instruction provided by the text.
- ***Applets*** – Within each module, over 50 applets are referenced that provide students interactive, graphic simulations to improve their understanding of presented concepts. For the convenience of students and instructors these are all linked from one central location.

Additional Features: In addition to the text features, OP-TEC offers a Glossary of Terms (below) and an alphabetical index for *Fundamentals of Light and Lasers* as free resources available for download from the OP-TEC online store at www.optecstore.org.

Glossary of Terms in *Fundamentals of Light and Lasers*

Absorption – when a substance takes in the electromagnetic radiation of light, converting it to internal energy, often thermal energy

Amplitude – the maximum displacement of the wave

Angle of deviation – an angle equal to the difference between the angle of incidence and the angle of refraction of a ray of light passing between two mediums with different refractive indexes

Antireflection coating – a coating that greatly reduces reflection

Beam divergence – the increase of the diameter of the laser beam as it travels, which is an indirect measure of beam coherence

Beam waist – the position where the beam converges to a minimum diameter before diverging

Blackbody radiation – also called thermal radiation is the spectrum of electromagnetic radiation emitted by an object at some absolute temperature T

Broadband filters – filters that transmit a certain band of wavelengths of light and block the light outside of this band

Coherent light – light consisting of waves which all have the same wavelength and phase angle

Concave – curving inward, like the topside of a spoon (where the food goes)

Convex – curving outward, like the underside of a spoon

Crest – the high point of a wave's amplitude

Critical angle – the angle of incidence beyond which rays of light passing from a medium with a higher refractive index to a medium with a lower refractive index are no longer refracted, but are totally reflected

Cut-off filters – filters that allow radiation up to a specific wavelength to pass through and abruptly cut off the remaining wavelengths

Diffraction – the slight bending of light as it passes around an object

Displacement – the vertical distance measured from the equilibrium position at any point along the wave

Focal length – the distance between the center of a lens or cured mirror and its focal point

Focal point – the point at which rays meet after reflection or refraction

Frequency – the number of cycles of the optical/laser wave in one second expressed in the unit hertz (Hz)

Ground state – the lowest energy level of an atom

High-reflection coating – a coating that significantly increases the surface reflectance of a surface

Incoherent light – light consisting of waves with differing wavelengths and/or differing phase angles

Index of refraction – the ratio of the speed of light in a vacuum to its speed in a material or the ratio of the sine of the angle of incidence over the sine over the angle of refraction

Interface – where two mediums meet

Interference – when two or more waves are superimposed to form a resultant wave of greater, lesser, or equal amplitude

Irradiance – radiant power per unit area upon the surface with a symbol E expressed in watts per centimeter squared.

Joule – the unit of energy in the international system of units (SI). 1 joule = 1 watt-second

Light ray – an imaginary line directed along the path that light energy follows

Light-emitting diodes (LEDs) – semiconductor devices that are directly modulated by varying input current

Longitudinal modes – modes based on standing waves created between the two reflecting mirrors on either end of the cavity

Luminous efficiency – the ratio of the visible light energy produced by a light source to the electrical energy needed to power the light source

Maximum permissible exposure (MPE) – limits that indicate the greatest exposure that most individuals can tolerate without sustaining injury

Monochromatic Radiation – the laser light's property of containing only one pure color and a narrow range of wavelengths

Narrow-band filters – filters that are usually interference based, where many layers are coated on a substrate so that only a specific wavelength is transmitted and the rest are reflected

Neutral-density filters – filters that have the same transmission for all wavelengths over a broad range of the spectrum

Nominal hazard zone (NHZ) – see *normal hazard distance*

Normal hazard distance (NOHD) – the region within which the level of direct, reflected, or scattered laser radiation is above the allowable MPE

Numerical aperture – a number [NA] that depends on the index of refraction of the cladding to that of the core of an optical fiber

Optical bench – see *optical rail*

Optical density (OD) – the logarithm to the base ten of the reciprocal of the transmittance at a particular wavelength

Optical filters – devices that attenuate a certain portion of the electromagnetic spectrum, either in terms of wavelength or intensity

Optical rail – a long stable base on which optical components can be mounted

Optical tables – used instead of optical rails when optical elements must be aligned along more than one axis, and when vibration isolation is required

Optical thickness – a medium's optical thickness is the product of its refractive index and thickness

Period – the interval of time over which the wave repeats itself

Phase – the angular displacement of a point from the last positive zero crossing of the wave

Phase difference – the difference between the phase between two waves

Photometric filters – filters that mimic the human eye and transmit maximum light at 550 nm

Photon – the smallest division of a light beam that retains the properties of the beam, it is an elementary particle

Polarization – the direction or orientation of vibration of the electric field as the wave propagates through space

Polarized light – light in which the electric field oscillates all in the same direction

Q-switching – a method for obtaining short pulses from a laser by modulating the intracavity losses

Radiometric filters – filters that transmit light equally at all wavelengths

Reflection – when light waves bounce off of a surface

Refraction – when light waves are bent as they enter a medium from another medium with a different index of refraction

Refractive index – see *index of refraction*

Scattering – the redirection of light caused by its interaction with matter

Selective absorption – a substance only absorbs certain wavelengths of light and transmits

Sputtering – a technique used for larger substrates, which uses high voltage to knock particles onto the substrate where they condense and form a uniform coating

Substrate – the optical element on which the material is deposited

Surface abrasion – abrasion of a surface includes scratches on the surface due to harder materials coming into contact with the surface or by improper cleaning procedures

Total internal reflection (TIR) – a phenomenon that occurs when light strikes an interface at an angle greater than the critical angle, and is totally reflected within the initial medium

Transverse – perpendicular to or across an optical or electromagnetic wave front

Transverse modes – the pattern of the cross-section of a laser, in a plane perpendicular to the beam itself, caused by electric and magnetic fields

Trough – the low point of a wave's amplitude

Unpolarized light – light that has no specific orientation of electric field

Wave front – a series of adjacent points along which all motions of the wave are identical

Wavelength – the distance over which the wave repeats itself can be measured from crest to crest or trough to trough along the wave front

Course 2, *Laser Systems and Applications*

Course 2: *Laser Systems and Applications* covers more advanced concepts in photonics and the operating principles, output characteristics, diagnostics, and applications for the six most widely used laser types. All important lasers are described and classified according to their active medium, output wavelength, and applications.

Prerequisites: Course 1, *Fundamentals of Light and Lasers*

Content: *Laser Systems and Applications* can be taught as a one or two semester course. It consists of the ten modules; five modules are typically taught in one semester. For a one semester course, Modules 1, 2, and 3 should be taught first. Instructors can then choose two additional modules from Modules 4 through 10 to tailor the course to meet local needs and to make use of available resources. OP-TEC staff members are available to assist faculty in module selection. Course 2 can be extended to a second semester by teaching the remaining modules not used in the first semester. OP-TEC recommends all Course 2 modules are taught in a two-semester offering, but the final decision on presenting this course as a one or two semester offering should be based on financial means as well as input from the photonics advisory committee.

The modules in *Laser Systems and Application*s are listed below with a brief description:

- ***Module 2-1: Laser Q-Switching, Mode Locking, and Frequency Doubling*** covers the basic principles and techniques of Q-Switching, the generation of ultrashort laser pulses through mode locking, and frequency doubling of laser output using nonlinear materials.
- ***Module 2-2: Laser Output Characteristics*** covers laser beam characteristics, optical detectors, and important measurements.
- ***Module 2-3: Laser Types and Their Applications*** covers laser materials, excitation techniques, and output characteristics; laser types and their operational dynamics; as well as present and future laser applications.
- ***Module 2-4: Carbon Dioxide Lasers and Their Applications*** covers molecular energy levels, CO_2 laser composition and energy processes, continuous wave CO_2 lasers, intercavity devices for CO_2 lasers, applications of carbon dioxide lasers, safety considerations, and troubleshooting.
- ***Module 2-5: Fiber Lasers and Their Applications*** covers basic structure and operation of fiber-lasers, from pump to output, master oscillator power amplifier, pulsing methods, output characteristics of fiber lasers, advanced structures, fiber laser applications, safety considerations, and troubleshooting.
- ***Module 2-6: Diode Lasers and Their Applications*** covers energy transfer in semiconductor lasers, basic semiconductor laser design, output characteristics of semiconductor lasers, materials used in semiconductor lasers, developments in semiconductor laser types, damage mechanisms for semiconductor lasers and prevention of damage, applications of semiconductor lasers, safety considerations, and troubleshooting.
- ***Module 2-7: Argon-Ion Lasers and Their Applications*** covers energy transitions in ion lasers, ion laser plasma tube design, operating parameters of ion lasers, optical cavities of ion lasers, applications of argon-ion lasers, safety considerations, and troubleshooting.
- ***Module 2-8: Nd:YAG Lasers and Their Applications*** covers CW Nd:YAG lasers, pulsed Nd:YAG lasers, applications of Nd:YAG lasers, safety considerations, and troubleshooting.
- ***Module 2-9: Excimer Lasers and Their Applications*** covers excimer laser concepts, problems with excimer lasers, applications of excimer lasers, safety considerations, and troubleshooting.
- ***Module 2-10: Systems Integration in Photonics*** covers the basics of system integration, the role of the PST in systems integration, and steps in performing systems integration.

Components and Features: The text for Course 2 is similar to Course 1 in layout with a few notable exceptions. Course 2 modules do not include an introductory scenario or the "Meet the Technician" features. Instead the modules include two different features, "Safety Considerations" and "Troubleshooting Strategies" which are described below:

- "Safety Considerations" provide safety protocols for radiation sources and information on how to implement them as prescribed in ANSI Z136.1 – Safe Use of Lasers.
- "Troubleshooting Strategies" provides the basic strategies for determining the sources of failure in malfunctioning photonics systems and identifying common failure modes in various types of lasers.
- "Acronym Glossary" offers an alphabetical list of all acronyms found within the text, along with their meanings.

Acronym Glossary

ADP – ammonium dihydrogen phosphate

COIL – chemical oxygen-iodine laser

CW – continuous wave

DBR – distributed Bragg reflector

DFB – distributed feedback

DL – diode laser

DPFL – diode pumped fiber laser

DPSS – diode pumped solid state

DUV – deep ultraviolet

ESD – electrostatic discharge

ESD – electrostatic discharge

ESI – engineering systems integration

EUV – extreme ultraviolet

HeNe – helium neon

HR – high-reflectivity

IR – infrared

KDP – potassium dihydrogen phosphate

LD – laser diode

LED – light emitting diode

LIDAR – light detection and ranging

LMA – large mode area

LN – lithium niobate

LSO – laser safety officer

MCA – monolithic crystal assembly

MOPA – master oscillator power amplifier

MOPFA – master oscillator power fiber amplifier

MPE – maximum permissible exposures

NA – numerical aperture

NLO – nonlinear optics

OC – output coupler

OD – optical density

OFCS – optical fiber communications system

OPA – optical parametric amplifier

OPMS – optical power measuring system

OPO – optical parametric oscillator

OPSL – optically pumped semiconductor laser

PET – photonics enabled technology

PRF – pulse repetition frequency

PRR – pulse repetition rate

PRT – pulse repetition time

PST – photonics systems technician

QCL – quantum cascade laser

SESAMs – semiconductor saturable absorber mirrors

SHG – second harmonic generation

SOP – standard operating procedure

TEC – thermoelectric cooler

TEM_{00} – fundamental mode

UV – ultraviolet

VCSEL – vertical cavity surface emitting laser

WDM – wavelength division multiplexing

YAG – yttrium aluminum garnet

Program Support

The remainder of this section provides information that will be helpful to those offering new programs. It includes information on teaching laser maintenance and troubleshooting, safety considerations, and example course schedules. Information on the OP-TEC website and the support that can be obtained there is also included.

Tailoring the PST Curriculum to Focus on the Unique Technician Needs of Employers Supporting and Hiring from your College

Groups of employers in a particular region of the country will naturally support and expect to hire completers from a nearby college. The PST curriculum materials contain many "stand-alone" modules, some of which may or may not have content that is appropriate to the local employers' needs. The college should be responsive to these needs by selecting appropriate lasers (Modules 2-4 through 2-9) to teach, to emphasize particular concepts, and to select PET modules with applications that are most appropriate to their employers' needs.

This "tailoring process" of the curriculum is best conducted through consensus of the employer advisory committee. The content of the curriculum and teaching materials was determined by examining *The National Skill Standards for Photonics Systems Technicians*. This document reflects the consensus of hundreds of photonics technician employers across the country.

OP-TEC staff recommends that the college photonics faculty facilitate the examination of the Skill Standards by the advisory to identify topics that need to be added and topics which can be eliminated. Please contact OP-TEC if you require assistance in interpreting the Skill Standards, or would desire advice on effective strategies for amending the Skill Standards to identify topics for tailoring the PST curriculum.

Use of PET Modules to Enhance Laser Applications for Modules 2-4 through 2-9

The sixteen modules on Photonics Enabled Technologies (PET), described earlier (page 2) study laser applications in five fields:

- Manufacturing/Materials Processing
- Optoelectronics (Nanotechnology and Photovoltaics)
- Biomedicine
- Environmental Monitoring
- Forensic Science and Homeland Security

These PET modules, which are available by request from the OP-TEC online store at www.optecstore.org, can be used in the study of specific lasers to introduce appropriate applications. For example, materials processing PET modules can accompany the study of CO_2 and fiber lasers; and medical diagnostic and therapeutic applications of lasers can accompany the study of Nd:YAG, argon and diode lasers.

Teaching Laser Maintenance and Troubleshooting

Maintenance and troubleshooting are job responsibilities of Photonics Systems Technicians. Some maintenance practices are discussed under Laboratory Resources for Course 1 and 2. If the suggestions presented in that section are practiced during lab activities—and if the students are required to follow these practices, they will learn most of what will be required on the job—and these good work habits will prove rewarding to them throughout their career.

The troubleshooting and repair of lasers and associated equipment may fall under different skill and knowledge levels; some may be beyond the capability of PSTs. However, it is the PST's responsibility to see that appropriate troubleshooting and repair is accomplished. Most of the teaching of troubleshooting and repair is addressed in Course 2. The design of this course assumes that PST students have already been taught electronics troubleshooting from earlier courses in the electronics core curriculum. Therefore, the strategies and approaches to troubleshooting should be understood. Some major subsystems in a laser are electronic or electrical (power supplies, controllers, measurement devices etc.) The PST will be able to address issues with these devices.

But when the electrical/electronic elements seem to be working properly, troubleshooting and repair efforts are refocused on optical measurements of the laser beam (and visual inspection of the optics). In Module 2-2, The PST student is taught how to make measurements on the various properties of the laser output beam. The data can be compared to the system specifications as outlined in the laser maintenance manual. If the laser output is not meeting performance specifications, and there is no observable degradation in the optical elements, then further understanding of the laser is required to determine if the cavity is misaligned or if other defects are present. Some of these are beyond the scope of understanding and experience of a PST. In many cases, these determinations are the responsibility of the laser manufacturer.

Nevertheless, the PST is required to "characterize the performance" of the laser and be able to communicate effectively with the manufacturer. Repairs may be made by instruction from the manufacturer, or replacing a subsystem provided by the manufacturer, by the manufacturer sending a rep to the site, or by returning the laser back to the manufacturer for repair.

In Module 2-3, this general approach to troubleshooting and repair is explained. The section from this module is shown in the following section. In addition, in each of the Course 2 laser modules (4-9) information is provided that is specific to troubleshooting and repair of that particular laser.

Excerpt from Module 2-3

Maintenance of Lasers

The efficient and safe operation of lasers requires that one or more workers be assigned to maintain the work area and equipment. Specifically, these assignments include the following:

- *All equipment and maintenance manuals provided by the manufacturer should be obtained and kept in a file that is available to the staff.*
- *Supplies and spare parts for all equipment should be secured, labeled, and stored appropriately.*
- *Components, such as lenses, filters, prisms, and optical supports, should be labeled (focal length, diameter, material, etc.) and stored in a clean and organized manner.*
- *Lenses, mirrors, prisms, filters, and other optical or electro-optical components should be checked periodically to ensure that they are clean and show no apparent defects or deterioration.*
- *Laboratories or work stations must be well organized to assure safe mobility when lighting is reduced or eliminated during optical alignments.*
- *Appropriate safeguards for the facility should be ensured to prevent electrical shock, chemical contamination, and eye damage. Specific laser safety goggles should be available—and used when needed.*

Troubleshooting Laser and Other Equipment Malfunctions

Performance of equipment according to specifications is essential for successful work and personnel safety. Most equipment in laser facilities consists of some combination of electrical, electronic, optical, and laser systems. Diagnostic techniques and procedures for measuring equipment performance are available in electronics courses and in Module 2-2 of this course, Laser Output Characteristics. When equipment is not operating according to specifications, it is the responsibility of the laser technician to determine the cause of the malfunction and take steps to correct it.

Electrical and Electronic Problems in Lasers

Well-developed education and training materials for troubleshooting electrical and electronics systems are available. Typically, the photonics technician student has completed a course in electronics troubleshooting before studying laser systems and applications. In addition to peripheral electronic and electrical equipment in the laser facility, laser equipment also includes the following electrical and electronic devices:

- *Power supplies and capacitor discharge circuits*
- *Equipment interlocks*
- *Amplifiers and control devices*
- *Optical and laser detectors, power meters, and controllers*
- *Diagnostic and monitoring equipment*

If a laser system is malfunctioning, the first approach to troubleshooting should be to examine the electrical and electronic devices contained within it. Typical electrical problems in laser systems include:

- *Interlock problems*
- *Visually observed, burned out components and wiring, or evidence of overheating and insulation deterioration*
- *Overvoltage or under-voltage problems*

Typical electronic problems in laser systems include:

- *Burned-out or overheated components and circuit boards*
- *Water or moisture damage*
- *Electrostatic discharge (ESD) problems*

If the laser has a cooling system, coolant flow rate or fan cooling should also be examined.

Optics Problems

If the electrical and electronic subsystems of a laser appear to be operating normally, the next step should be to visually examine the optical components (lenses, mirrors, prisms, beam splitters, etc.) external and internal to the laser. Some problems to look for are:

- *Pitted, scratched, missing, or dirty optics; overheated optics that cause cracks; or damaged mirror coatings*
- *Mounting problems that misalign or loosely support the optical elements, causing them to be intermittently misaligned*
- *Misalignment of the optical axis or the optical resonator cavity*

Output Beam Problems

- *Low output beam energy or power*
- *Temporal characteristics*
  - *Incorrect pulse shape or duration*
  - *Incorrect pulse repetition frequency*
  - *Flickering (intermittent temporal variations)*
- *Spatial characteristics*
  - *Improper beam divergence*
  - *Poor beam quality (mode quality)*
  - *Incorrect beam profile*
- *Spectral characteristics*
  - *Wrong output wavelength*
  - *Improper bandwidth*

What Does Troubleshooting Require?

In some cases of laser malfunctions, the technician at the worksite may be able to diagnose the problem and repair it. This is particularly true for electrical and electronic problems. It can also be true for optical component damage or misalignments. In many cases, it may be *necessary to contact the manufacturer of the laser equipment to obtain advice or technical support. Before doing this, the PST should prepare careful notes of the diagnostic tests and be prepared to communicate them to the manufacturer's representative.*

The following steps outline a procedure for troubleshooting most laser systems:

1. *Identify and classify the malfunction. Perform a detailed visual inspection.*
2. *Define the status of the defective laser by understanding what is working and what is not working.*
3. *Check the electrical and electronics subsystems first.*
4. *Ensure that the optics are clean and not damaged.*
5. *Measure the malfunction.*
6. *Attempt to determine when the failure occurred and what may have caused the failure.*
7. *Is the problem intermittent?*
8. *Is the problem temperature dependent?*
9. *If possible, replace defective components.*
10. *Work with the laser manufacturer in the following ways:*
    a) *Obtain and study manufacturer's maintenance manuals.*
    b) *Communicate with the manufacturer's representative about the nature of the problem and the things you have done to understand the problem and correct it.*
    c) *Receive and replace a subunit provided by the manufacturer.*
    d) *Allow the manufacturer to correct the problem, either by using a field representative or by sending the equipment back to the manufacturer.*
    e) *Contacting the manufacturer for assistance in troubleshooting and repair of the laser*

Check the manufacturer's manuals or website to identify to whom and how you can report the malfunction. In some cases, there may be a person to assist you. If possible, before you call, certain pertinent information should be provided in an email to the appropriate representative in the manufacturer's organization.

My organization XXX obtained Model XXX Laser Device from you in (Date).

It is being used for XXX.

My responsibility is XXX.

The device is malfunctioning in the following ways: XXXX.

Diagnostic measurements I have performed include: XXXX.

Please contact me @ XXXX (email and phone number) to provide advice and/or assistance to repair this device.

In Course 2 modules about specific types of lasers (Modules 2-4 through 2-9), additional troubleshooting information is provided that is unique to the particular laser discussed in that module.

Teaching Photonics Systems Integration

Photonics is an "enabling technology". This statement means that lasers, LEDs, electro-optical systems and optics are used in a wide variety of equipment, devices and processes: either as the critical (enabling) element, or to improve the performance of the equipment or process. Several examples illustrate the enabling power of photonics.

Photonics in IT and Communication Systems
High speed internet systems use laser diodes for transmitters, optical detectors for receivers and fiber optic cable for the transmission medium. Using these photonics devices increases the bandwidth (data rate capacity) over one million times the bandwidth of systems using copper wire. For more information on these systems, review the LASER-TEC module, *Fiber Optics for Technologist.*

Lasers in Materials Processing Systems
Lasers are used as the directed heat source for welding, drilling, cutting, etching and other processes where melting or partial vaporization of the material is required. A laser is chosen to be used for these operations because it allows more accurate control, aiming and precision. Laser materials processing can also reduce distortion of the material and produce cleaner cuts, holes, welds, etc. For more information on these systems review, the two OP-TEC modules on laser materials processing; *Laser Welding and Surface Treatment* and *Laser Material Removal: Drilling, Cutting, & Marking*.

Lasers in Digital Optical Disc Storage Systems (CD and DVD Recorders & Players)
Laser beams are used to create surface irregularities to record sound and video data on compact discs and digital video discs. Lasers are also used to "read these discs" by scanning the irregularities on the disc so that an optical detector can view the reflections of the laser beam. The irregularities on the disc modulate the reflected beam, producing digital signals that can be converted to audio and video information.

Photonics in Laser Surgery Systems
Lasers are used as the "scalpel" to cut or remove (by vaporization or ablation) tissues in the eye, skin, tumors and certain organs. Sometimes the laser beam is applied directly to the tissue; sometimes it is directed through a fiber optic cable to avoid invasive surgery. The particular wavelength of a laser beam will allow it to be selectively absorbed (through dyes, etc.) in one tissue region or organ, and not affect surrounding tissues. Lasers are also used to photocoagulate bleeding tissue or veins, such as those in the retina of the eye. For more information on these systems see the OP-TEC PET module *Lasers in Medicine and Surgery.*

Photonics in Laser Jet Printer Systems
Lasers are used in printers and copy machines to transpose digital images (letters, words, pictures, etc.) onto the photoreceptor that applies toner to the paper. These printers use dry ink known as "toner", which is charged with static electricity, then heated, to place and bond the ink, which may contain colors, onto the paper.

3D Printers: A 3D image of an object can be created using a scanner or a 3D CAD design program, which is then sent to the printer. The printer then forms the desired shape of an item by depositing granular material (e.g. plastic, resin) in layers, starting with the bottom layer, onto a platform, sometimes using a UV light or laser to harden the material before proceeding to the next layer. Each layer may change shape so that the composite layers form an irregular shape that cannot be created by machining. This action of 3D printers is sometimes called “additive manufacturing” because the process “creates objects”, as compared to “subtractive manufacturing” in which machining, removes material to form objects. Additive manufacturing allows the creation of irregular-shaped objects, such as artificial bones, which cannot be created by machining.

Lasers in Radars, Guidance and Ranging Systems
Laser beams can be aimed at objects to illuminate them. The reflected laser wavelength can then be detected to determine the position and distance to the object. A modulated (usually pulsed) laser beam allows the detecting device to determine distance by measuring the time to transmit and receive the reflected pulse, from which distances can be accurately measured. These “laser radars” are used for military fire control; they are also used by highway patrolmen to catch speeding cars.

In each of the examples above, a laser, electro-optic device or optical assembly (photonics device) is a key element in the equipment; it may deliver digital signals, directed heat (laser beam), manipulate light energy characteristics, or just provide illumination. But for the device to operate properly the photonics component must be mounted, activated, controlled and measured by other devices (subsystems). It’s useful to consider equipment as *systems* that are composed of *subsystems*. Other subsystems in the equipment described earlier are power supplies, mounting fixtures, heating or cooling devices, material transporters, digital controllers, collimating optics, aiming devices, and various electronic circuits.

In order to integrate subsystems into a working system, each element, or subsystem, must be made to complement, or support the other elements. When all subsystems are complementary to each other, and performing according to design specifications, the subsystems are said to be *compatible*. Typical compatibilities related to photonics subsystems are:

- Electrical compatibility
- Power requirements/voltage levels
- Electronics compatibility
- Input/output interfaces
- Environmental compatibility
- Mechanical/structural compatibility
- Mounting/aligning optical components & systems
- Stability
- End-to-end checkout procedures

Engineering systems integration teams are uniquely prepared to assure that each system performs according to the systems design specifications, and that subsystem interfaces are compatible. PSTs are members of the systems integration because they are required to accurately measure the photonics subsystem performance characteristics, and if these characteristics are substandard, to make appropriate adjustments to bring the subsystem to design specifications. The role of the PST is to install, test, maintain and repair a photonics-enabled system in order for it to perform according to required specifications. To do this, PSTs are also required to examine the interfaces between the photonics device, subsystems that support it and subsystems that the photonics device supports. Other technicians working in this team may be specialists in electronics, mechanics, fluids, computer controls, software and manufacturing processes. It is not likely that any of these technicians will possess experience or working knowledge of lasers or optics. But photonics systems technicians (PSTs) will not only have a specialty in lasers/optics, but also have a broad understanding of electrical, electronics, mechanical, computer and control systems which make them particularly suitable to serve on the team.

As a capstone experience to the *Laser Systems and Applications* course, Module 2-10 introduces the PST student to the purpose, process and job responsibilities of systems integration, and the contributions a PST makes to the systems integration team.

Using Local Employers to Tailor Photonics Systems Integration to their Needs

Module 2-10 uses two common "photonics-enabled systems" as examples for teaching systems integration knowledge and strategies: 1) Laser Welding Systems, and 2) Laser/Fiber Optics Communications Systems. However, you may want to customize this module to familiarize the PST students with systems that are used by local employers. The following plan is proposed for customizing Module 2-10 to the needs of local employers:

- Meet together with a subcommittee of 3-4 employers from your Advisory Committee.
- Ask the subcommittee members to read Module 2-10 in advance of the meeting.
- Select one or two systems that use photonics devices as a subsystem.

Ask the subcommittee members to rewrite the "Example", "Assignment" and "Lab" (problem) sections of the module to support the particular photonics-enhanced systems they have selected.

If possible, ask one or more of the employers on the subcommittee to:

- Provide and support internships for PST students to work on a systems integration assignment.

or

- Host "after hours" sessions at their worksite to use their equipment to teach systems integration.

Recommended Course Schedule

A recommended course schedule is provided below that depicts the ideal pacing guide for Course 1, *Fundamentals of Light and Lasers,* and Course 2, *Laser Systems and Applications*. Because situations are rarely ideal, OP-TEC staff will work with faculty to adjust this pacing chart to work around the specific limitations of a given program. The need to adjust the pacing chart becomes more challenging with Course 2 because of equipment limitations.

COURSE 1 CLASS AND LAB SCHEDULE

WEEK	MONDAY (1 hour)	WEDNESDAY (1 hour)	FRIDAY (I hour)	LABORATORY (3 hours/week)
1	Classroom Orientation	[1-1] Properties of Light (pp. 1-10)	[1-1] The Nature of E-M Waves (pp. 10-19)	Lab Safety (pp. 30-32) Fundamentals of Lab Safety
2	[1-1] Light Interactions (pp. 20-26)	[1-1] Spectra of Light Sources (pp. 27-32)	[1-1] Review Problem, Exercises & Questions (PEQ) (pp. 44-45)	LAB 1-1A Speed of Red Light LAB 1-1B Wavelength of Red Light
3	[1-1] Workplace Scenario (WPS) (pp. 42-43)	[1-1] Review for TEST 1	[1-1] TEST 1	LAB 1-1C The Spectrum of Color Light LAB 1-1D The Polarization of Light
4	[1-2] Refractive Indices, Absorption, Reflection, Transmission (pp. 1-10)	[1-2] Polarization, Thermal and Mechanical Properties, Chemical Properties and Coatings (pp. 10-23)	[1-2] Filters & Positioning Equipment (pp. 23-37)	LAB 1-2A Familiarization with Optical Equipment and Components
5	[1-2] Inspection Methods (pp. 37-41)	[1-2] WPS (p. 46) Review PEQ (pp. 47-48) Review for TEST 3	[1-2] TEST 2	LAB 1-2B Care and Cleaning of Optics) LAB 1-2C Building an Inexpensive Spectrometer
6	[1-3] Light Sources and Lasers (pp. 1-9)	[1-3] Eye Hazards & Skin Hazards (pp. 9-17)	[1-3] Laser Standards and Safety Classifications (pp. 18-20)	LAB 1-3A Irradiance LAB 1-3B Laser Eye Protection LAB 1-3C Window & Mirrors
7	[1-3] MPE & NHZ Laser Signage Other Hazards (pp 21-31)	[1-3] WPS (pp. 43-44) Review PEQ (pp. 45-46) Review for TEST 3	[1-3] TEST 3	LAB 1-3D Optical Filters LAB 1-3E Optical Photometer
8	[1-4] Law of Reflection and Refraction (pp. 1-8)	[1-4] Index of Refraction (pp. 9-14)	[1-4] Refraction in a Prism (pp. 14-17)	LAB 1-4A Prisms and Lenses
9	[1-4] Mirrors (pp. 18-23)	[1-4] Mirrors (pp. 24-31)	[1-4] Lenses (pp. 32-36)	LAB 1-4B Optical Alignment Techniques LAB 1-4C Law of Reflection
10	[1-4] Lenses (pp. 37-43)	[1-4] WPS (pp. 53-54) Review PEQ (pp. 55-56) Review for TEST 4	[1-4] TEST 4	LAB 1-4D Lenses
11	[1-5] Light Waves and Physical Optics (pp. 1-10)	[1-5] Interference (pp. 11-18)	[1-5] Thin Films and Coatings (pp. 18-24)	LAB 1-5A Working with Diffraction Patterns, Wavelengths and Polarization
12	[1-5] Diffraction (pp. 24-36)	[1-5] Polarization (pp. 36-44)	[1-5] WPS (p. 59)	LAB 1-5B Interference and Diffraction
13	[1-5] Review PEQ (pp. 60-63)	[1-5] Review for TEST 5	[1-5] TEST 5	LAB 1-5C Polarization
14	[1-6] Generation of Laser Light (pp. 1-13)	[1-6] Cavities and Modes (pp. 13-24)	[1-6] Beam Characteristics (pp. 24-35)	LAB 1-6A Measurement of Beam Diameter and Beam Divergence
15	[1-6] Different Type of Lasers (pp. 35-39)	[1-6] WPS (pp. 46-47) Review PEQ (pp. 48-49) Review for TEST 6	[1-6] TEST 6	LAB FINALS
16	MAKE-UP ASSIGNMENTS DUE	MAKEUP TEST DUE	REPORTING/POSTING GRADES DUE	<contingencies>

COURSE 2, SEMESTER 1 CLASS AND LAB SCHEDULE

WEEK	MONDAY (1 hour)	WEDNESDAY (1 hour)	FRIDAY (I hour)	LABORATORY (3 hours/week)
1	Classroom Orientation	Course 1 Review/ Course 2, Semester 1 Preview	Laboratory Preview	Safety and Lab Orientation
2	[2-1] Basic Concepts (pp. 1-16) Q-Switching	[2-1] Q-Switching (pp. 1-16)	[2-1] Q-Switching (pp. 1-16)	Lab 2-1 Diode Pumped Q-Switched & Frequency Doubled Nd:YAG Laser Lab
3	[2-1] Mode-Locking (pp. 17-22)	[2-1] Mode-Locking (pp. 17-22)	[2-1] Frequency Doubling (pp. 22-30)	Lab 2-1 Diode Pumped Q-Switched & Frequency Doubled Nd:YAG Laser Lab
4	[2-1] Frequency Doubling (pp. 22-30)	[2-1] WPS (pp. 38-39) [2-1] Review PEQ (p. 40) [2-1] Review for TEST	[2-1] TEST	LAB 2-1 Diode Pumped Q-Switched & Frequency Doubled Nd:YAG Laser Lab
5	[2-2] Basic Concepts (pp. 1-9) Laser Beam Characteristics	[2-2] Laser Beam Characteristics (pp. 1-9)	[2-2] Laser Beam Characteristics (pp. 1-9)	LAB 2-2 Measuring Laser Output Characteristics
6	[2-2] Optical Detectors (pp. 9-20)	[2-2] Optical Detectors (pp. 9-20)	Measurements (pp. 19-31)	LAB 2-2 Measuring Laser Output Characteristics
7	[2-2]Measurements (pp. 20-31)	[2-2] WPS (p. 38) [2-2] PEQ (p. 39) [2-2] Review for TEST	[2-2] TEST	LAB 2-2 Measuring Laser Output Characteristics
8	[2-3] Basic Concepts (pp. 1-10)	[2-3] Laser Types Gas, Solid State and Fiber lasers (pp. 11-36)	[2-3] Laser Types; Gas, Solid State and Fiber Lasers (pp. 11-36)	2-3 Semiconductor Lasers (pp. 36-49) Lab Demo of Gas, Solid State and Fiber Lasers
9	[2-3] Semiconductor Lasers (pp. 36-49)	[2-3] Laser Applications (pp. 49-59)	[2-3] Laser Applications (pp. 49-59)	2-3 Semiconductor Laser Demo and Applications of Lasers. (internet video or teleconference with employer)
10	[2-3] Applications of Lasers (pp. 49-59)	[2-3] PEQ (p 70) [2-3] Review for TEST	[2-3] TEST	[2-3] WPS (p. 68)
11	[2-4] Basic Concepts (pp. 1-14) Molecular Energy Levels	[2-4] Basic Concepts (pp. 1-14) Molecular Energy Levels	[2-4] Basic Concepts (pp.1-14) Intracavity Devices for CO_2 Lasers (pp. 14-15)	2-4 Measuring Laser Output of CO_2 Laser
12	[2-4] Applications of CO_2 Lasers (p 16-17)	[2-4] WPS (pp 24-26) [2-4] PEQ (p 27) [2-4] Review for TEST	[2-4] TEST	2-4 Measuring Laser Output of CO_2 Laser
13	[2-5] Basic Concepts (pp. 1-11)	[2-5] Basic Concepts (pp. 1-11)	[2-5] Basic Concepts (pp. 1-11)	2-5 Measurement of CW & Pulsed Output from a Fiber Laser
14	[2-5] Output Characteristics of Fiber Laser (pp. 12-16)	[2-5] Output Characteristics of FiberLaser (pp. 12-16)	[2-5] Fiber Laser Applications (pp. 16-29)	2-5 Measurement of CW & Pulsed Output from a Fiber Laser
15	[2-5] Fiber Laser Applications (pp. 16-29)	[2-5] WPS (p. 39) [2-5] PEQ (p. 40) [2-5] Review for TEST	[2-5] TEST	LAB FINAL TEST
16	MAKE-UP ASSIGNMENTS DUE	MAKEUP TEST DUE	REPORTING/POSTING GRADES DUE	<contingencies>

COURSE 2, SEMESTER 2 CLASS AND LAB SCHEDULE

WEEK	MONDAY (1 hour)	WEDNESDAY (1 hour)	FRIDAY (I hour)	LABORATORY (3 hours/week)
1	Classroom Orientation	Course 2, Semester 1 Review/ Course 2, Semester 2 Preview	Laboratory Preview & Safety	LAB 2-6 Diode Laser Operations and Measurements
2	[2-6] Energy Transfer in Semiconductor Lasers (pp. 1-9)	[2-6] Output Characteristics of Semiconductor Lasers (pp. 9-14)	[2-6] Materials Used in Semiconductor Lasers (pp. 14-22)	LAB 2-6 Diode Laser Operations and Measurements
3	[2-6]Applications of Semiconductor Lasers (pp. 22-32)	[2-6] WPS (Workplace Scenario) (pp. 44-45) [2-6] Review PEQ(Problems, Exercises and Questions) (p. 46) [2-6] Review for TEST 1	[2-6] TEST 1	LAB 2-6 Diode Laser Operations and Measurements
4	[2-7] Energy Transfer of Ion Laser (pp. 1-6)	[2-7] Ion Laser PlasmaTube Design (pp. 6-8)	[2-7] Operating Parameters of an Ion Laser (pp. 8-13)	LAB 2-7 Argon-Ion Laser Operation & Measurements
5	[2-7] Optical Cavities of Ion Lasers (pp. 13-16)	[2-7] Applications (pp. 17-18)	[2-7] Safety & Troubleshooting (pp. 19-20)	LAB 2-7 Argon-Ion Laser Operation & Measurements
6	[2-7] WPS (p. 28) [2-7] Review PEQ (p. 29)	[2-7] Review for TEST 2	TEST 2	LAB 2-7 Argon-Ion Laser Operation & Measurements
7	[2-8] CW Nd:YAG Lasers (pp. 1-6)	[2-8] Energy Losses in CW Nd:YAG Lasers (pp. 7-11)	[2-8] Semiconductor Diode Pumped Nd:YAG (pp. 11-13)	LAB 2-8 Measurement of CW and Pulsed Output from a Nd:YAG Laser
8	[2-8] Pulsed Nd:YAG (pp. 13-17)	[2-8] Output Characteristics (pp. 17-20)	[2-8] Safety (p. 21)	LAB 2-8 Measurement of CW and Pulsed Output from a Nd:YAG Laser
9	[2-8] WPS (pp. 29-30) [2-8] PEQ (p. 31)	[2-8} Review for TEST 3	[2-8] TEST 3	LAB 2-8 Measurement of CW and Pulsed Output from a Nd:YAG Laser
10	[2-9] Excimer Lasers (pp. 1-6)	[2-9] Characteristics of Excimer Laser (pp. 6-7)	[2-9] Problems and Applications (pp. 7-10)	LAB 2-9 Measurement of Output for an Excimer Laser
11	[2-9] Safety (pp. 11-12)	[2-9] Troubleshooting (pp. 12-14)	[2-9] WPS (p. 19)	LAB 2-9 Measurement of Output for an Excimer Laser
12	[2-9] Review PEQ 04 (p. 20)	[2-9] Review for TEST 4	[2-9] TEST 4	LAB 2-9 Measurement of Output for an Excimer Laser
13	[2-10] Systems Integration Technique (p. 1-8)	[2-10] Making Sub-Systems Fit (pp. 8-11)	[2-10] Systems Integration Steps (pp. 11-15)	LAB 2-10 Developing a Fiber-Optic Communication System
14				
15				LAB FINAL TEST
16	MAKE-UP ASSIGNMENTS DUE	MAKEUP TEST DUE	REPORTING/POSTING GRADES DUE	<contingencies>

OP-TEC Website

The OP-TEC website, www.op-tec.org, was designed to inform and educate visitors about optics, photonics and technician education. The site provides visitors an instant, convenient and reliable source for OP-TEC information, curriculum, and other materials. OP-TEC utilizes its website to assist in the recruitment of new college programs by providing colleges with access to photonics education resources and contacts. The website also informs visitors of available educational opportunities and provides online registration for those opportunities when possible.

OP-TEC maintains a password protected download page that provides partners instant and convenient access to review copies of all of its curriculum materials and uses a file sharing site that allows OP-TEC to gather and compress large files for emailing download links to partners and other contacts.

OP-TEC staff is available to assist college faculty wanting to learn more about the curriculum and other activities of the center.

LABORATORY RESOURCES FOR COURSE 1 AND COURSE 2

Laboratories and Safety

This section of the guide includes information about maintaining a laboratory and the laboratory activities themselves. It includes suggestions for maintaining lab notebooks, equipment lists by course, and lists of vendors from which the equipment can be obtained and information on the lab videos.

In addition to the materials in this section, there are videos of the laboratory activities available at www.optecvideo.opteccrm.org. The videos are not intended to replace hands-on activities, but rather to enhance them. The presenters demonstrate equipment, setups, procedures, and point out potential problem areas. These videos can be used to introduce students to the lab exercises before they try them for themselves.

PST Lab Organization & Safety

Laser and optics labs need to be well organized and operated in accordance with appropriate guidelines. Laser and electro-optics equipment, as well as optical components and supplies should be organized and stored in a manner that will preserve their usefulness, identify/specify each item or element, and render them accessible for each lab procedure.

These tasks should be accomplished by the students, working under the direction of an experienced faculty member and following prescribed guidelines. The benefits of this effort are:

Well organized labs provide students a means to effectively use their time and avoid the loss of valuable lab time in searching for parts and equipment. This will leave more lab time for understanding the phenomena being measured and ensuring appropriate equipment performance.

Lab safety is enhanced through orderly arrangements of equipment that frequently is operated in the dark.

Technician students learn habits, procedures and skills in lab maintenance that they will need in their future jobs.

Technicians need to understand that proper maintenance of labs, equipment, components and supplies is their responsibility.

The following guidelines and suggestions come from OP-TEC staff and the experienced faculty at Indian Hills Community College IA, a photonics program with large college enrollments, high placement rates and high school dual-credit students on campus.

Course 1 Laboratories

Course 1 labs introduce new photonics students to optical components (lenses, mirrors, prisms, and beam splitters), component supports and low power lasers. Laboratory eye hazards are minimal. The labs for Course 1 can be conducted in a 20’x30’ room with six lab stations, each built on a 3’x6’ table with a 2’x3’ metal plate having a two inch matrix of threaded holes to anchor the component supports. Figure 2 shows an example of an optical breadboard. Each lab station should have a 2’x3’ vertical board on both ends to prevent the optical (laser) beam from exiting the station and projecting into the other work areas. The six lab stations are typically located along each of the three 30’ walls. The power requirement for each station is a 120VAC, 15 amp outlet with a three prong, grounded socket.

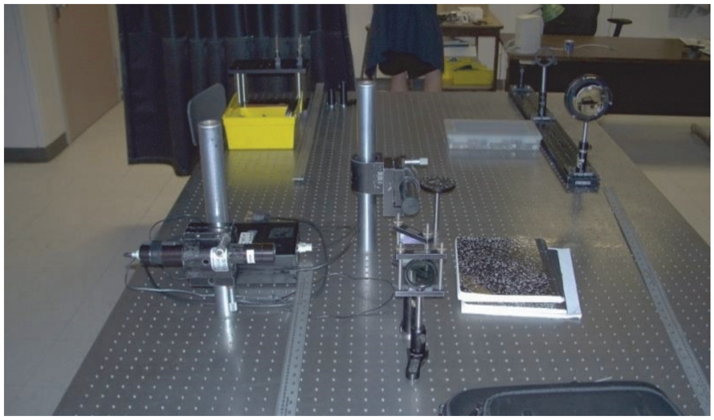

Figure 2 *Lab bench with optical breadboard top*

In the center of the room is a 3’x16’ work table with chairs (for discussions) where equipment and supplies can be placed for the lab experiment. See Figure 3.

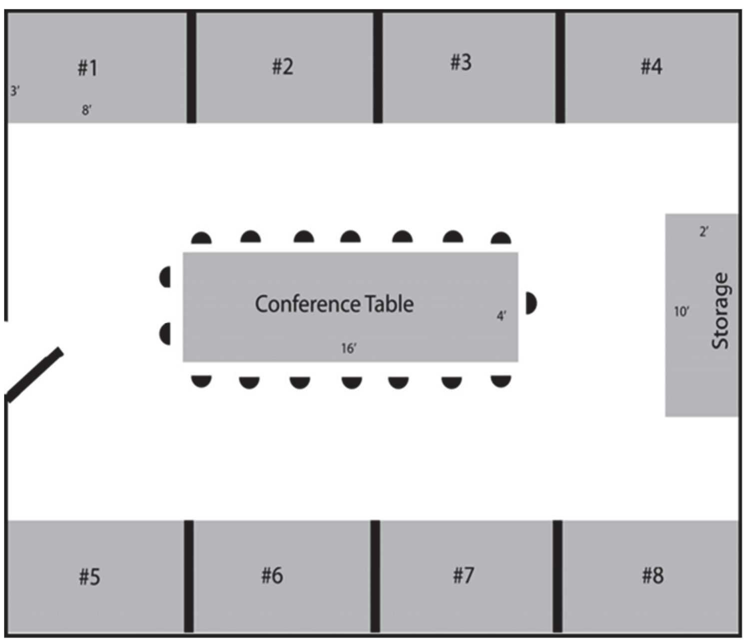

Figure 3 *Low-power (Class 2, 2M) laser laboratory*

In the Course 1 labs, students will learn to select, handle, clean and store optical components (positive and negative lenses, prisms, filters, plane and curved mirrors, and beam splitters). Critical lab equipment maintenance includes storage, retrieving, handling and cleaning of optical components. Students will understand positive and negative focal lengths of lenses and mirrors, and how to measure this parameter. They will also understand the optical density (OD) of filters and how to measure this parameter. Students will recognize beam degradation caused by dirty optics and know how to clean them.

Storage of Optical Components, Devices and Supplies

Most optical components will not have their focal lengths or optical densities marked on them. Therefore, when the components are stored they must be carefully placed in containers where they are protected from contaminants and identified according to their diameters, focal lengths, optical densities etc. The following pictures illustrate one effective strategy for storing optical components and supplies.

Marked shelves are used to store larger lasers and electro-optic devices. See Figure 4.

Figure 4 *Storage on labeled shelves*

Peg boards with marked places are used to store small optical components. These components are wrapped and placed in sealable plastic envelopes which can be attached or hung on peg board hardware. Figure 5 gives an example of storage using peg boards. Note optical components are stored in small, clearly labeled plastic zippered bags while supports and larger equipment are hung directly from pegs.

Figure 5 *Peg-board storage of optical components*

Cabinets, with labeled storage places are used for storing large optical components.

At the end of each semester, students are assigned responsibilities to remove the components from storage, test them to assure their properties, examine them for dirt, smudges or scratches, clean them, and replace them to the appropriate, designated storage locations.

Course 2 Laboratories

Course 2 laboratories deal with higher power lasers and will require safety compliance with the ASNI Z136.5 Standard for the Safe Use of Lasers in Educational Institutions. (Available from the Laser Institute of America at www.lia.org). Detailed information about laser safety can also be found in OP-TEC Module 1-3.

In addition to eye hazards associated with high power lasers, there are other possible hazards such as high voltages, unusual chemicals or gasses, flammables etc. For this reason, and to protect the security of these expensive devices, labs for Course 2 are usually housed in separate rooms, with appropriate warnings, lights, interlocks and other safety considerations. Often the lasers used in Course 2 labs may be integrated with equipment for a particular application. A typical room for a Course 2 lab is shown in Figure 6.

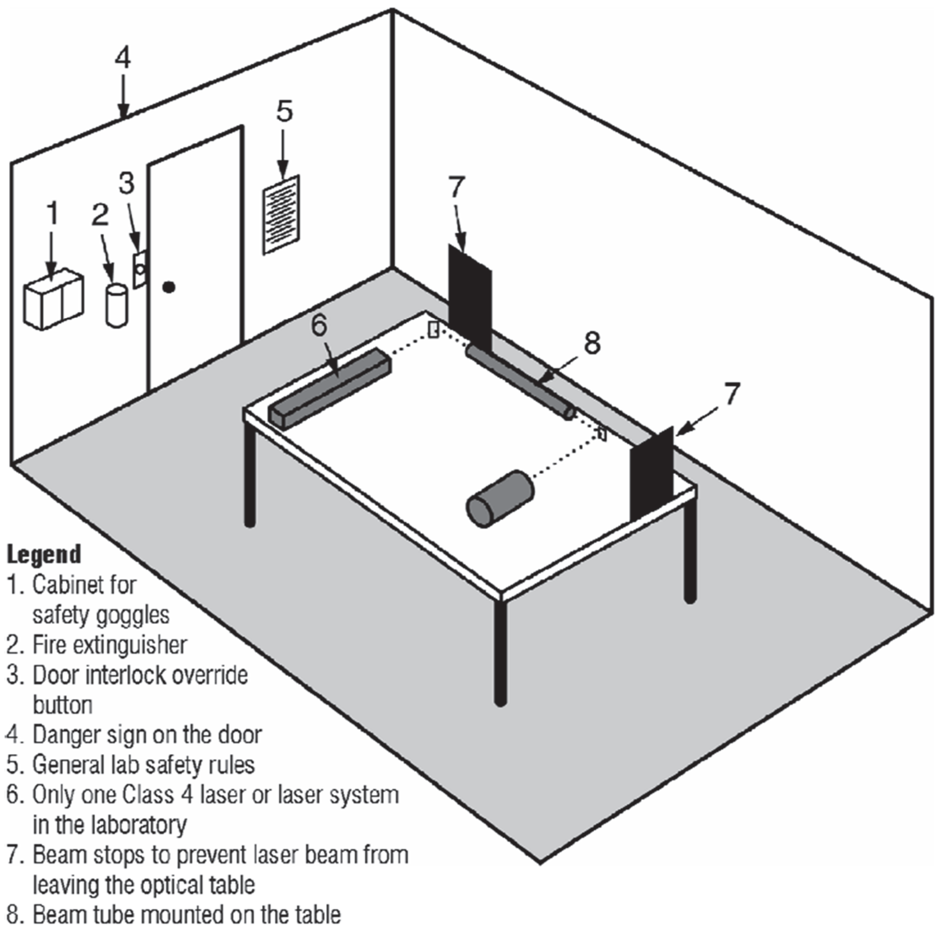

Figure 6 *Suggested Class 3B and Class 4 Laser Laboratory*
from ANSI Z136.5 Standard for the Safe Use of Lasers in Educational Institutions (Appendix H, p. 57).

Safety in the Laboratory

IHCC has prepared the following lists of laboratory rules and procedures.

Personal and General Laboratory Safety

Do not eat, drink, or smoke while working in the laboratory.

Read labels on instruments, supplies, and chemicals carefully.

Wear safety glasses or face shields when working with hazardous materials and/or equipment.

When handling dangerous substances, wear gloves, laboratory coats, and safety shield or glasses. Shorts and sandals should not be worn in the lab at any time.

If you have long hair or loose clothes, make sure it is tied back or confined.

Keep the work area clear of all materials except those needed for your work. Coats should be hung in the hall or placed in a locker. Extra books, purses, etc. should be kept away from equipment that requires air flow or ventilation to prevent overheating.

Disposal – Students are responsible for the proper disposal of used material, if any, in appropriate containers.

Equipment Failure – If a piece of equipment fails while being used, report it to your instructor or lab aide.

If you need to leave a lab unattended, turn off all ignition sources, lights and lock the doors.

Clean up your work area before leaving.

Electrical Safety

Obtain permission from your instructor or lab aide before operating high voltage equipment.

Maintain unobstructed access to all electrical panels.

Wiring changes or other electrical modifications must be requested through your instructor to the Maintenance Shop or the Building Coordinator.

Avoid using extension cords whenever possible. If you must use one, obtain a heavy- duty one that is electrically grounded, with its own fuse, and install it safely. Extension cords should not go under doors, across aisles, be hung from the ceiling, or plugged into other extension cords.

Do not modify, attach, or otherwise change any high voltage equipment.

Make sure all capacitors are discharged (using a grounded cable with an insulating handle) before touching high voltage leads or the "inside" of any equipment, even after it has been turned off. Capacitors can hold charge for many hours after the equipment has been turned off.

When you are adjusting any high voltage equipment or a laser which is powered with a high voltage supply, use only one hand. Your other hand is best placed in a pocket or behind your back. This procedure eliminates the possibility of an accident where high voltage current flows up one arm, through your chest, and down the other arm.

Mechanical Safety

When using compressed air, only use approved nozzles. Do not direct the air towards any person.

Protective guards on machinery must be in place when the machinery is in operation.

Exercise care when working with or near hydraulically- or pneumatically-driven equipment. Sudden or unexpected motion can inflict serious injury.

Chemical Safety

Treat all chemicals as if they are hazardous.

Make sure all chemicals are clearly and currently labeled with the substance name, concentration, date, and name of the individual responsible.

Do not return chemicals to reagent bottles. (Try for the correct amount and share any excess.)

Comply with fire regulations concerning storage quantities, types of approved containers and cabinets, proper labeling, etc. If uncertain about regulations, contact the building coordinator.

Use volatile and flammable compounds only in a fume hood. Procedures that produce aerosols should be performed in a hood to prevent inhalation of hazardous material.

Do not allow a solvent to come in contact with your skin. Use gloves.

Do not "smell a solvent." Read the label on the solvent bottle to identify its contents.

Dispose of waste and broken glassware in proper containers.

Clean up spills immediately.

Do not bring food in laboratories.

Laboratory Activities in Course 1: *Fundamentals of Light and Lasers*

The following lists the laboratory activities for Course 1 by module, lab number, and title and provides a brief description of each. **NOTE:** For High Schools using *Fundamentals of Light and Lasers*, there is a separate lab manual using less expensive alternative equipment to accomplish the same goals of the labs. The *High School Photonics Lab Manual* is available by request from the OP-TEC online store at www.optecstore.org.

Module 1-1: Nature and Properties of Light

1-1A: Finding the Speed of Red Light in Optical-Grade Plastic – Students experimentally determine the index of refraction for a plastic block and using this value calculate the speed of red light through the block using the definition of index of refraction.

1-1B: Determining the Wavelength of Red Light – Students calculate the wavelength of a red laser beam by passing it through a diffraction grating and calculating the diffraction angle then using the first-order diffraction angle to determine the wavelength of the red light.

1-1C: The Spectrum of Colored Light – Students use a diffraction grating to produce a color spectrum. They then use colored filters to determine the components of different colors of light.

1-1D: The Polarization of Light – Students explore polarized light using polarizing filters.

Module 1-2: Optical Handling and Positioning

1-2A: Familiarization with Optical Equipment and Components – Students familiarize themselves with optical equipment and components and create a purchase requisition for a new set of parts.

1-2B: Care and Cleaning of High Grade Optical Components – Students practice cleaning optical components using standard procedures.

1-2C: Building an Inexpensive Spectrometer – Students observe light spectra from fluorescent and incandescent light sources. They then calculate the photon energy of each of the estimated wavelengths.

Module 1-3: Light Sources and Laser Safety

1-3A: Irradiance – Students use an optical power meter to determine the power and irradiance of laser light. They will pass the beam through a diverging lens and prepare a graph of irradiance vs. distance from the lens.

1-3B: Laser Eye Protection Equipment – Students determine the optical density of the eye protection needed to safely use a specific laser and then use the internet to obtain pricing from at least two different vendors

1-3C: Windows and Mirrors – Students observe Fresnel reflection in an optical window, measure reflection and transmission coefficients of an optical window and measure and compare reflection and transmission coefficients of front and rear surface mirrors.

1-3D: Optical Filters – Students measure the power incident on and power transmitted through four different color filters and on filter sets. They will then calculate the transmission through the various filters and the optical density and absorption coefficient of each filter.

1-3E: Optical Photometer Use and Stability – Students learn about optical photometers their specs, and how to properly use them.

Module 1-4: Basic Geometrical Optics

1-4A: Prisms and Lenses – Students experiment with prisms and lenses to determine the index of refraction of the materials and to determine the focal lengths of convex and concave lenses.

1-4B: Optical Alignment Techniques – Students practice basic optical alignment techniques using an optical breadboard.

1-4C: Law of Reflection – Students investigate the law of reflection.

1-4D: Lenses – Students experimentally measure real images formed by converging lenses.

Module 1-5: Basic Physical Optics

1-5A Working with Diffraction Patterns, Wavelengths, and Polarization – Students carry out a quantitative mapping of the intensity variation across a Fraunhofer airy-defraction pattern, determine the wavelength of light by using a machinist's rule as a reflection grating, and convert randomly polarized light to polarized light by reflection at Brewster's angle.

1-5B: Interference and Diffraction – Students measure diffraction effects from a single slit and pinhole; experimentally measure the grove spacing of a diffraction grating and human hair; and experimentally measure the wavelength range of visible light.

1-5C: Polarization – Students investigate the Law of Malus and build a LCD display, a polariscope, and an optical isolator.

Module 1-6: Principles of Lasers

1-6A: Measurement of Beam Diameter and Beam Divergence – Students measure the beam diameter and beam divergence of a HeNe laser.

1-6B: Laser Basics – Students research lasers using the internet.

1-6C: HeNe Laser and High Voltage Testing – Students measure the operating efficiency of a HeNe laser.

Laboratory Activities in Course 2: *Laser Systems and Applications*

The laboratory activities in Course 2 are more complex and time consuming than those in Course 1; therefore only one lab is provided per module.

Module 2-1: Laser Q-Switching, Mode Locking, and Frequency Doubling

2-1: Diode Pumped Q-switched and Frequency Doubled Nd:YAG Laser Lab – Students set up, run, and characterize a diode laser pump and a diode pumped Nd:YAG laser , a diode pumped frequency doubled Nd:YAG laser, and a diode pumped Q-switched Nd:YAG laser.

Module 2-2: Laser Output Characteristics

2-2: Measuring Laser Output Characteristics – Students measure a variety of laser output characteristics including beam power, focused beam power, beam profile, divergence of a laser beam and divergence of a laser beam at a focal point.

Module 2-3: Laser Types and Their Applications

No lab is included in Module 2-3.

Module 2-4: Carbon Dioxide Lasers and Their Applications

2-4: Measuring Laser Output of a CO_2 Laser – Students measure the output power of continuous wave (CW) and pulsed CO_2 lasers.

Module 2-5: Fiber Lasers and Their Applications

2-5: Measurement of CW and Pulsed Output from a Fiber Laser – Students measure the output characteristics of CW and pulsed fiber laser systems including power, wavelength, mode (TEM), beam diameter at 2.54 cm from beam exit, divergence, power stability, energy, average and peak power, and pulse duration/width, pulse repetition rate, and pulse repetition time.

Module 2-6: Diode Lasers and Their Applications

2-6: Diode Laser Operations and Measurements – Students operate a diode laser and use a diode laser test station to measure critical laser parameters.

Module 2-7: Arogon-Ion Lasers and Their Applications

2-7: Argon-Ion Laser Operations and Measurements – Students operate an argon-ion laser and measure its critical parameters.

Module 2-8: Nd:YAG Lasers and Their Applications

2-8: Measurement of CW and Pulsed Output from a Nd:YAG – Students measure the output characteristics of CW and pulsed Nd:YAG laser systems including power, wavelength, mode (TEM), beam diameter at 2.54 cm from beam exit, divergence, power stability, energy, average and peak power, and pulse duration/width, pulse repetition rate, and pulse repetition time.

Module 2-9: Excimer Lasers and Their Applications

2-9: Measurement of Output from an Excimer Laser – Students operate an excimer laser and make measurements of pulse characteristics.

Module 2-10: Systems Integration in Photonics

2-10: Developing a Fiber-Optic Communication System – In this open-ended lab, students develop a fiber-optic communication that must include one LED or transistor transmitter, plastic fiber medium, and an opto-detector receiver.

Laboratory Videos

In addition to the materials in this section, there are videos of the laboratory activities available at http://optecvideo.opteccrm.org/. The videos are not intended to replace hands on activities, but rather to enhance them. The presenters demonstrate equipment, set-ups, procedures, and point out potential problem areas. These videos can be used to introduce students to the lab exercises before they try them for themselves.

Maintaining a Laboratory Notebook

All students studying *Fundamentals of Light and Lasers* and *Laser Systems and Applications* should be required to maintain a laboratory notebook to prepare them for future careers. Technicians in the workplace are required to document their work. Procedures may vary from company to company, but the need to document work is critical for many different reasons including patent filings, maintaining ISO or other certifications, to enable procedures to be duplicated at another time, or simply to pass information from technicians on one shift to another. The following is an example of the lab notebook requirements at Indian Hills Community College. Instructors should feel free to adapt these requirements to meet the needs of their situation. The last page assigns point values for each required part of a lab write-up so a grade can be assigned.

What Is a Lab Logbook? How Should It Be Used?

A logbook is a permanent record of data and notes about ideas, progress, results, or performance relating to a lab procedure. It is used in industry to keep a continuing record of activities prepared in chronological order as the lab activity is carried out. Keeping a logbook is not just a lab assignment; it is a required task for most technicians. Notes written on scraps of paper and then copied over into a logbook are not considered official data.

Properly kept logbooks serve several important purposes:

- Logbooks are used to retrieve information for writing a summary report or paper.
- Logbooks record the exact process used so an experiment can be repeated by the technician who created the entry, or by others.

- A logbook may provide data and material for patent filings. It can answer such questions as, “Is the data original, recorded, backed up with conclusions, and signed and dated?”
- Logbooks may also be used as evidence in legal proceedings.

Logbook Write-Up Requirements:

Each student is required to keep his/her own logbook of completed lab activities. The following are suggested guidelines instructors can adapt for use with their students.

Use all of your resources (texts, handouts, research materials, and so forth) to complete the beginning sections (1.0-6.0 below) of the lab write-up before beginning the lab and you will save a great deal of time.

Be prepared when you go to the laboratory and know what you will be doing, so that you do not waste time in the lab, or delay other students who need to use the same equipment while you are trying to figure out what to do. Think and plan ahead of time.

Keep your logbook current at all times. Failure to do so will result in a grade reduction.

All labs will be graded, based on the given point system, at the time of lab completion. Lab/table space will be assigned. A lab schedule will be issued.

Make sure your lab is signed off by your instructor before you disassemble the equipment.

Return all equipment to its proper place upon completion of lab.

Only use a pen to permanently record in a logbook. Use of a pencil is not acceptable.

Corrections are to be lined out neatly (one line only) and initialed.

All “Intentionally Left Blank” (ILB) areas are to be lined out, dated, and initialed.

Include a table of contents at the beginning of the logbook which has column headings that show: Lab #, Lab name, Page #, Lab grade, and Time to complete.

Previous procedures may be referred to when they are duplicated.

Use standard technical writing format as shown below.

Headings with Explanation:

1. Name of lab.
2. Person(s) involved in lab.
    - 2.1 Your name.
    - 2.2 Team member's name, spelled correctly.
3. Date and time in/out of lab.
    - 3.1 Does not include write-up time before lab set-up or after lab completion.
    - 3.2 Use table format shown below. NOTE: All tables are enclosed.

Date	Time In	Time Out	Total Time
		Grand Total	

4. Objective(s) (NOT THE PROCEDURE)
    - 4.1 Be very specific in stating the objective(s) of the lab.
    - 4.2 Use complete sentences.
5. References
    - 5.1 Include texts, handouts, people, etc.
        - 5.1.1 Informal material should be inserted into the back of the logbook.
        - 5.1.2 Keep this sheet, lab point sheet, lab instruction sheet, and any other appendixes you deem necessary secured at the end of the logbook.
6. Equipment table/list
    - 6.1 Be specific
    - 6.2 Make a table (see 3.0) to include the headings below

Qty	Item	Manufacturer	Model #	Serial #	Description	Location

        - 6.2.1 Set on page in landscape placement with top to the left.
    - 6.3 Include all equipment used, even those items not in the final set-up. (This is where pre-planning the lab and pre-writing the lab could be helpful.)
7. Procedure (NOT THE OBJECTIVE)
    - 7.1 List each step taken (right or wrong) to complete the lab. Incorrect steps will need addendums. Addendums should be referenced with circled numbers giving page numbers.

7.2 Use technical writing and avoid the use of personal pronouns such as I, we, they, their, them, you, and so forth.

7.3 Include enough detail that someone else can duplicate the lab and produce the same results.

7.4 All procedures should be written so that progress is clear, and a co-worker can continue the operation/project/lab in your absence.

7.5 Data, observations, results, and measurements must be referenced and specified where located.

NOTE: For sections 8.0 – 12.0, created items should be large and easily readable. Use full landscape placement for all drawings, diagrams, graphs, etc.

NOTE: 8.0 – 12.0 to be referenced (See 7.1) in the lab write-up procedure.

8. Drawings (such as layouts, figures, schematics)

8.1 Include a diagram of the lab set-up.

8.2 Include dimensions (in metric), labels, units, etc.

8.3 Do not make freehand drawings. Use drawing templates, software etc.

9. Equations, calculations, etc.

9.1 Enter each equation once.

9.2 Record every equation used.

9.3 Show one calculation per equation. All other calculations can be included in 13.0.

10. Data Table

10.1 All data (correct or incorrect) that is calculated, observed, collected, or analyzed, must be recorded in a data table.

11. Graphs, charts, plots, photos, drawings of results, observations, etc.

11.1 Describe and enhance data with graphs and charts.

11.2 Label axis and include a legend.

12. Analysis of data, conclusions, observations, results, recommendations. This section includes the interpretation of data and describes what was learned.

12.1 Compare discovered data to known data.

12.1.1 Describe what you learned from the data taken?

12.1.2 Explain variances between measured and known/given data.

12.2 Recommend actions to be taken and why.

12.3 Do not write statements such as “objective was met,” “due to human error” (this can be overcome), I, We, They, “there wasn’t enough time,” “this lab was really easy,” etc.

13. Notes and Scribbles.

13.1 Allow two (2) blank pages at end of each lab for making calculations, making notes to yourself etc. If any of these pages are not used, mark ILB (intentionally left blank), date, and initial.

Lab/Logbook Criteria for Accumulating Points

		Points	
Logbook up to date, subject to a random check.		0 – 5	
			Total: 5
Equipment/component Set-up:			
	Securely mounted:	0 – 2	
	Safety:	0 - 2	
	Properly used equipment:	0 - 1	
			Total: 5
Objective(s) met at equipment set-up:			
	Objective(s) met per parameters/specifications	0 - 5	
			Total: 5
Lab write-up/Logbook entry:			
	Sentence composition, grammar, and spelling will be graded:	0 - 6	
1.0	Name of lab:	0 – 1	
2.0	Person(s) involved:	0 – 1	
3.0	Date, Time In/Time out:	0 – 1	
4.0	Objective:	0 – 10	
5.0	References:	0 – 1	
6.0	Equipment List:	0 – 10	
7.0	Procedure:	0 – 10	
8.0	Diagrams, layouts, etc:	0 – 10	
9.0	Equations/Calculations:	0 – 5	
10.0	Data Tables:	0 – 10	
11.0	Graphs, charts, etc:	0 – 10	
12.0	Analysis:	0 - 10	
			Total: 85
			Grand Total: Labs – 100

Laboratory Equipment and Vendor Information

This section includes equipment lists for the labs in Course 1 (postsecondary and secondary) and Course 2. After the equipment lists is a list of vendors who can supply the equipment for Course 2 laboratory activities. It includes vendor contact information, a list of items that are available, as well as information on pricing and discounts as available. For the most up-to-date information on equipment pricing and discounts, visit the OP-TEC website.

Course 1 College Equipment List (Optical Breadboard Arrangement)

(one work station, Course 1)*

Equipment Description	Qty	Unit Cost*	Total Cost	Vendor	Part/Model #
Optics Cleaning Kit	1	25.00	25.00	Orion Telescopes	05825
Diffraction Grating Package, 300-800 lines/mm, 2×2", 25 ea.	1	25.50	25.50	Edmund Optics	39-502
Color Filters Kit; red, green, blue, cyan, magenta, yellow; 8×10" ea.	1	12.00	12.00	Arbor Scientific	33-0190
7 Piece Glass Prism and Lens Set	1	59.95	59.95	Scientifics Direct	3052107
Smoked Acrylic Block Lens Set, 4pcs.	1	99.00	99.00	Arbor Scientific	P2-7009
Deluxe Green Laser Pointer	2	75.00	150.00	Arbor Scientific	P2-7675
Polarizing Filters Package, 35mm, 50 ea.	1	35.00	35.00	Arbor Scientific	P2-9405
Support Stand, 6×11" base, 36×½" rod	1	22.70	22.70	Carolina	70-7167
Buret Clamp, accommodates ½" rod	2	11.35	22.70	Carolina	70-7362
Straight Forceps	1	9.60	9.60	Carolina	625330
Spectrometer	1	47.90	47.90	Sargent-Welch	470003-848
Neutral-density filter D= 2.0 (1% transmission)	1	47.50	47.50	Edmund Optics	NT30-938
Spherometer Kit**	1	325.00	325.00	Edmund Optics	A53-859
Photoelectric power meter	1	250.00	250.00	Edmund Optics	NT54-038
Maglite 2AA NBCF Mini Maglite	1	9.99	9.99	Home Depot	M2AMW6
Red Laser Diode Class II-A	2	24.25	48.50	Carolina	755432
Linear Stage	1	255.00	255.00	Newport	423
Optics Kits	1	7,355.00	7,355.00	Newport	OEK-STD
SM Sries Vernier Micrometer	1	117.00	117.00	Newport	SM-25
Prism Set	1	45.35	45.35	Carolina	754930
Microscope Slide, glass, 3×1", 1-1.2mm thick, 72 ea.	1	7.90	7.90	Sargent-Welch	470016-270
Meter Stick, wood	1	5.20	5.20	Sargent-Welch	470017-044
Front/Rear Surface Mirror	1	19.00	19.00	Newport	10SJ00ER.3
Lab Jack	2	98.88	197.76	Sargent-Welch	470123-538
SUPPLIES					
Protractor					
Screen, white cardboard					
Index cards					
Paper, 11×17"					
Masking tape					
Razorblade					
Incandescent light bulb and lamp					
General purpose finger cots (or gloves)				Finger Cots	
TOTAL: **$9,192.55**					

VENDORS			
1	Orion Telescopes and Binoculars (www.telescope.com)	5	Carolina Biological Supply Company (www.carolina.com)
2	Edmund Industrial Optics (www.edmundoptics.com)	6	Newport (www.newport.com)
3	Arbor Scientific (www.arborsci.com)	7	Sargent-Welch (www.sargentwelch.com)
4	Scientifics Directs (www.scientificsonline.com)	8	Finger Cots (www.fingercots.net)

*Prices as of February 2018 **Optional

Course 1 High School Equipment List

High School Equipment List for Course 1 (reduced cost), a modified lab manual has been produced to reduce the cost of equipment for schools. The list of the equipment below is needed for one lab station.

(One work station, *Fundamentals of Light and Lasers* course using high school lab manual)

Equip List Ref #	Quantity	P/N	Item	Vendor	Price	Total
1	1	MB1218	Base Plate	Thorlabs	$188.00	$188.00
2	2	1323155	Energizer LED Pen Flashlight	Frey Scientific	$10.69	$21.38
3	2	1400712	Frey Scientific Laser Pointer, 1.2 cm Dia X 14.5 cm L, Red	Frey Scientific	$12.99	$25.98
4	2	VB-1	76.2 mm V-Block Mount	Newport	$39.00	$78.00
5	2	M33-501	1" Mounted First Surface Mirrors	Edmund Optics	$60.00	$120.00
6	5	M58-961	1.5" Post	Edmund Optics	$10.00	$50.00
7	5	M58-977	1.5" Post Holder	Edmund Optics	$13.25	$66.25
8	1	M54-038	Industrial Fiber Optics Digital Photometer	Edmund Optics	$250.00	$250.00
9	1	110-6156	Delta Education Glass Demonstration Lens Set - 38 mm Diameter Lens - Set of 6	Frey Scientific	$9.19	$9.19
10	3	LMR1	1" Fixed Lens Mount	Thorlabs	$15.23	$45.69
11	3	BA2	Mounting Base	Thorlabs	$7.30	$21.90
12	2	88-084	Left-Handed Circular Polarizing Film	Edmund Optics	$11.00	$22.00
13	2	DH1	Dual Filter Holder	Thorlabs	$15.30	$30.60
14	1	33-0175	Primary/Secondary Color Sheets	Arbor Scientific	$2.50	$2.50
15	1	01_3900	Metric Ruler	Arbor Scientific	$10.00	$10.00
16	1	P2-7009	Smoked Acrylic Block Lens Set	Arbor Scientific	$99.00	$99.00
17	2	33-0990	Diffraction Grating	Arbor Scientific	$3.50	$7.00
18	2	07-3051	Microslides 72/pk	Arbor Scientific	$6.00	$12.00
19	2	10SJ00ER.3	Broadband Metallic Mirror, 25.4 mm Square	Newport	$19.00	$38.00
20	1	P2-7061	Quantitative Spectroscope	Arbor Scientific	$10.00	$10.00
21	2	P2-7015	Lens and Prism Acrylic Set	Arbor Scientific	$45.00	$90.00
22	1	43-5248-000	Precision Pinhole 25mm Mount, 25um	Ealing Catalog	$49.00	$49.00
23	1	S100R	Mounted Slit 100um	Thorlabs	$95.75	$95.75
24	1	RP01	Rotational Platform	Thorlabs	$95.63	$95.63
25	2	KM100	Kinematic Mirror Mount	Thorlabs	$38.70	$77.40
26	2	ME1-G01	25.4 mm Round Protected Aluminum Mirror	Thorlabs	$13.97	$27.94
27	1	591720	Lens Cleaning Kit	Carolina Biological Supply	$15.50	$15.50
28	1	470156-704	Plastic Forceps	Ward's Science	$5.95	$5.95
				Total		**$1,564.66**
Supplies or Incidental Equipment List						
29	1	N/A	8.5" × 14" White Paper	N/A		
30	1	N/A	Roll of Masking Tape	N/A		
31	1	N/A	Protractor	N/A		
32	1	N/A	Pencil	N/A		
33	1	N/A	Set of Colored Pencils	N/A		
34		N/A	Books	N/A		
35	1	N/A	Silly Putty or Equivalent	N/A		
36	1	N/A	Index Cards	N/A		

Course 2 Laboratory Equipment List

EQUIPMENT DESCRIPTION	QTY	VENDOR	STOCK NUMBER	LAB 2-1	LAB 2-2	LAB 2-3	LAB 2-4	LAB 2-5	LAB 2-6	LAB 2-7	LAB 2-8	LAB 2-9
ElectroViewer - IR Viewer	1	Cascade Laser Corp.	SOF914644	X				X			X	
1000:1 Optical Attentuator	1	Coherent	1098318	X	X			X		X		
High-Sensitivity Optical Sensor OP-2 VIS Sensor	1	Coherent	1098313	X	X			X		X	X	
LabMax-TO Laser Power/Energy Meter	1	Coherent	1104619				X			X	X	X
PM30 TOP (RoHs) Detector	1	Coherent	1098314				X				X	X
ExciStar XS 200	1	Coherent										X
Carbon Dioxide Laser	1	Coherent	Diamond C-20				X					
Beam Imaging Camera, 190-1350 nm	1	DataRay Inc.	WCD-XHR					X	X	X	X	
Wedge Beamsplitter 3-10%	1	DataRay Inc.	CUB					X	X	X		
Argon-Ion Laser, 150mW; Selectable Multi-line	1	Edmund Optics	58-453							X		
Ytterbium Single-mode CW Lasers, 10 W	1	IPG Photonics	YLR-10-AC					X				
Nd:YAG Laser	1	e-LAS Americas	CA-1230	X							X	
Frequency Doubling Crystal	1	e-LAS Americas	CA-1231	X								
Active Q-switch	1	e-LAS Americas	CA-1232	X								
High Speed Photodetrctor, 1.5GHz	1	Newport Corporation	818-BB-20					X				X
Laser Diode	1	Newport Corporation	HL6320G T09						X			
Red Tide Spectrometer, 350-1000 nm	1	Ocean Optics	USB-650						X	X		
UV-VIS Collimating Lens, 200-2000 nm	1	Ocean Optics	84-UV-25							X		
Lab-grade Bifurcated Fibers, 200 micron	1	Ocean Optics	BIF200-VIS-NIR							X		
ESD Benchtop Grounding Mat	1	Digi-Key Electronics	16-1206-ND						X			
Oscilloscope*	1	use available item		X			X	X			X	X
Computer**	1	use available item						X	X	X	X	

SAFETY EYEWEAR				LAB 2-1	LAB 2-2	LAB 2-3	LAB 2-4	LAB 2-5	LAB 2-6	LAB 2-7	LAB 2-8	LAB 2-9
Laser Safety Glasses	2	Laser Safety Industries	100-10-125	X								
Laser Safety Glasses	2	Laser Safety Industries	100-38-115		X				X			
Laser Safety Glasses	2	Laser Safety Industries	100-50-101				X					
Laser Safety Glasses	2	Laser Safety Industries	100-38-120					X				
Laser Safety Glasses	2	Laser Safety Industries	100-10-110							X		
Laser Safety Glasses	2	Laser Safety Industries	100-10-125								X	
Laser Safety Glasses	2	Laser Safety Industries	100-50-101									X

*Recommended Oscilloscope should include the a minimum of:

- 200 MHz Bandwidth
- 2 to 4 Channel Models
- Up to 1GS/s Sample rate
- 2.5k Point Record Length/Channel
- Advanced Triggers

**Recommended Computer should include the minimum of:

- 2 GHz Processor
- 2 MB of Cache
- 8 GB RAM
- 500 GB Hard Drive
- 10/100 Ethernet
- USB Port
- 64-bit Processor

Laser and Optical Equipment Suppliers

Cascade Laser Corp
101 N. Elliot Rd.
Newberg, Oregon 97132
www.cascadelaser.com
Tel.: 503-554-1926 phone
Toll Free: 800-443-5561 phone
info@cascadelaser.com

Qty	P/N	Description	Unit Price
1	SOF914644	Handheld IR viewer	$1,690

Coherent Inc.
5100 Patrick Henry Drive
Santa Clara, CA 95054
www.coherent.com
Tel.: 408-764-4000
Toll Free: 800-227-4800
tech.sales@coherent.com

Qty	P/N	Description	Unit Price
1	1098318	1000:1 Attenuator (RoHs)	--*
1	1098313	OP-2VIS Semiconductor Sensor (RoHs)	--*
1	1104619	LabMax – TO laser power meter (RoHs)	--*
1	1098314	PM30 TOP (RoHs) Detector	--*
1	--	ExciStar XS 200 157 nm	--*
1	--	Diamond E-1000 (CO2 laser)	--*

DataRay Inc
1675 Market Street
Redding, CA 96001
www.dataray.com
Tel.: 530-776-0843
Toll Free: 866-946-2263
sales@dataray.com

Qty	P/N	Description	Unit Price
1	CUB	Wedge Beamsplitter	$660
1	WCD-XHR	WinCamD-XHR – ½" CMOS System	$2,750

Digi-Key Electronics
701 Brooks Avenue South
PO Box 677
Thief River Falls, MN 56701-0677
Tel 218-681-6674
Toll Free: 1-800-344-4539
sales@digikey.com
www.digikey.com

Qty	P/N	Description	Unit Price
1	16-1206-ND	ESD Benchtop Grounding Mat	$98.39

Edmund Optics/America
101 East Gloucester Pike
Barrington, NJ 08007
www.edmundoptics.com
Tel.:856-547-3488
Toll Free: 800-363-1992
techsup@edmundoptics.com

Qty	P/N	Description	Unit Price
1	58-453	Multi-Line 150m W, Argon-Ion Laser	$9,990

e-Las Americas
14271 Jeffrey Road, Suite 432
Irvine, CA 92620
949-573-3901 phone
info@elas.net

Qty	P/N	Description	Unit Price
1	CA-1230	Nd:YAG laser education kit	$14,124
1	CA-1231	Nd:YAG laser option for frequency doubling	$4,705
1	CA-1232	Nd:YAG laser option for active Q-switch	$7,196

IPG Photonics
50 Old Webster Road
Oxford, MA 01540
www.ipgphotonics.com
Tel.:508-373-1100
Toll Free: 877-980-1150
support@ipgphotonics.com

Qty	P/N	Description	Unit Price
1	YLR-100-AC	Ytterbium Single-mode CW Laser	-

Newport Corporation

1791 Deere Avenue
Irvine CA 92606
www.newport.com
Tel.: 949-863-3144
Toll Free: 877-835-9620

Qty	P/N	Description	Unit Price
1	818-BB-20	High speed photodetector, 1.5GHz	$396
1	HL6320G-TO9	Laser Diode	$101

Ocean Optics

8060 Bryan Dairy Road
Largo, FL 33777
www.oceanoptics.com
Dunedin, FL 34698
Tel.: 727-733-2447

Qty	P/N	Description	Unit Price
1	USB-650	Red Tide spectrometer, preconfigured	--*
1	Oceanview	Software with graphical user interface; 1 license (2 installations)	--*
1	BIF200-VIS-NIR	Lab-grade Bifurcated Fibers, 200 micron	--*
1	84-UV-25	UV/VIS Collimating Lens, 200-2000 nm	--*

--* Contact company for pricing information