Laboratory Emphasis in Interdisciplinary Photonics Related Courses

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Abstract

The facilities of an undergraduate optics teaching laboratory that were developed with National Science Foundation support have been incorporated in a sequence of courses in optics, lasers, photonics and optical signal transmission. Students with majors in physics and engineering have learned professional optics techniques and obtained hands-on experience in a well-equipped optics teaching laboratory. We will share lessons learned over the past eight years of developing and teaching these laboratory intensive courses.

Introduction

The primary objective of the National Science Foundation (NSF) optics education project at North Dakota State University was the development of an undergraduate optics laboratory to serve the needs of a general optics course (Physics/ECE 411/611) that is the joint responsibility of the Departments of Physics and Electrical and Computer Engineering. This course includes ten experiments in a lab that was established with the support of NSF and adapted from work done at New Jersey Institute of Technology [1]. The course, Physics/ECE 411/611, Optics for Scientists and Engineers, was introduced in Fall Semester, 2001 and has been offered during most subsequent fall semesters. The primary goal of this course is to provide students with the fundamentals necessary to enable them to successfully apply optics in their respective majors. This is accomplished through hands-on use of research grade equipment to experience and understand the most important concepts and phenomena of optics (including fiber optics). The course is open to undergraduate and graduate students in engineering and science who have completed calculus-based university physics.

The now well-established optics course has become the base course for interdisciplinary optics options for undergraduate majors in the ECE and Physics Departments: the Optical Engineering Option in Electrical Engineering and the Optical Science and Engineering Option in Physics. These courses also have a first-year graduate student option for graduate students in any science and engineering discipline that did not have the equivalent optics training as undergraduates. The NDSU photonics sequence now includes: Physics/ECE 411 Optics for Scientists and Engineers, Physics 413 Lasers for Scientists and Engineers, Physics 415 Elements of Photonics and ECE 417 Optical Signal Transmission.

NDSU optics sequence with embedded laboratories

Physics/ECE 411 Optics for Scientists and Engineers

The optics base consists of a 3 semester-credit-hour lecture course and a co-requisite 1 semester-credit-hour course. Lectures are based on Eugene Hecht's *Optics* to provide the background required for performing the experiments. The laboratories are scheduled in three-hour blocks. Students are paired to maximize their hands-on experience. A graduate student teaching assistant is present in the laboratory for all the groups. Our optics course was implemented by adapting successful laboratory experiments developed under NSF funding, at the New Jersey Institute of Technology, and through commercially available fiber optics kits from Newport Corporation. The labs were selected and are continuously revised to support important concepts covered in the lecture course. The ten labs are:

Lab 1. Detection of light

Lab 2. Absorption

Lab 3. Index of refraction, total internal reflection, and critical angle

Lab 4. Lenses and simple lens systems

Lab 5. Preparing optical fibers and fiber optic numerical aperture

Lab 6. Fiber optic light attenuation

Lab 7. Single-mode fibers

Lab 8. Optical polarization

Lab 9. Interference and diffraction

Lab 10. Spectrometry

A major optics experiment is selected by groups of three to four students for the last four-week project. During this period, students devote both lecture and laboratory course time to their project. Each group presents their results in class during the last week and writes a research paper on their experiment

In general the course has awakened an interest in optics among engineering and science majors. The course is limited to 24 students per semester due to the emphasis on hands-on work (three sections of eight students, two per optical table).

ECE 417 Optical signal transmission

The undergraduate optics teaching lab was first employed in NDSU's optical signal transmission course (ECE 417/617) in 2003. The lecture portion of this course is based on Gerd Keiser's *Optical Fiber Communications* [1] and includes topics such as basic electromagnetics, propagation of light in cylindrical dielectric structures, solid-state sources, and photodetectors. It culminates with a study of

digital signal transmission over optical fibers. It serves undergraduates and beginning graduate students in electrical engineering, computer engineering, and physics.

Three experiments adapted from a Newport fiber optics kit [2] are useful to ECE 417/617: measurement of numerical aperture, use of the cutback method to measure optical fiber attenuation, and observation of linearly polarized (LP) modes in a four-mode fiber. The lab is outfitted with enough components so that all four laboratory stations have sufficient material to allow four student groups to do their experiments independently. Physics/ECE 411/611 is not a prerequisite for 417/617. In 417/617 the study of optics itself is confined to what is necessary for comprehending optical communication.

The ECE 417/617 lectures are more meaningful when related to the experimental or "hands-on" work done by each student. The numerical aperture experiment helps the student understand the light-gathering capability of a fiber. Attenuation measurements clearly show the impact of a loss of several dB of optical power. The single-mode fiber experiment allows the student to become familiar with a technology that is in common use in telecommunications. An optional lab involving audio transmission over fiber can be done at a pre-college level, but it certainly can be approached from a more comprehensive senior or graduate perspective in 417/617. Another optional experiment involving polarization-preserving fibers makes use of techniques that are useful in building optical communication lab skills.

The NSF-funded lab for undergraduate optics education gives students a chance to develop a professional competency in optical techniques for optical communications. The faculty involved have found this to be a rewarding teaching experience.

[1] Keiser, G., *Optical Fiber Communications*. New York: McGraw-Hill, 2000.

[2] Newport Corporation Web site: http://www.newport.com.

Physics 413 Lasers for Scientists and Engineers

This undergraduate/first year graduate level course with minimum course prerequisites (University Physics II, electricity and magnetism) was originally offered as a two semester-credit-hour summer course centered around laboratory experiments using the optics teaching laboratory. Student feedback has resulted in offering it as a three semester-credit-hour course with the laboratory experiments embedded. Lectures are based on the text *Fundamentals of Photonics, 2nd ed.*, by Saleh and Teich to provide the background required for performing the experiments. The laboratories are scheduled in three-hour blocks and each laboratory replaces one lecture period. Students are paired to maximize their hands-on experience. The topics covered include optical resonators, Fabry-Perot interferometers, Gaussian beams, spontaneous and stimulated transitions (Einstein coefficients), line-broadening, gain of an optical frequency amplifier, gain saturation, theory of laser oscillation, rate equations, transverse modes, and characteristics of common lasers. The laser labs include:

Lab 1 Setting up an open cavity HeNe laser

Lab 2 Characterization of open cavity HeNe laser

Lab 3 Gaussian optics with beam profiler

Lab 4 Expanding laser beams, diffraction of circular apertures

Lab 5 Spectral characterization of light sources

Lab 6 Scanning Fabry-Perot interferometer

Lab 7 Laser diode/LED characteristics

Physics 415 Elements of Photonics

This undergraduate/first year graduate level course has evolved from an optical electronics course and we are in the process of developing and embedding laboratory experiments. The goals of this course are to introduce selected principles of photonics including the polarization states of optical waves, physical origin of optical nonlinearities and applications to optical second harmonic and parametric generation and the electro-optic modulation of laser beams. In the future, lectures will also be based on the text *Fundamentals of Photonics, 2nd ed.*, by Saleh and Teich used for the laser course.

Lessons Learned

- A well equipped optics teaching lab can benefit multiple courses
- Experiences in this lab are significantly different than those obtained in many common computer-oriented or circuits-oriented labs.
- Students develop skills that are radically different from those obtained in other labs.
- The lab allows students to visually experience abstract concepts in optics.
- The major experiments encourage the students to be creative and resourceful.
- The courses and student projects are occasions for fruitful collaborations across disciplines.