Efficient Optoelectronics Teaching In Undergraduate Engineering Curriculum

M. A. Matin
University of Denver

Abstract

The Engineering Department's vision for undergraduate education for the next century is to develop a set of laboratory experiences that are thoughtfully sequenced and integrated to promote the full development of students in all courses. Optoelectronics is one of the most important and most demanding courses in Electrical and Computer Engineering. Therefore, an effective teaching initiative is needed in the undergraduate curriculum. For traditional teaching methods, most teachers preside over lecture sessions focusing on the various types of optoelectronics devices such as LEDs, LASERs, photodiodes, and passive devices. This material traditionally focuses on the devices' fabrication, physical properties and characteristics. It is also necessary to quantitatively assess the quality, performance and characteristics of devices. Often students develop little conceptual understanding of the devices and many misconceptions. In the teaching method proposed, student will perform various experiments to better understand the subject and augment their understanding of the theoretical aspects of optoelectronics.

IndexTerms—LASERs, LEDs, Optoelectronics, Traditional teaching methods, Undergraduate education.

I. INTRODUCTION

Optoelectronics typically refers to devices and systems that are essentially electronic in nature, but involve light such as light-emitting diodes, photodetectors and lasers. These devices are becoming increasingly important in the engineering world and consequently drive instructors to improve upon their teaching to adequately address this multidisciplinary topic. Technologies involving high-speed data transmission rely on optoelectronic sources and detectors as well as waveguides. The push toward optical computing will require electrical engineers to understand the interaction of light with materials, modulation of light, optoelectronic integrated circuits, and integrated optics [1]. Engineers outside the field of optoelectronics will need to understand optical fibers, optical properties of materials and optical devices such as lasers, detectors, sensors, LEDs etc. Hence, there is a critical need in industry for graduates to be exposed to more photonics topics in the undergraduate curriculum [1]-[4]. Students at the Georgia Institute of Technology enter the design course, "An Optical Communication Design Laboratory", with a background consisting of lecture and structured laboratories in fiber communications [5]. In our proposed method, the development of the material will be presented using a series of experiments focusing on significant device parameters that will be measured. The student will determine how well a device is performing [6]. For example, a laboratory involving laser diode characterization can be broken down into five categories, electrical, spatial, spectral, optical and dynamic characterization [7]. The integration of the laboratory with the lectures, focusing on the theoretical aspects of the devices combined with the characterization of real devices will form the basis of an effective learning strategy to integrate a higher level of optoelectronics in the engineering curriculum. This article focuses on the laboratories that would be used to augment and develop a meaningful understanding of a laser diode.

II. EXPERIMENTS OUTLINE

Students will study the optoelectronics device properties and characteristics of operation. The laboratories described here investigate the characteristics of a laser diode. The students will perform a series of experiments and compare the results with concurrent theoretical studies. The experiments will investigate the following aspects of the laser diode: Input current versus output intensity, threshold current density, slope of the LI curve, the Internal Quantum Efficiency, the Cavity Dependence of the Threshold Current Density, Transparency Threshold Current Density, Internal Loss, Temperature Characteristics, Spectrum and Peak Wavelength Emission, Temperature Dependant Wavelength Shifts and Mode Hopping. The development of the theoretical basis for such devices presented within the framework of the student's actual measurements will foster a deeper understanding of the device's capabilities and limitations. For example, the first experiment EXP 1, involving the laser diode measures "current versus light". This is perhaps the most important characteristic of a laser diode and is simply a measurement of the amount of light the diode emits as a function of the current injected into the device.

EXP1: "Current versus Light Measurement"

One of the most important characteristics of a laser diode is the amount of light it emits for a given device current. The measurement of the light output of a laser diode as a function of the device current results in the Output light versus Input Current curve more commonly referred as a L.I. curve, as shown in Figure 1. Several important features of the laser diode's operational characteristics are easily seen in Figure 1. As the injected current is increased, the laser first demonstrates spontaneous emission, which increases very gradually. At a threshold current (I_{th}), the device begins to emit stimulated radiation: this is the laser action that students will be able to visualize. The first parameter of interest is the exact value of the threshold current. The threshold current is one measure used to quantify the performance of laser diodes.

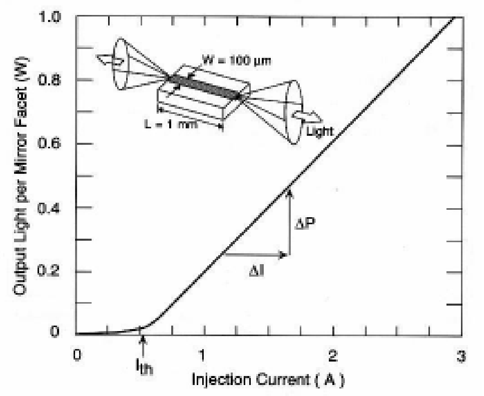

FIGURE 1

A TYPICAL LIGHT VS. CURRENT (L.I.) CURVE ASSOCIATED WITH HIGH POWER LASER. I_{TH} REPRESENTS THE THRESHOLD CURRENT AT WHICH THE DEVICE BEGINS TO LASE. THE EFFICIENCY OF THE LASER IN CONVERTING ELECTRICAL POWER TO LIGHT POWER IS DETERMINED BY THE SLOPE OF THE L.I. CURVE, DENOTED BY THE CHANGE IN OUTPUT POWER OVER THE CHANGE IN CURRENT (ΔP/ΔI). THE INSET SCHEMATICALLY SHOWS A BROAD AREA (100 µM WIDE STRIPE AND 1 MM LONG) LASER DIODE EMITTING RADIATION FROM BOTH ITS FRONT AND BACK MIRROR FACETS [6].

The threshold current generally depends upon the quality of the semiconductor material from which the device was fabricated and on the general design of the waveguide structure. However, the threshold current also depends upon the size and the cross-sectional area of the laser device. One laser diode could demonstrate a much higher threshold current than another device and yet be considered a much better laser, because the cross sectional areas of the devices differ. It is more appropriate to refer to threshold current density (J_{th}) rather than threshold current (I_{th}). Threshold current density is determined by dividing the experimentally obtained threshold current by the cross sectional area of the laser.

It is desirable to reach laser action in a given device at a low threshold current, and to generate the most light out of the device with the minimum current. A laser diode, which has a good conversion rate of input electric power to output light power, is obviously a device that performs well. A direct measure of the ability of the device to do this is the slope of the LI curve, above the threshold current point. This slope is denoted as ΔP/ΔI (shown in Figure 1) and has the units of Watts per Amperes (W/A) or mW/A for a low power lasers.

The students will measure the LI curve in the laboratory and determine both I_{th} and the slope of the LI curve. From these measurements, they will also determine the External Differential Quantum Efficiency (η_d) parameter. This parameter is a measure of the efficiency of a laser device in converting injected electron hole pairs (input electric charges) into photons emitted from the device (output light). Students will be able to determine the External Differential Quantum Efficiency value of real laser diodes by measuring the slopes of their L.I. curves, (ΔP/ΔI), above the threshold current.

EXP2 "Spectrum and Peak Wavelength Measurement":

The optical spectrum of laser diodes depends on the particular characteristics of the laser's optical cavity. Most conventional gain guided or index guided devices have a spectrum with multiple peaks similar to that shown in Figure 2.

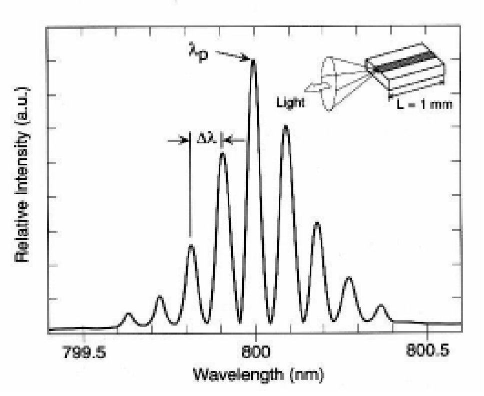

FIGURE 2

A TYPICAL SPECTRUM OF A 1 MM CAVITY LENGTH LASER DIODE OPERATING JUST ABOVE THRESHOLD. THE PEAK WAVELENGTH OF EMISSION (λP) IS AT 800 NM. THE SEPARATION BETWEEN ADJACENT PEAKS (Δλ) IS ABOUT 0.09 NM [6].

The number of spectral lines which a laser is capable of supporting, is a function of the cavity structure and the operating current. In general, most multimode laser diodes exhibit spectral outputs having many emission peaks around their center wavelength. The optical waves propagating in the laser cavity form standing waves between the two mirror facets of the laser. The wavelength of these standing waves is determined by the distance L between the two mirrors and the index of refraction of the material (Figure 2). In this experiment, the students will estimate the length of the laser cavity. The students will also compare the spectral behaviors of multi-mode and single mode lasers at various output power levels (Figure 3).

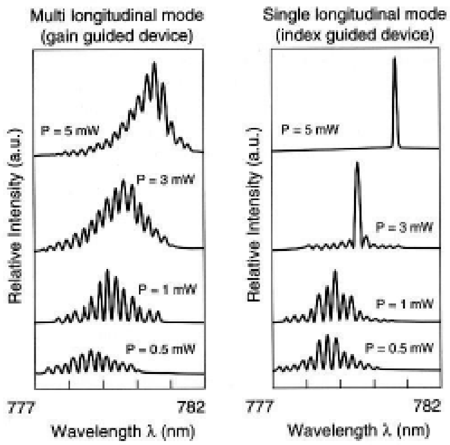

FIGURE 3

EFFECT OF INCREASING OPERATING CURRENT (AND POWER) LEVEL ON THE OUTPUT SPECTRA OF MULTIMODE GAIN GUIDED DEVICE AND SINGLE MODE INDEX GUIDED DEVICE [6].

EXP3 "Temperature Effect in Peak Wavelength of Emission":

The center wavelength of a laser diode is directly proportional to its operating temperature. This relationship is shown in Figure 4. As the device temperature is increased, the center wavelength also increases. This characteristic can be both useful and problematic. For example, in spectroscopic applications, the temperature of the device can be used to tune the output wavelength. Conversely, if a constant wavelength source is required for an application, the temperature of the laser diode may need to be very carefully controlled. The laser diode can be accurately temperature tuned to the specific properties of the material with which the laser diode is interacting.

This experiment will require the student to measure the center wavelength of the laser diode as a function of temperature in order to investigate its sensitivity, compare the results to thermodynamic parameters of the device and characterize its usefulness for various applications

EXP4 "Characteristic Temperature":

In most applications the ability of the laser diode to perform well at elevated temperatures is of great interest. This is especially of concern in the case of high power-laser diodes, where the amount of heat generated causes the device temperature to rise significantly. As a result, it is of utmost importance for the semiconductor crystal to be robust enough so as not to degrade due high temperatures effects. The characteristic temperature of the laser diode is denoted by T_0, and it is a measure of the temperature sensitivity of the device. Higher values of T0 imply that the threshold current density and the External Differential Quantum Efficiency of the device increase less rapidly with increasing temperatures. In order to measure the characteristic temperature of a laser diode, it is necessary to experimentally measure the L-I curve of a laser at various temperatures as shown in Figure 5. The results are then tabulated and the T_0 determined.

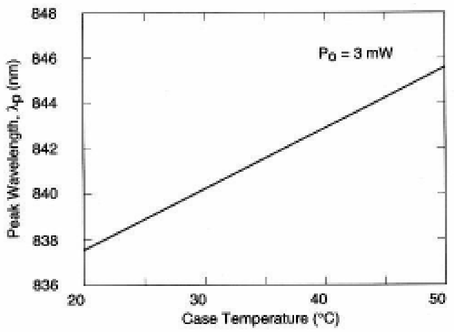

FIGURE 4

EFFECTS OF TEMPERATURE ON CENTER WAVELENGTH [6].

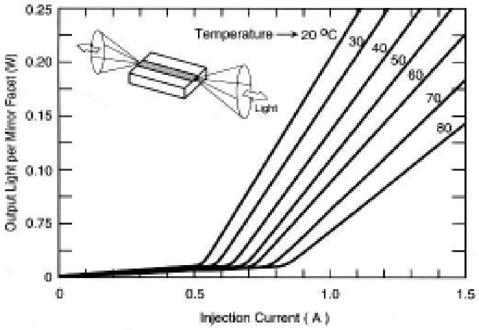

FIGURE 5

LIGHT VS. CURRENT CHARACTERISTIC CURVES FOR A LASER DIODE OPERATING AT VARIOUS TEMPERATURES [6].

With these experiments, students will also be able to observe the Mode hopping, dynamic resistance of the lasers, and also be able to calculate the internal quantum efficiency and internal loss of lasers. This experience will give the students a solid foundation for further studies and research in the optical communication area.

In this optoelectronics course the students will have the opportunity to investigate other optical devices such as Photodiodes, Phototransistor, Photoconductivity and photocells that were developed under the NSF funded project [8].

III. SUMMARY AND CONCLUSIONS

The proposed method will address the optoelectronics course by incorporating modern technology and various learning approaches in undergraduate engineering education. It described the development of an efficient optoelectronics course with the addition of a substantial number of laboratory experiments. This course will also utilize non-traditional pedagogical approaches to help capture the genuine interest and excitement of optoelectronic devices. It will also provide a means for introducing modern equipment such as Spectrum Analyzer, Laser Driver, Temperature Controller and technology into the undergraduate curriculum. A key element to these approaches will be laboratory-based activities involving situations encountered in real scientific endeavors and real-world situations.

The traditional "class-room" teaching will be less, and more emphasis will be given to the laboratory experiments. Other modern tools like video, DVD for animation movie and internet for virtual laboratory will be used to give the student an enjoyable learning environment.

REFERENCES

[1]. Anderson B. L., Pelz L. J., Ringel S. A., Clymer B. D., and Collins, Jr. S. A: "Photonics Laboratory with Emphasis on Technical Diversity", IEEE Transaction on Education, Vol. 41, No. 3, pp.194-202, 1998.

[2]. Corones J.: "Fiber optic experiments for electrical/optical engineering technology laboratories," in Proc. 24th Conf. Frontiers in Education, pp. 123-127, 1994.

[3]. Cathey W. T.: "Recommendations for Optoelectronics education," Opt. Phot. News, pp.15-18, 1991.

[4]. Bergh A. A.: "American optoelectronics: Pavement for a bumpy economic road," IEEE Circuit Devices, pp. 32-38, 1990.

[5]. Buck J. A., Owen H. W. L., Uyemura J. P., Verber C. M., and Blumenthal D. J.: "An Optical Communication Design Laboratory", IEEE Transaction on Education, pp.138-143, 1999.

[6]. Mobrahan, Kamran S: "Test and Characterization of Laser Diodes: Determination of Principal Parameters", Application Note, Newport, CVR2, 1999.

[7]. Hertsens, T: "Measuring Diode Laser Characteristics", Application Note, No.5, ILX Lightwave, 1989.

[8]. A. James Mallmann and Thomas E. Bray, " Optonics and Photonics for the 21st Century An Innovative Interdisciplinary Modular Laboratory Curriculum", 4410 DUE COURSE & CURRICULUM PROG, NSF Award no. 955504.

Dr. M. A. Matin is an Assistant Professor of Electrical Engineering in the School of Engineering and Computer Science, University of Denver. Prior to joining Denver University he was a senior research associate in the Department of Electrical and Computer Engineering, University of Toronto, Canada. He received his PhD from the University of Nottingham, England, United Kingdom. His research interest is optoelectronics & photonics devices and systems, Bio-Photonics, Fiber Bragg Grating Sensor and their applications. He is a senior Member of IEEE and presently, the Vice-chair of student activities in the IEEE Denver Section.