EFFECTIVE UTILIZATION OF OPTICAL SPECTRUM ANALYZERS FOR ENRICHMENT OF UNDERGRADUATE PHOTONICS LABORATORY COURSES

Samuel Agbo, Michael Wollman, Michael Fukatsu, Thompson Lewis
California Polytechnic State University, San Luis Obispo

ABSTRACT

The optical spectrum analyzers which we recently added to our photonics laboratory, thanks to an NSF ILI grant, has enabled us to introduce four new experiments into our two undergraduate laboratory courses: Fiber Optics Laboratory and Photonics Engineering Laboratory. The new experiments are (1) Spectral Attenuation of Optical Fibers, (2) Optical Wavelength Spectral Analysis of Laser Sources and Light-emitting Diodes, (3) Dynamic Narrowing of Linewidth and Changes in Modal Structure of Laser Diodes in the Vicinity of the Threshold Current, and (4) Spectral Responsivity of PIN Photodiodes. We have also prepared a video to demonstrate the dynamic changes in laser diode spectra as the drive currents are changed.

We have effectively utilized the LabVIEW graphical programming environment to implement computer control of the experiments over a GPIB interface. This enhances the speed of data collection, and the sophistication of data processing in these experiments. Such computer control of the experiments is very helpful in the dynamic measurements entailed in the experiments. This paper discusses the new experiments, their enriching effect on the courses, and their stimulating and motivating effect on the students.

INTRODUCTION

Photonics is a well established component of our electrical engineering program. About 105 students take the two undergraduate laboratory courses offered in our photonics laboratory annually. Our 1992 NSF ILI grant offered us the great opportunity of enriching these laboratory courses by adding one optical spectrum analyzer (OSA) to each of three work stations in our photonics laboratory. Our experience points to the unique importance of the OSA in a photonics laboratory and its role in stimulating learning in electro-optics as the only real-time, graphic display instrument in the optical frequency/wavelength range.

Our OSA employs a double-pass monochromator which provides a high dynamic range (-55 dBm at 0.5 nm from the signal peak) and high sensitivity (better than -85 dBm). It can display the optical spectrum over the wavelength range of 350 nm to 2000 nm. This range includes visible light and the infrared region relevant to fiber optic communications. However, for calibrated display, the range is 600 nm to 1700 nm. It is capable of sweeping the full wavelength range in 500 ms, thus saving hours in measurement time, compared to experimental arrangements which do not employ OSAs. The OSA can save data in many ways. In addition to being displayed, the experimental results can be sent directly to a plotter or printer, stored in the OSA memory, or can otherwise be accessed via computer control.

A main feature of our laboratory is the use of the graphical programming environment of LabVIEW. Like other instruments in each workstation, the OSAs were configured for LabVIEW programming and computer control of experiments over a GPIB interface. This greatly increases the speed, quantity and sophistication of data acquisition and data processing. Four new experiments, breed on the OSAs, have been developed and added to the two undergraduate laboratory courses- A video demonstration of the dynamic changes in laser diode spectra in response to variations in the drive current has also been prepared. The new experiments and the video are briefly described below.

Spectral Attenuation of Optical Fibers

In this experiment the students measure the total spectral attenuation of optical fibers. The experimental set-up is shown in Figure 1. The OSA is switched to the stimulus-response mode, which allows the output light from the monochromator to be passed through the device under test, after which it is reinserted into the OSA for spectral analysis. The output light from the built-in light source is coupled into the double-pass monochromator with a short length of 62.5/125 mm fiber. The output of the monochromator is coupled into the photodetector input with a short (dummy) optical fiber of length $L_X = 2$ m, which is identical to the fiber to be tested. A measurement is taken, which means that a series of values of optical power is recorded for corresponding wavelengths as a vector, say $\underline{X}$. The short length of fiber is replaced with the fiber being tested, of length LY, about 1 km long or more. Another measurement is taken and stored as a vector, $\underline{Y}$.

Setup for calibrating normalization of the fiber measurement

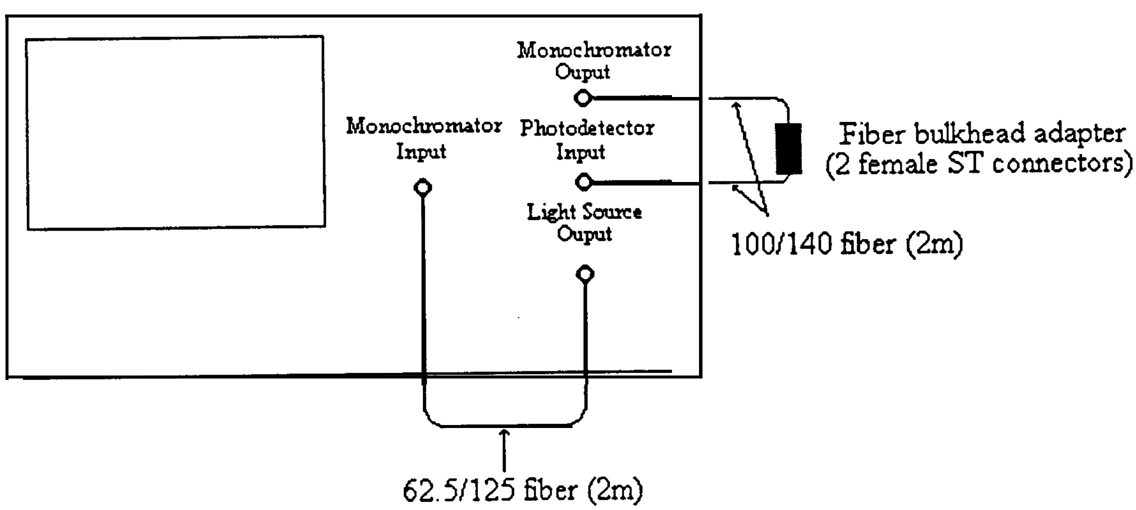


Figure la: Measurement of fiber spectral attenuation.

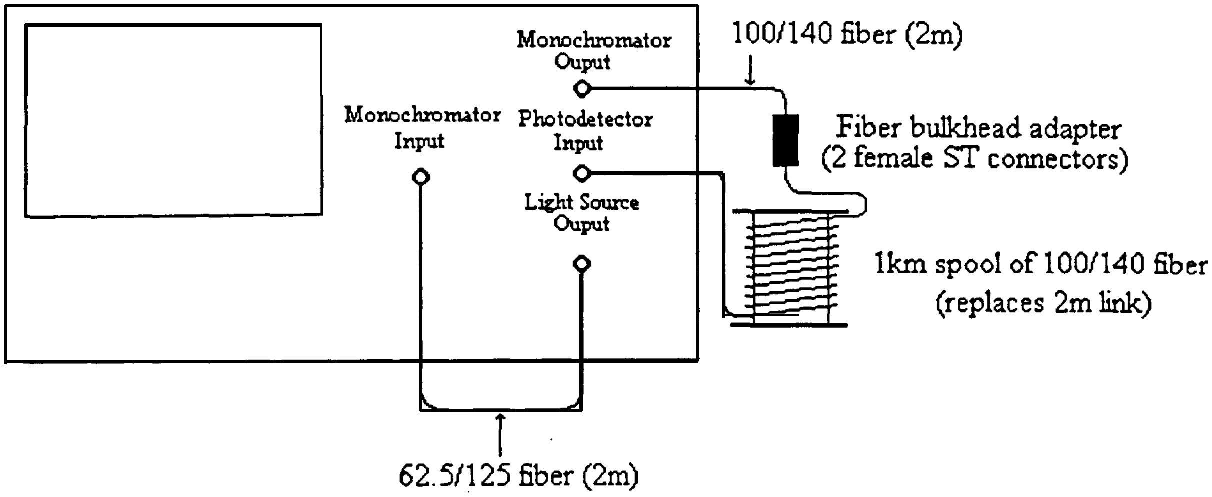


Figure 1b: Measurement of fiber spectral attenuation.

Let $x(\lambda)$ be the scalar value of the vector $\underline{X}$ and $y(\lambda)$ be the scalar value of the vector $\underline{Y}$ at a given wavelength λ. The spectral attenuation as a function of wavelength 1 may be displayed in a linear scale or a log (dB) scale. The spectral attenuation is given for a linear scale and a log scale at a given wavelength by equation (1) and equation *(2)*, respectively.

$$\alpha(\lambda) = 10\left[\log_{10} y(\lambda) - \log_{10} x(\lambda)\right] dB \bullet Km\text{-}' \qquad 1$$

$$\alpha(\lambda) = y(\lambda) / x(\lambda)\ Km\text{-}l \qquad 2$$

Because the effective length of the fiber under test used for the computation in equation (1) is L_Y - L_X, this procedure approximates the cut-back technique [1, 2]. The same connectors are used for coupling both the fiber under test and the short length of dummy fiber between the monochromator output and the photodetector input. This arrangement has the advantage of not requiring a cut back, which reduces the length of the fiber being tested, each time the test is performed. Figure 2 shows the spectral attenuation obtained with this procedure when a 1 km long, 100/140 mm, GRIN fiber was tested.

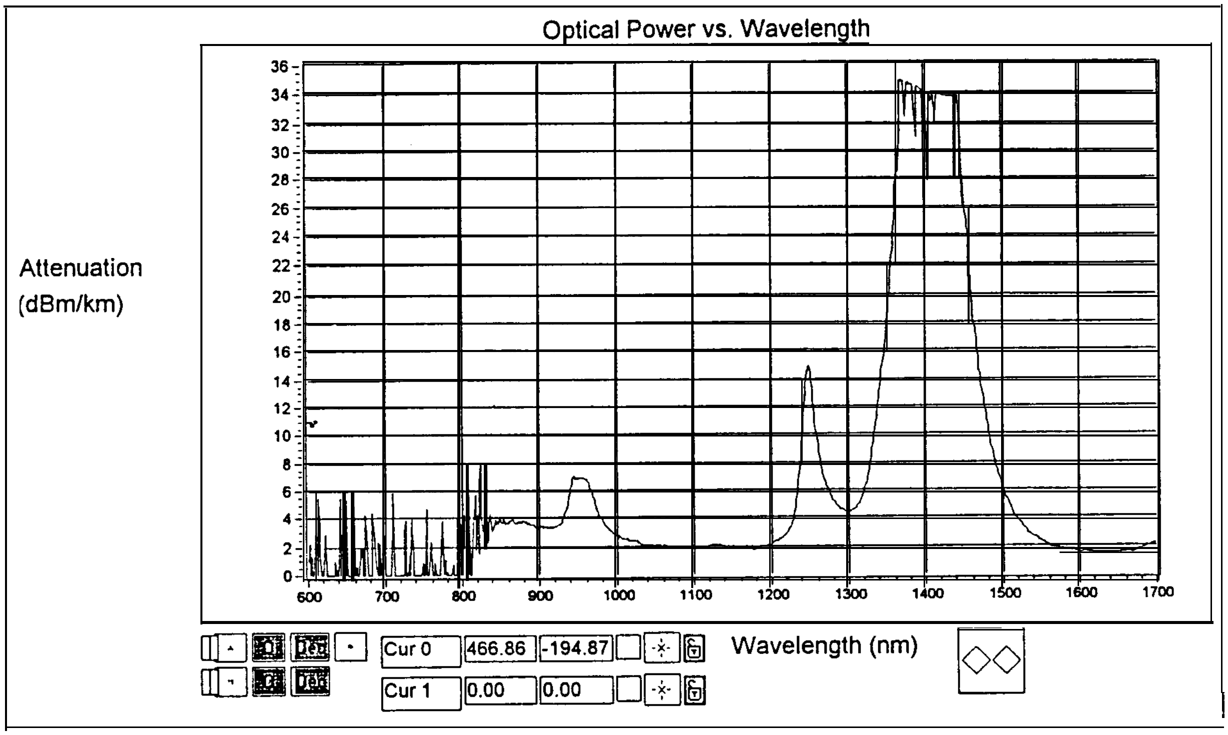


Figure 2: Measured spectral attenuation for a 100/140 mm GRIN fiber.

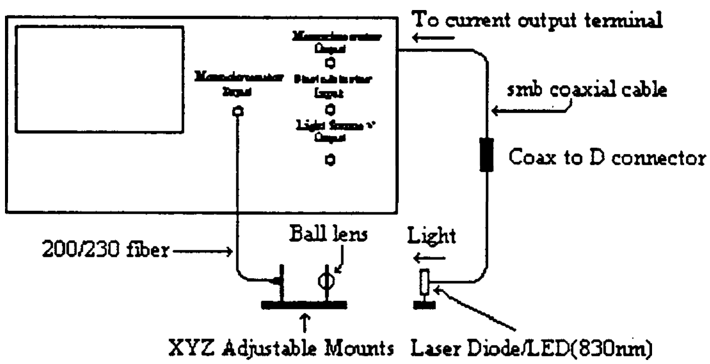
Spectral Analysis of Outputs of Lasers and Light-emitting Diodes

The experimental set up for measurement of the wavelength spectrum for a laser or an LED is shown in Figure 3. *The* laser or the LED output, rather than the OSA white light source, is coupled to the monochromator through a short length of 200/230 mm fiber. The monochromator input is selected, so that the monochromator output is internally coupled to the OSA photodetector. The laser or LED maybe driven by a suitable circuitry, or by the built-in programmable current source as shown in Figure 3. In our procedure, a dc current of appropriate magnitude is obtained from the built-in current source.

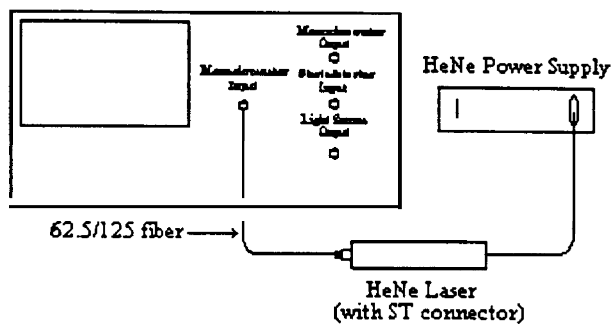
For this experiment, the lasers are biased beyond the threshold current. The spectrum may be displayed with the spectrum analyzer in the OSA mode. In this basic mode, the spectrum is displayed with precise amplitude accuracy and less than * 0.5 dB polarization sensitivity. Alternatively, one of the three advanced measurement functions (DFB, FP and LED) may be used. These functions offer advanced auto-measure features, which are additional to the basic automatic measurement features of the instrument. The DFB function permits automatic measurement of the center wavelength side-mode suppression ratios, peak power and, stop-band characteristics for DFB lasers. The FP function permits automatic measurement of the spectral FWHM, center wavelength, mode spacing, and total power of a Fabry-Perot laser. The LED measurement automatically provides measurements of the spectral FWHM, the mean wavelength, and peak power for an LED.

The advanced measurement functions are recommended and used in our experiments because of the savings they offer in computation time. Additional savings in computation time result from taking advantage of these advanced functions and other auto measure-functions in the LabVIEW programs. Figure 4 shows the power spectra which were obtained for a 780 nm Fabry-Perot laser, a 633 nm He-Ne laser, and an 88o and 830 nm surface emitting LED. The DFB function, which is suitable for single longitudinal mode lasers, was used for the He-Ne laser.

Setup for Laser Diode and 830nm LED (plots 1 and 4)



Setup for Measuring HeNe Laser (plot 2)



Setup for measuring 880nm LED

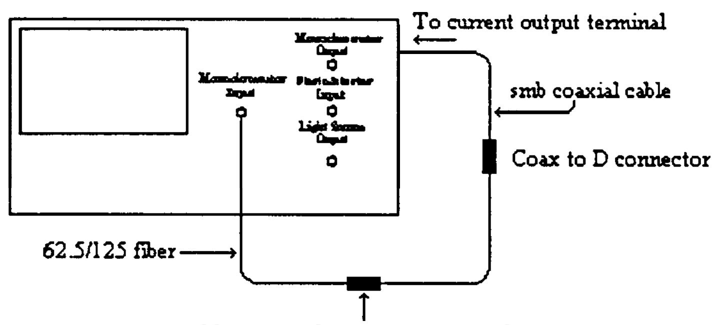


Table mounted LED(880nm) in ST housing

Figure 3: Experimental measurement of laser and LED spectra.

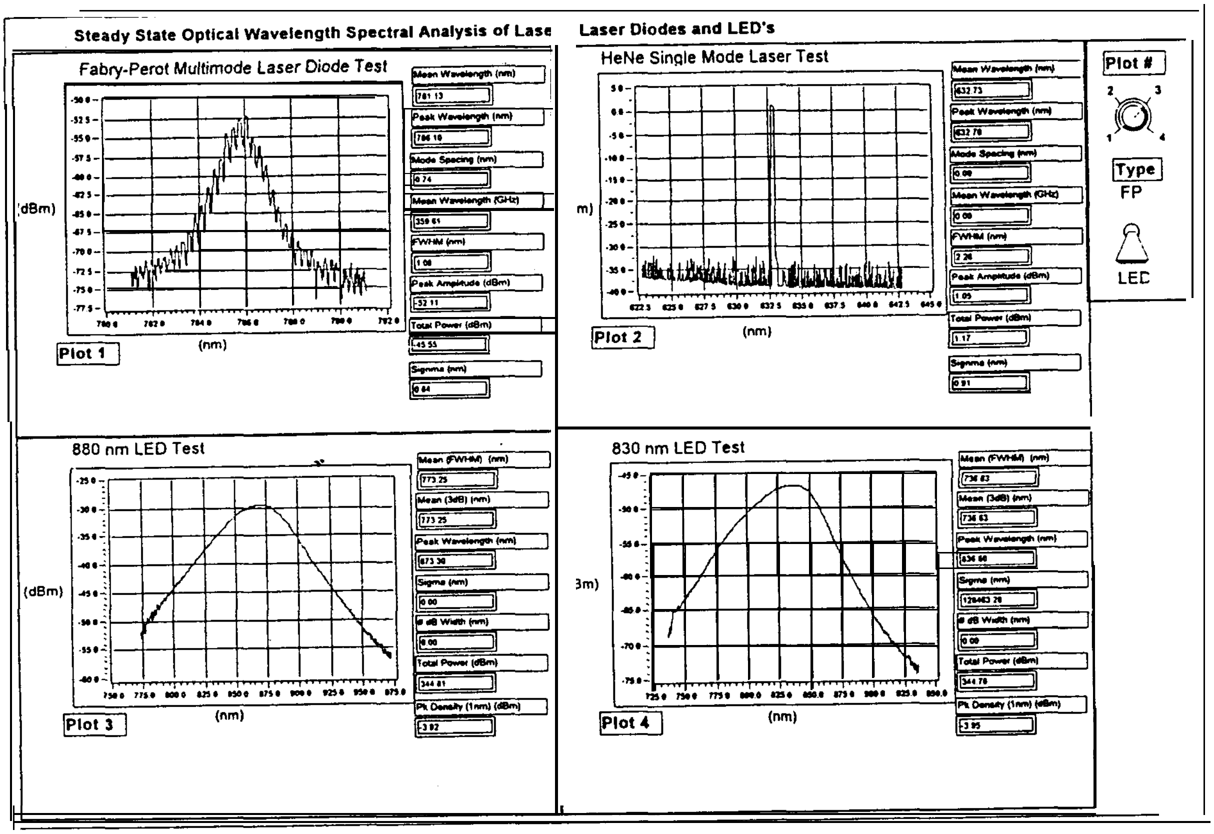


Figure 4: Power spectra of optical sources (1) 780 nm Fabry-Perot laser spectrum, (2) 633 nm He-Ne laser spectrum, (3) 880 nm LED spectrum, (4) 830 nm LED spectrum.

Dynamic Changes in Laser Spectra in The Vicinity of the Threshold Current

The purpose of this experiment is to investigate the dynamic changes which occur in the laser diode power spectrum in the form of changes in the modal structure and the linewidth, in response to changes in the drive current, in the vicinity of the threshold current. The experimental set-up is the same as that of Figure 3, which was used for obtaining the power spectrum for an optical source. Under LabVIEW program control, the dc current from the built-in programmable current source is increased in steps from well below to well above the threshold current.

Figure 5 shows six samples of the power spectrum, illustrating the dynamic changes in the spectrum which occur in response to changes in the drive currents for a 780 nm Fabry-Perot laser diode. Theory predicts that below threshold, the laser diode behaves much like the LED. Just above threshold, laser diode emission is characterized by many longitudinal modes. As the drive current is further increased beyond threshold, the linewidth decreases, and the power gradually concentrates into one dominant mode [3, 4]. Students show much interest in interpreting the results of this experiment and comparing the dynamic changes in the power spectra with the predictions of laser diode theory. Such interpretations and comparisons tend to be very engaging and stimulating to their learning.

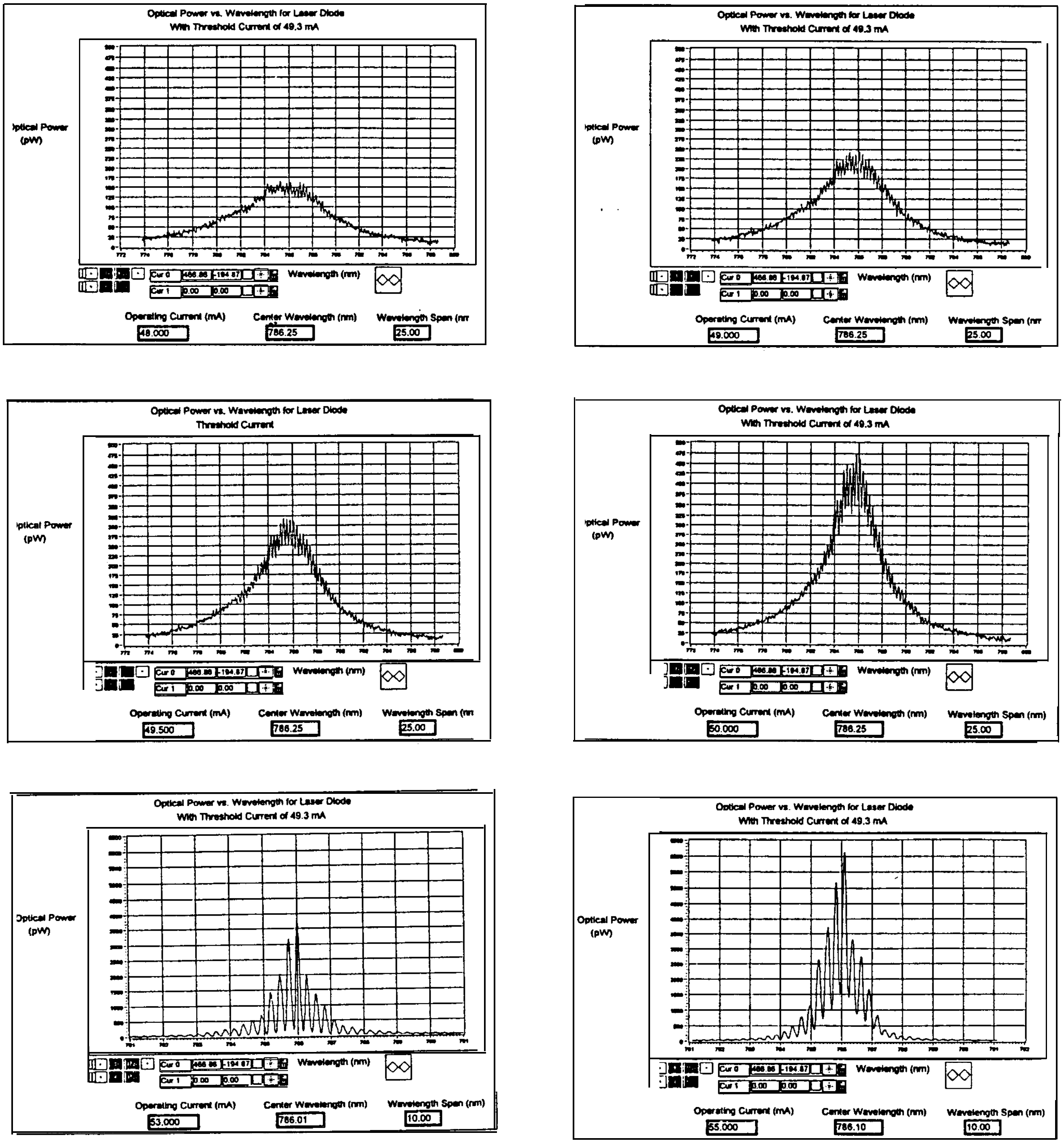
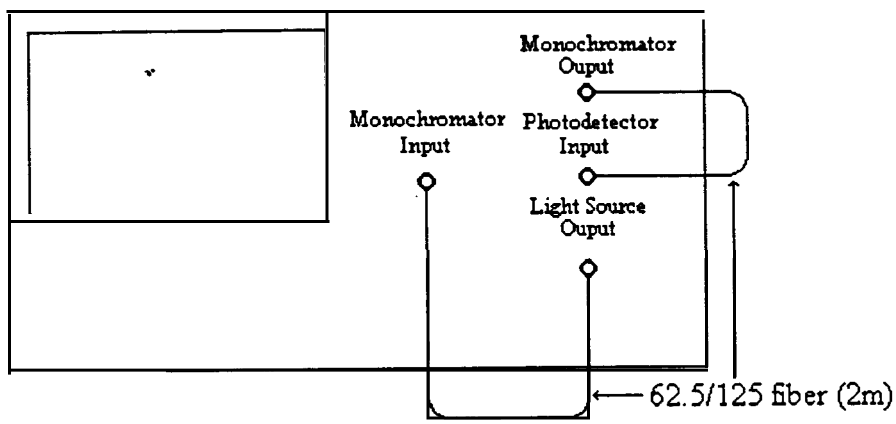


Figure 5: Dynamic changes in a Fabry-Perot laser diode spectra in the vicinity of the threshold current showing samples of the spectra at different drive currents.

Spectral Responsivity of PIN Photodiodes

Figure 6 shows the set-up for experimental measurement of the spectral responsivity of photodiodes with the OSA. The output of the built-in white light source is coupled to the monochromator input with a short length of 62.5/125 mm fiber. The output of the monochromator is first coupled to the OSA photodetector input with a similar short length of 62.5/125 mm fiber. Next, the monochromator output is disconnected from the OSA photodetector input and coupled to the photodetector being tested with the same short length of fiber.

Setup for storing white light power output



Setup for measuring responsivity of a photodiode

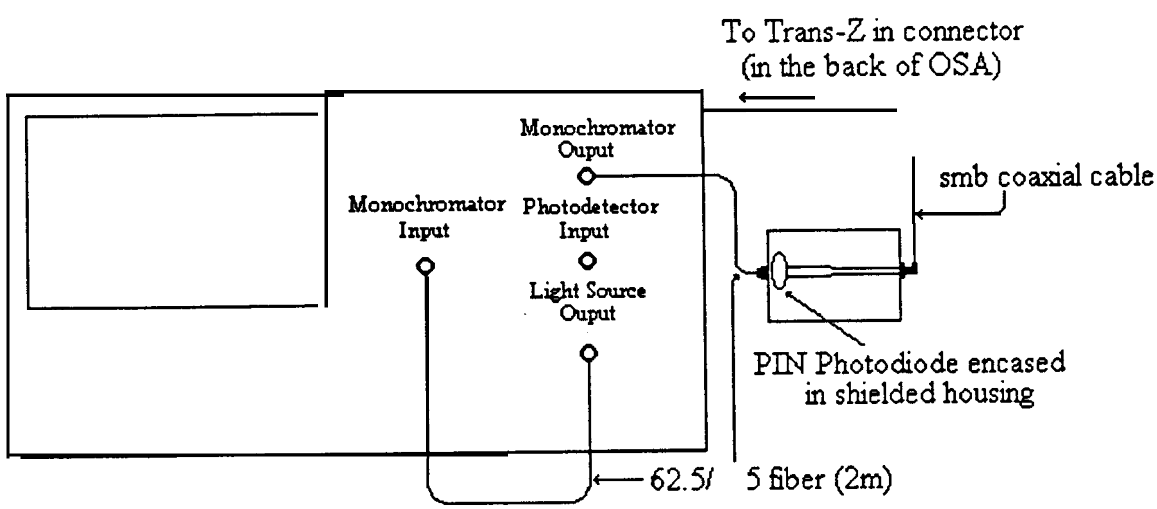


Figure 6: Measurement of spectral responsivity of photodiodes.

The first measurement is taken with the monochromator output coupled to the OSA photodetector input. This measurement stores the optical power in mW at the respective wavelengths as a vector **P**. The light output of the monochromator is then disconnected from the input to the OSA photodetector and coupled to the photodetector under test. The output of this photodetector is a current which is connected to the transimpedance input of the OSA bother measurement is now recorded as a vector **I**, which represents the currents in mA for the photodetector under test at the respective wavelengths.

Let $P(\lambda)$ be the scalar value of the power vector!? and $I(\lambda)$ be the scalar value of the current vector **I** at a given wavelength λ. The spectral responsivity of the photodiode displayed on a log (dB) scale and on a linear scale are given respectively by equation (3) and equation (4).

$$R(\lambda) = 10\left[\log_{10} I(\lambda) - \log_{10} P(\lambda)\right] dB \qquad 3$$

$$R(k) = I(\lambda) / P(\lambda)\ mA / m\ W \qquad 4$$

Figure 7 shows the spectral responsivity obtained by performing the experiment described above using a silicon PIN photodiode. The responsivity was displayed on a linear scale.

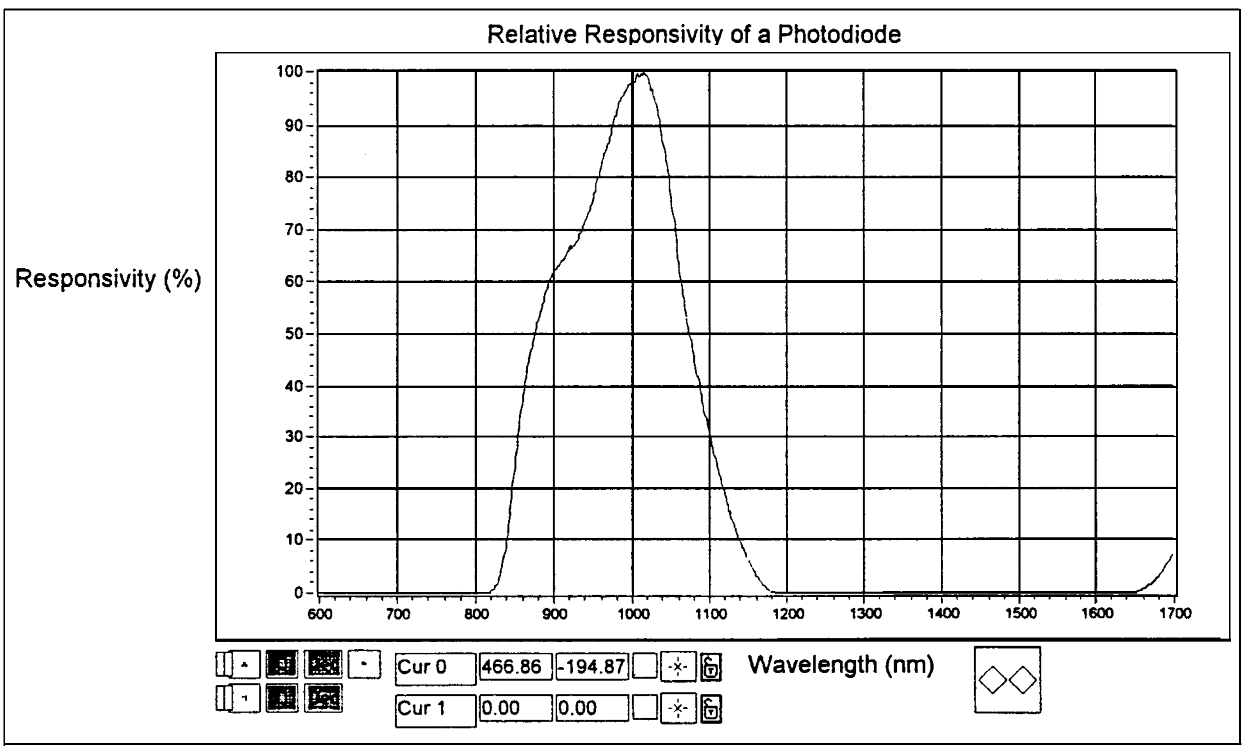


Figure 7: Spectral responsivity of a PIN photodiode.

Video Demonstration of the Dynamic Changes in Laser Diode Spectra as the Drive Current is Vaned

The video was based on data acquired by repeating the experiment on “Dynamic Changes in Laser Diode Spectra in the Vicinity if the Threshold Current”, with a few changes. The experimental set-up was still that of Figure 3. The same 780 nm Fabry-Perot Laser was employed, but the range of drive currents was larger, and the current steps were much smaller, to permit the generation of many snapshots of the spectra.

Under LabVIEW program control, the drive current was varied from 10 mA to 60 mA, in steps of so mA, the resolution of the programmable built-in current source. This resulted in a total of 1,000 snapshots. By displaying two snapshots per second, this resulted in an 8.3 minutes long video. The video is accompanied by an oral commentary. It constitutes an interesting and instructive introduction to laser diode characteristics in our laboratory.

Conclusion

Our experience indicates that OSAS have a very important place in an undergraduate photonics laboratory. The new experiments, based on the OSAs, greatly extend the scope of learning in our photonics laboratory courses. In addition, these experiments have a very stimulating effect on the students’ interest in photonics. More of the students are taking the second set of photonics lecture and laboratory course electives, after the first set. More of the students than ever before are opting for photonics/fiber optic senior projects. Their performance in these senior projects is greatly facilitated by the availability and their exposure to the OSAs.

References

1. Senior, J. M., *Optical Fiber Communications Principle and Practice,* 2nd Ed, Prentice Hall International Series in Optoelectronics; 1992, New York.

2. FOTP-46. Spectral Attenuation Measurement for Long-length Graded-index Optical Fibers.

3. Palais, J. C., *Fiber Optic Communications*, (3rd Ed.), Prentice Hall, Englewood Cliffs, 1992.

4. Syms, R. and Cozens, J., *Optical Guided Waves andDevices,* McGraw-Hill International, London, 1992.

Biographical Information

SAMUEL AGBO has been an Assoc. Professor of Electrical Engineering at California Polytechnic State Univ., since 1991. He received his B. Sc. in 1975 from Univ. of Nigeria, Nsukka, his M. S.E.E. in 1978 from Univ. of Michigan, Ann Arbor, and his Ph.D. in 1984 from Univ. of Houston, all in EE. He was an Asst. Professor at Texas Southern Univ., Houston for one year and at Florida Atlantic Univ., Boca Raton for five years.

MICHAEL WOLL MAN received the B.E.E. from Cornell Univ., M. S.E.E. from the Univ. of Hawaii, and Ph.D. in Electrical Engineering from UCSB. He worked for Hughes Aircraft, 3M Corp., was president of Meta-

morphosis Inc., was a research fellow at the Mayo Clinic in Rochester, Minnesota, and currently consults for LLNL. He developed a photonics program at California Polytechnic State Univ. where he has taught since 1982.

MICHAEL FUKATSU received his B.S. in Electronic Engineering with a concentration in communications from California Polytechnic State Univ., San Luis Obispo in June of 1995. He is currently a student in the M. S.E.E. program at California Polytechnic State Univ. in San Luis Obispo and will graduate in March of 1997. His interests include optical fiber communications and photonic technologies.

THOMPSON LEWIS is a senior in the Electrical Engineering Department at California Polytechnic State Univ., San Luis Obispo. He will receive his B.S. in June of 1996. His interests are in Fiber Optic Communications.