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Optoelectronic Device and Fiber Link Characterization
in Computer Integrated Electronics Laboratory

Abstract

This paper describes how automated measurement capabilities of a Computer-Integrated Electronics laboratory can be adapted to establish a laboratory resource to do optoelectronic device and optical fiber link characterization measurements and SPICE modeling work to augment Optoelectronics courses. It is shown that with minimal additional investment in an Optical Spectrum Analyzer and a ThermoStream temperature controller, light sources, such as LASER diodes, LEDs, Incandescent and Discharge Lamps, and detectors such as Photodiodes and Solar Cells, and optoelectronic combinations of them like Optical Isolators and Optical Fiber Links can be characterized for their electrical, opto-electrical and spectral characteristics. Examples of experimental results are given with descriptions of circuits, experimental setups and measurement methodology.

1. Introduction

Proliferation of fiber optic system as the most reliable, inexpensive and wide bandwidth communication systems for both long distance and local data and voice communication is demanding Electrical Engineering curricula to adapt and include courses in Optoelectronics and Fiber Optics. This paper describes utilization of existing Computer-Integrated-Electronics Laboratory equipment to facilitate typically lecture-only Optoelectronics courses with a laboratory with minimal additional investment.

Automated measurement capabilities of a Computer-Integrated Electronics Laboratory can be used to give the student an opportunity to do many experiments in a short time by saving on the manual activity of point by point data collection and free the time for educationally more valuable activities like evaluation, analysis and interpretation of the data.

The Computer-Integrated-Electronics laboratory equipment used for the automated measurement system reported here consists of a Hewlett Packard Digitizing Oscilloscope (Model 54501A), a Tektronix Arbitrary Function Generator (AFG 5101) and a Tektronix Programmable Digital Multimeter (DM 5120) all with GPIB interface, and a Tektronix Triple Power Supply (PS 250). A Pentium IV computer equipped with National Instrument's IEEE488.2 card controls the setup. Such a combination is typically used in to test and debug electronic circuits. The author has shown that the same set of instruments can also be employed for the automated measurement of I-V and C-V characteristics of semiconductor devices and sensors and, to extract SPICE parameters from them in the laboratory (Guvench[1],[3],[5]).

With the addition of an inexpensive Ocean Optics Model HR2000CG-UV-NIR optical spectrometer and a Thermostream Model AM-003 sample cooler/heater to the electronics
laboratory equipment, various light sources including Light-Emitting Diodes, Laser Diodes and incandescent and metal vapor lamps were characterized for their spectral output, and variation of these within a wide range of temperature. For electrical and opto-electrical transfer characterization, current-voltage, photo-diode current versus light emitter current or optical output power versus electrical power data were automatically gathered with the help of a code developed in the laboratory for the GPIB interfaced instruments. Such extensive data and graphs generated in the laboratory can also be used to extract accurate SPICE equivalent models and parameters of these devices for electro-optic system simulations with SPICE.

In the following sections, the electrical and opto-optical measurement set-ups used are described and extensive examples of measurement results are given which were obtained with the automated measurements with these setups on various light sources and source-detector combinations optically coupled to each other, including source-detector coupling in a fiber link.

2. The Electrical and Opto-Electrical Measurement System

The measurement system reported here employs a standard set of bench-top instruments consisting of a Hewlett Packard Digitizing Oscilloscope (Model 54501A), a Tektronix Arbitrary Function Generator (AFG 5101), a Tektronix Programmable Digital Multimeter (DM 5120). All of these instruments are equipped with GPIB interface and therefore can be controlled to do automated measurements in a sequential and coordinated manner. A Pentium IV computer equipped with National Instrument's IEEE488.2 card controls the setup.

A system schematic of the measurement setup is given in Figure 1.

![Figure 1. Schematic Drawing of the Automated Measurement Setup](image-url)
The red box shown in the middle represents a cylindrical Pyrex glass constituting our “Temperature Controlled Test Chamber”. The blue box on top represents a Thermostream Model AM-003 cooler/heater which blows temperature conditioned/controlled dry air into the test chamber with temperature feedback from a thermocouple placed in the chamber. The devices under test are kept inside the chamber for temperature controlled experiments. These include the “light emitting device” (LED, Laser Diode, etc.), the photodetecting device (photodiode, solar-cell, etc.) and the light coupling medium which is a coiled optical fiber for fiber link characterization. To do optical power output characterization of LEDs or Laser Diodes a calibrated solar cell large enough to intercept the directed output of the emitter is used. This arrangement, instead of a “Light Integrating Sphere”, has been found to be more practical to do batch testing of up to 10 emitters without opening the chamber. The emitters (and the solar cell) were mounted on a PVC block machined to support them and the facing the solar cell at about 1 inch separation. This structure served to provide a large thermal mass for temperature stability as well as mechanical stability during the measurement.

For the I-V measurements, the GPIB controlled function generator (the orange box on the left) is used in its DC setting as a stepped DC voltage source. The digital multimeter (the blue box on the left) measures both the voltage across the light emitting device and also the current flowing through it. This is accomplished by taking advantage of the separate voltmeter and ammeter inputs of the multimeter and by employing the multimeter as a multiplexing meter switched between its voltmeter and ammeter modes, all controlled by the GPIB interfaced computer and our software. Note that the voltmeter and the ammeter inputs of the multimeter share a common (ground) terminal. Therefore, the voltage measurement has to be corrected by calculating and subtracting the voltage burden (the voltage drop on the finite internal resistance) of the ammeter from the voltmeter reading depending on the range of the ammeter setting and the internal resistance corresponding to it. Details of this technique were reported earlier (Guvench [5], [8]).

The code developed sets the function generator at its DC voltage mode and instructs it to start from a minimum bias voltage. It steps the voltage up in increments until the maximum bias voltage value or a maximum safe current value specified is reached. All these values are initially inputted by the user to the control code. During each and every stepped bias point, the code instructs the digital multimeter to measure the voltage and then switch over to ammeter mode and measure the current. The voltage drop in the ammeter is determined and subtracted from the measured voltage to determine the actual cell voltage, and the results are sent into a data (*.txt) file for further processing and interpretation by the user.

In our optical output power and current transfer measurements, we adapted Guvench's technique[5] and the QBasic code developed to achieve automated measurement of them. The calibrated solar cell, in combination with a home-designed “Transresistance Amplifier,” helped to convert the optical output of the emitter into a proportional voltage. The Transresistance Amplifier, which is the circuit contained in the green box on the right in Figure 1, is a “Current-to-Voltage Converter” with practically zero input resistance, and keeps the solar cell (or the photodiode) at zero bias while absorbing all of its optically generated current. This biasing arrangement does not generate leakage current, and therefore, the circuit’s output voltage ($V_{out} = - R_F . I_{cell}$) is due to amplified cell current containing its photo generated component only, and not
contaminated by the P-N junction’s highly temperature dependent leakage current (Donati \[^9\]). The feedback resistance, \( R_F \) has to be as high as possible in order to deliver the highest conversion factor. However, it cannot be made higher than a maximum value, 
\[ R_{F\text{Max}} = \frac{V_{\text{OutMax}}}{I_{\text{Cell Max}}} \]
which drives the operational amplifier’s output to its saturation, \( V_{\text{OutMax}} \).

Depending on the position of the switch connecting the voltmeter the system can be used to measure \( I_{\text{Emitter}} \) vs \( V_{\text{Emitter}} \), i.e. the I-V characteristics of the light emitting device, or in “\( V_{\text{Out}} \)” position, \( I_{\text{Cell}} \) vs \( I_{\text{Emitter}} \). Note that \( I_{\text{Emitter}} \) is an indication of the optical power emitted by the emitter. By doing both measurements, (while maintaining the temperature setting constant, of course), with a calibrated solar cell, one can generate \( P_{\text{Out}} \) vs \( P_{\text{In}} \) of the emitter as well as \( I_{\text{Cell}} \) vs \( I_{\text{Emitter}} \).

![I-led vs V-led](image)

**Figure 2. I-V Characteristics of LEDs and Laser Diodes Measured**

Figure 2 displays results of I-V characteristics measured with this setup of various LEDs, a Laser Diode (650nm, red) and a small incandescent lamp. It is observed the the turn-on voltage of the diodes follow the color of emission in the sequence of IR, Red, …, Blue, which is the increasing order of the energy of photons emitted, \( E = h\nu \), a number which is close to the bandgap energy, \( E_G \) of the semiconductor material the diode is made from (Kasap \[^6\]).

Figure 3 displays the same I-V characteristics plotted on a semi-log scale to see the exponential nature of the forward characteristics of these diodes. By combining the information of the slopes and absolute values in the linear and semilog plots, one can extract the SPICE parameters, IS, n, and RS of these diodes following the procedure outlined by the author in an earlier publication (Reference \[^5\]).
Figure 3. I-V Characteristics of LEDs and Laser Diodes Measured (Semi-Log scale)

Figure 4. Current Transfer Characteristics of a LED-Photo Diode Optical Communication Pair at Three Different Ambient Temperatures, -30C, 25C and 70C
Figure 4 is displaying the Current Transfer Characteristics of a Red-LED Photo-Cell optically coupled to each other. Note that an optic fiber link would be tested the same way and yield a similar set of curves. An Opto-Isolator, which is a LED and a photo-diode electrically isolated but optically coupled in a package would also be tested the same way and yield similar set of characteristic curves. It is observed that there is a perfect linear coupling relation between the cell current and the emitter current, as expected from the physics of operation of the two devices. It is observed that the coupling is severely affected by temperature, mainly because an LED’s optical power emission becomes inefficient at higher temperatures due to increased component of thermally generated leakage current. (See, References [4] and [6]).

3. The Spectral Output Measurements

![Figure 5. Effect of Temperature on the Spectral Output of a Red LED (Tested at Three Ambient Temperatures, -30C, 25C and 70C)](image)

Figure 5 is displaying the spectral output of a Red-LED, again tested at three different temperatures. These measurements were done by employing an Ocean Optics, Inc. Model HR2000CG-UV-NIR optical spectrometer. The HR2000CG-UV-NIR is a high resolution wide spectral range spectrometer covering a wavelength range of 400nm to 1100nm, i.e. from ultraviolet to near infrared, with a Silicon CCD sensor. It is easily interfaced to a PC or labtop via USB. Light to be analyzed by this instrument has to be inputted through an SMA-905 port. A premium grade 400micron multimode fiber cable terminated with SMA-905 connector, QP400-2-VIS/NIR, is used to couple the emitters’ output into the instrument. The other end of the cable is plugged into a CC-3-UV Cosine Corrector with PTFE diffuser, forming a flexible light probe.
In order to avoid damaging this fiber and the diffuser during temperature testing of emitters (-30°C to +70°C), this probe had to be kept outside the test chamber. Glass walls of the chamber made such measurements possible. However, due to non-flat transmission spectra of the glass, the spectra measured from outside is expected to include some distortion. Nonetheless, for LED and Laser spectral measurements which are very narrow, such gradual filtering effects should not be a problem.

The spectral output of the LED shown in Figure 5 clearly shows a shift in the wavelength of peak emission to longer (lower energy) wavelengths. This is correlated with the decrease of bandgap energy, $E_G$, of the semiconductor material since $\frac{h\cdot c}{\lambda} = E_G$, where $\lambda$ is the wavelength of photons emitted due to direct recombination of electron-hole pairs in a P-N junction. Also observed from Figure 5 is the fact that the LED’s output decreased with operating temperature, in agreement with the current transfer results shown in Figure 4, earlier.

![Figure 6. Light Emission Spectra of Various Light Sources Measured (Various Colored LEDs, a Red Laser Diode and an Incandescent Lamp)](image)

In Figure 6 results of the spectral measurements done on various LEDs (with different emission wavelengths), and also on a laser diode and an incandescent lamp are combined for a perspective view and comparison. The colors of the plots are chosen to reflect the color of peak emission of the device. These are the same devices whose I-V characteristics were measured and displayed in Figures 2 and 3. It is again observed that the devices with the smaller wavelengths of the peak emission are the ones which required the largest forward voltage to turn on, in agreement with the relationship, $\frac{h\cdot c}{\lambda} = E_G$ for radiative recombination which is responsible for light emission in semiconductors.
Particularly interesting is the spectrum displayed by the “White” LED. It clearly reveals that it is actually a “Blue” LED, with a peak emission at 450 nm, but with the help of a fluorescent dye in the package some of its blue emission has been converted into other colors displayed by the much wider second peak at 560 nm, thereby rendering an overall impression of “White” in the human eye. However, this finding also raises an issue and need for awareness on the potential safety hazards of looking, directly and at a short distance, at high power white LEDs and arrays, used in vehicle headlights, for possible damage to the photoreceptor cells in the human retina due to their excessive intensity and blue content. (See, Reference [10] by G.R.Davies [\textsuperscript{10}])

4. Conclusions and Remarks

The experiments were integrated into a senior level Optoelectronics course delivered at the University of Southern Maine. The course was originally offered as a lecture-only course. These experiments were introduced in the second offering as add-on semester projects. Students did the experiments with great enthusiasm and presented their results in final reports in written form and delivered them as oral power point presentations. As a matter of fact, most of the data used in this paper are from experiments conducted by the students. The author wants to take this opportunity to praise the enthusiasm, dedication and hard work shown by all of his students in ELE467 Optoelectronics, particularly those in the Class of 2004-05.

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