

[This is a “lab manual” I wrote for students in an introductory course on solid-state physics and optical properties of materials at Cleveland State University. Target audience was undergraduate and master’s degree majors in engineering, physics, and chemistry.]

PHY 480/482/580
Lab #1

Monday March 17, 2008

If necessary, we will use part of the class time on Wednesday March 19 for help on data analysis.

Introduction

- There are three short experiments, described on the following pages. You will take all the data on March 17. Please work in groups of two people. Each group will take one set of data from each experiment.
- Each group member must prepare and hand in his/her own lab report. Each experiment’s description states what should be included in the report. Please staple all three sections together and hand in as one package.
- Data analysis and plotting must be done by computer. Several different programs are suitable for Experiments 1A and 1B. Experiment 1C will produce a computer-generated data file designed to open with Microsoft Excel. Therefore, it is most convenient to use Excel for that experiment.
- Lab reports are due **Monday March 24. To get credit, you must attend the lab and hand in the report on March 24. Late reports will not be accepted.**

Units used in this manual

p: pico, 10^{-12} Example: 1 pA = 1×10^{-12} ampere

n: nano, 10^{-9}

μ : micro, 10^{-6}

m: milli, 10^{-3}

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Exp. 1A: Diode Current-Voltage relationship

This relationship is a little more complicated than the one we derived in class. (See Neamen, page 304). For forward bias, a more correct formula is:

$$I = I_s \left[e^{\frac{V_a}{nkT}} - 1 \right],$$

where $n \sim 1$ for large forward bias (the case we studied) and $n \sim 2$ for small forward bias. ($k = 8.63 \times 10^{-5}$ eV/K, and I_s is the maximum reverse leakage current). In our diode, the “-1” can be neglected for forward currents larger than 1 nA. We therefore get:

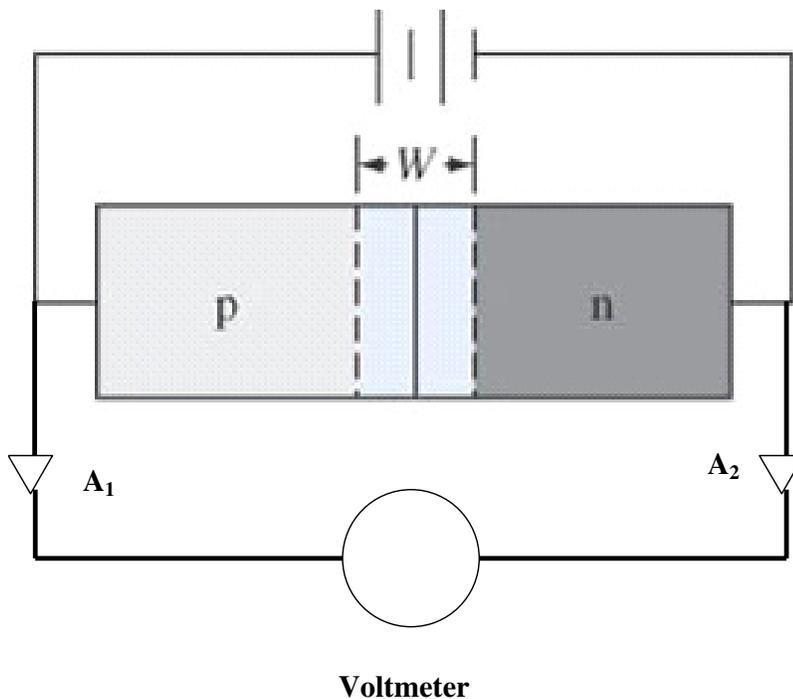
$$\ln I = \ln I_s + \frac{V_a}{nkT}.$$

If we plot $\ln I$ versus V_a , with forward bias, we expect an (approximately) linear graph. The slope is $1/(nkT)$ and the intercept at $V_a = 0$ is I_s . (See Neamen page 304).

As you know, the current rises abruptly as V_a is increased in the forward direction. If we apply “constant” voltages and measure the current, slight fluctuations of voltage will cause big changes in current. Thus, we will use a constant current source to force a steady current through the diode and will measure the voltage V_a with a voltmeter.

The circuit is shown below. Amplifiers A_1 and A_2 , which have gain of X1 but very high input resistance, prevent current from flowing through the voltmeter rather than through the diode.

Constant-Current Power Source



Procedure:

1). Measure and write down the voltage (with sign) at the currents shown on the blank data sheet at the back of this manual. Discard any readings for which voltage is larger than 16 volts since this exceeds the maximum voltage for which the current source is accurate.

Analysis:

- 1). Graph current vs voltage as you did in PS 8, problem 2, using logarithmic scale for current and linear scale for voltage. Show the actual data points, not just a fitted smooth line.
- 2). Graph natural log (ln) of current (amperes) vs voltage for positive current values. Show actual data points, not just a fitted smooth line. To get natural log with Excel, the operator is LN(), where the designation of the cell whose log you are taking goes between the parentheses. Since the currents are smaller than 1 ampere, these logs will be negative – that is OK.
- 3). Fit a linear trendline to your data to get slope and intercept at $V_a = 0$.
- 4). From the slope, calculate n. Assume $T = 293 \text{ K}$ (20°C).
- 5). From the intercept, calculate I_s – the maximum reverse leakage current.

NOTE: Theoretically, the value of I_s obtained in 5) should equal what you measured with negative currents and voltages. I found this wasn't the case. I'm still thinking about that.

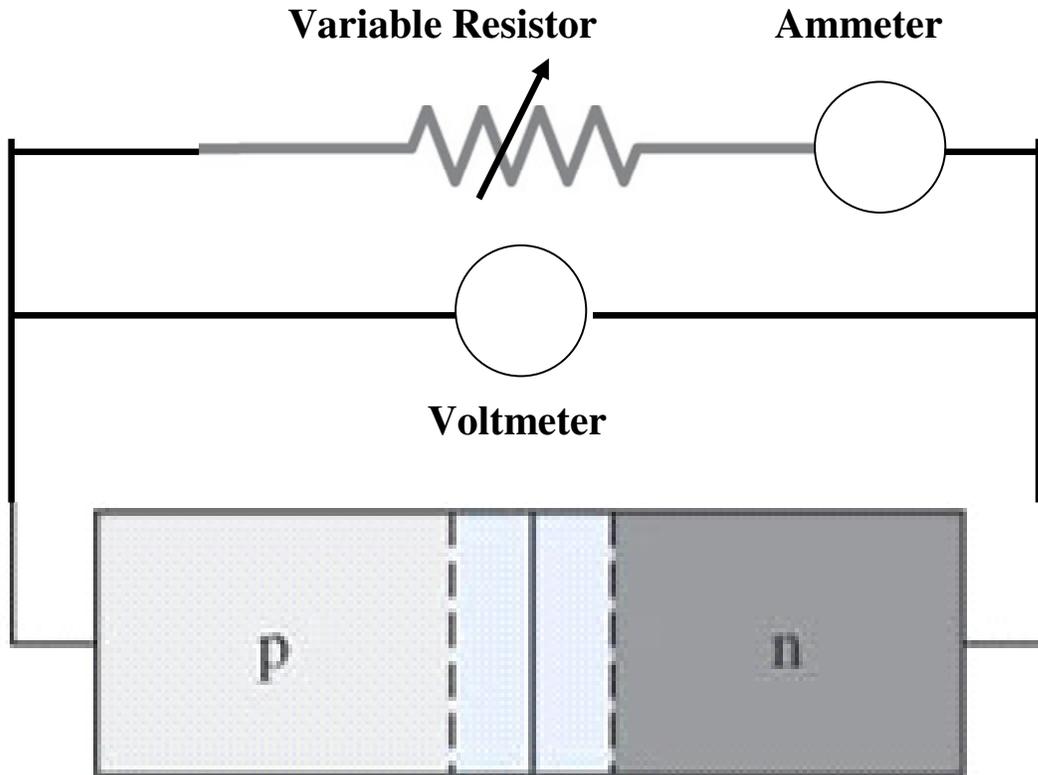
Report:

Include a copy of your group's data sheet, your graphs of Analysis items 1) and 2), and your calculations of Analysis items 4) and 5).

Exp. 1B: Solar Cell current-voltage relationship

In this experiment, you will measure and plot the current-voltage characteristics of a silicon solar cell that is illuminated by an LED.

The circuit is shown below. The variable resistor can be adjusted to draw various amounts of current. Current and voltage are measured by an ammeter and voltmeter. Current flowing through voltmeter is small enough to be neglected.



Procedure:

- 1). Adjust variable resistor, then record readings of voltmeter and ammeter. Take data for at least 15 voltage/current settings, especially where the current is dropping rapidly (see Neamen page 624, Fig. 14.7).
- 2). Read the short-circuit current after you have short-circuited the variable resistor with a shorting plug (its prongs are connected together with a short piece of wire). This is necessary because variable resistors usually have some resistance even when turned all the way to the end of their travel.
- 3). Read the open-circuit voltage after you have unplugged the variable resistor from the circuit board.

Analysis:

- 1). Using Neamen's Eq. 14.10 on page 624, Find I_s (the maximum reverse leakage current) from your measured open-circuit voltage (V_{oc}) and short-circuit current (I_L).
- 2). Plot measured current vs voltage (linear scale for both) similar to Neamen's Fig. 14.7. Include your values for short-circuit current and open-circuit voltage. Show the actual data points on your graph, not just a fitted smooth line.
- 3). Plot "theoretical" current vs voltage from Neamen's Eq. 14.7 (page 623), using your measured short-circuit current for I_L and the value of I_s determined in Analysis item 1). If possible, put this on the same graph as Item 2). If you're using Excel, I can show you how to put two data series on the same graph.

Report:

Include a copy of your group's data sheet, and your calculations and graphs of Analysis items 1), 2) and 3).

Exp. 1C: LED Spectra

In this experiment you will record and graph the spectra of yellow, blue and white LEDs. Light from each LED is fed to a grating spectrometer via an optical fiber. Spread-out light emerging from the grating hits a linear array of 2048 charged-coupled devices. The computer stores data on the intensity of radiation at 2048 wavelengths in the range ~ 190 – 900 nm. The data files can be read, manipulated and graphed with Microsoft Excel.

Procedure: (Repeat for each of the three LEDs).

- 1). Carefully push plastic cap with LED onto the plastic tube leading to the optical fiber. Please do not bend the fiber optic cabled sharply; the fiber might break.
- 2). Connect LED cable to power supply cable, aligning the tabs for correct polarity. If plug is backwards, the LED will be reverse-biased and won't light up.
- 3). Turn on power supply and set for 10 volts.
- 4). You will soon see a spectrum on the monitor. The small green box in the fiber optic line is an attenuator. Adjust the black thumbwheel so the tallest peak has an intensity between ~ 3,000 and 4,000 counts. If peak is too tall, the CCDs will be overloaded and mess up your data. To get faster response while adjusting, set "Average" to 1 (see Screenshot on next page).
- 5). After attenuator is set, set "Average" to 30. The system will now update once every 9 seconds. Thus you must wait at least 10 seconds (preferably 20) before saving your data.
- 6). Selected File/Save/Sample. Computer is set so your file will be saved in a My Documents folder named LED spectra. For filename use your name, your partner's name and the LED color.
- 7). If you have a USB flash drive, you can copy your three files to your drive. There is a shortcut on the Windows desktop that will lead you to the file folder. If you don't have a USB drive with you, see me - I will provide a CD and burn your files on it.

Analysis: (Repeat for each of the three LEDs).

- 1). The spectrometer files are similar to .dat files, but they have the extension .Sample. They can be opened with Excel. The easiest way is to change the extension from ".Sample" to ".xls". Then just double-click on the file in Windows Explorer. Now you can add columns, graphs, etc and save it as an Excel file.
- 2). The file will have two columns of figures. The left-hand one is wavelength in nanometers. The other is intensity, in arbitrary units.
- 3). Since most spectral data is presented in terms of wavelength rather than photon energy, graph intensity vs wavelength over the entire range covered by the spectrometer.
- 4). Now graph intensity vs photon energy (eV) over the entire energy range covered by the spectrometer. $E = 1240/\text{wavelength}$.
- 5). For the yellow and blue LEDs, make more detailed graphs, just of the wavelength range covered by the LED output.

6). The white LED has output over a broad range of energies. So, make a detailed graph covering this energy range.

7). Using your graphs for the yellow and blue LEDs, determine the full width at half maximum (FWHM). This is the difference (eV) between the two energies for which intensity is $\frac{1}{2}$ the peak value. Excel will tell you the wavelength and intensity of a data point if you hover the cursor over the point. Or, you can look at the data table.

Report:

Include graphs and FWHM results for Analysis items 3) thru 7). Don't bother to print out the data tables – each has 2048 rows!

