Experiment 6

Working with LED's

Estimating Semiconductor Band Gap using LED's

Objective: Observe visible light-emitting diodes (LED's) in simple electrical circuits, and relate the composition of semiconductor materials with their behaviors. Estimate the band gap of a semiconductor material.

Review of Scientific Principles:

Colored light can be produced in a number of ways. On the one hand, ordinary incandescent light bulbs may be used with filters that select out a portion of the complete color spectrum that is emitted from the glowing wire filament. On the other hand, the familiar orange-red glow of neon lights is generated by electrically ionizing very small amounts of gases inside sealed glass tubes. LED's contain neither a wire filament nor any gases. The light emitting portion of a solid state diode is quite small so you will need a magnifying glass to see it clearly. Even though the diode may be enclosed in a colored plastic lens, the lens is not the cause for the color of the light observed.

In LED's, electrical energy is converted into light energy. The voltage required to switch on the LED is proportional to the energy of the light emitted from that LED. Also by comparing the color of the light with a chart of the visible light spectrum, it is possible to assign a wavelength to the color of each LED. Using this wavelength, a simple calculation can be made to approximate the energy of the electron transition taking place at the junction in the diode. The colored light (made up of photons) is being produced by electrons that are relaxing across the energy gap in the semiconductor material. The reverse process may also be observed in which light shining on a diode can be converted into electrical energy.

Applications:

LED's are very common and are frequently used as indicator lamps. When the light goes on, electricity is flowing. Whether it is a compact disc player, electric guitar amplifier, computer, monitor, or video game module, we always look for the little colored light to let us know it is working. As common as they are, however, most people have no idea how LED's produce their bright, colored light; they simply expect it to happen.

Time: One hour. (More time is required if students will be assembling the circuits themselves).

Materials and Supplies:

Each student group will need:

variable power supply (at least 0-6 VDC) with leads

one panel containing several different visible LED's (see note 1)

digital multimeter (DMM) and test leads with small alligator clips

magnifying lens

9V battery and snap connector,

470 ω resistor

LED socket (see note 2)

small, bright flashlight

General Safety Guidelines:

*Do not stare long at any of the brightly lit LED's.

*Some of the wires may have sharp edges.

*Do not grasp any bare wires or connections with your hands.

*Be sure the power supply is set for 0-6 V (DC). Turn it off when not in use.

Procedure:

1. Obtain a panel containing several different visible LED's.

2. Connect the power supply 0-6V DC to the panel leads.

3. Connect the DMM across the circuit, and set it for DC.

4. With the power supply at its lowest setting, turn it on.

5. Slowly dial up the voltage until and effect is noticed at one of the LED's.

6. Continue to slowly dial up voltage until you have observed all the LED's (do not let the voltage reading on your DMM exceed 2.5V).
7. Now slowly dial the voltage back down, and observe the LED's.
8. Repeat steps 5-7. Record the voltage at which you observe each LED to go on and off.
9. With all LED's on and shining brightly, compare their colors with a chart of the visible light spectrum. Or view the lighted LED's with a calibrated spectroscope. Record the wavelength in nanometers of the color that matches each LED.
10. Turn off the power supply, and disconnect only its positive lead from the circuit. Leave the DMM on and its leads in place across the LED circuit.
11. With the room darkened, shine a small, bright flashlight on each of the LED's in the panel. Record the maximum voltage that you read from the DMM for each LED.
12. Obtain a 9V battery and snap connector with appropriate resistor and socket. Insert a green light LED in the socket with the long leg on the red side. Shine it directly over and against each of the LED's in the panel. Record the maximum voltage for each that you read from the DMM.
13. Repeat step 12 replacing the green LED with a red LED. Record the voltage readings.
14. Test what happens when an LED is placed in the socket backwards.
15. Using a magnifying glass, make two scaled drawings of an LED--one from the top and one from the side. Indicate on your drawings where the light is produced.

Video Clip Demo

Data and Analysis:

LED Color	Turn-on	Wavelength of light Emitted	Energy of Light Emitted	Band Gap of Material	Composition of Material

Questions:

1. In what order do the LED's light when the voltage is increased slowly from zero?

2. Place the LED's in order according to increasing wavelengths.

3. What is the relationship between the lists in questions one and two?

4. From your observations, what kind of mathematical relationship exists between the numerical values for electrical energy (volts) and the wavelength of the colored light emitted?

5. What effect does the white light source have on the LED's? Why?

6. Which color of LED caused a voltage reading in every LED on the panel?

7. Which color of LED caused a voltage reading in only one LED on the panel?

8. Explain your answers to questions six and seven by discussing the relationship between energy and color of light.

9. In which LED is the diode composed of a material with the largest band gap?

10. Calculate the band gap for the material in each diode in units of electron volts (eV) by using the equation $E = 1240 / \lambda$. Where λ is the wavelength of light in nanometers (10^{-9} meters).

11. Compare the values calculated with a list of semiconductors and their band gaps. Which materials do you believe are present in the LED's that you used?

Teacher Notes:

*Teacher preparation time for this lab is approximately one hour.

*The panels can be constructed in a number of ways, but one that seems to work uses ordinary 1/4 inch pegboard. Cut a square that has at least five rows and columns of holes (more or less depending on the number of LED's). Make a red line down one side of a row. Pop an LED of each color (use colorless lens LED's to ensure that students realize the colored light is not due to the plastic case) into a mounting clip. Then press these through the holes in the pegboard with the longer leg of the LED on the side of the red line. The legs may now be trimmed to any convenient length, but leave enough for solder connections. Now solder a noninsulated copper wire to each of the "red" legs and one to each of the "black" legs leaving a least 2 cm for connections to the power supply. Then solder a 470 ω resistor to the wire on the red side.

*Solder a 470 ω resistor to the red lead of the 9V battery snap connector. Then solder an LED socket to the other end of the resistor and the black lead from the snap connector.

*Sources for materials are: Radio Shack, Mouser Electronics (800)346-6873, Cal-West

Electronics (800)892-8000 (blue LED's can be purchased for $2.50 each)

*Rohm super-bright LED's from the Mouser catalog are a good choice at $0.15/lamp. These are the catalog numbers:

red 592-SLH34-VT3

orange 592-SLH34-DT3

yellow 592-SLH34-YT3

green 592-SLH34-MT3

*See Ken Werner's article *Higher visibilty for LED's* in July 1994 IEEE Spectrum

magazine for a great summary of LED technology.

Answers to Questions:

1. red, orange, yellow, green, blue

2. blue, green, yellow, orange, red

3. opposite order

4. from observation, it is opposite or inverse

5. a voltage is produced in the circuit when it is shone on each LED because white light is a

combination of all colors of visible light

6. green (or blue)

7. red

8. green (blue) light is of the highest energy, and it is able to promote electrons across the

band gap in all the LED's, but low energy red light can only affect electrons in the red LED with the small band gap

9. green (blue)

10. green (blue)

11. The published values of wavelengths for the LED's are red at ~650 nm, orange ~610 nm, yellow ~585 nm, green ~565 nm, blue ~470 nm observed colors may vary but should fall between about 460 - 700 nm

Use the following information:

SiC	**2.64 eV**	**blue**
GaP	**2.19 eV**	**green**
GaP.85As.15	**2.11 eV**	**yellow**
GaP.65As.35	**2.03 eV**	**orange**
GaP.4As.6	**1.91 eV**	**red**

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