Light Emitting Diodes

Center for Nanotechnology Education

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Light Emitting Diodes

Abstract

This module demonstrates the concepts of semiconductor band gaps and the quantum nature of light using readily available and inexpensive LEDs. It uses a simple fact which surprises many students – LED can detect light (i.e., act as small solar cells) as well as generate light. The lab can be completed in a 1.5 hour period in addition to prior introductory lecture and post lab discussion.

Outcomes

Upon completion of this module students should be able to

- Describe the band gap structure of LEDs
- Describe the quantized nature of light
- Perform calculations to determine the energy of a photon as a function of wavelength
- Build a simple LED circuit and perform measurements using it

Prerequisites

- Understanding the relationship between light wavelength and color
- Knowledge of energy bands in semiconductors
- Ability to calculate the energy of a photon is related to its wavelength

Science Concepts

- The photoelectric effect
- The quantum nature of light
- The interaction of light with solid materials
- The use of light emission and absorption to probe the structure of matter

Nanoscience Concepts

- The energy bandgap structure of certain semiconductors leads to characteristic light absorption and emission
- The tools of nanofabrication have led to advances in LED development

Background Information

A light-emitting diode (LED) is a solid state light source made from semiconductors. LEDs are made up of stacks of semiconducting material and emit light when electric current flows through the structure. Unlike thermal light sources (like a tungsten filament in a light bulb) or plasma emitters (like the glowing gas in a fluorescent bulb), LEDs emit light via an energy transition of charge carriers within the solid.

In a semiconductor like those found in LEDs, the atoms making up the solid form a tightly bound crystal lattice. The electrons on the outermost orbital positions of these atoms are weakly bound to the atom, and fraction of these weakly bound electrons will have enough energy to detach from their home atom, allowing them to move freely throughout the solid lattice as a “free electron.” The orbitals where these electrons were formerly bound, called “holes”, acquire a net positive charge and act like physical particles similar to the electrons, in that they can move throughout the solid. Free electrons and holes will move through the solid under the influence of an applied electric field, electrons in one direction and holes in the opposite direction. These free electrons and holes make up the charge carriers in an LED.

It takes energy to shake loose a bound electron to form an electron-hole pair. If an electron recombines with a hole, energy is given off in the form of electromagnetic radiation, more specifically, a photon of light. The color (or wavelength) of the photon emitted by the LED is determined by the energy of this transition. In semiconductors, the energy states of the electrons are described by regions called bands; there is an energy band containing the bound electrons, and a higher energy band that describes the free electrons and holes. Between these bands is a region called the bandgap, which corresponds to the transition energy when an electron and hole recombine. Thus, the energy of the photon given off by an electron-hole recombination is equal to that of the bandgap energy. An LED, or any other semiconductor with a bandgap, can also absorb photons if their energy is equal to or greater than the bandgap energy. The energy of the bandgap and the color of the light emitted by an LED can be selected based on LED material composition. LEDs are available that emit from the infrared (IR) region through the visible spectrum and on up to the ultraviolet (UV) region.

The first practical LEDs appeared commercially in 1962. These early LEDs emitted low-intensity IR light; such LEDs are still used in remote control devices for consumer electronics. The first visible light LEDs were of low intensity and limited to the color red, and are still commonly used for indicators in electronic panels. Modern LEDs are available across the visible, ultraviolet (UV), and infrared wavelengths, with high light output. High intensity white light can be produced with LEDS by using multiple colored semiconductor emitters, or by adding a layer of yellow light-emitting phosphor to a blue-light LED. The blue light from the LED excites the phosphor which fluoresces in the yellow, and the combination appears as a brilliant blue-white to the human eye.

Current and Future Applications

Light emitting diodes have many advantages over older light sources; these include much lower energy consumption, longer lifetime, more compact size, and physical robustness. They are replacing incandescent lamps in applications as diverse as traffic signals, car headlamps, flashlights, camera flashes, and medical devices. Recently LEDs have overtaken compact fluorescent lighting for energy efficient general and domestic lighting, with the advantages of longer life, lower energy consumption, and the lack of mercury used in manufacturing.

Future LED development will explore the use of cheaper materials and simpler manufacturing processes. Currently, LEDs require elements like indium and gallium, which are relatively rare. Current research is attempting to use much more Earth-abundant materials such as silicon and carbon in LEDs. Future LEDs may also be made much more economically using a liquid coating process, rather than the current process modeled on the multiple-step vacuum-deposition process of semiconductor fabrication.

Learning Activity: Light Emitting Diodes

Activity Flow Chart:

Describe LED bandgaps and light quantization - preparatory material lecture

$E=h\nu$

Observe LED behavior and calculate LED energies - lab (~.5 hr)

Measure voltage produced by LED as a funtion of illuninating color- lab(~1hr)

Discussion - Quantum concepts interpretation of data and social and economic implications (post lab lecture)

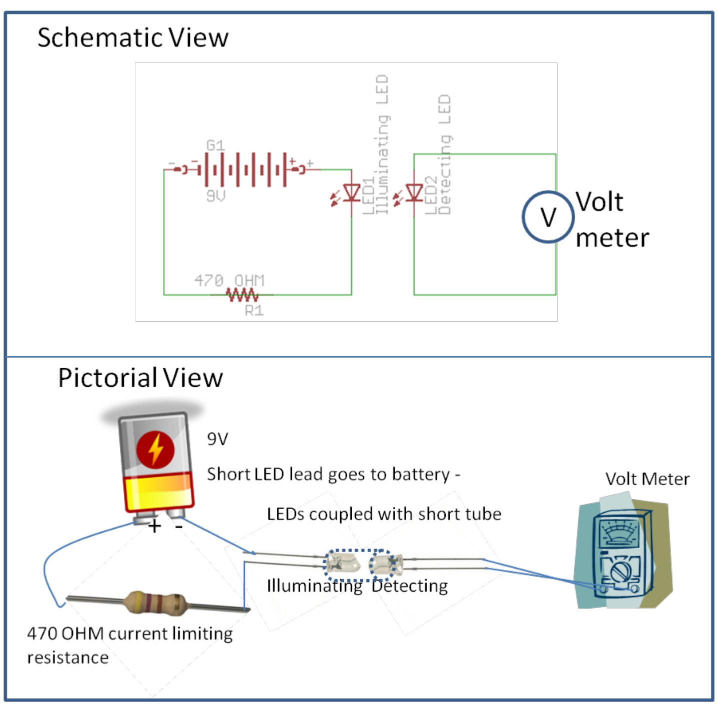
Light Emitting Diodes

Materials and Equipment

- Light Emitting Diodes **-** Assorted LED's of different colors
- Leads with alligator clips or similar to make connections.
- A 9V battery or equivalent low voltage low amperage power supply
- Current limiting resistors, ~470 Ohm, necessary to protect the LED from over current.
- Small diameter opaque tubing
- Voltmeter
- Red laser pointer
- Optional – soldering equipment, circuit boards, or breadboard circuits

Procedure

1. Assemble the LED illuminating and detecting circuits, according to the diagram below, Connect the resistor, source LED, and power source in series for light emission, Connect the detector LED and voltmeter in series for voltage detection. Couple the two LEDs with a short length of opaque tubing.
    a. Connections can be made via alligator clip jumpers and/or twisting wire leads together.
    b. This activity will require using numerous combinations of LEDs; for example if 6 colors are available, 6x6=36 observations need to be made. Both LEDs should be easily changed. Simple color coded alligator clip leads work.



2. Verify Operation: Try the LED with forward and with reversed polarity. Does it light up?
3. Calculate the energy corresponding to each LED
    a. Find the wavelength (in meters) of the LEDs by looking at the product specifications
    b. Using the wavelength, calculate the energy using

$$E=hc/\lambda$$

where λ= wavelength (in meters), h = Plank's Constant, and c = speed of light.

4. Collect Data
    a. Go through all possible combinations of LED colors for the illuminating and detecting LEDs
    b. Note whether there is a signal observed in the detecting LED
    c. Record the results in the table below.
    d. Replace the illuminating LED by a red laser pointer for the final set of measurements

Data Table

			Detector				
		Color	IR	RED	YELLOW	GREEN	BLUE
		Energy					
Illuminator	Color	**Energy**					
	IR						
	RED						
	YELLOW						
	GREEN						
	BLUE						
	Laser Ptr						

Discussion Questions

1. Review the data you collected. Is there a general trend in the data?

2. How do higher and lower energy LEDs interact?
3. What did the laser pointer do?

Contributors

This module was
- Developed and written by Dr. Sam Levenson of Harper College, Palatine IL
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Resources

Books

1. E. Fred Schubert, Light-Emitting Diodes, 2nd ed., Cambridge, UK ; New York: Cambridge University Press 2006, 422 pages.

Online Resources

1. "Some Basic Information of LEDs", www.ledinside.com/knowledge/2008/6/Some_Basic_Information_of_LEDs_20080618
2. "The Basics of LEDs", www.lightingdesignlab.com/sites/default/files/pdf/Basics%20of%20LEDs.pdf
3. "LED Basics", www.energy.gov/eere/ssl/led-basics
4. Nanohub: http://nanohub.org/resources/11829,