Drexel University
ECE-E302, Electronic Devices
Lab I: Light Emitting Diode
Modified April. 2016

Light Emitting Diode

Learning Objectives

1. Learn relation between semiconductor bandgap and its emission spectrum.
2. To obtain the emission spectrum and I-V characteristics of a light emitting diode (LED) and relate it to the material composition of the LED.

Simple Theory of Light Emitting Diode

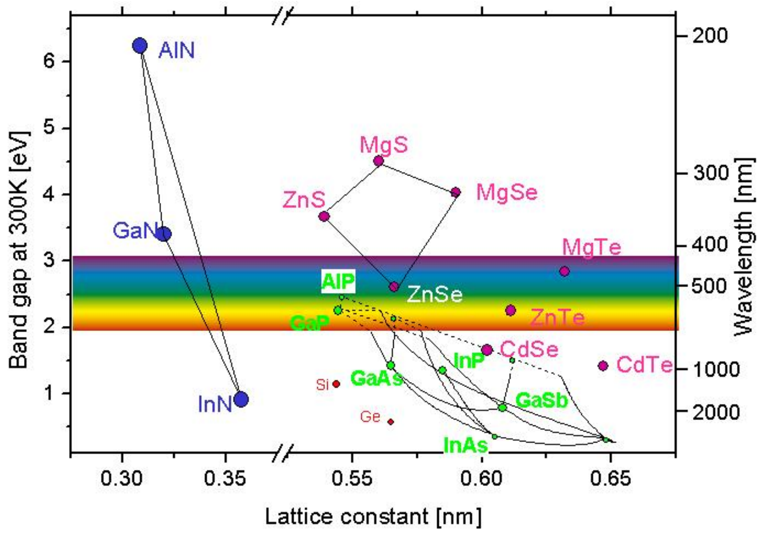
In a junction LED, photons of near-bandgap energy are generated by the process of injection luminescence or electroluminescence in which large population of electrons, injected by forward bias into a normally empty conduction band on the p-side of a PN junction, recombine with holes in the valence band emitting photons with energy near the bandgap. Likewise, holes injected by forward bias into the n-side radiatively recombine with electrons and contribute to the production of photons. Thus the LED converts the input electrical energy into output optical radiation in the visible or infrared portion of the spectrum depending on the semiconductor material used. The energy conversion takes place in two stages; first the energy of carriers in the semiconductors is raised above their equilibrium value by electrical input energy, and second most of these carriers, after having lived a mean life time in the higher energy state, recombine with holes, causing spontaneous emission of photons with energy nearly equal to the bandgap E_g of the semiconductor. Under forward bias, minority carriers are injected on both sides of the junction and these excess minority carriers diffuse away from the junction, recombining with the majority carriers as they do so.

Most of the excess minority carriers on both sides of the junction recombine radiatively with the majority carriers to create photons of frequency υ given by

$$E = h\upsilon \tag{1}$$

The wavelength of light emission required usually dictates the semiconductor materials required, in terms of their bandgap energy. An equally important factor is the ability to heavily dope these materials n- and p-type and thereby fabricate a junction diode. Lower bandgap materials are required for infrared and far-infrared applications, and larger bandgap materials are needed for a light source in the visible part of the spectrum.

Diagram below shows the Energy Bandgap versus lattice constant for common elemental and compound semiconductors



(Source of this information is from T. Paskova and K. R. Evans "GaN substrates-Progress, status and prospects", IEEE J. Sel. Topics Quantum Electron., vol. 15, no. 4, pp.1041-1052 2009). The visible spectrum is identified in the above diagram. It is seen here that GaN substrate may be used for high energy/short wavelength range such as blue, and GaAs for infrared, near infrared, and red. However neither material has the right bandgap, so GaN should be mixed with InN in order to provide the right bandgap for emission in blue. Similarly a compound of GaAs and GaP produces GaAsP which can have a bandgap needed for emission of red light.

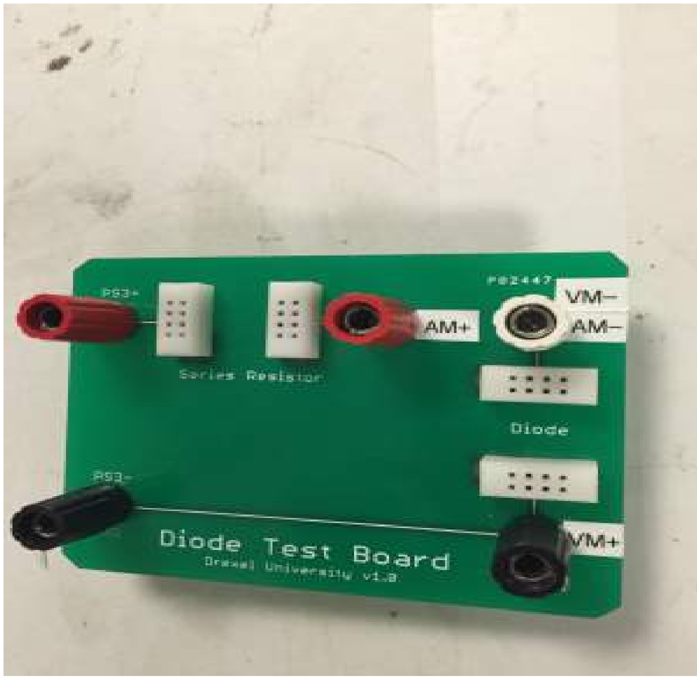
In this lab you will measure the emission spectrum of the several LEDs and determine what was the material composition of the PN junction diode that produced this emission spectrum.

<u>Procedures</u>

a) Obtain the emission spectrum of the white, red, green, blue and yellow LEDs.
   1. Connect OceanOptics Spectrometer and Fibers to lab PC, open the program **OceanOptics -> Spectrum Suite**
   2. Use breadboard to build a series circuit to drive your LEDs.

b) Show that the LEDs are diodes (You only need to perform this part on red LED):
   1) Using curve tracer board to automatically obtain the I-V curve and observe

the light intensity changing with voltage bias.



Diode Curve Tracer Board

2) Use the cables to connect the curve tracer board to the corresponding equipment.

PS3+	third terminal (+) of power supply
PS3-	third terminal (-) of power supply
AM+	Ampere Meter (+)
AM-	Ampere Meter (-)
VM+	Volt-Meter (+)
VM-	Volt-Meter (-)
Series Resistor	50kohm

3) Open the program Lab resources -> LabView vi’s -> CurveTracer. Make sure all your instruments are ON. Then select diode mode, enter the parameters.

Start Voltage (V)	0 V
Vps_max (V)	5 V
# of points	How many points you want to measure

c) Produce current - peak intensity plots, note if there is a threshold, or if the relation is linear. You need to build a series circuit on the bread board to drive the LED.

Questions to answer:

1) Are the LEDs photodectectors as well? Reverse bias an LED and shine a laser light from a laser pointer, check to see that the current changes.
2) Relate the peak of the emission spectrum to the bandgap of semiconductor. Use the figure above to find the candidate material which can produce this light. What is the compound? What is the mole fraction[1] of the compound that emits the light? (Search online for what is mole fraction and how to calculate it if you don't know.) In addition to your measurements you can find information from the manufacturer of the LEDs.
3) Read the paper (on the BBlearn website) written by Dr. Shuji Nakamura who is the Nobel prize winner in physics last year, please write a paragraph about the white LED. Why is the white LED so important? How to make white LED in terms of the materials and semiconductor physics? You can use any references that you want to, but make sure you have cited those references.

Extra Credit Questions:

4) What is the lighting method of Samsung S7 or iPhone 6S? Are LEDs used for backlighting only or are they used as pixels as well?
5) What is the market size of LEDs for lighting in the U.S.? How does it compare to LEDs for displays?

Additional Reading Material

Introduction to LED's (link on the ECE-E302 course website)

[1] Mole fraction x, is noted in compounds as $Al_xGa_{1-x}As$ meaning the compound is a mix of x% AlAs and (1-x)% GaAs. So, $Al_{0.3}Ga_{0.7}As$ is 30% AlAs, and 70%GaAs.