Semiconductors and Planck's Constant

Introduction

In 1900 Max Planck was able to explain the spectral profile of blackbody radiation by postulating that the energy of the radiation was proportional to the frequency of the radiation or E = h*f*. The proportionality constant (h) is known today as the Planck constant which is 6.63×10^{-34} J·s. In the experiment we use the electrical and optical properties of a light-emitting diode (LED) to determine the Planck constant.

A LED is a special type of semiconductor with a p-n junction. A semiconductor is characterized by a band-gap between the valence band and the conduction band, as shown in Figure 1.

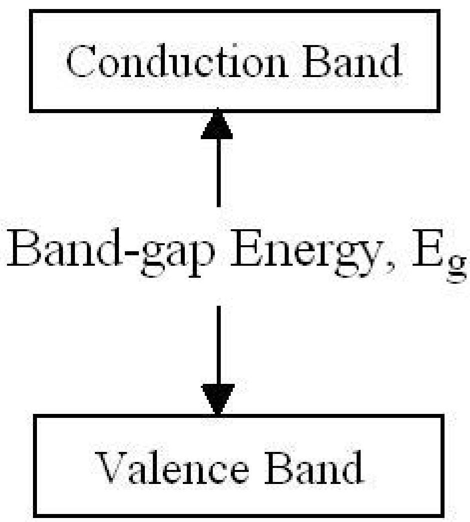


Figure 1 Energy Diagram

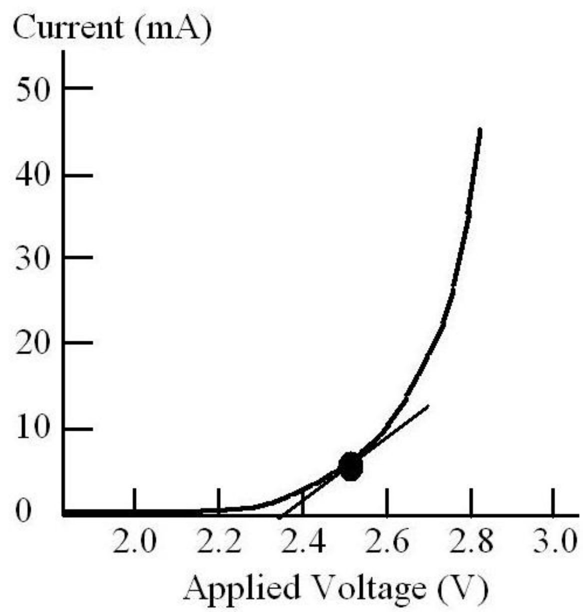


Figure 2 LED I-V Curve

Electrons can be promoted from the valence to the conduction band by applying a voltage across of LED. They increase the electrical conductivity of the LED. The relationship between the current (I) in the LED and the applied voltage (V) is similar to any other diode. A typical I-V curve of the LED used in the experiment is shown in Figure 2. To find the voltage (V_o) that corresponds to the band-gap energy we first find the inflection point ($\frac{d^2I}{dV^2} = 0$) on the I-V curve and draw a line tangent to that point. The intersection between the tangent line and the axis of the Applied Voltage provides V_o. Figure 2 shows V_o to be about 2.35 V. With the definition of V_o we have ,

$$eV_o = E_g \qquad [1]$$

where e is electronic charge and E_g is band-gap energy of the LED.

An excess electron in the conduction band can fall spontaneously to the valence band and combines with a hole in the valence band. The electron-hole recombination leads to light emission. It is assumed that the center of the emission spectrum corresponds to E_g. According to Planck's postulate,

$$E_g = hf = \frac{hc}{\lambda} \qquad [2]$$

where f is the frequency of the photon emitted by the LED, c is the speed of light, and λ is the wavelength of the photon. Equations [1] and [2] yield

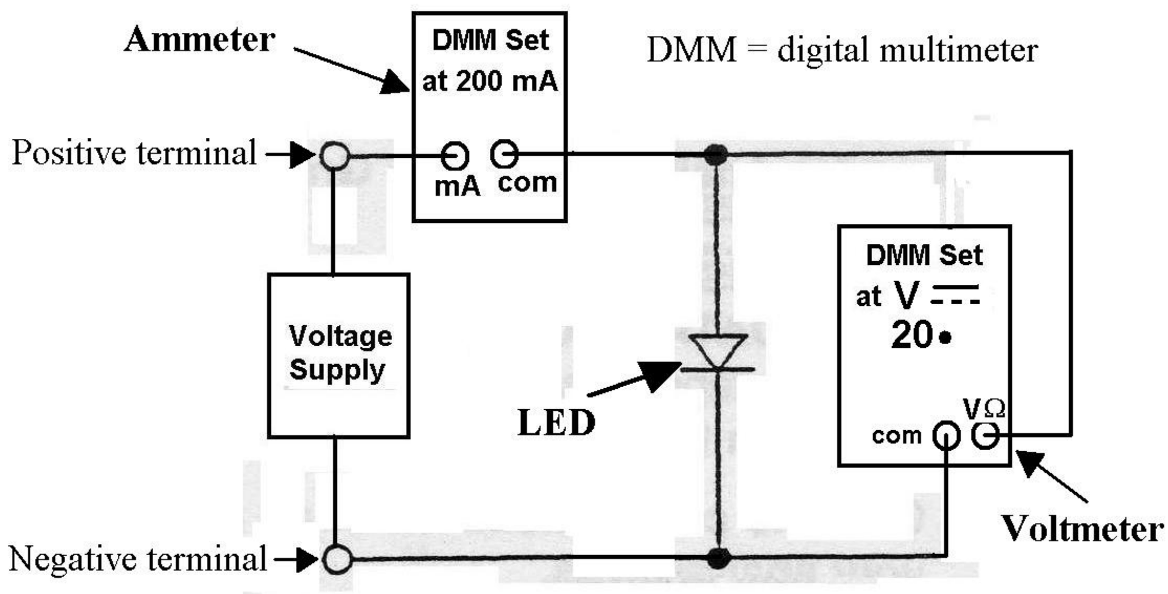
$$h = \frac{eV_o\lambda}{c} \qquad [3]$$

In the experiment we measure V_o and λ of a green LED. Equation [3] yields h, the Planck constant.

Experimental Procedure

Measurement of the Current vs Voltage curve to determination of V_o

You are given a green LED. The goal is to measure the voltage across the LED and the current in the LED to obtain V_o. Connect the LED according to the following circuit.



Procedure

Measurement of V_o

The relevant data lie between 2.2 V and 2.8 V

1. Measure the voltage across of LED with the voltmeter and the current with the ammeter. Enter the voltage and current in the DATA SHEET.
2. Check to make sure you have enough data points around V_o.

Measurement of the LED emission wavelength

1. Place the LED in front of the entrance slit of the grating spectrometer.
2. Slowly increase the output voltage of the power supply to about 3 V.
3. Look into the telescope of the spectrometer. Move the telescope to the left of the central axis until you can see the green light of the LED. When the light intensity is perceived to be maximum, record the angle of the grating table as θ_L. Enter the angle in the DATA SHEET.
4. Move the telescope to the right of the central axis until you can see the green light of the LED. When the light intensity is perceived to be maximum, record the angle of the grating table as θ_R. Enter the angle in the DATA SHEET.

Report

1. Plot the I-V of the LED. The plot should show the current (I) on the vertical axis and the voltage (V) on the horizontal axis. Use the plot to determine V_o. Report V_o.

2. Calculate the absolute value of $\theta_R - \theta_L$. Let $\theta = \frac{1}{2} |\theta_R - \theta_L|$. Use the following formula to calculate the wavelength λ of the LED green light: $\lambda = 3.33 \sin\theta$ where λ is in units of microns

3. Use $h = \frac{eV_o\lambda}{c}$ to determine the Planck constant. Show calculations and report your calculated the Planck constant.

4. Use your Planck constant to calculate the percent error in the determination of the Planck constant. Use the following equation,

$$\%\,error = \frac{\left| your\ \ value - 6.63 \times 10^{-34} \right|}{6.63 \times 10^{-34}} \times 100\%$$

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DATA SHEET

1. I-V data for the green LED

As you collect pairs of (V,I) data, plot the data on a graph (I vs V) so that you would be able to tell whether you have sufficient data to show a useful I-V curve.   The following table has 20 slots for your data. You might not need that many pairs of measurements.

Voltage (V)	Current (mA)		Voltage (V)	Current (mA)

Diffraction angle of light from the green LED

Angle dial reading	
θ_L	θ_R