EE236: Experiment No. 1
Diode I-V Characteristics

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1 Overview of the experiment

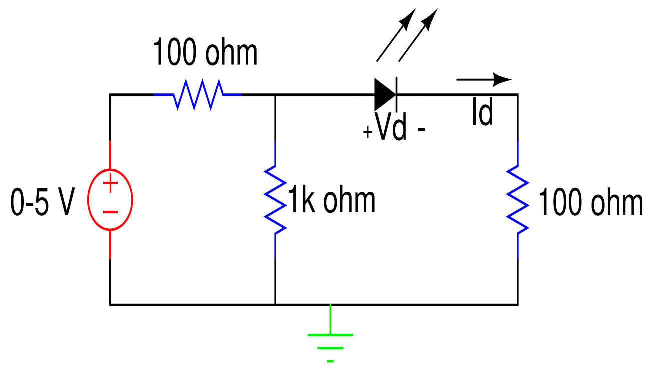
1.1 Aim of the experiment

Aim of this experiment is to analyze the forward bias I-V characteristics of diodes made up of different materials.
To determine if these characteristics depend on the band gap of the material of which the semiconductor is made.

1.2 Methods

Firstly, I read and understood the background theory of light emitting diodes and the concept of band gap. Then, I wrote the netlist for simulation model and simulated each diode one by one and then combined all in a single I_d vs V_d graph using dc analysis for V_d varying from 0-5V. Similarly, I obtained the $\log(I_d)$ vs V_d graph. Then, I calculated the slopes, ideality factors (η), saturation currents (I_s) using y-intercepts and band gaps (E_g) using emission wavelengths.

2 Design



This is the circuit for simulation of light emitting diodes. I simulated all the given LED models namely 1N914, RED, GREEN, BLUE, WHITE and plotted I_d vs V_d [Plot 1] and log(I_d) vs V_d [Plot 2] graphs.
I found the slope of each line using $\frac{y_2-y_1}{x_2-x_1} = m$ and also y-intercepts using $y = mx + c$.
Then, using this given equation,

$$slope = \frac{lnI_{D2} - lnI_{D1}}{V_{D2} - V_{D1}} = \frac{1}{\eta V_T} \tag{1}$$

I calculated the η value of each diode by taking V_T as 26mV.
From the y-intercept, I calculted the Saturation current (I_s) of each diode using,

$$I_s = e^{(y-intercept)} \tag{2}$$

After this, I noted the values of wavelengths of blue, green, white and red LEDs as 450nm, 520nm, 625nm and 445nm by looking their emission intensity spectrums.
I calculated the value of band gap (E_g) of each diode using,

$$E_g = \frac{hc}{\lambda} \tag{3}$$

Lastly, I found the values of V_d corresponding to I_d = 1mA by manually selecting the points on the graph and plotted the E_g vs V_d graph to find the correlation between them.

3 Simulation results

3.1 Code snippet

```
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Blue Diode LED Analysis
Including Blue Diode LED model file
.include blue_5mm.txt
Resistors
R1 In 1 100
R2 1 0 1k
R3 3 0 100
Diode
D1 2 3 BLUE
Battery
Vin In 0 dc 0.01
Vbl 1 2 dc 0
DC Analysis
.dc Vin 0.01 5 0.01
.control
run
set color0 = white
set color1 = black
set color2 = blue
set color3 = red
set xbrushwidth = 2
Id vs Vd plot
let V = V(2) - V(3)
plot I(Vbl) vs V
.endc
.end
```

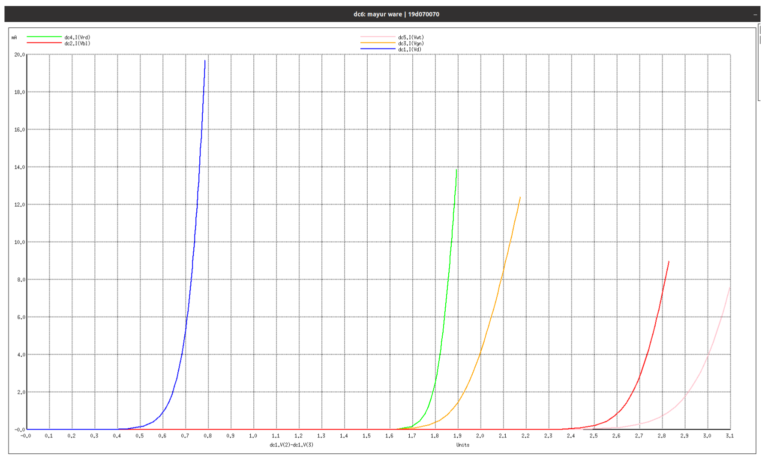
Similar files for WHITE, RED, GREEN and 1N914 diodes using the respective models.

Commands for combined plts :

```
plot dc1.I(Vd) vs dc1.V(2)-dc1.V(3) dc2.I(Vbl) vs dc2.V(2)-dc2.V(3)
dc3.I(Vgn) vs dc3.V(2)-dc3.V(3) dc4.I(Vrd) vs dc4.V(2)-dc4.V(3) dc5.I(Vwt)
vs dc5.V(2)-dc5.V(3)
```

```
plot log(dc1.I(Vd)) vs dc1.V(2)-dc1.V(3) log(dc2.I(Vbl)) vs dc2.V(2)-dc2.V(3)
log(dc3.I(Vgn)) vs dc3.V(2)-dc3.V(3) log(dc4.I(Vrd)) vs dc4.V(2)-dc4.V(3)
log(dc5.I(Vwt)) vs dc5.V(2)-dc5.V(3)
```

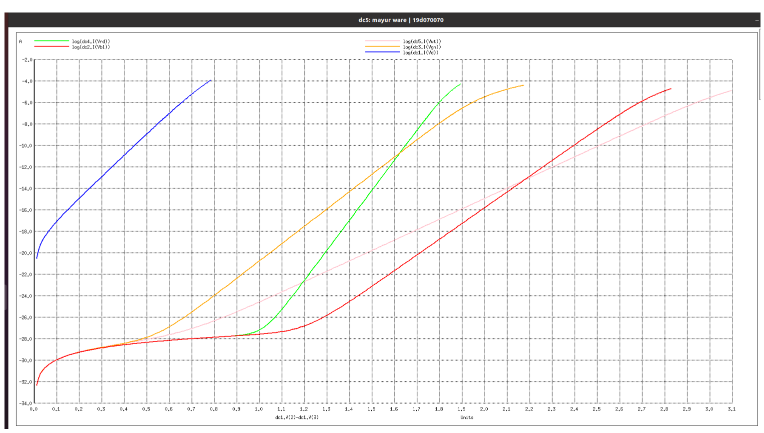
3.2 Simulation results



Combined plot for I_d vs V_d

In this plot, we can observe that all diodes have similar nature but they are showing deviation in forward bias voltages. 1N914 and white LED have the lowest and highest forward bias voltage respectively.
These curves follow the diode I-V characteristic equation,

$$I_d = I_0 e^{\frac{E_g}{kT}} (e^{\frac{qV_d}{\eta kT}} - 1) \tag{4}$$



Combined plot for $log(I_d)$ vs V_d

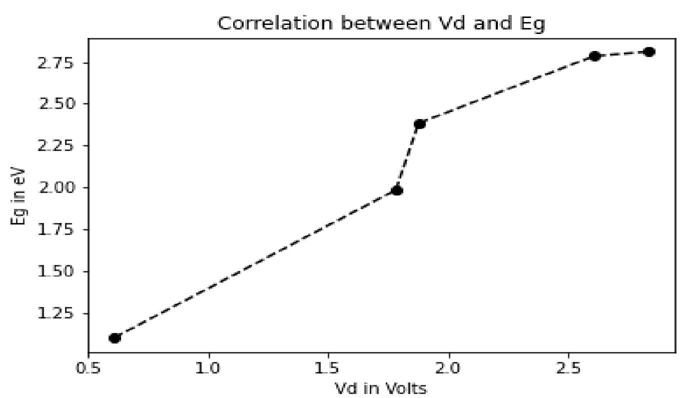
After certain thresholds, graphs are straight lines with different slopes and y-intercepts.
Calculated values of Slope of line (m), Ideality factor (η), Saturation current (I_s), Voltage across diode (V_d) and Band gap (E_g) for each diode are given in the following table :

	m	η	I_s (in A)	V_d (in V)	E_g (in eV)
1N914	19.8128	1.9415	6.601e-9	0.611	1.1
RED	27.6365	1.3916	6.914e-25	1.782	1.984
GREEN	16.00	2.4038	1.149e-16	1.877	2.384
BLUE	14.4769	2.6567	3.504e-20	2.607	2.786
WHITE	9.4393	4.0745	2.250e-15	2.831	2.813

Correlation between V_D ang E_g :

$$ln(\frac{I_D}{I_{00}}) + \frac{E_g}{kT} = \frac{qV_D}{kT} \tag{5}$$

From this equation, we can note that V_D will increase with increase in E_g for constant I_D and I_{00}.



Correlation between V_d and E_g

But, there is a slight variation in the linearity of graphs due to i) Ideality factor (η) is not equal to 1 in real experiments and ii) Saturation currents of all LEDs are not same as we have assumed.

4 Experimental results

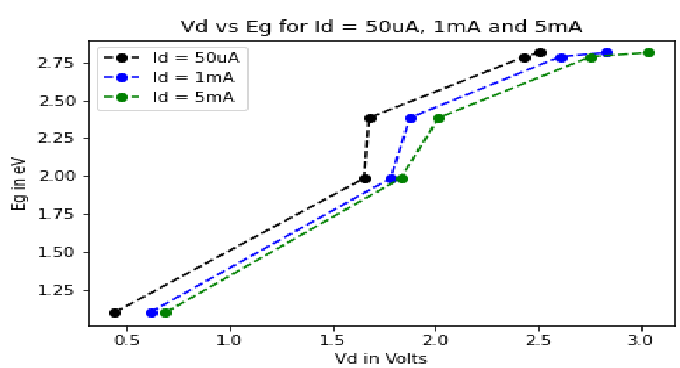
This section is not applicable for this experiment.

5 Experiment completion status

I have completed all sections as well as exercises in this lab.

6 Questions for reflection

Q1) `What is the material a White LED is made of? What value of` E_g `will you choose for it?`
Answer : The White LED is made up of typical Blue LED material and a Yellow phosphorous coating. This combination of Blue + Yellow light emits White light. This can be confirmed by looking at the emission spectrum of White LED which has two peaks corresponding to Blue and Yellow colors.
I chose the highest peak (Blue) as the major contributor in the spectrum. So, I calculated the value of E_g according to it.
Q2) `Are the equations (2) and (3) satisfied for the entire range of` V_D`?`
Answer : We have assumed the voltage comes entirely across the depletion region of diode and have ignored the $I_d * R$ drop in neutral diode region. But, for the higher values of V_d, thus I_d, this drop will be significant and can't be neglected.
Also, we have assumed q$V_D >> kT$ to establish the proportionality between V_d and E_g. So, for lower values of V_d, this assumption will not be valid and we also have take into consideration the R-G Process as well as drift current.
Q3) `Look at the correlation between Vd and Eg by choosing a current ID of 50A and 5mA and see how non-ideality of I-V affects the experiment.`
Answer :



Correlation between V_d and E_g for I_d = 50uA, 1mA and 5mA

All the plots are almost of the same nature.

$$I_D = I_{00} e^{\frac{-E_g}{kT}} (e^{\frac{qV_D}{lkT}} - 1) \tag{6}$$

I_{00} is constant for a ideal diode. But, it varies in non-ideal diode, so the correlation between E_g and V_D doesn't vary too much.