EE 236: Experiment No. 1
Estimation of Band Gap of Different Semiconductor Materials through Diode I/V Characterization

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1 Overview of the experiment

1.1 Aim of the experiment

To determine whether the forward I-V characteristics of a diode depend on the bandgap of the semiconductor material of the diode.

1.2 Methods

We considered 5 diodes in the experiment: Red, Green, Blue, White, 1N914. We targeted at:

- Proving that the bandgap of different diodes are different.
- Determining the bandgaps of the 5 diodes.

The first step was to write the netlist for the circuit given in the lab handout for all 5 diodes. I created 5 different parallel circuits with a common voltage source and ground. Then I ran the program for a DC analysis of the voltage source to obtain the IV characteristics. Further steps involved finding the corresponding voltages to 1mA current for all 5 diodes.

2 Design

The netlist of the circuit contains 2 100 Ω and 1 1 kΩ resistors, a voltage source and the particular diode. DC analysis was performed by varying V_{in} from 0.01 to 5V in steps of 0.01V to obtain the I-V characteristics. The circuit diagram is given below.
We plotted I vs V across the diode which is given by:

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

Next step was to plot $ln(I)$ vs V, given by:

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

The slope obtained from the steady state part of the plot gave us $\frac{q}{kT}$. The slope is given by:

$$\frac{ln(I_{D2}) - ln(I_{D1})}{V_{D2} - V_{D1}} = \frac{1}{\eta V_T}$$

where, η is the ideality factor of the diode.

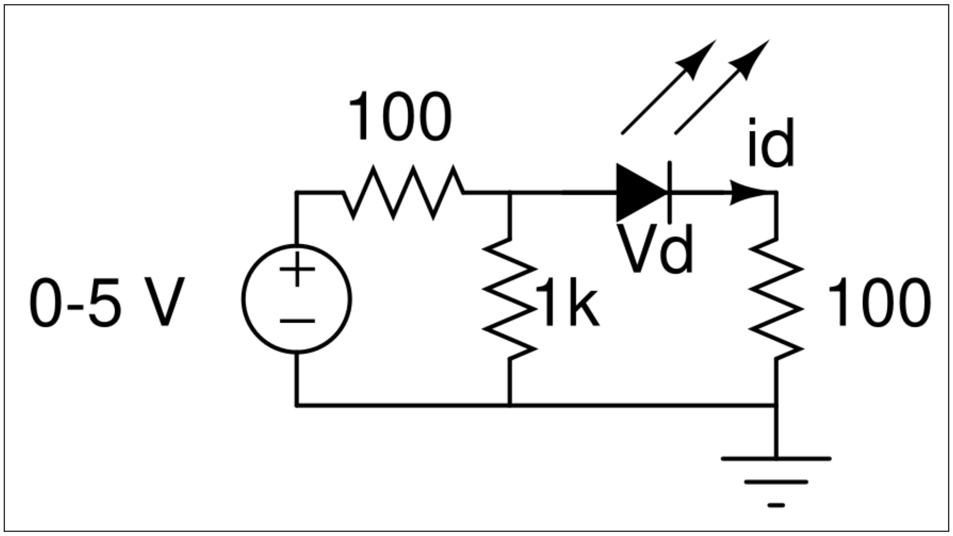


Figure 1: The IV Characterization Circuit

The y-intercept of the graph gives us the saturation current, I_S.
Then, the emission wavelengths of the colours were obtained from the peaks of the graphs. A constant value of I_D was chosen to obtain corresponding values of V_D. Using these values, E_g vs V_D was plotted for $I_D = 1$ mA.

3 Simulation results

3.1 Code snippet

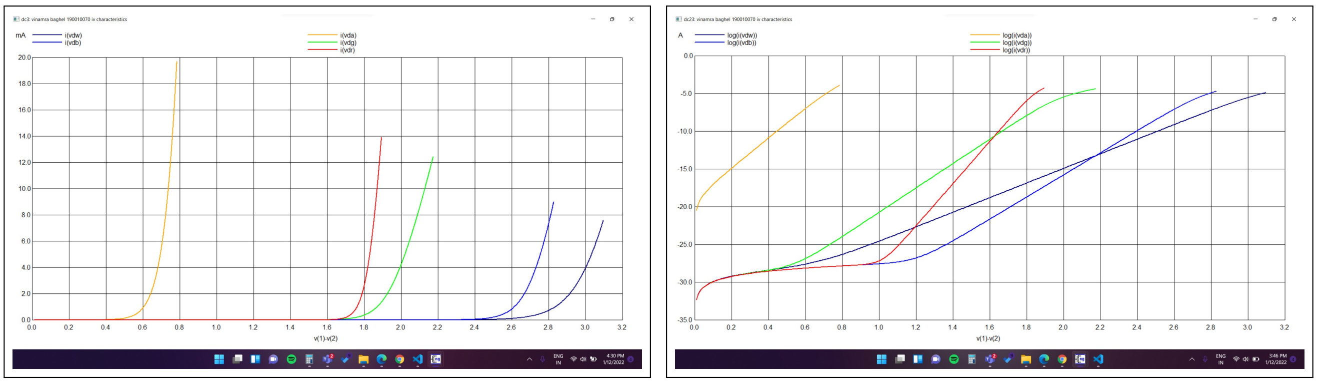
```
Vinamra Baghel 190010070 IV Characteristics

.include red_5mm.txt
.include blue_5mm.txt
.include green_5mm.txt
.include white_5mm.txt
.include Diode_1N914.txt

*Netlist
r1 in 1 100
r2 3 gnd 100
r3 1 gnd 1k
Dr 1 2 RED
Vdr 2 3 0

r4 in 4 100
r5 6 gnd 100
r6 4 gnd 1k
Db 4 5 BLUE
Vdb 5 6 0

```

```
r7 in 7 100
r8 9 gnd 100
r9 7 gnd 1k
Dg 7 8 GREEN
Vdg 8 9 0

r10 in 10 100
r11 12 gnd 100
r12 10 gnd 1k
Dw 10 11 WHITE
Vdw 11 12 0

r13 in 13 100
r14 15 gnd 100
r15 13 gnd 1k
Da 13 14 1N914
Vda 14 15 0

Vin in gnd 0

*Analysis
.dc Vin 0.01 5 0.01

*Control
.control
run
set color0 = white
set color1 = black
set color2 = red
set color3 = blue
set color4 = green
set color5 = navy
set color6 = orange
set xbrushwidth = 2

*plot I(Vdr) vs V(1)-V(2) I(Vdb) vs V(4)-V(5) I(Vdg) vs V(7)-V(8) I(Vdw) vs V(10)-V(11) I(Vda) vs V(13)-V(14)
plot log(I(Vdr)) vs V(1)-V(2) log(I(Vdb)) vs V(4)-V(5) log(I(Vdg)) vs V(7)-V(8) log(I(Vdw)) vs V(10)-V(11) log(I(Vda)) vs V(13)-V(14)
let Vd1 = V(1)-V(2)
let Vd2 = V(4)-V(5)
let Vd3 = V(7)-V(8)
let Vd4 = V(10)-V(11)
let Vd5 = V(13)-V(14)
meas dc Vd1 find Vd1 when I(Vdr) = 1m
meas dc Vd2 find Vd2 when I(Vdr) = 1m
meas dc Vd3 find Vd3 when I(Vdr) = 1m
meas dc Vd4 find Vd4 when I(Vdr) = 1m
```

```
meas dc Vd5 find Vd5 when I(Vdr) = 1m
.endc
.end
```

3.2 Simulation results

The first graph below is of the I-V characteristics of the diodes. The second one is of ln(I) vs V. The second graph has a steady state part later which is a straight line, satisfying the 2nd equation above.



(a) I vs V (b) log(I) vs V

Figure 2: IV Characteristics

The third graph below is of E_g vs V for a given value of $I_D = 1$ mA. The expected relation between the 2 is linear and monotonically increasing. We do see a slight deviation from this in the plot obtained which might be attributed to changing I_{00} with material.

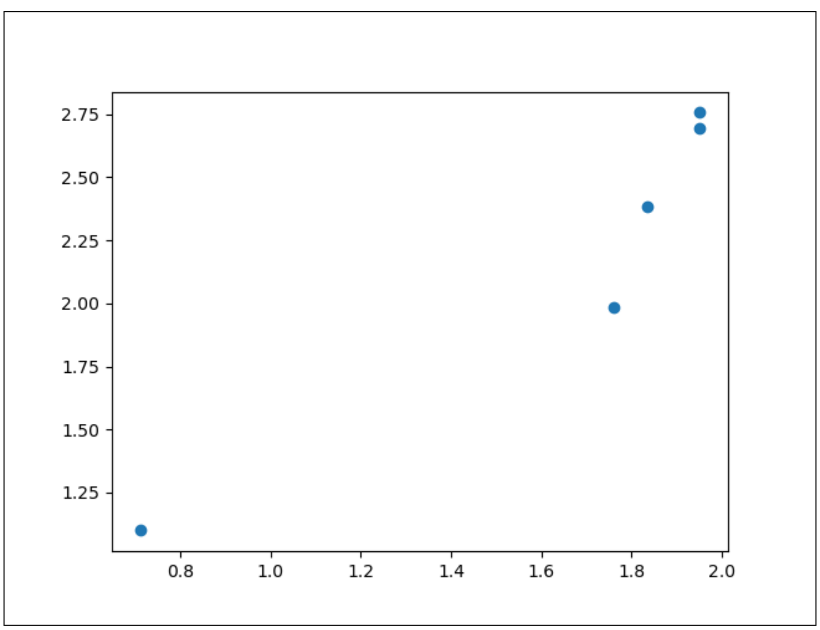


Figure 3: E_g vs V_d

4 Experimental results

The values obtained for the 5 diodes: Red, Blue, Green, White and 1N914 are as follows:

Diode	**Wavelength**, λ (in nm)	**Ideality Factor**, η (in V^{-1})	**Saturation Current**, I_S (in A)	**Bandgap**, E_g (in eV)
Red	625	1.383	4.880 e-25	1.984
Blue	460	2.646	3.279 e-20	2.696
Green	520	2.376	8.876 e-17	2.385
White	450	3.986	1.380 e-15	2.756
1N914	-	1.993	8.963 e-9	1.1

Diode	V_D for $I_D = 1$ mA (in V)
Red	1.761
Blue	1.952
Green	1.834
White	1.952
1N914	0.711

5 Experiment completion status

I could complete all the parts of the lab. There was no hardware involvement as it was all simulation based. The results were shown to the TA and then submitted.

6 Questions for reflection

Question 1. What is the material a White LED is made of? What value of E_g will you choose for it?
White LED is made of a phosphor material over a Blue LED. It emits a broad spectral distribution. Some blue light is converted to yellow by the phosphor while the rest mixes with this yellow light to form white light. The E_g value for white light would be 2.756 for a wavelength of 450 nm (larger peak of the spectral distribution).

Question 2. Are the equations (2) and (3) satisfied for the entire range of V_D?
Equation (2) is satisfied for the entire range of V_D except the forward and reverse **breakdown regions**. Equation (3) has an added condition of $qV_D >> kT$ as it is an approximation.

Question 3. Look at the correlation between V_γ and E_g by choosing a current I_D of 50 μA and 5 mA and see how non-ideality of I-V affects the experiment.
For 5 mA and 50 μA respectively,

- For RED, 1.830 V and 1.651 V.
- For BLUE, 2.607 V and 1.660 V.
- For GREEN, 1.997 V and 1.653 V.
- For WHITE, 2.719 V and 1.660 V.
- For 1N914, 0.742 V and 0.695 V.