EE236: Lab 1
Diode I/V Characterization and Band Gap of Semiconductor Materials

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1 Aim of the experiment

1. To study the forward bias I/V characteristics of diodes and estimate the band gap of the semiconductor material which the diode is made of.

2. To measure and contrast the I/V characteristics of a silicon P-N junction diode, a Schottky diode and a Zener diode.

2 Design & Working

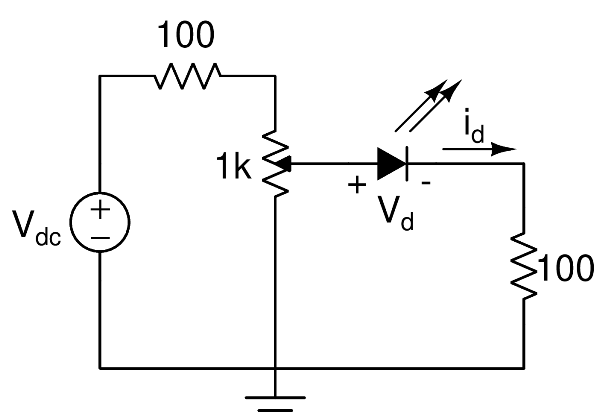


Fig. Circuit to measure I/V characteristics

3 Simulation

3.1 Code Snippet

```
Diode I–V Characteristics and Band–Gap

.include red_5mm.txt
.include green_5mm.txt
.include blue_5mm.txt
.include white_5mm.txt
.include Diode_1N914.txt
Vs 1 0 dc 20
D1 1 2 1N914
D2 1 3 RED
D3 1 4 GREEN
D4 1 5 BLUE
D5 1 6 WHITE
R1 2 12 100
R2 3 13 100
R3 4 14 100
R4 5 15 100
R5 6 16 100
V1 12 0 dc 0
V2 13 0 dc 0
V3 14 0 dc 0
V4 15 0 dc 0
V5 16 0 dc 0
.dc Vs 0.01 5 0.01
.control
run
plot i(V1) vs v(1,2), i(V2) vs v(1,3), i(V3) vs v(1,4),
& i(V4) vs v(1,5), i(V5) vs v(1,6)
plot ln(i(V1)) vs v(1,2), ln(i(V2)) vs v(1,3), ln(i(V3))
& vs v(1,4), ln(i(V4)) vs v(1,5), ln(i(V5)) vs v(1,6)
.endc
.end
```

3.2 Simulation Results

Given below is the plot for I_D vs V_D waveforms for the given 6 diodes obtained from the dc analysis of the circuit:

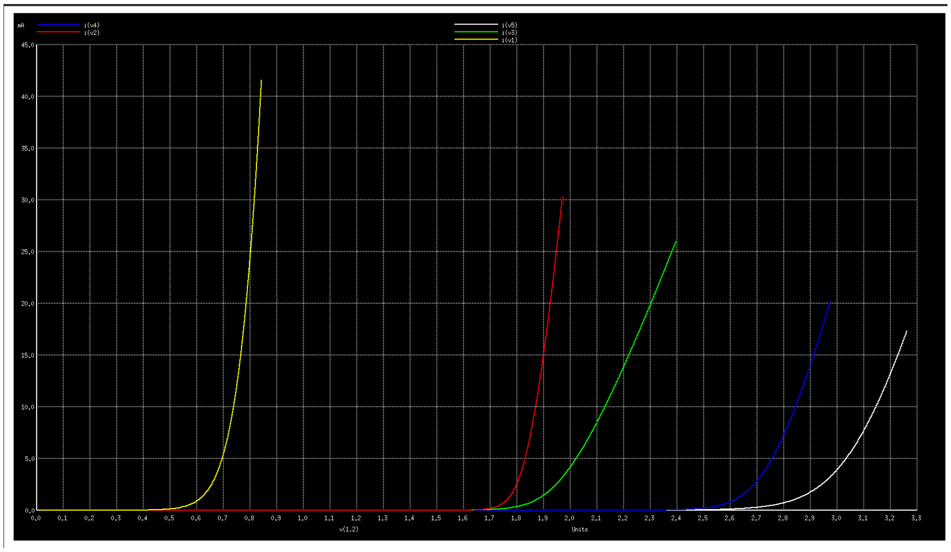


Fig. I-V Plot for the 6 diodes

Given below is the plot for $ln(I_D)$ vs V_D waveforms for the given 6 diodes obtained from the dc analysis of the circuit:

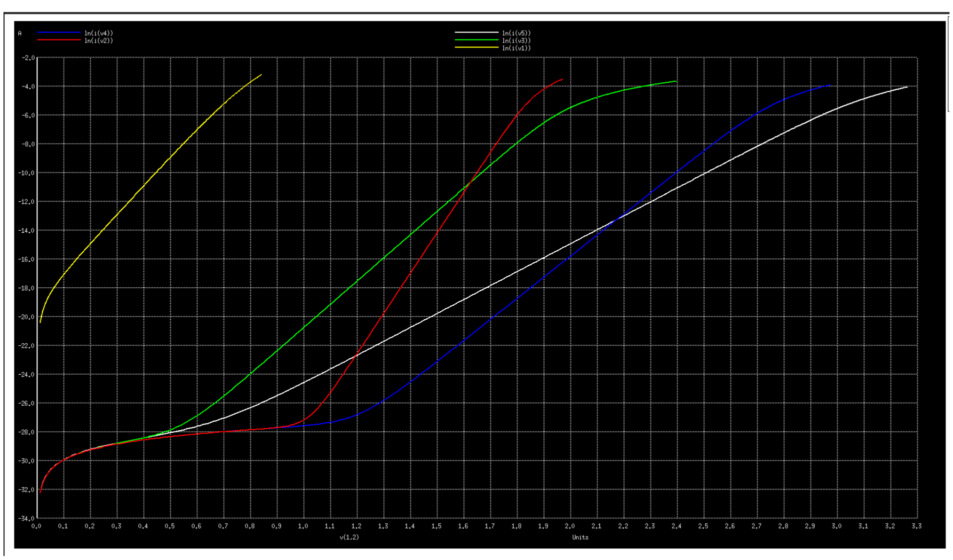


Fig. ln(I)-V Plot for the 6 diodes

4 Experimental Results

The I/V characteristic of a forward biased diode is given by:

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

The saturation current I_S is given as $I_S = I_{00} e^{\frac{E_g}{kT}}$
Assuming $qV_D >> \eta kT$,

$$ln(\frac{I_D}{I_{00}}) + \frac{E_g}{kT} = \frac{qV_D}{\eta kT} \tag{2}$$

The peak emission wavelength of the LED is a measure of the band gap:

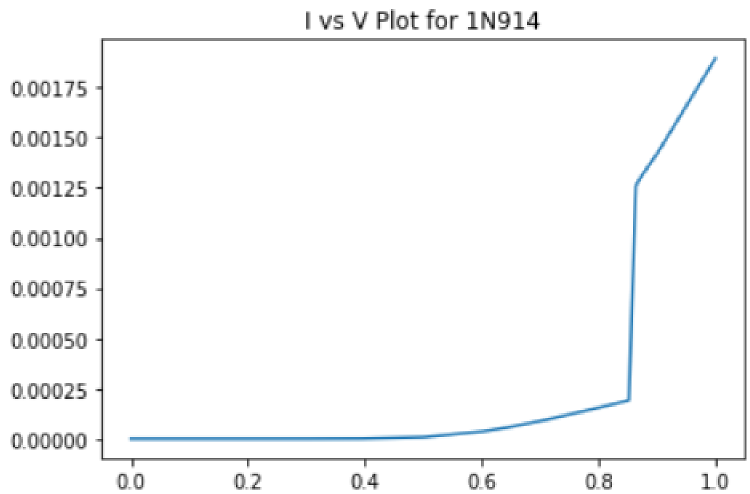
$$E_g = \frac{hc}{\lambda} = \frac{1240}{\lambda} \tag{3}$$

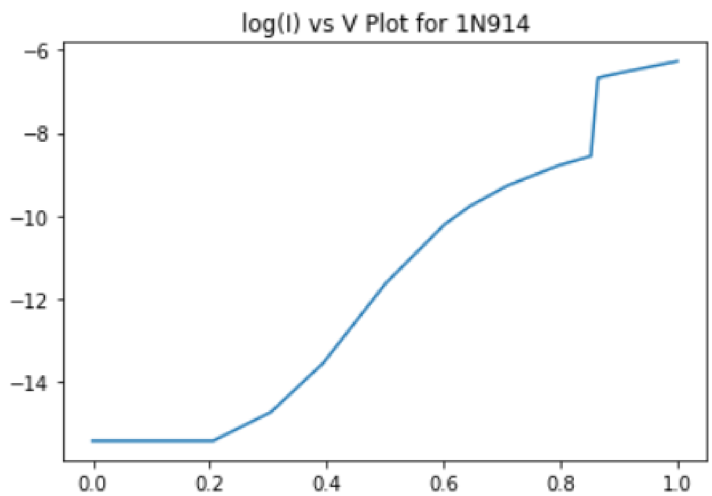
E_g: band gap of the material in units of electron Volts (eV)
λ: emission wavelength in nanometers (nm)

4.1 1N914 Diode

Current (mA)	ln(Current)	Voltage (V)
0.0002	-15.42	0
0.0002	-15.42	0.104
0.0002	-15.42	0.206
0.0004	-14.73	0.305
0.0013	-13.55	0.394
0.0089	-11.63	0.501
0.037	-10.20	0.602
0.057	-9.77	0.645
0.094	-9.27	0.709
0.153	-8.78	0.797
0.192	-8.58	0.852
1.261	-6.68	0.864
1.305	-6.64	0.873
1.427	-6.55	0.902
1.893	-6.27	1.000

Given below is the I-V characteristic plot for the 1N914 Diode:



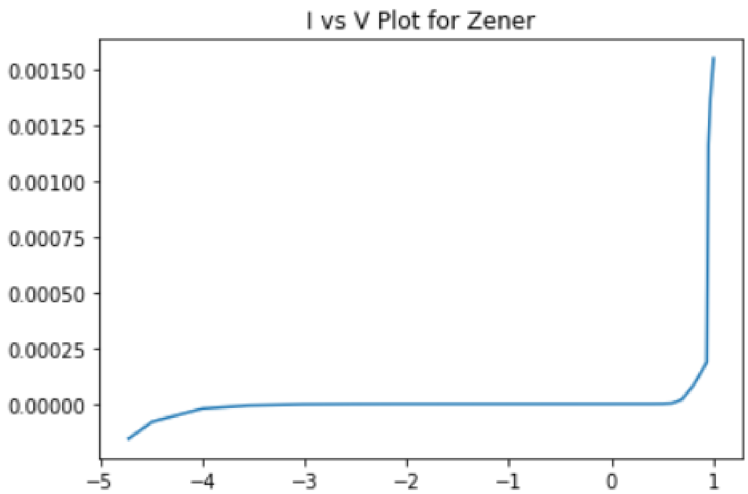


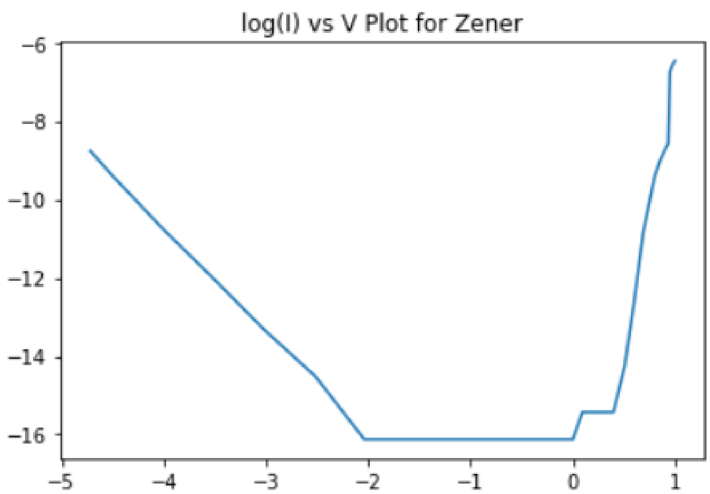
Using the above graphs, we find out the ideality factor for 1N914 Diode, $\eta = 2.541$ and cut-in voltage $V_\gamma = 0.86V$. NGSPice simulations gave a cut-in voltage of $0.6V$

4.2 Zener Diode

Current (mA)	ln(Current)	Voltage (V)
-0.156	-	-4.72
-0.0799	-	-4.49
-0.0209	-	-4.00
-0.0066	-	-3.55
-0.0016	-	-3.01
-0.0005	-	-2.52
-0.0001	-	-2.04
0.0001	-16.12	0
0.0002	-15.42	0.094
0.0002	-15.42	0.197
0.0002	-15.42	0.297
0.0002	-15.42	0.398
0.00065	-14.25	0.508
0.0031	-12.72	0.595
0.0197	-10.83	0.690
0.0815	-9.41	0.801
0.1212	-9.02	0.853
0.1673	-8.69	0.909
0.189	-8.57	0.934
1.165	-6.76	0.950
1.37	-6.59	0.970
1.554	-6.47	1.000

Given below is the I-V characteristic plot for the Zener Diode:



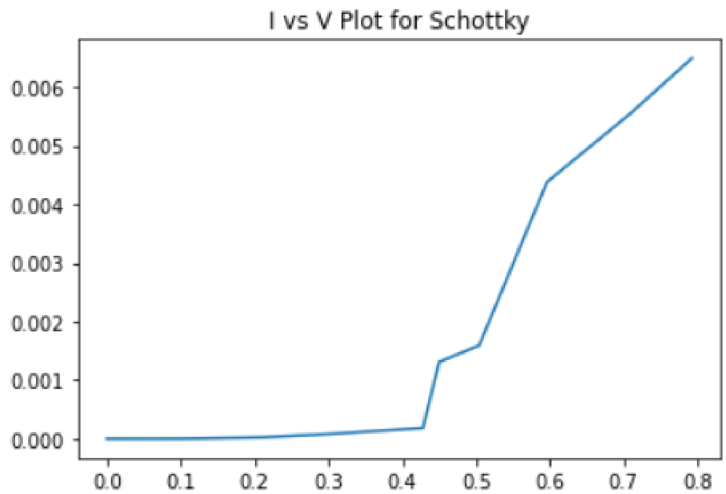


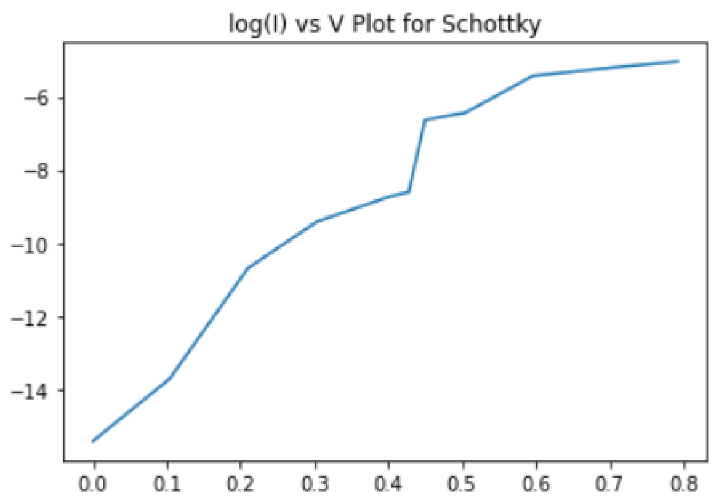
Using the above graphs, we find out the ideality factor for Zener Diode, $\eta = 2.942$ and cut-in voltage $V_\gamma = 0.94V$

4.3 Schottky Diode

Current (mA)	ln(Current)	Voltage (V)
0.0002	-15.42	0
0.0011	-13.72	0.104
0.0227	-10.69	0.210
0.0813	-9.42	0.304
0.1607	-8.74	0.402
0.1816	-8.61	0.428
1.31	-6.64	0.450
1.45	-6.54	0.477
1.59	-6.44	0.504
4.38	-5.43	0.596
5.55	-5.19	0.709
6.49	-5.04	0.792

Given below is the I-V characteristic plot for the Schottky Diode:



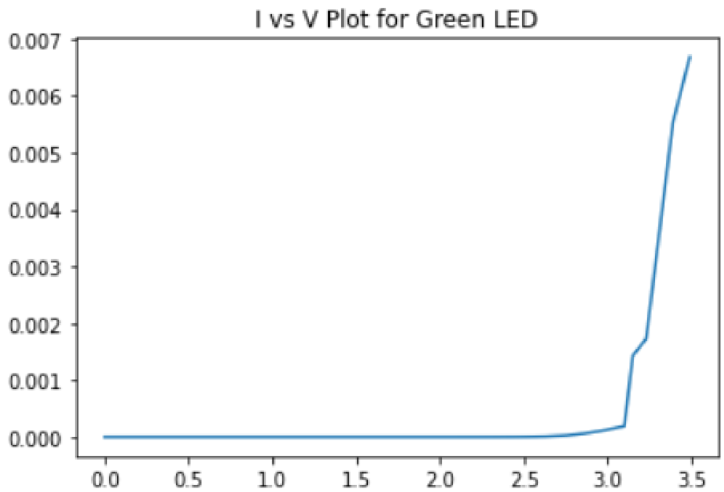


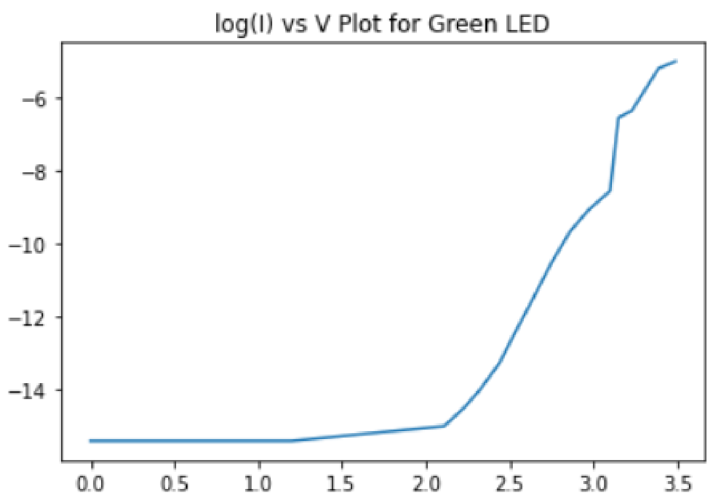
Using the above graphs, we find out the ideality factor for Schottky Diode, $\eta = 2.844$ and cut-in voltage $V_\gamma = 0.44V$

4.4 Green LED

Current (mA)	ln(Current)	Voltage (V)
0.0002	-15.42	0
0.0002	-15.42	0.107
0.0002	-15.42	0.210
0.0002	-15.42	0.315
0.0002	-15.42	0.394
0.0002	-15.42	0.513
0.0002	-15.42	0.811
0.0002	-15.42	1.002
0.0002	-15.42	1.197
0.0003	-15.02	2.11
0.0005	-14.51	2.23
0.0008	-14.04	2.32
0.0017	-13.28	2.44
0.0035	-12.56	2.52
0.0091	-11.61	2.63
0.0265	-10.54	2.75
0.0621	-9.69	2.86
0.1126	-9.09	2.97
0.1911	-8.56	3.10
1.427	-6.55	3.15
1.727	-6.36	3.23
5.53	-5.20	3.39
6.68	-5.01	3.49

Given below is the I-V characteristic plot for the Green LED:





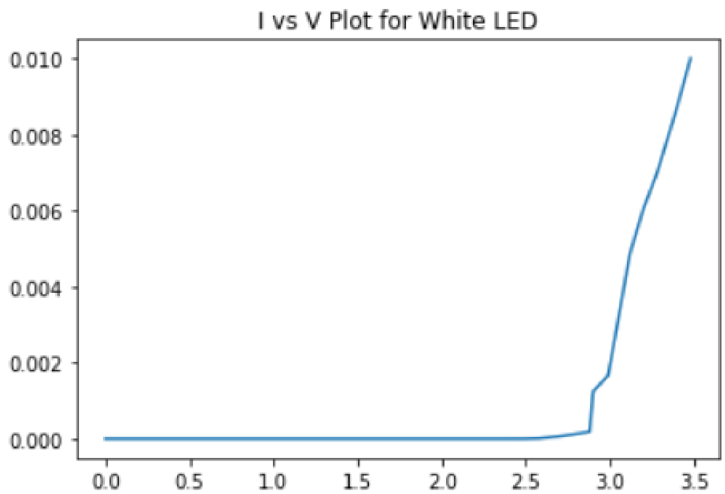
Using the above graphs, we find out the ideality factor for Green LED, $\eta = 4.591$ and cut-in voltage $V_\gamma = 3.12V$. NGSPice simulations gave a cut-in voltage of $1.9V$

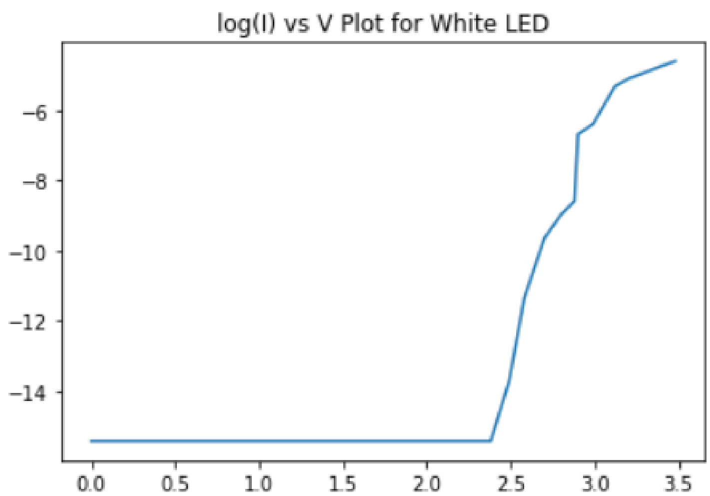
The wavelength for Green LED is around 522nm and using this, the band gap $E_g = 2.38eV$

4.5 White LED

Current (mA)	ln(Current)	Voltage (V)
0.0002	-15.42	0
0.0002	-15.42	1.057
0.0002	-15.42	1.600
0.0002	-15.42	2.08
0.0002	-15.42	2.38
0.0011	-13.72	2.49
0.0117	-11.36	2.58
0.0645	-9.65	2.70
0.1271	-8.97	2.80
0.1861	-8.59	2.88
1.24	-6.69	2.90
1.67	-6.39	2.99
4.88	-5.32	3.12
6.05	-5.11	3.20
6.98	-4.96	3.28
8.57	-4.76	3.39
10.0	-4.61	3.48

Given below is the I-V characteristic plot for the White LED:





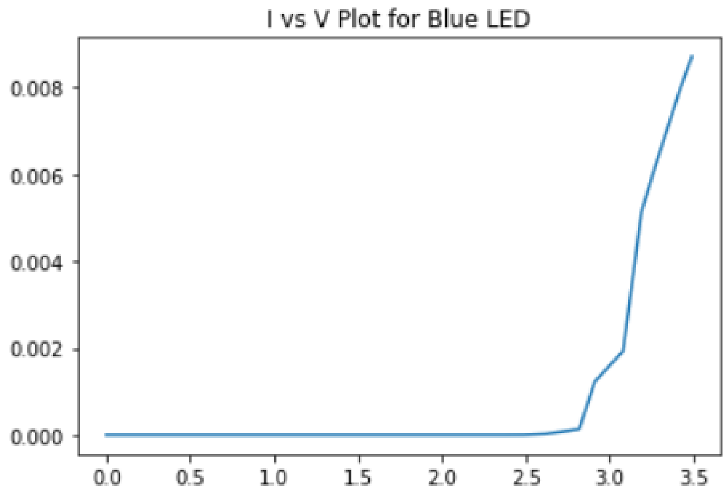
Using the above graphs, we find out the ideality factor for White LED, $\eta = 2.523$ and cut-in voltage $V_\gamma = 2.89V$. NGSPice simulations gave a cut-in voltage of $2.9V$

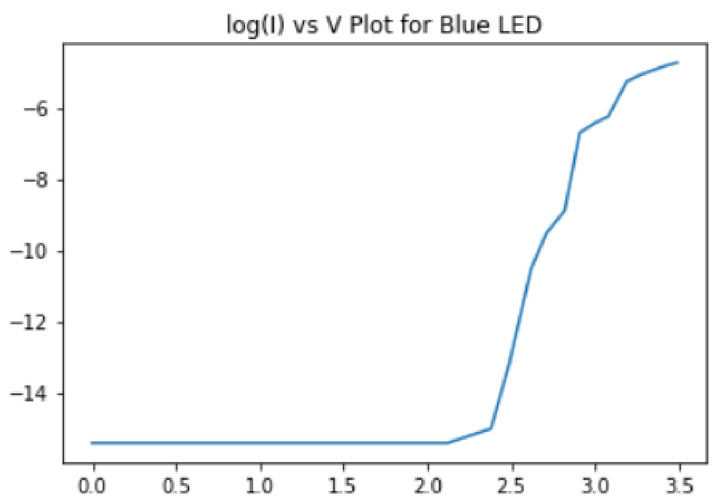
The wavelength for White LED is around 450nm and using this, the band gap $E_g = 2.76eV$

4.6 Blue LED

Current (mA)	ln(Current)	Voltage (V)
0.0002	-15.42	0
0.0002	-15.42	2.12
0.0003	-15.42	2.38
0.0019	-14.73	2.49
0.027	-13.55	2.62
0.0719	-11.63	2.71
0.1366	-10.20	2.82
1.22	-9.77	2.91
1.6	-9.27	3.00
1.93	-8.78	3.08
5.14	-8.58	3.19
6.16	-6.68	3.27
7.96	-6.64	3.42
8.71	-6.55	3.49

Given below is the I-V characteristic plot for the Blue LED:





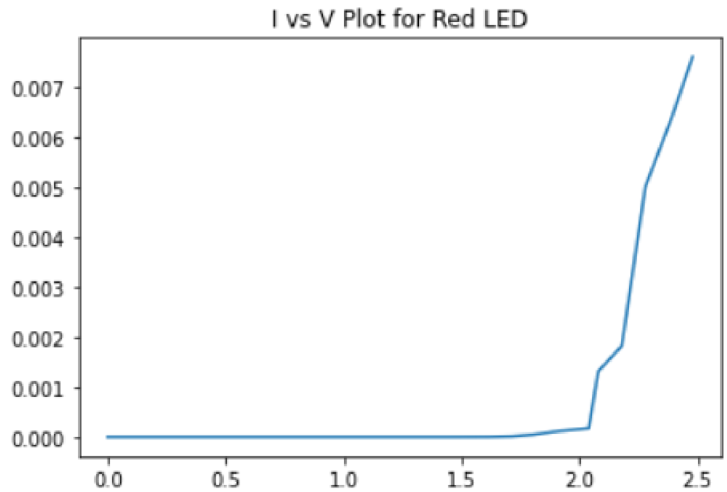
Using the above graphs, we find out the ideality factor for Blue LED, $\eta = 3.375$ and cut-in voltage $V_\gamma = 2.85V$. NGSPice simulations gave a cut-in voltage of $2.7V$

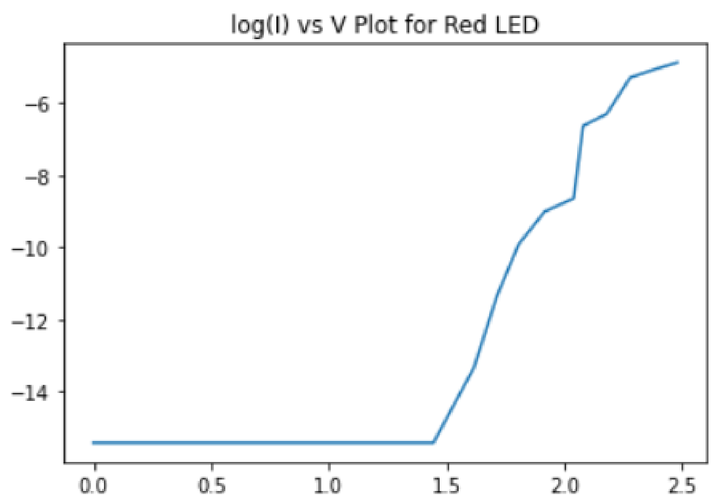
The wavelength for Blue LED is around 455nm and using this, the band gap $E_g = 2.73eV$

4.7 Red LED

Current (mA)	ln(Current)	Voltage (V)
0.0002	-15.42	0
0.0002	-15.42	1.444
0.0016	-13.35	1.616
0.0119	-11.34	1.715
0.0490	-9.92	1.806
0.1217	-9.01	1.916
0.1758	-8.65	2.04
1.314	-6.63	2.08
1.825	-6.31	2.18
5.01	-5.30	2.28
6.37	-5.06	2.39
7.61	-4.88	2.48

Given below is the I-V characteristic plot for the Red LED:





Using the above graphs, we find out the ideality factor for Red LED, $\eta = 2.551$ and cut-in voltage $V_\gamma = 2.05V$. NGSPice simulations gave a cut-in voltage of $1.8V$
The wavelength for Red LED is around 628nm and using this, the band gap $E_g = 1.97eV$

5 Simulation Exercise

5.1 Code Snippet

```
.include Diode_1N914.txt
*Zener Subcircuit
.SUBCKT ZENER 1 2
D1 1 2 DF
DZ 3 1 DR
VZ 2 3 10.8
.MODEL DF D ( IS=27.5p RS=0.620 N=1.10 CJO=78.3p VJ=1.00 M=0.330 TT=50.
.MODEL DR D ( IS=5.49f RS=50 N=1.77 )
.ENDS
Vs 1 0 dc 20
R1 1 2 100
R2 2 0 1k
$ D1 2 3 1N914
X1 2 3 ZENER
Vdummy 3 4 dc 0
R3 4 0 100
.dc Vs -200 5 0.01
.control
run
plot i(Vdummy) vs v(2,3)
.endc
.end
```

5.2 Simulation Results

Given below is the I-V Characteristic plot for 1N914 Diode under Reverse breakdown voltage:

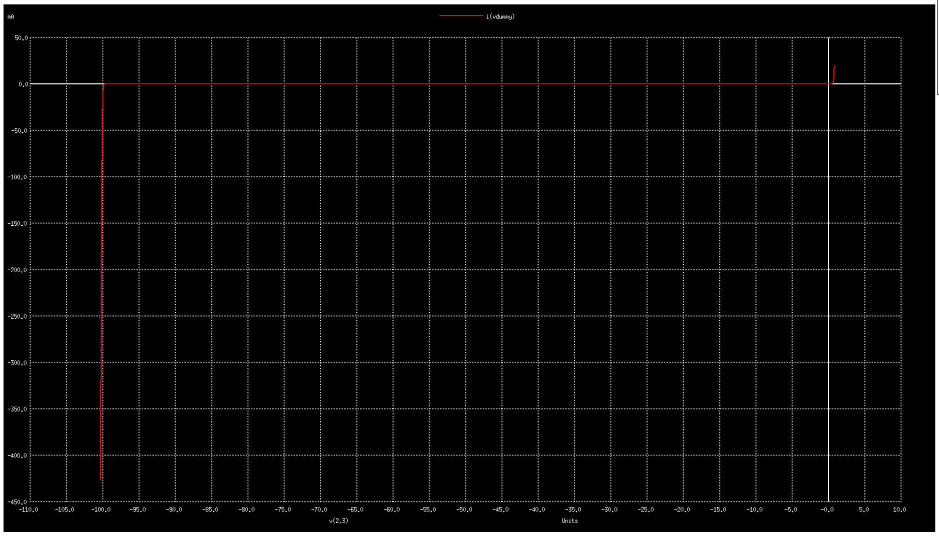


Fig.
I-V Plot for the 1N914 diode

Given below is the I-V Characteristic plot for Zener Diode under Reverse breakdown voltage:

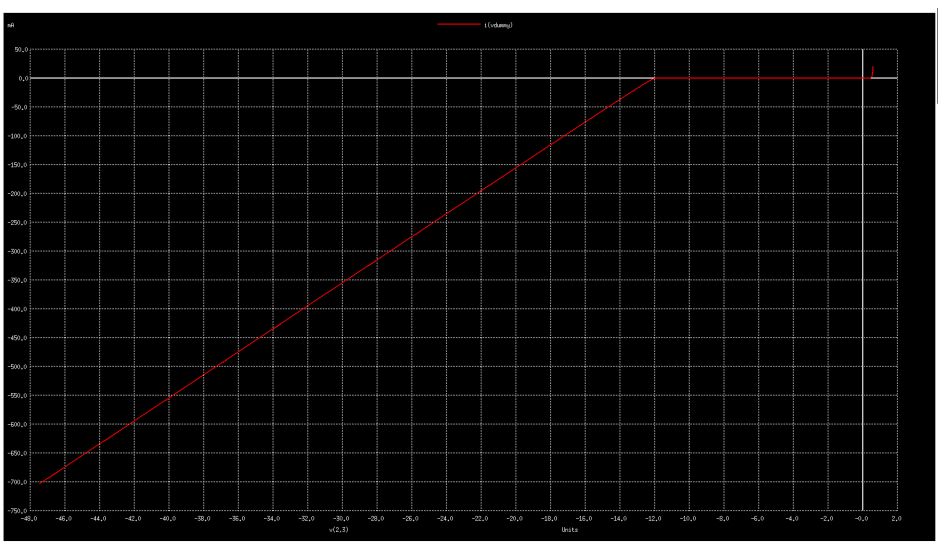


Fig. I-V Plot for the Zener diode

In these plots we can observe that the reverse breakdown I-V slope for the 1N914 diode and Zener diode is nearly constant after reaching the breakdown voltage but the 1N914 diode has a much higher slope than the Zener diode.

The 1N914 diode has a reverse breakdown voltage of about $-100V$ whereas the Zener diode has a reverse breakdown voltage of $-12V$.