EE 236: Experiment 1
Diode I-V Characterization and Bandgap of Semiconductors

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1 Aim

To study the I-V characteristics of diodes and estimate the band gap of semiconductors and measure and contrast their values for PN junction diode and various Light emitting diodes to estimate the band gap, and calculate the ideality factor, reverse saturation current and doping densities of each.

2 Approach

I-V plots of various diodes were simulated on NGSPICE. The diodes were also physically connected on a breadboard, and the current corresponding to varying voltage was recorded and tabulated. The plots were compared, and the values of required parameters cut-in Voltage V_γ and ideality factor η were estimated from these data points. A plot was made to see the dependence of V_γ on E_g.

3 Formulae and theory

I/V characteristics of a diode:

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

$$I_S = I_{00}e^{\frac{-E_g}{kT}} \tag{2}$$

simplifying the equation 1 assuming $e^{\frac{qV_D}{\eta kT}} >> 1$,

$$ln(I_D) = (\frac{q}{\eta kT})V_D + ln(I_S) \tag{3}$$

NOTE: Equation (1) is applicable only to a forward biased diode. Also, at very high forward bias, physical effects like series resistance and high-level injection become significant.

Equation (3) is also limited to large values of V_D.
LEDs produce light as a result of energy released due to electron-hole recombination in the diode as a result of application of bias voltage. The band gap can be calculated as:

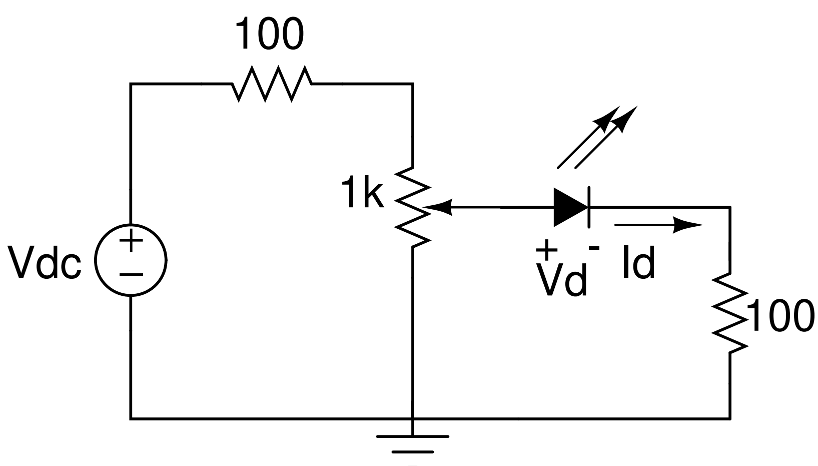
$$E_g = \frac{hc}{\lambda} = \frac{1240}{\lambda(nm)} eV \tag{4}$$

4 NGSPICE Code

```
*IV Characteristics

*Jatin Kumar 22B3922
.include yellow_5mm.txt
.include red_5mm.txt
.include green_5mm.txt
.include blue_5mm.txt
.include white_5mm.txt
.include Diode_1N914.txt

vs 1 0 dc 0

vyellow 21 31 dc 0
da 1 21 YELLOW
ra 31 0 100

vred 22 32 dc 0
db 1 22 RED
rb 32 0 100

vgreen 23 33 dc 0
dc 1 23 GREEN
rc 33 0 100

vblue 24 34 dc 0
dd 1 24 BLUE
rd 34 0 100

vwhite 25 35 dc 0
de 1 25 WHITE
re 35 0 100

v1n914 26 36 dc 0
df 1 26 1N914
rf 36 0 100

.dc vs 0.001 5 0.01
```

```
.control

run
plot i(vyellow) vs v(1) - v(21) i(vred) vs v(1) - v(22) i(vgreen) vs v(1)
- v(23) i(vblue) vs v(1) - v(24) i(vwhite) vs v(1) - v(25) i(v1n914) vs v(1) - v(26)

plot ln(i(vyellow)) vs v(1) - v(21) ln(i(vred)) vs v(1) - v(22) ln(i(vgreen)) vs v(1)
- v(23) ln(i(vblue)) vs v(1) - v(24) ln(i(vwhite)) vs v(1) - v(25) ln(i(v1n914)) vs v(1) - v

.endc

.end
```

5 Circuit diagram



6 Readings

Readings were taken at different voltage points and varying numbers for all the different diodes.

6.1 1N4007

V_D (V)	I_D (mA)	$\ln(I_D)$
0.1	0.00	-
0.3	0.00	-
0.58	0.4	-0.3979
0.61	0.6	-0.2218
0.623	1.1	-6.807
0.63	1.3	-6.643
0.635	1.5	-6.516
0.642	1.6	-6.439
0.66	2.5	-6.008
0.675	3.4	-5.758
0.686	4.3	-5.458
0.704	6.1	-5.089
0.734	10.3	-4.570
0.76	15.5	-4.162
0.773	19.4	-3.955

6.2 White

V_D (V)	I_D (mA)	$\ln(I_D)$
0.00	0	-
1.90	0.1	-9.21034
2.56	0.2	-8.51719
2.60	0.5	-7.60090
2.63	1.3	-6.64385
2.66	1.9	-6.25042
2.68	2.4	-6.02237
2.73	3.9	-5.46511
2.75	4.6	-5.35947
2.77	5.7	-5.15982
2.80	6.4	-5.04342
2.82	7.3	-4.93081
2.84	8.4	-4.77196
2.85	8.6	-4.75913

6.3 Blue

V_D (V)	I_D (mA)	$\ln(I_D)$
0.00	0	-
2.69	0.1	-9.21034
2.73	0.2	-8.51719
2.76	0.3	-7.80943
2.77	0.4	-7.52285
2.80	0.8	-7.14309
2.83	1.3	-6.64385
2.85	1.6	-6.43955
2.87	2.1	-6.26101
2.90	3.5	-5.65761
2.90	3.3	-5.72701
2.92	3.8	-5.56908
2.94	4.7	-5.35656
2.95	5.4	-5.23045
2.97	6.5	-5.03442
2.99	7.8	-4.84948

6.4 Red

V_D (V)	I_D (mA)	$\ln(I_D)$
0.00	0	-
1.70	0.1	-9.21034
1.75	0.4	-7.52285
1.77	1	-6.90775
1.80	1.8	-6.33719
1.82	2.8	-5.87421
1.84	3.8	-5.56908
1.85	5.1	-5.28918
1.86	6.5	-5.03442
1.88	8.9	-4.72739
1.90	11.2	-4.78555
1.91	13.5	-4.78555

6.5 Green

V_D (V)	I_D (mA)	$\ln(I_D)$
0.00	0	-
2.28	0.2	-8.51719
2.35	0.7	-7.15548
2.42	1.2	-6.82124
2.48	1.9	-6.25042
2.56	3	-5.80943
2.60	3.4	-5.76618
2.65	4.1	-5.48159
2.70	5.2	-5.25957
2.80	7.1	-4.94442
2.86	8.4	-4.77068

7 Plots

7.1 Plot1

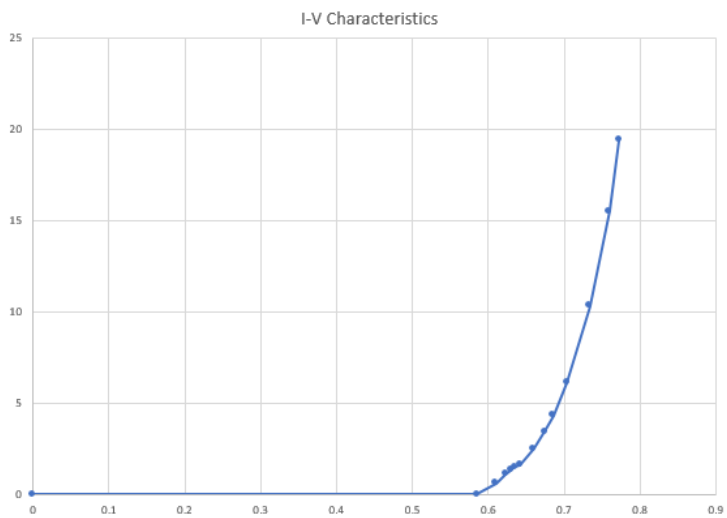


Figure 1: 1N4007

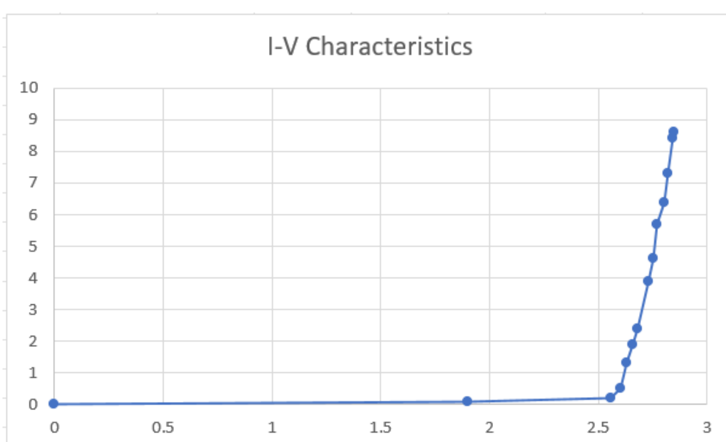


Figure 2: White LED

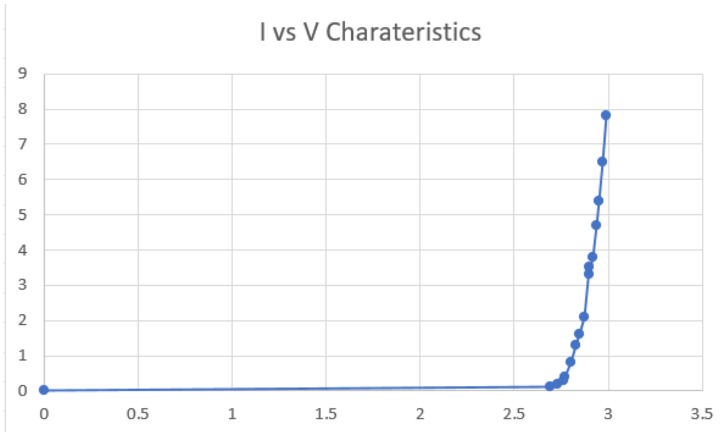


Figure 3: Blue LED

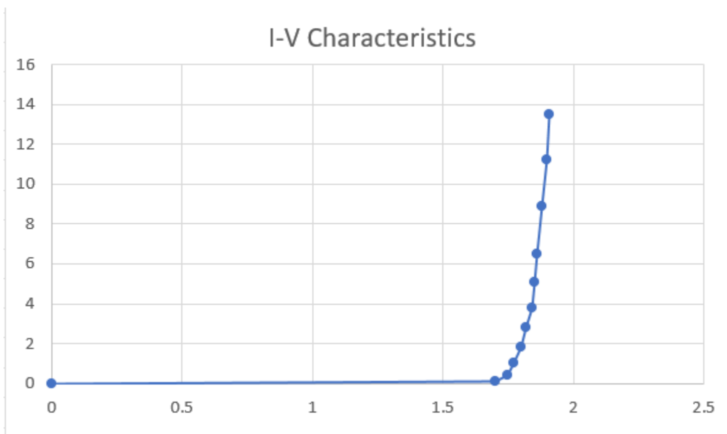


Figure 4: Red LED

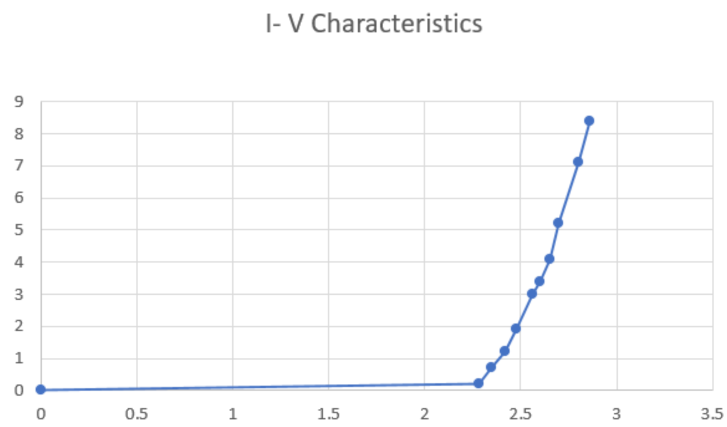


Figure 5: Green LED

7.2 Plot2

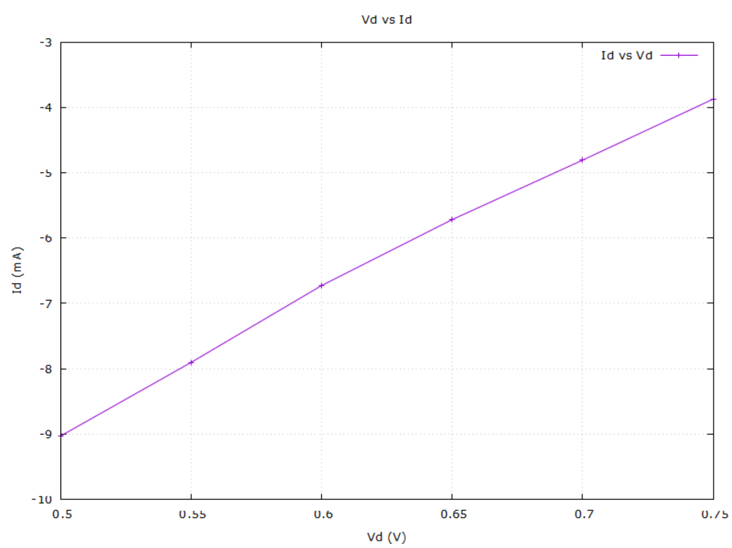


Figure 6: 1N4007 - $ln(I_D)$ v/s V_D

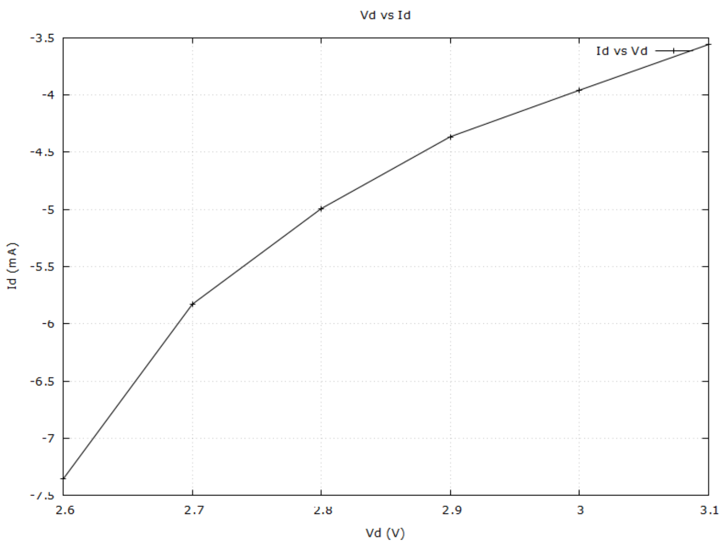


Figure 7: White LED - $ln(I_D)$ v/s V_D

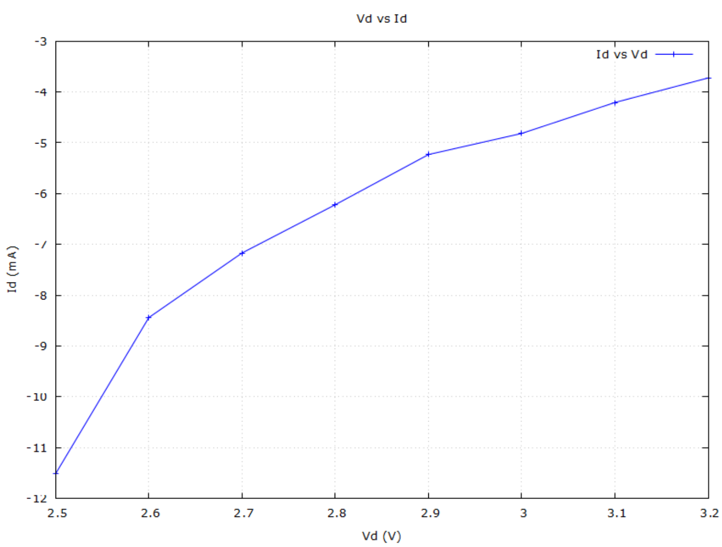


Figure 8: Blue LED - $ln(I_D)$ v/s V_D

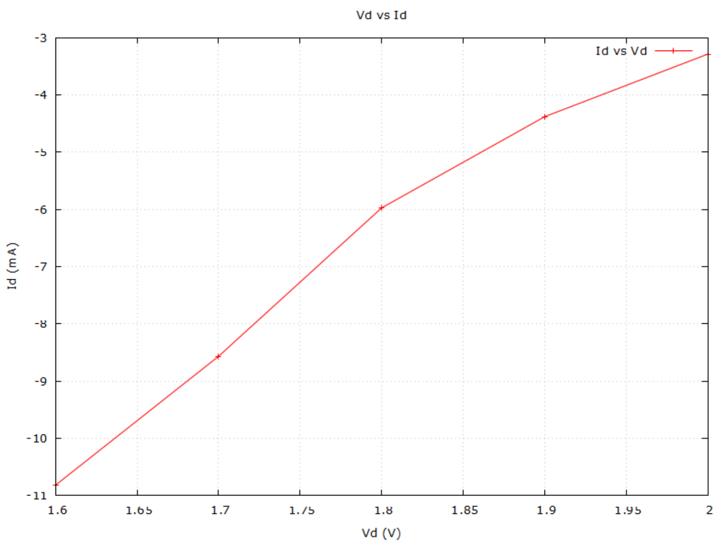


Figure 9: Red LED - $ln(I_D)$ v/s V_D

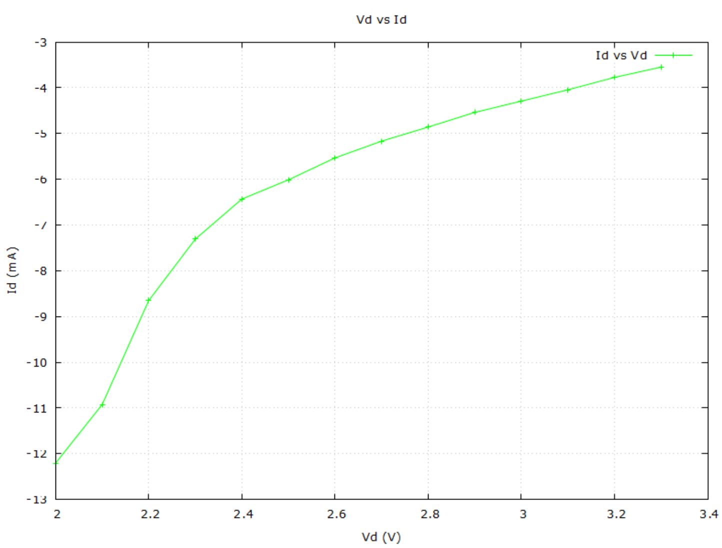


Figure 10: Green LED - $ln(I_D)$ v/s V_D

8 Calculations

8.1 Band Gap

Diode	Wavelength(nm) used	E_g(eV)
1N4007	-	1.1
White	451	2.75
Blue	455.8	2.72
Red	629.4	1.97
Green	525.4	2.36

8.2 Non-ideality factor and Saturation current

These parameters were obtained by applying linear regression to the linear region of the log plots, followed by using equation (3).

$$ln(I_D) = mV_D + c \tag{5}$$

$$\eta = \frac{q}{mkT} \tag{6}$$

$$I_S = e^c \tag{7}$$

Diode	η	I_S (nA)
1N4007	1.866	4.47
White	8.178	13.9
Blue	5.688	0.0116
Red	1.998	1.21×10^{-9}
Green	12.859	1.65×10^{3}

8.3 Cut-in voltage

Cut-in voltage was taken to be the voltage where I_D crosses 5mA.

Diode	V_γ (V)
1N4007	0.65
White	2.8
Blue	2.88
Red	1.82
Green	2.65

8.4 Intrinsic doping densities

$$n_i \propto e^{\frac{-E_g}{2kT}} \tag{8}$$

The proportionality constant C depends on the effective electron and hole masses for the semiconductor material making up the diode. This is GaAs for LEDs

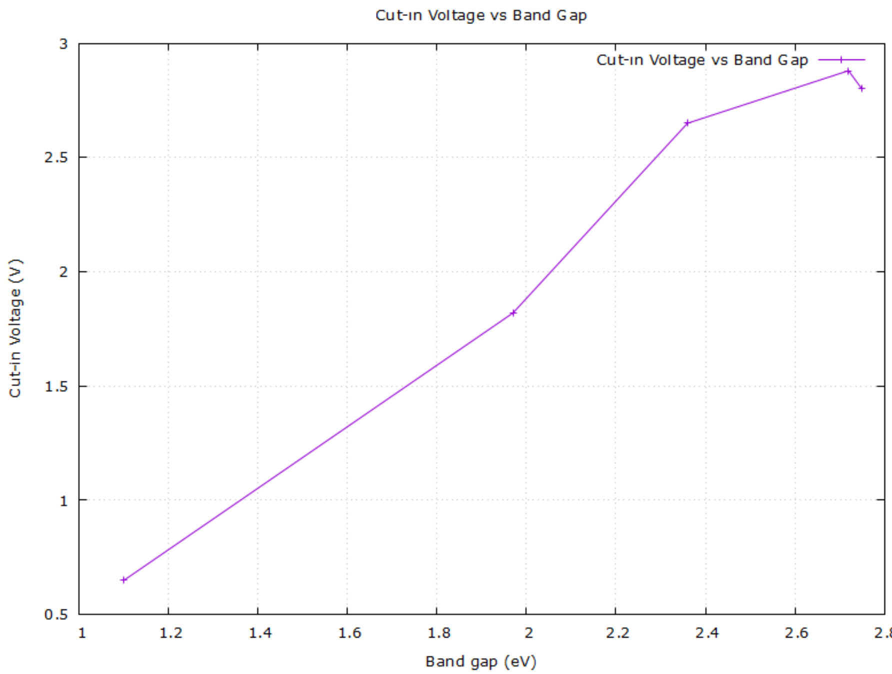
and Si for 1N4007.
For GaAs:
$C \approx 10^{27}\ m^{-3/2}K^{-3/2}$
For Si:
$C \approx 7.7 \times 10^{27}\ m^{-3/2}K^{-3/2}$

Diode	n_i (m^{-3})
1N4007	5×10^{18}
White	1.08×10^{4}
Blue	1.92×10^{4}
Red	3.52×10^{10}
Green	1.95×10^{7}

8.5 Doping densities

Diode	V_{bi} (V)	$N_A = N_D$ (m^{-3})
1N4007	0.7	3.51×10^{24}
White	3	1.22×10^{29}
Blue	2.8	4.66×10^{27}
Red	1.8	3.8×10^{25}
Green	2	9.85×10^{23}

9 V_γ v/s E_g



10 Questions Solved

- **Equation Analysis:** $\mathrm{I} = \mathrm{I}_s e^{\frac{qV_D}{kT}} - 1 \;\; \ln\left(\frac{I_D}{I_s}\right) = \frac{qV_D}{kT} + \ln I_s$
- Are equations 1 and 2 satisfied for the entire range of V_D?
- Yes, the equations seem to hold over the entire range of V_D (0-3V) as observed from the plots.
- **Correlation Between V_γ and E_g:** Observe 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. The non-ideality factor (η) affects the cut-in voltage. For a higher η, the V_γ will be higher for the same I_D compared to an ideal diode ($\eta = 1$). This factor reflects the deviation from ideal diode behavior and can be influenced by practical aspects like recombination and series resistance in the diode. Thus, both I_D and η will impact the measured V_γ, and observing these variations helps in understanding the non-ideal characteristics of diodes in practical scenarios.

- **Diode Applications:**
- Rectifiers to convert AC to DC.
- Flyback diodes to protect circuits from voltage spikes.
- Prevention of damage to circuits if power is connected with reverse polarity.
- Utilized in AM radio receivers in demodulation circuits.
- Used as status indicators in electronic devices.
- Employed in seven-segment displays, digital clocks, and scoreboards.
- Used in backlighting for keyboards, screens, and meters.
- Infrared LEDs used in remote controls.
- **1N914 Diode:** Best for general rectification, switching, and signal processing.
- **Red LED:** Ideal for indicators, displays, and decorative lighting.
- **Green LED:** Suitable for indicators, traffic signals, and display technology.
- **Blue LED:** Used in high-intensity lighting, displays, and UV applications.
- **White LED:** Perfect for general illumination, automotive lighting, and display backlighting.

11 Completion Status

- Completion status: 100%