Semiconductor Diode Characteristics

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1 Prelab

Semiconductor - Diode
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1) Semiconductors used in LED are GaAs, GaP, GaN, InGaN, AlGaAs, ZnSe etc.
They are different from Si & Ge diodes as their band gap are exactly appropriate for emitting visible light in specific frequency ranges while the band gap for Si & Ge are too low for effective generation of visible light.

2) A Fermi level is the highest energy level occupied by electrons at 0K.
In p-type semiconductors the majority carriers are holes. At room temperature, holes are mostly occupy the valence band, so the Fermi level is closer to the valence band.
In n-type semiconductors, majority carriers are electrons. At room temperature, most electrons occupy the conduction band, so the Fermi level lies close to the conduction band.

3) ~~For an npn transistor,~~

Emitter	Collector
• ~~n-type~~, heavily doped	• ~~n-type~~, moderately doped
• smaller in size	• larger in size
• injects electrons/holes into base region	• collects electrons/holes that pass through the base region.

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2 Graphs

2.1 PN Junction Diodes

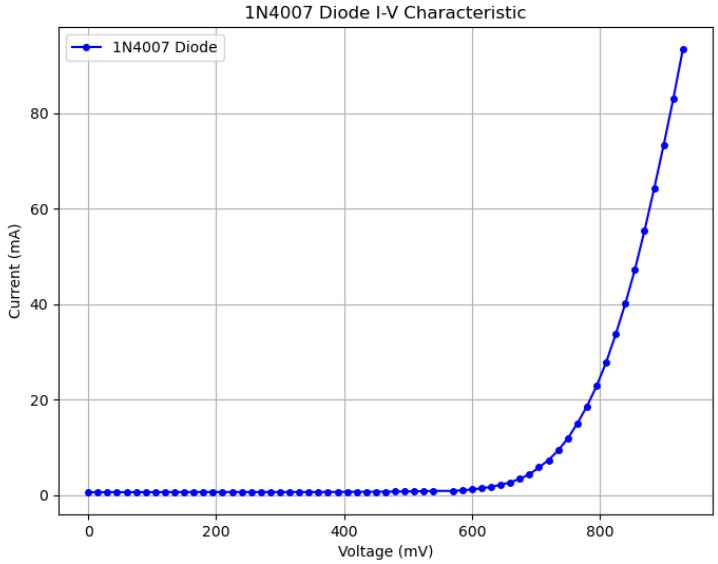

Figure 1: 1N4007 Forward Bias (Linear Scale)

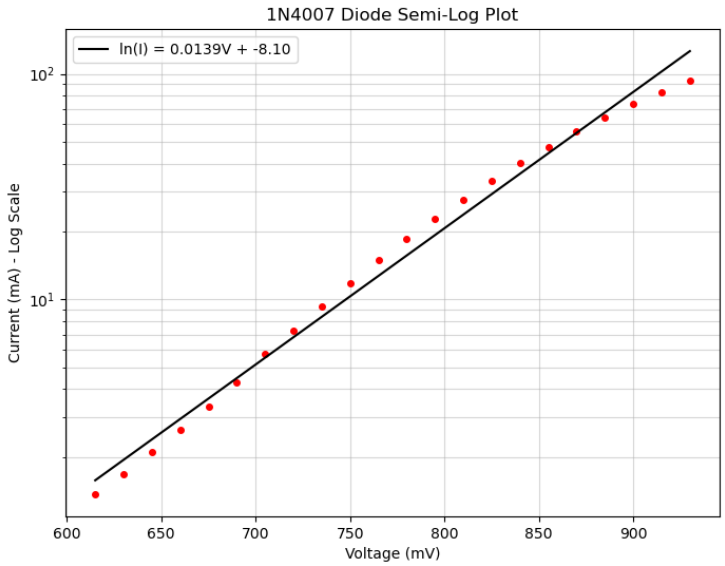

Figure 2: 1N4007 Ideality Factor Plot (Log-Linear Scale)

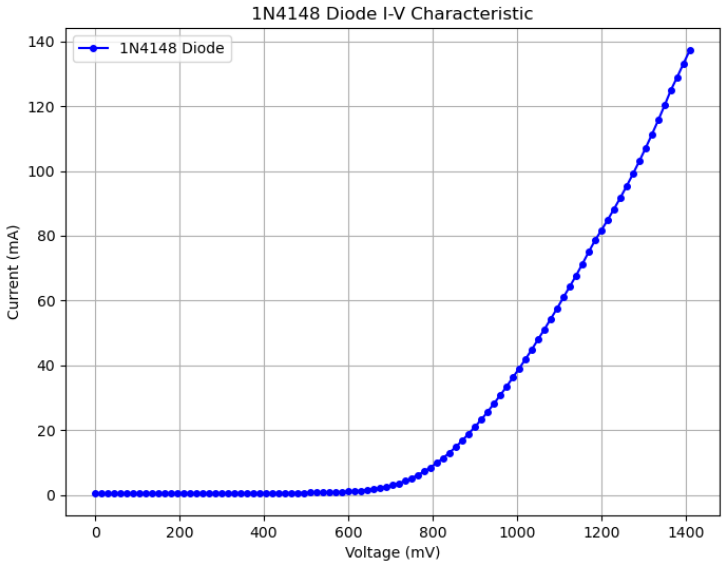

Figure 3: 1N4148 Forward Bias (Linear Scale)

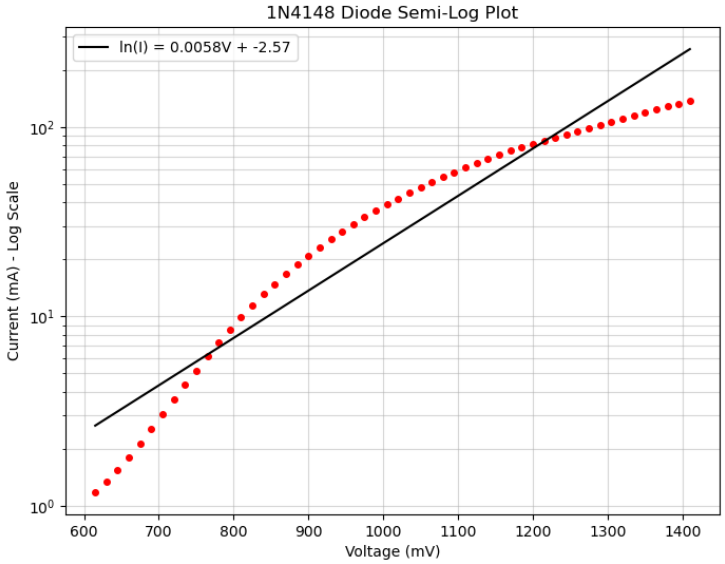

Figure 4: 1N4148 Ideality Factor Plot (Log-Linear Scale)

2.2 Transistor Junctions

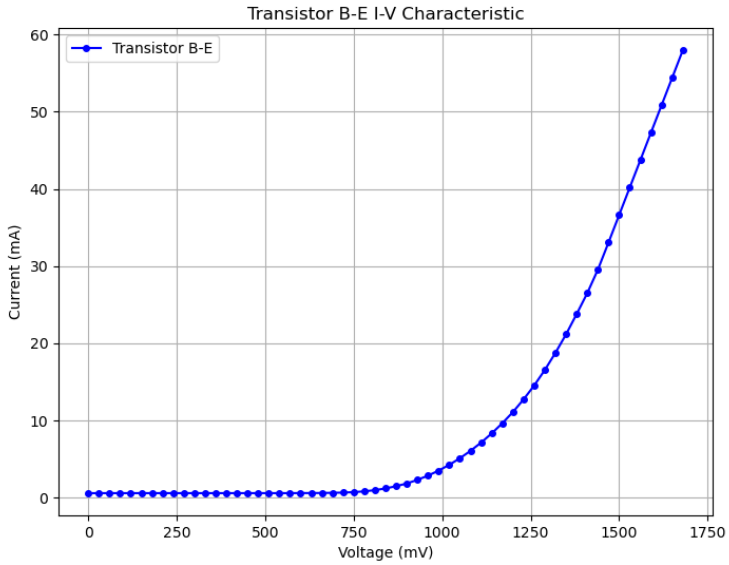

Figure 5: Base-Emitter Junction I-V Characteristic

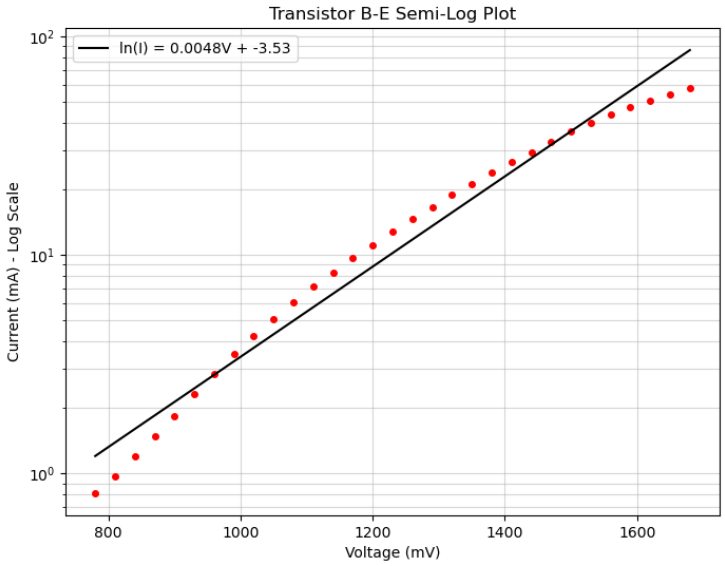

Figure 6: Base-Emitter Junction Ideality Factor Plot

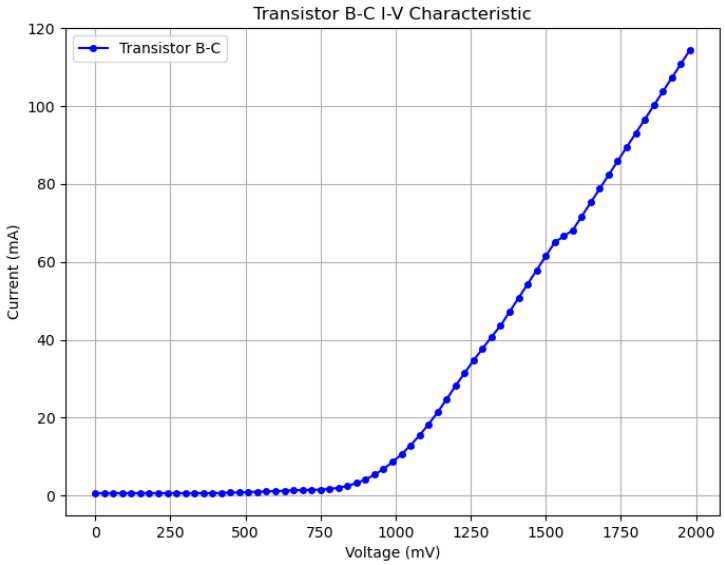

Figure 7: Base-Collector Junction I-V Characteristic

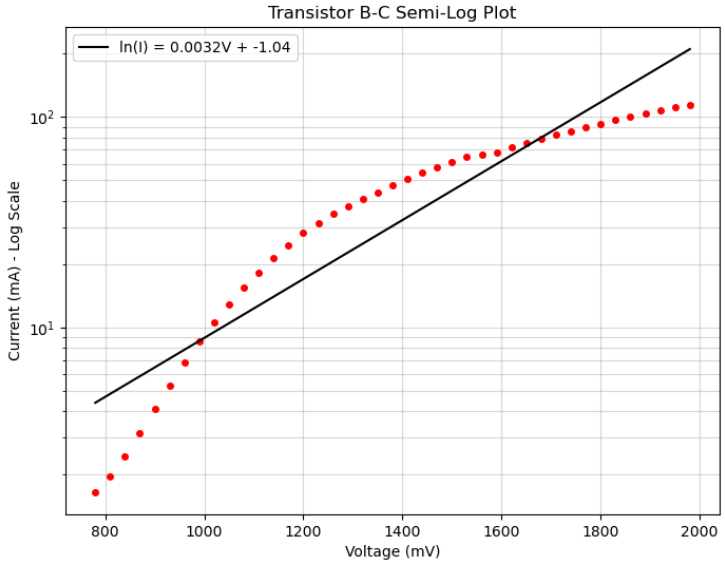

Figure 8: Base-Collector Junction Ideality Factor Plot

2.3 LED Characteristics

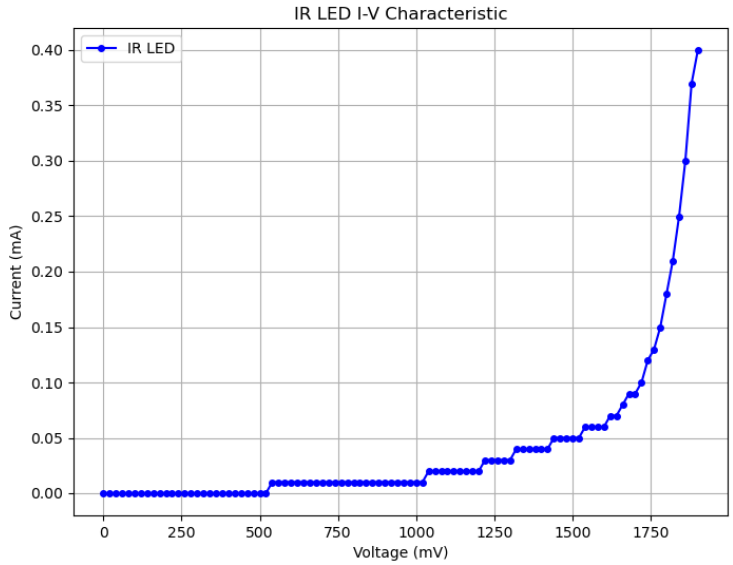

Figure 9: IR LED I-V Characteristic

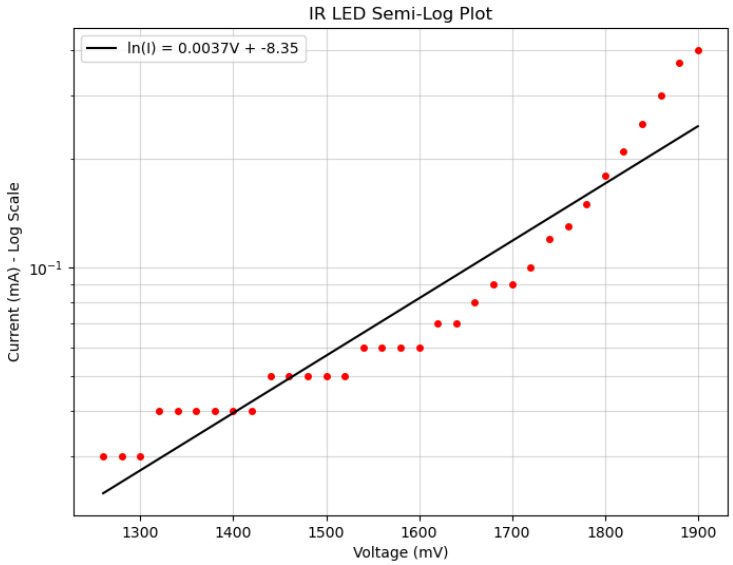

Figure 10: IR LED Ideality Factor Plot

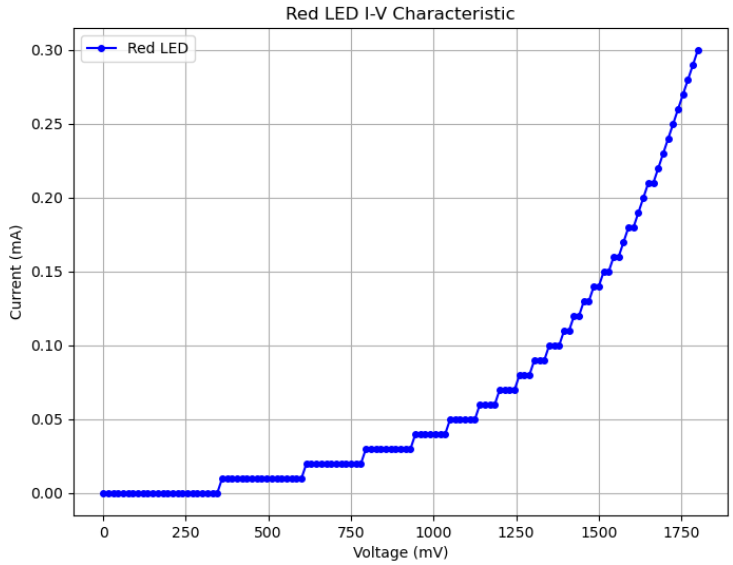

Figure 11: Red LED I-V Characteristic

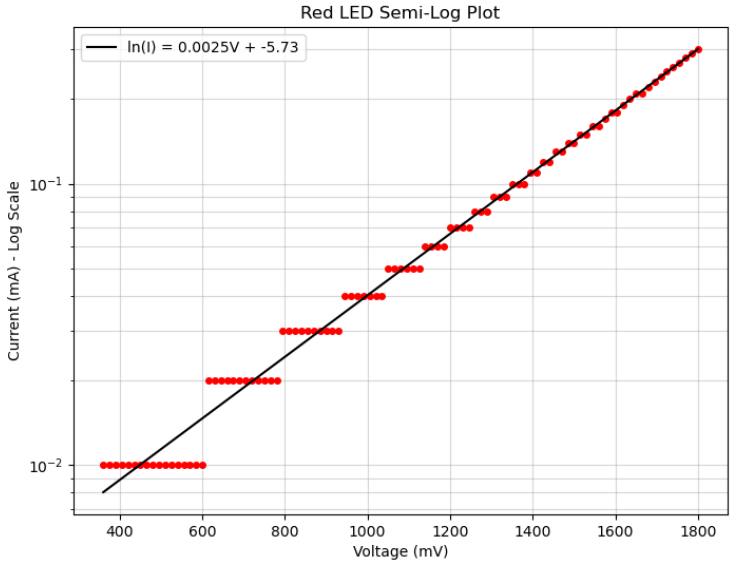

Figure 12: Red LED Ideality Factor Plot

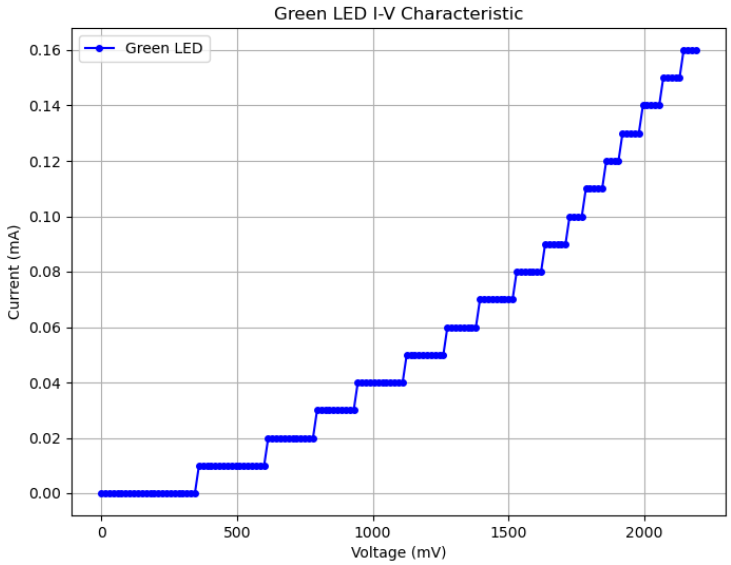

Figure 13: Green LED I-V Characteristic

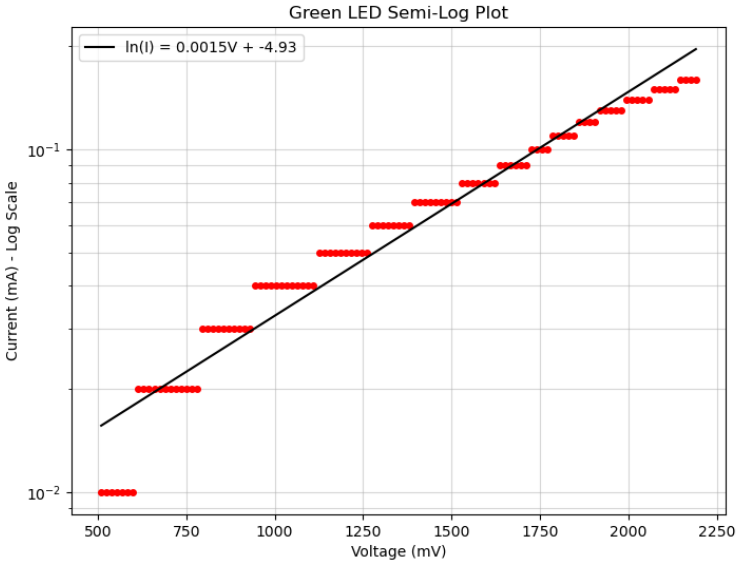

Figure 14: Green LED Ideality Factor Plot

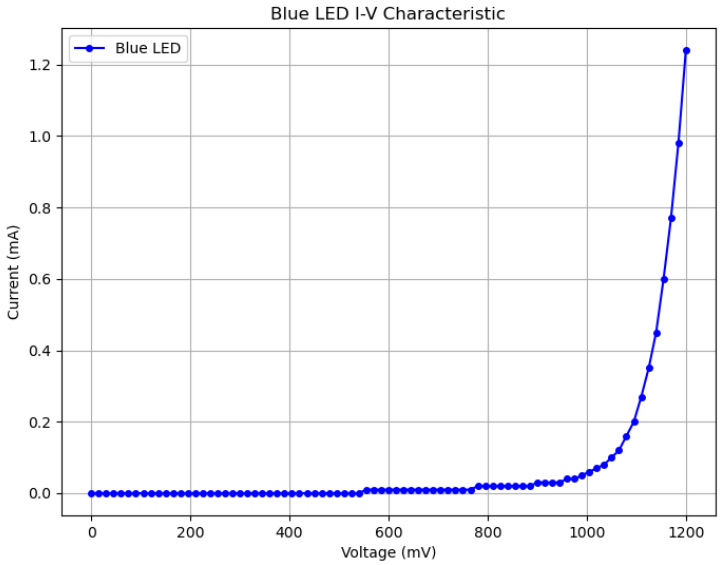

Figure 15: Blue LED I-V Characteristic

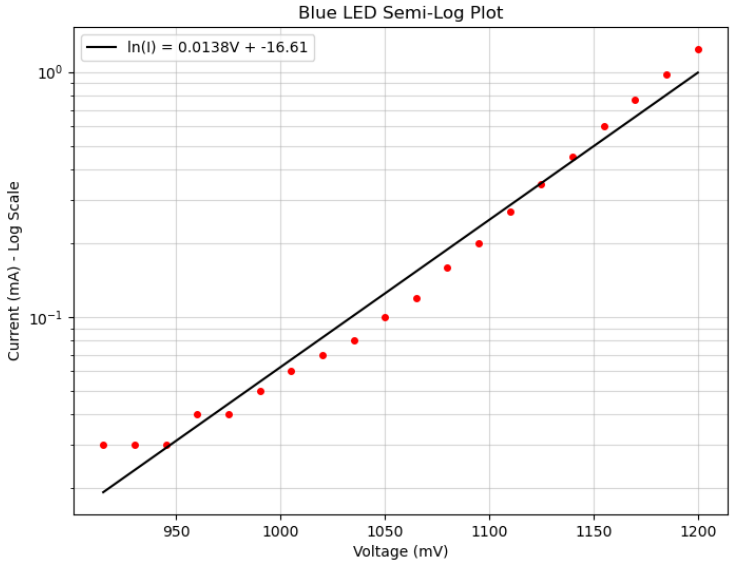

Figure 16: Blue LED Ideality Factor Plot

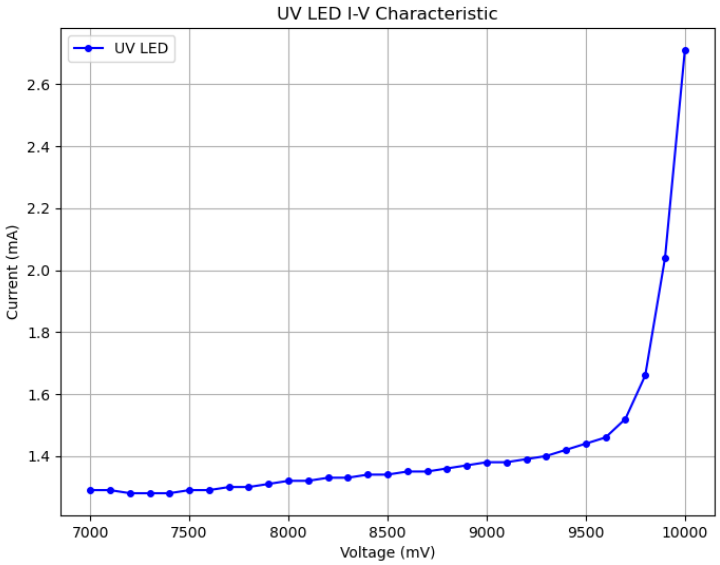

Figure 17: UV LED I-V Characteristic

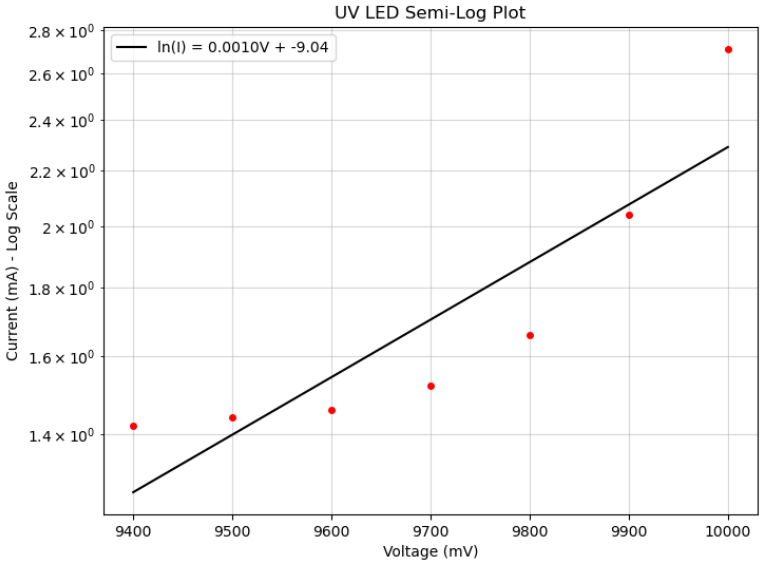

Figure 18: UV LED Ideality Factor Plot

2.4 Transistor Output Characteristics

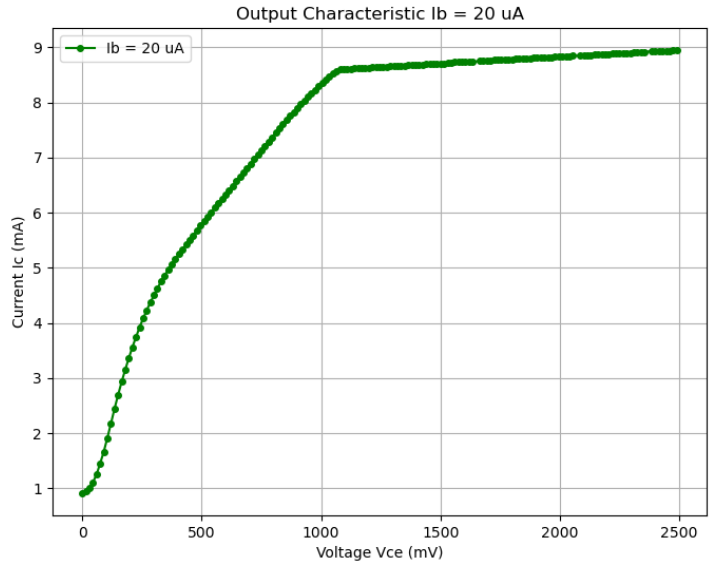

Figure 19: Transistor Output Characteristic ($I_B = 20\mu A$)

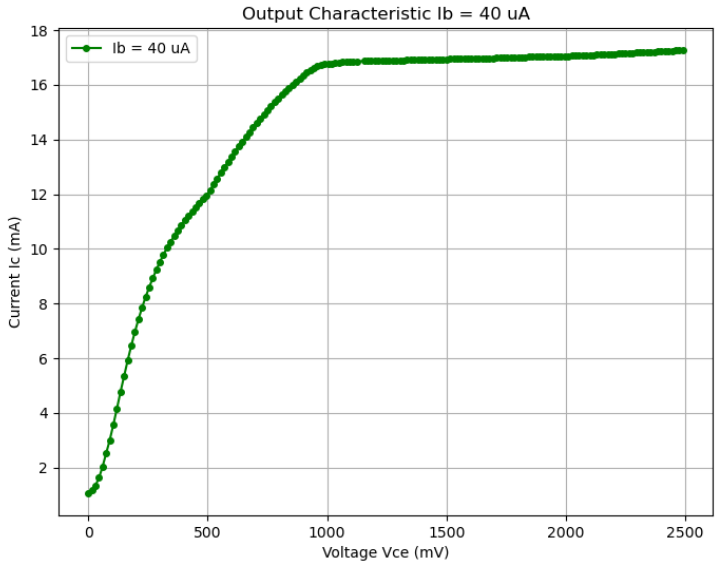

Figure 20: Transistor Output Characteristic ($I_B = 40\mu A$)

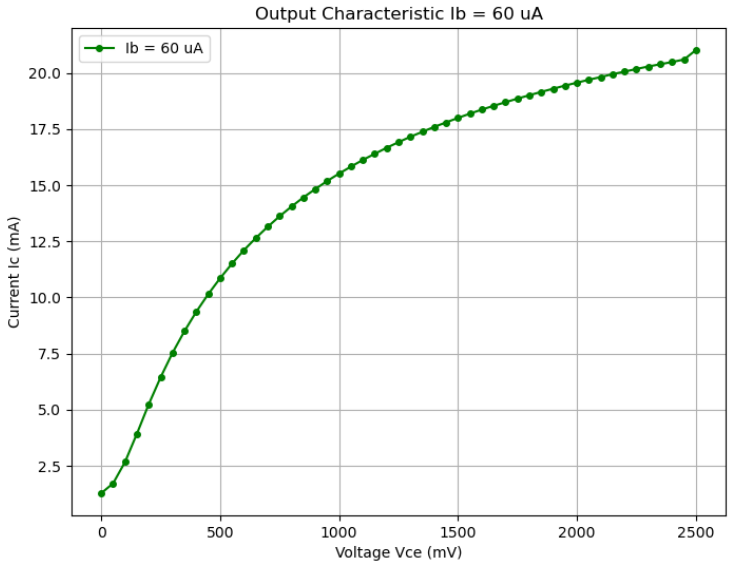

Figure 21: Transistor Output Characteristic ($I_B = 60\mu A$)

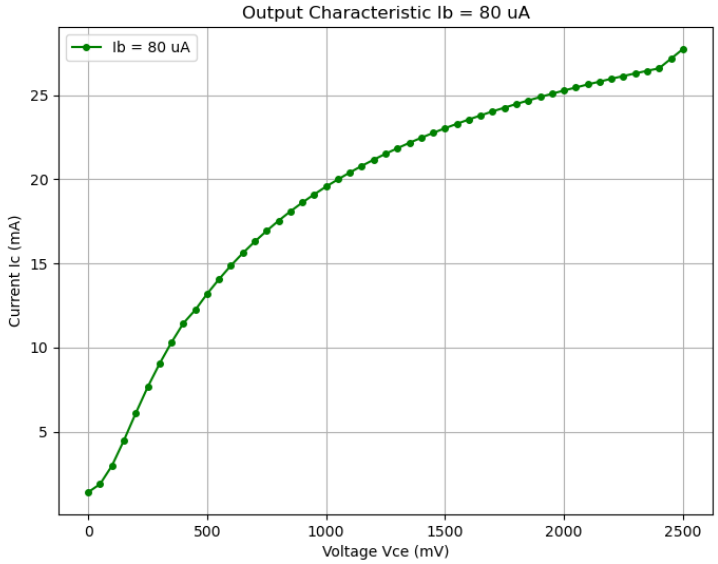

Figure 22: Transistor Output Characteristic ($I_B = 80\mu A$)

3 Analysis

3.1 Determination of Ideality Factor (η)

To find the ideality factor, the natural logarithm of the current, $\ln(I)$, was plotted against the voltage V. Rearranging the diode equation for the forward bias region ($V \gg \eta kT/q$):

$$\ln(I) = \frac{q}{\eta kT} V + \ln(I_s) \tag{1}$$

The slope m of the linear region of this graph relates to η by:

$$\eta = \frac{q}{mkT} \approx \frac{38.955}{m} \quad \text{(at 298K)} \tag{2}$$

Using the slope obtained from the semi log plots, the ideality factor for each device was calculated and tabulated.

Table 1: Slope and Ideality Factor from Semi-log Plot

Device	**Slope of Semi-log Plot**	**Ideality Factor**
1N4007 Diode	0.0139 mV^{-1}	2.80
1N4148 Diode	0.0058 mV^{-1}	6.77
Base-Emitter Junction	0.0048 mV^{-1}	8.19
Base-Collector Junction	0.0032 mV^{-1}	12.08
IR LED	0.0037 mV^{-1}	10.66
Red LED	0.0025 mV^{-1}	15.48
Green LED	0.0015 mV^{-1}	25.88
Blue LED	0.0138 mV^{-1}	2.82
UV LED	0.0010 mV^{-1}	39.46

3.2 Determination of Knee Voltage (V_{knee})

The knee voltage was determined graphically as the voltage at which the current begins to increase significantly (interpolated at approx. 1 mA for standard diodes). This voltage corresponds to the energy barrier required for charge carriers to cross the depletion region.It is tabulated below for each device.

Table 2: Knee Voltages for Tested Devices

Device	**Knee Voltage (V)**
1N4007 Diode	0.585
1N4148 Diode	0.585
Transistor B-E	0.810
Transistor B-C	0.570
IR LED	1.900
Red LED	1.800
Green LED	2.145
Blue LED	1.185
UV LED	7.200

3.3 Transistor Output Characteristics

The output characteristics of the transistor were plotted for various constant base currents ($I_B = 20\mu A, 40\mu A, 60\mu A, 80\mu A$). The plots show the collector current (I_C) as a function of collector-emitter voltage (V_{CE}). The active region, saturation region, and cutoff region were roughly identifiable from the plots, confirming the transistor's operation as a current-controlled amplifier.

4 Results

The calculated parameters for all tested devices are summarized in Table 3.

Table 3: Experimental Results: Knee Voltages and Ideality Factors

Device	**Knee Voltage (V)**	**Ideality Factor (η)**
1N4007 Diode	0.585	2.80
1N4148 Diode	0.585	6.77
Transistor B-E	0.810	8.19
Transistor B-C	0.570	12.08
IR LED	1.900	10.66
Red LED	1.800	15.48
Green LED	2.145	25.88
Blue LED	1.185	2.82
UV LED	7.200	39.46

5 Conclusion

- The silicon diodes (1N4007 and 1N4148) exhibited typical rectifying behavior with a knee voltage of 0.585 V, though their calculated ideality factors (2.80 and 6.77) indicated non-ideal recombination effects.
- The LED characteristics confirmed the direct relationship between bandgap energy and turn-on voltage, with knee voltages increasing as Red (1.800 V) < Green (2.145 V) < UV (7.200 V), though the IR LED showed a higher knee voltage (1.900 V) than Red and Blue showed a lower knee voltage (1.185 V) than green.
- The transistor junctions functioned effectively as diodes, and the output characteristics verified the BJT's operation as a current-controlled amplifier with distinct saturation and active regions.