E207
Non-Ohmic Devices 2 - Diode

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# 1 Theoretical Background

## 1.1 Diode

A diode is a semiconductor device. These devices act non-ohmic in a circuit. Their $I$-$V$ characteristic is not linear. Basically, diodes are made of two semiconductor materials that have different charge carrier concentration and this structure is known as P-N junction shown in Figure 1. Electron concentration is more in N area just as hole concentration is more in P area. In forward feed, electrons pass the junction and create current. But when backward feed, electrons and holes split and are dragged to opposite edges of the device. Therefore no current occurs.

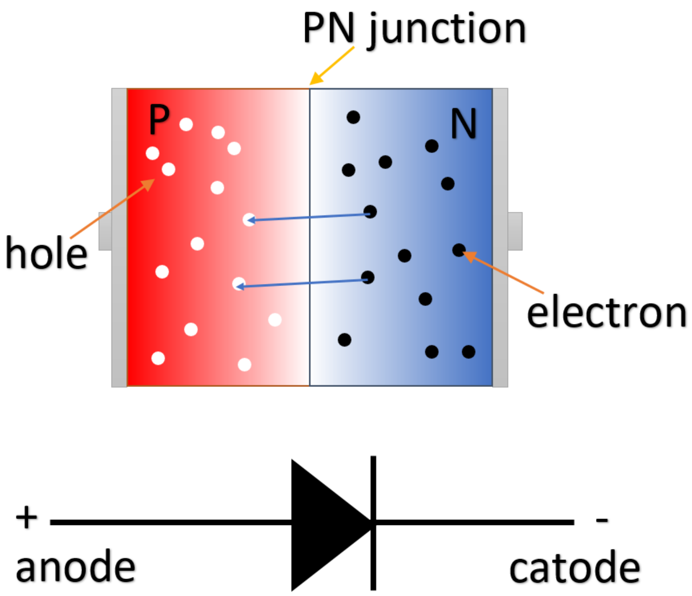


Figure 1: P-N junction in a diode.

$I$-$V$ characteristic of a diode is given in Figure 2, schematically. This characteristic is expressed by Shockley ideal diode equation as follows,

$$I = I_S(e^{\frac{V}{nV_T}} - 1), \quad V_T = \frac{kT}{q} \tag{1}$$

where $I$ is the current passing through the diode, $I_S$ is scale current, $V$ is the voltage across the diode, $n$ is ideality or quality factor and $V_T$ is the thermal voltage. The theoretical value for thermal voltage in room temperature is 25.86 mV. This equation models both forward and backward feed but the reverse breakdown region is not modeled by the Shockley diode equation. The graph of this equation is non-linear. In order to obtain a linear graph, the Shockley diode equation must be linearized. To do so, you may use the following theorem. As $M \to \infty$,

$$log(M + A) = log(M(1 + S)), \tag{2}$$

where $S = \frac{A}{M}$ is a small number. This way we get,

$$\begin{aligned} Log(M + A) &= log(M) + log(1 + S) \\ &\approx log(M). \end{aligned} \tag{3}$$

Since all known values for $I_S$ is of order -12 and in this experiment the measured current values are in milli-order, $I/I_S$ is a big number compared to 1. Thus, we may use Equation (3) to linearize Shockley equation as follows,

$$V = nV_T ln(I) - nV_T ln(I_S) \tag{4}$$

where $nV_T ln(I_S)$ is the y-intercept, $ln(I)$ is independent variable (*i.e.* the x-axis) and $nV_T$ is the slope of the graph. The theoretical value for saturation current $I_S \sim 10^{-12}$.

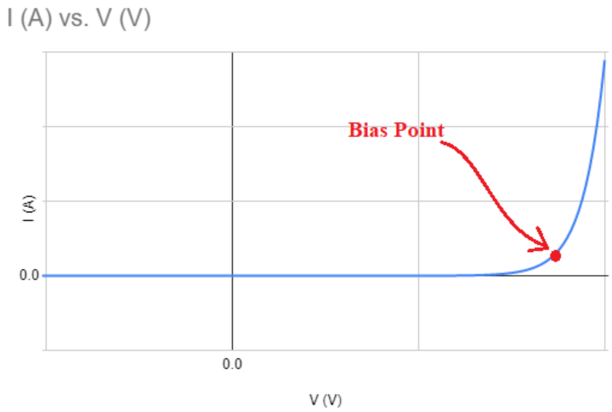


Figure 2: I-V characteristic of a diode.

In Figure 2, bias point is shown. Bias point the the point that $I$-$V$ characteristic curve bends. Voltage value of this point is a characteristic for different materials. For example, this value is 0.65 V for Zener diodes and 0.3 V for Germanium diodes.

## 1.2 Zener Diode

Zener diodes are specially constructed silicon diodes. Zener diode is a P-N junction designed to operate in the reverse breakdown region. In the right half of characteristic curve, zener diode is in forward feed. In this part behave to rectifiers.

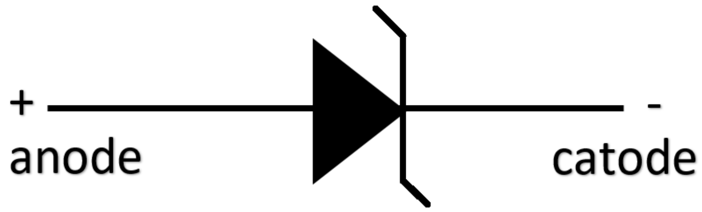


Figure 3: Zener diode

At bias voltage, the current increases rapidly with very little voltage change across the diode. In the left half of characteristic curve, zener diode is in backward feed.At first, when receiving reverse voltage the current is very small. When the voltage reaches the break point, the current increases. The voltage at the break point is called the zener voltage ($V_z$). The diode biased in a reverse direction will prevent conduction untill the amplitude of the input signal reaches the zener region. When the amplitude of input signal reaches the zener region, the reverse biased diode conducts, and the voltage drop across the series resistor limits the output signal at that amplitude until the amplitude of the input signal drops below the zener region.

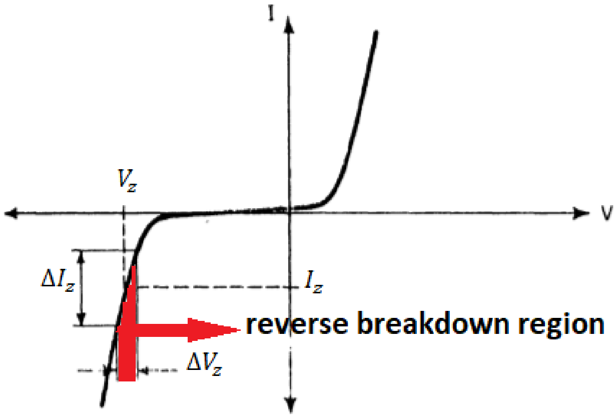


Figure 4: Characteristic curve of zener diode

# 2 Procedure

## 2.1 Experimental Procedure

## Part A: Diode

### 2.1.1 Forward Feed

1. Build the circuit given in Figure 5(a).
2. Adjust the scales of multimeters.
3. Open the power supply while its voltage value is zero.
4. Increase the source voltage a little bit. The voltage you read from voltmeter should be 0.1 V.
5. Write down the values from ammeter and voltmeter in the table in Section 3.
6. Repeat the steps 4-5 until you reach the 1.00 V in voltmeter. Voltage difference between sequential measurement should be 0.1 V.

### 2.1.2 Backward Feed

1. Build the circuit given in Figure 5(b). To do so, just remove the diode and attach it again backward.
2. Adjust the scales of multimeters.
3. Open the power supply while its voltage value is zero.
4. Increase the source voltage a little bit. The voltage you read from voltmeter should be -0.1 V.
5. Write down the values from ammeter and voltmeter in the table in Section 3.
6. Repeat the steps 2-3 until you reach the -1.00 V in voltmeter. Voltage difference between sequential measurement should be 0.1 V.

## Part B: Zener Diode

### 2.1.3 Forward Feed

1. Set the circuit given in Figure 6(a).
2. By using the power supply, adapt the source voltage to the 1st source voltage value at Table (2).
3. Write down the values from ammeter and voltmeter in the table in Section 3.
4. Repeat the steps 2-3 until you reach the 0.95 V in voltmeter.

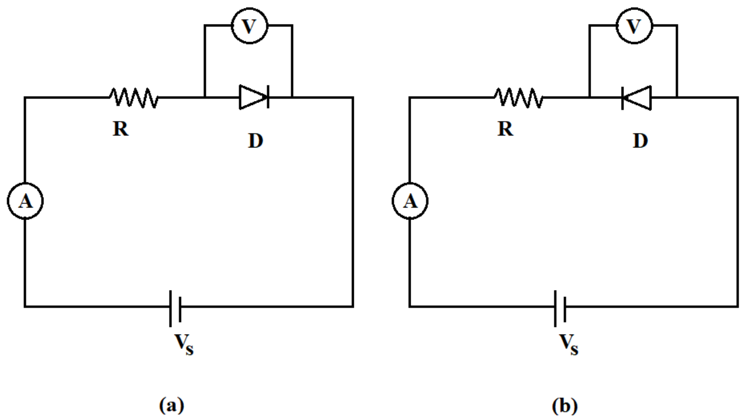


Figure 5: (a) Forward feed (b) Backward feed circuits.

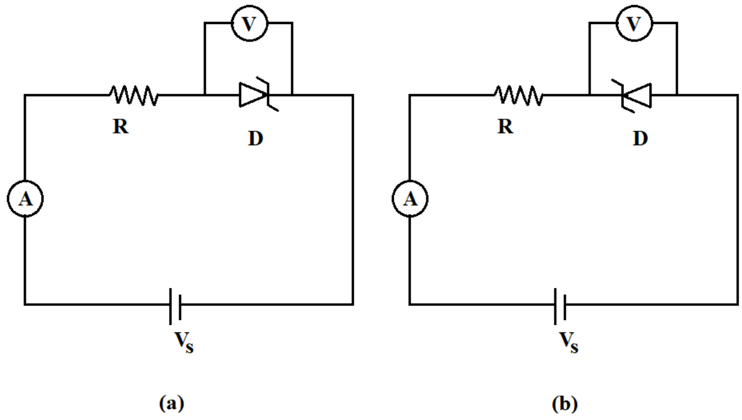


Figure 6: (a) Forward feed (b) Backward feed circuits.

#### 2.1.4 Backward Feed

1. Set the circuit given in Figure 6(b).
2. By using the power supply, adapt the source voltage to the 1st source voltage value at Table (3).
3. Write down the values from ammeter and voltmeter in the table in Section 3.
4. Repeat the steps 2-3 until you reach the 13 V in voltmeter.

## 2.2 Analysis Procedure

## Part A: Diode

### Plot to find bias point

- Plot the $I$ vs. $V$ graph. Use all of your data taken for diode and plot only one graph. This graph is first graph.
- Observe the bias point and write it down in Section 3.
- Determine the material of the diode used in the experiment.

### Plot to find $V_T$

- Intuition from Equation (4), plot the $V$ vs. $Ln(I)$ graph. Use only the data taken for diode in forward feed. This graph is second graph.
- Fit the plot and calculate the slope.
- Using Equation (4) and slope of the graph determine the experimental value for $V_T$. Use $n = 1.90$ if you have 1N4001 diode.
- Calculate the percentage error for $V_T$.

## Part B: Zener Diode

### Plot to find bias point and zener voltage

- Plot the $I$ vs. $V$ graph. Use all of your data taken for zener diode and plot only one graph. This graph is third graph.
- Observe the bias point and write it down in Section 3.
- Observe the zener voltage and write it down in Section 3.
- Determine the material of the diode used in the experiment.

### Plot to find $V_T$

- Intuition from Equation (4), plot the $V$ vs. $Ln(I)$ graph. Use only the data taken for zener diode in forward feed. This graph is third graph.
- Fit the plot and calculate the slope.
- Using Equation (4) and slope of the graph determine the experimental value for $V_T$. Use $n = 1.10$ if you have BZX84C10L zener diode.
- Calculate the percentage error for $V_T$.

# 3 Data & Analysis

## Part A: Diode

Table 1: Part A, current and voltage values for different supply voltages with diode.

| Forward Feed | | | | Backward Feed | | | |
|---|---|---|---|---|---|---|---|
| # | $V_S$(V) | $I$ (________) | $V$ (________) | # | $V_S$ (V) | $I$ (________) | $V$ (________) |
| 1 | 0.1 | | | 1 | -0.1 | | |
| 2 | 0.2 | | | 2 | -0.2 | | |
| 3 | 0.3 | | | 3 | -0.3 | | |
| 4 | 0.4 | | | 4 | -0.4 | | |
| 5 | 0.5 | | | 5 | -0.5 | | |
| 6 | 0.6 | | | 6 | -0.6 | | |
| 7 | 0.7 | | | 7 | -0.7 | | |
| 8 | 0.8 | | | 8 | -0.8 | | |
| 9 | 0.9 | | | 9 | -0.9 | | |
| 10 | 1.0 | | | 10 | -1.0 | | |

- Voltage value of Bias point of diode (according to plot#1):

- Type of diode:

- Slope of the $V$ vs. $Ln(I)$ graph (according to plot#2) (do the math explicitly):

- Experimental value for $V_T$ (do the math explicitly):

- Percentage error for $V_T$ (do the math explicitly):

## Part B: Zener Diode

Table 2: Part B, current and voltage values for different supply voltages with zener diode.

| Forward Feed | | | | | | | |
|---|---|---|---|---|---|---|---|
| # | $V_S$ (V) | $I$ (_________) | $V$ (_________) | # | $V_S$ (V) | $I$ (_________) | $V$ (_________) |
| 1 | 0.05 | | | 11 | 0.55 | | |
| 2 | 0.10 | | | 11 | 0.60 | | |
| 3 | 0.15 | | | 12 | 0.65 | | |
| 4 | 0.20 | | | 13 | 0.70 | | |
| 5 | 0.25 | | | 14 | 0.75 | | |
| 6 | 0.30 | | | 15 | 0.80 | | |
| 7 | 0.35 | | | 16 | 0.85 | | |
| 8 | 0.40 | | | 17 | 0.90 | | |
| 9 | 0.45 | | | 18 | 0.95 | | |
| 10 | 0.50 | | | 20 | 1.00 | | |

| Backward Feed | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | -2.0 | | | 21 | -11.1 | | |
| 2 | -4.0 | | | 22 | -11.2 | | |
| 3 | -6.0 | | | 23 | -11.3 | | |

| # | $V_S$ (V) | $I$ (________) | $V$ (________) | # | $V_S$ (V) | $I$ (________) | $V$ (________) |
|---|---|---|---|---|---|---|---|
| 4 | -8.0 | | | 24 | -11.4 | | |
| 5 | -9.0 | | | 25 | -11.5 | | |
| 6 | -9.2 | | | 26 | -11.6 | | |
| 7 | -9.4 | | | 27 | -11.7 | | |
| 8 | -9.6 | | | 28 | -11.8 | | |
| 9 | -9.8 | | | 29 | -11.9 | | |
| 10 | -10.0 | | | 30 | -12.0 | | |
| 11 | -10.1 | | | 31 | -12.1 | | |
| 12 | -10.2 | | | 32 | -12.2 | | |
| 13 | -10.3 | | | 33 | -12.3 | | |
| 14 | -10.4 | | | 34 | -12.4 | | |
| 15 | -10.5 | | | 35 | -12.5 | | |
| 16 | -10.6 | | | 36 | -12.6 | | |
| 17 | -10.7 | | | 37 | -12.7 | | |
| 18 | -10.8 | | | 38 | -12.8 | | |
| 19 | -10.9 | | | 39 | -12.9 | | |
| 20 | -11.0 | | | 40 | -13.0 | | |

- Voltage value of Bias point of zener diode (according to plot#3):

- Zener voltage of zener diode (according to plot#3):

- Type of diode:

- Slope of the $V$ vs. $Ln(I)$ graph (according to plot#4) (do the math explicitly):

- Experimental value for $V_T$ (do the math explicitly):

- Percentage error for $V_T$ (do the math explicitly):

## 4 Conclusions

## 5 Contributions

## 6 Notes