Study of Normal and Zener Diode Characteristics

Gayatri P
2nd year, Integrated M.Sc. Physics
Roll No.: 2211185
(Dated: August 23, 2023)

A Diode is one of the most important and useful devices used in modern electronics. It has various uses in communication systems to rectifying circuits and power supply systems. The main feauture of a diode is that it only allows the unidirectional flow of current. In this experiment, we try to find the I-V characteristics of the different types of diodes namely the normal PN junction diode and the Zener diode. We also try to determine the variation of the resistance of the diode with applied resistance.

I. THEORY

A. Introduction

Diodes are non-linear circuit components which only allows the unidirectional flow of current. A diode basically consists of a P-N junction with metallic contacts at the end for application of external voltage. The direction of arrow indicates the conventional direction of current flow, from P-side to N-side.

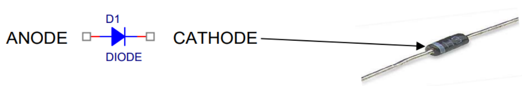


FIG. 1: Circuit symbol of a diode and a commercial diode

During the formation of the P-N junction, due to the concentration gradient across P, and N-sides, holes diffuse from P-side to N-side and electrons diffuse from N-side to P-side. This gives rise to a **diffusion current**, and a **depletion region** is formed at the junction consisting of immobile charges. Due to this, there is a **barrier potential** across the depletion region.

Theoretical equation for the diode current (I_D) is,

$$I_D = I_s \left[\exp\left\{ \frac{V_D}{nV_T} \right\} - 1 \right] \tag{1}$$

where V_D = voltage drop across the diode, I_S = saturation current, $V_T = k_B T/q$ ($\approx 0.026V$ at $T = 300K$) is the thermal voltage, and n is the emission coefficient. The emission coefficient accounts for recombinations of electrons and holes in the depletion region, which tends to decrease the current. For discrete diodes, $n = 2$ and in intergrated circuits, $n = 1$.

An *ideal* diode works as a short circuit in forward bias and an open circuit in reverse bias. However, in a real diode, the current faces resistance due to the potential barrier. When the applied potential is more than the potential barrier, the current through the diode increases steeply.

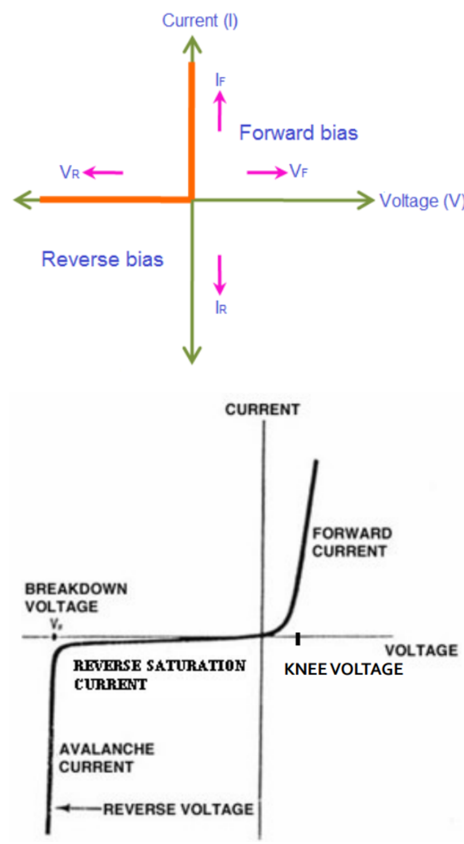


FIG. 2: I-V characteristics of (a) an ideal diode and (b) a real diode

1. *Biasing a diode*

1. **Forward bias:** When the P-side is connected to the positive and N-side to the negative terminals of the power supply, it reduces the potential barrier. As a result current flows from P to N-type in forward direction. When the applied voltage is more than the barrier potential, the resistance is small (ideally 0) and the current increases rapidly. This point is called the *Knee-point* or *threshold voltage*. This voltage is about 0.3 V Ge-diodes and 0.7 V for Si diodes.

2. **Reverse bias:** Here, the P-side of the junction diode is connected to the negative and N-side is connected to the positive terminal of the power supply. This increases the potential barrier due to which ideally no current should flow. But in practice, the minority carriers can tr, known as the *reverse saturation current*. This current is about 2-20 μA for Ge diodes and 2-20 nA for Si diodes.

If the reverse bias is made too high, the current through the diode increases abruptly at a certain voltage, known as the **breakdown voltage**. In conventional (lightly doped) diodes, this is due to collisions of large number of thermally generated electrons in a phenomena called the **avalanche breakdown**.

B. Zener Diodes

These are a specific type of diodes with heavily doped PN junctions. The forward characteristic of a zener diode is similar to a normal diode. **Zener voltage** is the reverse voltage above which there is a controlled breakdown which does not damage the diode. The voltage drop across the diode remains constant at zener voltage no matter how high the reverse bias voltage is.

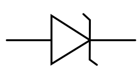


FIG. 3: Circuit symbol of a zener diode

Since the PN-junction is heavily doped, the depletion layer is narrow for a zener diode. At high reverse voltages, the high electric field created at the narrow depletion region generates a large number of electron hole pairs causing high current to flow. This process is called the **Zener breakdown**.

C. Static and Dynamic Resistance

The static or the DC resistance, R_D at any given point is given by inverse of the slope at that point of the I-V characteristic of the diode. The static resistance is higher below the knee voltage than above the knee voltage.

$$R_D = \frac{V_D}{I_D} \tag{2}$$

Since diode resistance dynamically varies with the input voltage, we define a term dynamic resistance — r_D — to measure the resistance at an instantaneous operating point. The dynamic resistance or the AC resistance is defined as the ratio of change in voltage and change in current around the DC operating point.

$$r_D = \frac{\Delta V_D}{\Delta I_D} \tag{3}$$

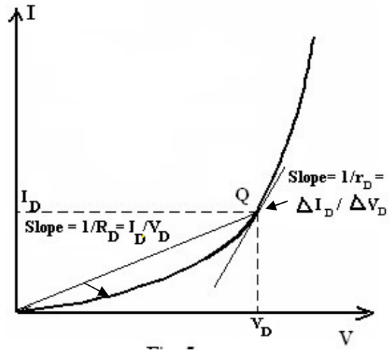


FIG. 4: Finding Static and Dynamic Resistance of diode from the I-V plot

D. Application

Diodes have extremely important applications in modern electronics. They are used in communication systems as limiters, clippers, gates, in power supply systems as rectifiers and inverters, voltage multipliers and so on.

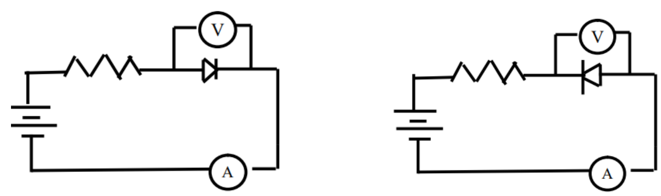
Zener diodes in particular are used for voltage regulation as the voltage drop across the diode remains constant over a wide range of voltages. They are also used as surge suppressors to prevent accidental overloads in circuits.

II. EXPERIMENTAL SETUP

A. Apparatus Used

1. Breadboard
2. 0-30V Power supply
3. Multimeters
4. Resistors
5. Jumper wires and banana clips
6. Silicon diode
7. Zener diode

B. Circuit Diagram

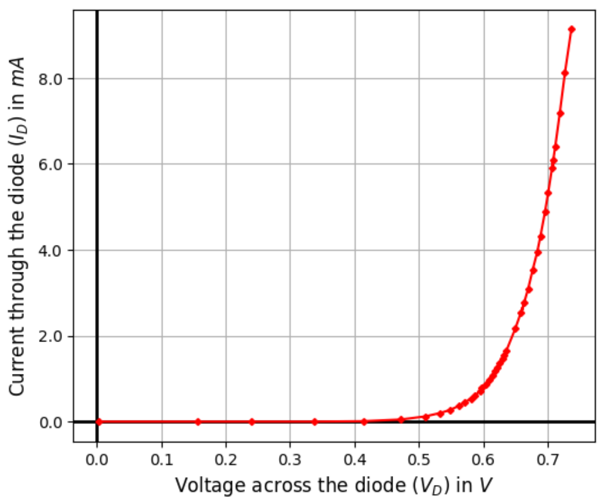


(a) Forward Bias (b) Reverse Bias

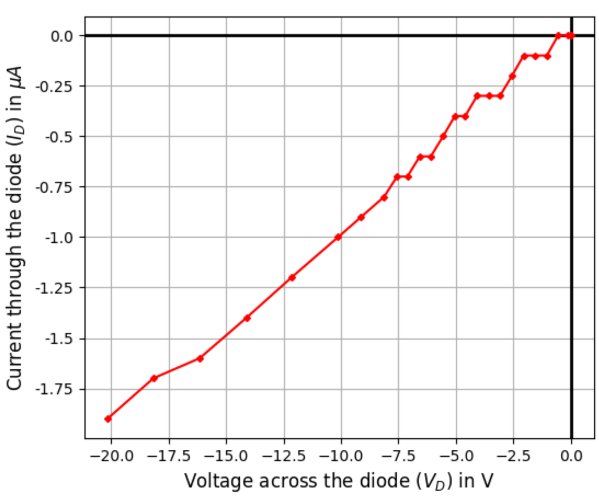
FIG. 5: Circuit diagrams for the experimental setup

III. DATA ANALYSIS

A. IV Characterstics of Silicon Diode (IN4148)



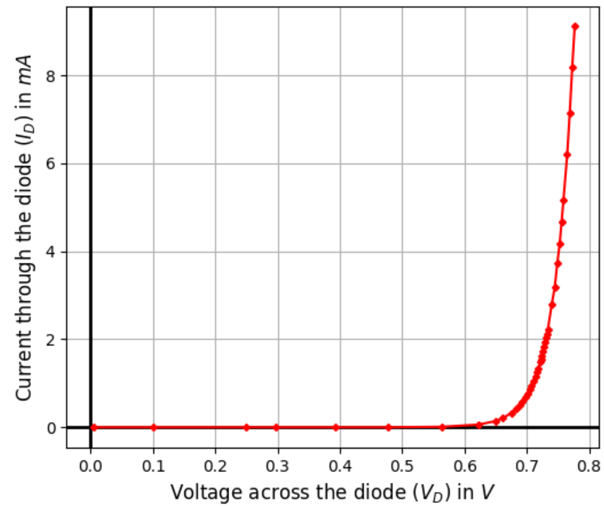
(a) Si diode under forward bias



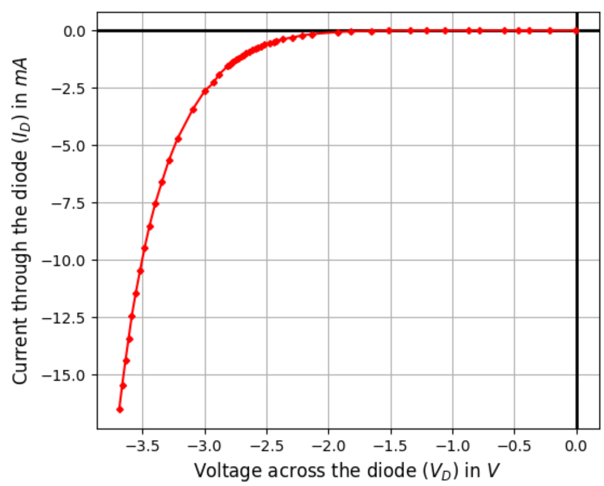
(b) Si diode under reverse bias

FIG. 6: I-V characteristics graph of a Silicon Diode. The knee voltage is 0.65V but the breakdown voltage could not be detected. Note that the scale of y-axis in plot (b) is 3 order of magnitude less that plot (a), i.e. there is negligible current flowing through the diode under reverse bias.

B. IV Characterstics of Zener Diode (C3V3PH)



(a) Zener diode under forward bias



(b) Zener diode under reverse bias

FIG. 7: I-V characteristics of the Zener Diode. The knee voltage is approximately 0.68V and the breakdown voltage is approximately 2.5V

C. Calculations

We can see from Fig 1(a) that the operating point point of the diode may lie somewhere above 0.72V. Let's take approximately $V_D = 0.727V$.

Static resistance at $0.727V$,

$$
\begin{aligned}
R_D &= \frac{V_D}{I_D} \\
&= \frac{0.727}{8.12 \times 10{-}3} = 89.53\Omega
\end{aligned}
$$

Similarly, dynamic resistance at $0.727V$,

$$\begin{aligned} r_D &= \frac{\Delta V_D}{\Delta I_D} \\ &= \frac{0.727 - 0.719}{(8.12 - 7.18) \times 10{-3}} \\ &= 8.51\Omega \end{aligned}$$

IV. RESULTS AND DISCUSSION

Both the diodes show I-V characterstics as expected.

The Silicon diode under forward bias shows no current until it reaches the threshold voltage, and under reverse bias shows currents of order 3 magnitudes less, which is practically negligible.

Threshold voltage for the Silicon diode was found to be around

$$V_{\text{threshold}} = 0.65V$$

Static and dynamic resistances at close to the oprating point was found to be 89.53 Ω and 8.51 Ω respectively.

The Zener diode also shows similar characterstics as the Silicon diode under forward bias. Under reverse bias, after a certain breakdown voltage, current rapidly increases in the circuit.

For the zener diode, the threshold voltage and the zener breakdown voltage was observed to be around,

$$\begin{aligned} V_{\text{threshold}} &= 0.68V \\ V_{\text{breakdown}} &= 2.50V \end{aligned}$$

V. PRECAUTIONS

1. Power supply voltage must be varied slowly.
2. Be sure to not send high amounts of current through the circuit or the circuit components may heat up.
3. Do not supply more than the breakdown voltage for silicon diodes, or they may get damaged.
4. Test the parts of the circuit before starting the experiment to make sure they are working.

[1] SPS. Lab manual. *Website*, 2023. `https://www.niser.ac.in/sps/sites/default/files/2-a-diode%20characteristics.pdf`.