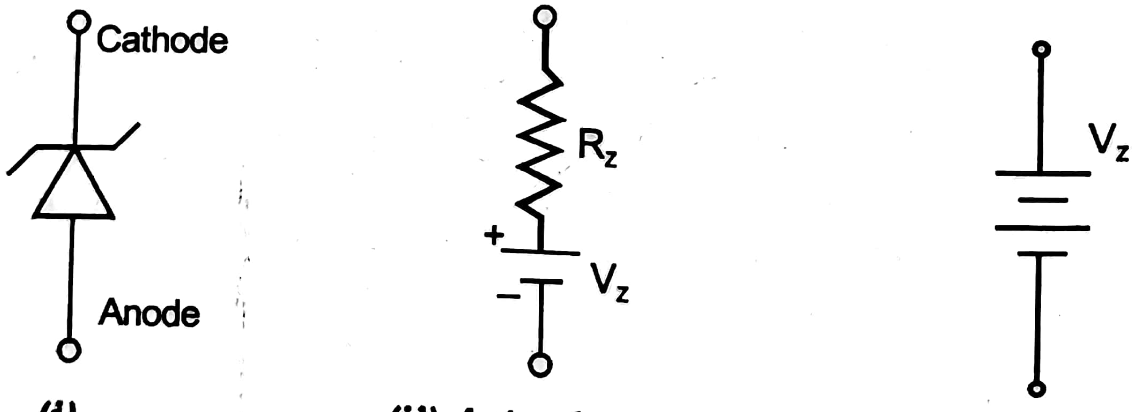
4.7 ZENER DIODE

- In a general purpose PN diode, the doping is light. As a result of this, the breakdown voltage is high. If P and N region are heavily doped, then the breakdown voltage can be reduced.
- When the doping is heavy, even if the reverse voltage is low, the electric field at barrier will be so strong and thus the electrons in the covalent bonds can break away from the bonds. This effect is known as **Zener effect**.
- A diode which exhibits the zener effect is called a **Zener diode**. Hence, it is defined as a reverse biased heavily doped PN junction diode which operates in breakdown region. The zener diodes have been designed to operate at voltages ranging from a few volts to several hundred volts.
- **Zener breakdown** occurs in junction which is heavily doped and have narrow depletion layers. The breakdown voltage sets up a very strong electric field. This field is strong enough to break or rupture the covalent bonds thereby generating electron hole pairs.
- Even a small reverse voltage is capable of producing large number of current carrier. When a zener diode is operated in the breakdown region, care must be taken to notice that the power dissipation across the junction is within the power rating of the diode. Otherwise heavy current will flow through the diode and may destroy it.

Equivalent Circuit of Zener Diode

The schematic symbol of zener diode and its equivalent circuit is shown in figure 4.10. It is similar to that of normal diode except the line representing cathode is bent at both end is shown in figure 4.10.



(i) *(ii) Actual case* *(iii) Ideal case*

Figure 4.10 Symbolic representation of zener diode and its equivalent circuit

When the reverse bias voltage across zener diode exceeds the breakdown voltage V_z, the current increases very sharply. It means that voltage across zener diode is constant at V_z even though the current through it changes. Therefore in breakdown region, a zener diode may be represented by a battery of voltage V_z in series with the zener resistance as shown in figure 4.10.

4.6.5 Breakdown Mechanisms in Semiconductor Diodes

When a diode is reverse biased, the depletion layer widens to set up a large potential barrier which prevents diffusion of majority carriers from one side to other. Thus, there is no current due to the majority carriers. Under normal reverse voltages, only very small reverse current due to minority carriers exists. It is in the order of micro amps and is further temperature-dependent. As reverse bias voltage is further increased, it reach a point where the reverse current suddenly shoots up.

This occurs due to the junction breakdown. The junction breakdown mechanism is of two types

1. Zener breakdown
2. Avalanche breakdown

Zener Breakdown

This occurs primarily in heavily doped diodes. In these diodes, the depletion region is very small.

When reverse biasing a diode, a very strong electric field exists across the depletion region at near breakdown voltage levels. For an applied reverse bias voltage of 6 Volts or less, the electric field is in the order of 2×10^7 V/m. This very high electric field breaks covalent bonds and creates new electron hole pairs which increases the reverse current dramatically and thus a large reverse current flows.

For lightly doped diodes, the zener breakdown voltage is quite high and so breakdown predominantly occurs through avalanche mechanism.

Avalanche Breakdown

As mentioned, this occurs in lightly doped diodes where the depletion layer is very wide and electric field is very low.

Here, the reverse voltage applied imparts high energy to the minority carriers. The minority carriers with sufficient kinetic energy disrupt covalent bonds in the crystal, thus releasing the valence electron. This process is called **"impact ionization"**. The newly released valence electrons gain enough energy to disrupt other covalent bonds. The process is like a uncontrolled chain reaction and is a cumulative process and is known as **avalanche multiplication**. It leads to a avalanche or flood of charge carriers thus increasing the reverse current dramatically.

Temperature Dependence of Breakdown Voltage

In heavily doped diodes like zener diodes, an increase in temperature increases the energies of valence electrons, and hence makes it easier for these electrons to escape from covalent bonds. Thus, less applied voltage is sufficient to knock or pull these electrons from their respective position in the crystal and convert them into conduction electrons. Thus, the zener breakdown voltage decreases with temperature.

In lightly doped diode like PN junction diode, an increase in temperature increases the probability of collision of electrons and increases the depletion width. Thus, the electrons and holes needs a high voltage to cross the junction. Therefore, the avalanche voltage is increased with increased temperature.

Comparison of zener breakdown and avalanche breakdown

No.	*Zener breakdown*	*Avalanche breakdown*
1.	It occurs in heavily doped junction.	It occurs in lightly doped junction
2.	It occurs with reverse bias voltage is less than 6 V.	It occurs in PN junction diode with reverse voltage greater than 6 V.
3.	Temperature coefficient is negative.	Temperature coefficient is positive.
4.	The reverse bias VI characteristics is very sharp in breakdown region.	The VI characteristics in reverse bias is not sharp (i.e., soft).
5.	It occurs by breaking covalent bonds due to very high electric field established by the reverse bias.	It occurs by breaking covalent bonds due to collision of accelerated electrons as a chain reaction.
6.	The breakdown voltage decreases if the junction temperature increases.	The breakdown voltage increases if the junction temperature increases.

V-I characteristics of Zener Diode

Figure 4.11 shows the V-I characteristics of zener diode.

The forward characteristics of a zener diode is similar to that of a P-N Junction diode. The reverse characteristics of zener diode is obtained as follows.

- The reverse current that is present at the origin and the knee of the curve is due to the reverse leakage current due to the minority carriers. This current is specified by stating its value at 80% of the zener voltage V_Z.

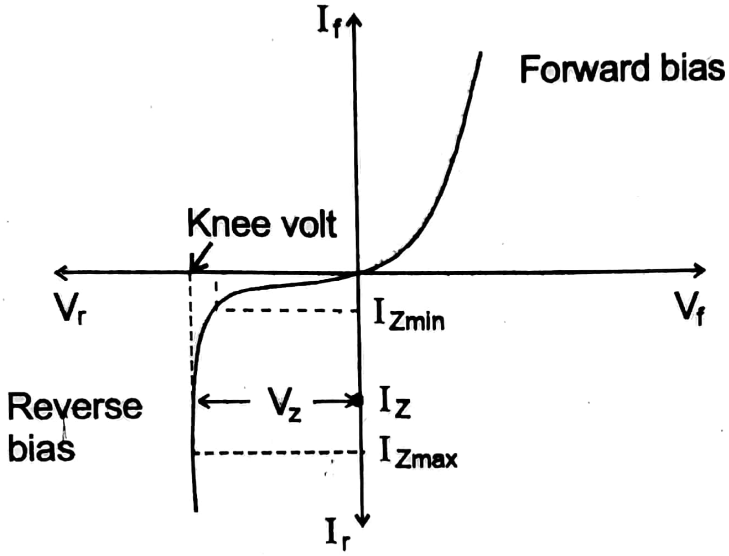


Figure 4.11 VI Characteristics of zener diode

- As the reverse voltage is gradually increased, the breakdown occurs at the knee and the current increases rapidly. To control this current, a suitable external resistance has to be used. The maximum permissible value of the current is denoted by I_{zmax}. The minimum usable current is I_{zmin}.

- The voltage across the terminals of the diode for a current I_z which is the approximate midpoint of the linear range of the reverse characteristics in called the **Zener voltage V_Z**. At the knee point, the breakdown voltage remains constant between I_{zmax} and I_{zmin}. This ability of a diode is called regulating ability and is an important feature of a zener diode.

Application of Zener Diode

It can be used

a) as voltage regulators

b) as peak clippers

c) for reshaping waveforms

d) protection of meter against damage from accidental application of excessive voltage.