13.7. Tunnel Diode

It has been observed that if the concentration of impurity atoms is greatly increased in a normal PN junction (by 1000 times or more), its characteristics are completely changed. This gives rise to a new type of diode known as *tunnel diode*. It was invented in 1958 by Dr. Leo Esaki. That is why, a tunnel diode is also known as Esaki diode.

In a normally doped PN junction, the impurity concentration (*i.e.,* doping level) is of very small value (*i.e.,* about one part in 10^8 atoms). With this amount of doping, the width of depletion layer is of the order of one micron (which is equal to 10^{-6} m). This constitutes a potential barrier at the junction, which controls the flow of charge carriers (*i.e.,* electrons and holes) across the junction. The charge carriers cannot cross-over the potential barrier, unless they acquire sufficient energy to overcome it. However, when impurity concentration is increased (say about one part in 10^3 atoms), the width of depletion layer reduces to about 10 nanometer (where one nanometer = 10^{-9}m). Under such conditions, the charge carriers will penetrate through the junction at the speed of light, even though they do not have enough energy to overcome the potential barrier. As a result of this, a large to overcome the potential barrier. As a result of this, a large forward current is produced, even if the applied forward voltage is much less than 0.3 V.

The phenomenon of penetrating the charge carriers, directly through the potential barrier, instead of climbing over it, is called tunneling. That is why, highly doped PN junction devices are called tunnel diodes. These diodes are usually made of germanium (Ge) or gallium-assenide (GaAs).

Fig. 13.7 shows two commonly used symbols for a tunnel diode. The tunnel diodes should be handled with a great care, because they are low power devices and can be easily damaged by heat and static electricity.

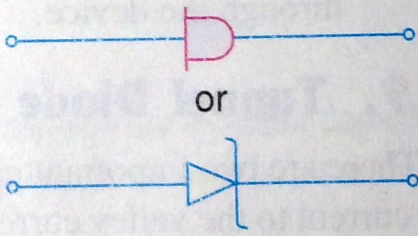

Fig. 13.7. Symbols for tunnel diodes.

13.8. V-I Characteristics of a Tunnel Diode

Fig. 13.8 shows V-I characteristics of a tunnel diode. From the characteristic curve, we see that as the applied forward voltage is increased from zero, the current increases very rapidly, till it reaches its maximum value known as peak current (I_P) as indicated by the point *A*. The corresponding value of the forward voltage is indicated by peak voltage (V_P). The value of this voltage is typically 65 mV for germanium and 160 mV for gallium arsenide tunnel diode.

It will be interesting to know that if the forward voltage is further increased (*i.e.,* beyond V_P), the current decreases, till it reaches its minimum value known as valley current (I_V) as indicated by the point *B*. As the voltage is further increased, the current increases in a usual manner as in a normal PN junction diode. It has been observed that the current again reaches its peak value (*i.e.*, I_P) as indicated by the point *C*. The corresponding value of the voltage is indicated by V_F as shown in the figure. For larger values of voltages, the current increases beyond these values.

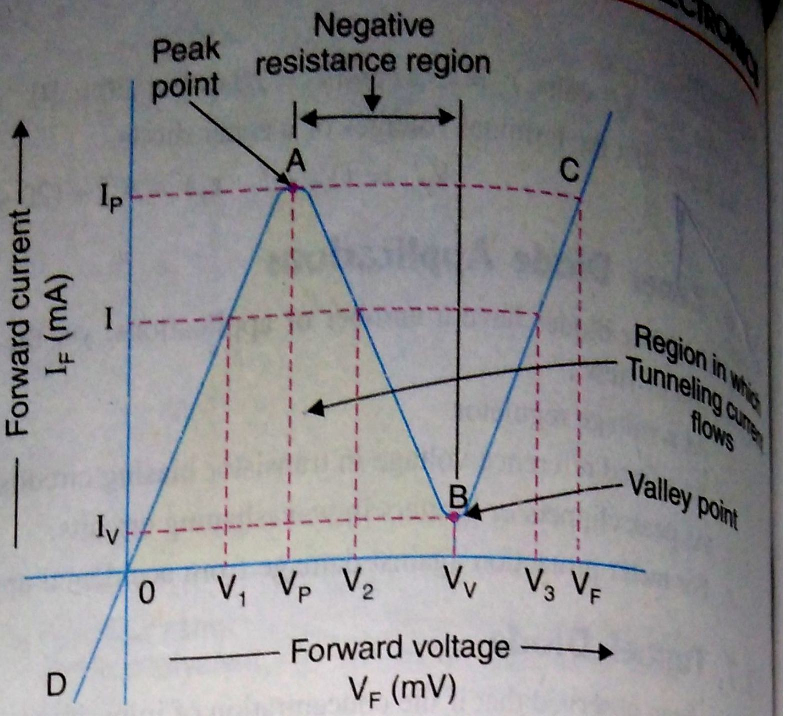

Fig. 13.8. V-I characteristic of a tunnel diode.

If the tunnel diode is reversed biased (*i.e.*, P side of junction is made negative with respect to its N-side), it acts like an excellent conductor, *i.e.*, the reverse current increases with the increase in reverse voltage. It is indicated by the curve *OD* in the figure. Following are some of the important points of the characteristics of a tunnel diode.

1. Between the peak point *A* and valley point *B*, the current decreases with the increase in voltage. Therefore, the tunnel diode possess a negative resistance in this region as indicated in the figure. This feature makes the tunnel diode useful in high frequency oscillators.
2. For currents, whose values are between I_V and I_P, the curve is triple valued. It means that each current can be obtained at three different applied voltages. It is indicated in the figure by the voltages V_1, V_2 and V_3 for the current *I*. This multivalued feature makes the tunnel diode useful in pulse and digital circuits.
3. The portion *BC* of the characteristic is similar to that of a forward-characteristic of a normal PN junction.
4. The shaded region in the figure indicates the region in which the tunnelling current flows through the device.

13.9. Tunnel Diode Parameters

There are two important parameters of a tunnel diode namely negative resistance and the ratio of peak current to the valley current (*i.e.*, I_P/I_V). These parameters are discussed in more detail as below:

1. ***Negative resistance.*** It is the resistance of a tunnel diode which it offers when operated in a negative resistance region. The negative resistance is given by the relation,

$$R_n = -\frac{\Delta V_F}{\Delta I_F}$$

where ΔV_F = Change in forward voltage between any two points lying within the negative resistance region of the V-I characteristic, and

ΔI_F = Corresponding change in forward current.

The negative resistance region may also be expressed in terms of slope of the characteristic in the negative resistance region. Its value depends upon the semiconductor material used for manufacturing tunnel diodes and the value may range from 10 W to 200 Ω.

2. *Ratio of peak current to valley current (I_P/I_V).* This parameter is important in high speed switching circuits, which are used in computers. The ratio I_P/I_V for germanium type tunnel diode is 6 and for gallium arsenide type is 10. The silicon type tunnel diode has a low I_P/I_V ratio which is about 3. It is because of this fact that silicon type tunnel diodes are not manufactured in actual practice.

13.10. Tunnel Diode Equivalent Circuit

Fig. 13.9 shows a small signal equivalent circuit for a tunnel diode. It consists of a series resistance (R_S), inductance (L_S), the junction capacitance (C) and a negative resistance ($-R_N$). The series resistance is the resistance due to leads, contacts and semiconductor material. Its typical value may range from 1 to 5 ohms. The series inductance is due to lead lengths. Its typical value may range from 0.1 to 4 *n*H.

The junction capacitance is due to diffusion capacitance and the applied voltage. Its typical value may range from 0.35 to 100 pF as shown in Fig. 13.9.

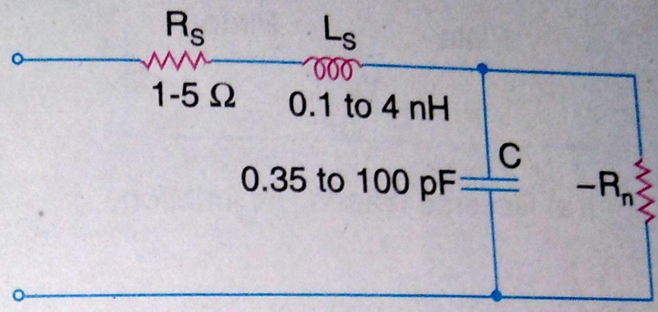

Fig. 13.9. Equivalent circuit of a tunnel diode.

13.11. Tunnel Diode Applications

The tunnel diodes exhibit a specific characteristic called negative resistance. They have extremely low values of inductance and capacitance. These features make them useful in a number of applications as discussed below:

1. As an ultra high-speed switching device. It is possible due to the tunneling mechanism, which takes place at the speed of light. The switching time is of the order of nono-seconds (10^{-9} sec).
2. As a logic memory storage device. It is possible due to the triple valued of the curve for current between I_P and I_V.
3. As a microwave oscillator at frequencies in the order of 10 GHz. It is possible due to extremely low values of inductance and capacitance of the device.
4. In relaxation oscillator. It is possible due to negative resistance of the device.