III.8. THE TUNNEL DIODE

1. Theory

The Japanese physicist Leo Esaki invented the tunnel diode in 1958. It consists of a p-n junction with highly doped regions. Because of the thinness of the junction, the electrons can pass through the potential barrier of the dam layer at a suitable polarization, reaching the energy states on the other sides of the junction. The current-voltage characteristic of the diode is represented in Figure 1. In this sketch i_p and U_p are the peak, and i_v and U_v are the valley values for the current and voltage respectively. The form of this dependence can be qualitatively explained by considering the tunneling processes that take place in a thin p-n junction.

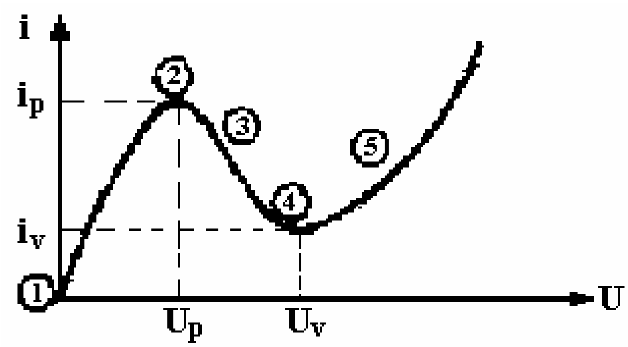

Figure 1.

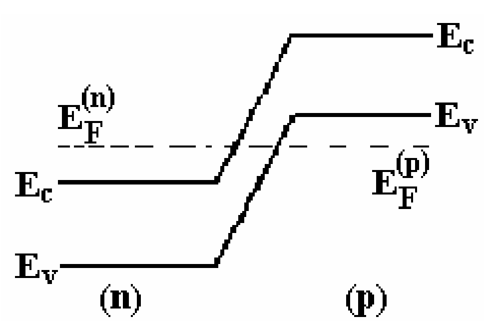

Figure 2.

For the degenerated semiconductors, the energy band diagram at thermal equilibrium is presented in Figure 2.

In Figure 3 the tunneling processes in different points of the current-voltage characteristic for the tunnel diode are presented.

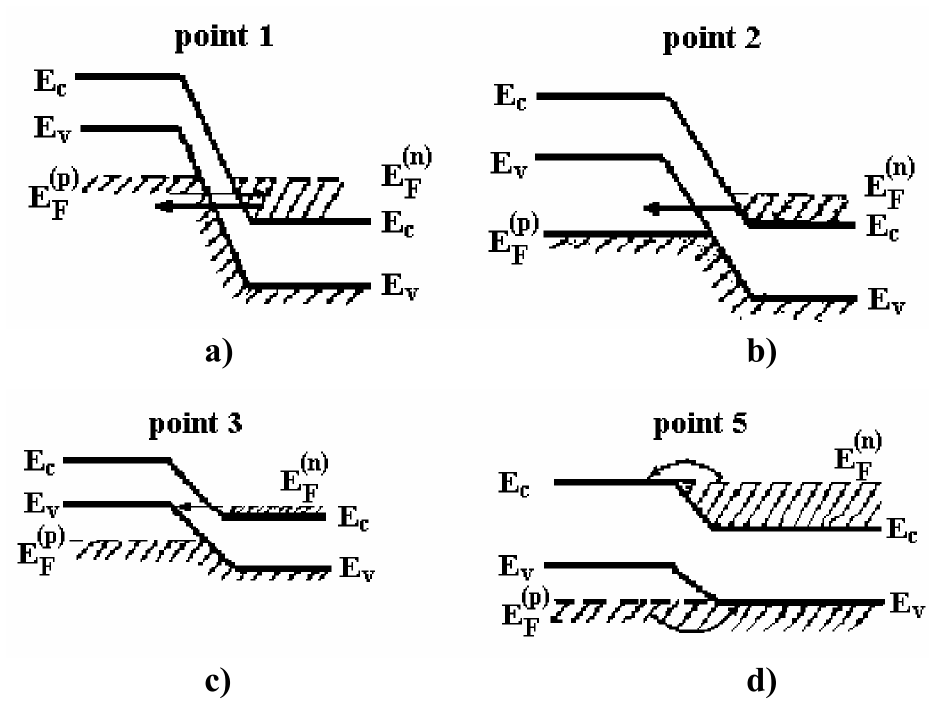

Figure 3.

In Fig. 3a, the thermal equilibrium situation corresponding to point 1 from the Fig. 1 diagram presented; in this case the electrons will uniformly tunnel in both directions, so the current will be null.

At a direct polarization, a non-zero electron flow will tunnel from the occupied states of the conduction band of the n region to the empty states of the valence band from the p region.

The current attains a maximum when the overlap of the empty and occupied states reaches the maximum value; a minimum value is reached when there are no states for tunneling on the sides of the barrier. In this case, the tunnel current should drop to zero, but thanks to the tunneling through the local levels from the semiconductor forbidden band, a finite current, called valley current, will exist. For $U > U_v$, a thermal current passes through the diode, which is the normal p-n junction current.

2. Experimental determination of the I –U characteristic

Theoretical determination of the I – U characteristics in the presence of the tunneling phenomena is extremely difficult; this is why we have to use an empirical dependence of the form:

$$i = A[U\exp(-\alpha U)] + B[\exp(\beta U) - 1], \tag{1}$$

where α, β, A, and B are positive constants of the diode. They can be obtained from the experimental values i_p, U_p, i_v, and U_v, either by numerically solving the transcendent system

$$i_p = AU_p\exp(-\alpha U_p) + B[\exp(\beta U_p) - 1], \tag{2a}$$

$$0 = A(1 - \alpha U_p)\exp(-\alpha U_p) + \beta B\exp(\beta U_p), \tag{2b}$$

$$i_v = AU_v\exp(-\alpha U_v) + B[\exp(\beta U_v) - 1], \tag{2c}$$

$$0 = A(1 - \alpha U_v)\exp(-\alpha U_v) + \beta B\exp(\beta U_v), \tag{2b}$$

or by applying a fitting procedure. As Eq. (1) gives a good description at the process only in the 1-2 region from Fig. 1, the fit will not be very good.

3. Experimental set-up

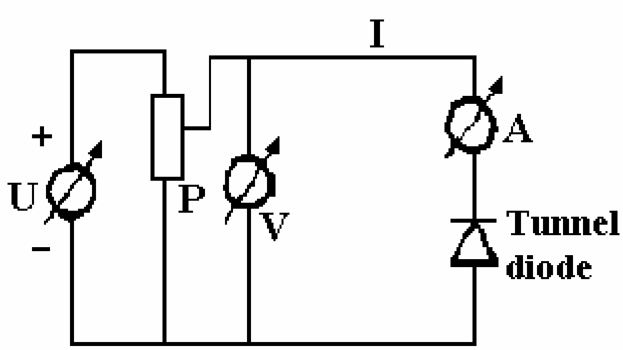

Figure 4.

The draft used for the determination of the current-voltage characteristic is presented in Figure 4. Here U is a voltage source, P a potentiometer that allows us to adjust the polarization voltage for the diode (measured with the voltmeter V), and the current is measured with the milliammeter A.

4. Working procedure

One measures the current increasing the voltage from 0 to 24 V, in steps of 1 V; the milliammeter will be set on the 24 mA scale; the voltage adjustments will be made using the source potentiometer.

After each voltage change, on waits the stabilization of the current. In the rapid current drop region (region 2-4 in Fig. 1), the voltage steps will be as small as possible. After reaching 24V, we repeat the measurements decreasing the voltage back to zero. The cycle is repeated three times.

5. Experimental data processing

On millimetric paper one represents the mean increase and decrease I – U curves. If possible, one also represents the theoretical curves given by Eq. (1), with the parameters resulted from the system (2) or from the application of a fitting program.

From the graph, tracing the tangent in the inflexion points (3 in Fig. 1), one determines the values for the negative differential diode resistance.

6. Questions

1. What are the reasons of the difference between the increasing and the decreasing voltage characteristics?
2. Which are the practical applications of a tunnel diode?