P-N junction diode

Basic structure of P-N junction:

Figure 1 represents two blocks of semiconductor material, one P-type, and the other N-type. The P-type semiconductor block has mobile holes (shown by small circles) and the same number of fixed negative acceptor ions (shown by encircled minus sign). Similarly, the N-type semiconductor block has mobile or free electrons (shown by dots) and the same number of fixed donor positive ions. Normally the holes, which are the majority charge carriers in P-type of material, are uniformly distributed throughout the volume of that material. Similarly, the electrons, which are the majority charge carriers in N-type of material, are uniformly distributed throughout the volume of that material. Each region is electrically neutral because each of them carries equal positive and negative charges.

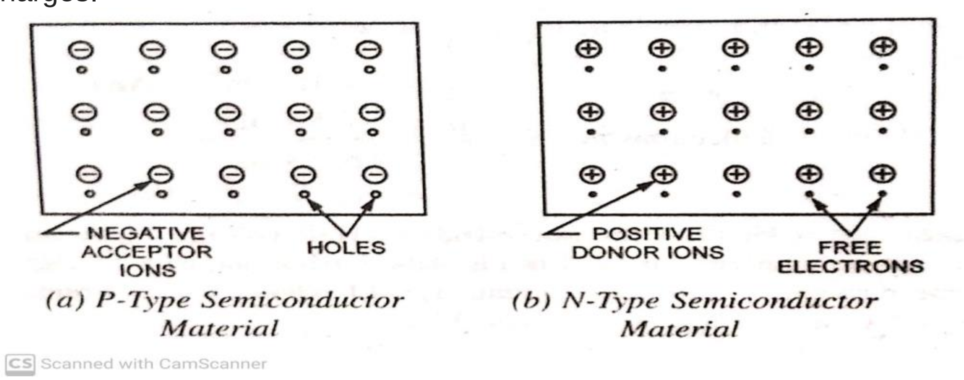


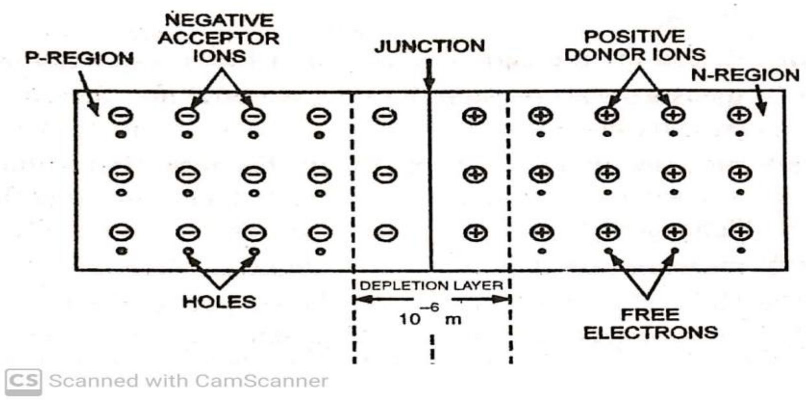
Fig.1

On the formation of P-N junction some of the holes from P-type material tend to diffuse across the boundary into N-type material and some of the free electrons similarly diffuse into the P-type material, as illustrated in Fig. 2.(a) This happens due to density gradient (as concentration of holes is higher on P- side than that on N-side and concentration of electrons is higher on N-side than that on P-side). This process is known as diffusion. The potential distribution diagram is shown in Fig. 2(a). From Fig. 2(a), it is obvious that a potential barrier V_B or V_O is developed which results in an electric field. This field prevents the respective majority carriers from crossing the barrier region. The doping profile of an ideal uniformly doped P-N junction is depicted in Fig. 2.

The electrons also leave positive ions (atoms with one fewer electron than the number of protons) behind them on the N-side. As negative ions are created on the P-side of the junction, the P-side acquires a negative potential. Similarly, the positive ions are created on the N-side and the N-side acquires a positive potential. The negative potential on the P-side prevents the migration of any more electrons from the N-type material to the P-type material. Similarly, the positive potential on the N-side prevents any further migration of holes across the boundary. Thus, the initial diffusion of charge carriers creates a barrier potential at the junction. The magnitude of barrier potential V_o is of the order of few tenths of a volt (0.3 V in case of Ge and 0.7 V for Si).

The region around the junction is completely ionized. As a result, there are no free electrons on the N-side, nor holes on the P-side. The region around the junction is termed as **depletion region** because the mobile charge carriers (i.e., free electrons and holes) have been emptied in this region. **Barrier voltage depends on doping density, electronic charge and**

temperature. For a given junction, the first two factors are fixed, thus making barrier potential dependent on temperature.



(a)

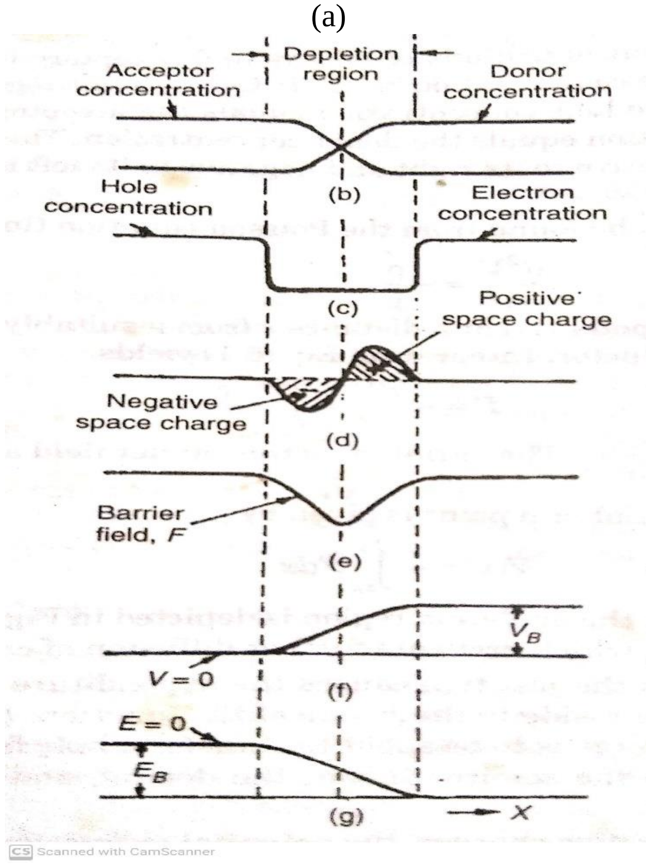


Fig. 2.(a) Schematic diagram of a p-n junction (b) variation of donor and acceptor ion concentration (C) variation of electron and hole concentration (d) concentration of uncovered charges (e) electric field variation (f) variation of electrostatic potential (g) electron energy variation

Energy-band Diagram

For an n-type semiconductor, the Fermi level E_F, lies near the conduction band edge Ec while for a p-type semiconductor it lies near the valence band edge Ev. When a p-n junction is produced, under equilibrium condition, the Fermi energy E_F attains a constant value throughout the system, as shown in Fig.3. In this situation, the conduction band edge E_{CP} of the p-side will be at a higher level than the conduction band edge Ecn of the n-side. Similarly, the valence band edge Evp of the p-side will lie higher than the valence band edge Evn of the n-side.

The barrier energy is E_B = Ecp –Ecn = Evp - Evn

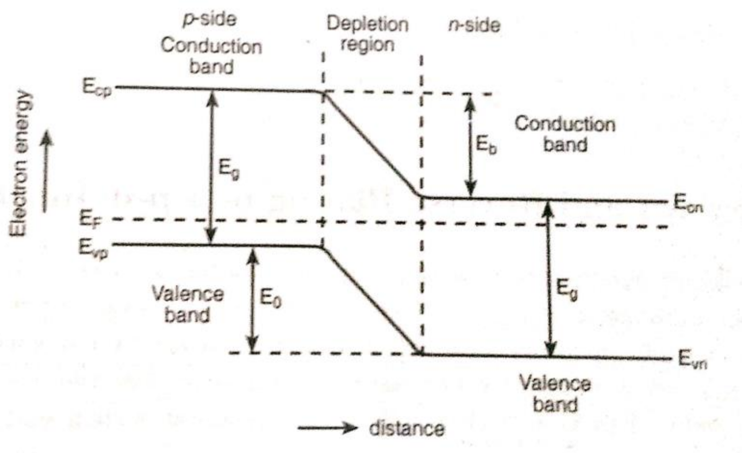


Fig.3. Energy band diagram of an unbiased p-n junction

P-N junction diode:

P-N junction diode is a device which conducts when forward biased and practically does not conduct when reverse biased. The behavior of P-N junction diode under forward biasing will be Discussed here

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Forward Biasing

When an external field, with P-region connected to positive terminal and N-region connected to negative terminal of the battery, is applied across the junction, as shown in Fig.4, the junction is said to be forward biased. In this circuit arrangement, the holes on the P-side being positively charged particles are repelled from the positive bias terminal and driven towards the junction. Similarly, the electrons on the N-side are repelled from the negative bias terminal and driven towards the junction. The result is that the depletion region is reduced in width, and the barrier potential is also reduced. If the applied bias voltage is increased from zero, the barrier potential gets progressively smaller and smaller until it effectively disappears and charge carriers can easily flow across the junction. Electrons from the N-side are then attracted across to the positive bias terminal on the P-side, and holes from the P-side flow across to the negative bias terminal on the N-side. Thus a majority carrier current flows. Since barrier potential is very small (0.3 V for Ge and 0.7 V for Si), a small forward voltage is sufficient to eliminate the barrier completely. Once the barrier is eliminated by the application of forward voltage, junction resistance becomes almost zero and a low resistance path is established in the entire circuit. The current, called the forward current, flows in the circuit.

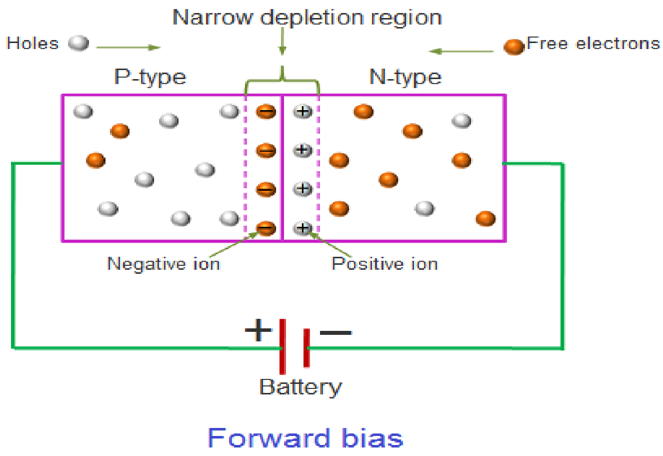


Fig. 4. Forward biasing

Reverse biasing:

If an external bias voltage is applied with positive terminal to N-side and negative terminal to the P-side of a P-N junction, as shown in Fig. 5, the junction is said to be reverse biased. In this arrangement, electrons from the N-side are attracted to the positive bias terminal, and holes from P-side are attracted to the negative bias terminal. Thus, as shown in Fig. 5, holes from the impurity atoms on the P-side of the junction are attracted away from the junction, and the electrons are attracted away from the atoms on the N-side of the junction. Thus, the depletion region is widened, and the barrier potential is increased by the magnitude of the applied bias. With the increased barrier potential, there is no possibility of majority carrier current flow across the junction. Thus the P-N junction is in a non-conductive state.

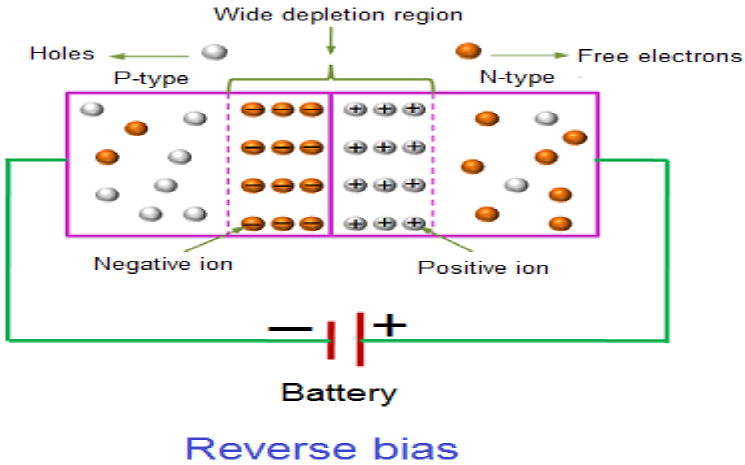


Fig.5. reverse biasing

Potential energy diagram:

In an open circuited p-j junction under thermal equilibrium the energy bands on two sides are separated by an intrinsic barrier E_b fig 6(a). When a forward bias voltage V is applied to the junction, the energy barrier is lowered to the value E_b –eV fig 6(b). When a reverse bias voltage V is applied to the junction the energy barrier is raised to the value E_b +eV fig 6(c).

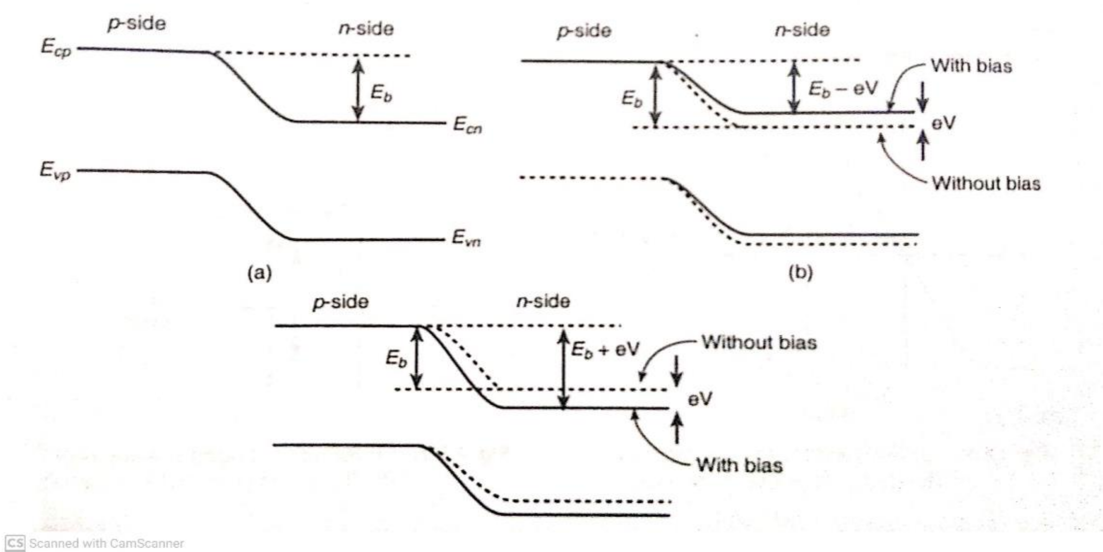


Fig.6. a) unbiased (b) forward bias (c) reverse bias

Current voltage characteristics of a p-n junction:

When a voltage V is applied across a p-n junction the total current I flowing through the junction is given by,

$$I = I_0(exp^{eV/\eta K_B T} - 1)$$

I_0= reverse saturation current, e=charge of electron=$1.6 \times 10^{-19} C$,
K_B=Boltzmann constant=1.38×10^{-23} J/K, T=300K, V=applied voltage, η=Dimensionless number=1 for Si and 2 for Ge.

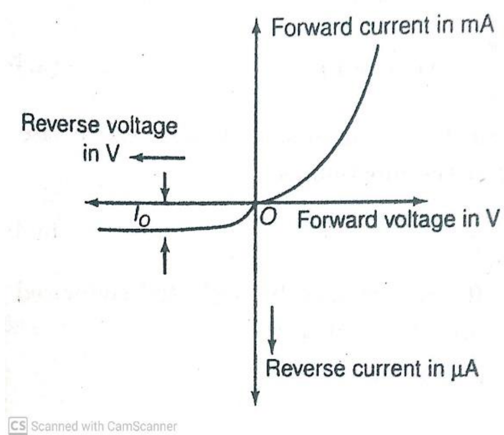


Fig.7. a) current voltage characteristics of an ideal p-n junction

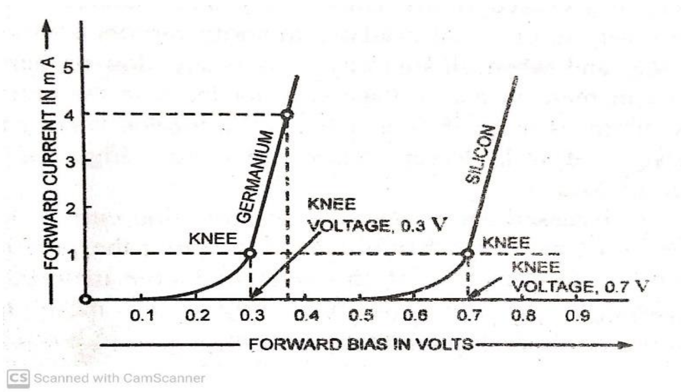
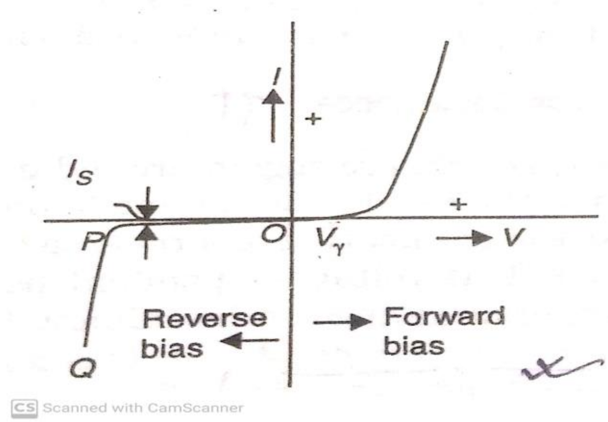


Fig. 7. b) forward characteristics of practical Ge and Si diodes.

In fig. 7 shows the plot of the current I vs V. this plot is termed the current voltage characteristics of a p-n junction diode. When V is less than V_γ in forward bias, current is very small. After that the current increases sharply. V_γ is known as threshold or cut-in voltage of the diode. V_γ =cut-in voltage=0.2 V for Ge and 0.6 V for Ge. For reverse bias very small current can flow. But at a reverse voltage, the reverse current increases abruptly, almost parallel to the current axis. This portion is called breakdown region. If a diode operate in this region is known as breakdown diode.



Junction resistance:

The static or d.c. resistance ($r_{d.c.}$) of a diode is defined as the ratio of the applied voltage V to the current i.e. $r_{dc} = \frac{V}{I}$, It is the resistance offered by the diode to the flow of steady current. Since the diode is a non-linear device its d.c. resistance varies with current.

For small signal operation current flowing through a diode varies about some d.c. operating current. The resistance offered by the diode to this varying component of current is called the dynamic resistance. $r_{ac} = \frac{\Delta V}{\Delta I}$

"The barrier potential across a p-n junction diode cannot be measured by placing a voltmeter across a diode terminal"-explain.

To show a reading a small amount of current must flow through the circuit. It causes joule heating in the circuit. Since there is no external source of energy, it must cause simultaneous cooling of the p-n junction. But from the principle of thermodynamics it is not possible to drive work by cooling a body below its equilibrium temperature. Thus no current can pass through the circuit and the voltmeter shows zero reading. Actually the barrier potential is balanced by the metal to semiconductor contact potentials in the circuit.

What will be the change in magnitude of the reverse saturation current in a p-n junction diode if the (i) amount of forward bias is increased (ii) temperature of the diode is increased?

i) Magnitude of the reverse saturation current remain unchanged due to increase of forward bias.

ii) If temperature of the diode is increased, then reverse saturation current increases. Experimentally shows that the reverse saturation current almost double for every 10 ^{0}C rise in temperature.