1.1 SEMICONDUCTOR

A semiconductor is a material which has electrical conductivity to a degree between that of a metal (such as copper) and that of an insulator (such as glass). Semiconductors are the foundation of modern electronics, including transistors, solar cells, light -emitting diodes (LEDs), quantum dots and digital and analog integrated circuits.

DIODE

Diode – Di + ode

Di means two and ode means electrode. So physical contact of two electrodes is known as diode and its important function is alternative current to direct current.

REVIEW OF INTRINSIC AND EXTRINSIC SEMICONDUCTORS

INTRINSIC SEMICONDUCTOR

An intrinsic semiconductor is one, which is pure enough that impurities do not appreciably affect its electrical behaviour. In this case, all carriers are created due to thermally or optically excited electrons from the full valence band into the empty conduction band. Thus equal numbers of electrons and holes are present in an intrinsic semiconductor. Electrons and holes flow in opposite directions in an electric field, though they contribute to current in the same direction since they are oppositely charged. Whole current and electron current are not necessarily equal in an intrinsic semiconductor, however, because electrons and holes have different effective masses (crystalline analogues to free inertial masses).

The concentration of carriers is strongly dependent on the temperature. At low temperatures, the valence band is completely full making the material an insulator. Increasing the temperature leads to an increase in the number of carriers and a corresponding increase in conductivity. This characteristic shown by intrinsic semiconductor is different from the behaviour of most metals, which tend to become less conductive at higher temperatures due to increased phonon scattering.

Both silicon and germanium are tetravalent, i.e. each has four electrons (valence electrons) in their outermost shell. Both elements crystallize with a diamond- like structure, i.e. in such a way that each atom in the crystal is inside a tetrahedron formed by the four atoms which are closest to it. Each atom shares its four valence electrons with its four immediate neighbours, so that each atom is involved in four covalent bonds.

EXTRINSIC SEMICONDUCTOR

An extrinsic semiconductor is one that has been doped with impurities to modifythe number and type of free charge carriers. An extrinsic semiconductor is a semiconductor that has been doped, that is, into which a doping agent has been introduced, giving it different electrical properties than the intrinsic (pure) semiconductor.

Doping involves adding doping atoms to an intrinsic semiconductor, which changes the electron and hole carrier concentrations of the semiconductor at thermal equilibrium. Dominant carrier concentrations in an extrinsic semiconductor classify itas either an n-type or p-type semiconductor.

A pure or intrinsic conductor has thermally generated holes and electrons. However these are relatively few in number. An enormous increase in the number of charge carriers can be achieved by introducing impurities into the semiconductor ina controlled manner. The result is the formation of an extrinsic semiconductor. This process is referred to as doping. There are basically two types of impurities: donor impurities and acceptor impurities. Donor impurities are made up of atoms (arsenic for example) which have five valence electrons. Acceptor impurities are made up of atoms (gallium for example) which have three valence electrons.

The two types of extrinsic semiconductor are

N-TYPE SEMICONDUCTORS

Extrinsic semiconductors with a larger electron concentration than hole concentration are known as n-type semiconductors. The phrase 'n-type' comes from the negative charge of the electron. In n-type semiconductors, electrons are the majority carriers and holes are the minority carriers. N-type semiconductors are created by doping an intrinsic semiconductor with donor impurities.

In an n-type semiconductor, the Fermi energy level is greater than that of the intrinsic semiconductor and lies closer to the conduction band than the valence band. Arsenic has 5 valence electrons, however, only 4 of them form part of covalent bonds.The 5th electron is then free to take part in conduction. The electrons are said to be the majority carriers and the holes are said to be the minority carriers.

P-TYPE SEMICONDUCTORS

As opposed to n-type semiconductors, p-type semiconductors have a larger hole concentration than electron concentration. The phrase 'p-type' refers to the positive charge of the hole. In p-type semiconductors, holes are the majority carriers and electrons are the minority carriers. P-type semiconductors are created by doping an intrinsic semiconductor with acceptor impurities. P-type semiconductors have Fermi energy levels below the intrinsic Fermi energy level.

The Fermi energy level lies closer to the valence band than the conduction band in a p- type semiconductor. Gallium has 3 valence electrons, however, there are 4 covalent bonds to fill. The 4^{th} bond therefore remains vacant producing a hole. The holes are said to be the majority carriers and the electrons are said to be the minority carriers.

PN JUNCTION DIODE

When the N and P-type semiconductor materials are first joined together a very large density gradient exists between both sides of the junction so some of the free electrons from the donor impurity atoms begin to migrate across this newly formed junction to fill up the holes in the P- type material producing negative ions.

FORWARD BIAS CONDITION

When positive terminal of the battery is connected to the P-type and negative terminal to N-type of the PN junction diode that is known as forward bias condition.

Operation

The applied potential in external battery acts in opposition to the internal potential barrier which disturbs the equilibrium.

As soon as equilibrium is disturbed by the application of an external voltage, the Fermi level is no longer continuous across the junction. Under the forward bias condition the applied positive potential repels the holes in P typeregion so that the holes move towards the junction and the applied positive potential repels the electrons in N type region so that the electrons move towards the junction.

When the applied potential is more than the internal barrier potential the depletionregion and internal potential barrier disappear.

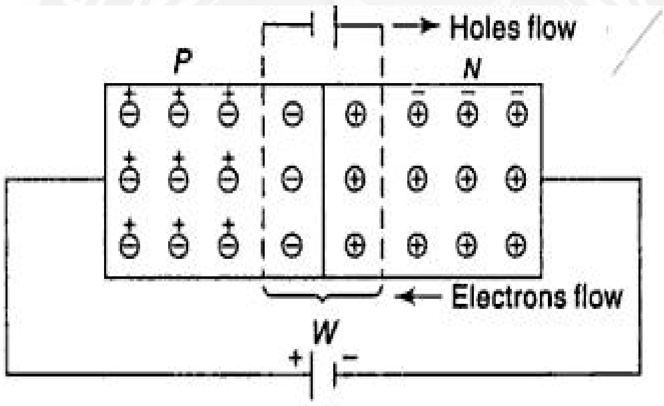

Figure: 1.1.1 PN Junctions under forward bias

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 110]

V-I Characteristics

As the forward voltage increased for $V_F < V_o$, the forward current I_F almost zero because the potential barrier prevents the holes from P region and electrons from N region to flow across the depletion region in opposite direction.

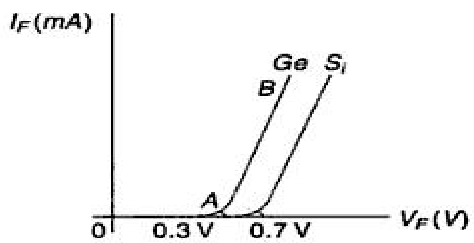

Figure: 1.1.2 V-I characteristics of a diode under forward bias

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 111]

For $V_F > V_o$, the potential barrier at the junction completely disappears and hence, the holes cross the junction from P to N type and electrons cross the junction to opposite direction, resulting large current flow in external circuit.

A feature noted here is the cut in voltage or threshold voltage V_F below which the current is very small. At this voltage the potential barrier is overcome and the current through the junction starts to increase rapidly.

- Cut in voltage is 0.3V for germanium and 0.7 for silicon.

UNDER REVERSE BIAS CONDITION

When the negative terminal of the battery is connected to the P-type and positive terminal to N-type of the PN junction diode that is known as forward bias condition.

Operation

The holes from the majority carriers of the P side move towards the negative terminal of the battery and electrons which from the majority carrier of the N side are attracted towards the positive terminal of the battery.

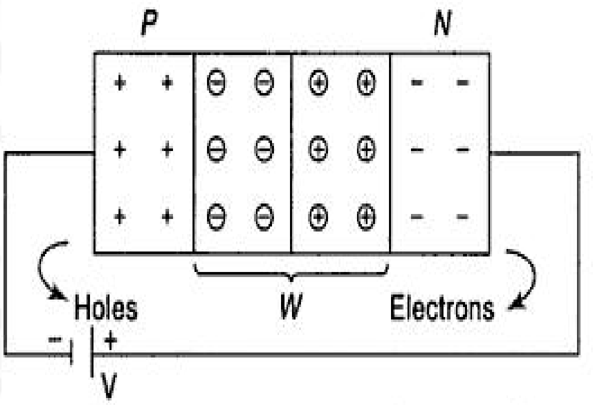

Figure: 1.1.3 PN junctions under reverse bias

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 111]

Hence, the width of the depletion region which is depleted of mobile charge carriers increases. Thus, the electric field produced by applied reverse bias, is in the same direction as the electric field of the potential barrier. Hence the resultant potential barrier is increased which prevents the flow of majority carriers in both directions. The depletion width W is proportional to under reverse bias.

V-I characteristics

Theoretically no current flow in the external circuit. But in practice a very small amount of current of the order of few microamperes flows under reverse bias.

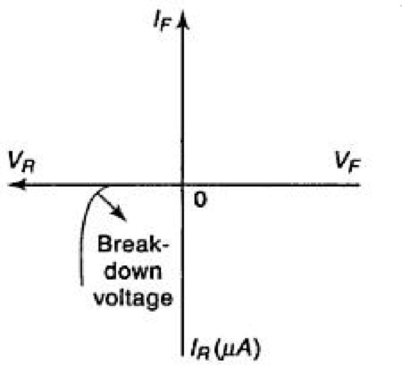

Figure: 1.1.4 V-I characteristics under reverse bias

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 112]

Electrons forming covalent bonds of semiconductor atoms in the P and N type regions may absorb sufficient energy from heat and light to cause breaking covalent bonds. So electron hole pairs continuously produced.

Consequently the minority carriers electrons in the P region and holes in the N region, wander over to the junction and flow towards their majority carrier side giving rise a small reverse current. This current is known as reverse saturation current Io.

The magnitude of this current is depends on the temperature because minority carrier is thermally broken covalent bonds.