SHORT NOTES: CLASS 12

CHAPTER 14: SEMICONDUCTOR ELECTRONICS MATERIALS, DEVICES AND SIMPLE CIRCUITS

Classification of Metals: On the basis of the relative values of electrical conductivity (σ) or resistivity (ρ = 1/σ), the solids are broadly classified as:

(i). Metals: They possess very low resistivity (or high conductivity). $\rho \sim 10^{-2} - 10^{-8}\ \Omega$ m, $\sigma \sim 10^{2} - 10^{8}$ S m^{-1}

(ii). Semiconductors: They have resistivity or conductivity intermediate to metals and insulators. $\rho \sim 10^{-5} - 10^{6}\ \Omega$ m, $\sigma \sim 10^{5} - 10^{-6}$ S m^{-1}

(iii). Insulators: They have high resistivity (or low conductivity). $\rho \sim 10^{11} - 10^{19}\ \Omega$ m, $\sigma \sim 10^{-11} - 10^{-19}$ S m^{-1}

Properties of Semiconductors:

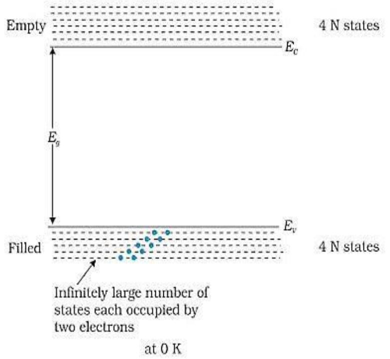
(i) The resistivity of a semiconductor is less than an insulator but more than a conductor.

(ii) Semiconductors have a negative temperature coefficient of resistance.

(iii) When a suitable metallic impurity is added to a semiconductor, its current conducting properties change appreciably.

Classification of Metals on the Basis of Energy Bands

Energy bands in solids:



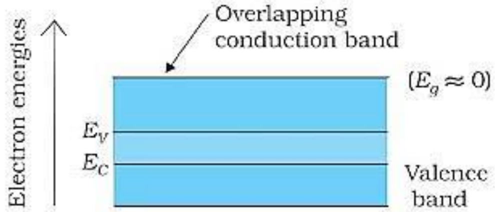
(i) Valence Band: The range of energies (i.e., band) possessed by **valence electrons** is known as the valence band.

(ii) Conduction Band: The range of energies (i.e., band) possessed by conduction band electrons (**free electrons**) is known as the conduction band.

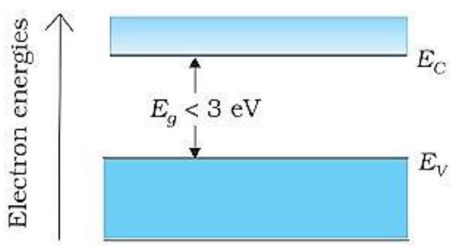
(iii) Forbidden energy gap: The separation between the conduction band and valence band on the energy level diagram is known as the Forbidden energy gap.

The greater the energy gap, the more tigh the valence electrons are bound to the nucleus.

(i). Metals: In metals, the conduction band and valence band are **overlapped** to each other. The electrons from the valence band can easily move into the conduction band. Normally, the conduction band is empty but when it overlaps with the valence band, electrons can move freely into it and it conducts electric current through it.



(ii). Semiconductors: In semiconductors, the valence band is almost full and the conduction band is almost empty. a small and finite energy band gap exists. Because of the small energy band gap some electrons from the valence band, at room temperature, acquire enough energy to cross the energy gap and enter the conduction band. These electrons are very few and can move in the conduction band. Hence, the resistance of **semiconductors** is not as high as that of the **insulators**.



Silicon and Germanium have energy gaps of 1.12 eV and 0.75 eV respectively.

Each time a valence electron enters the conduction band, a hole is created in the valence band. Holes also contribute to current. A hole attracts an electron from the neighboring atoms. This constitutes

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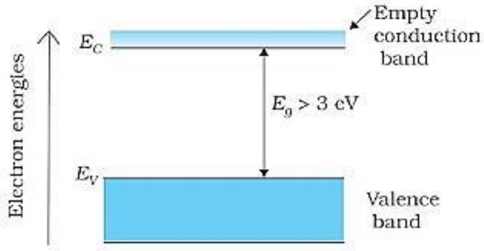
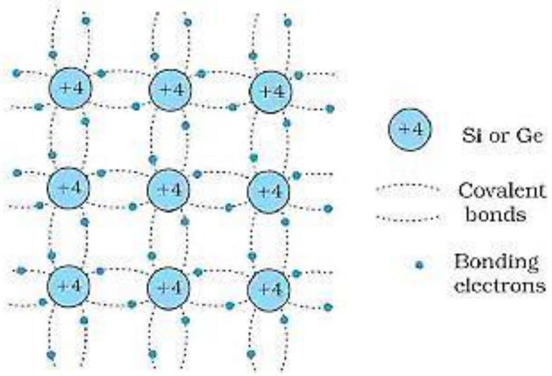
hole current. A hole is in the covalent bond. When a free electron combines with the hole, it becomes a valence electron.

(iii). Insulators: In insulators, a large energy band gap exists between the valence band and conduction band. The valence band is full while the conduction band is empty. Hence, electrical conduction is not possible under ordinary circumstances. It means that the energy gap is so large that electrons cannot be excited from the valence band to the conduction band by **thermal excitation**.



Intrinsic Semiconductor: It is a pure semiconductor without any significant dopant species present.



$n_e = n_h = n_i$

In the lattice structures of Ge and Si, each atom is surrounded by the **four** nearest neighbours. Si and Ge have four **valence electrons**. In its crystalline structure, every Si or Ge atom tends to share one of its **four valence** electrons with each of its four nearest-neighbor atoms. These shared electrons form a **covalent bond**. In intrinsic semiconductors, the number of free electrons per unit volume (n_e) is equal to the number of holes per unit volume (n_h).

At T=0, behaves like an insulator and at T> 0K, forms thermally generated electron-hole pairs.

Extrinsic Semiconductor

When a few parts per million (ppm) of a suitable impurity is added to the pure semiconductor, the conductivity increases many times. Such materials are known as **extrinsic semiconductors** or impure semiconductors. In a doped semiconductor, the following relation holds

$$n_e . n_h = n_i^2$$

In extrinsic semiconductors:

(i) Conductivity increases.

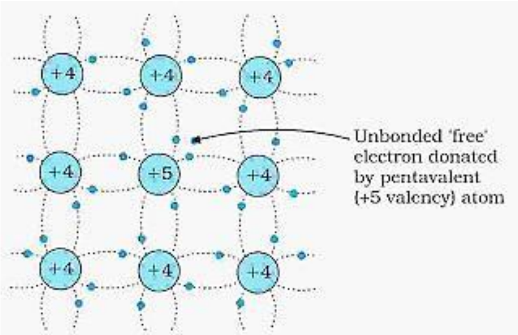
(ii) Conductivity is controlled by dopant.

Types of Semiconductor

Extrinsic semiconductors are basically of two types:

(i). n-Type Semiconductor:

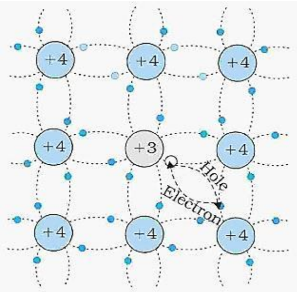
When a small amount of pentavalent impurity is added to a semiconductor, it is known as n-type semiconductor. The addition of pentavalent impurity provides a large number of free electrons in the semiconductor crystal. Typical examples of pentavalent impurities are arsenic and antimony. Search impurities which produce n-type semiconductors are known as **Donor impurities** because they donate or provide free electrons to the semiconductor crystal. Atom with 5 valence electrons is doped to a germanium crystal, it replaces one of the germanium atoms. Four of the five **valence electrons** form covalent bonds with one valence electron of four Ge atoms and the fifth **valence electron** becomes free to move in the crystal structure. This free electron acts as a charge carrier. Thus by introducing impurity in pure Ge, the number of free electrons increases, and hence the conductivity of the crystal increases.



$n_e > n_h$. it generates new energy level below the conduction band.

Since the majority of charge carriers in these crystals are negatively charged electrons, they are called **n-type semiconductors**.

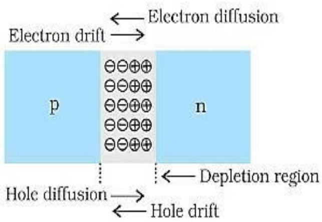
(ii). P-type Semiconductor: when a small amount of trivalent impurity is added to a pure semiconductor it is called a P-type semiconductor. Typical examples of trivalent impurities are gallium and Indium. Such impurities that produce p-type semiconductors are known as **acceptor impurities** because the holes created can accept the electrons.



When an impurity atom with 3 valence electrons is doped to a germanium crystal, it replaces one of the germanium atoms. The four germanium atoms surrounding the impurity atom can share one electron each with the impurity atom which has three valence electrons. For every trivalent impurity atom added, an extra hole will be created. As the trivalent impurity atoms accept electrons from the germanium crystal, it is called acceptor impurity. The Ge crystal so obtained is called a p-type semiconductor as it contains free holes.

Note: The current conduction in n-type semiconductors is predominantly by electrons file in p-type semiconductors it is by holes. n-type as well as P-type semiconductor is electrically neutral.

<u>p-n Junction</u>



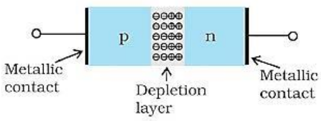
When p- and n-type semiconductors are combined to form a p-n unit, a number of new characteristics appear, which make the combination a very useful device, called the **p-n junction diode**.

p-n Junction Formation: In the n-region of a p-n junction, the concentration of free electrons is higher than that of holes, whereas in the p-region, the concentration of holes is much higher than that of free electrons.

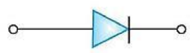
Therefore when a **p-n junction** is formed, some electrons from the n-region will diffuse into the **p-region**. Since the hole is nothing but the vacancy of an electron, an electron diffusing from the n- to the p-region simply fills this vacancy, i.e., it completes the covalent bond. This process is called **electron-hole recombination**.

As a result of electron-hole recombination, the electrons in the n-region are neutralized by holes, so in this small region, we are left with only ionized donor atoms. The positive and negative ions in a small region around the junction are bound and are, therefore, **immobile**. This small region in the vicinity of the junction which has been depleted of free charge carriers and has only immobile ions is called the **depletion region**.

Semiconductor Diode: A semiconductor diode is basically a p-n junction with metallic contacts provided at the ends for the application of an external voltage. The **symbol** for the simplest electronic device, namely the **p-n junction** is shown as. The direction of the thick arrow is from the p to the n-region. The p-side is called the **anode** and the n-side is known as the **cathode**.

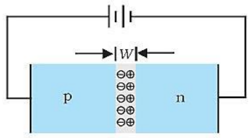


(a)



(b)

(i). p-n junction Diode as Forward Bias: If the positive terminal of the battery is connected to the p-side and the negative terminal to the n-side, the junction diode is said to be forward-biased.



With forward bias to pn Junction, The following points are worth noting:

(i) The potential barrier is reduced and at some forward voltage, it is eliminated altogether.

(ii) The junction offers low resistance called forward resistance to current flow.

(iii) The current flows in the circuit due to the establishment of a low resistance path the magnitude of the current depends upon the applied forward voltage

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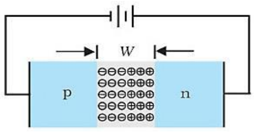


(ii). p-n junction Diode as Reverse Bias: If the positive terminal of the battery is connected to the n-side and the negative terminal to the p-side, the junction diode is said to be reverse-biased.

With a reverse bias to the p-n junction, the following points are worth noting:

(i) Potential barrier is increased.

(ii) The junction offers very high resistance called reverse resistance to current flow.

(iii) No current flows in the circuit due to the establishment of a high resistance path.

(V-I) Characteristics of Junction Diode

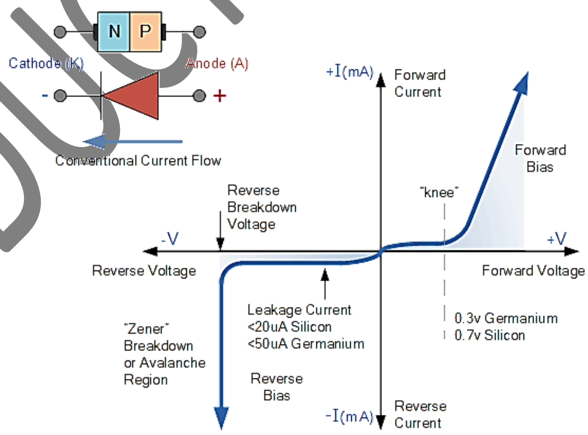
(i) **Knee voltage or cut-in voltage:** it is the forward voltage at which current through the junction starts to increase rapidly. when a diode is forward biased it conducts current very slowly until we overcome the potential barrier. once the applied forward voltage (0.7 V for Si and 0.3 V for Ge) exceeds the knee voltage the current starts increasing rapidly.

(ii) **Breakdown voltage** or **Zener voltage:** with reverse bias to the pn junction the potential barrier at the junction is increased. the minimum reverse voltage at which the PN junction breaks down with a sudden rise in reverse current is called the breakdown voltage. once the breakdown voltage is reached, a higher reverse current may damage the junction therefore care should be taken that the reverse voltage across a pn junction is always less than the breakdown voltage.

Avalanche Breakdown

When a reverse bias is applied to the p-n junction, some covalent bonds are broken in the depletion region, and electron holes are produced in pairs. These freed electrons move towards the n side under the influence of the barrier electric field, which again collides with atoms producing further electron-hole pairs.

This results in a continuous flow of current carriers in reverse bias and these newly generated charge carriers are also accelerated by the applied electric field in reverse bias leading to **avalanche breakdown**.



Zener Breakdown

When the reverse bias voltage is increased, the electric field across the depletion region also increases, and if we go on increasing the reverse bias voltage, at a particular value a large number of electrons and holes are produced. This is called **Zener breakdown**.

Advantages of Semiconductor Diodes

(i) The semiconductor diodes do not produce a humming noise during the operation.

(ii) The semiconductor diodes are set into operation as soon as the circuit is switched on.

(iii) They are very compact.

(iv) Semiconductor diodes require low voltage for their operation. Hence there is low power consumption.

Disadvantage: The main disadvantage of semiconductor diodes is the possibility of their breakdown due to a rise in temperature and the application of high voltage.

APPLICATION OF JUNCTION DIODE AS A RECTIFIER

A **rectifier** is a device that converts an alternating (AC) input voltage into a direct (DC) output voltage. Any electrical device which has a high resistance to current in one direction and low resistance to current in the opposite direction possesses the ability to convert AC into DC current.

Principle:

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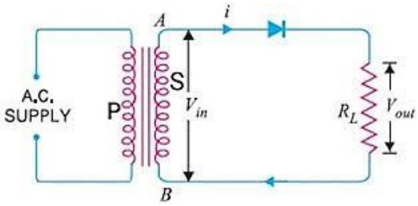
A p-n junction diode offers very low resistance in forward bias and extremely high resistance in Reverse bias. Due to this property, a p-n junction diode primarily allows the flow of current only in one direction. So, if an alternating voltage is applied across a diode, the current flows only in that part of the cycles when the diode is forward-biased. This property of the p-n junction diode is used to rectify alternating voltages and the circuit used for this purpose is called a **rectifier**. p-n junction diode can be used either as (a) half-wave rectifier or (b) full-wave rectifier.

(a) Half-wave Rectifier



Construction: The arrangement for a half-wave rectifier is shown in Fig. The AC input voltage is fed across the primary coil P of a suitable step-down transformer. The secondary coil S of the transformer is connected to the semiconductor p-n junction diode D and a load resistance R_L.

Working Method: During the first half of the AC input cycle, the end A of secondary S of the transformer is at positive potential and end B at negative potential. In this situation, the diode is forward-biased, and a current flows in the circuit. Consequently, an output voltage across load R_L is obtained.

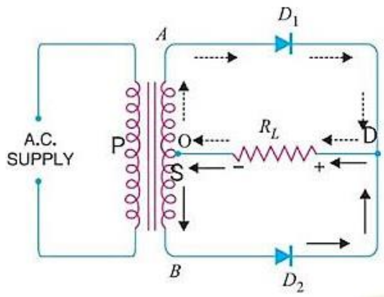
During the second half of AC input, the end A of secondary S of the transformer is at negative potential and diode D is in reverse bias. So, no current flows through load R_L and there is no output voltage across R_L.

In the next positive half-cycle of AC input, we again get the output, and so on. Thus, we get output voltage as shown in Fig. Here, the output voltage, though still varying in magnitude, is restricted to only one direction and is said to be rectified. Since the rectified output of the circuit is obtained only for half of the input AC wave, the device is called a **half-wave rectifier**.

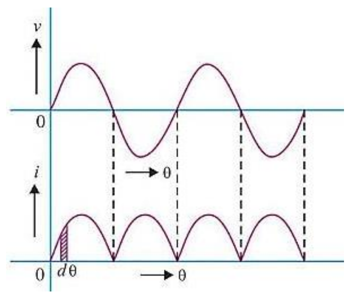
(b) Full-wave Rectifier

A full-wave rectifier is a rectifier that rectifies both halves of each AC input cycle and gives a unidirectional output voltage continuously.

Construction: In a full-wave rectifier, we use two semiconductor diodes that operate in a complementary mode. The AC input supply is fed across the primary coil P of a center tap transformer. The two ends A and B of the second S of the transformer are connected to the p-ends of the Diodes D_1 and D_2 respectively. A load resistance R_L is connected between the n-terminal of both the Diodes and the center tapping O of the second of the transformer. The DC output is obtained across load residence R_L.



Working Method: During the first half cycle of the input voltage, terminal A is positive with respect to O while B is negative with respect to O. Diode first is forward bias and conducts while diode second is reverse bias and does not conduct, the current flow through R_L from D To O. During the second half cycle, A is negative and B is positive with respect to O, thus diode first is reverse bias and diode second is forward biased. The current through R_L is in the same direction as during the first half cycle. The resulting output current is a continuous series.



As we are getting output in the positive half as well as the negative half of the AC input cycle, the rectifier is called a full-wave rectifier. Obviously, this is a more efficient circuit for getting rectified voltage or current than a **half-wave rectifier**.

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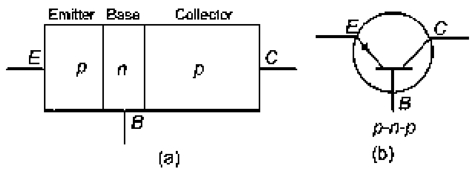
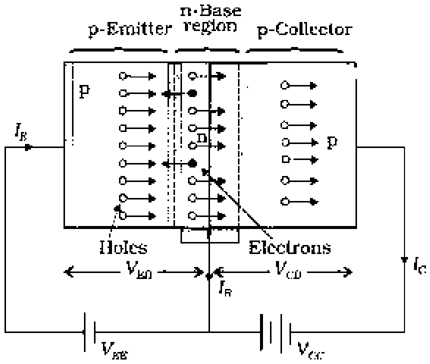
JUNCTION TRANSISTOR: A **transistor** (also called a junction transistor) is a three-terminal semiconductor device in which a p-type or n-type semiconductor is fabricated between two n-type or two p-type layers. There are two types of transistors.

(i) p-n-p transistor. (ii) n-p-n transistor.

(i) p-n-p Transistor: It consists of a very thin layer of n-type semiconductors developed between two thick layers of p-type semiconductors. In this symbolic representation, the direction of the arrow shows the direction of the conventional current. The central part (which is very thin) is called the "base" while the left and right parts are known as the emitter and the collector respectively. The emitter-base (p-n) junction is forward-biased and the base-collector (n-p) junction is reverse-biased in case of active operation of the junction transistor.



Action of p-n-p transistor

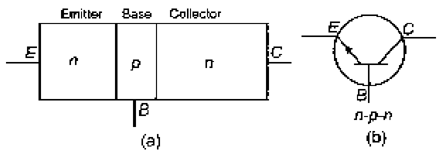


The emitter-base of the **p-n-p transistor** is forward-biased by connecting it to the positive pole of emitter-base battery V_{EE} and the collector is reverse-biased by connecting it to the negative pole of the collector-base battery V_{CC}.

Holes being the majority carriers in emitter are repelled due to forward bias towards the base. As the base is thin and lightly doped, it has a low density of electrons. Therefore, when the holes enter the base region, only about 5% electron-hole combination takes place.

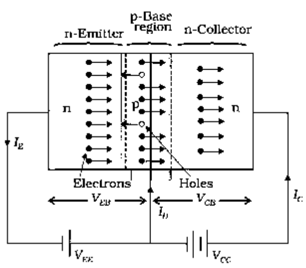
The remaining holes reach the collector under the influence of reverse collector voltage, an electron leaves the negative pole of the collector-base battery E_{CB} and neutralizes it. At the same time, an electron from some covalent bond in the emitter enters the positive terminal of E_{EB}, creating a hole in the emitter. Thus, the current in the p-n-p transistor is carried by holes, and at the same time, their concentration is maintained as explained above. In this case also, $I_E = I_B + I_C$

(ii). n-p-n Transistor: It consists of the thin layer of p-type semiconductors developed between two small n-type semiconductor layers.



The action of the n-p-n transistor: To understand the action of the **n-p-n transistor**, the n-type emitter is forward-biased with the help of battery V_{EE}, and the collector base is reverse-biased with the help of battery V_{CC}.

The electrons being majority carriers in the emitter are repelled due to forward bias towards the base. The base contains holes as the majority of carriers and some holes and electrons combine in the base region but the base is lightly doped. Due to this, the probability of electron-hole combination in the base region is very small (< 5%).



The remaining electrons cross into the collector region and enter the positive terminal of the battery V_{CC} connected to the collector.

At the same time, an electron enters the emitter from the negative pole of the emitter-base battery V_{EE}. Thus, in n-p-n transistors, the current is carried inside the transistor as well as in the external circuit by the electrons. If I_e, I_b, and I_c are the emitter current, the base current, and the collector current, respectively, then $I_E = I_B + I_C$

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