CHAPTER 1

UNIT I

Semiconductors

Contents :

Introduction of Semiconductor materials.

Syllabus Topic : Introduction of Semiconductor Materials

Semiconductors

Q. 1.1 What are semiconductors ?

Ans. :

As far as the electronic components are concerned, semiconductors are the most important type of materials. They have conduction properties which are in between those of conductors and insulators. We can say that semiconductors are neither conductors nor insulators. At very low temperatures of the order of 0°K (– 273°C), semiconductors act like insulators.

However with increase in temperature the valence electrons start acquiring additional energy and they can cross the narrow forbidden gap to enter into the conduction band. Thus at temperatures close to 20°C the conduction begins in semiconductors. The conduction increases with increase in temperature. The most widely used semiconductor materials are Silicon and Germanium.

Classification of Semiconductor

Q. 1.2 What are intrinsic and extrinsic semiconductors ?

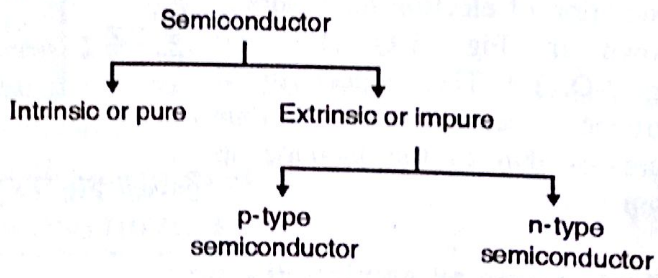
Ans. :

The semiconductors are classified into two categories as :

1. Intrinsic semiconductors and
2. Extrinsic semiconductors.

Intrinsic semiconductors :

Intrinsic means pure, so intrinsic semiconductors are the semiconductors in their purest possible form. The presence of impurity (i.e. atoms of other material) is as low as 1 part 100 million parts of the semiconductors.



(B-1) Fig. 1-Q. 1.2 : Classification of semiconductor

The intrinsic semiconductors are equivalent to insulators or very very poor conductors, at room temperature. Examples of intrinsic semiconductors are Silicon and Germanium. The increase in temperature or application of increased voltage does not increase their conductivity significantly. Therefore, the intrinsic semiconductors are not practically used for manufacturing of devices.

Extrinsic semiconductors and doping :

Extrinsic means impure, so we can obtain the extrinsic semiconductors from intrinsic ones by adding impurities to them. Impurity is nothing but some other material. The process of adding impurities is called as **"Doping"**.

Due to doping, the conductivity of the semiconductors increase. Thus extrinsic semiconductors have a better conductivity than the intrinsic semiconductors. Therefore they are used in manufacturing of all the electronic components such as diodes, transistors etc. Thus **Doping** is necessary for increasing the conductivity of the pure (intrinsic) semiconductors.

Extrinsic semiconductors are of two types namely :

1. n-type semiconductors
2. p-type semiconductors

The type of extrinsic semiconductor (n or p) depends on the type of impurity (or **dopant**) being used.

Conduction in Intrinsic Semiconductors

Q. 1.3 How does the behaviour of intrinsic semiconductor depend on temperature ? OR

Define a hole in a semiconductor. Indicate pictorially how a hole contributes to conduction ? OR **(AKTU : Sem.-I : 08-09)**

What will happen on number of free electrons in a semiconductor on increasing temperature ? **(AKTU : Sem.-I : 11-12)**

Ans. :

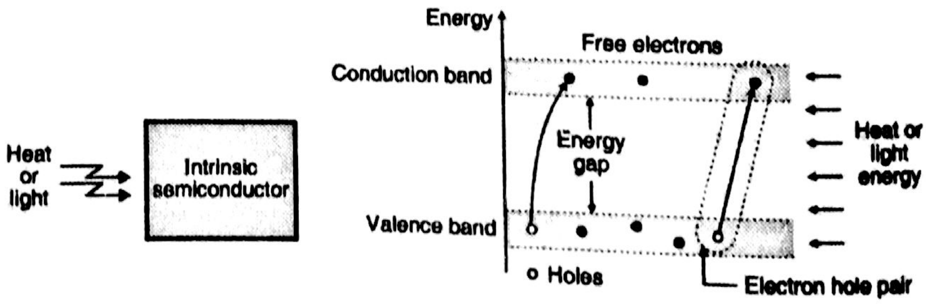
The intrinsic semiconductors behave like perfect insulators at the absolute zero temperature. But the behaviour changes with increase in temperature. At around the room temperature, electrons become available for conduction and current can flow. The generation of free electrons takes place as explained below.

With increase in temperature, many valence electrons will absorb the thermal energy, break the covalent bonds and go into the conduction band. Thus they become free for conduction. These electrons are called **conduction electrons.**

Generation of a hole :

When an electron breaks a covalent bond and becomes free, a vacancy is created in the broken covalent bond. This vacancy is called as **"hole"**. Thus corresponding to every free electron, a hole is created. Therefore the number of free electrons generated due to increased temperature is exactly equal to the number of holes. As the free electrons and holes get generated in pairs they are called as thermally generated electron hole pairs. The electrons and holes both can operate as charge carriers.

The hole is said to have a positive charge as it is nothing but absence of an electron. The generation of electron hole pairs is shown in Fig. 1-Q. 1.3 and Fig. 2-Q. 1.3. The conductivity of intrinsic semiconductor thus increases due to the increase in temperature.



(B-1581) **Fig. 1-Q. 1.3 : Valence electrons go to conduction band due to absorbed thermal energy**

Effect of light on semiconductor :

The effect of light incident on the semiconductor is the same as that of the heat. When light of adequate intensity and frequency is focussed on the semiconductor, the "photons" will impart energy to the electrons.

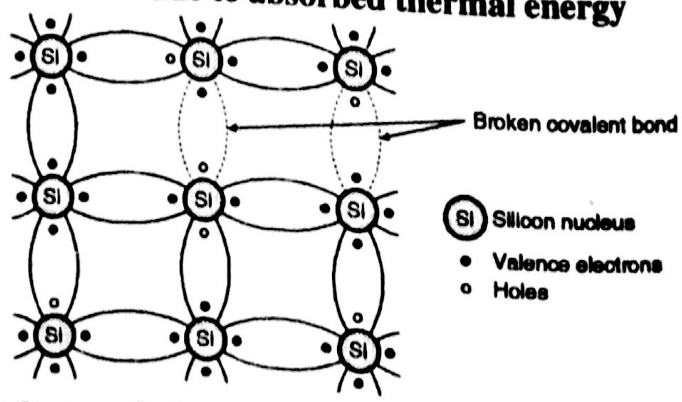


Fig. 2-Q. 1.3 : Generation of electron-hole pairs due to increased temperature

Due to this energy, electrons will break their covalent bonds and enter into the conduction band and become free for conduction. The conductivity of a semiconductor thus increases due to incident light. In other words the resistivity of the material decreases due to the light incident on it.

Doping a Semiconductor

Q. 1.4 What is doping ?

Ans. :

In order to increase the conductivity of intrinsic semiconductors we have to provide the heat energy or light energy externally. These methods of increasing the conduction are not practically usable. Therefore the conductivity is increased by means of the Doping process. In the process of doping, impurities are added to the pure Silicon or Germanium and the doped semiconductor is called as an **Extrinsic Semiconductor.** The impurities are the materials used for **doping** the intrinsic semiconductor materials. These materials can be of two types :

1. Donor impurity
2. Acceptor impurity

Increasing the free electrons :

In order to increase the number of free electrons, **Pentavalent** atoms are added to the Silicon or Germanium. The material which is being used as impurity in the process of doping is called as "dopant". When the dopant is a pentavalent atom (i.e. the atom containing five valence electrons) then it is called as the "donor impurity" and the doping is called as "donor doping". Donor doping is used to manufacture n-type extrinsic semiconductor. The examples of pentavalent or donor impurities are Arsenic, Phosphorous and Antimony.

Increasing the number of holes :

We can increase the number of holes in a pure Silicon or Germanium by adding **trivalent atoms** to it. That means these trivalent atoms now act as dopants. When the dopant is a trivalent atom i.e. the atom consisting of only three valence electrons, then it is called as the "acceptor impurity" and the doping is called as "acceptor doping". Acceptor doping is used to manufacture p-type extrinsic semiconductors. The examples of trivalent or acceptor impurities are Boron, Gallium, Aluminium and Indium.

Two Types of Extrinsic Semiconductors

Q. 1.5 What are the types of external semiconductors ?

Ans. :

A semiconductor can be doped to have either excess free electrons or excess free holes. Due to this, there are two types of doped (extrinsic) semiconductors :

1. n-type semiconductor
2. p-type semiconductor.

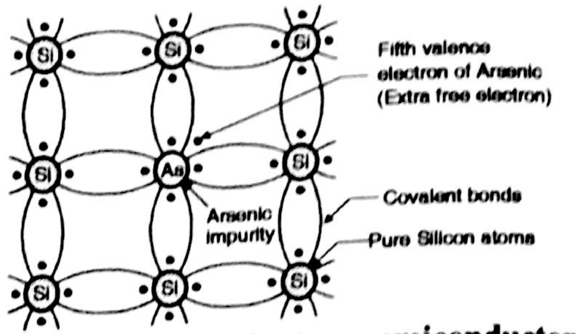
n-type Semiconductors

Q. 1.6 Explain n-type semiconductors.

Ans. :

The n-type semiconductor is formed by adding a small amount of "pentavalent" impurity to the pure Silicon or Germanium material which acts as a base material. The "pentavalent" element is the one which has 5 valence electrons. The examples of pentavalent materials are Antimony, Arsenic and Phosphorus etc.

The effect of addition of such pentavalent impurity atoms to the silicon base is as shown in Fig. 1-Q. 1.6. When a pentavalent impurity such as Arsenic is added to the intrinsic semiconductor, four valence electrons of Arsenic atom form four covalent bonds with four valence electrons of the neighbouring Silicon atoms, as shown in Fig. 1-Q. 1.6.



(B-1586) **Fig. 1-Q. 1.6 : Formation of n-type semiconductor**

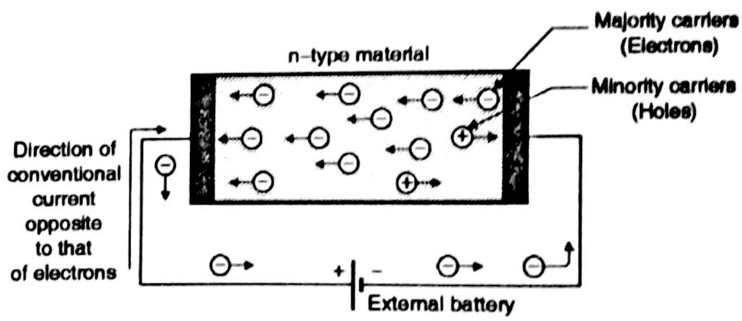
The fifth electron of the Arsenic atom does not have a chance to form a covalent bond. This is an additional valence electron which can enter the conduction band very easily to be a free electron. Thus corresponding to each impurity atom an extra electron becomes available for conduction. This increased number of electrons will make the semiconductor an "n-type semiconductor". It is possible to control the number of free electrons available for conduction by changing the number of pentavalent atoms added to Silicon material. Thus conductivity is increased in a controlled manner with the help of the doping process. Each pentavalent impurity atom generates a free electron. The number of free electrons will be equal to the number of impurity atoms added. As each impurity atom "donates" one free electron, the pentavalent impurities are known as the "donor" impurities.

Majority and minority carriers in the n-type material :

A large number of free electrons are present alongwith a small number of thermally generated holes in an n-type semiconductor. So the conduction largely takes place due to the free electrons. Therefore the free electrons are called as "majority carriers" and holes are known as "minority carriers".

Conduction in n-type material :

When an external DC voltage is applied to the n-type semiconductor material, the free electrons move towards the positive terminal of the source and holes move towards the negative end as shown in Fig. 2-Q. 1.6. As electrons outnumber the holes, the conduction in n-type material is mainly due to the majority carriers "electrons".



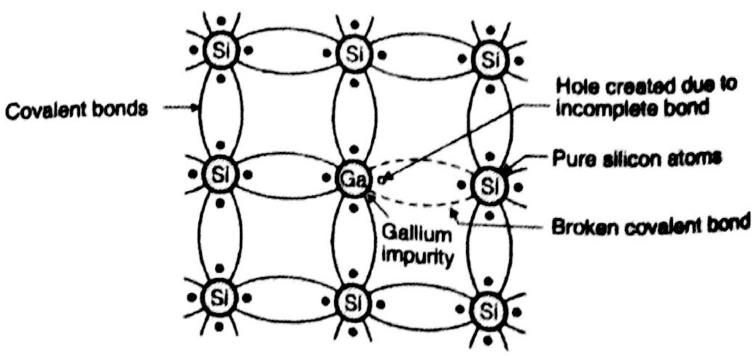
(B-1588) **Fig. 2-Q. 1.6 : Conduction in n-type material**

p-type Semiconductors

Q. 1.7 Explain p-type semiconductors.

Ans. :

The p-type semiconductors are formed by doping a pure Germanium or Silicon crystal with the "trivalent" impurity atoms. The materials having three valence electrons per atom are known as the trivalent materials. Examples of "trivalent" materials are : Boron, Gallium and Indium. The effect of adding one of these elements "Gallium" on the base of silicon is as shown in Fig. 1-Q. 1.7.



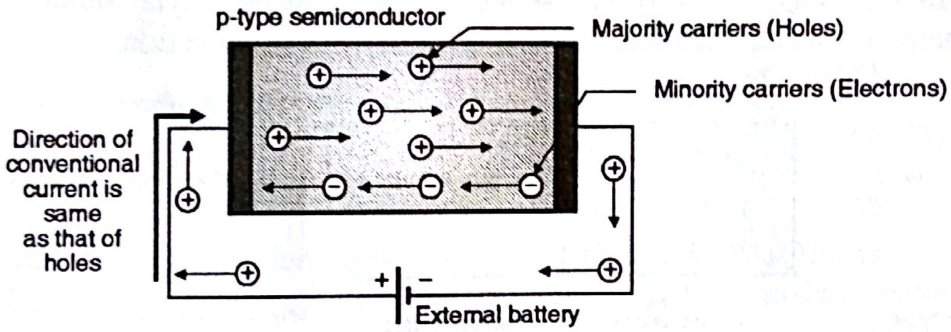
(B-1589) **Fig. 1-Q. 1.7 : Formation of p-type semiconductor**

As shown in Fig. 1-Q. 1.7, when a Gallium atom is added to the silicon base, its three valence electrons will form covalent bonds with the valence electrons of three neighbouring silicon atoms.

The fourth covalent bond however, remains incomplete as the Gallium atom has only three valence electrons. The resulting vacancy is called as a "hole" and it is represented by a small circle in Fig. 1-Q. 1.7. A hole is positively charged as it represents the absence of a negative charge. Thus corresponding to each trivalent impurity atom added, a hole is created. This increased number of holes will make the semiconductor a p-type semiconductor. It is possible to control the number of holes by controlling the "doping concentration" of trivalent impurity atoms. Since the vacancy resulting due to the incomplete covalent bond will readily accept a free electron, the trivalent impurities are called as acceptor impurities.

Majority and minority carriers in p-type material : A large number of holes are present in a p-type semiconductor along with a small number of thermally generated electrons. Hence the conduction largely takes place due to the holes. Therefore holes are called as the "majority carriers" and electrons are "minority carriers" for a p-type semiconductor. This is exactly opposite to what we learnt for the n-type semiconductor.

Conduction in p-type semiconductors : The conduction inside a p-type semiconductor is as shown in Fig. 2-Q. 1.7. When an external dc source is applied across a p-type material, the holes move in the valence band. The movement of holes is towards the negative terminal of the supply. The free electrons move towards the positive terminal of the battery, as shown in Fig. 2-Q. 1.7. Note that the p and n type semiconductors are electrically neutral. p or n does not mean that they are positively or negatively charged.



(B-1591) **Fig. 2-Q. 1.7 : Conduction in a p-type semiconductor**

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