

## Introduction to semiconductor

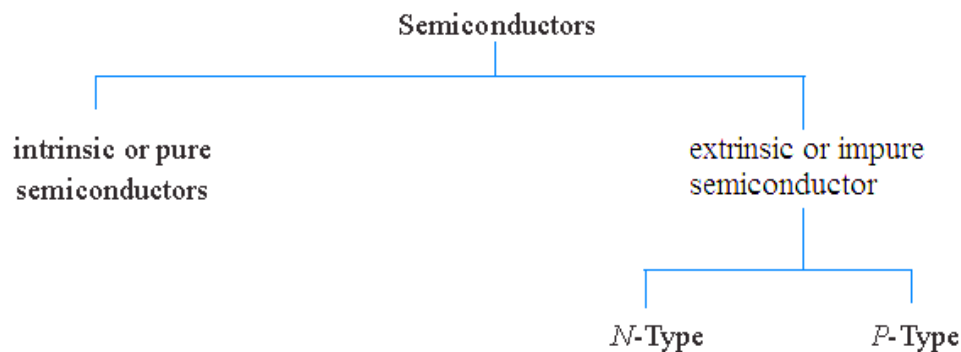
### Semiconductors:

A semiconductor material is one whose electrical properties lie in between those of insulators and good conductors. Examples are: germanium and silicon.

In terms of energy bands, semiconductors can be defined as those materials which have almost an empty conduction band and almost filled valence band with a very narrow energy gap (of the order of 1 eV) separating the two.

### Types of Semiconductors:

Semiconductor may be classified as under:



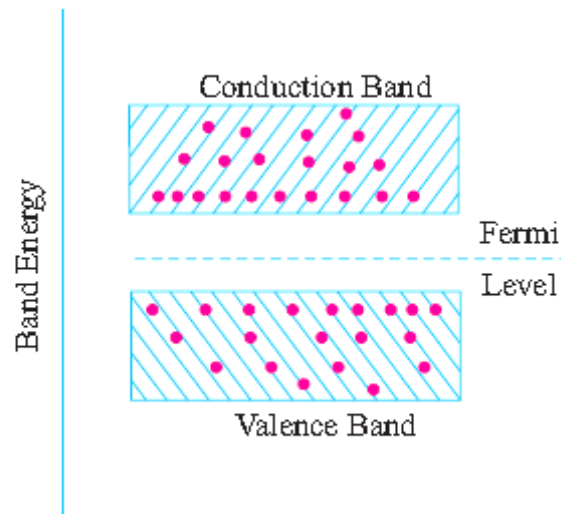
#### a. Intrinsic Semiconductors

An intrinsic semiconductor is one which is made of the semiconductor material in its extremely pure form.

Examples of such semiconductors are: pure germanium and silicon which have forbidden energy gaps of 0.72 eV and 1.1 eV respectively. The energy gap is so small that even at ordinary room temperature; there are many electrons which possess sufficient energy to jump across the small energy gap between the valence and the conduction bands.

Alternatively, an intrinsic semiconductor may be defined as one in which the number of conduction electrons is equal to the number of holes.

Schematic energy band diagram of an intrinsic semiconductor at room temperature is shown in Fig. below.



### **b. Extrinsic Semiconductors:**

Those intrinsic semiconductors to which some suitable impurity or doping agent or doping has been added in extremely small amounts (about 1 part in  $10^8$ ) are called extrinsic or impurity semiconductors.

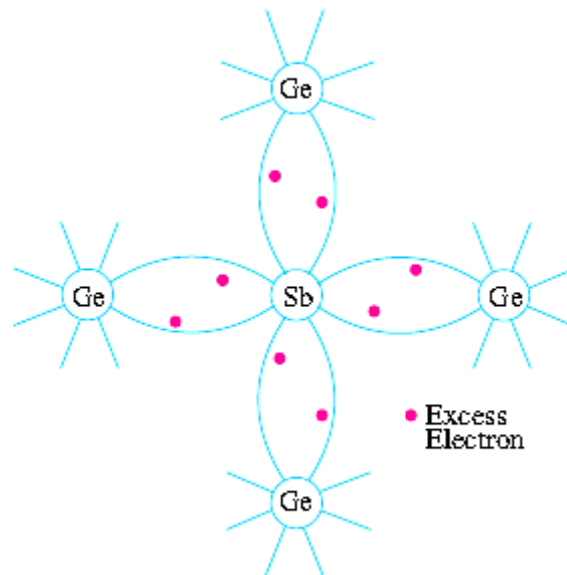
Depending on the type of doping material used, extrinsic semiconductors can be sub-divided into two classes:

- (i) N-type semiconductors and
- (ii) P-type semiconductors.

**(i) N-type Extrinsic Semiconductor:**

This type of semiconductor is obtained when a pentavalent material like antimony (Sb) is added to pure germanium crystal. As shown in Fig. below, each antimony atom forms covalent bonds with the surrounding four germanium atoms with the help of four of its five electrons. The fifth electron is superfluous and is loosely bound to the antimony atom.

Hence, it can be easily excited from the valence band to the conduction band by the application of electric field or increase in thermal energy. It is seen from the above description that in N-type semiconductors, electrons are the majority carriers while holes constitute the minority carriers.

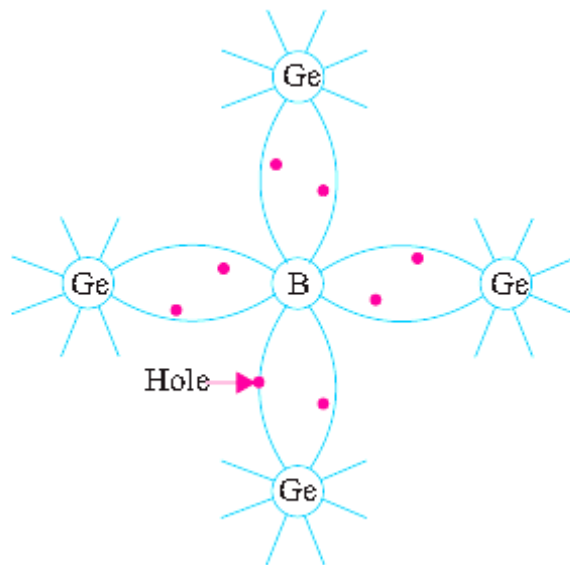


### **(ii) P-type Extrinsic Semiconductor:**

This type of semiconductor is obtained when traces of a trivalent like boron (B) are added to a pure germanium crystal. In this case, the three valence electrons of boron atom form covalent bonds with four surrounding germanium atoms but one bond is left incomplete and gives rise to a hole as shown in Fig. below.

Thus, boron which is called an acceptor impurity causes as many positive holes in a germanium crystal as there are boron atoms thereby producing a P-type (P for positive) extrinsic semiconductor.

In this type of semiconductor, conduction is by the movement of holes in the valence band.



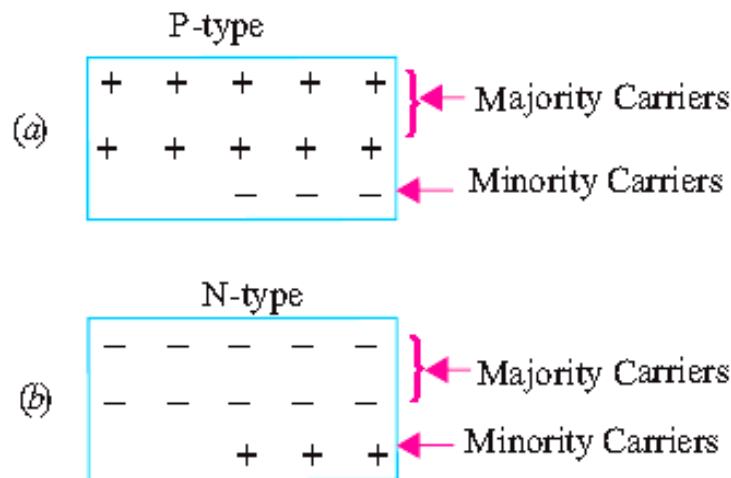
### **Majority and Minority Carriers:**

In a piece of pure germanium or silicon, no free charge carriers are available at 0°K. However, as its temperature is raised to room temperature, some of the covalent bonds are broken by heat energy and as a result, electron-hole pairs are

Produced. These are called thermally-generated charge carriers. They are also known as intrinsically-available charge carriers. Ordinarily, their number is quite small. An intrinsic of pure germanium can be converted into a P-type semiconductor by the addition of an acceptor impurity which adds a large number of holes to it. Hence, a P-type material contains following charge carriers:

- (a) Large number of positive holes—most of them being the added impurity holes with only a very small number of thermally generated ones.
- (b) A very small number of thermally-generated electrons (the companions of the thermally generated holes mentioned above).

Obviously, in a P-type material, the number of holes (both added and thermally-generated) is much more than that of electrons. Hence, in such a material, holes constitute majority carriers and electrons form minority carriers as shown in Fig. below (a). Similarly, in an N-type material, the number of electrons (both added and thermally-generated) is much larger than the number of thermally-generated holes. Hence, in such a material, electrons are majority carriers whereas holes are minority carriers as shown in Fig. below (b).



## P-N Junction Diode

### 1. Construction

It is two terminal devices consisting of a P-N junction formed either in Ge or Si crystal. Its circuit symbol is shown in fig. (1-a). The P and N type regions are referred to as anode and cathode respectively. In fig. (1-b) arrowhead indicates the conventional direction of current flow when forward biased. It is the same direction in which hole flow takes place.

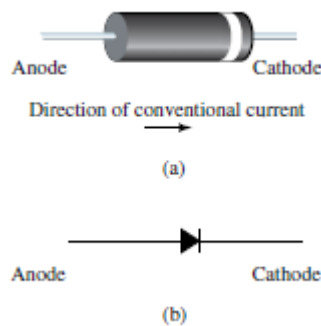


Fig.1

### 2. Working

A P-N junction diode is a one way device offering low resistance when forward biased and behaving almost as an insulator when reverse biased. Hence such diodes are mostly used as rectifiers for converting alternating current into direct current.

### 3. V/I Characteristic

Fig.2 shows the static voltage current characteristics for a low power P-N junction diode.

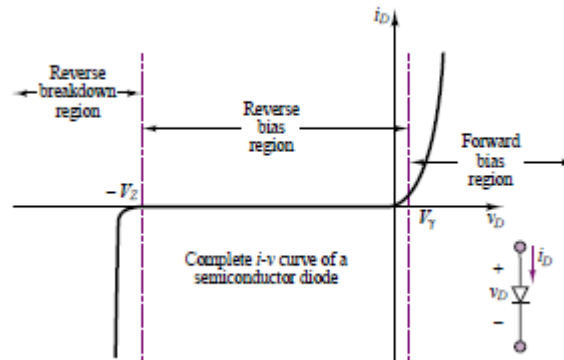


Fig. 2

#### 3.1 Forward characteristic

When the diode is forward biased and applied voltage is increased from zero hardly any current flows through the device in the beginning. It is so because the external voltage is being opposed by the internal barrier voltage  $V_B$  whose value is 0.7 V for Si and 0.3 V for Ge. As soon as  $V_B$  is neutralized, current through the diode increases rapidly with increasing applied battery voltage. It is found that as little a voltage as 1.0 V produces a forward current of about 50 mA.

#### 3.2 Reverse characteristic

When the diode is reverse biased majority carriers are blocked and only a small current (due to minority carriers) flows through the diode. As the reverse voltage is increased from zero, the reverse current very quickly reaches its maximum or saturation value  $I_0$  which is also known as leakage current. It is of order of nano amperes (nA) for Si and micro amperes ( $\mu A$ ) for Ge. As seen from fig.2 when reverse voltage  $V_{BR}$ , the leakage current

suddenly and sharply increases, the curve indicating zero resistance at this point.

#### 4. Diode Parameters

##### 4.1 Bulk resistance ( $r_B$ )

It is the sum of the resistance values of the P and N type semiconductor materials of which the diode is made of

$$r_B = r_P + r_N$$

Usually, it is very small, it is given by

$$r_B = \frac{V - V_K}{I_F}$$

It is the resistance offered by the diode well above the knee voltage when current resistance is large.

Obviously, this resistance is offered in the forward direction.

##### 4.2 Junction resistance ( $r_j$ )

It is value for forward biased junction depends on the magnitude of forward dc current.

$$r_j = \frac{25 \text{ mV}}{I_F \text{ mA}} \dots\dots\dots \text{ for Ge}$$

$$r_j = \frac{50 \text{ mV}}{I_F \text{ mA}} \dots\dots\dots \text{ for Si}$$



### 4.3 Dynamic or ac resistance

$$r_{ac} \text{ Or } r_d = r_B + r_j$$

For large values of forward current,  $r_j$  is negligible. Hence,  $r_{ac} = r_B$  for small values of  $I_F$ ,  $r_B$  is negligible as compared to  $r_j$

$$r_{ac} = r_j$$

### 4.4 Forward voltage drop

It is given by the relation

$$\text{forward voltage drop} = \frac{\text{power dissipated}}{\text{forward dc current}}$$

Reverse saturation current ( $I_0$ )

Reverse breakdown voltage ( $V_{BR}$ )

Reverse dc resistance ( $R_R$ )

$$R_R = \frac{\text{reverse voltage}}{\text{reverse current}}$$

## 5. Equation of diode current

The analytical equation which describes both the forward and reverse characteristics is called the Boltzmann's diode equation given

$$I = I_0(e^{40V} - 1) \dots \dots \dots \text{for Ge}$$

$$I = I_0 e^{40V} \quad \text{if } V > 1 \text{ volt.}$$

$$\text{And } I = I_0(e^{20V} - 1) \dots \dots \dots \text{for Si}$$

$$I = I_0 e^{20V} \quad \text{if } V > 1 \text{ volt.}$$

Where  $I_0$  reverse saturation current.  $V$  voltage across the diode.