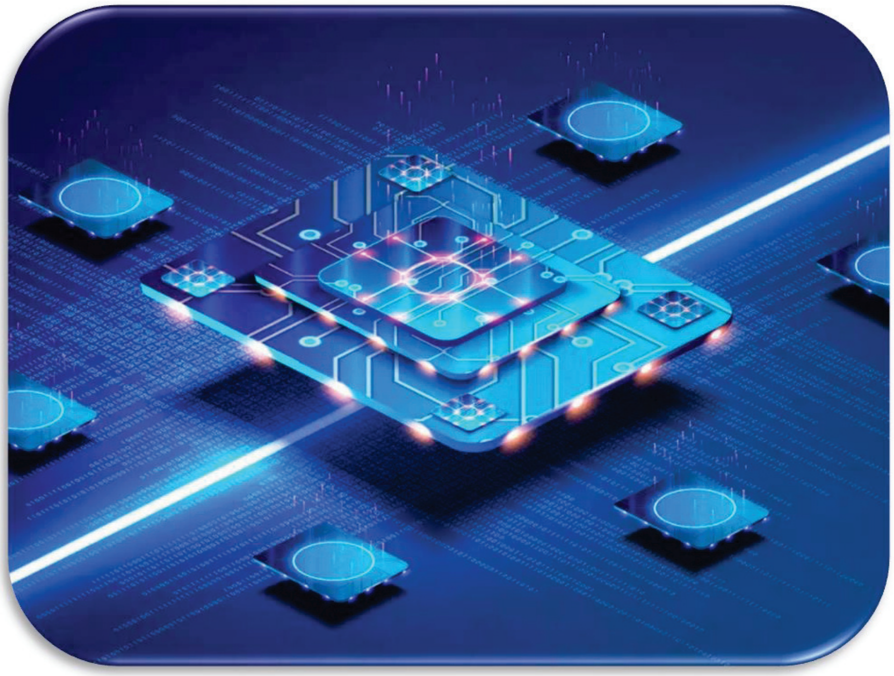
Semiconductor Electronics



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Semiconductor Electronics

Materials, Devices and Simple Circuits

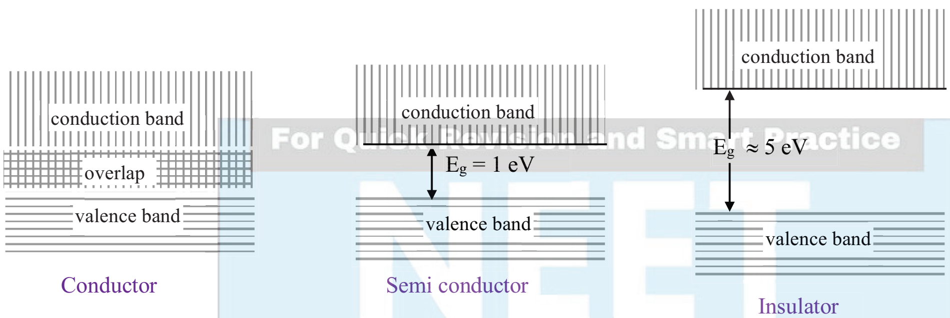
Introduction

Materials having the following electrical properties are semiconductors:

1. Considerably greater resistivity than that for metals and less than that for insulators.
2. Temperature co-efficient of resistance is negative and high.
3. Number density (number of charge carriers / unit volume) n is considerably smaller than that for metals but greater than that for insulators.

Silicon and germanium are commonly used semiconducting materials for electronic devices. Now-a-days, silicon is widely used. Both silicon and germanium are tetravalent Z = 14 for silicon and Z = 32 for germanium. Crystal structure of Ge or Si is the same as that of diamond, i.e., pure carbon. The atoms are held in the crystal lattice by covalent bonds.

Classification of solids based on the Bond theory of solids



Energy band diagram of solids

Extrinsic semiconductors

- The extra element added to an intrinsic semiconductor is called the *impurity atom*.
- The process of adding impurity into an intrinsic semiconductor is called *doping*.
- A pentavalent atom is used as a *donor impurity*. Eg. P, Sb, As
- A trivalent atom is used as an *acceptor impurity*. Eg. In, B, Al
- In addition to the equal number of electrons and holes already existing due to breaking of bonds (at a temperature)
  - (a) there are as many extra holes as the number of acceptor atoms, in a p-type semiconductor.
  - (b) there are as many extra free electrons as the number of donor atoms, in a n-type semiconductor.

  Both p- and n-type semiconductors are electrically neutral.

Effect of doping

- For the same semiconductor material (whether Si or Ge etc), the pn product is constant independent of the type or density of the impurity and depends only on temperature.

$$p_n n_n = p_p n_p = p_i n_i = p_i^2 = n_i^2$$

where n_n = electron density, p_n = minority hole density in a N-type semiconductor

p_p = hole density, n_p = minority electron density in a P-type semiconductor

p_i = hole density, n_i = electron density in a intrinsic semiconductor

Differences between intrinsic and extrinsic semiconductors

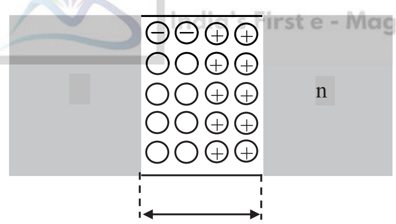
Sl. No.	Intrinsic Semiconductor	Extrinsic Semiconductor
1.	Pure Ge or Si crystal is known as intrinsic semiconductor.	The semiconductor with specific impurities in controlled quantities is known as extrinsic semiconductor.
2.	Conductivity is low.	Conductivity is high.
3.	At any given temperature, the number of electrons is always equal to the number of holes.	The number of electrons and holes are always unequal.

Differences between p-type and n-type semiconductor

Sl.	p-type	n-type
1.	A p-type semiconductor is obtained by doping a trivalent impurity like B or Al with intrinsic semiconductor.	An n-type semiconductor is obtained by doping a pentavalent impurity like P or As with intrinsic semiconductor.
2.	Majority charge carriers are holes and minority charge carriers are electrons.	Majority charge carriers are electrons and minority charge carriers are holes.
3.	The impurity atom accepts the electron from valence band and contribute to increased conductivity.	The impurity atom donates an electron to conduction band and contributes to increased conductivity.
4.	The acceptor impurity energy level is close to the valence band.	The donor impurity energy level is close to the conduction band.

p-n junction or semiconductor diode (unbiased)

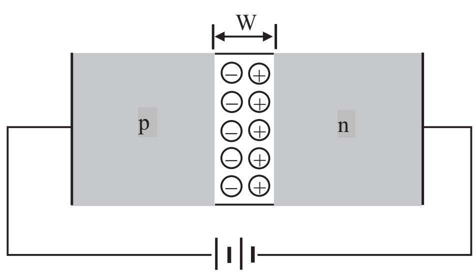
The charge depletion region has a thickness of about one-tenth of a μm and the junction voltage is about 0.3 V for a germanium diode and 0.7 V for a silicon diode at 20 °C.



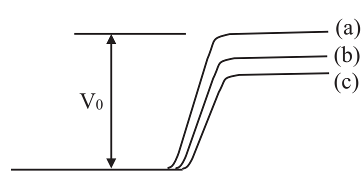
Depletion region

Biasing of a p-n junction or (Semiconductor) diode

Forward bias



W → width of depletion region
p-n junction diode under forward bias

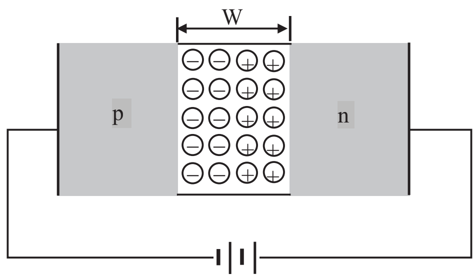


Barrier potential
(a) without battery
(b) low batter voltage
(c) high battery voltage

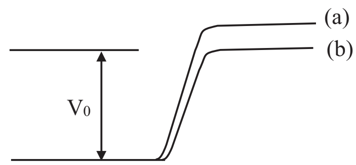
When in forward bias, a diode

- offers negligible (ideally zero) resistance
- behaves like a closed switch
- external voltage opposes the junction voltage.

Reverse bias



Diode under reverse bias



When in reverse bias, a diode

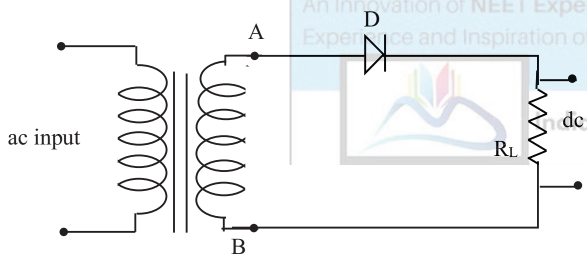
- offers very large (ideally infinite) resistance
- behaves like an open switch
- external voltage aids the junction voltage.

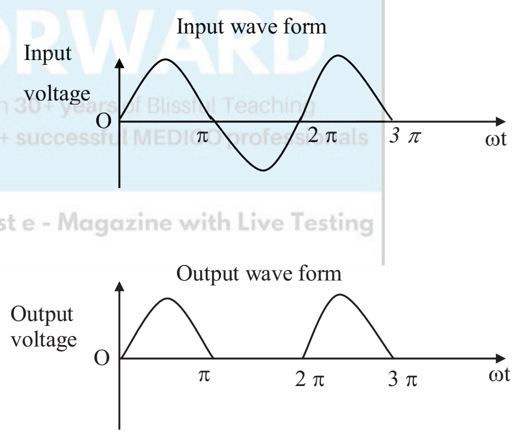
At a very large reverse voltage, reverse breakdown occurs and, hence, a large current flows through the device. This voltage is about 400 V for germanium and 1000 V for silicon.

Rectifiers

A rectifier is a circuit that converts an ac signal into a dc signal. The unidirectional property of a diode is used in the construction of a rectifier.

Half wave rectifier





The output of a half-wave rectifier, is still pulsed, and hence it is not pure dc. (Thus a filter is required to remove the ripples)

$f_{output} = f_{input}$

Full wave rectifier