UNIT II

SEMICONDUCTING MATERIALS

CONTENTS

2.4 Extrinsic semi conductor

Impure form of semiconductor is called extrinsic semiconductors.Extrinsic semiconductors are produced by adding impurity with the pure semiconductor.

Doping:

Addition of impurity with the pure semiconductor is called doping. Addition of impurity increases the number of free electrons and holes and hence its conductivity increases.

Depends upon the type of impurities the extrinsic semi conductors are classified into two types

N type semiconductor

(ii)P type of semi conductor.

2.4.1 N type semi conductor

- When a pentavalent impurity is added with the pure semiconductor it is called n type semi conductor
- A pentavalent impurity (Phosporous) having five valance electrons is added to a pure semiconducting material having four valance electrons (germanium).
- The four valance electrons of the impurity atoms bond with four valanceelectrons of the semiconductor atom and remaining 1 electron of the impurity atom is left free asshown fig.
- Therefore number of free electrons increases, then they are the majority charge carrier in n –type semiconductor and holes are the minority charge carriers.

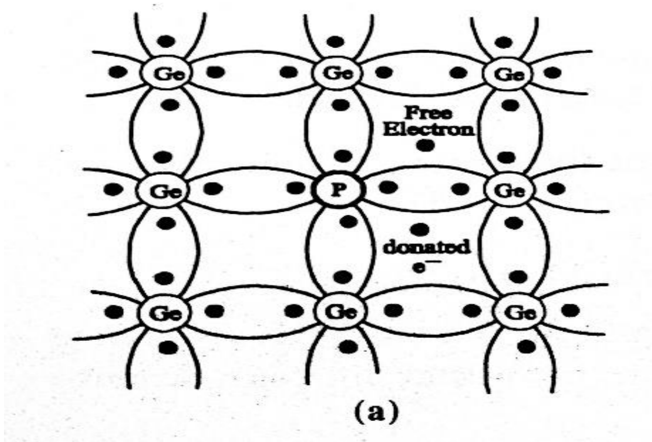


Fig 2.4.1 crystal structure-N type semiconductor

CARRIER CONCENTRATION IN N–TYPE SEMICONDUCTOR

Density of electrons in conduction band

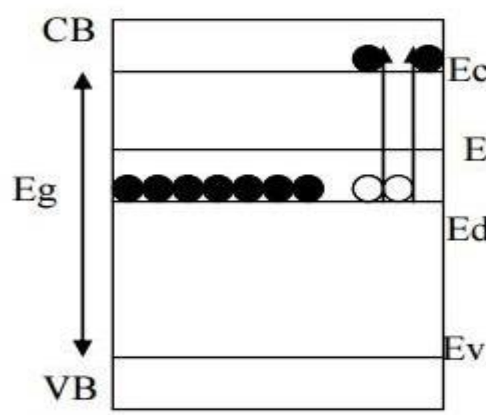
$$n = 2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}} e^{\frac{Ef-Ec}{kT}} ------(1)$$

Electrons are moving from donor level to conduction when a pentavalent element is added with the pure semiconductor as shown in fig

Therefore

The number of electrons in conduction band is equal to the number of holes in donor level.

Let Nd be the number of donor energy levels Some electrons donated from donor energy level to conduction band .



Density of holes in donor level $= N_d \left(1 - \frac{1}{1+e^{\frac{Ed-Ef}{KT}}}\right)$

$$N_d \left(\frac{1+e^{\frac{Ed-Ef}{KT}}-1}{1+e^{\frac{Ed-Ef}{KT}}}\right)$$

(Since Ed<<Ef

$Ed - Ef \ll KT$

Fig 2.4.2–Energy band diagram for N type semiconductor

$1 + e^{\frac{Ed-Ef}{KT}} \approx 1$

$Density\ of\ holes\ in\ donor\ level = N_d e^{\frac{Ed-Ef}{KT}}$------------------(2)

At equilibrium condition

Number of electrons in conduction band (electron density) =Number of holes in donor level

$$2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}} e^{\frac{Ef-Ec}{kT}} = N_d e^{\frac{Ed-Ef}{KT}}$$

$$\frac{e^{((Ef-Ec)/kT)}}{e^{((Ed-Ef)/kT}} = \frac{N_d}{2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}}}$$

$$\frac{2E_F - Ec - Ed}{kT} = \log\frac{N_d}{2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}}}$$

$$E_F = \frac{Ec+Ed}{2} + \frac{KT}{2}\log\frac{N_d}{2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}}}$$-----------------(3)

Carrier concentration in n type semi-conductor

$$n = 2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}} e^{\frac{Ef-Ec}{kT}}$$-------------(4)

$$e^{(\frac{Ef-Ec}{KT})} = e^{\frac{\frac{Ec+Ed}{2}+\frac{KT}{2}\log\frac{N_d}{2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}}} - Ec}{kT}}$$

$$= e^{\frac{\frac{-Ec+Ed}{2}+\frac{KT}{2}\log\frac{N_d}{2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}}}}{kT}}$$

$$= e^{\frac{-Ec+Ed}{2kT}+\frac{KT}{2KT}\log\frac{N_d}{2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}}}}$$

$$= e^{\frac{-Ec+Ed}{2kT}+\frac{1}{2}\log\frac{N_d}{2\frac{(2\pi m_e^* kT^{\frac{3}{2}}}{(h^2)^{3/2}}}}$$

$$= e^{\frac{-Ec+Ed}{2kT}} e^{\log(\frac{N_d}{2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}}})^{1/2}}$$

$$e^{(\frac{Ef-Ec}{KT})} = e^{\frac{Ed-Ec}{2kT}} \frac{Nd^{1/2}}{2^{1/2}\frac{(2\pi m_e^* kT)^{\frac{3}{4}}}{(h^2)^{3/4}}} \text{-------------(5)}$$

Sub this in (4)

$$n = 2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}} e^{\frac{Ed-Ec}{2kT}} \frac{Nd^{1/2}}{2^{1/2}\frac{(2\pi m_e^* kT)^{\frac{3}{4}}}{(h^2)^{3/4}}}$$

$$n = (2Nd)^{1/2}\frac{(2\pi m_e^* kT)^{\frac{3}{4}}}{(h^2)^{3/4}} e^{\frac{Ed-Ec}{2kT}}$$

This is the expression for the carrier concentration for n type semi-conductor

2.4.2.Variation of Fermi level with temperature and impurity concentration for N type semi-conductor

Fermi level depends upon the temperature and impurity concentration

Variation with temperature.

$$E_F = \frac{Ec+Ed}{2} + \frac{KT}{2}\log\frac{N_d}{2\frac{(2\pi m_e^* kT)^{\frac{3}{2}}}{(h^2)^{3/2}}}$$

(i) At T = 0K

$$E_F = \frac{Ec+Ed}{2}$$

Fermi level lies half way between the donor level and conduction band,

(ii) When the temperature is increased, more number of electrons are moving from valence band to conduction band.

(iii) At very high temperature the number of electrons movind from valence band electrons exceeds the electrons moving from donor level to conduction band. Thus Fermi level shifts downward and finally reaches the middle of band gap which is for intrinsic semiconductor.

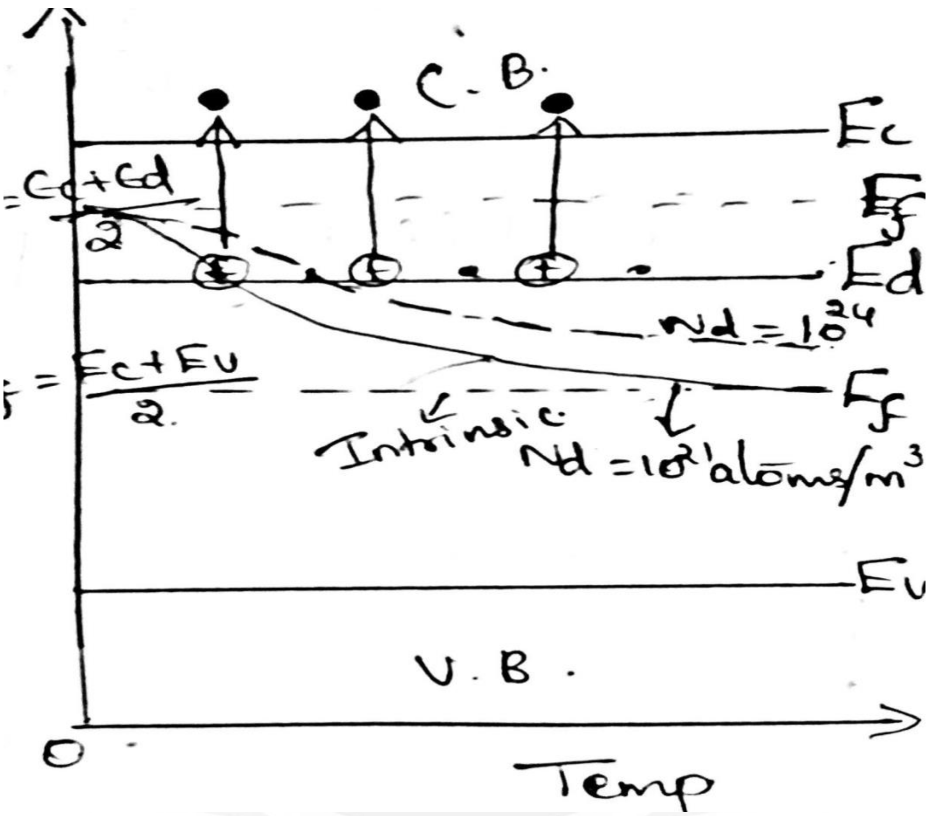


Fig 2.4.2-Variation of Fermi level with temperature