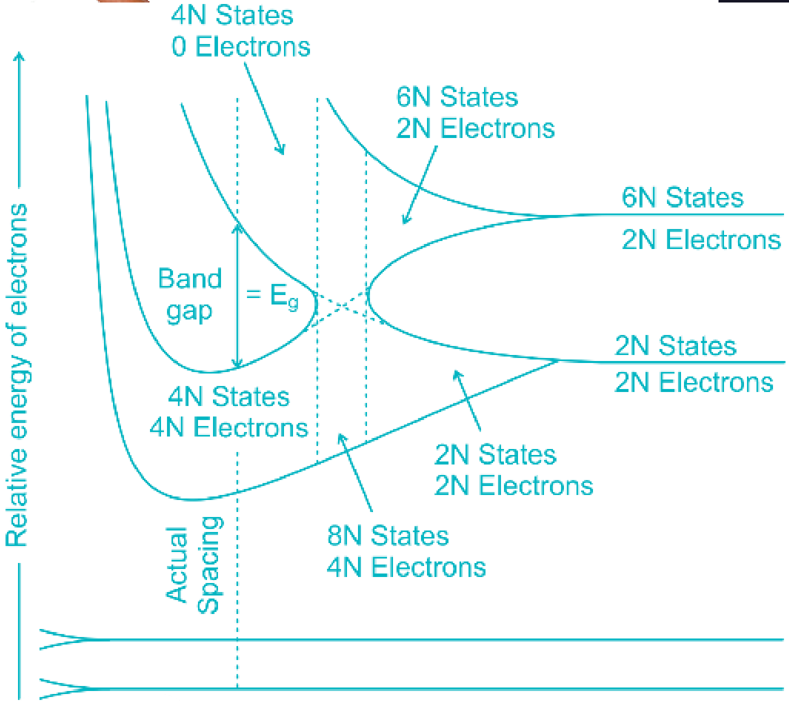
Electronic Devices for GATE EC - Study Notes on Semiconductor Physics!

Semiconductor physics form the basics for Electronic Devices and Analog Circuits. Every year questions for 2 or 3 marks are asked repeatedly from this topic in GATE exam. If you are preparing for Engineering exams like GATE, ESE, ISRO, DMRC and other PSU exam, you might find questions from this topic asked frequently. In this article on Electronic Devices for GATE EC, you will learn about the Fermi levels, carrier concentration and electron mobility and practice them with Previous Year Questions & quick quiz to test your knowledge.

Electronic Devices for GATE EC - Energy Bands

Each isolated atom has discrete energy levels associated with itself. These discrete energy levels can be the same for two atoms as long as do not interact. As atoms are brought near, due to Pauli's exclusion principle there is a splitting of energy levels of the isolated atoms which gives rise to Band of energy and hence Bandgap.



Energy levels splitting in Si as a function of interatomic distance

Various formulas associated with bandgap:

Energy bandgap ($E_g = E_c - E_v$) is the difference between the highest level of the valence band and the lowest level of the conduction band

The probability that an energy state E will be occupied by an electron at temperature T is given by **Fermi Dirac distribution function f(E).**

$$f(E) = \frac{1}{1+\exp(E-E_f)/kT}$$

k = Boltzmann constant

Bandgap energy of semiconductor depends on temperature

$E_g = E_{go} - \beta T$ eV

Where E_g is the bandgap at any temperature T and E_{go} is the bandgap at 0K

some typical values of bandgap in eV

	0 K	300 K
Si	1.21	1.1
Ge	0.785	0.72

Bandgap in Intrinsic semiconductors

$$E_f = \frac{E_c+E_v}{2} - \frac{kT}{2} \, ln\left(\frac{N_c}{N_v}\right) E_f = \frac{E_c+E_v}{2} - \frac{3kT}{4} \, ln\left(\frac{m_n}{m_p}\right)$$

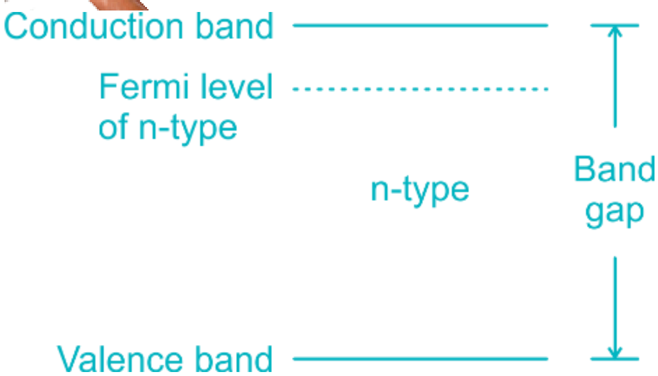
Fermi level in doped semiconductors

The fermi level moves away from intrinsic level due to doping. Mathematically shift in the position of fermi-level with respect to intrinsic fermi level can be expressed as:

For n-type: shift = KT ln $\left(\frac{N_D}{n_i}\right)$ For p-type: shift = KT ln $\left(\frac{N_A}{n_i}\right)$

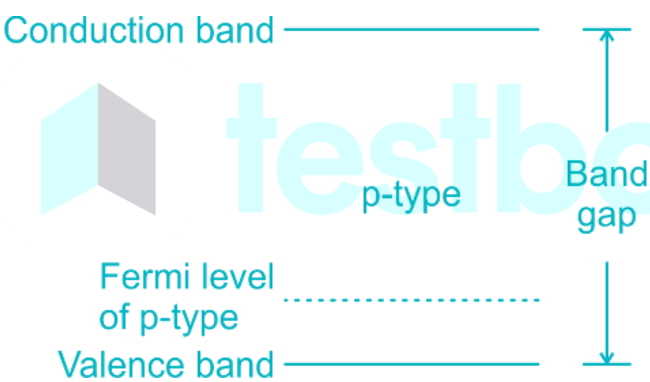
The distance of Fermi level from the edge of the conduction band in an n-type semiconductor is:

$E_c - E_f = KT \ln\left(\frac{N_c}{N_D}\right)$



The distance of fermi level from the edge of valence band in a p-type semiconductor is:

$$E_f - E_v = KT \ln\left(\frac{N_v}{N_A}\right)$$



Electronic Devices for GATE EC - Carrier Concentration

The effective density of states (DOS) in the conduction band is given by

$$N_C = 2\left[\frac{2\pi\, m_n^* KT}{h^2}\right]^{3/2}$$

The concentration of electrons in conduction Band:

$$n_0 = N_c\, e^{-(E_c - E_f)/KT}$$

Effective Density of states in the valence band

$$N_v = 2\left[\frac{2\pi\, m_p^* KT}{h^2}\right]^{3/2}$$

Corresponding hole concentration in valence band

$$p_0 = N_v\, e^{-(E_f - E_v)/KT}$$

In intrinsic semiconductors

$n_0 p_0 = n_i^2$ (law of mass action)

$$n_i = \sqrt{N_c N_v}\, e^{-E_g/2KT}$$

$$n_i^2 = A_0 T^3 e^{-\frac{E_g}{KT}}$$

Electronic Devices for GATE EC - Mobility

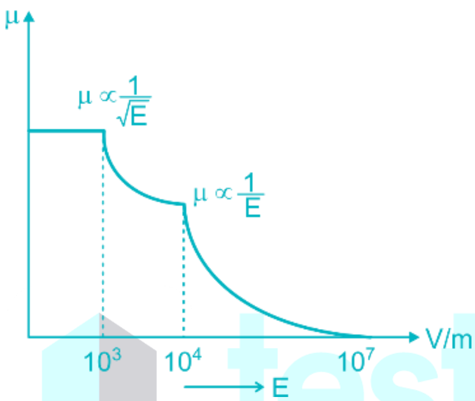
It is the measure of the speed of charge in a semiconductor under the application of electric field.

Various formulas and results associated with mobility

$$\mu = \frac{Drift\ velocity}{Electric\ field} = \frac{V_d}{E}$$

$\mu \propto T^{-m}$

Variation of mobility with electric field



Mobility is affected by different scattering mechanisms

Overall mobility:

$$\frac{1}{\mu} = \frac{1}{\mu_1} + \frac{1}{\mu_2} + \frac{1}{\mu_3} + - - -$$

Electronic Devices for GATE EC - Conductivity

Conductivity depends on carrier concentration & mobility.

For intrinsic semiconductor :

$\sigma = q\ n\ \mu_n + q\ p\ \mu_p$

For extrinsic semiconductor:

n -type $\sigma_n \cong q\, N_d\, \mu_n$

p -type $\sigma_p \cong q\, N_a\, \mu_p$

minimum conductivity in the semiconductor is at

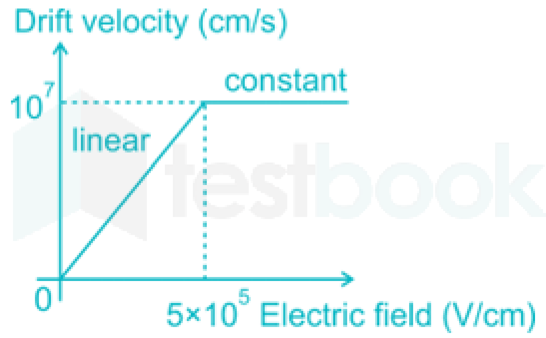
$$n = n_i\sqrt{\frac{\mu_p}{\mu_n}}; \quad p = n_i\sqrt{\frac{\mu_n}{\mu_p}}$$

$$\sigma_{min} = 2\, n_i\, q\, \sqrt{\mu_n\, \mu_p}$$

Test your Understanding on Electronic Devices for GATE EC

1. The dependence of drift velocity of electrons on electric field in a semiconductor is shown below. The semiconductor has a uniform electron concentration of $n = 1 \times 10^{16}\ cm^{-3}$ and electronic charge $q = 1.6 \times 10^{-19}$ C. If a bias of 5 V is applied across a 1 μm region of this semiconductor, the resulting current density in this region, in kA/cm^2, is __________.

(GATE 2017 Set 1)



Range : Start : 1.5 End : 1.7

Solution:

The electric field corresponding to given bias voltage

$$E = \frac{V}{l} = \frac{5}{1 \times 10^{-6}}$$

$= 5 \times 10^6$ V/m

$= 5 \times 10^4$ V/cm

From the given curve

Slope of curve $= = \frac{10^7}{5\times10^5}$

Drift velocity $= = \frac{10^7}{5\times10^5} = \frac{V_d}{5\times10^4}$

$V_d = 10^6$ cm/s

Current density

$J = \sigma E$

$= n\mu_n e\ E$

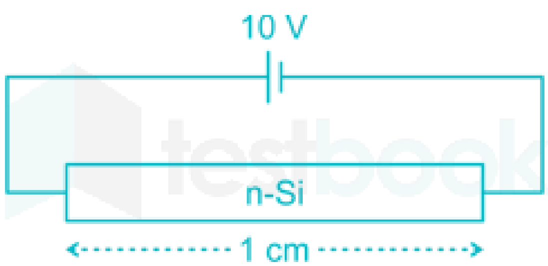
$V_d = \mu_n\ E$

$= n\ eV_d$

$= 10^{16} \times 1.6 \times 10^{-19} \times 10^6 = = 1.6$ KA/cm^2

2. A DC voltage of 10V is applied across an n-type silicon bar having a rectangular cross-section and a length of 1cm as shown in the figure. The donor doping concentration ND and the mobility of electrons are and respectively. The average time (in μsec) taken by the electrons to move from one end of the bar to other end is_________.

(GATE 2015 Set 2)



Range : **Start** : 95 **End** : 105

Solution:

We have, field intensity $E = \frac{v}{d} = \frac{10}{1} = 10\frac{V}{cm}$

Now, drift velocity, $v_d = \mu_n \times E$

$\Rightarrow v_d = 1000 \times 10 = 10^4 \frac{cm}{sec}$

Thus, average time taken for transit,

$$t = \frac{d}{v_d} = \frac{1}{10^4} = 10^{-4}sec$$

$$\Rightarrow t = 100\mu sec$$

Hence, t (in μsec) $= 100$

Learn more about various other topics important for GATE 2018 by clicking on the links given below!

Electronic Devices & Circuits Quiz for GATE EC

Recommended Books for GATE EC 2019

Introduction to Fourier Series - GATE 2019