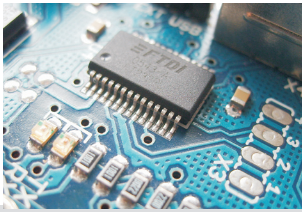
A Handbook on

Electronics & Communication Engineering



Contains well illustrated formulae & key theory concepts

For

IES, GATE, PSUs

& OTHER COMPETITIVE EXAMS

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Director's Message

B. Singh (Ex. IES)

During the current age of international competition in Science and Technology, the Indian participation through skilled technical professionals have been challenging to the world. Constant efforts and desire to achieve top positions are still required.

I feel every candidate has ability to succeed but competitive environment and quality guidance is required to achieve high level goals. At MADE EASY, we help you to discover your hidden talent and success quotient to achieve your ultimate goals. In my opinion IAS, IES, GATE & PSU's exams are tool to enter in to main stream of Nation serving. The real application of knowledge and talent starts, after you enter in to the working system. Here in MADE EASY you are also trained to become winner in your life and achieve job satisfaction.

MADE EASY aluminae have shared their winning stories of success and expressed their gratitude towards quality guidance of MADE EASY. Our students have not only secured All India First Ranks in IES, GATE and PSU entrance examinations but also secured top positions in their career profiles. Now, I invite you to become aluminae of MADE EASY to explore and achieve ultimate goal of your life. I promise to provide you quality guidance with competitive environment which is far advanced and ahead than the reach of other institutions. You will get the guidance, support and inspiration that you need to reach the peak of your career.

I have true desire to serve Society and Nation by way of making easy path of the education for the people of India.

After a long experience of teaching in Electroics Engineering over the period of time MADE EASY team realised that there is a need of good *Handbook* which can provide the crux of Electronics Engineering in a concise form to the student to brush up the formulae and important concepts required for IES, GATE, PSUs and other competitive examinations. This *handbook* contains all the formulae and important theoretical aspects of Electronics Engineering. It provides much needed revision aid and study guidance before examinations.

B. Singh (Ex. IES)
Founder & Director, MADE EASY Group

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A Handbook on Electronics Engineering

01

Electronic Devices & Circuits

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1. Energy band and Charge Carriers in SC

- Difference between the lower energy level conduction band E_c and upper energy level valence band E_v is called ***energy band gap***.
- In ***metals*** the band either overlap on partially filled.
- In ***insulator*** energy band gap is very high.
- In ***semiconductor*** band gap is relatively small.
- An empty state in valence band is referred as hole.
- A perfect semiconductor crystal with no impurities or lattice defects is called ***intrinsic*** semiconductor.
- When a semiconductor is doped such that equilibrium concentration n_0 and p_0 are different from intrinsic carrier concentration n_i, the material is said to be ***extrinsic***.

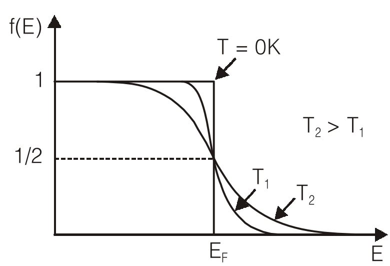
Fermi Level

- Fermi level is energy state having probability 1/2 of being occupied of an electron if there is no forbidden band exists.
- Energy of fastest moving electron at 0K is called fermi energy level.
- ***Fermi dirac function*** f(E) gives the probability that an available energy state E will be occupied by an electron at absolute temperature T, under conditions of thermal equilibrium

$$\boxed{f(E) = \frac{1}{1 + \exp[(E - E_F)/kT]}}$$

where, $E_F \rightarrow$ fermi energy level
$K \rightarrow$ Boltzmann's constant
$T \rightarrow$ absolute temp. in Kelvin

- The fermi dirac distribution function is given as



NOTE: [1 – f(E)] gives the probability that energy state E will be occupied by a hole.

- Concentration of electron in conduction band is given by

$$\boxed{n_0 = N_c\, e^{-(E_C - E_F)/kT}}$$

where, $n_0 \rightarrow$ concentration e^-_s in conduction band
$E_F \rightarrow$ fermi energy level
$E_C \rightarrow$ energy level of lowest conduction level
$k \rightarrow$ Boltzmann's constant
$T \rightarrow$ absolute temperature
$N_C \rightarrow$ effective density of states in conduction band

- Effective density of states N_C is given by

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

where, $m_n^* \rightarrow$ is the effective mass of electrons

$h \rightarrow$ Plank's constant

- Concentration of holes in valence band is given by

$$\boxed{p_0 = N_v\, e^{-(E_F - E_v)/kT}}$$

where, $p_0 \rightarrow$ concentration of holes

$N_v \rightarrow$ effective density of states in valence band

$E_F \rightarrow$ fermi energy level

$E_v \rightarrow$ highest energy level of valence band

- Effective density of sates in valence band is given by

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

where, $m_p^* \rightarrow$ is the effective mass of holes

Mass Action Law

- It states that at thermal equilibrium product of concentration of free electrons and holes is equal to the square of intrinsic concentration at that temperature i.e.

$$\boxed{n_0 p_0 = n_i^2}$$

where, $n_0 \rightarrow$ concentration of electron in conduction band

$p_0 \rightarrow$ concentration of holes in valence band

$n_i \rightarrow$ intrinsic concentration at given temperature

- Intrinsic concentration is given by

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

where, $E_g \rightarrow$ band gap

- n_i can also be given as

$$\boxed{n_i^2 = A_0 T^3 e^{-E_g/kT}}$$

where, $A_0 \rightarrow$ is a constant

- Concentration of electron in conduction band can also be given as

$$\boxed{n_0 = n_i\, e^{(E_F - E_i)/kT}}$$

where, $E_i \rightarrow$ intrinsic level lies near the middle of bandgap

- Concentration of holes in valence band can also be given as

$$\boxed{p_0 = n_i\, e^{(E_i - E_F)/kT}}$$

NOTE

Intrinsic concentration depends on temperature. As temperature increases the intrinsic concentration increases as $T^{3/2}$.

Space Charge Neutrality

- If the material is to remain electrostatically neutral, the sum of positive charges must balance the sum of negative charges i.e.

$$\boxed{p_0 + N_d^+ = n_0 + N_a^-}$$

where, $N_d^+ \rightarrow$ concentration of donor atoms
$N_a^- \rightarrow$ concentration of acceptor atoms
$p_0 \rightarrow$ concentration of holes
$n_0 \rightarrow$ concentration of electrons

Mobility of Charge Carriers

- It is drift velocity per unit electric field.
- It defines how fast the charge travels from one place to other and is given by

$$\boxed{\mu = \frac{v_d}{E}}$$

where, $v_d \rightarrow$ drift velocity
$E \rightarrow$ electric field

	Ge	Si
• e^- mobility	3800 cm^2/V sec	1300 cm^2/V sec
hole mobility	1800 cm^2/V sec	500 cm^2/V sec

> **NOTE**
> - Electron's mobility is always greater than hole mobility in a given material. Hence electron can travel faster so contribute more current for same electric field than hole as explained by quantum mechanical physics.

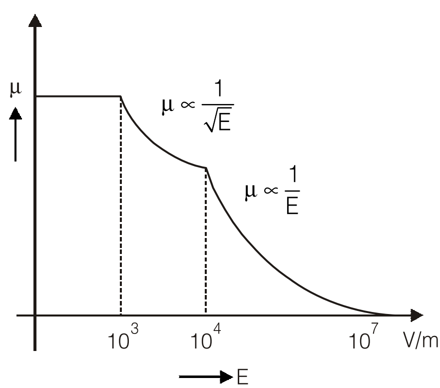
- Mobility of charge carriers decreases with temperature and varies as

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

where, m is a constant
m = 1.66 for e^- and 2.33 for hole for Ge
m = 2.5 for e^- and 2.7 for hole for Si

- Mobility also varies with electric field applied as

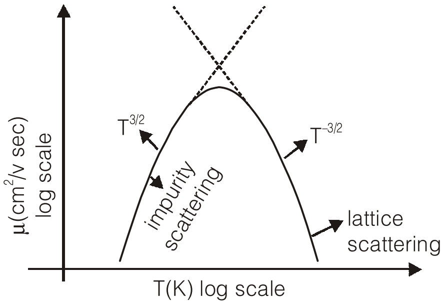
> **NOTE**
> - At smaller electric field mobility is constant.
> - At very high electric field product of mobility and electric field becomes constant and is equal to saturation value of drift velocity.



Effect of Scattering of Mobility

- There are two types of scattering mechanism that influence electron and hole mobility are lattice scattering and impurity scattering.

- The variation of mobility in accordance with scattering is as



- Overall mobility is given by

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

where, $\mu \rightarrow$ overall mobility
$\mu_1, \mu_2, \mu_3 \rightarrow$ mobility corresponding to different scattering mechanism

Energy Gap (E_g)

- Energy gap depends on temperature and interatomic spacing.
- Variation of energy gap with temperature is as

$$\boxed{E_g = E_{g0} - \beta_0 T} \text{ eV}$$

where, $E_{g0} \rightarrow$ energy gap at 0K, $\beta_0 \rightarrow$ material constant,
$\beta_0 = 2.2 \times 10^{-4}$ eV/k for Ge $= 3.6 \times 10^{-4}$ eV/k for Si
$E_g \rightarrow$ energy gap at temperature T(K)

NOTE
- E_{g0}—0.785 eV(Ge), 1.21 eV(Si)
- E_{g0} — xxx (GaAs)
- E_{g300}—0.72 eV (Ge), 1.1 eV(Si)
- E_{g300} — 1.47 eV (GaAs)

Hall Effect

- It states that if a specimen (metal or semiconductor) carrying a current I is placed in transverse magnetic field B an electric field is induced in a direction perpendicular to both I and B.
- Value of hall voltage is given by

$$\boxed{V_H = Ed}$$

or

$$\boxed{V_H = \frac{BI}{\rho W}}$$

where, E $\rightarrow$ electric field induced
d $\rightarrow$ separation between upper and lower surface of specimen or height of specimen
W $\rightarrow$ width of specimen
B $\rightarrow$ applied magnetic field
I $\rightarrow$ current flowing in specimen
$\rho \rightarrow$ charge density

- $\frac{1}{\rho}$ is called *Hall coefficient* R_H i.e. $\boxed{R_H = \frac{1}{\rho}}$
- V_H can also be given as $\boxed{V_H = R_H \frac{BI}{W}}$
- By hall experiment, mobility is given by

$$\boxed{\mu = \frac{8}{3\pi}\sigma R_H}$$

where, $\mu \rightarrow$ mobility of charge carriers
$\sigma \rightarrow$ conductivity of material

> **NOTE**
> - Hall effect is utilized in determining whether a given material is metal, n-type SC or p-type SC.
> - For metal, value of V_H is lesser compare to SC.
> - Hall voltage is +ve for metal or n-type SC.
> - Hall voltage is –ve for p-type SC.
> - Hall voltage is zero for intrinsic SC.
> - It can be used in finding mobility of charge carries, concentration of charge carriers, and type of semiconductor.
> - It is utilized in Hall effect multiplier.

- In metal, R_H increases with temperature.
- In pure SC, R_H decreases with temperature.
- In extrinsic SC, R_H increases with temperature.

Conductivity (σ)

$$\boxed{\sigma = q.n\,\mu_n + q\,p\,\mu_p}$$

where, $n \rightarrow$ concentration e^-_s in conduction band
$p \rightarrow$ concentration of holes in valence band
$\mu_n \rightarrow$ mobility of e^-_s
$\mu_p \rightarrow$ mobility of holes

- Conductivity of pure SC is given by

$\boxed{\sigma = qn_i[\mu_n + \mu_p]}$ where, $n_i \rightarrow$ intrinsic concentration

> **NOTE**
> - Conductivity of pure SC increases with temperature.
> - Conductivity of pure SC at 0 K is zero.

- Conductivity of extrinsic SC is given by

$\boxed{\sigma \cong qN_d\,\mu_n}$ for n-type

$\boxed{\sigma \cong qN_a\,\mu_p}$ for p-type

where, $N_d \rightarrow$ donor concentration
$N_a \rightarrow$ acceptor concentration

NOTE
- Conductivity of extrinsic SC decrease with increase in temperature above normal temperature.
- Conductivity of extrinsic SC initially increases when, temperature rises from 0 K.
- Conductivity increases with increase in doping temperature,
- Conductivity of extrinsic SC at 0K is zero.
- At curie temperature conductivity becomes equal to intrinsic conductivity.

Fermi Level in Intrinsic and Extrinsic SC

- Fermi level E_F in intrinsic SC is given by

$$\boxed{E_F = \frac{E_C + E_V}{2} - kT\ln\left(\frac{N_C}{N_V}\right)}$$

where, $E_C \rightarrow$ lowest energy level of conduction band
$E_V \rightarrow$ highest energy level of valence band
$N_C \rightarrow$ density of states in conduction band
$N_V \rightarrow$ density of states in valence band
$k \rightarrow$ Boltzmann's constant

NOTE
- If $N_V \cong N_C$ then fermi level lies in the middle of energy gap.
- At 0 K Fermi level lies in the middle of energy gap.
- Fermi level in pure SC depends on temperature.
- As temperature increases fermi level moves away from the middle of bandgap.

- Fermi level in n-type SC is given by

$$\boxed{E_F = E_C - kT\ln\left(\frac{N_C}{N_D}\right)}$$

where, $N_C \rightarrow$ density of states in conduction band
$N_D \rightarrow$ donor concentration

NOTE
- In n-type SC fermi level depends on both temperature and donar concentration.
- At 0K fermilevel coincides with E_C.
- As temperature increases fermi level moves towards the middle of bandgap.
- As donar concentration increases fermi level moves towards the E_C.
- At $N_C = N_D$, E_F coincides with E_C and this is the saturation value of E_F, E_F can't be greater than this value.
- Normally fermi level lies close to E_C.

- Fermi level in p-type SC is given by

$$\boxed{E_F = E_v + kT \ln \frac{N_V}{N_A}}$$

where, $N_v \rightarrow$ density of states in valence band
$N_A \rightarrow$ concentration of acceptors

NOTE

- In p-type SC fermi level E_F at 0K coincides with E_V.
- In p-type SC fermi level lies close to valence band.
- In p-type SC fermi level moves away from valence band as temperature increases.
- In p-type SC fermi level moves towards valance band as N_A increases and attains a saturation value of E_v at $N_A = N_v$. Further increase in N_A will not change E_F.

- Shift in the position of fermi level with respect to intrinsic fermi level in n-type SC is given by

$$\boxed{\text{Shift} = kT \ln\left(\frac{n}{n_i}\right) \simeq kT \ln\left(\frac{N_D}{n_i}\right)}$$

- Shift in position of fermi level in p-type SC with respect intrinsic fermi level is given by

$$\boxed{\text{Shift} = kT \ln \frac{p}{n_i} \cong kT \ln \frac{N_A}{n_i}}$$

Remember

In a material at equilibrium there is no discontinuity in fermi level. More generally we can say that fermi level at equilibrium must be constant throughout the material i.e.

$$\boxed{\frac{dE_F}{dx} = 0}$$

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