SEMICONDUCTOR MATERIAL & DEVICES

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CONTENT

CHAPTER-1

INTRODUCTION

1) Thermal Voltage (V_T)

It represents "*temperature in terms of voltage*".

$$V_T = \frac{\overline{K}T}{q}\text{Volt} \qquad \overline{K}, = \text{Boltzmann constant}$$

$\overline{k} = kq$

q = 1.6 × 10^{-19} K

K = 8.62 × 10^{-5}ev/°K

Boltzmann constant is ratio of universal gas constant to Avogadro's number

$$\therefore \quad K = \frac{8.314}{6.022\times10^{23}} \quad J/{}^{o}K \quad = 1.38\times15^{23}J/{}^{\circ}K$$

$$\because \quad 1ev = 1.6\times10^{-19}J. \quad \therefore \quad K = 1.38\times10^{-23}J/{}^{\circ}K = 8.62\times10^{-5}ev/{}^{\circ}K$$

$$V_T = KT = \frac{T}{11600}Volt.$$

At room temperature T = 300 K

V_T at room temperature $V_T = \frac{300}{11600}$ = 0.256Volt.

$$\boxed{V_T = 26\text{ mV}}$$

2) Standard Temperature

(i) Absolute Temperature 0° K = –273° C

(ii) Room Temperature 300° K = 27° C

(iii) Ambient TempératureT$_A$290° K = 17° C

Key Points :

→ Temperature in °C =Temperature in °K – 273

→ Temperature in °K =Temperature in °C + 273

3) Electron Voltage (Ev)

Electron Volt: Unit of Energy

For energies involved in electron devices, 'joule' is too large a unit. Such small energies are Conveniently measured in electron volt, abbreviated as eV. The electron volt is the kinetic energygained by an electron, initially at rest, in moving through a potential difference of 1 volt.

Since e = 1.6 × 10^{-19}C

1 ev is defined as the energy gain by the electron in moving through a potential difference of 1 volt. It is the unit of 'Energy'

1 ev = $|q| \times p_d$

= 1.6×10^{-19}C × 1 volt = 1.6×10^{-19} J

4) Leakage Current (I_o)

This current is generated only due to temperature variation.

$$I_{o(T_2)} = Io_{\ T_1}\ 2^{\left[\frac{T_2 - T_1}{10}\right]}$$

It is also called minority carrier current or Reverse saturation current or thermally generated current.

Advantages: The**Si** has small leakage current*i.e.***Si** has small I_0

$$I_o = \overset{Si}{\eta_A}\ \overset{Ge}{\mu_A}$$

→ I_O doubles for every 10° rise in temperature.

Alternatively, we can say that I_0 increases by 7% for every 1°C (or 1°K) rise in temperature.

5) Current (I)

Rate of change of charge carriers. $i = \frac{dq}{dt}\ Ampere.$

→ In a Semiconductor current is carried by both e^- and holes.

→ In Semiconductor thereare two types of current.

i) Drift Current ii) Diffusion Current

(i) **Drift Current**: The steady flow of e' in one direction caused by applied electric field constitutes an electric current, called the 'Drift Current'.

OR

→ It is the current due to Potential Gradient.

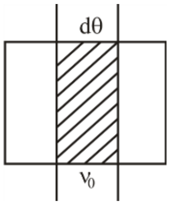
(ii) **Diffusion Current**: It is the current due to concentration gradient.

6) Current Density (J)

Current density is a measure of the density of an electric current flowing through a solidper unit area.

Current density is a vector which points in the direction of current flow.

$$\vec{J} \Rightarrow |\vec{J}| = \frac{I}{A} = \frac{Current}{Area}\left(\frac{\text{A}}{\text{m}^2}\right) = \frac{d\theta}{dt \times A}$$



$\frac{d\theta}{dt}$ = Number of change carrier flow in 1 second at apoint.

$$d\theta = \rho \times A \times V_d$$

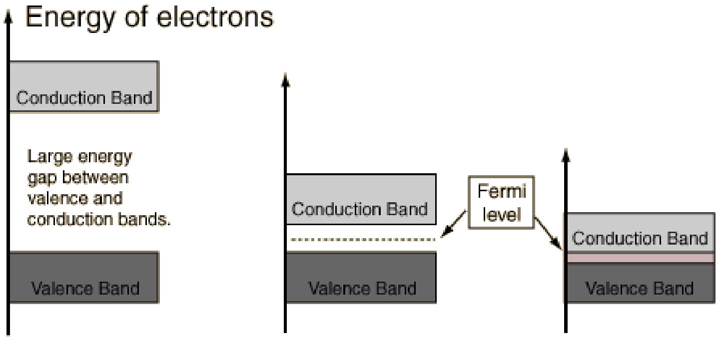
Let the energy above the Fermi energy E_F be E_1 Then $\Delta E = E_1$ ΔE_F, and the probability of occupancy $f(E_1)$ of the level E_1 is given by the FD distribution function, i.e.

$$J = nq\,V_d = nq\,\mu_E$$

$$\underbrace{J = \sigma E}_{\text{Ohm's law in Point form.}} \qquad \text{Where } \sigma = nq\,\mu$$

Where σ = Conductivity

7) Energy Band in Solid



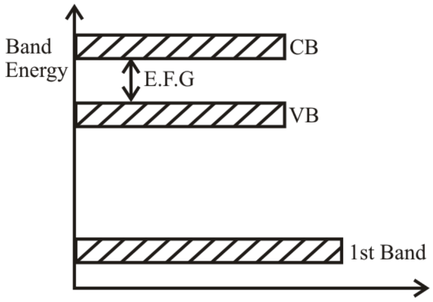
a. Insulator b. Semiconductor c. Conductor

The range of energies possessed by an $\overset{-}{e}$ in a solid is known as "Energy Band"

1) **Valence Band:** The range of energy possessed by in band e^- is known as "Valence Band". They are not free to conduct , thus, no contribution to conductions .

2) Conduction Bond: In certain material the valence e^- are loosely attached to the nucleus some valence electron may get detached to become free e^- which are responsible for the conduction of current in a conductor, they are called conduction e^-. The range of energies possessed by conduction e^- is known as conduction band. The e^- in the conduction band are free e^-.

3) Forbidden Energy Gap: The difference in energy between C.B. and V.B. in the energy band diagram is known as F.E.G.



→ No electron can stay in the forbidden energy gap.

Typical values of the energy gap:

	0K	300K
Ge	0.785 ev	0.72 ev
Si	1.21 ev	1.1 ev

Energy gap decreases linearly with temperature

$$Eg(T) \cong Eg(T) - 3.46 \times 10^{-4} T$$

Key Point: Free e^- exist only in conduction band and holes exist only in V.B.

Effect of Temperature: Due to thermal energy electron jumps from V.B. to C.B. and gets free.

→ When temperature increases then carrier concentration also increase and both $\bar{e}$ & holes (C.B.) decrease.

Then the conductivity ↑ and Band gap ↓

8) Classification of Solids According to the BAND GAP

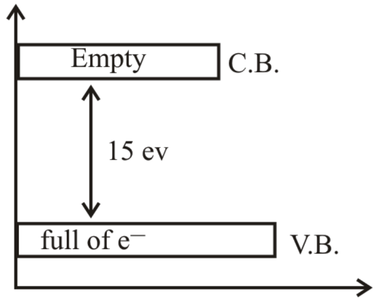
i) Insulator :

An insulator, also called a dielectric or non-conductor, is a material that resists the flow of electric current.

An electrical insulator is a material whose internal electric charges do not flow freely, and which therefore does not conduct an electric current, under the influence of an electric field. A perfect insulator does not exist, but some materials such as glass, paper and Teflon, which have high resistivity, are very good electrical insulators. Examples include rubber-like polymers and most plastics.

An insulating material used in bulk to wrap electrical cables or other equipment is called insulation.

The valance band is full of e^- while the conduction band is empty and the energy gap between V.B. and C.B is very large i.e. 15 ev.



For Insulator: Temperature (Increases) →Resistance (Decreases) : Negative temperature of resistance coefficient.

At room temperature it behaves as a perfect insulator. The resistance of the insulator decrease with increase in temperature so insulators have negative temperature Co-efficient of resistance.

Some insulating / non-conducting materials

- Plastics and solidified resins
- Rubber and Silicones
- Glass and ceramics
- Most metal oxides
- Most minerals and crystals
- cold, un-ionized gases (including Air)
- Oil
- Vacuum
- Water, if purified and de-ionized
- The depletion zone within a semiconductor
- asphalt
- fiberglass
- porcelain
- ceramic
- quartz
- (dry) cotton
- (dry) paper
- (dry) wood
- plastic
- diamond

Application :

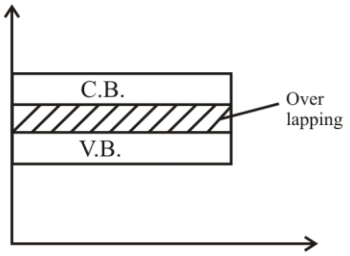
- Insulators are commonly used as a flexible coating on electric wire and cable. Since air is a non-conductor, no other substance is needed to "keep the electricity within the wires".

- In microelectronic components such as transistors and ICs, the silicon material is normally a conductor because of doping, but it can easily be selectively transformed into a good insulator by the application of heat and oxygen. Oxidized silicon is quartz, i.e. silicon dioxide.
- In high voltage systems containing transformers and capacitors, liquid nonconductor oil is the typical method used for preventing sparks. The oil replaces the air in any spaces which must support significant voltage without electrical breakdown.

ii) **Conductor:** The substance which easily allow the passage of electric current through it.

In terms of energy band gap the V.B. and C.B. are overlapping, a slight potential difference across the conductor cause the free e^- to constitute a electric current.

Silver is the best known conductor, but in an oxygen rich environment it tarnishes. Silver is used in specialized equipment, such as satellites, and as a thin plating to mitigate skin effect losses at high frequencies.
As a general conductor copper is the most commonly used on Earth because it's cheap, reasonably flexible, reasonably light and the 2nd best conductor and the best per unit weight. Copper allows for ease of soldered and crimped/clamped connections.



→ Positive temperatureco-efficient**.**Due to overlapping

$R_{(T_1)} = R_{(t0)}[1+\alpha(T_1 - T_0]$

"α" called temperature coefficient measured in "/ºC" and is positive for metals.

Example: $Al = 13 = 2+8+\underset{\mapsto free\ \bar{e}}{3}$

Here are a few common examples of conductors and insulators:

- Silver
- Gold
- Iron
- Brass
- Mercury
- concrete
- copper
- aluminum
- steel
- bronze
- graphite

9) DOPING :

It is the process of adding impurity to the pure semiconductors according to our requirements.

Impurities change the conductivity of the material so that it can be fabricated into a device.

- Group V impurities are called ***Donors***, since they “donate” electrons into the Conduction Band.
  - *Semiconductors doped by donors are called n-type semiconductors.*
- **Acceptor energy levels**
  - Ge: 10 meV
  - Si: 45 – 160 meV
  - GaAs: 25 – 30 meV
  - ZnSe: 80 – 114 meV
  - GaN: 200 – 400 meV
- Acceptor and donor impurity levels are often called ***ionization energies*** or ***activation energies***

If both types of impurities are present :

If the total concentration of donors (N_D) is larger than the total concentration of acceptors (N_A) have an ***n-type semiconductor,*** in the opposite case we have a ***p-type semiconductor***
There are two types of Dopants.

i) **Trivalent impurities:** It is also called acceptor type impurities.

Example: Boron, Aluminum, Gallium, Indium, Telenium for P type.

ii) **Pentavalent impurities:** It is also called Donor type impurities.

Example: Bismuth, Phosphor, Arsenic, Antimony for N type.

Charge Neutrality Equation :

To calculate the charge concentration, the charge neutrality condition is used, since the net charge in a uniformly doped semiconductor is zero

Otherwise, there will be a net flow of charge from one point to another resulting in current flow.

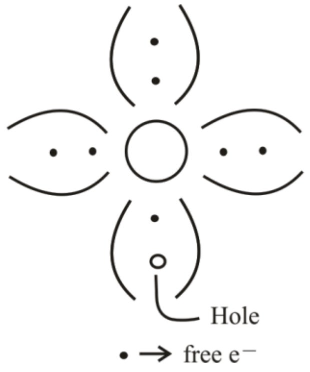
$$p + N_D^+ = n + N_A^-$$

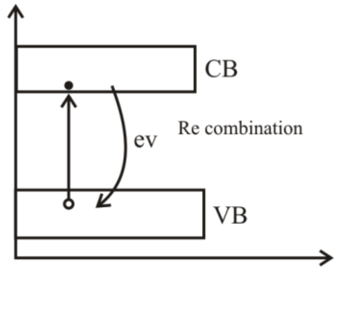
- p is the concentration of holes in the valence band.
- $n$is the electron concentration.
- $N_D^+$is the ionized donor concentration.
- N_A^- is the ionized acceptor concentration.

10) Type of Semiconductor

i) Intrinsic Semiconductor ii) Extrinsic Semiconductor

i) **Intrinsic Semiconductor:** There are pure Semiconductor's in which no impurity is added. At 0ºK it behaves a perfect insulator.





Always present in VB

In intrinsic Semiconductornumbers of e^- = no. of holes = η_i

Where η_i — intrinsic concentration.

e^- and holes always moves in opposite direction but they contributes current in the same direction. So the direction of current is opposite to the flow of e^- but in the same direction of flow of holes. Hole is the charge carrier having q = 1.6×10^{-19} C.

Conductivity: $\sigma = \eta q \mu$ (σ = conductor)

For Semiconductor: $\sigma = nq\mu_e + pq\mu_h$

$$\sigma_i = n_i q(\mu_e + \mu_n)\, mho/cm$$

n = no. of e^- p = no. of holes q = charge

$\mu_e, \mu_h = mobility\ of\ e^-\ \&\ holes$

Where mobility is defined as the ratio of drift velocity to the applied electric field.

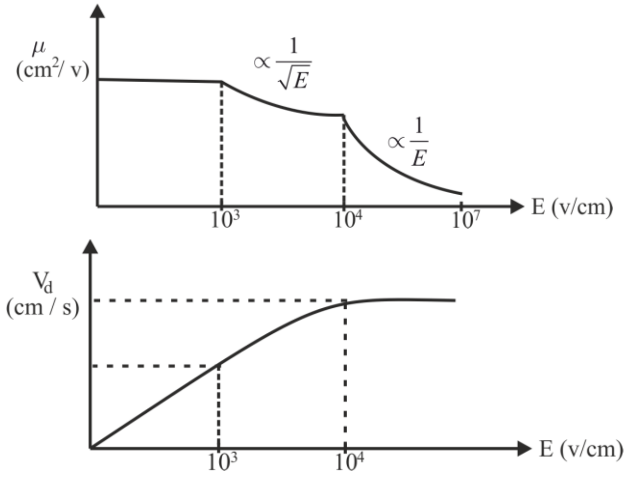
Mobility varies inversely with the temperature as $\mu \propto T^{-m}$, where "m" is an empirical constant.

Mobility v/s applied electric field:

$\because \quad \mu = \dfrac{V_d}{E}$

$\therefore \quad V_d\ v/s$ E groups will be :

The drift velocity first increases linearly,and then sub-linearly and finally becomes saturated with respect to the applied electric field.



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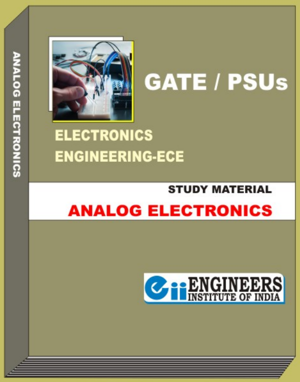
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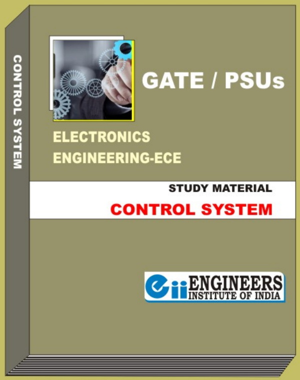
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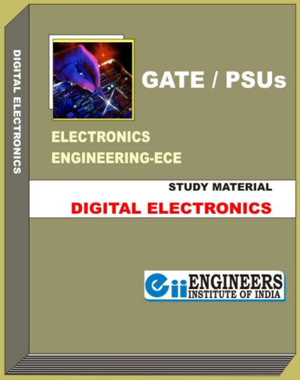
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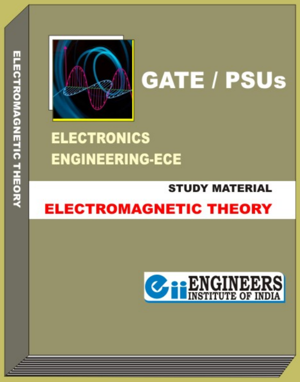
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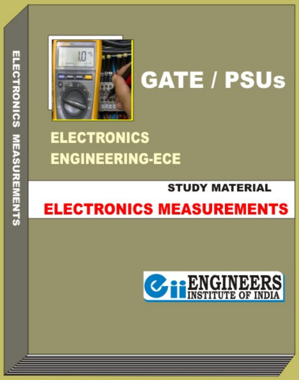
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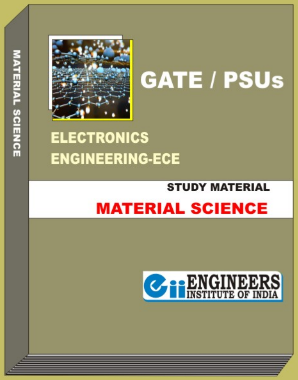
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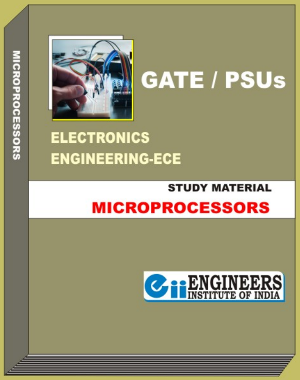
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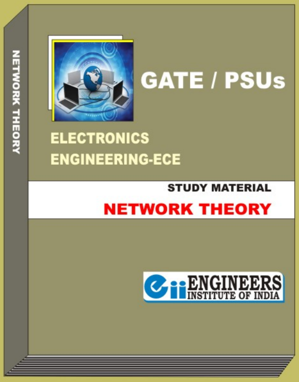
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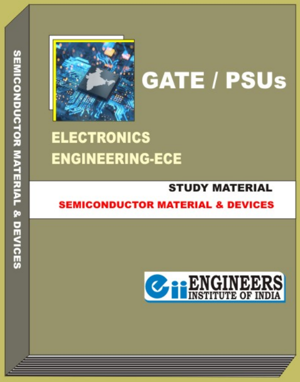
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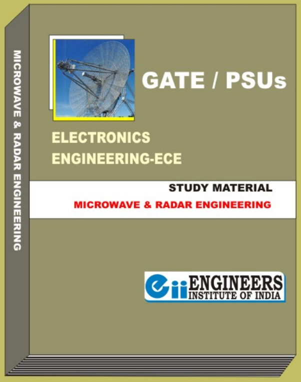
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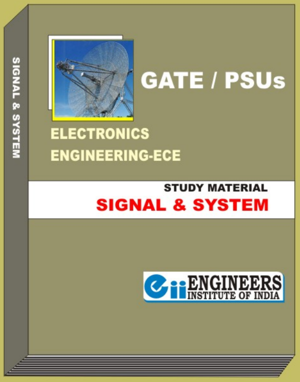
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