14/6/16 Venkat sir

E.D.C UNIT-2

*Electronics: Electronics is a field of science and Engineering which deals with the Electronics devices and their utilisation.

(OR)

Electronics deals with the study of the movement of electrons under the influence of externally applied electric field & magnetic field.

* Electronic devices: A device in which conduction takes place by movement of electrons through vaccum, gas & semi conductor

* Circuit: A set of components arranged in a systematic order is called "Circuit."

*Applications of Electronics:

1. In communication field
   - wired.
   - wireless

2. In defence
   - Radar
   - Guided missiles.

3. In medical
   → X-rays, ECG, SCAN, EG

4. In Instrumentation

(i) CRO → cathode ray oscilloscope.

(ii) DMM → Digital Multimeter.

(iii) Voltmeter

(iv) Powermeter.

5. For Industry

→ Robotics.

6. For Entertainment

→ Radio, TV.

Metric - prefix

10^3 – Kilo – K

10^6 – Mega – M

10^9 – Giga – G

10^{12} – Tera – T

10^{15} – peta – P

10^{18} – Exa – E

10^{-3} – milli – m

10^{-6} – micro – μ

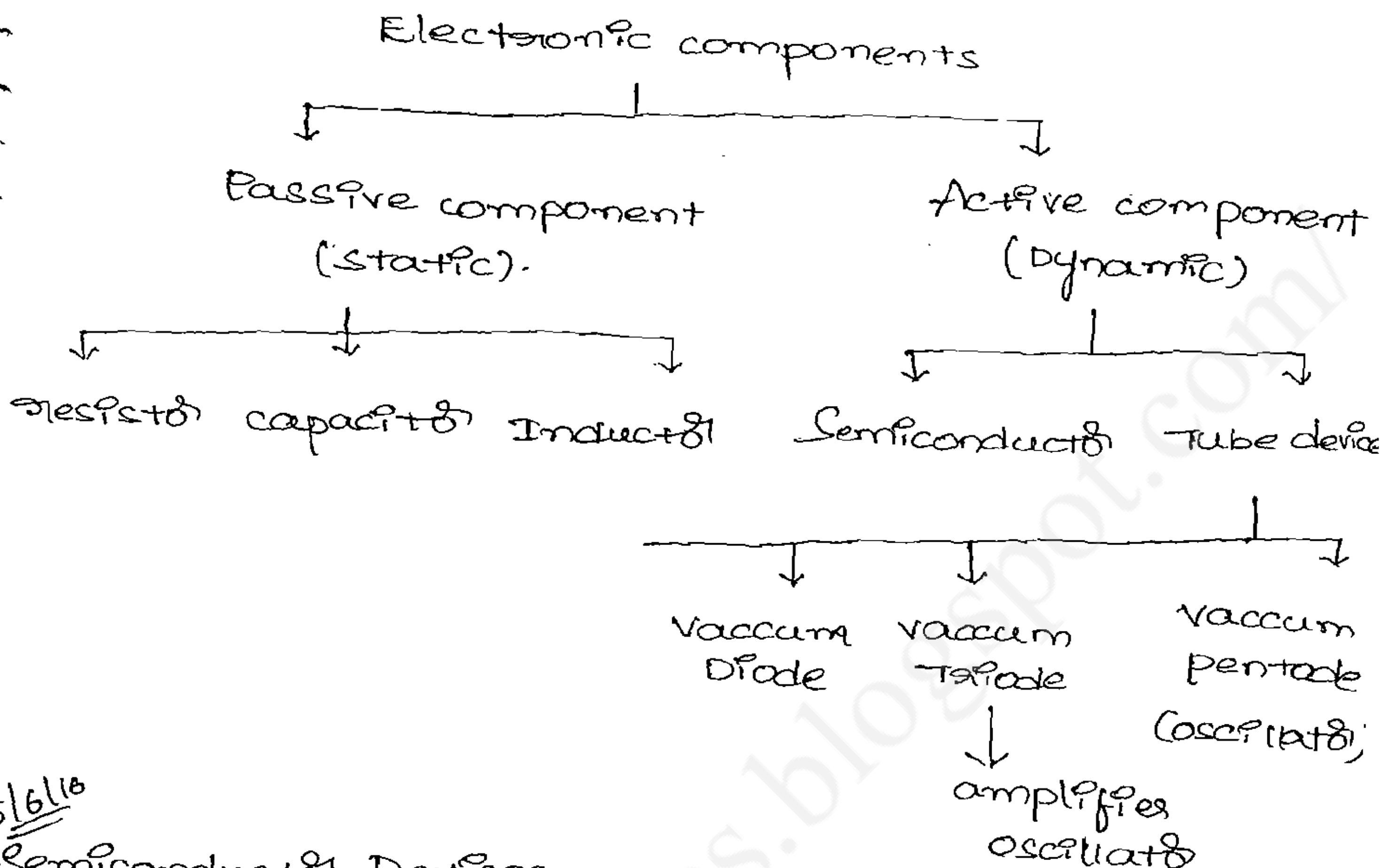
10^{-9} – Nano – n

10^{-12} – pico – p

10^{-15} – Femto – f

10^{-18} – atto – a

* Basic components

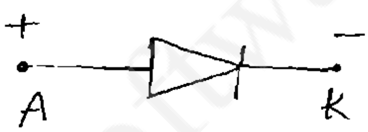


15/6/18

Semiconductor Devices

1. Junction Diode

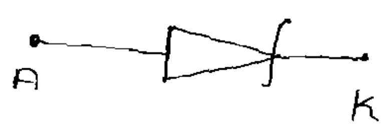
* Symbol :



* Applications: 1. Rectifier
2. Switching circuits.

2. Zener Diode

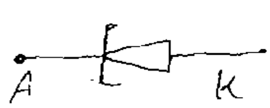
* Symbol:



* Applications: Voltage regulator (which maintain constant DC voltage).

3. Tunnel Diode

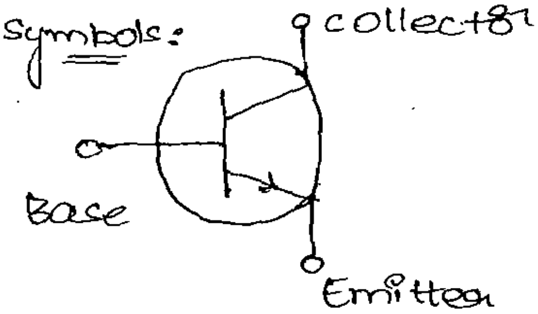
* Symbol :



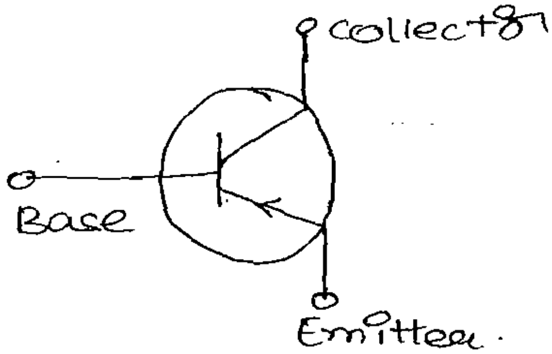
* Applications : Oscillator (without any input it gives output)

4. BJT (Bipolar Junction Transistor).

* Symbols:



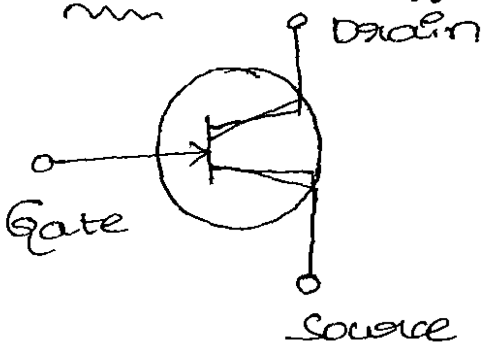
NPN

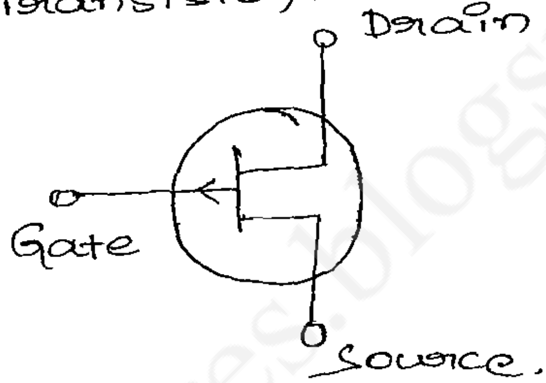


PNP

* Applications: Amplifier, oscillator.

5. FET (Field Effect Transistor).





* Applications: Amplifier, oscillator.

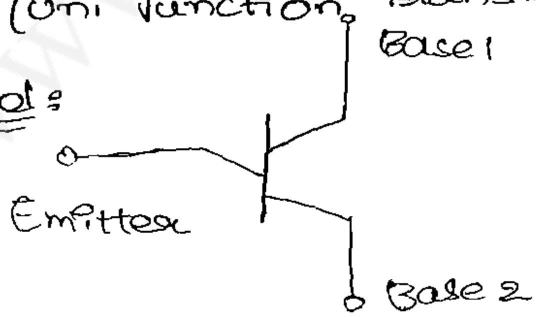
6. SCR (silicon controlled Rectifier).

* symbol:

* Applications: Speed control of motors.

7. UJT (Uni Junction Transistor).

* Symbol:



* Application: power control.

* Resistor

* Which resist the flow of electrons.

(or)

* Flow of charge through any material encounters an opposing force. This opposing force is called the resistance of the material.
* the device of the component to do this is called resistor. It is measured in ohms (Ω).

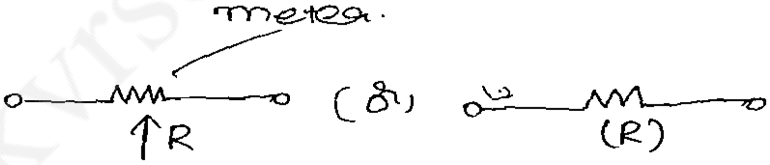
Symbol: 

(i) fixed resistor

(ii) variable resistor

Fixed resistor: It has low voltage. It ranges from few ohms to 22 mΩ.

Variable resistor: Variable resistor is also known as rheostart. In sometimes Electronic circuits is called potentiometer.

Symbol: 

* colour coading $\boxed{\text{BB ROY GB VGW}}$

Colour	Digit	Multiplier	Tolerance.
Black	0	10^0	–
Brown	1	10^1	–
Red	2	10^2	–
Orange	3	10^3	–

Yellow	4	10^4	-
Green	5	10^5	-
Blue	6	10^6	-
Violet	7	10^7	-
Gray	8	10^8	-
White	9	10^9	-
Gold	-	-	$\pm 5\%$
Silver	-	-	$\pm 10\%$
No colour	-	-	$\pm 20\%$

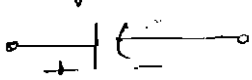
Eg 1 :- 1st band - yellow
2nd band - violet
3rd band - orange - 47×10^3
$= 47$ kilo Ω
5% 47 kilo Ω

2) White, Black, Brown - $90 \times 10^1 = 900\Omega$

3) Red
orange
Orange $\rightarrow 23 \times 10^3 = 23$ kilo Ω
$= \pm 10\%$ 23 kilo Ω
$= 2300\Omega$

Capacitor

It stores the Electrical Energy or Electrons. It is measured in faradays. It blocks the AC components.
DC $\rightarrow$ store



i) Fixed ii) capacitor

16/6/16 **Variable capacitor:** In some circuits such as tuning circuits it is desirable to able to change the value of capacitance. This is done by means of variable capacitor.

The most commonly used variable capacitor is Air-Gang capacitor.

capacitor consists of 2 parts seperated by a insulating material is known as di-Electric. According to the di-electric material the capacitor. They are.

1. Air capacitor
2. paper capacitor
3. mica capacitor.
4. Seramic capacitor.
5. Electrolytic capacitor.
6. plastic film capacitor.

*Definition of capacitance: $C = \frac{Q}{V}$

Where Q = charge on the capacitor

V = applied voltage.

Reactance of the capacitor.

$$X_C = \frac{1}{\omega C}\ \Omega$$

Where $\omega = 2\pi f$

f = frequency.

Series capacitance

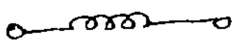
If two capacitors C_1 and C_2 are in series then the resultant capacitance is $\boxed{1/C = 1/C_1 + 1/C_2}$

parallel capacitance: $C = C_1 + C_2$

* **Current in a capacitor**

$$i_C = C \cdot \frac{dv}{dt}$$

Inductor: When a current flows through a wire that has been coiled it generates a magnetic field. This magnetic field react so as to oppose any change in the current. This reaction of magnetic field is known as Inductance. The electronic component producing inductance is called "INDUCTOR".



Air core fixed.

Units are henry's

Inductor
- Fixed
- Variable.

* **Variable Inductor**

Air core variable.

Note: one of the most important property of inductor it opposes sudden changes in current.

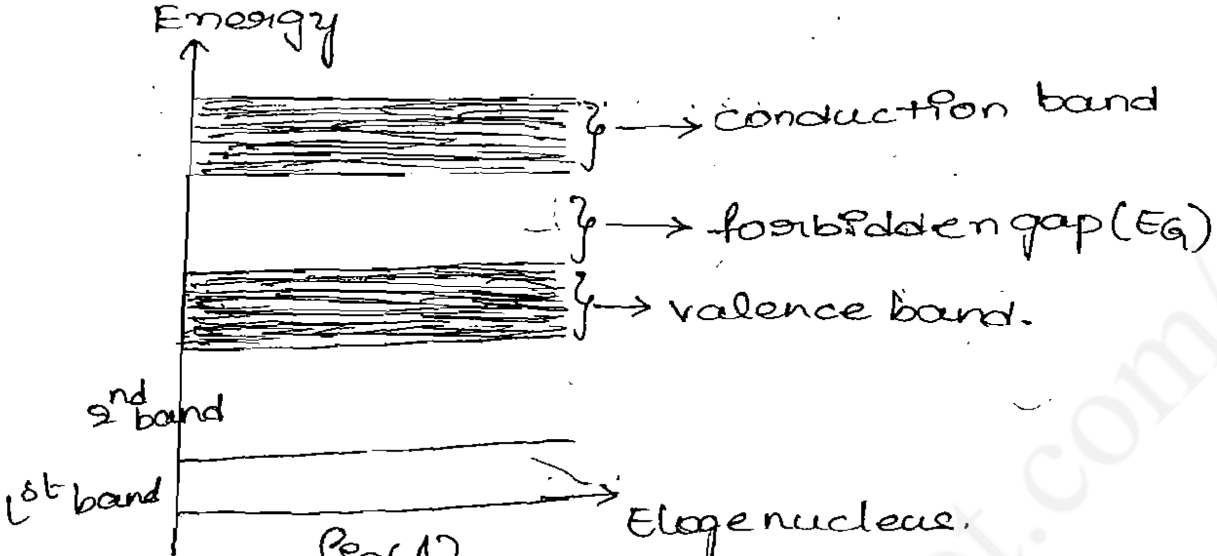
Inductive reactance: $X_L = \omega L\ \Omega$

$\omega = 2\pi f$

f = frequency.

$X_L = 2\pi f L\ \Omega$

17/6/2016 * Energy band diagram



fig(1)

The energy levels of electrons in each orbit merge into each other to form a energy band.

→ The energy levels of valency electrons merged to each other to form a valency band.

→ When a valency electrons absorbs energy it becomes free electron the energy levels of all the free electrons merg into each other to form a conduction band.

→ The energy difference b/w conduction band and VB is called forbidden gap energy denoted by E_G.

→ The graphical representation of energy bands is called energy band diagram as shown in fig(a).

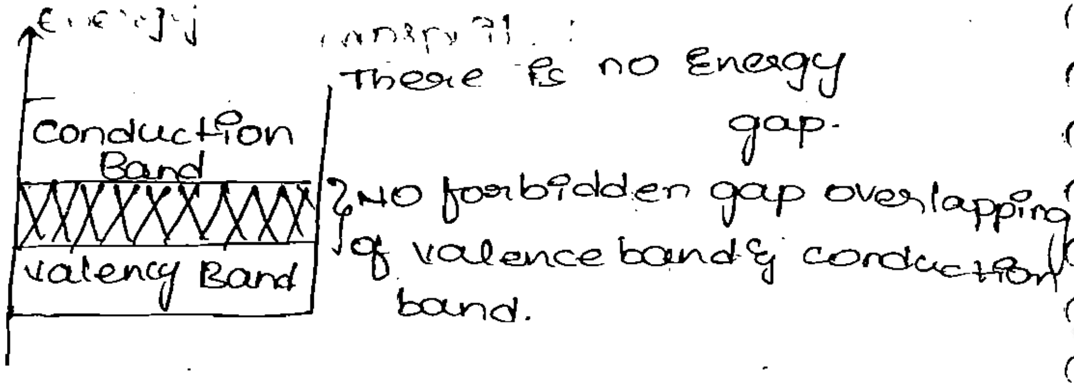
→ E_G measured in the unit electron volt $\boxed{E_G \approx eV}$

Classification of material in the bases of electron conductivity

1. conductors.
2. Insulators
3. Semiconductor,

18/6/16 CONDUCTORS

Def: A metal which is very good carrier of electricity is called conductor



fig(a):- Energy band diagram of conductor.

→ In conductor large no. of free Electrons Exists at normal room temparature so Energy gap E_G does not Exist. The valency band conduction band are overlapped. This is shown in fig(a).

Ex:- copper, Al, Silica etc.

*INSULATOR

Def:- A very poor conductor of Electricity is called "Insulator".

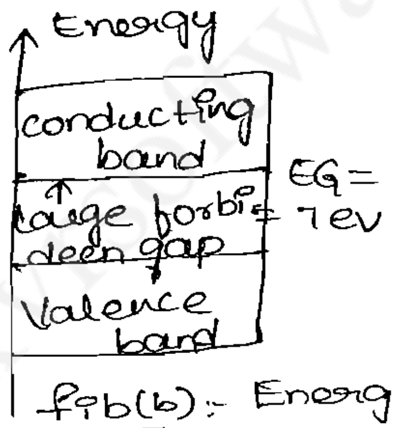


fig b(b):- Energy Band diagram of Insulator.

→ In insulator the Energy gap E_G is very high about seven electron volt ie $\boxed{E_G \simeq 7eV}$ at very high voltage or temparature also the Electrons cannot move from valency band to conduction band. This is shown in fig (b).

Ex:- Wood, Mica, paper etc.

* Semiconductor

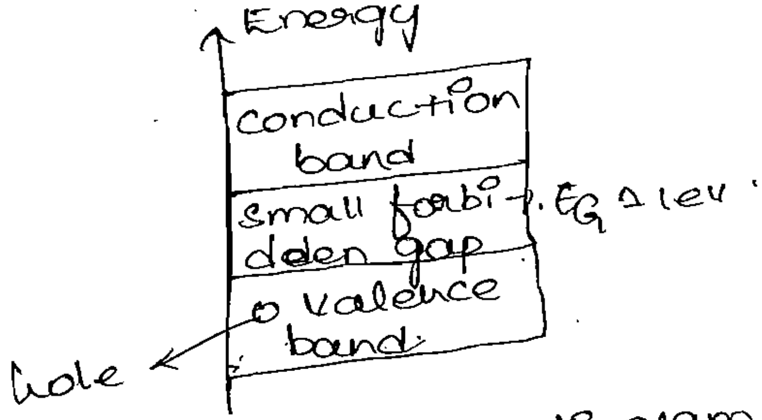


fig (c):- Energy band diagram of Semiconductor

→ A metal having conductivity level somewhere b/w the extremes of an Insulator and conductor ie is Semiconductors.

→ At 0°K the semiconductor materials behaves like perfect Insulator. At room temparature they acts as Insulator.

→ As the temparature increases it acts as a good conductor.

→ In case of semiconductors Energy band gap depends on the temparature

→ For Germanium (Ge) Energy gap (E_G)

$E_G \simeq 0.78eV$

For silicon $E_G \simeq 1.21eV$

For Galium Asimate (GaAs) $E_G \simeq 1.41eV$

These are at 0°K.

* Classification of Semiconductor

1. Intrinsic semiconductor.
2. Extrinsic Semiconductor.

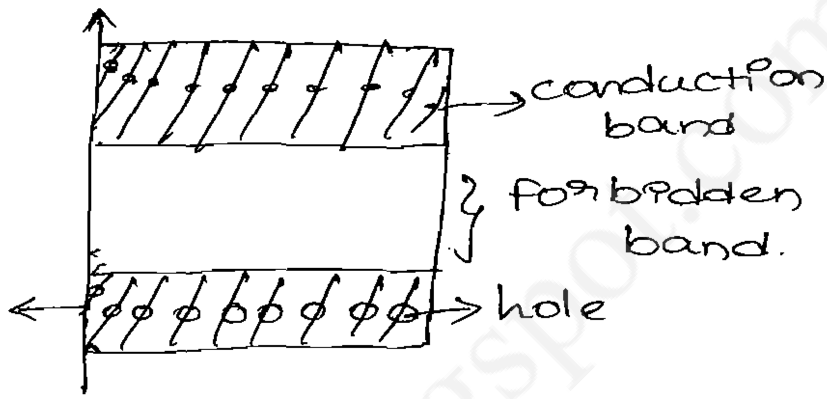
* Intrinsic Semiconductor

→ Pure semiconductors are called Intrinsic semiconductors.

→ The absence of an electron in valency band is represented by a small circle called "hole".

→ Intrinsic semiconductors have equal concentration of electrons and holes under the conditions of thermal equilibrium.

$\boxed{n = p = n_i}$



Extrinsic Semiconductor

In order to change the properties of intrinsic semiconductor a small amount of some other material is added to it. This process of adding other material to the crystal of intrinsic material to improve its conductivity is called doping. Doped semiconductor material is called extrinsic semiconductor.

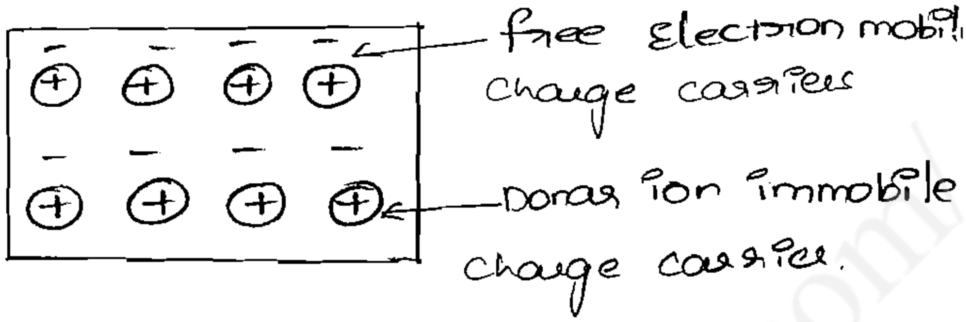
→ There are basically 2 types of impurities.

1. Pentavalent impurity./D/ n-type imp
2. Trivalent impurity./A/ P.

N-type

When small amount of pentavalent impurity is added to the pure semiconductor is called N-type semiconductor.

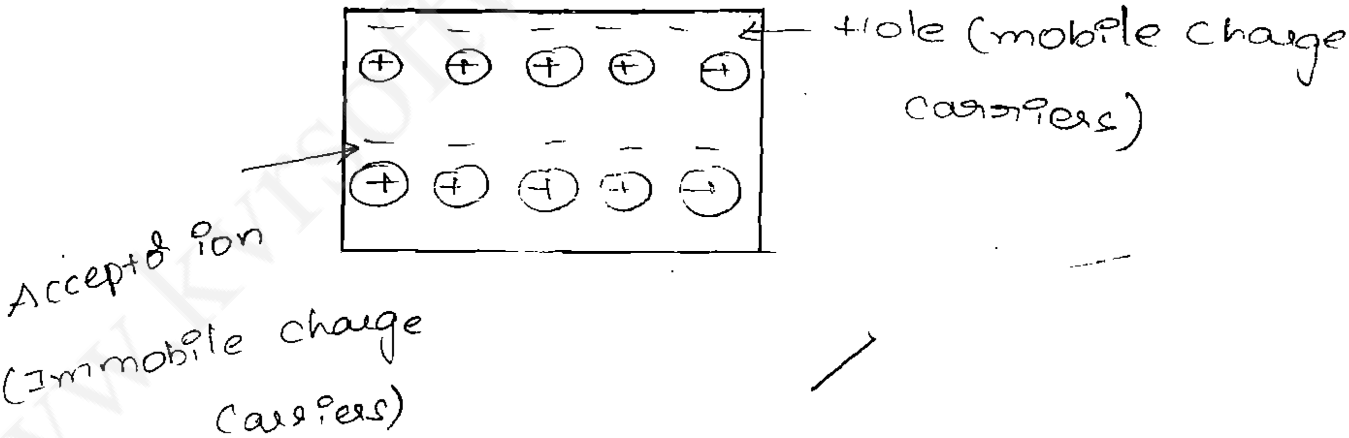
In N-type semiconductor majority charge carriers are electrons minority charge carriers are hole



P-type Semiconductor

When small amount of trivalent impurity is added to pure semiconductor is called p-type semiconductor.

* In p-type semiconductor majority charge carriers are holes and minority charge carriers are Electrons.



Table

*comparision b/w conductor, semiconductor and insulator.

conductor	Semiconductor	Insulator.
A metal which is a good carrier of Electricity. is called "conductor."	A metal having conductivity level b/w the Extremes of an insulator and conductor is known as "S.c."	poor conductor of electricity is known as "Insulator."
It has "1" valency Electrons in its outermost orbit.	It has "4" valency Electrons in its outermost orbit.	It has "8" valency Electrons in its. outermost orbit.
Resistance is very small.	Resistance is high	Resitance is very high
Conductivity is high.	conductivity is medium.	conductivity is Low. (negligible).
As Temparature increases resistance increases and it is +ve ~~pass~~ through Tempar coefficient	As Temp increases its resistance is decreases and it is negative Temparature coefficient.	Negative temparature coefficient.
Ex: metal, copper, Al, Ag etc.	Examples: Silicon, Germanium GaAs etc.	Examples: Wood, plastic, Rubber, mica etc.
conductors are formed by metallic bonding.	S.c are formed by covalent bonding.	Insulators are formed by Ionic bonding.

* Mobility of Semiconductors

When some Electric field applied across through a material of Electrons with avarage velocity is called Drift velocity. respond by moving

$$V_d = \mu \times E$$

E = Electric field

$$\mu = \frac{V_d}{E}, \qquad n_i = p = n.$$

→ The conductivity is proportional to the free electron. of material

→ In s.c the free Electrons lies b/w 10^7 & 10^{28} e/m^3

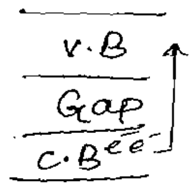
→ S.c acts as Insulator when V.B having Electrons and C.B is Empty. When we increase temparature Some of e⁻ the V.B aquires of thermal energy then > G.E ~~greater~~ the e⁻ directly goes to the C.B.

$$J_n = n \cdot \mu_n \cdot q \cdot E = \sigma_n E \text{ (conductivity of Electron)}$$

μ_n = Mobility of Electrons.

q = Charge of electron

E = Electric field.



The valency band looses e⁻ and having holes (o).

$$J_p = P \cdot \mu_p \cdot q \cdot E.$$

* The mobility of Electron is defined as ratio of drift velocity to Electric field. i.e) $\boxed{\mu = \frac{V_d}{E}}$

→ The current density due to the motion of the Electrons is given by

$$J_n = n \mu_n q E = \sigma_n E \rightarrow (1)$$

where μ_n = Mobility of Electrons

n = no. of Electrons per unit volume

E = Electric field.

q = charge of Electrons

→ The absence of electrons in valency band is represented by a small circle and is called a "hole".

→ The hole may serve as a carrier of Electricity whose effectiveness is comparable with the free Electrons.

→ The hole conduction current density is given by $J_p = p \cdot \mu_p \cdot q \cdot E = \sigma_p E$

where μ_p = hole mobility

p = no. of holes per unit volume

→ Hence the total current density J in a s.c is

$$J = (n\mu_n + p\mu_p) \cdot qE$$

$$= \sigma E.$$

where $\sigma = (n\mu_n + p\mu_p) \cdot q$.

→ For pure semi conductors the no. of free Electrons is equal to the no. of holes.

$\therefore n_i = p = n$.

→ Thus the total current density is $J = n_i(\mu_n + \mu_p) \cdot qE$

$$\boxed{J = n_i (\mu_n + \mu_p) q E}$$

Where $n = p = n_i$,

→ In the intrinsic concentration of a s.c

* conductivity of a semiconductor

→ In pure sc the no. of holes is equal to the no. of electrons.

→ Due to thermal agitation continueax to produ new electron - hole pairs and the electron. hole pair is created to charge carring particles a formed.

→ One is negative which is free electron with mobility μ_n and the another one is positive ie the hole with mobility μ_p.

→ The electrons and holes moving in opposite directions in an electric field E but since they are opposite sign.

→ The current due to each is the same direction.

→ Hence the total current density J with in the intrinsic semiconductor is given by

$$\boxed{J = J_n + J_p}$$

$$J = n(\mu_n) qE + p \cdot \mu_p \cdot qE$$

$$= qE(n\mu_n + p\mu_p)$$

$$J = (n\mu_n + p\mu_p) qE$$

$$= \sigma E \rightarrow (1)$$

Where J_n = Electron drift current density

J_p = hole drift current density.

→ Hence "σ" is the conductivity of a semi conductor which is Equal to

$$\sigma = (n\mu_n + p\mu_p) q.$$

→ The resistivity (ρ) of semiconductor is the resiprocal of a the conductivity ie $\boxed{\rho = \frac{1}{\sigma}}$

→ for pure intrinsic s.c ie $n = p = n_i$ ie

$$J = n_i(\mu_n + \mu_p) q E.$$

→ The conductivity of Intrinsic S.c is

$$\sigma_i = q \cdot n_i \cdot (\mu_n + \mu_p)$$

→ Hence it is a clear the conductivity of an intrinsic s.c depends upon its intrinsic concentration (n_i) and mobility of Electron & holes.

→ conductivity of n and p type s.c

→ The conductivity of an intrinsic s.c

$$\sigma_i = q\, n_i (\mu_n + \mu_p)$$

$$= q \cdot (n\mu_n + p\mu_p) q.$$

→ for n-type semiconductors as $n >> p$ then the conductivity $\boxed{\sigma = q \cdot n \cdot \mu_n}$

→ For p-type s.c as $p >> n$ then the conductivity

$$\sigma = q \cdot n \cdot \mu$$

Problems

1. The mobility of free electrons and holes in pure germanium are 3800 and 1800 $cm^2/v\text{-}s$ the corresponding values for pure silicon are 1300 and 500 $cm^2/v\text{-}s$ respectively. Determine the values of intrinsic conductivity for both germanium and silicon. Assume intrinsic concentration $(n_i) = 2.5 \times 10^{13} cm^{-3}$ for Ge and $n_i = 1.5 \times 10^{10} cm^{-3}$ for Si.

Ans: The intrinsic conductivity for Ge $= q n_i (\mu n + \mu p)$

$$q = 1.602 \times 10^{-19} \text{ columobs}$$

$$= 1.602 \times 10^{-19} \times 2.5 \times 10^{13} cm^{-3} (3800 + 1800) = q$$

$$= 0.0224 \text{ siemens}/cm^2$$

The intrinsic conductivity for si $= q n_i (\mu n + \mu p)$

$$= 1.602 \times 10^{-19} \times 1.5 \times 10^{13} (1300 + 500)$$ p-holes-n

$$= 4.325 \times 10^{-6} \text{ Siemens}/cm^2$$

* Drift current and Diffusion current

The flow of charge ie current through a SC material are 2 types namely

1. Drift (current)
2. Diffusion (current).

The net current flows through a p-n junction diode also has a 2 components

1. Drift current
2. Diffusion current

Drift current (****)

* When an External Electricfield is applied across the Semiconductor material the charge carriers attain certain drift velocity v_d which is equal to the product of mobility of charge carriers and applied Electricfield intensity 'E' ($v_d = \mu \times E$).

* The holes moves towards the -ve terminal of the battery and electrons move towards the +ve terminal of the battery and the combined effect of movement of charge carriers constitutes a current known as "Drift current".

(or)

* The "Drift current" is defined as the flow of Electric current due to the motion of the charge carriers under the influence of an External electric field.

The Equation for the drift current density (J_n) due to the free Electrons is given by

$$J_n = n \cdot q \cdot \mu_n \cdot E \ A/cm^2$$

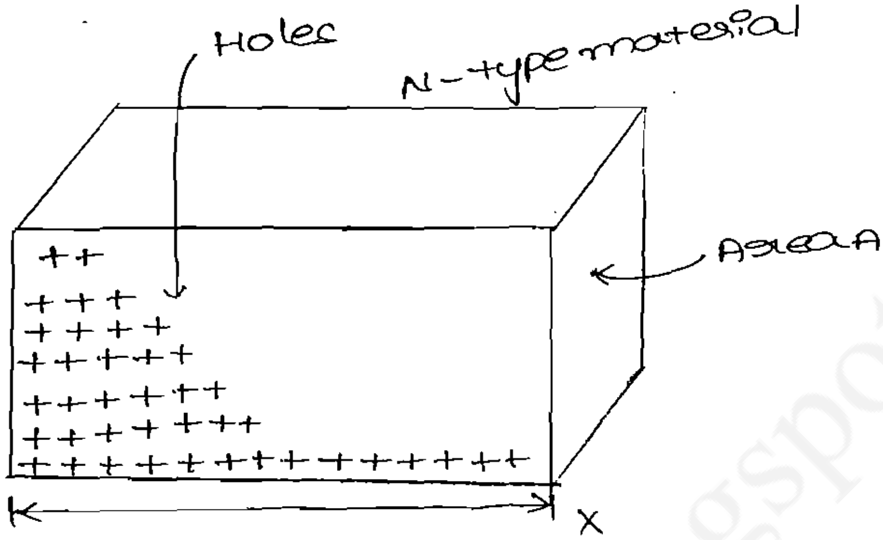
* The eqn for the drift current density (J_p) due to the free Electrons is given by

$$J_p = p \cdot q \cdot \mu_p \cdot E \ A/cm^2$$

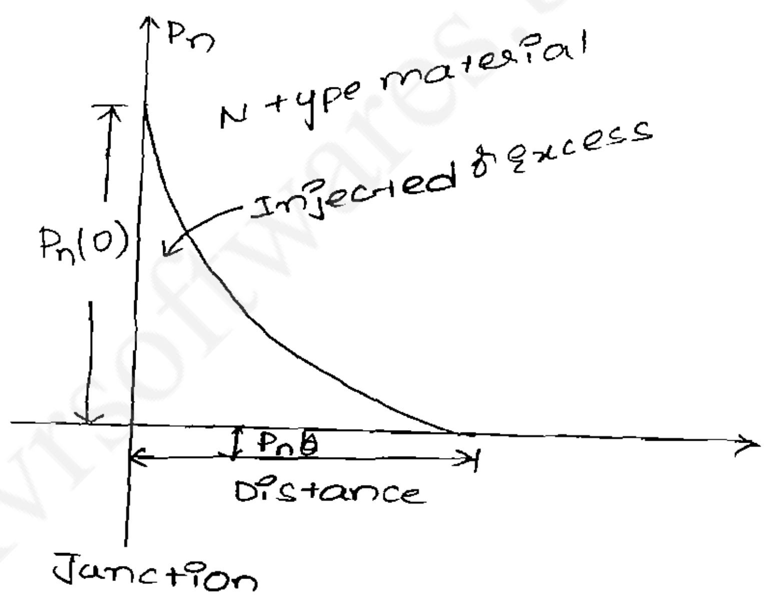
Diffusion current (****)

* It is possible for an Electric current to flow in a SC even in the absence of applied voltage provided concentration gradient exists in the given material.

* A concentration gradient exists if the no. of either electrons & holes is grater in one reagion of semi conductor as compared to the rest of the region.



fig(a) Excess hole concentration.



fib(b) Resulting Diffusion current concentration

* A shown in fig(a) the hole concentration p(x) in a semiconductor bar varies from high value to low values
* Along the x-axis and is constant in y and z direction
* Diffusion current density due holes Jp is given by

$$J_p = -q D_p \frac{dp}{dx} \, A/cm^2$$

* Since hole density p(x) decrease with increasing x

As shown in fig (b) ie $\frac{dp}{dx}$ is negative (-ve).

* Diffusion current density due to the free electron J_n is given by

$$J_n = q\, D_n \frac{dn}{dx} \ A/cm^2$$

where $\frac{dp}{dx}$ and $\frac{dn}{dx}$ concentration gradient for electrons and holes.

* Total Current

* the total current in a SC is the sum of drift and diffusion currents.

* therefore, for a p-type semiconductor the total current per unit area ie the total current density is given by

Drift current for p-type

$$J_p = p \cdot q \cdot \mu_p \cdot E$$

Diffusion current $J_p = -q \frac{dp}{dx} \cdot D_p \ A/cm^2$

$$\therefore J_p = q\left(\mu_p p \cdot E - D_p \frac{dp}{dx}\right)$$

For n-type sc the total current per unit area ie total current density is given by

Drift current $J_n = n \cdot q \cdot \mu_n \cdot E$

$$J_p = -q\, D_n \frac{dn}{dx} \ A/cm^2$$

$$\therefore J_n = q\left(\mu_n n \cdot E - D_n \frac{dn}{dx}\right)$$

*Charge densities in Semiconductor

Under thermal equilibrium for any semiconductor the product of no. of holes and electrons is constant and is independent of the amount of donor and acceptor impurity doping. This relation is known as mass action law and is given by

$$\boxed{n \cdot p = n_i^2}$$

where n is no. of electrons per unit volume
p = no. of holes per unit volume
n_i = intrinsic conc. of S.C.

Charge densities in n-type and p-type semiconductor

*Let ND be the law of mass action as given the relationship between free electron concentration and hole concentration.

⊕ → donor
⊖ → acceptor

→ Let N_D be the concentration of donor atoms in n-type semiconductor in order to maintain electric neutrality of the crystal we have

$$n_N = N_D + P_N$$

$$\boxed{n_N \simeq N_D}$$

Where n_N and P_N are the electron hole concentration of n-type s.c.

The value of P_N is obtained from the relation of mass action law has

$$\boxed{P_N = \frac{n_i^2}{N_D}} \qquad \boxed{P_N = \frac{n_i^2}{n_N}}$$

→ which << n_N & N_D

milarly, p-type semiconductor we have

$$P_p = N_A + n_p$$

$$\boxed{P_p \simeq N_A}$$

Where N_A, P_p and n_p are the concentration of acceptor impurities, holes and electrons respectively in p-type s.c.

→ from mass action law,

$$\boxed{n_p = \frac{n_i^2}{P_p}}$$

$$\boxed{n_p = \frac{n_i^2}{N_A}}$$ which << P_p & N_A.

*Extrinsic conductivity (siemens/cm²) ← units

The conductivity of n-type s.c is given by

$$\sigma_N = q \cdot n_N \mu_n = q N_D \cdot \mu_n \text{; since } \boxed{n_N \simeq N_D}$$

he conductivity of p-type s.c is given by

$$\sigma_p = q \cdot P_p \mu_p = q \cdot N_A \cdot \mu_p \text{, since } \boxed{P_p \simeq N_A}$$

e doping intrinsic s.c consider by α increases ts conductivity.

Problems

Find the conductivity of silicon

i) In intrinsic condition at room temperature of 300K

With donor impurity of 1 in 10^8.

Acceptor Impurity of 1 in 5×10^7.

With both the above impurities present simultaneously

given that n_i for Si at 300K is $1.5\times10^{10}\,cm^{-3}$, $\mu_n = 1300\,cm^2/V.s$

$\mu_p = 500 cm^2/v\text{-}s$, no. of silicon atoms $/cm^3 = 5\times10^{22}$.

1) a) $\sigma_i = q\cdot n_i(\mu_n+\mu_p)$

$= 1.67\times10^{-19}\times1.5\times10^{10}(1300+500)$

$= 4.3254\times10^{-6} S\ cm$

(b) Number of silicon atoms

$= 5\times10^{22}$

$N_D = \frac{5\times10^{22}}{10^8} = 5\times10^{14} cm^{-3}$

$n \simeq N_D$

$P = \frac{n_i^2}{n} = \frac{n_i^2}{N_D} = \frac{(1.5\times10^{10})^2}{5\times10^{14}} = \frac{(1.5)^2\times10^{20}}{5\times10^{14}}$

$= 0.46\times10^6 cm^{-3}$

P<<n Hence p may be neglected calculating conductivity

$\sigma = nq\cdot\mu_n$

$= N_D\cdot q\cdot\mu_n$

$= (5\times10^{14})(1.602\times10^{-19})(1300)$

$= 0.104\ S/cm$

(c) $N_A = \frac{5\times10^{22}}{5\times10^7}$

$= 10^{15} cm^{-3}$

further $P = N_A$

$n = \frac{n_i^2}{P} = \frac{n_i^2}{N_A}$

$= \frac{(1.5\times10^{10})^2}{10^{15}}$

$= 2.25\times10^5 cm^{-3}$

P >> n, n may be neglected

$\sigma = P\cdot q\cdot\mu_p = N_A\cdot q\cdot\mu_p$

$= (10^{15}\times1.602\times10^{-19}\times500)$

$= 0.08\ S/cm$

(d) $N_A' = N_A - N_D = 10^{15} - 5\times10^{14}$

$= 5\times10^{14} cm^{-3}$

$\sigma = N_A'\cdot q\cdot\mu_p$

$= (5\times10^{14})(1.602\times10^{-19})500$

$= 0.04\ S/cm$.

2) A sample of silicon at given temp in intrinsic S.C as a resistivity of $25 \times 10^4 \Omega/cm$ (Ω-cm). The sample is now doped to the extent of 4×10^{10} donar atoms/cm^3 and 10^{10} acceptor atoms/cm3. Find the total conduction current density if an Electric field of 4v/cm is applied across the sample given that mobility of Electrons (μ_n) = 1250 cm^2/v-s and Mobility of holes (μ_p) = 475 cm^2/v-s at the given temparature.

$$\sigma_i = q \cdot n_i (\mu_n + \mu_p)$$

$$= \frac{1}{25 \times 10^4}$$

$$\therefore n_i = \frac{\sigma_i}{q(\mu_n + \mu_p)}$$

$$= \frac{1}{(25 \times 10^4)(1.602 \times 10^{-19})(1250 + 4750)}$$

$$= 1.45 \times 10^{10} cm^{-3}$$

Net donor density $N_D = n$

$$= 4 \times 10^{10} - 10^{10} = 3 \times 10^{10} cm^{-3}$$

$$P = \frac{n_i^2}{N_D} = \frac{(1.45 \times 10^{10})^2}{3 \times 10^{10}} = 0.7 \times 10^{10} cm^{-3}$$

$$\sigma = q(n\mu_n + P\mu_p)$$

$$= (1.602 \times 10^{-19})(3 \times 10^{10} \times 1250 + 0.7 \times 10^{10} \times 475)$$

$$= 6.532 \times 10^{-6} S/cm$$

$\therefore$ Total conduction current density,

$$J = \sigma E$$

$$= 6.532 \times 10^{-6} \times 4$$

$$= 26.128 \times 10^{-6} A/cm^2$$

→ the current entering the volume at x is I and leaving at x+dx is I+dI, The no.of columbs/sec.

(i) Decreases with in the volume = dI → (1)

→ Decreadue to the recombination, no of columbs/ decreases with in the volume is given by

= (charge on hole) x (holes/sec per unit volume) x (volume

$$= q \times P/\tau_p \times Adx = qAdx \frac{P}{\tau_p} \longrightarrow (2)$$

Let "g" is the rate at which Electron hole pair are generated by thermal generation per unit volume.

→ Due to this no.of columbs/sec increases with in the volume = (Charge on hole) x (Rate of combination) x (volume)

$$= q \times g \times Adx = qg\,Adx \longrightarrow (3)$$

→ The total charge in no.of columbs/see is because of 3 factors as indicated by the equations 1,2,3.

→ The total charge in holes/unit volume per sec is $\frac{dP}{dt}$. Hence the total charge in columbs/sec with in the given volume = $q \cdot \frac{dp}{dt}$ (volume)

$$= q \cdot Adx \cdot \frac{dP}{dt} \longrightarrow (4)$$

→ According to law of conservation of charges

$$q \cdot Adx \frac{dp}{dt} = qgAdx - qAdx\frac{p}{\tau_p} - dI \longrightarrow (5)$$

Note: the -ve sign indicate decrease while +ve indicates increases in no.of columbs/sec.

$$qA\,dx\,\frac{dp}{dt} = qA\,dx\left(g-\frac{p}{\tau_p}\right) - dI$$

$$\frac{dp}{dt} = \frac{-p}{\tau_p} + g - \frac{dI}{qA\,dx} \longrightarrow (6)$$

But current density $(J) = \frac{I}{A} \Rightarrow J = \frac{I}{A}$

$I = JA$ ie $dI = A\,dJ$ as A is constant.

Sub $dI = A\,dJ$ in (6)

$$\frac{dp}{dt} = \frac{-p}{\tau_p} + g - \frac{A\,dJ}{qA\,dx} \longrightarrow (7)$$

The total current density J is due to drift and diffusion currents.

$$J = \underbrace{-q\,D_p\frac{dp}{dx}}_{\text{Diffusion}} + \underbrace{pq\,\mu_p E}_{\text{Drift currents.}} \longrightarrow (8)$$

If the semiconductor is in the thermal equilibrium and subjected to know external electric field then whole density will attain a constant value P_o under this condition $I=0$ ie $J=0$ and $\frac{dp}{dt}=0$ due to equilibrium

Sub these values in Equ (7)

$$0 = -\frac{P_o}{\tau_p} + g - 0 \text{ ie } \boxed{g = \frac{P_o}{\tau_p}} \longrightarrow (9)$$

The equation (9) indicates thermal equilibrium that is the rate at which wholes are thermally generated just equal to the rate at which holes are lost due to the recombination. using equn (8), (9) in (7)

$$\frac{dp}{dt} = \frac{-p}{\tau_p} + \frac{P_o}{\tau_p} - \frac{d\left(-q\,D_p\frac{dp}{dx} + pq\,\mu_p E\right)}{qA\,dx}$$

$p \ll n$, p is neglected.

$\therefore \sigma = e N_D \mu_n$

$= (1.602 \times 10^{-19})(4.2 \times 10^{22})(0.38)$

$= 2.554 \times 10^{3}\ S/m$

$\therefore$ resistivity $\rho = \frac{1}{\sigma}$

$= \frac{1}{2.554 \times 10^{3}}$

$= 0.392 \times 10^{-3}\ \Omega\text{-}m$

Resistance $R = \frac{\rho L}{A}$

$= \frac{0.392 \times 10^{-3} \times 5 \times 10^{-3}}{(5 \times 10^{-6})^{2}}$

$= 78.4\ K\Omega$

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* Hall effect (***)

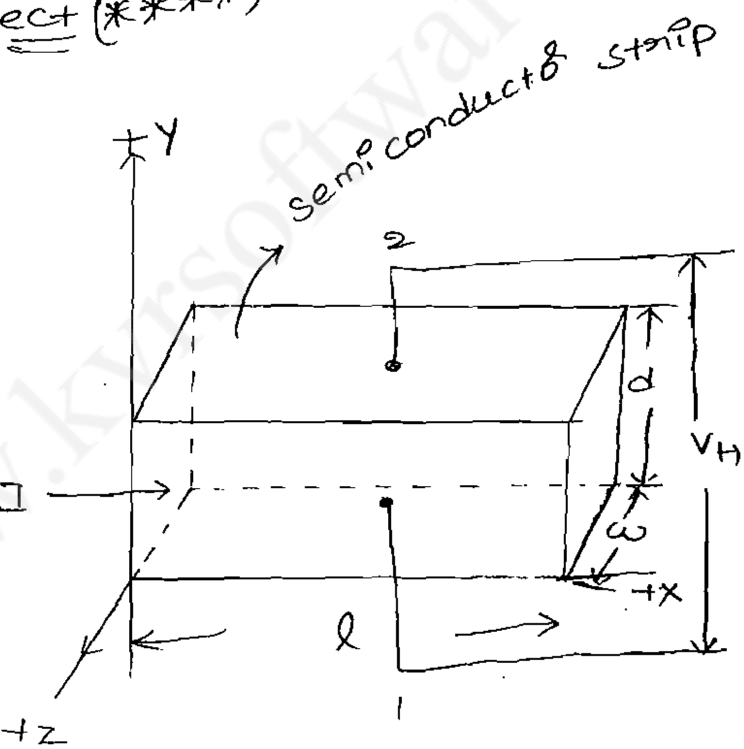


fig (a) Hall effect

(3) A semiconductor of pure germanium at 300K as a density of charge carriers $2.5\times10^{19}/m^3$ it is doped with donor impurity atoms at the rate of one impurity atom every 10^6 atoms of germanium. All impurity atoms are supposed to be ionised the density of germanium atom is 4.2×10^{28} atoms$/m^3$. Calculate the resistivity of the doped germanium if the electron mobility is $0.38\ m^2/V\text{-}sec$ If the ge bar is 5×10^{-3}m long and has a cross sectional area of $(5\times10^{-6})^2\ m^2$. Determine its resistance and voltage drawn across the S.C bar for a current of 1 microamperes a flow through it.

Sol:- Density of added intensity atom is

$$N_D = \frac{4.2\times10^{28}}{10^6}$$

$$= 4.2\times10^{22}\ \text{atoms}/m^3$$

$$n \simeq N_n$$

$$P = \frac{n_i^2}{n}$$

$$= \frac{n_i^2}{N_D}$$

$$= \frac{(2.5\times10^{19})^2}{4.2\times10^{22}}$$

$$= 1.488\times10^{16}\ m^{-3}$$

$P << n$, P may be neglected.

$$\therefore \sigma = e N_D \mu_n$$

$$= (1.602\times10^{-19})(4.2\times10^{22})(0.38)$$

$$= 2.554\times10^{3}\ S/m$$

* If a metal or semiconductor carrying a current 'I' is placed in a transverse magnetic field 'B', an Electric field 'E' is induced in the direction ⊥ to both current and magnetic field and this phenomenon is known as "Hall effect".

* Consider a semiconductor strip carrying current 'I' as shown in fig(a) is the positive x-direction and 'B' is in the positive z-direction, a force will be exerted in the -ve y-direction on the current carriers.

* If a semiconductor is n-type so that the current is carried by electrons these electrons will be forced downward towards side 1 and in fig (a) and side 1 becomes negatively charged w.r.to side 2.

* Thus there exists a potential difference across the side 1 and side 2 this voltage is called "Hall voltage" denoted by "V_H".

* In the equilibrium condition the electric field intensity due to the hall effect must exert force on the carrier which just balances the force exerted by the magnetic field.

$$+qE = Bqv$$

$$E = Bv \longrightarrow (1)$$

Where q = Magnitude of the charge on the carrier

v = Drift speed.

Now $E = \frac{V_H}{d} \longrightarrow (2)$

$V_H = E \cdot d \longrightarrow (2)$

Where d = distance b/w the side 1 and side 2

* the current density J is given by

$$J = \frac{I}{wd} \, A/m^2 \longrightarrow (3)$$

* While the current density can be expressed in terms of charge density as

$$J = \rho v \longrightarrow (4)$$

Where ρ = charge density in cm/m^3

v = speed in m/s

and

w = width of the strip in direction of B.

Equating Eqn (4) and (3), we get

$$\rho v = \frac{I}{wd} \Rightarrow v = \frac{I}{\rho wd}$$

$$\therefore V_H = Ed = Bv \cdot d$$

$$= B \cdot \frac{I}{\rho \cdot w \cancel{d}} \cdot \cancel{d}$$

$$\Rightarrow \boxed{V_H = \frac{BI}{\rho w}} \longrightarrow (5)$$

* Applications of Hall effect

→ Hall effect is used to determine wheather sc is n-type or p-type and to find out the carrier concentration.

→ To measuring the conductivity (σ) and mobility (μ) can be calculated.

* Measurement of Mobility and Conductivity

→ If the polarity of V_H is such that the surface to is -ve then carriers are electrons and we can write $\rho = n \cdot q \rightarrow$ (6)

$p = p \cdot q \rightarrow$ (7)

If side 2 is positive and we can write it as

$\rho = p \cdot q \rightarrow$ (7)

* practically a constant R_H is called Hall coefficient is defined as

$$R_H = \frac{1}{n \cdot q} = \frac{1}{\rho} \rightarrow (8)$$

Substitue Eqn (8) in Eq (5)

$$V_H = \frac{B I R_H}{\omega}$$

$$\boxed{R_H = \frac{V_H \omega}{B I}} \rightarrow (9)$$

* the conductivity σ for Extrensic semiconducti is given by

$$\sigma = n \cdot q \cdot \mu$$

$$\sigma = \frac{\mu}{R_H}$$

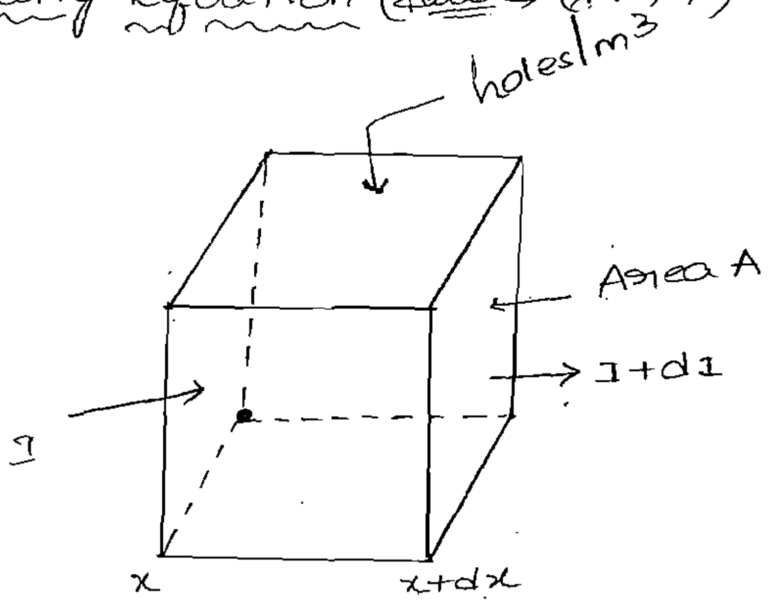
$$\boxed{\mu = \sigma R_H}$$

$$\boxed{\mu = \sigma \frac{V_H \omega}{B I}}$$

$$\sigma = \text{conductivity} = \frac{1}{\text{Resistivity}}$$

$$\boxed{\therefore \mu = \frac{1}{\text{Resitivity}} \times \frac{V_H \omega}{B I}}$$

25/01/18 *Continuity Equation (Repeat) (*****)



fig(a) Relating to the conservation of charge

$\tau_p \rightarrow$ mean life time period of hole. P/τ_p

* The carrier concentration in the body of a SC is a function of time and distance mathematically a partial differential equation governs this functional relationship b/w carrier concentration, time and Distance (x) such an Equation is called "continuity Equation".

→ This equation based upon the fact that charge can be neither created nor destroyed.

→ consider the infinitesimal element of volume of Area(A) and length dx as shown in fig(a) the average hole concentration is P.

→ If τ_p is mean life of time of the holes then P/τ_p Equal the holes/sec losted by recombination per unit volume.

→ In general the current will vary with distance within semiconductor if as indicated in fig(a).

$$\frac{dp}{dt} = \frac{1}{\tau_p}(P_0 - P) + \frac{1}{q}\left[q D_p \frac{d^2}{dx^2} P - \mu_p q \frac{dPE}{dx}\right]$$

(18)

$$\boxed{\frac{dp}{dt} = \frac{P_0 - P}{\tau_p} + D_p \frac{d^2 P}{dx^2} - \mu_p \frac{dPE}{dx}} \longrightarrow (10)$$

This is called Equation of Conservation of charge & continuity Equation.

As holes in ~~Entire~~ n-type material are considere let us use the suffix n as concentration is a function of both time and distance. Let us use partial differentiation hence the final continuity Equation takes the form of

$$\boxed{\frac{\partial P_n}{\partial t} = \frac{(P_n - P_{no})}{\tau_p} + D_p \frac{\partial^2 P_n}{\partial x^2} - \mu_p \frac{\partial (P_n E)}{\partial x}} \longrightarrow (11)$$

Similarly the continuity Equation for Electrons in p-type material can be written as

$$\boxed{\frac{\partial n_p}{\partial t} = \frac{-(n_p - n_{po})}{\tau_n} + D_n \frac{\partial^2 n_p}{\partial x^2} - \mu_p \frac{\partial (n_p E)}{\partial x}} \longrightarrow (12)$$

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Concentration independent of distance and Electric field

$E = 0$

The Equation reduced as the concentration is not dependent on x and Electric field $E=0$ is

$$\boxed{\frac{dP_n}{dt} = \frac{-(P_n - P_{no})}{\tau_p}}$$

where $\boxed{P_n - P_{no} = K \exp^{-t/\tau_p}}$

Concentration independent of time and Electric field E=0

The Equation reduced as the concentration is not dependent on x and E=0

$$0 = -\frac{(P_n - P_{n0})}{\tau_p} + D_p \frac{\partial^2 P_n}{\partial x^2}$$

$$D_p \frac{\partial^2 P_n}{\partial x^2} = \frac{P_n - P_{n0}}{\tau_p}$$

$$\frac{\partial^2 P_n}{\partial x^2} = \frac{(P_n - P_{n0})}{D_p \tau_p}$$

$$= \frac{P_n - P_{n0}}{L_p^2}$$

Where $\sqrt{D_p \tau_p} = L_p$ = Diffusion Lenght of holes.

* Problems on Hall effect

1) A n-type silicon ball whose resistivity is 1000Ω-m and width 1cm is used in the hall effect Experiment if the current in the bar is 100μA and the hall voltage is 40mV. What is the intensity 'B' of the applied magnetic field. Assume μn(mobility of e^-) = 1300 cm²/V-s.

Ans:- resistivity = 1000Ω/m×100

d = 1cm = 10×10⁻² m/cm

I = 100μA.

V_H = 40mV.

μ_n = 1300 cm²/V-S

$$\boxed{\mu = \frac{1}{\text{Resistivity}} \times \frac{V_H w}{BI}}$$

$$1300 = \frac{1}{1000\times10^{2}} \times \frac{40\times10^{-3}}{10\times10^{-6}\times B}$$

$$B = \frac{10^{-3}\times40\times10^{-3}\times1\times10^{-2}}{1300\times10^{-2}\times10\times10^{-6}}$$

$$\boxed{B = 0.3077\ \text{wb}/m^2}$$

(4) A n-type silicon ball whose resistivity 1000Ω-m and width 1cm is used hall effect Experiment if the current in the ball is 100μA and the hall voltage is 40mV. what is intensity 0.3077 wb/m² and also find out hall effect.

<u>Ans</u>:- Resistivity = 1000Ω-m

$w = 1cm$

$V_H = 40mV = 40\times10^{-3} V$

$I = 10\mu A = 10\times10^{-6} A.$

$$\boxed{\sigma = \frac{1}{\text{Resistivity}} = \frac{1}{1000}}$$

$$R_H = \frac{40\times10^{-3}\times1\times10^{-2}}{0.3077\times10\times10^{-6}}$$

$$= \frac{4}{0.3077}\times\frac{10^{-4}}{10^{-5}}$$

$$= \frac{40}{0.3077}$$

$$= 129.996$$

$$\boxed{\therefore R_H = 130}$$

3) The conductivity of N-type SC is 10 simal/meter and Electron mobility is $50\times10^{-4} m^2/v\text{-}s$. Determine the Electron concentration.

Ans:- conductivity = 10 simal/meter. (σ)

mobility = $50\times10^{-4}\ m^2/v\text{-}s$.

$$\boxed{\sigma = q \cdot n \cdot \mu n}$$

$$10 = q \cdot 1.602\times10\times50\times10^{-4}$$

$$q = \frac{10}{1.602\times10^{-19}\times50\times10^{-4}} = \frac{10^{23}}{0.8010}$$

$m3$

$$\boxed{q = 1.24\times10^{22}\, m^{-3}}$$

4) A current of 20amperes is passed through a thin metal strip which is subjected to a magnetic flux density of 1.2 web/m². The magnetic field is directed perpendicular to the current. The thickness of strip in the direction of magnetic field is 0.5mm. The hall voltage is 60volts. find the Electron density.

A: $I = 20A$

$B = 1.2\ web/m^2$

$V_H = 60$ volts

$M.F = 0.5mm$

$$\boxed{n = \frac{BI}{V_H \cdot q\, W}}$$

$$= \frac{1.2\times20}{60\times1.602\times10^{-19}\times0.5\times10^{-3}} = 5\times10^{21} m^3$$

$$= 4.993\times10^{21} m^3$$

⑤ An Entire semiconductor has hall volt coefficient of $200 cm^3$ and its conductivity is 10 simens/m. find its electron mobility.

Ans:- $\Rightarrow R_H = \frac{1}{nq} = \frac{1}{\rho}$

$R_H = 200 cm^3$

$= 200 \times 10^{-6}$

$\Rightarrow \boxed{\mu = \sigma R_H}$

$= 10 \times 200 \times 10^{-6}$

$\boxed{\mu = 2000 \; cm^2/V\text{-}s}$

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⑥ Fermi Derac Function

→ In Energy band diagram probability that Energy level is occupied by an Electron is given by fermi probability function denoted as F(E) it is given by the Expression $F(E) = \frac{1}{1 + e^{-(E-E_F)/KT}}$

Where K = Boltzman's constant in ev/°K.

T = Temparature in °K.

E_F = fermi level.

E = Energy level occupied by an Electron in eV.

Fermi level in Intrinsic Semiconductor

Representation of fermi level in intrinsic semiconductor.

→ In Intrinsic Semiconductor the probability of finding an Electron in conduction band is zero.

→ The probability of finding a hole in valence is zero at 0°k ie T = 0°K.

→ Now, let E_c be the lowest Energy level in the conduction band while E_v be the highest Energy level in valency band.

→ As temperature increases equals no. of Electrons holes are generated. Hence probability of finding electron in conduction band and finding a hole in valency band is same.

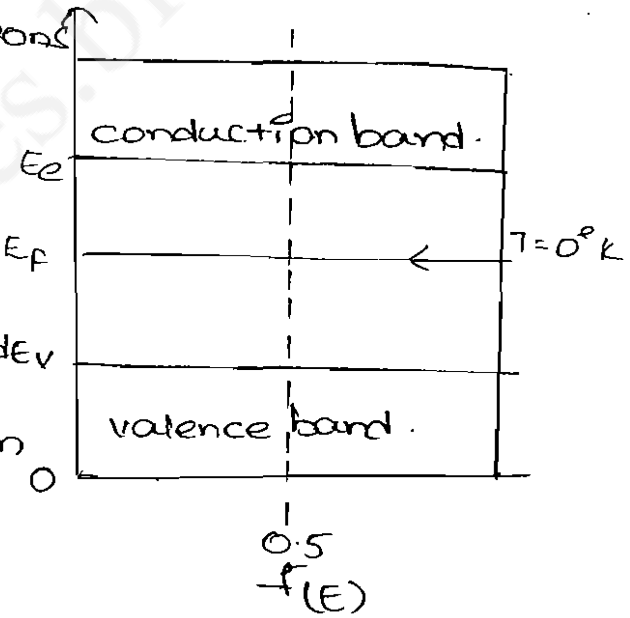
$$\boxed{\therefore E_F = \frac{E_C + E_V}{2}}$$

→ Thus in the Energy band diagram the fermi level the intrinsic semiconductor lies at the centre of the forbidden Energy band.

→ The concentration of Electrons in the conduction is given by

$$n = N_C e^{-(E_C - E_F)/KT} \longrightarrow ①$$

where N_C = effective density of Electrons in conduction band



→ The concentration of holes in the valence band is given by

$$p = N_V e^{-(E_F - E_V)/KT} \longrightarrow ②$$

where N_V = Effective density of holes in valency band

→ In intrinsic semiconductor the $n = p = n_i$

so, Equating Equn's ① & ②

$$N_C e^{-(E_C - E_F)/KT} = N_V e^{-(E_F - E_V)/KT}$$

$$\frac{N_C}{N_V} = \frac{e^{-(E_F - E_V)/KT}}{e^{-(E_C - E_F)/KT}}$$

$$\frac{N_C}{N_V} = e^{-(E_F + E_V + E_C - E_F)/KT} \longrightarrow (3)$$

Taking natural "log" on both sides.

$$\ln \frac{N_C}{N_V} = \frac{-2E_F + E_C + E_V}{KT}$$

$$E_F = \frac{E_C + E_V}{2} - \frac{KT}{2} \ln \frac{N_C}{N_V}$$

* In intrensic semiconductor $N_C = N_V$

$$\boxed{\therefore E_F = \frac{E_C + E_V}{2}}$$

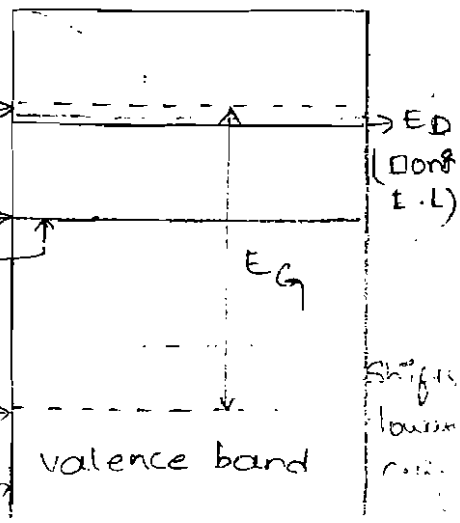
Fermi level in Extrensic semiconductor

→ In an extrensic semiconductor it is not only the holes and electrons which have charge but ionised impurity atoms (donor, acceptor) are also present and they too are charged. Let N_D be the equal concentration of donor atoms. If P is the no. of holes in semiconductor then the total +ve charge density $N_D + P$. Similarly if N_A is the concentration of acceptor ions and the no. of electrons is 'n'. Then the total charge density is $N_A + n$.

* Since the semiconductor is electrically neutral ie

$$\boxed{N_D + P = N_A + N}$$

* In N-type semiconductor donor impurity is added due to this large no. of electrons get created in conduction band. The donor energy level corresponding to donor impurity gets introduced which



is indicated as E_D and is very close to the conduction band gets below it.

* Concentration of Electrons is given as

$$\boxed{n = N_C\, e^{-(E_C - E_F)/KT}}$$

* In N-type material $n \simeq N_D$ so $N_D = N_C \cdot e^{-(E_C-E_F)/KT}$

$$\frac{N_D}{N_C} = e^{-(E_C-E_F)/KT}$$

Taking 'log' on both sides.

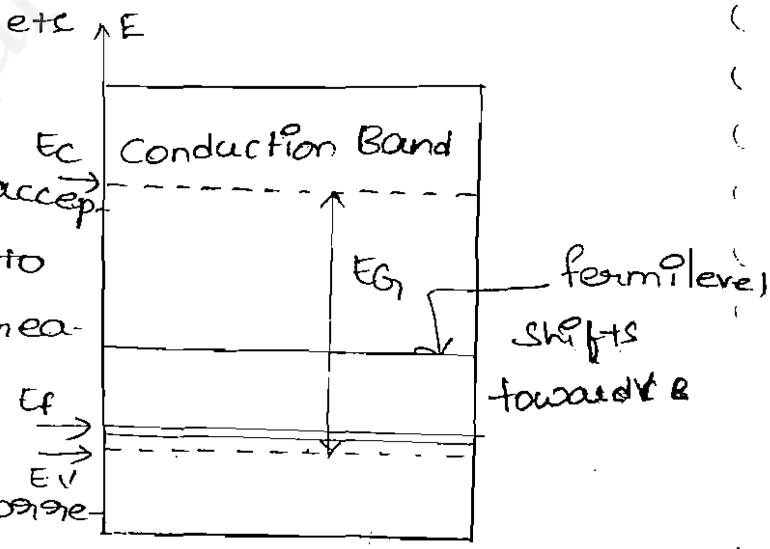
$$\ln \frac{N_D}{N_C} = -E_C + E_F / KT$$

$$\boxed{E_C - E_F = KT \ln \frac{N_C}{N_D}}$$

$$\boxed{E_F = E_C - KT \ln \frac{N_C}{N_D}}$$

* In N-type fermi level lies gets below the conduction band.

* In P-type Semiconductor acceptor impurity is added due to this large no. of holes are created in valency band.



* The acceptor Energy level corresponding to acceptor impurity gets introduced which is indicated as E_A and is very close to the valency band gets below it.

* Concentration of holes is given as $p = N_V e^{-(E_F - E_V)/KT}$

In p-type material $p \approx N_A$