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EDC

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19|05|2011

Thermal voltage:

"volt equivalent of Temp"

where Temp. in terms in volts

$$V_T = \frac{\bar{K}T}{q} \text{ volts}$$

T = Temp. in kelvin

q = charge 1.6×10^{-19} C

$\bar{K}$ = Boltzmen's constant (1.38×10^{-23} J/deg kelvin)

K and $\bar{K}$ both are Boltzman's constant

$K = 8.62 \times 10^{-5}$ eV/°K

$\bar{K} = 1.38 \times 10^{-23}$ J/°K

$$V_T = \frac{T}{11600} \text{ volts}$$

if T = 300°K

$$V_T = \frac{300}{11600} = 0.0256 \text{ volts}$$

$$V_T = 26 \text{mv}$$

The standards Room Temp. the 300K is i's equal to ~~28~~ 26 mV

$$V_T = 26 \text{mv}$$

⇒ Temp. in °C = Temp in °K − 273

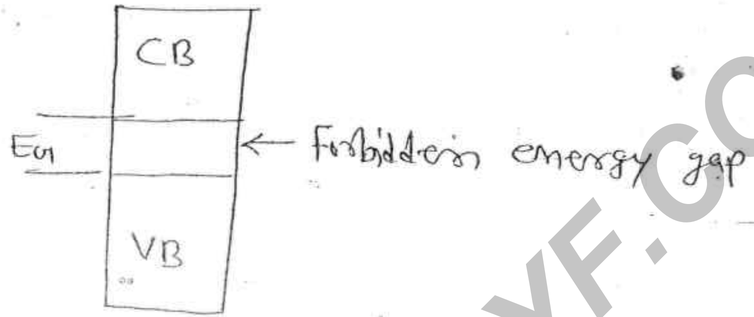
e.g. T = 300°K (standard Room Temp)
= 27°C

$T = 0°K$ (Absolute Temp)

$= -273°C$ (No device can operate)

$\Rightarrow$ **Temp in °K = Temp in °C + 273**

Energy Gap (E_g) : it is the gap b/w two band (Band-gap)



E_{G0} = Energy gap at 0°K.

	Ge	Si
E_{G0}	0.785 eV	1.21 eV
E_{G300}	0.72 eV	1.1 eV

Energy gap decreases with the Temp.↑

$$E_g \propto \frac{1}{\text{Temp}}$$

Standard formula to obtain E_G

$$E_{G(T)} = E_{G0} - \beta_0 T \text{ eV}$$

β_0 = Constant (material constant)

β_0 unit is eV/°K

For Ge :

$$E_G(T) = 0.785 - 2.2\times10^{-4}\,T \text{ eV}$$ 22

$T = 0^\circ K$; $E_G(T) = 0.785$ eV

$T = 300^\circ K$; $E_G(T) = 0.72$ eV

$T = 400^\circ K$, $E_G(T) = 0.697$ eV

For Si

$$E_G(T) = 1.21 - 3.6\times10^{-4}\,T \text{ eV}$$ 36

Si is most suitable for High Temp.

⇒ if energy gap is large the semiconductor is most suitable for high Temp. Application. when compared to Ge,

~~→ Si is most suitable for high Temp. Applications.~~

⇒ As Temp. increasing in the semiconductor the atom will be vibrating and due to this thermal vibration occur the energy Gap slightly decreases.

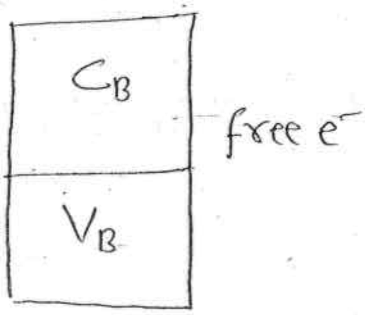
** ⇒ Electron can not stay in E_G therefore its is known forbidden gap.

⇒ Applicable Natural element only.

⇒ in the forbidden energy band gap electron stay is prohibitted, this Rule is applicable for pure element. (Natural element).

Energy Band Diagram in metals:

Metal / conductors

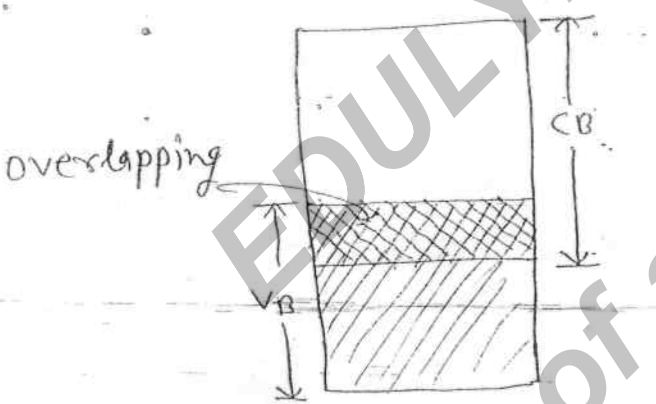


$E_G = 0$ at $0^\circ K$

→ free electron concentration is always available even at $0^\circ K$.

→ metal is a good conductor of current even at $0^\circ K$.

→ if Temp. is increase →



at $300^\circ K$

overlapping of VB & CB increases with temp ↑.

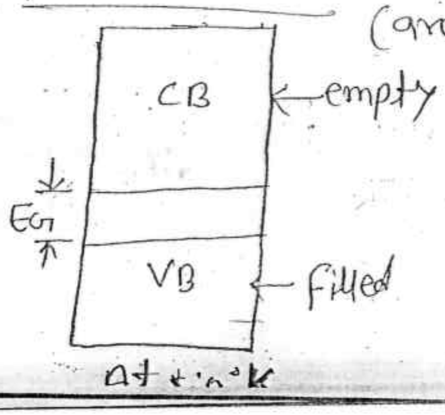
NOTE The free electron concentration in the metal is independent of Temp.

⇒ Energy Band Gap in Semiconductor :⇒

(around 1 ev.)

E_G = small

$E_g \simeq 0.7$ ev to 1.3 ev

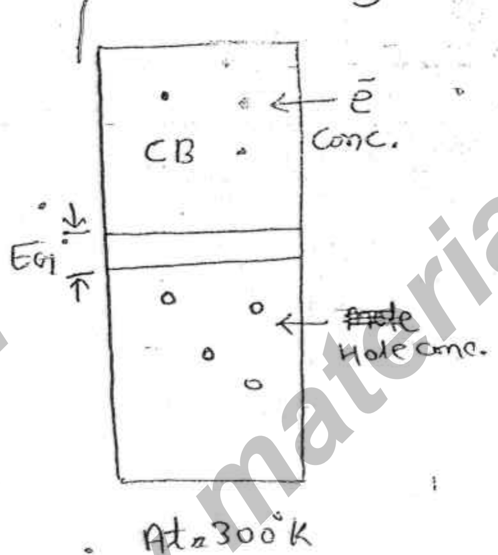


At $0^\circ K$

NOTE → → AT 0°K all semiconductor are insulators

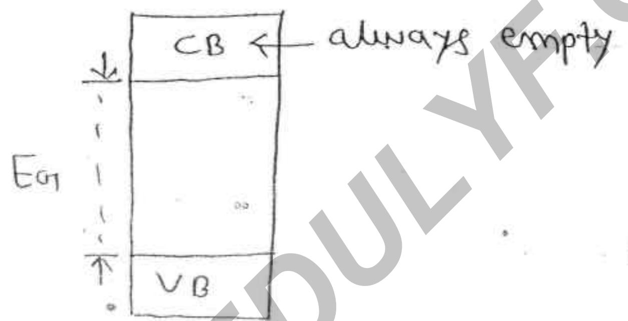
→ semiconductor are bipolar.

At room temp. charge carrier are created and there will be the conductivity in the semiconductor.



* Energy band gap in Insulators:

Eg → Large (>5 eV)



⇒ all insulators are Bad conductors of current some ex. are using in electronics:

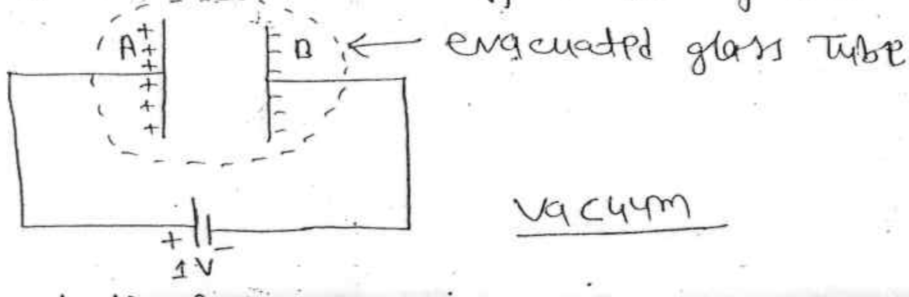
Eg: mica, ceramic, Bakelite, porcelain, Cotton, wood, Diamond, glass, plastic

NOTE: Diamond Eg is Highest

* Electron-volt eV:
↳ unit of energy

⇒ practical unit for energy in electronics.

⇒ 1 eV is define as the energy gained by the e^- in moving to a potential difference of 1V.



$= 1.6 \times 10^{-19} \times 1$ volt

$= 1.6 \times 10^{-19}$ C-volt → Joule → N-m

$$1\,eV = 1.6 \times 10^{-19}\,J$$

NOTE

$$1\,N\cdot m \Rightarrow 1\,J$$

* Kinetic energy:

$$KE = \frac{1}{2} m v^2 \text{ Joule}$$

$\Rightarrow PE = qV$ Joule

V = Applied voltage

KE gained = PE loss by the e^-

$$\frac{1}{2} m v^2 = qV$$

velocity of the e^- = $v_e = \sqrt{\frac{2qV}{m}}$ m/sec

* Mobility of charge carriers: (μ)

$$\mu = \frac{\text{Drift velocity}}{\text{field intensity}} \quad \frac{m/sec}{V/m} = m^2/V\text{-sec}$$

unit of mobility = m^2/V-sec or cm^2/V-sec

* mobility indicates how fast is the e^- and hole is moving from one place to another place.

	Ge	Si
Electron mobility (μ_n)	3800 $cm^2/v\text{-}sec$	1300 $cm^2/v\text{-}s$
Hole mobility (μ_p)	1800 $cm^2/v\text{-}sec$	500 $cm^2/v\text{-}se$
μ_n/μ_p	~~2.1~~ 2.1 : 1	2.6 : 1

NOTE ⇒ Electron mobility is always greater than others and conductivity also large.
So, e^- can travel faster and also contribute more current than a hole.

NOTE

Ge → Higher Conductivity
Ge → more suitable for HF applications.

Si → switching time is very small so it is more suitable for switching applications
Si → High power Applications

NOTE mobility of e^- and Hole is decrease with Tem

* mobility of charge carrier decrease with Temp.

As Temp. increases due to thermal vibration mobility of charge carrier is decreas.

$$\mu \propto \frac{1}{Temp}$$

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

or $\mu\downarrow$ with Temp↑

m is material constant.

For Ge m

$m = 1.66$ for e^-
$= 2.33$ for Hole

for Si m

$m = 2.5$ for e^-
$= 2.70$ for Hole

16 . 23 . 25 . 27

* mobility decreases with Temp. as non-linear variati ⇒

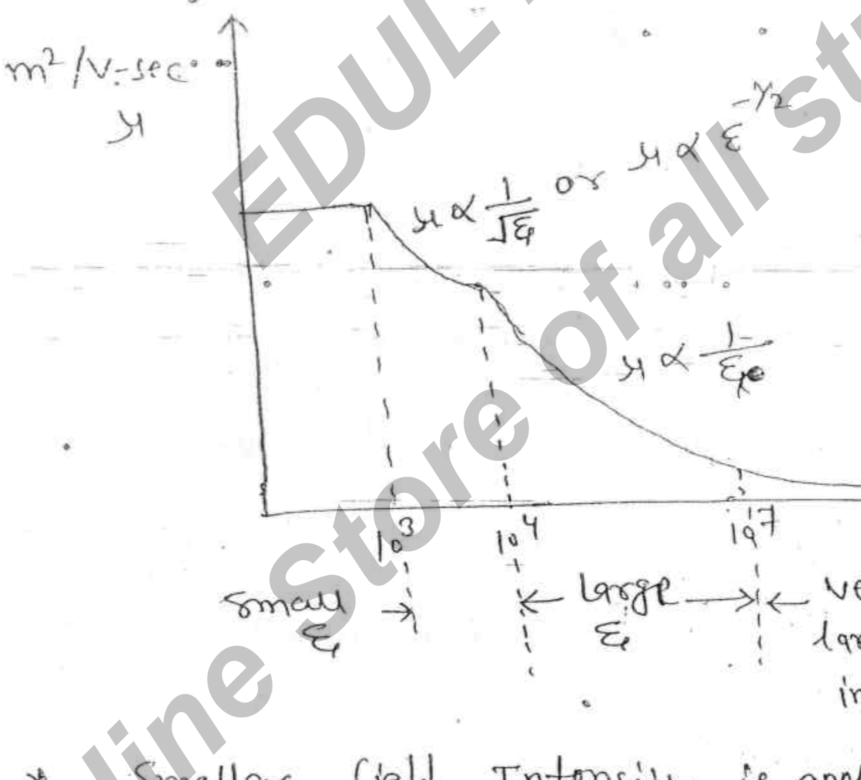
Drift velocity > velocity

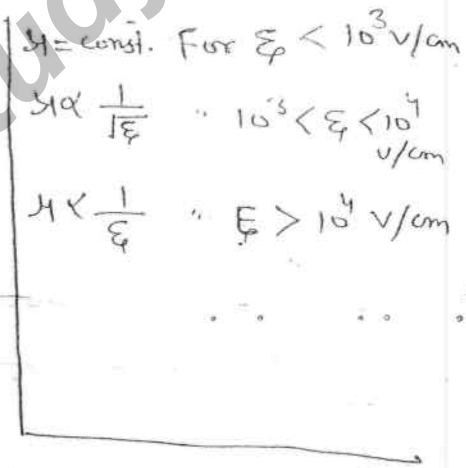
Drift means by force

$$\mu = \frac{\text{Drift velocity}}{\text{field intensity}} \quad \frac{v}{\varepsilon} \text{ or } \frac{v}{E}$$

Drift velocity $\boxed{v = \mu \varepsilon}$ m/sec

Field Intensity curve for a semiconductor :⇒





* Smaller field Intensity is applied :⇒
  → mobility of charge carrier will remain constant
  → drift velocity linearly increases with field intensity

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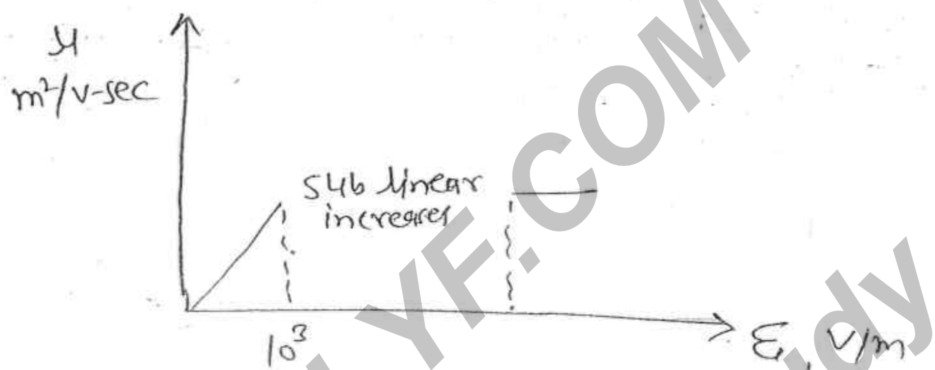
* for Large field Intensity / very High field Intensity is applied:

→ mobility of charge carrier will become very small and
→ drift velocity will remain almost constant.

In semiconductor:



→ In a semiconductor as field intensity is gradually increase from in the begining,
→ Drift velocity sub linear increase.
→ at larger field intensity the Drift velocity enters into saturation.

LEAKAGE CURRENT (I_0):

Also called minority carrier current and Reverse Saturation current or Thermal generated current.

→ I_0 is depend upon the minority carriers.
→ minority carrier is depend upon the Temp.
→ So, I_0 is directly proportional / depend upon the Temp.
→ it is independent of applied voltage.

I_0 = μA (micro-Amp) for Ge

I_0 = nA (nano-Amp) for Si

NOTE Leakage current are more in germanium with compare to Si.

⇒ Highly sensitive to Temp.

⇒ I_0 depend upon the No. of minority Carriers.

⇒ minority carrier concentration is depend upon Temp.

Temp in T

I_0 is 1 μA

Temp ↑ by 1°c

$I_0 = T + 1°C = 1.07\ \mu A$ { generally increase 7% per 1 °c }

if T ↑ by 10°c

$I_0 = (1.07)^{10} = 1.96$

NOTE → I_0 double for every 10°c both Ge and Si.

→ for 1°C, I_0 approximately increases with 7%.

⇒ I_0 is independent of applied voltage.

→ I_0 is saturated with applied voltage and Hence the name saturation current.

$$I_0(T_2) = I_0(T_1)\left[2^{\frac{(T_2 - T_1)}{10}}\right]$$

⇒ $2^{\frac{T_2 - T_1}{10}}$

where $T_2 > T_1$

T_2 = higher Temp. , T_1 = Lower Temp.

Current (I)

current is define as Rate of change of charge.

mathematically

$$\boxed{i = \frac{dq}{dt}} \text{ amp.}$$

* Drift Current:

It is flow of current in material or device under the influence of electric field intensity.

* Unipolar

Eg. i) FET < n-channel, p-channel

ii) Vaccum Tube

Current is carried by single type of charge carrier electron or hole.

* Bipolar

Current carried by two diff. type of charge carrier. both e^- and holes.

Eg. Bip-polar device is "BJT"

* Temperature Coefficent (TC) : (per °c)

NTC (Negative Temp. Coefficent)

Eg E_G

PTC (positive Temp. coefficent)

Eg :→ I_0

→ Any parameter decreasing with the Temp.↑ so it is include in NTC

→ The TC for the mobility is NTC

→ Any parameter increasing with Temp. so it's called PTC.

* ~~Resis~~

20/may/2011

* Resistivity (ρ)

→ specific Resistence of the matprial.

unit for ρ → Ωm or Ωcm

For metals

$R \propto \rho$ Exihibits PTC of Resistence
R↑ with Temp.

ρ↑ with Temp

For SC

Exihibitis NTC of Resistance R↓ with T

ρ↓ with T

* Conductivity :→ (current carring capacity)

→ It is the Reciprocal of Resistivity
→ conductivity denotes current carring capacity of matprial ~~of~~ or device.

unit of $\sigma = \frac{1}{\Omega m}$ or $\frac{\mho}{m}$ or $\frac{\mho}{cm}$ or $\frac{S}{m}$

Conductivity in more factors :-

Imp

Counductivity = Carrier Conc. × charge × mobility

Conductivity $\propto$ Carrier Conc. × mobility

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For metals:

$\sigma = nq\mu_n$

n = no. of electron
q = charge of e^-
μ = mobility

σ↓ with Temp

when Temp. increases
→ A metal free e^- concentration is independent of Temp.
** → As Temp increases in metal conductivity decreases.

For semiconductor:

$\sigma = nq\mu_n + pq\mu_p$

σ↑ with Temp.

In a semiconductor as Temp ↑, mobility decreases and this will slightly Reduce the conductivity but at the same time because of Temp. the No. of covalent bonds will be broken creating e^-s and hole and there by conductivity increase by a larger valu and the net Result conductivity inc. with Temp.
→ The intrinsic SC σ↑ with Temp.
→ In a SC σ mainly depends upon carrier conc.

Current Density:

It is the current passing per unit area.

$J = \frac{I}{Area}$ Amp/m²

$J = \sigma \mathcal{E}$ A/cm²

$\sigma = \frac{℧}{cm}$ (units)
$\mathcal{E} = V/cm$
$J = \frac{℧}{cm} \times \frac{V}{cm} = A/cm^2$

For metals

$$J = nq\mu_n \mathcal{E}_0 \quad A/cm^2$$

for SC

$$J = (nq\mu_n + pq\mu_p)\mathcal{E}_0 \quad A/cm^2$$

Thermal equilibrium means constant Temp.

Mass Action Law :

$$np = n_i^2$$

n = Concentration of e^-
p = " " hole

In a SC under thermal equli., the product of concentration of electrons (n_e) and concentration of holes (n_h^p) is a ~~constant~~ always a constant and this is equal to the square of intrinsic concentration.

→ The law is mainly used to calculate minority carriers.

N-Type SC

majority carrier are = n_n
minority carrier are = p_n

$$p_n = \frac{n_i^2}{n_n}$$

P-Type SC

majority carrier are p_p
minority carrier are n_p

$$n_p = \frac{n_i^2}{p_p}$$

Minority carrier Con = $\frac{n_i^2}{\text{majority carrier conc.}}$

imp majority carrier conc. $\propto$ Doping conc.

imp minority carrier conc. $\propto \frac{1}{\text{Doping conc.}}$

Intrinsic conc. (n_i) :

→ It indicates the conc. of charge carrier in pure sc in at a given Temp.

→ In an intrinsic sc

$$n = p = n_i$$

standard formula for calculate Intrinsic sc conc.

$$n_i^2 = A_0 T^3 e^{-E_{G0}/KT}$$

T = Temp in K

K = 8.62×10^{-5} eV/°K

A_0 = material constant

Intrinsic conc. Depends on

(i) Temp.

(ii) Energy gap

$$n_i^2 \propto T^3$$

intrinsic concen. n_i is $\propto$ $T^{3/2}$

intrinsic concen. n_i^2 is $\propto$ T^3

...en No. of to Silicon from germenium has intrinsic conc. and this is due to smaller value of energy gap.

$n_i = 2.5 \times 10^{13}$ atoms/cm^3 for Ge at Room Temp.

$n_i = 1.5 \times 10^{10}$ atoms/cm^3 for Si at Room Temp.

Einstein's Equation:

In a SC

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T = \frac{T}{11600}$$

or

$$\frac{\mu_n}{D_n} = \frac{\mu_p}{D_p} = \frac{1}{V_T} = \frac{11600}{T}$$

D_n = Diffusion constant of e^-

D_p = " " of Hole

It is used the Relationship b/w Diffusion constant, mobility and Thermal voltage

$$\frac{D}{\mu} \propto T$$

→ The unit for mobility to Diffusion const. is $\frac{1}{Volt}$ or V^{-1}

→ The unit for Diffusion to mobility " = Volts

Diffusion Constant of Charge carrier: ⇒

e^- Diffusion constant $D_n = \mu_n V_T$

Hole " " $D_p = \mu_p V_T$

Unit for Diffusion constant $= \frac{cm^2}{V\text{-}sec} \cdot V$

$= \frac{cm^2}{sec}$ or m^2/sec

→ It is the material constant Responsible for the property of Diffusion. 9

*→ Diffusion is constant with Temp., because it is independent of Temp.

for Ge at Room Temp.

$D_n = \mu_n V_T$

$= 3800 \times 26 \times 10^{-3}$

$D_n = 98.8 \ cm^2/sec$

$D_p = \mu_p . V_T$

$= 1800 \times 26 \times 10^{-3}$

$= 46.8 \ cm^2/sec$

for Si

$D_n = \mu_n V_T$

$= 1300 \times 26 \times 10^{-3}$

$= 34 \ cm^2/sec$

$D_p = 500 \times 26 \times 10^{-3}$

$= 13 \ cm^2/sec$

⇒ Diffusion constant cannot be Negative.

⇒ Conductivity Variation in SC :-

In Intrinsic SC conductivity increases with Temp

for 1°C σ of Ge ↑ by 6%.

Si ↑ by 8%.

When compare to Ge, Si is more sensitive to temp. but Silicon (Si) is more ~~pe~~ preferable for high Temp. Application and this is due to smaller leakage current.

operating Temp:-

For Ge −60°c to +75°c

max. Temp ⇒ +75°c

for Si

−60°c to 175°c

* Normal working Temp : 100k to 400k

* Electrical properties of Ge & Si :

Properties	Ge	Si
1) Atomic NO.	32	14
2) Total NO. of Atoms or Density of Atoms/cm^3	4.421×10^{22}	5×10^{22}
3) Intrinsic concentration at room temp. atoms/cm^3	2.5×10^{13}	1.5×10^{10}
4) Intrinsic Resistivity ρ_i Ω-cm	45	230,000
5) maximum operating Temp.	75°c	175°c
6) Leakage current (I_0)	μA	nA
7) power Handling capacity	Low	High
8) μ_n cm^2/v-sec	3800	1300
9) μ_p cm^2/v-sec	1800	500
10) D_n cm^2/sec	99	33.8
11) D_p cm^2/sec	46.8	13
12) E_{G0}	0.785	1.21
13) E_{G300}	0.72	1.1

when compare to Ge, Si is more perferable: 10

- → Plenty available on the surface
- → cheap
- → Smaller leakage current
- → suitable for High Temp. Applications
- → High power Handling
- → can be brought in to SiO_2, this the main Reason
- → Si is mainly used via SC device manufactures due to plenty available on the surface of ~~edge~~ earth.

Disadvantage of Si:

Conductivity is less.

⇒ Diffusion and Diffusion current:

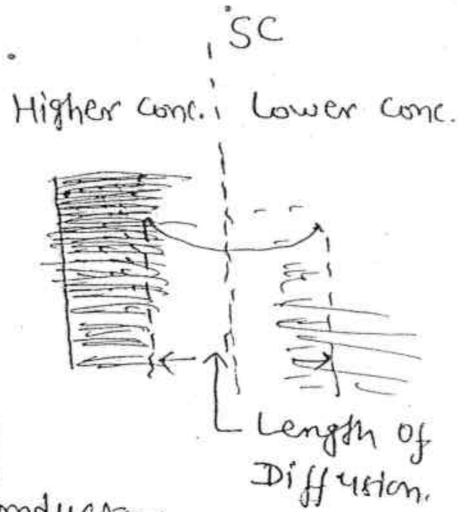
Diffusion is define as the migration of charge carrier from Higher conc. to lower conc. or from Higher density to lower Density.

→ Diffusion is mainly due to conc. gradient.

gradient = d/dx

$\frac{dn}{dx}$ = e^- Conc. gradient

$\frac{dp}{dx}$ = hole conc. gradient



⇒ Diffusion current → only semiconductor

⇒ In SC diffusion is due to unequal distribution of charge carrier.

→ In A S.C. diffusion is ... with random motion of charge carrier due ... thermal agitation.

Length of diffusion: $L = \sqrt{D \cdot \tau}$ cm

but $D = \mu \cdot V_T$

$$L = \sqrt{\mu V_T \cdot \tau} \text{ cm}$$

τ = carrier life time

→ Diffusion length depend on

<i> Diffusion constant

<ii> mobility

<iii> Temp.

<iv> Carrier life time

e^- diffusion length:

$$L_n = \sqrt{D_n \cdot \tau_n} \text{ cm}$$

$\tau_n \to e^-$ life time

21 May 2011

Electron Diffusion current density : J_n (Diff)

$$J_n(\text{Diff}) = +q D_n \frac{dn}{dx} \quad A/cm^2$$

Hole Diffusion current density

$$J_p(\text{Dff}) = -q D_p \frac{dp}{dx} \quad A/cm^2$$

Total current Density in a SC

→ Semiconductor are bipolar and we get four Diff. current component.

→ In a S.C the total current density

$$J = J_n + J_p$$

when

~~$J_n = J_n(\text{Drift}) + J_n(\text{Diffusion})$~~

$$J_n = nq\mu_n E + q D_n \frac{dn}{dx}$$

Similarly

$$J_p = J_p(\text{Drift}) + J_p(\text{Diffusion}).$$

$$J_p = pq\mu_p E - q D_p \frac{dp}{dx}$$

Conductivity of intrinsic sc / Intrinsic conductivity:

we know that

$$\sigma = nq\mu_n + pq\mu_p$$

for ~~ex~~ intrinsic conductivity

$$n = p = n_i$$

$$\boxed{\sigma_i = n_i q [\mu_n + \mu_p]}$$

$\sigma_i \propto n_i$

and $n_i \propto T^{3/2}$ $\quad \because n_i^2 = AT^3 e^{-E_{G0}/KT}$

so, σ_i is ↑ with Temp.

→ In intrinsic sc conductivity increases with Temp as a non-linear variation.

Que. If the drift velocity of Holes under a field gradient of 100 v/m is 5 m/sec. find its mobility.

Solⁿ

$\mathcal{E} = 100$ v/m

$v = 5$ m/sec

$$\mu = \frac{v}{\mathcal{E}} = \frac{5}{100} \ m^2/v\text{-}sec$$

Que. The carrier mobility in sc is $0.4 m^2/v\text{-}sec$ is diffusion constant and T = 300 K.

Solⁿ

$\mu = 0.4 \ m^2/v\text{-}sec$

$T = 300 \ ^\circ K$

$D = ?$

AT room Temp. $V_T = 26$ mv

$$D = \mu V_T = 0.4 \times 26 \times 10^{-3} \ m^2/sec$$

Que. The minority carrier life time and Diffusion Constant in a SC material 100 μsec and the 100 cm²/sec Respectively. the diffusion length of the charge carrier.

Solⁿ

$$L = \sqrt{D \cdot \tau} \text{ cm}$$

$$\tau = 100 \text{ cm}^2/\text{sec} \quad D = 100 \ \mu\text{sec}$$

$$L = \sqrt{100 \times 10^{-6} \times 100} = 100 \times 10^{-3} = 0.01 \text{ cm}$$

Que. A sample of n-Type SC as electron density $6.25 \times 10^8/\text{cm}^3$ AT 300°K. if the intrinsic conc. of carrier is sample is $2.5 \times 10^{13}/\text{cm}^3$ Hole conc:

$$p = \frac{(2.5 \times 10^{13})^2}{6.25 \times 10^{18}}$$

$$= \frac{(2.5)^2}{6.25} \times 10^8/\text{cm}^3 = 10^8/\text{cm}^3$$

Que. A flat Al strip with a Resistivity of 3.44×10^{-8} Ωm, length of 5mm with a cross section area 2×10^{-4} mm², find the voltage drop across the strip, current of 50mA is proceed to it.

Solⁿ

$$\rho = 3.44 \times 10^{-8} \ \Omega\text{m}$$

$$L = 5 \times 10^{-13} \text{ m}$$

$$I = 50 \times 10^{-3} \text{ A}$$

$$A = 2 \times 10^{-4} \times 10^{-6} \text{ m}^2$$

$$R = \rho \frac{L}{A} \qquad V = I/R$$

$$R = 3.44 \times 10^{-8} \times \frac{5 \times 10^{-3}}{2 \times 10^{-4} \times 10^{-6}}$$

$$R = 0.86 \ \Omega$$

$$V = IR = 50 \times 10^{-3} \times 0.86 \Rightarrow V = 0.043 \text{ V}$$

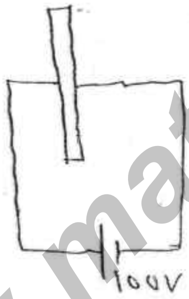
Que A semiconductor wafer with a thickness 0.5 mm there a potential 100 mv is applied across the thickness.

<i> what is the electron drift velocity if the mobility is $0.2\ m^2/v\text{-sec}$

<ii> How much time is Required for an e^- to move across this thickness.

Solⁿ <i> $V = 100\ mv$

$l = 0.5 \times 10^{-3}\ m$



$$\boxed{v = \mu E}$$

$$= 0.2 \times 200 \times 10^{-3}$$

$$E = \frac{\text{Voltage}}{\text{Distance}} = \frac{100 \times 10^{-3}}{0.5 \times 10^{-3}} = 200\ V/m$$

Drift velocity

$$v = 200 \times 0.2 = 40\ m/sec$$

<ii> distance = thickness

$$= 0.5 \times 10^{-3}\ m$$

$$\text{time} = \frac{\text{distance}}{\text{velocity}}$$

$$= \frac{0.5 \times 10^{-3}}{40} = 12.5\ \mu sec.$$

Que A small conc. of minority carrier is injected in place Homogenous semiconductor crystal at one point.

(i) an electric field 10 mv is applied across the crystal so that the minority carrier will be moving a distance of 1 cms in 20 μsec.

calculate mobility in $cm^2/v\text{-sec}$.

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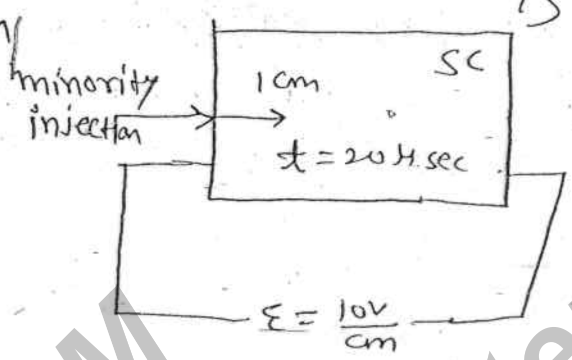
Sol^n

$E = 10\ V/cm$

$l = 1\times10^{-2} m$ or $1 cm$

$t = 20\times10^{-6}$ sec



$\mu = v/E$

$$v = \frac{distance}{Time}$$

$$= \frac{1}{20\times10^{-6}} = 50000\ cm/sec$$

$$\mu = v/E = \frac{50000}{10} = 5000\ cm^2/sec$$

Que Let the leakage current in Germenium 5 μA at 10°C find its value when temp is 25 °C.

Sol^n

$$I_0(T_2) = I_0(T_1)\left[2^{\frac{T_2 - T_1}{10}}\right]$$

$$I_0(25°C) = 5\ \mu A\left[2^{(25-10)/10}\right]$$

$$= 5\ \mu A \times 2^{1.5}$$

$$I_0(25°C) = 14.14\ \mu A$$

Que find the intrinsic carrier concentration of Ge if the intrinsic Resistivity at 300°K $\rho = 0.47\ \Omega m$, it is given that e^- and Hole mobility at 300°K are $\mu_n = 0.38\ m^2/V sec$ $\mu_p = 0.19\ m^2/V\text{-}sec$

Sol^n

$$n_i = \frac{1}{\rho_i q[\mu_n + \mu_p]} = \frac{1}{0.47\times 1.6\times10^{-19}[0.38+0.19]}$$

$$= 2.33\times10^{19}\ atom/m^3$$ Ans

IES 2009 — On applied an electric [illegible] of intensity 10V/cm Across a semiconductor [illegible] certain Temp. the average drift velocity is 70 m/sec of free e⁻ mobility is

Soln

$$\mu = \frac{70\times10^2}{10} = \frac{7000}{10} = 700\ cm^2/V\text{-}sec$$

2009 — The Diffusion constant of Holes in Si is $13\ cm^2/sec$ what is the Diffusion current if the gradient of the Hole conc. $\frac{dP}{dx} = -2\times10^{14}$ holes/cm³/cm

or

-2×10^{14} holes/cm³ per cm

Soln

$$D_P = 13\ cm^2/sec$$

$$\frac{dP}{dx} = -2\times10^{19}\ holes/cm^3$$

$$-q\mu_P P + q D_P \frac{dP}{dx} \quad J_P(diff.) = -q D_P \frac{dP}{dx} \quad A/cm^2$$

$$= -1.6\times10^{-19}\times13\times(-2\times10^{+14})$$

$$= 1.6\times13\times2\times10^{-5}$$

$$= 0.416\ mA/cm^2$$

$$I_P(Diff) = J_P(Diff)\times Area$$

Let area = $1\ cm^2$

$$I_P(Diff) = 0.416\ mA$$

IES 2011

Given that at Room temp. the volt equt. of Temp. is 26mv. hole mobility is 500 cm²/V-sec and the life time of Hole is 130 nsec in a sample of N-type semiconductor bar (Rectangular shape) that explosion of variation of one end what is the drift length.

Solⁿ

$V_T = 26\,mV, \mu = 500\ cm^2/V\text{-}sec$

$\tau = 130 \times 10^{-9}\ sec$

$L = \sqrt{D \cdot \tau}\ cm$

$D = \mu V_T = 500 \times 26 \times 10^{-3}\ V \cdot cm^2/V\text{-}sec$

$= 13\ cm^2/sec$

$L = \sqrt{13 \times 130 \times 10^{-9}} = 13 \times 10^{-4} = 1300\ \mu cm$ — Ans

classification of semiconductors :⇒

SC

Direct band Gap SC (DBG SC)

→ Eg. GaAs (The Best example)

GaN, ZnS

GaSb, CdS

CdSe

InAs, (InP)

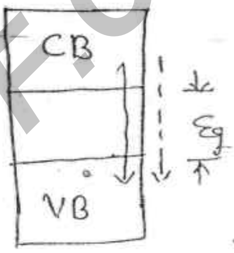
indirect band gap (IBG SC)

→ Eg. Ga & Si (The Best example)

→ Eg. AlP, AlAs, AlSb

PbS

PbSe, (GaP)



Direct band gap SC	Indirect band gap SC
→ 99% e^- Released the light due to falling from CB to VB. ~~1% e^- Released the heat due~~ to collide with crystal. (orientation of Atoms)	→ 99% e^- Relesed the energy in form of heat. 1% e^- Released the light
→ Direction of falling e^- is remain same.	→ The electron of falling change direction due to collision.
→ most of the energy will be Released in the form of light.	→ most of the energy will be Released in the form of heat.
→ during the Recombination majority of falling e^- will be directly falling from CB to VB and they will be Releasing the energy in the form of light But very few falling e^- get Collinate with the crystal. and	→ The energy will Released by the falling e^- directly in the form of light hence the name direct band gap

→ these crystal will be absorbing the energy and the desipate (dissipate) the energy in form of Heat.

→ The direction of the falling e^- will Remain the same that is uneffected.

→ Energy of falling e^- is changes (KE and PE changes)

→ The moment of the falling e^- slightly changes.

→ Compeeratively carrier life time is small.

⇒ During Recombination most of falling e^- gets Collide of crystal of atoms. and thus crystal will be absorbing the energy and gets heated up and there Released the energy in form of Heat. 15

But very few falling e^- may be escaping the collision and their will be directly falling to CB to VB And Releases the energy in the form of light.

→ most of the falling e^- will be Releasing energy through the crystal of atom in the form of heat. Hence the name indirect band gap SC.

→ The direction of falling e^- slightly change due to a no. of collisions with crystal of atoms.

→ The energy of falling e^- is changes (Both KE and PE).

→ The momentum is also change Here.

→ compartively larger carrier life time.

Que G... example for ~~BDG~~ DBG SC

<i> ... SC ✓

<ii> ...

<iii> Wid... and gap SC ← does not exist in

<iv> Narrow-band gap SC ← environment

~~as only~~ i of these correct statement

a) only i

b) i & iv

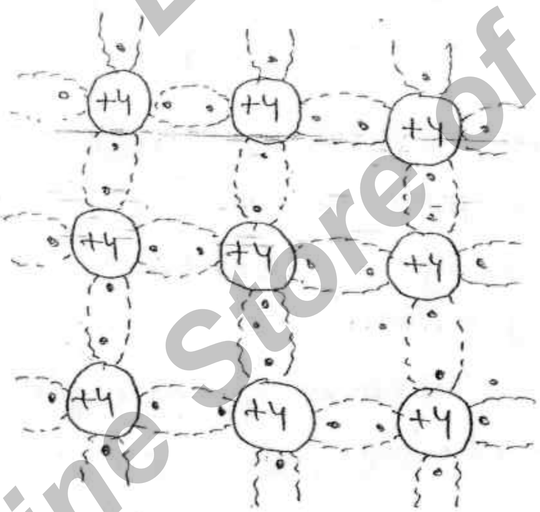
c) i & iii

d) only iii

	Ge	Si	GaAs
EG 300	0.72 eV	1.1 eV	1.47 eV

Intrinsic Semiconductor :

It is also known as pure SC or Non-degenerated SC



AT = 0 °K

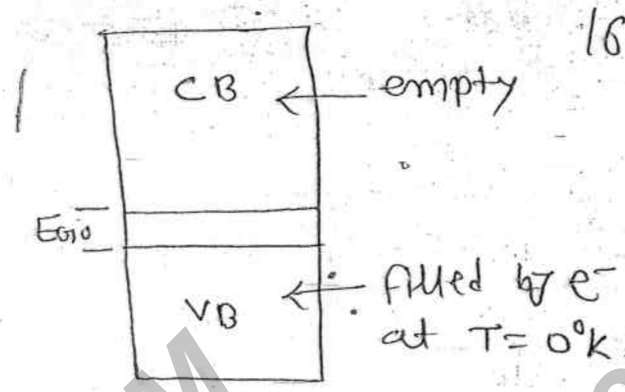
Types of Bonding	
Metallic Bonding	→ metals
Covalent "	→ SC
Ionic "	→ Insulator

at 0°K semiconductor is pure insulator.

→ The max. no. of valency e^- are 8.

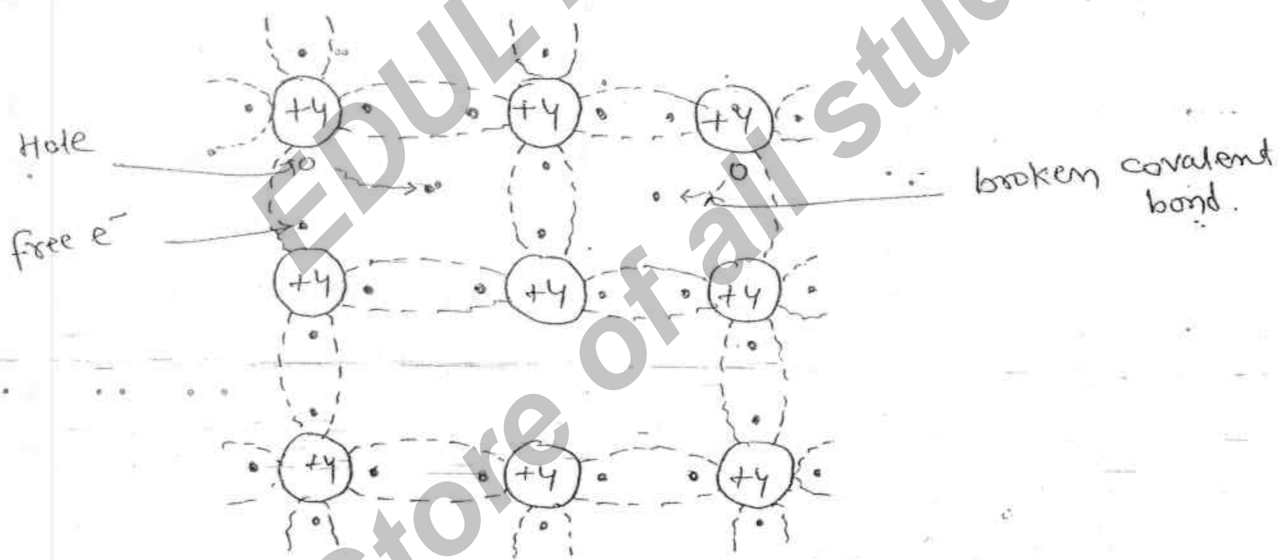
→ The sharing of e^- with neighboring atom is called Covalent bonding.

Energy-band Diagram

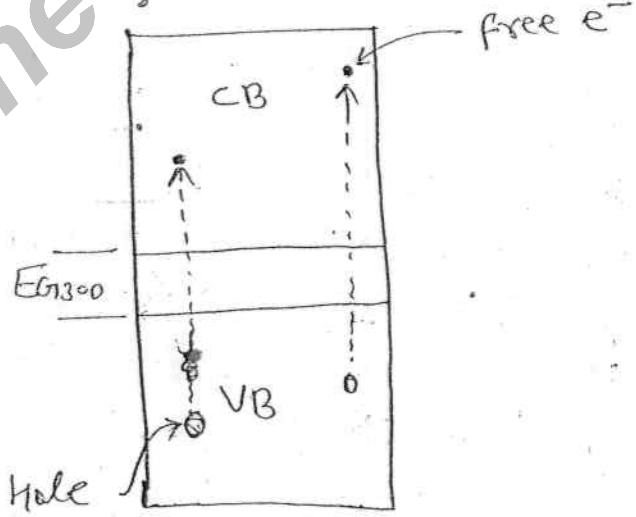


→ at 0°K intrinsic sc all valency electrons are in perfect covalent bonding.

→ Intrinsic semiconductor at 0°K will work as a perfect insulator. (eight valency e^-)



at T = 300°K



At T= 300°K

When a covalent Bond is Broken, it will create one e^- and one hole. (The e^- will be Jumping from VB to CB and become a free e^- but the hole remain in VB).

→ Hole is define as the defficiency of one e^- in the broken covalent bond.

→ Hole is a carriers of current and is associated with positive charge of $+1.6 \times 10^{-19} C$.

In intrinsic semiconductor the condition is

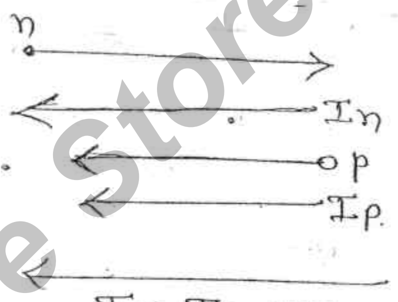
$$\boxed{n = p = n_i}$$

→ Because of opposite polarities e^- and Hole always move in the opposite direction.

→ Current Direction is opposite to the flow of e^- or current direction in the direction of hole flow.

→ e^- and Hole always moves in opposite direction but they contribute the current in the same direction.

In a S.C



$I = I_n + I_p$

$\boxed{\text{but } I_n > I_p}$

→ In a S.C. The free e^- will be moving in the CB and will contribute the current but the same time Holes will be moving in the valancey band in the opposite direction and will contribute the current so, that $\boxed{I = I_n + I_p}$

$\sigma_i = nq\mu_n + pq\mu_p$ ℧/cm

but $n = p = n_i$

Imp

$$\boxed{\sigma_i = n_i q[\mu_n + \mu_p] \text{ ℧/cm}}$$

$$\rho_i = \frac{1}{\sigma_i}$$

Imp

$$\boxed{\text{Resistivity } \rho_i = \frac{1}{n_i q[\mu_n + \mu_p]}} \ \Omega\text{-cm}$$

$\sigma_i \propto n_i$

but $n_i \propto T^{3/2}$

Hence $\sigma_i \uparrow$ with T

Disadvantage of SC :

Conductivity is very small (This is due to the small value of n_i Both in Ge and Si).

Generation of e^- Hole pairs :→

it is also known as ionization.

→ when covalent broken because of Temp. equal No. of e^- and Holes are created and this is called ionisation or generation of e^--hole pairs.

Re-Combination:

→ During the Recombination the free e^- will be falling from CB to VB to combine with the Hole and energy will be ~~desipated~~ dissipate both in the form heat and light.

→ When the free e^- pair with hole, it is called Recombination.

→ During the Recombination free e^- and Hole will disapear and a covalent is found.

Carrier life time (τ):

→ it is the interval of time from breaking of covalent bond untill its Recombination.

→ τ is ~~varies~~ range from μ sec to m sec.

Reverse saturation current in a p-n diode

$$I_0 = Aq\left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right) n_i^2$$

Que find intrinsic conductivity and intrinsic resistivity of Ge at room temp. assume $n_i = 2.5 \times 10^{13}$ atoms/cc, $\mu_n = 3800\ cm^2/V\text{-}sec$, $\mu_p = 1800\ cm^2/V\text{-}sec$.

Soln

Room Temp = 300°K

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

$$= 2.5 \times 10^{13} \times 1.6 \times 10^{-19} (3800 + 1800)$$

$$= 0.0224\ \mho/cm$$

$$\rho_i = \frac{1}{\sigma_i} = \frac{1}{0.0224} = 44.45\ \Omega\text{-}cm$$

Que find the conductivity and resistivity of pure silicon at room temperature. $n_i = 1.5 \times 10^{10}$ atoms/cm³, $\mu_n = 1300\ cm^2/V\text{-}sec$, $\mu_p = 500\ cm^2/V\text{-}sec$

Soln

$$\sigma_i = n_i q (\mu_n + \mu_p) \quad (n_i \rightarrow \text{intrinsic conc})$$

$$= ~~1.5 \times 10^{10} (1300 + 500)~~$$

$$= 1.5 \times 10^{10} \times 1.6 \times 10^{-19} (1300 + 500)$$

$$= 1.5 \times 10^{-7} \times 1.6 \times 18$$

$$= 2.40 \times 18 \times 10^{-7}$$

$$= 43.2 \times 10^{-7}$$

$$= 4.32 \times 10^{-6}\ \mho/cm$$

Soln

$$\sigma_i = 1.5 \times 10^{10} \times 1.6 \times 10^{-19} (1300 + 500)$$

$$\sigma_i = 4.32 \times 10^{-6}\ \mho/cm$$

$$\rho_i = \frac{1}{\sigma_i} = \frac{1}{4.32 \times 10^{-6}}$$

$$= 231,481\ \Omega\text{-}cm$$

Dopping it is the process of adding impurities to the pure semi conductor.

Doping increasing the Number of charges carrier and therefore increases the conductivity.

III → Trivalent / acceptor impurities — SC: III IV V

↳ B, Al, Ga. & In

V → Pentavalent / Donar Impurities

↳ P, As, Sb & Bi

(B, P) ⟶ more affinity (attraction) to Si

$1:10^6$ or 1 in 10^6 or $\frac{1}{10^6}$ → 1 impurity atom in 10^6 semiconductor atoms.

Standard Dopping Level!

(i) moderate (normal) Dopping (avg.) ⇒ $1:(10^6 \text{ to } 10^8) \rightarrow P, N$

2. Lightly Dopping ⇒ $1:10^{11} \rightarrow P^-, N^-$

3. Highly (Heavy) ⇒ ~~1:10^3~~ $1:10^3 \rightarrow P^+, N^+$

a Highly Dopped semiconductor exhibits metallic properties such as

1. Very High conductivity
2. NTC can be converted into PTC
3. Can become unipolar.

with $1:10^8$ impurities, in Ge, $\sigma \uparrow$ by 12 times

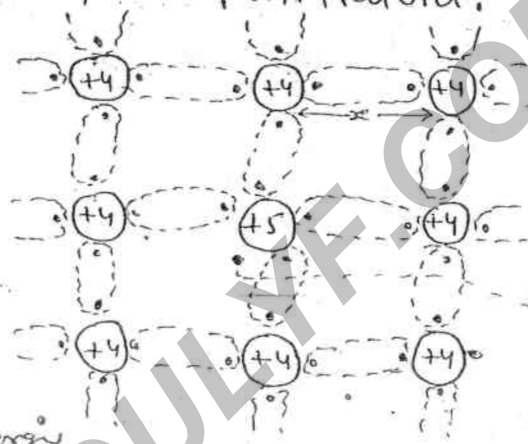
$1:10^7$ " " " " 120 times.

The minimum impurity Required to convert intrinsic to extrinsic SC is $1:10^8$.

Extrinsic Semiconductor (Doped SC, or Impurity SC or Artifical SC or De-generate SC or compensated SC)
- → N
- → P

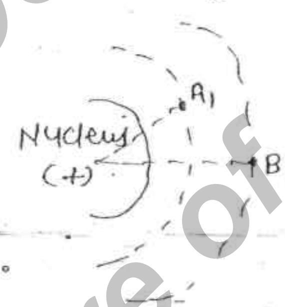
(i) N-type SC OR DONAR: (Negative type)

The impurity is pentavalent.

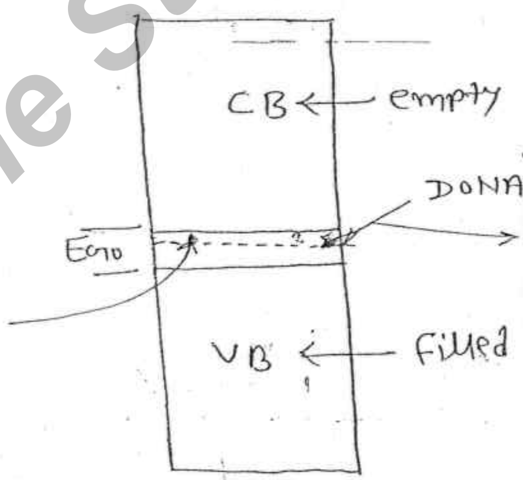


New Discrete allowable Energy level.

at T = 0K
→ 5th e^- or → excess e^- (unable to participate in covalent bonding)
→ (Not a free e^-)
→ bonded e^- (having force of attraction towards Nucleus (Parent atom)



Energy band diagram:-



↳ This gap depends on interatomic spacing of the element (x)

at T = 0K
↳ N-type semiconductor working as perfect Insulator.

Notes

⇒ DONAR energy level (ED) exists Just below the conduction band.

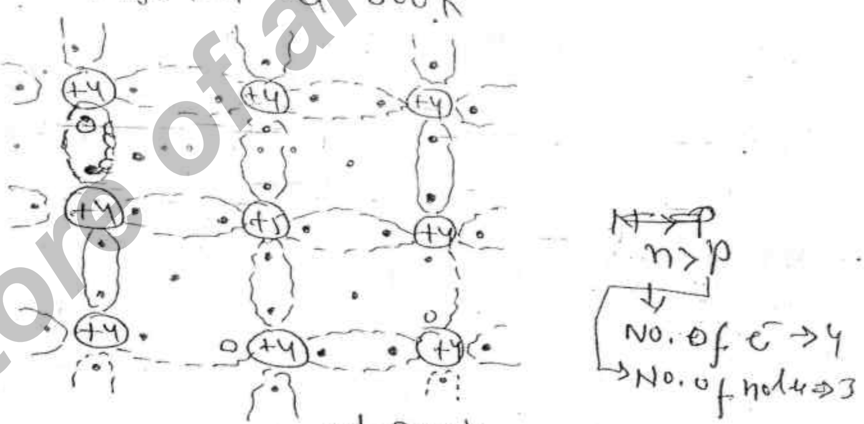
⇒ DONAR energy level denotes the energy level of all the pentavalent atoms added to the pure semiconductor.

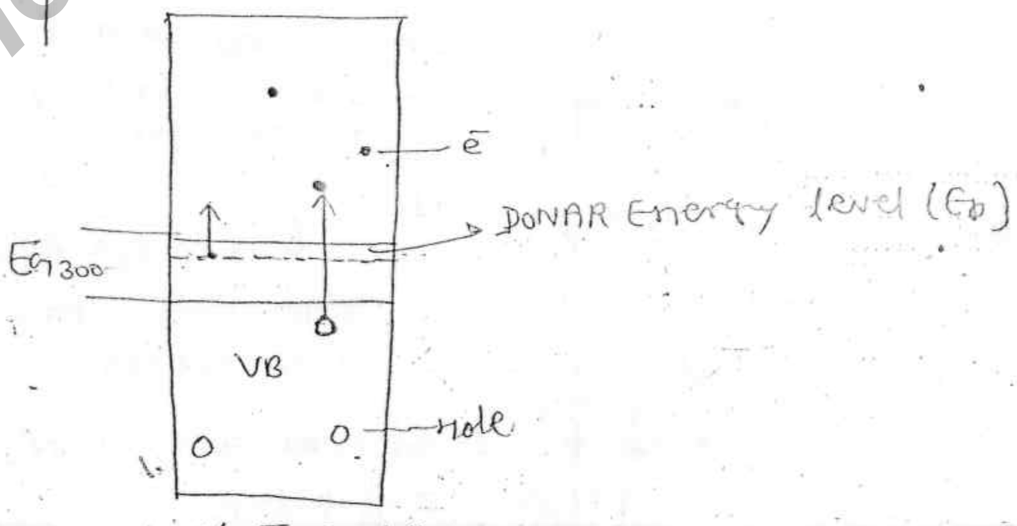
⇒ at 0°K The 5th e^- of all the impurity atoms are existing in the doNAR energy level.

⇒ The additional energy Required to detach the 5th e^- from its orbit is equal to 0.01 ev for Ge and 0.05 ev for Si.

⇒ N type semiconductor at 0K will be working as a perfect insulator.

Energy band diagram at 300 K





at T=300k

DONAR LEVEL IONISATION: means moving the e^-s from DONAR Energy level to CB

→ in the entire semiconductor every impurity atom will be donating 1 e^- into the conduction band. (Hence N-type will also called DONAR).

⇒ DONAR level ionisation increases with the Temp. (as temp. is increasing the 5th electron of the impurity atom will be moving from DONAR Energy level into conduction band).

⇒ at room temp. (300 K) DONAR Level Ionisation Completed.

⇒ at room temp. the 5th e^- of all the impurity atom will be shifted into conduction band.

⇒ in N-type semiconductor. as temp. is increasing ~~the 5th electrons~~ will be moving from DONAR energy level into conduction band and also due to the temp. a large No. of covalent bond will be broken creating equal Number of electrons and Holes. and the electrons will be shifted into the conduction band so that electron concentration in the conduction band is ~~far more~~ greater than Hole concentration. Hence e^-s are majority carriers and Holes are minority carriers.

⇒ according to the law of electrical ~~neutra~~ Neutrality

$$N_D + p = N_A + n$$

In N-type SC. $N_A = 0$

$$\boxed{n = N_D + p}$$

Since $n >> p$

$$\Rightarrow \boxed{n \simeq N_D}$$

Where $N_D \rightarrow$ DONAR concentration and indicates the actual Number of pentavalent atoms added to the pure semiconductor.

$$N_D = \frac{\text{Total NO. of Atoms}}{\text{volume}} \times \text{Impurity ratio}$$

ex → $1\,cm^3$, $1:10^7$

$$N_D = 4.421 \times 10^{22} \times \frac{1}{10^7}$$

$$= 4.421 \times 10^{15} \text{ atom}/cm^3$$

$$n >> p$$

⇒ In N-type SC the free e^- concentration is approximately equal to DONAR concentration

$$\boxed{n \simeq N_D}$$

⇒ Majority carriers will contribute more current with less Noise.

⇒ minority carriers will contribute less current with more Noise.

⇒ Minority carrier Noise is a thermal noise and it increases with temp.

⇒ The conductivity due to minority carries is almost negligible.

⇒ In N-type semiconductor is predominately (mainly) dominated by the flow of electrons.

⇒ The conductivity of N type semiconductor is (σ_N)

$$\sigma_N = nq\mu_n + pq\mu_p \ \mho/cm$$

$$\simeq N_D q \mu_n \ \mho/cm$$

⇒ The condition for N-type semiconductor is 21

$n > n_i$ /
$p < n_i$

$n = p = n_i$

⇒ IN N-type ~~semi~~ SC as e^- concentrations increases above n_i the Hole concentration falls ~~between~~ below n_i and this is due to a large number of recombinations.

Analysis

In a pure SC (Si) $n = p = n_i = 1.5 \times 10^{10}/cm^3$

Let pentavalent impurity of $1:10^6$ is added $N_D = ?$

$$N_D = 5 \times 10^{22} \times \frac{1}{10^6} \Rightarrow 5 \times 10^{16} \text{ atoms}/cm^3$$

so No. of pentavalent / impurity atoms added is equal to 5×10^{16} atoms/cm^3.

As Temp↑ No. of electrons moving from ~~DONAR~~ E_D into CB is equal to $5 \times 10^{16}/cm^3$

Let at Room Temp. Let 1.5×10^{10} covalent Bonds are broken. This creates Thermally generated e^-s ⇒ $1.5 \times 10^{10}/cm^3$

∴ Holes $= 1.5 \times 10^{10}/cm^3$

Hence No. of e^-s moving from VB to CB is $1.5 \times 10^{10}/cm^3$

Finally

No. of e^- in the CB ⇒ $(5 \times 10^{16} + 1.5 \times 10^{10})/cm^3$

⇒ $5 \times 10^{16}/cm^3$

No. of Holes in the VB is $1.5 \times 10^{10}/cm^3$

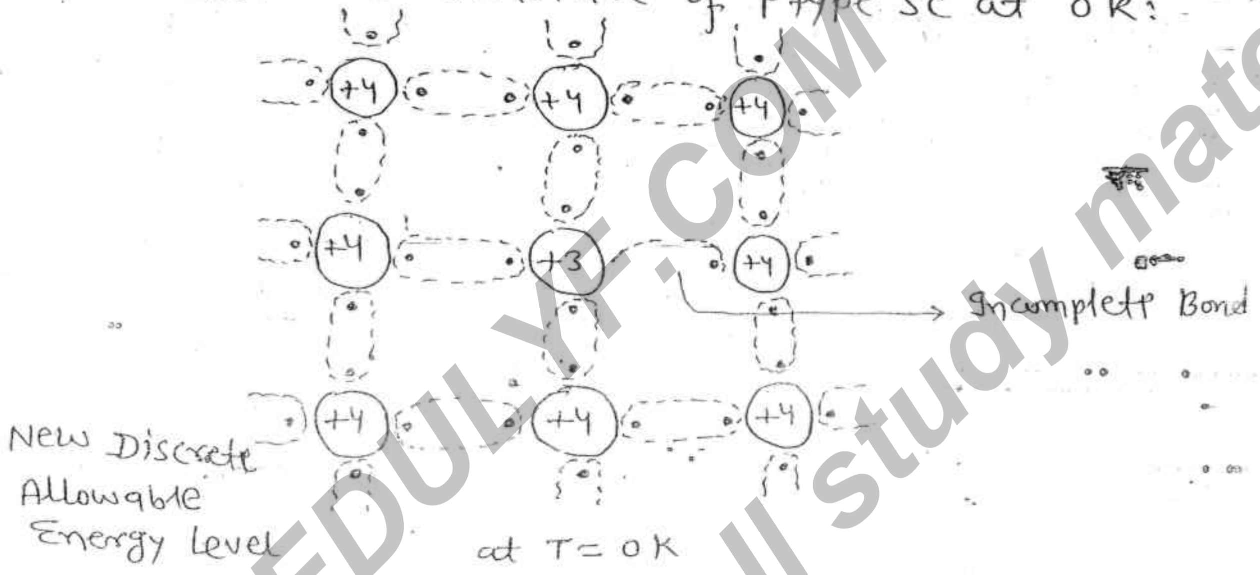
Hence $n >> p$

⇒ The Hole concentration in the valancing band will be less than $1.5 \times 10^{10} / cm^3$ and this is due to a large number of Recombination.

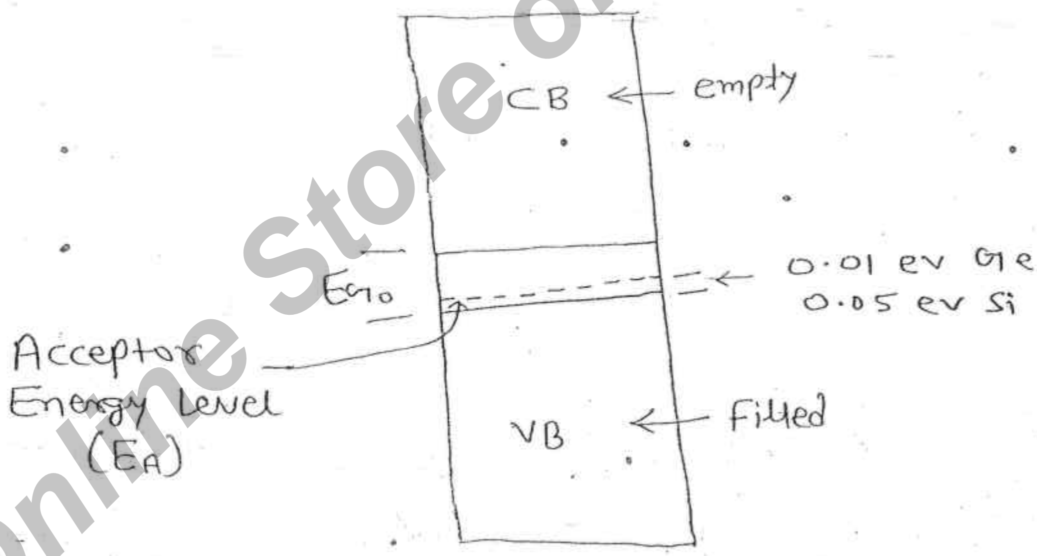
⇒ **P-Type Semiconductor OR Acceptor:**

The Impurity is trivalent.

Crystalline structure of p type SC at 0K:



at T=0K



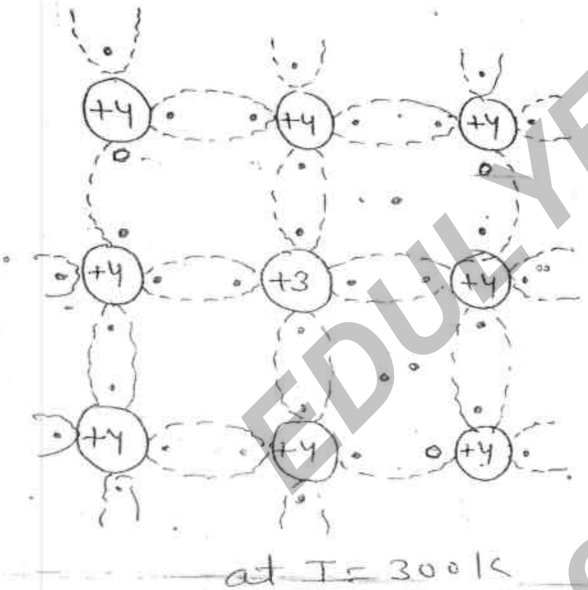
at T=0K

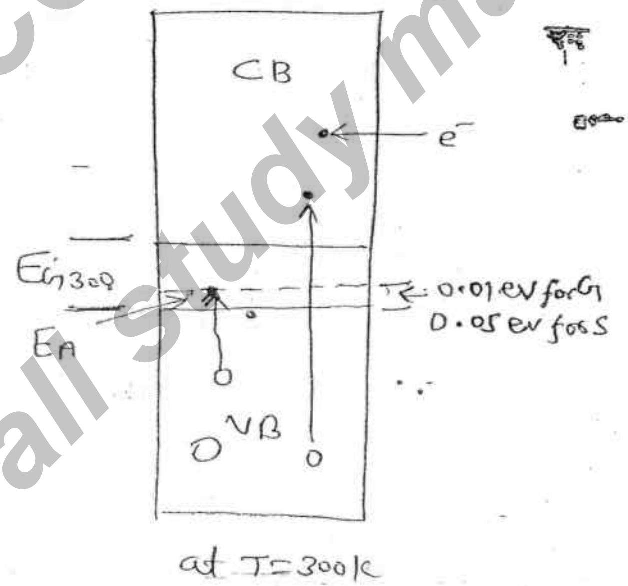
⇒ Acceptors Energy level is created just above the valency band.

⇒ E_A denotes the energy level of all the trivalent impurities added to the pure semiconduct.

⇒ P-Type SC at 0 K will behave as an insulator. (Not perfect)

at 300k





⇒ In P-type SC every Impurity atom will be receiving one e^- to complete its covalent bonding (Hence P-type is also called Acceptor)

⇒ In P-type SC as Temp. increases else ~~due~~ to ~~the~~ thermal energy a large number of covalent bond will be broken creating equal No. of e^-s and Holes, most of these e^-s will be moving from valency band into Acceptor energy level for bonding and very few electrons will be moving from valency band to conduction band so that Hole concentration in the valency band is far greater than electron concentration in the

- Holes and minority carriers are electrons.

⇒ In p-type SC current is dominated by holes.

⇒ The condⁿ for p-type sc is

$$\boxed{\begin{matrix} p > n_i \\ n < n_i \end{matrix}}$$

$$n = p = n_i$$

⇒ In p-type ~~semi~~ SC, as Hole concentration increases above n_i ~~el~~ e⁻ concentration falls below n_i and this is due to bondings.

⇒ According to the law electrical nutrality

$$N_D + p = N_A + n$$

In p-Type SC, $N_D = 0$

$$\Rightarrow \boxed{p = N_A + n}$$

Generally, In p-type sc, $p >> n$ (negligible)

$$\Rightarrow \boxed{p = N_A}$$

N_A is called Acceptor Concentration and it denotes the exact Number of trivalent atoms added to the pure semiconductor.

$$N_A = \frac{\text{Total No. of Atoms}}{\text{Volume}} \times \text{Impurity ratio}$$

⇒ The conductivity of p-type semiconductor (σ_p)

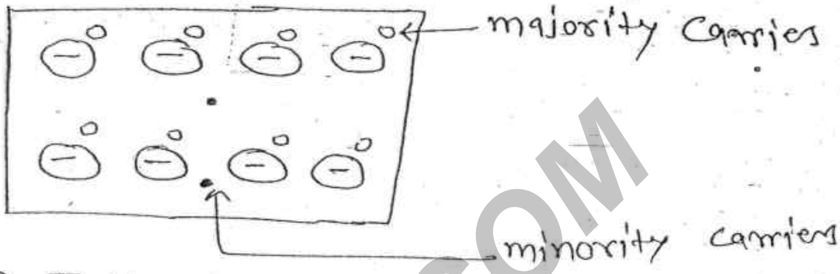
$$\sigma_p = nq\mu_n + pq\mu_p \ \ ℧/cm$$

$$\sigma_p \simeq pq\mu_p$$

$$\sigma_p \simeq N_A q \mu_p$$

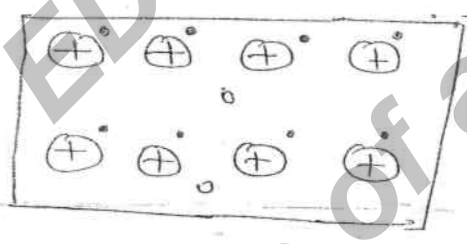
⇒ The conductivity due to minority carries is almost neglible.

Representation of P-Type semiconductor:



⇒ In P-Type SC, the Impurity atom after Receiving the e^- will be gaining the ⊖ve charge and becomes ⊖ve ion.

Representation of N-type Semiconductor:



⇒ In N-type SC, the Impurity atom will be donating one e^- and therefore will be gaining the ⊕ve charge Hence it becomes a ⊕ve ion.

The LAW of Electrical Nutrality:

Total +ve charge = Total -ve charge

$$N_D + p = N_A + n$$

N_D → DONAR concentration Represents a ⊕ve charge
N_A → Acceptor " " " ⊖ve charge

$$\boxed{N_D - N_A = n - p}$$

Intrinsic SC,

$N_D = 0, \quad N_A = 0$

$\Rightarrow \quad p = n$

$\Rightarrow$ Intrinsic SC, is always electrically neutral.

N-type SC,

$N_A = 0$

$n = N_D + p$

Since p is negligible

$n \approx N_D$.

P-type SC,

$N_D = 0$

$p = N_A + n$.

Since $n \rightarrow$ negligible

$p \approx N_A$

***

$\Rightarrow$ All semiconductors are electrically neutral. i.e. ~~the net charge is~~ zero.

Que 1 A pure SC (Ge) is doped with donar impurities to the extent of 1 : 10^7 Calculate

(i) DONAR concentration

(ii) concentration of electrons and Holes

(iii) Conductivity and Resistivity of the Doped SC.

(iv) How many times the conductivity is increase due to the Doping.

Total No. of atoms in Ge, is $4.42 \times 10^{22}/cm^3$,

$n_i = 2.5 \times 10^{13}$ atoms/cm^3

$\mu_n = 3800\ cm^2/v\text{-sec}$

$\mu_p = 1800\ cm^2/v\text{-sec}$.

Sol^n (i) Since the DONAR impurities are added to the semiconductor become N-type

$$N_D = \text{Total No. of } \frac{\text{Atoms}}{\text{volume}} \times \text{Impurity ratio}$$

$$= 4.421 \times 10^{22} \times \frac{1}{10^7}$$

$$= 4.421 \times 10^{15} \text{ atoms/cm}^3$$

(ii) In N-type SC,

$$n = N_D$$

$$n = 4.421 \times 10^{15} /\text{cm}^3$$

$$p = \frac{n_i^2}{n} = \frac{(2.5 \times 10^{13})^2}{4.421 \times 10^{15}}$$

$$p = 1.41 \times 10^{11} /\text{cm}^3$$

(iii) pure SC $n = p = n_i = 2.5 \times 10^{13} /\text{cm}^3$

After impurities are added

$n \uparrow$ 10^{13} to 10^{15} /cm^3

$p \downarrow$ 10^{13} to 10^{11} /cm^3

$$\sigma_N = N_D q \mu_n$$

$$\simeq 4.421 \times 10^{15} \times 1.6 \times 10^{-19} \times 3800$$

$$\simeq 2.68 \text{ ℧/cm}$$

and $\rho_N = \frac{1}{\sigma_N} = \frac{1}{2.68} = 0.373 \ \Omega \text{ cm}$

(iv) $\sigma_i = n_i q (\mu_n + \mu_p) = 0.0224$ ℧/cm

By adding $1 : 10^7$ impurities

$\sigma \uparrow$ from 0.0224 ℧/cm to 2.68 ℧/cm

$$\sigma \uparrow = \frac{2.68}{0.0224} = 119.6 \simeq 120 \text{ times}$$

Que A pure semiconductor (Si) is doped with Acceptor Impurities to extent of 4 impurity atom for every one million (10^6) atoms. Calculate its conductivity

Total No. of Si is $5 \times 10^{22}/cm^3$

$n_i = 1.5 \times 10^{10}$ atoms$/cm^3$

$\mu_n = 1300$ $cm^2/V\text{-}sec$

$\mu_p = 500$ $cm^2/V\text{-}sec$

Solⁿ

Since the Acceptor Impurities are added to semiconductor become p-type

$$N_A = \frac{\text{Total No. of atoms}}{\text{volume}} \times \text{impurity ratio}$$

$$= 5 \times 10^{22} \times \frac{4}{10^6}$$

$$= 2 \times 10^{17} \text{ atoms}/cm^3$$

$$\sigma_p \simeq N_A q \mu_p$$

$$\simeq 2 \times 10^{17} \times 1.6 \times 10^{-19} \times 500$$

$$= 16 \, \mho/cm.$$

Que A pure SC (Si) is doped with donor impurities to the extent of $1:10^6$ calculate

(i) conductivity due to majority carriers

(ii) Conductivity due to minority carriers

Assume Total No. of atoms $= 5 \times 10^{22}/cm^3$

$n_i = 1.5 \times 10^{10}$ atoms$/cm^3$

$\mu_n = 1300$ $cm^2/V\text{-}sec$

$\mu_p = 500$ $cm^2/V\text{-}sec$

Soln

$N_D = 5\times10^{22}\times\frac{1}{10^6} = 5\times10^{16}$ atoms/cm³

S.C. Turns N type

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(i) $\sigma_{majority} = n q \mu_n$

$= 5\times10^{16}\times1.6\times10^{-19}\times1300$

$= 104\times10^{-1}$ ℧/cm

$= 10.4$ ℧/cm (Due to majority carrier)

$\rightarrow n \simeq N_D$ and $p = \frac{n_i^2}{n} = \frac{(1.5\times10^{10})^2}{5\times10^{16}}$

$p = 0.45\times10^{4}$

$\simeq 4500/cm^3$.

(ii) $\sigma_{minority} = p q \mu_p$

$= 4500\times1.6\times10^{-19}\times500$

$= 3.6\times10^{-13}$ ℧/cm

IES

Que In a SC at room temp., the intrinsic concentration and Resistivity are $1.5\times10^{16}/m^3$ and 2×10^3 Ωm respectively it is converted into an extrinsic SC with a doping concentration of $10^{20}/m^3$ for the extrinsic SC calculate, (i) minority carrier concentration (ii) electron mobility (iii) Resistivity of the doped semiconductor (iv) minority carrier concentration when temperature is increase to a value at which the intrinsic carrier concentration Doubles. Assume $V_T = 26mV$ for room temperature and let mobility of majority carriers is equal to the mobility of minority carriers.

Sol^n (i) Majority carrier concentration
≈ Doping conc.

⇒ majority carrier conc. = $10^{20}/m^3$

minority carrier concentration = $\frac{n_i^2}{\text{Dopping conc.}}$

$$= \frac{(1.5\times10^{16})^2}{10^{20}}$$

$$= 1.5\times10^{12}/m^3$$

(ii) $\mu_n = ?$

$\mu_n \equiv \mu_p \equiv \mu$

$$\rho_i = \frac{1}{n_i q[\mu_n+\mu_p]}$$

$$\rho_i = \frac{1}{n_i q 2\mu}$$

$$\mu = \frac{1}{\rho_i n_i \cdot 2}$$

$$= \frac{1}{2\times10^3\times1.5\times10^{16}\times1.6\times10^{-19}\times2}$$

$\mu = 0.1042\ m^2/v\text{-sec}$
→ μ_n

(iii) ρ_{Doped}

$$\rho_{Doped} = \frac{1}{\text{Doping Conc}\times q\times\mu}$$

$$= \frac{1}{10^{20}\times1.6\times10^{-19}\times0.1042}$$

$= 0.598$

$\approx 0.6\ \Omega m$