IES/GATE

Electrical Engineering

VOLUME-III

Basic Electronics Engineering
Control System

CONTENT

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Toppersnotes
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ELECTRONIC DEVICES & CIRCUITS

1. Integrated Electronics
   by Millman Halkias
2. Micro Electronics
   by Sedra & Smith.
3. Electronics devices & circuits.
   By Neamen.

Classification of Temprature:

(1) Absolute temp $0K = -273C$

[2] Room Temp $300K = 27°C$ [for semiconductor devices by default this temp is considered]

[3] Ambient Temp $[T_A]$ $290K = 17°C$ (Surrounding Temp). [For communication system Ambient temp took as default temp].

$$\text{Temp in °C} = \text{Temp in Kelvin} - 273$$

$$°K = K$$

Thermal voltage :- (V_T):-

* "Volt equivalent of temprature"

$$V_T = \frac{KT}{q} \text{ volt}$$

T = Temprature in K
q = magnitude of charge
$= 1.6023 \times 10^{-19}$ coulomb.
K = 1.381×10^{-23} J/K.

K (Boltzman Constant):

$K = 1.381 \times 10^{-23}$ J/K.

$K = 8.62 \times 10^{-5}$ eV/K.

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

$$V_T \propto T$$

If $T = 0K$ $V_T = 0$

If $T = 300K$ $V_T = \frac{300}{11600} = 0.02568$ volt $\simeq 26$ mvolt.

The standard room temprature corresponds to a voltage of 26.

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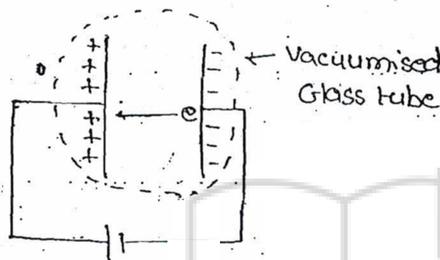
* For a large variation in temprature we get a minute variation in thermal voltage.

Electron volt (eV):-

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



ϵ_r (air) = 1.01 ≈ 1

ϵ_r (Vacuum) = 1

$1\,ev = |q| \times P.D.$ $\quad V = \frac{W}{q}$

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

$= 1.6 \times 10^{-19}$ Coulomb-Volt or Joule.

$$\boxed{1\,eV = 1.6 \times 10^{-19}\ \text{Joule}}$$

* Electron volt indicates the kinetic energy gained by the electron or potential energy lost by the electron.

$K.E. = \frac{1}{2} m v^2$ → mass of e^- (9.1×10^{-31} k.g.).

$P.E = q.V.$

K.E. gained = P.E loss

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

Velocity of e^- $\boxed{v = \sqrt{\frac{2qV}{m}}}$ meter/sec

Electric Field Intensity ($\mathcal{E}$ or E):-

Normally called as Field intensity, field gradient or field.

By Definition $\boxed{\mathcal{E} = -\frac{dv}{dx}}$ volt/meter

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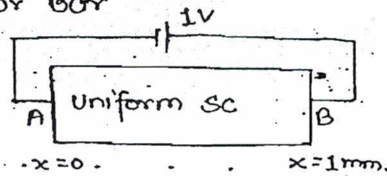
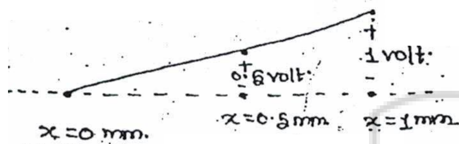
$$|\mathcal{E}| = \frac{|\text{Voltage}| \text{ existing}}{\text{spacing or distance}}$$

Ex: Considering a uniform semiconductor Bar





Magnitude of field intensity at end B.

$$|E|_B = \frac{|V_B|}{x_B} = \frac{1 \text{ volt}}{1 \times 10^{-3} m} = 10^3 \text{ V/m}.$$

Magnitude of field at centre of bar.

$$|E|_C = \frac{|V_C|}{x_C} = \frac{0.5}{0.5 \times 10^{-3}} = 10^3 \text{ V/m}.$$

$$|E|_A = \frac{|V_A|}{x_A} = \frac{0}{0} = \text{undefined}.$$

Mobility of Charge Carrier (μ):-

Mobility denotes the current carrying capacity or how fast the charge carrier is moving from one place to another place.

Mobility is defined as drift velocity to field intensity

$$\mu = \frac{V_d}{E} \quad m^2/\text{V-s or } cm^2/\text{V-sec}$$

$$\mu = \frac{\text{Drift Velocity}}{\text{field intensity}}$$

e^- mobility (μ_n or μ_e).

hole mobility (μ_p or μ_h)

μ	Ge	Si
μ_e	3800 cm^2/V-sec	1300 cm^2/V-sec
μ_p	1800 cm^2/V-sec	500 cm^2/V-sec

$$\frac{\mu_n}{\mu_p} = 2.1 \quad (\text{for Ge})$$

$$\frac{\mu_n}{\mu_p} = 2.6 \quad (\text{for Si})$$

Electron mobility is always greater than hole mobility.

Electron can travel faster & also contribute more current than hole.

Ge
- Higher conductivity (Due to larger mobilities)
- Relatively more suitable for high frequency application [due to large B.W]

Si
- Relatively more suitable for switching applications (Better thermal stability).
- Best suit for high power application (Natural Property).

Mobility of charge carrier always decreases with the temprature.

As temprature increases atoms of the material will vibrate & due to this thermal vibration or thermal agitation the mobility of charge carrier [illegible].

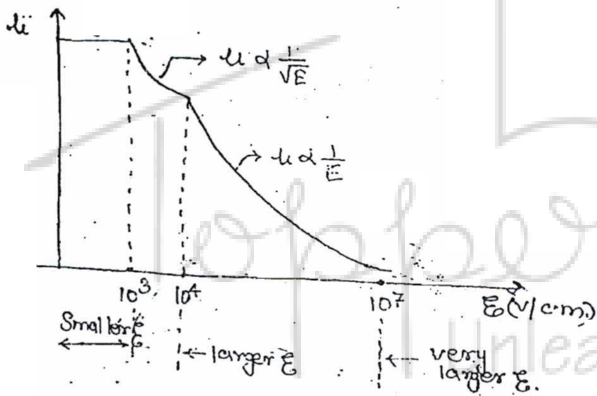
$$\mu \propto T^{-m}$$

where m is constant and is given as

for Si	for Ge
m = 2.5 for e⁻	m = 1.66 for e⁻
= 2.7 for hole.	= 2.33 for hole.

Mobility decreases with the temprature as a non linear variation.

μ V/S E curve for a S.C. :-
(Experimentally plotted).



$V_d = \mu E$

Question: when smaller field intensities are applied to the semiconductor

(a) mobility of charge carrier's remain constant.

b) Drift velocity linearly increases with the field intensity.

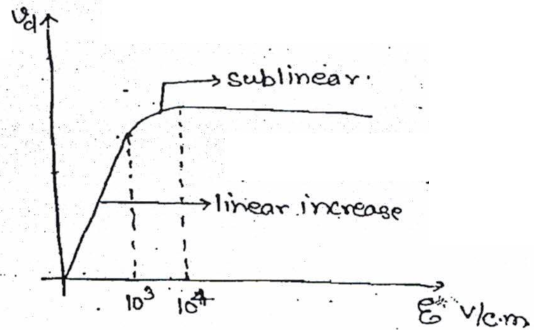
$$V_d = \mu E$$

Question: when larger field intensities are applied to the semiconductor

(a) mobility of the charge carrier decreases.

b) Drift velocity enter's into saturation.

Vd V/S E Curve for S.C :-

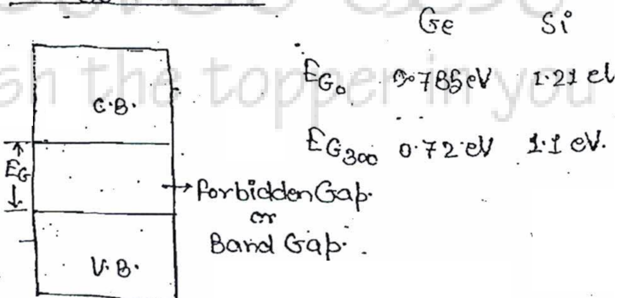


Question: In a semi conductor when field intensity are increasing the drift velocity

(a) linearly increases.

(b). Sublinearly increases & enter's into saturation with larger field's applied.

Energy Gap (E_G) :-



	Ge	Si
E_{G_0}	0.785 eV	1.21 eV
$E_{G_{300}}$	0.72 eV	1.1 eV.

In semiconductor, E_g (or) energy gap decreases with temprature.

$$E_g \propto \frac{1}{Temp(T)}$$

Imp

$$E_G(T) = E_{G_0} - \beta_0 T \text{ eV}.$$

β_0 = material constant (eV/°K).

for Si $\beta_0 = 3.6 \times 10^{-4}$ eV/°K.

$$E_G(T) = 1.21 - 3.6 \times 10^{-4} T$$

for Ge $\beta = 2.33\times10^{-4}$

So $E_G(T) = 0.785 - 2.33\times10^{-4}\,T$

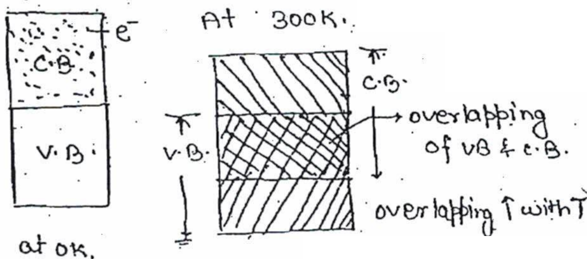
Classification of Element's into conductor's, semiconductor's, & insulators:-

Conductor's or Metal's:-

* very good conductor's of currents.
* Valance electron's are ≤ 3
* All metal's are unipolar.
* I, II & III group of periodic table (metallic or non metallic).
* In metal free e^- concentration is very high.

$$\text{Concentration of } e^-(\eta) = 10^{28}/m^3$$

* metallic Bonding is present
* Energy gap $E_g = 0$ at 0K.



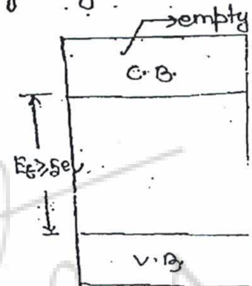
* In metal's free electron's are available even at 0°K.

  In metal's free electron concentration is independent of temprature.
* Because of overlapping a valance band & conduction band metal will exhibit PTC of resistance.
* In metal's there is only a dri[ft] current.

E.g. → Gold, Silver, Tungsten, Platinum, [Alu]-minium, Copper, Tin, Iron, Uranium.

Insulator's:

Bad conductors of current.
Valency electron's are 7 or 8.
Ionic bonding
NTC. (Negative Temprature Co-effici[ent] of resistance
Energy gap is very large
$E_g \geq 5\,eV$.
Conductivity is zero for ideal insulators.
σ = negligible for practical insulators.



In insulator's E_G (Energy Gap) sli[ghtly] decreases with the temprature ↑
Insulator's are subjected to brea[k] -down.

E.g. Diamond, SiO_2, Air, Mica, cerami[c], parcelain, Bakelite, Paper, Rubber, Co[tton], PVC, Leather, wood, glass, Plastic, fiber.

Semi Conductor's (S.C.):-

* Semi-conductors are element's wh[ose] conductivity lies between the conductivity of an insulator & conductivity of a conductor.
* Valance electron's are 4. (IV group belong to S.C.)

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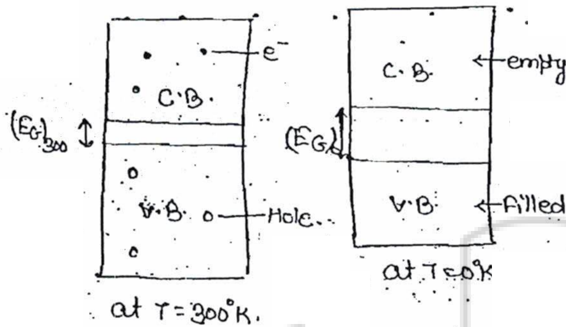
2. Covalent Bonding.

3. All semiconductors are insulators at 0°K.

4. Energy gap is small (0.7eV to 1.5eV) or ≃ 1eV.

Energy Band Diagram at 0°K.



5. At 0°K carrier concentrations are zero & therefore conductivity is 0. & semiconductor at 0°K will be working as an insulator.

6. At 300°K because of thermal energy a no. of covalent bond will be broken & equal no. of electron & hole's are created & there will be a conductivity in a semiconductor.

7. Semiconductor's are Bipolar having two different type of charge carriers. electrons & holes.

8. In a semiconductor there will be a diffusion current.

9. All semiconductor's are temprature sensitive.

10. In a SC energy gap decreases with temprature.

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

E.g. Si, Ge.

05/07/2013

Why carbon is not considered as a SC element?

* Carbon belongs to IV group of the periodic table but it is never considered as a semiconductor element because energy band gap is more than 1.5 ev.
It has very unreliable & unpredictable properties.
Graphite → behaves as SC & conducts at different temprature.
Diamond → behaves as

Einstein's Equation:-

* It was given just as a mark of respect to great physicist Einstein.
* In a SC

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

* It gives the relationship b/w diffusion constant, mobility & thermal voltage

$$\frac{\mu_n}{D_n} = \frac{\mu_p}{D_p} = \frac{1}{V_T} \quad V^{-1}$$

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* The unit of mobility to diffusion constant is V^{-1}
* The unit for $\frac{D}{\mu}$ is volt.

Diffusion Constant of Charge Carriers:-

e⁻ diffusion Constant $(D_n) = \mu_n V_T$
the hole diffusion constant $(D_p) = \mu_p V_T$

Unit for D → cm^2/sec or m^2/sec.

$$D = \mu V_T$$

* Diffusion constant of charge carrier decreases with the chapter temp^r.

Diffusion constant for Ge at 300K:-

$D_n \approx 99\ cm^2/sec$
$D_p \approx 47\ cm^2/sec$

For Si at 300K:

$D_n = 34\ cm^2/sec$
$D_p = 13\ cm^2/sec$

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

or $\boxed{\frac{D_n}{D_p} = \frac{\mu_n}{\mu_p}}$ or $\boxed{D_n \mu_p = D_p \mu_n}$

For Ge

$$\frac{D_n}{D_p} = 2.1$$

For Si

$$\frac{D_n}{D_p} = 2.6.$$

* Diffusion constant is a material const associated with the property called diffusion & it can not be negative.

MASS ACTION LAW:-

$$\boxed{np = n_i^2}$$

mass action law states that in a sc (intrinsic or extrinsic) under thermal equilibrium the pro of electrons & holes is alw a constant & it is equal to square of intrinsic concentr

* The law is particularly used extrinsic semiconductors to cc minority carrier concentration

N-Type Semiconductor

Majority carriers are e⁻s $= n_n$
Minority carriers are holes = h

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

P-Type Semiconductor:-

Majority carriers are holes =
Minority carrier are e⁻s = n

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

→ In a pure semiconduct e⁻s & hole concentrations are respectively by adding impu atom into the semiconductor e⁻ & holes concentration are n respectively.. then followi relation are applicable.

$$\boxed{n_1 p_1 = n_2 p_2 = n_i^2}$$

Intrinsic Concentration (n_i):-

Intrinsic ≡ Pure

$n = p = n_i$

$$\boxed{n_i^2 = A_0 T^3 e^{-E_G/KT}}$$

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√ $$n_i = \sqrt{A_0} \cdot T^{3/2} e^{\frac{-E_G}{2KT}}$$

A_0 = Material constant

* Intrinsic concentration is a function of temprature & energy gap

I a. sc, Intrinsic concentration (n_i^2) ∝ --
(a) T^3 b) $T^{3/2}$

In a sc, intrinsic concentration n_i ∝ --
(a) T^3 (b) $T^{3/2}$

* Intrinsic concentration increases with the temprature as a non linear variation

* when compared to Silicon, germanium has larger value of n_i & this is due to smaller value of energy gap.

At 300K
In Ge, $n_i = 2.5 \times 10^{13}$ atom/cm²
Si, $n_i = 1.5 \times 10^{10}$ atom/cm³.

Resistivity (ρ) :-
(Specific Resistance)

Unit for ρ → Ω-cm.
or Ω-m.

* In metal resistivity increases with temprature.

* In semiconductor resistance decreases with temprature.

Conductivity (σ):-

* The Reciprocal of resistivity · e $\frac{1}{\Omega\text{-m}}$.

* It denotes current carrying capacity of device or material

* It denotes current

Imp
$$\sigma = \text{Carrier Conc}^n \times q \times \text{mobility}$$

* Conductivity depend's on carrier concentration, magnitude of charge & mobility.

* Conductivity variation may be due to variation in carrier concentration & variation in mobility

$$\sigma = n q \mu_n$$

* In metal's conductivity decreases as temprature.

* In metal's free electron concentration is independent of temprature so conductivity does not depend on carrier concentration.

For semi conductor's (Bipolar)

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

* In Intrinsic semiconductor, conductivity increases with the tempr.

* In Intrinsic semiconductor, as tempr increases mobility decreases and this will slightly reduce the conductivity & at the same time because of thermal energy a large no. of covalent bond will be broken & equal no. of e⁻ & holes are generated

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• & this will increase the conductivity by a larger value & that's why conductivity increases with temp^r in intrinsic sc.

* In sc conductivity mainly depends on carrier concentration.

Current Density (J):

It is the current passing per unit area.

$$J = I/A \; A/m^2 \text{ or } A/cm^2$$

$$J = \sigma E$$ E → electric field intensity

In metal's

Current density(J) = $nq\mu E$

In sc

$J = nq\mu_n E + pq\mu_p E$

$$J = qE(\mu_n n + p\mu_p) \; A/m^2$$

Current:-

* Rate of change of charge is known as current.

$$i = \frac{dq}{dt}$$ Ampere.

Drift Current:

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

Diffusion Current & Diffusion:-

Diffusion is a natural property. Diffusion is defined as the migration of charge carriers from higher concentration to lower concentration or from higher density to lower density.

Gradient (slope) = $\frac{d}{dx}$

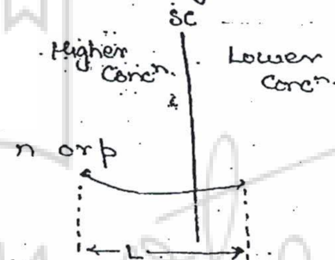
$\frac{dn}{dx}$ = e^- concentration gradient

$\frac{dp}{dx}$ = hole concentration gradient

Unit $\frac{dn}{dx}$ = $e^-/cm^3/cm$.

Unit $\frac{dp}{dx}$ = holes$/cm^3/cm$.

* Diffusion is mainly occured due to concentration gradient.



* Diffusion current flows only semiconductor's.

* In a semiconductor diffusion is due to unequal distribution of charge carrier's

Note: In metal's conc^n of e^- are very high & also they exist with equal distribution & there is no diffusion.

Length of Diffusion:-

$$L = \sqrt{\tau D} \; cm.$$

but $D = \mu V_T$

$$L = \sqrt{\mu V_T \tau} \; cm.$$

τ → carrier lifetime

τ → Average carrier life

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* carrier lifetime is average lifetime
* Length of Diffusion is average length.
* Length of Diffusion depends on diffusion constant, carrier lifetime mobility of charge carriers & temp^n.

e^- Diffusion length $L_n = \sqrt{D_n \tau_n}$ cm.
hole's " " $L_p = \sqrt{D_p \tau_p}$ cm.

$\boxed{\tau_n \neq \tau_p}$

e^- Diffusion current density $[J_{n(diff)}]$:-

$$\boxed{J_{n(diff)} = +q D_n \frac{dn}{dx} \ A/cm^2}$$

hole Diffusion Current density $[J_{p(diff)}]$:-

$$\boxed{J_{p(diff)} = -q D_p \frac{dP}{dx} \ A/cm^2}$$

e^- Diffusion Current $I_{n(diff)} = J_{n(diff)} \times Area$
hole Diffusion current $I_{p(diff)} = J_{p(diff)} \times Area$

* If Area is not specified in the problem then by default always Consider unit cross sectional area.

Total current density in a semiconductor

$J = J_n + J_p$

$J_n = (J_n)_{drift} + (J_n)_{diff}$

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

$J_p = (J_P)_{drift} + (J_P)_{diffusion}$

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

$$\boxed{J = \underbrace{qn\mu_n E}_{(J_n)_{drift}} + \underbrace{\frac{dn}{dx} D_n q}_{(J_n)_{diffusion}} + \underbrace{qP\mu_p E}_{(J_p)_{drift}} - \underbrace{qD_p \frac{dP}{dx}}_{(J_p)_{diffusion}}}$$

$$\boxed{J = qn\mu_n E + qP\mu_p E + qD_n \frac{dn}{dx} - qD_p \frac{dP}{dx}}$$

* Drift current depends on carrier concentration, mobility of charge carriers & field intensity.
* Drift current mainly depends on electric field intensity
* Diffusion current mainly depends on concentration gradient.

Operating Temperatures

i) for Ge

-60°c to +75°c

Maximum operating temperature = 75°C.

ii) for Si

-60°c to 175°c

Maximum operating temperature = 175°c

⇒ Normal working temperature :-

$\boxed{100K \text{ to } 400K}$

Leakage Current's (I_o) :-

* This is also called as reverse saturation current or minority carrier current.
* It is also called as temperature generated or thermally generated current.
* It never depends on applied voltage across the material.

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* This current is saturated w.r.t voltage only when we will increase voltage the current will not vary (saturates).

* It increases with increase in temprature.

* for 1°c rise in temprature, the value of current (I) increase by 7%.

* I_0 gets doubled by increasing 10°c of temprature in both Ge & Si.

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

	Ge	Si
I_0	μA	nA

I_0 of Ge > I_0 of Si

* I_0 - depends on minority carriers and minority carrier concentration will be dependending on temprature. Hence this current is generated only because of temp^r. hence called thermally generated current.

* It is highly sensitive to temp^r.

* for Better performance leakage currents must be smaller. If leakage currents are small the temprature effect on the material or device will be small & this indicates better thermal stability.

* Si is having better thermal stability than Ge.

* The greatest advantage of Si is smaller leakage currents.

Conductivity sensitivity :-

1. In Intrinsic semiconductor, conductivity increases with the temprature.

Imp:
- for 1°c rise in Ge, σ↑ by 6%.
- for 1°c rise in Si, σ↑ by 8%.

2. when compared to Ge. Si is having higher sensitivity to the temprature but Si is more suitable for high temprature application & this due to the smaller leakage currents.

Electrical Properties of Ge & Si

↓ Properties	Ge	Si
1. Atomic Number	32	14
2. Total no. of Atoms (Density of atoms)	4.421×10^{22} /cm³	5×10^{22} /c…
3. Intrinsic Concentration $(n_i)_{300K}$ (atom/cm³)	2.5×10^{13}	1.5×10^{10}
4. Intrinsic Resistivity ρ_i (300K) (ohm-cm)	45	2,30,000
5. Leakage Current (I_0)	≃μA	≃nA
6. Max^m operating Temp^r	75°C	175°C
7. Power handling Capability	low power	High p…

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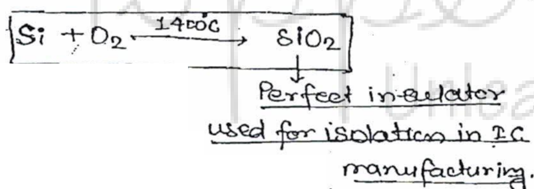
* when compare to Ge, Si. is more preferrable due to

[a] Smaller leakage Current.
[b] High temprature application.
[c] High power handling
[d] Si is plenty available on the surface of earth → This is the primary reason why silicon is widely used by semiconductor's device manufacturer's.
[e] Si is very cheap & economical.
[f] Favourable property to form SiO_2.
⇓
This is the main reason why Si is very fancy for IC manufacturing.



$$Si + O_2 \xrightarrow{1400°C} SiO_2$$

SiO_2 → Perfect insulator used for isolation in IC manufacturing.

Major Disadvantage of Silicon:-

* Smaller Conductivity than Ge

Note:- Silicon when exposed to 1400°C will melt & we get liquid Silicon & when reacted with the oxygen we get SiO_2

SiO_2 is a perfect insulator.

SiO_2 is used to provide isolation in between the components during the IC manufacturing.

Minimum Conductivity in SemiConductor

The conductivity of a semiconductor is

$$\boxed{\sigma = nq\mu_n + pq\mu_p} \quad \text{—(i)}$$

By mass action law we can write

$$p = \frac{n_i^2}{n} \quad \text{—(ii)}$$

Substituting (ii) in eqn (i)

$$\sigma = nq\mu_n + q\mu_p \cdot \frac{n_i^2}{n} \quad \text{—(iii)}$$

differentiating above equation wrt n

$$\frac{d\sigma}{dn} = q\mu_n + q\mu_p n_i^2\left(-\frac{1}{n^2}\right)$$

$$\frac{d^2\sigma}{dn^2} = q\mu_p n_i^2\left(\frac{2}{n^3}\right)$$

Since second derivative is positive we get the condition for minimum conductivity by $\frac{d\sigma}{dn} = 0$

$$q\mu_n + q\mu_p n_i^2\left(-\frac{1}{n^2}\right) = 0$$

$$\mu_n = \mu_p (n_i)^2 \frac{1}{(n^2)}$$

$$n^2 = \frac{\mu_p}{\mu_n} \cdot (n_i)^2$$

$$\boxed{n = n_i\sqrt{\frac{\mu_p}{\mu_n}}} \quad \text{—(iv)}$$

Putting this value in eqn (iii)

$$\sigma = n_i q\sqrt{\mu_n\mu_p} + q\mu_p \cdot \frac{n_i^2}{n_i}\sqrt{\frac{\mu_n}{\mu_p}}$$

$$\sigma = n_i q\sqrt{\mu_n\mu_p} + q n_i\sqrt{\mu_n\mu_p}$$

$$\boxed{\sigma = 2n_i q\sqrt{\mu_n\mu_p}} \quad \text{—(v)}$$

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eq^n (v) is the equation to calculate the minimum condictivity.

By eq^n (v) & eq^n (ii)

$$p = n_i \sqrt{\frac{\mu_n}{\mu_p}}$$

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

Question: If Drift velocity of hole's under a field gradient of 100 V/m is 5 m/sec find it's mobility

Solution:

$$\mu = \frac{5}{100} = 0.05 \ cm^2/V\text{-}sec$$

Question: The carrier mobility in a semiconductor is 0.4 m^2/V-s if diffusion constant at room $temp^r$ is ____

$$D = \mu V_T$$
$$= 0.4 \times 0.026$$
$$D = 0.0184 \ m^2/sec.$$

Q. The minority carrier lifetime & diffusion constant in a SC material are 100 µsec & 100 cm^2/sec respectively the diffusion length of charge carrier is

Solution

$$L = \sqrt{D\tau}$$
$$= \sqrt{100 \times 10^{-4} \times 100}$$
$$L = 1 \ cm$$ Answer

Question: A flat aluminium strip of a resistivity of 8.44×10^{-8} Ω m, a cross sectional area of 2×10^{-4} m & a length of 5 mm. is subject to a current flow of 50 mA. find voltage drop across the bo

Solution:

$$V = I \cdot R.$$
$$= 50 \times 10^{-3} \times 3.44 \times 10^{-8} \times \frac{5 \times 10^{-3}}{2 \times 10^{-4} \times 1}$$
$$50 \times 3.44 \times 2.5 \times 10^{-4}$$
$$= 125 \times 3.44 \times 10^{-4} \text{ volt}$$
$$= 43 \text{ mvolt}$$

Question A SC wafer (having neglegible thickness) is 0.5 mm thick. a potential of 100 mV is applied across the thickness

(a) what is the drift velocity if mobility is 0.2 m^2/V-sec

(b) How much time is required for an electron to move across the thickness

Solution:

(a) $E = \frac{100}{0.5} = 200$ V/m.

$V_d = \mu E = 0.2 \times 200$
$= 40$ m/sec

(b) $t = \frac{0.5 \times 10^{-3}}{40} = 1.25 \times 10^{-5}$

$t = 12.5$ µsec

Question: A small concentration of minority carrier's are injected into a homogeneous SC crystal at one point & having an electric field c

In N-type sc

$N_A = 0$

$$\boxed{n = N_D + P} \text{ or } \boxed{n > N_D}$$

or

All exam $\boxed{n \approx N_D}$

* N_D is called donor concentration or the density of donor atom's & it represent's the no. of pentavalent atoms added to the sc.

Imp.

$$\boxed{N_D = \text{Total no of atoms/cm}^3 \times \text{Impurity ratio}}$$

* In N-type sc free e^- concentration is approximately equal to N_D (the density of donor atoms).

* In N-type sc, ~~the~~ current is pre-dominately dominated by the flow of electrons.

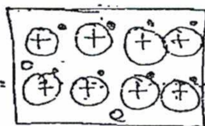
* The conductivity of entire sc is

$\sigma_N = nq\mu_n + pq\mu_p$ ℧/cm.

$\approx nq\mu_n$ ℧/cm.

$$\boxed{\sigma_N \approx N_D q \mu_n} \text{ ℧/cm.}$$

The conductivity due to minority carrier is almost neglegible entire sc is represented as



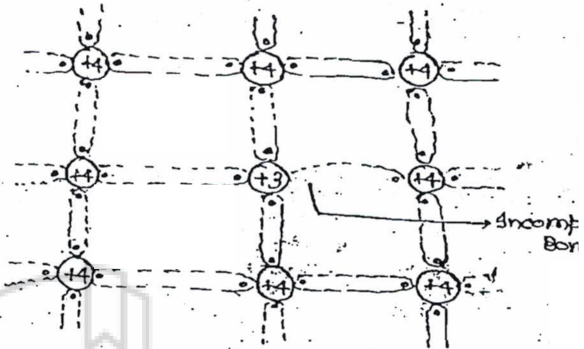
(+) ion → it is a neutral atom with $1e^-$ less.

* Ion's are called immobile charge particles.

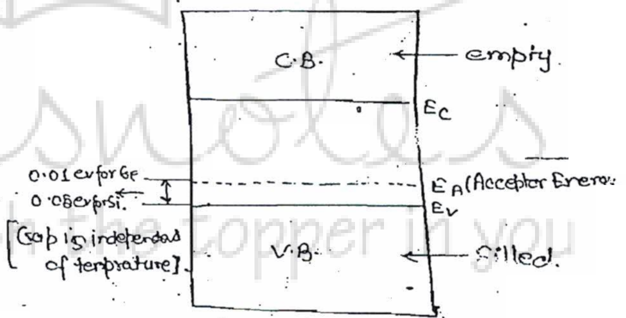
P-Type SemiConductor or Acceptors:-

* The impurity is trivalent.

Crystalline structure at 0°K.



Energy Band Diagram at 0°K.

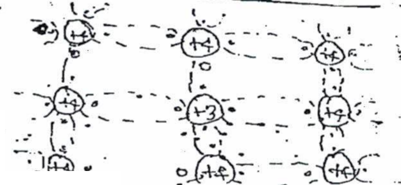


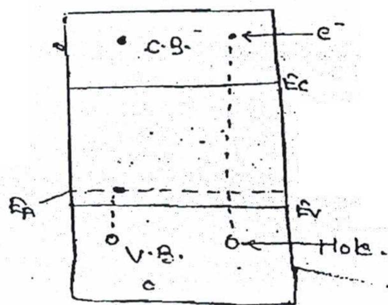
* Acceptor energy level is a discrete energy level created just above the valance band.

* Acceptor energy level denotes the energy level of trivalent atom's a to the sc.

* P-type sc at 0°K will be working an insulator.

Crystallite structure at 300°K.





Energy Band Diagram at 300 K.

* In p-type SC every impurity atom will be receiving 1 e^- to complete it's bonding hence p-type is also called as acceptor.
* $p >> n$.

Majority carrier's are holes, minority carrier's are e^-'s.

* When p-type SC is placed at room temprature, because of thermal energy a large no. of covalent bonds will be broken & equal no of electron's & hole's are generated most of these e^-'s will be moving into acceptor energy level to complete the bonding's & very few e^-'s will be moving from valance band to conduction band so that the hole concentration in the VB is far greater than e^- conc^n in the CB.
* In p-type SC current is mainly due to holes.
* The condition for p-type is

$p >> n$; $n < n_i$

The e^- conc^n is reducing below n_i due to a large no. of bonding's.

* according to the law of electrical neutrality —

$$N_D + p = N_A + n$$

Since $N_D = 0$.

$p = N_A + n$ only for IES.

or

$p \approx N_A$ for all exams

where N_A = acceptor concentration & it denotes the no. of trivalent atoms added to the SC.

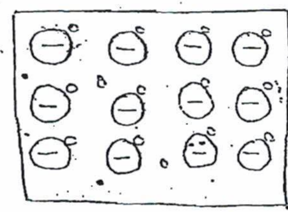
N_A = Total no. of atom's/cm^3 × Impurity ratio

* The conductivity of p-type SC is

$$\sigma_p = nq\mu_n + pq\mu_p \ \mho/cm.$$

$$\sigma_p \approx N_A q \mu_p \ \mho/cm.$$

* The conductivity due to minority carrier's is almost negligible.
* N-type SC is superior to p-type because $\mu_n > \mu_p$.
* p-type SC is represented as



LAW OF ELECTRICAL NEUTRALITY :-

* Based on law of conservation of charges
* Total positive charges = Total negative charges