IES/GATE

Electrical Engineering

VOLUME-III

Basic Electronics Engineering
Control System

Contents

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 = −273°C

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

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

$$\boxed{\text{Temp in } ^\circ C = \text{Temp in Kelvin} - 273}$$

$$\boxed{^\circ K = K}$$

Thermal voltage :- (V_T) :-

* "Volt equivalent of temprature" $\boxed{V_T = \frac{KT}{q}}$ volt.

T = Temprature in K.

q = magnitude of charge = 1.6023×10^{-19} coulomb.

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

K (Boltzman Constant):

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

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

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

$$\boxed{V_T \propto T}$$

If T = 0 K $V_T = 0$

If T = 300K $V_T = \frac{300}{11600} = 0.02568$ volt

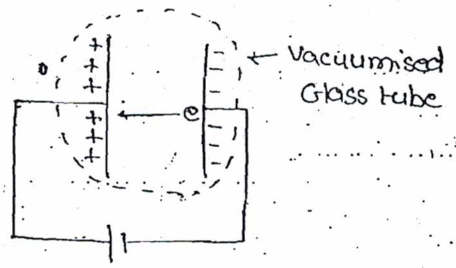
$\simeq 26$ mvolt

* The standard room temprature corresponds to a voltage of 26

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.



$\epsilon_r(\text{air}) = 1.01 \approx 1$

$\epsilon_r(\text{Vacuum}) = 1$

$1 \cdot ev = |q| \times P.D.$ $V = \frac{w}{q}$

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

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

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

* 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^- $(9.1 \times 10^{-31}$ k.g.).

$P.E = q.V.$

$K.E.$ gained $= P.E$ loss.

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

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

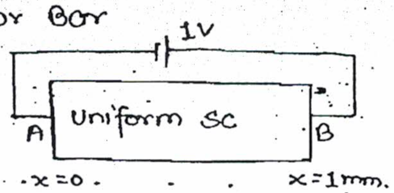
Electric Field Intensity ($\mathcal{E}$ or E):-

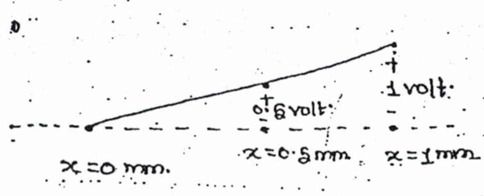
* Normally called as Field intensity, field gradient or field.

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

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

Ex. Considering a uniform semiconductor Bar





Magnitude of field intensity at end B.

$$|E|_B = \frac{|V_B|}{x_B} = \frac{1\ \text{volt}}{1\times10^{-3}\,m} = 10^3\ V/m.$$

Magnitude of field at centre of bar.

$$|E|_C = \frac{|V_C|}{x_C} = \frac{0.5}{0.5\times10^{-3}} = 10^3\ V/m.$$

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

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.

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

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

e^- mobility (μ_n or μ_e).

hole mobility (μ_p or μ_h)

μ	Ge	Si
μ_e	3800 $cm^2/V\text{-}sec$	1300 $cm^2/V\text{-}sec$
μ_p	1800 $cm^2/V\text{-}sec$	500 $cm^2/V\text{-}sec$

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

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

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 atom's the material will vibrate & due to this thermal vibration or thermal agitation the mobility of charge carrier and

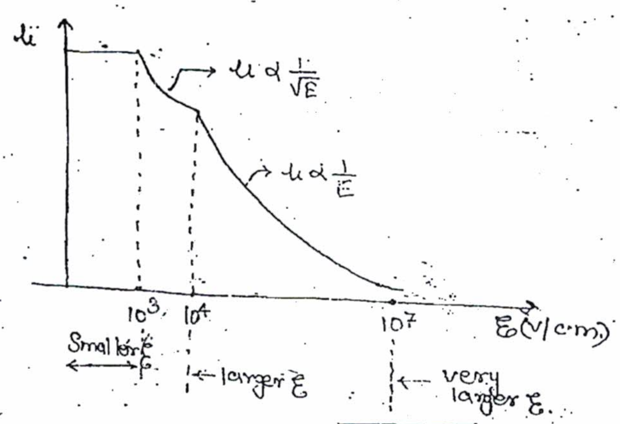
$$\mu \propto T^{-m}$$

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 $\mathcal{E}$ 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.

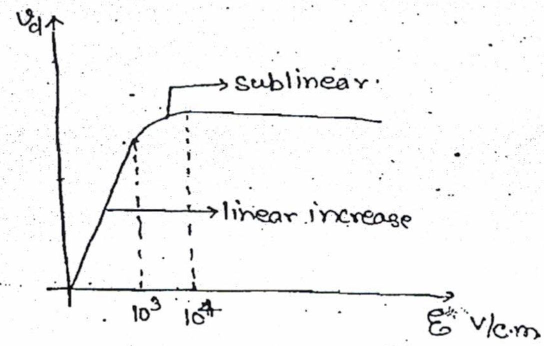
$$V_d = \mu E$$

Question: when larger field intensities are applied to the semiconductor

(a) mobility of the charge carrier decreases.

b) Drift velocity enter's into saturation.

V_d V/S $\mathcal{E}$ curve for S.C :-

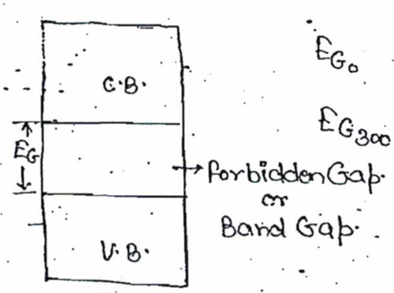


Question: In a semiconductor when field intensity are increasing the drift velocity ? -

(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.

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

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

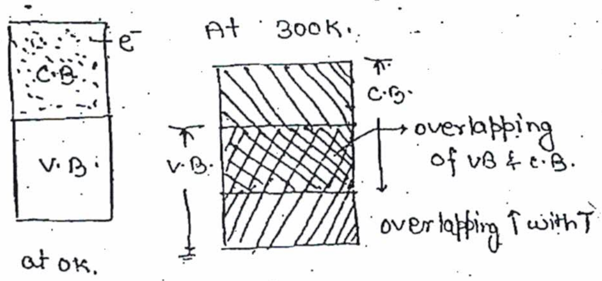
Classification of Elements into conductors, semiconductors, & insulators:-

Conductors or Metals:-

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

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

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

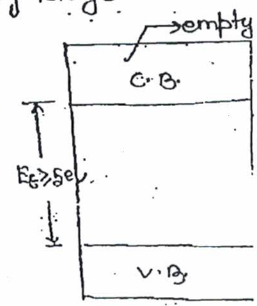


* In metals free electrons are available even at 0K.
* In metals free electron concentration is independent of temprature.
* Because of overlapping a valance band & conduction band metal will exhibit PTC of resistance.
* In metals there is only a drift current.

E.g. → Gold, Silver, Tungsten, Platinum, Aluminium, Copper, Tin, Iron, Uranium.

Insulators:-

Bad conductors of current.
Valency electrons are 7 or 8.
Ionic bonding
NTC (Negative Temprature Co-efficient of resistance.
Energy gap is very large
$E_g \ge 5\,eV$.
Conductivity is zero for ideal insulators.
σ = negligible for practical insulators.



In insulators E_G (Energy Gap) slightly decreases with the temprature ↑
Insulators are subjected to break-down.

E.g. Diamond, SiO_2, Air, Mica, ceramic, parcelain, Bakelite, Paper, Rubber, Cotton, Pvc, Leather, wood, glass, Plastic, fiber.

SemiConductors (S.C.):-

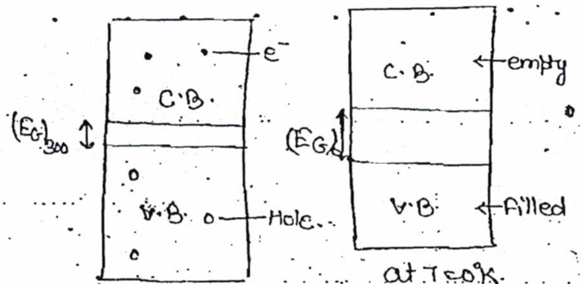
* Semi-conductors are elements whose conductivity lies between the conductivity of an insulator & conductivity of a conductor.
* Valance electrons are 4. (IV group belong to SC)

2. Covalent Bonding.

3. All semiconductor's are insulator's at 0°K.

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

Energy Band Diagram at 0°K.



at T=300°K. at T=0°K.

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

6. At 300K 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 carrier's, electron's & 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.

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Why carbon is not considered as a SC element?

* Carbon belong's 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 insulator.

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.

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

* 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 $D \rightarrow cm^2/sec$ 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 product of electrons & holes is always a constant & it is equal to square of intrinsic concentration.

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

N-Type Semiconductor

Majority carriers are e^-s $= n_n$

Minority carriers are holes $= p_n$

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

P-Type semiconductor:-

Majority carriers are holes $= p_p$

Minority carrier are e^-s $= n_p$

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

In a pure semiconductor e^-s & hole concentrations are ... respectively by adding impurity atom into the semiconductor ... & holes concentration are ... respectively. then following relation are applicable.

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

Intrinsic Concentration (n_i):-

Intrinsic ≡ Pure

$n = p = n_i$

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

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

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 $\frac{1}{\Omega \cdot m}$.

* It denotes current carrying capacity of device or material
* It denotes current

Imp
σ = Carrier Concⁿ × q × 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 with 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,

& 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.

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

$$J = \sigma E$$ 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.

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

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) = $\frac{d}{dx}$

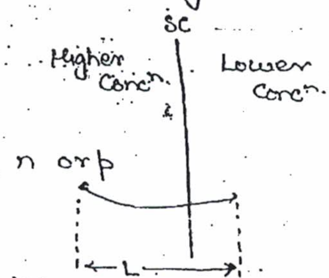
$\frac{dn}{dx}$ = e^- concentration gradient

$\frac{dp}{dx}$ = 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 in 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 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

* 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.	

$\tau_n \neq \tau_p$

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

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

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

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

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

$J = J_n + J_p$

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

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

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

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

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

$(J_n)_{drift}$, $(J_n)_{diffusion}$, $(J_p)_{drift}$, $(J_p)_{diffusion}$

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

* 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 Temprature's

i) for Ge

$-60°C$ to $+75°C$.

Maximum operating temprature $= 75°C$.

ii) for Si

$-60°C$ to $175°C$

Maximum operating temprature $= 175°C$

⇒ Normal Working temprature:-

100K to 400K

Leakage Current's (I_o):-

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

* 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_o) increase by 7%.
* I_o gets doubled by increasing 10°c of temprature in both Ge & Si.

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

	Ge	Si
I_o	μA	nA

I_o of Ge > I_o of Si

* I_o depends on minority carriers and minority carrier concentration will be depending on temprature. Hence this current is generated only because of tempr. hence called thermally generated current.
* It is highly sensitive to tempr.
* 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 is 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	2,30,00
5. Leakage Current (I_o)	≃μA	≃nA
6. Max^m operating Tempr.	75°C	175°C
7. Power handling capability	low power	High p

* 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.

$$Si + O_2 \xrightarrow{1400^\circ C} SiO_2$$

↓ 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 $\frac{d\sigma}{dn} = 0$

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

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

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

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

Putting this value in eqn (iii)

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

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

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

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 $0.4 \ m^2/v\text{-s}$ 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 cm²/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 a resistivity of $3.44 \times 10^{-8} \ \Omega m$, 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:

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

Question A sc wafer (having negligil thickness) is 0.5 mm. thick. a poten of 100 mv is applied across the thickness

(a) what is the drift velocity if mobility is $0.2 \ m^2/v\text{-sec}$

(b) How much time is required f an electron to move across th thickness

Solution:

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

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

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

$$t = 12.5 \ \mu sec$$

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

In N-type SC

$N_A = 0$

$\boxed{n = N_D + P}$ 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.

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

* 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 predominately dominated by the flow of electrons.

* The conductivity of entire SC is

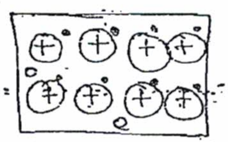
$\sigma_N = nq\mu_n + pq\mu_p$ ℧/cm.

$\approx nq\mu_n$ ℧/cm.

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

* The conductivity due to minority carrier is almost neglegible

* entire SC is represented as



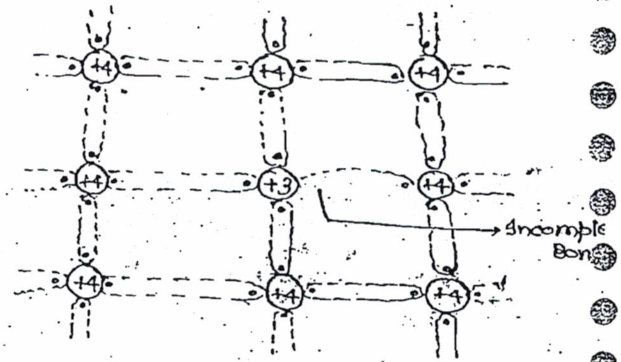
* (+) ion → it is a neutral atom with 1e less.

* Ion's are called immobile charge particles.

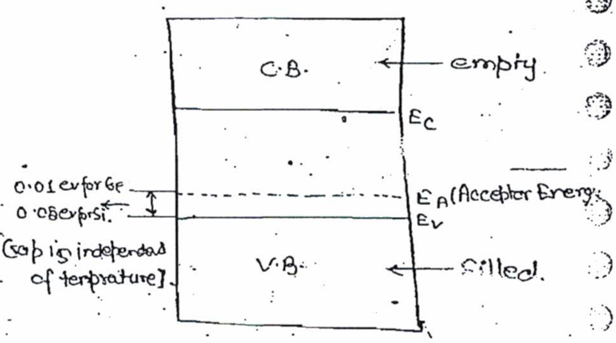
P-Type Semiconductor or Acceptors:-

* The impurity is trivalent.

Crystalline structure at 0°K.



Energy Band Diagram at 0°K.

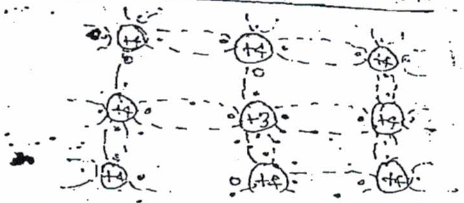


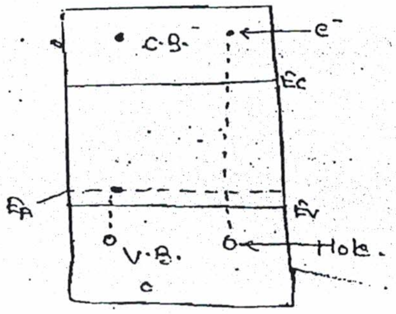
* Acceptor energy level is a discrete energy level created just above the valance band.

* Acceptor energy level denotes the energy level of trivalent atom's ad to the SC.

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

Crystalline 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

$p >> n_i$ $n < n_i$

The e⁻ conc^n is reducing below 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.

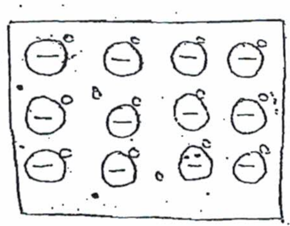
N_a = Total no of atom's/cm³ × Impurity ra

* The conductivity of p-type sc is

$$\sigma_p = nq\mu_n + pq\mu_p \ \text{℧/cm}.$$

$$\sigma_p \approx N_A q \mu_p \ \text{℧/cm}.$$

* 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 charge
* Total positive charges = Total negative charges

$N_D + P = N_a + n$

N_D = donor concentration is associated with positive charge.

N_a = Acceptor concentration is associated with negative charge.

or

$N_D - N_A = n - p$

* A sc which obey's law of electrical neutrality is always electrically neutral.

for N-type sc

$N_A = 0 \quad n = N_D + P$

$n \approx N_D$

for P-type sc

$N_D = 0, \; P = N_a + n$

$P \approx N_A$

In Intrinsic sc

$N_A = 0$ & $N_D = 0$

$P = n$

$P - N = 0$

∴ Intrinsic sc is electrically neutral.

∴ All sc are electrically neutral.

Question:- N type sc is _____.

(a) (−)vely charged (b) (+)vely charged

(c) No charge at all (d) electrically neutral.

Question: A pure sc (Ge) is doped with donor impurities to the extent of $1:10^7$ calculate

(i) donor concn

(ii) electron & holes concn in the doped sc.

(iii) Conductivity & resistivity of the doped sc.

(v) How many times ... is increased

in the sc due to doping

assume total no. of atoms $= 4.421 \times 10^{22}$

$n_i = 2.5 \times 10^{13}$ atoms/cm³

$\mu_n = 3800 \, cm^2/v\text{-sec} \quad \mu_p = 1800 \, cm^2/v\text{-sec}$

Solution.

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

(i) $N_D = 4.421 \times 10^{15} /cm^3$

(ii) e^- concn $= N_D = 4.421 \times 10^{15} /cm^3$

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

$N_A = 1.414 \times 10^{11} /cm^3$

(iii)

$\sigma = q N_d \mu_n$

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

$= 26.87968 \times 10^{-4}$

$= 2.688 \; ℧/cm.$

(iv) $\rho_n = \frac{1}{\sigma_n} = 0.372 \; \Omega\, cm.$

(v) $\sigma_i = n_i q [\mu_n + \mu_p]$

$= 2.5 \times 10^{13} \times 1.6 \times 10^{-19} \ldots$

$= 0.0224 \; ℧/cm.$

By adding donor impurities of $1:10^7$

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

$\uparrow \sigma$ by doping $= \frac{2.68}{0.0224} = 119.8$

$\simeq 120$ times.

Question: A pure sc (Si) is doped with acceptor impurities to the extent of 4 impurity atoms / 10^8 atoms find its conductivity

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