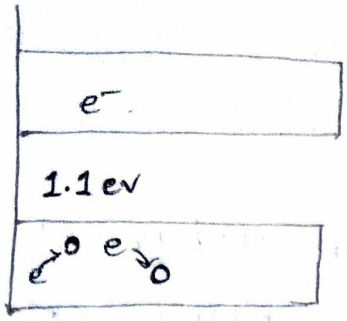
10/12/19



Silicon

- electron moment is always opposite to the hole moment.
- electron moment is greater than hole moment.
- Based on the conduction solids are classified into insulators, semiconductors and conductors. in a metal.

Valence Band:

A band which is occupied by valence electrons is called Valence Band.

conduction Band:

The Band occupies by free electrons are called as conduction Band. This Band may be empty or partially filled.

Forbidden Energy Gap:

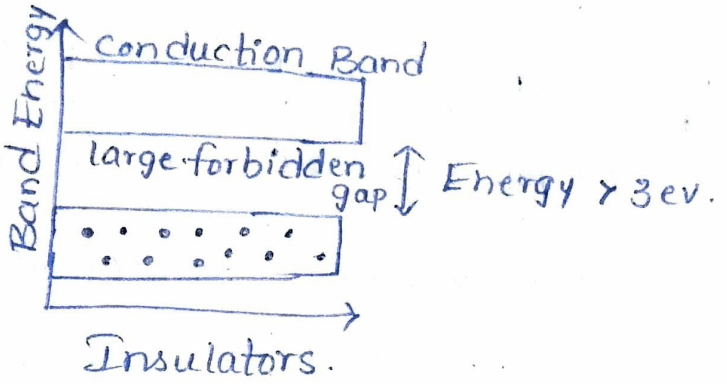
The seperation between Valence band and Conducti band is known as Forbidden Energy gap.

Insulator:

A very poor conductor of electricity is called an Insulator.

Eg:- plastic, Rubber, wood etc.

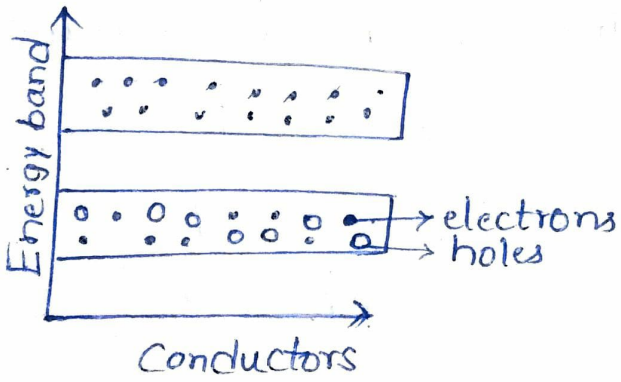
In an insulator forbidden gap is very large and the concentration of free electrons is small ($\sim 10^7$ per cubic meter). Energy gap is more than 3ev.



conductors:

Substances that conduct electricity efficiently are known as electric conductors. concentration of free electrons (10^{28} per cubic meter) that are free to move throughout the material.

Eg:- Silver, copper, Iron, gold etc,...



Semi-conductors:-

Forbidden gap is about 1ev, the solid is called a Semiconductor. free electrons lies blw those of conductors and Insulators (10^{17} per cubic meter).

Eg:- Graphite, Germanium, Silicon.

Energy gap for pure silicon is "1.1ev" and for germanium "0.72 ev" at room temperature.

* Energy gap of a Semiconductor decrease with raise

in temperature.

* Holes occur only in Valence band.
* free electrons occur only in conduction band

depending upon the concentration of electrons and holes, the semiconductors are classified into 2 types.

(i) Intrinsic (ii) Extrinsic Semiconductors.

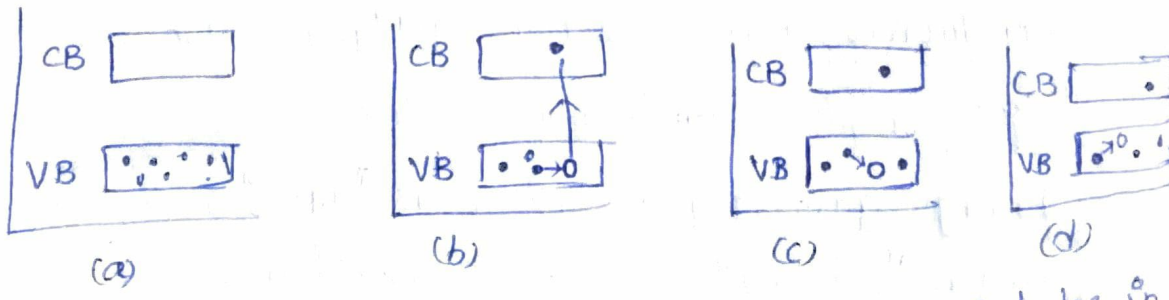
Intrinsic Semiconductor:

- Also known as pure Semiconductors, without any impurities in them are called as Intrinsic Semiconductors.

Eg:- pure germanium (4A group) [0.72 ev]
pure Silicon (IV A group) [1.1 ev]

at '0' kelvin, Germanium energy gap → 0.785 ev
Silicon energy gap → 1.21 ev.

* Valence band is completely filled with electrons and conduction band in empty.
* An Intrinsic Semiconductor at '0' kelvin behaves as insulator.
* Absence of electrons in valence band cause holes in valence band.



* No. of free electrons is equal to no. of holes in valence band

* Electrons move towards +ve terminal
* holes move in opposite direction towards -ve terminal

$$I = I_{hole} + I_{current}$$

$$I_{hole} = I_{current} \quad | \quad I_{hole} = I_{electron}$$

* Motion of holes in the valence band is called a hole current.

Extrinsic Semiconductors:

When small quantities of impurities are added to an intrinsic semiconductor, an extrinsic semiconductor is formed. Then the semiconductor is doped.

doping: the process of introducing impurities in small quantities into a material is called doping.

* depending upon the type of impurity, extrinsic semiconductor is of two types.

(i) p-type (ii) n-type.

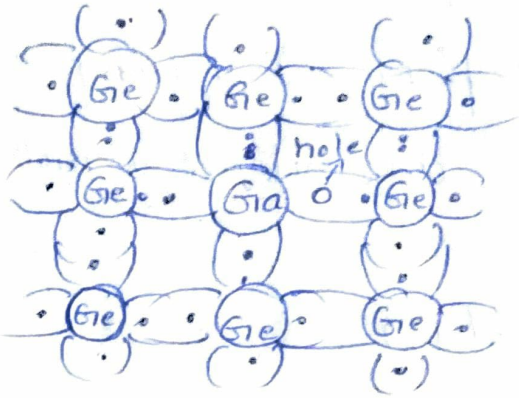
p-type:

trivalent impurity (such as Gallium (Ga), Indium (In), Aluminium (Al), Boron (B), etc..)

Gallium ($Z = 31$). with 28 inner shell e^- and 3 valence electrons. $[Ar]\ 3d^{10}\ 4s^2\ 4p^1$

* trivalent impurities are acceptors.
* In p-type holes are the majority carries. and electrons are minority carries.

A- p-type Semiconductor is formed when a small quantity of acceptor impurity is added to the pure Semiconductor."

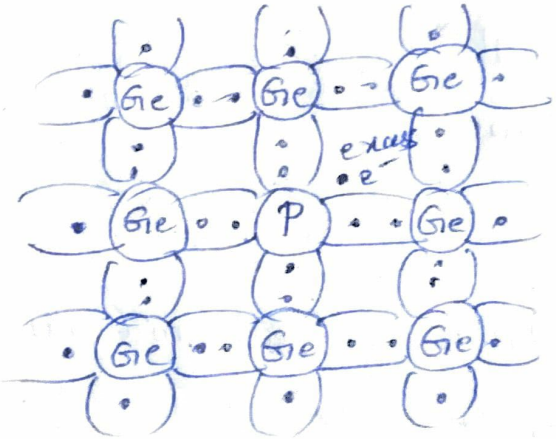


n-type Semiconductors:

Pentavalent Impurity (such as Arsenic (As), Antimony (Sb), phosphorous (P), etc...)

phosphorus ($z=15$) with 10 inner shell e^- and 5 valence e^-.

* pentavalent impurities are donars.



* A n-type Semiconductor is formed when a small quantity of donar is added to a pure Semiconductor".

* Electrons are the majority carries, and holes are minority carries.

11/12/19 There are three ways to excite the e

(i) By temperature.

(ii) By giving dc supply

(iii) By light source.

* generation: oformation of electron hole pair is called carrier generation.

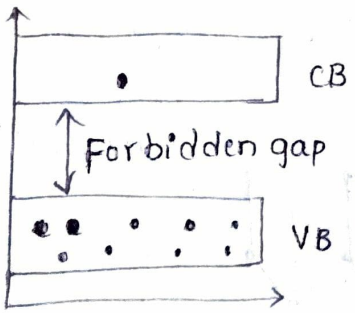
* Recombination: disappearence of electron and hole and it emits some amount of energy.

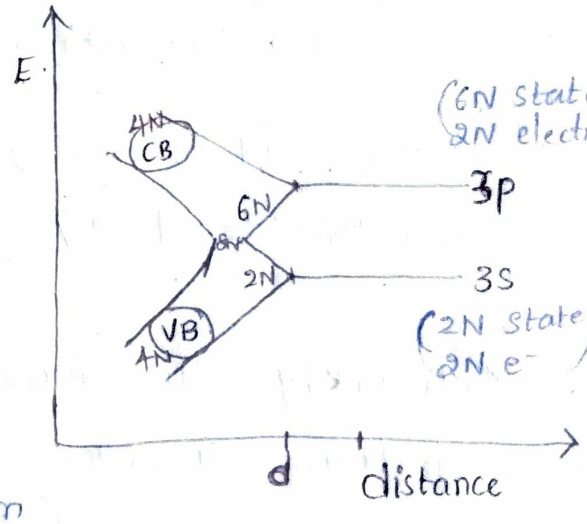
(i) temperature (phonons).

(ii) light. (in terms of photons).

* the dicde which release energy in the form of temperature is "phonons".

* the diode which release energy in the form of light is "photons".





* when two atoms are come closer then one atom will influence the other atom.

* At some point all states will merge and form conduction band and valance band and

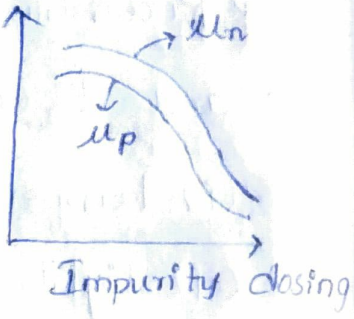
* In silicon atom we have 4N states in valence band and 6N states in conduction Band at some point they merge and form 8N states, 4N States in C.B and 4N states in V.B.

12/12/19 **Effect of mobility versus Impurity.**

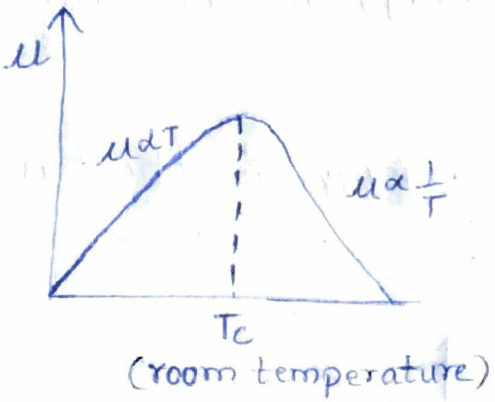
* mobility will decrease due to impurities.

effect of mobility verses temperature.

If we increase the temperature, effect of the impurities on e^- will decreases.

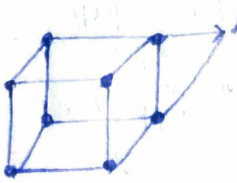


$t \propto \frac{1}{\mu}$



* If temperature is less than room temperature, mobility will increase
* If temperature is greater than room temperature, mobility will decreases.

(i) Impurity scattering
(ii) Lattice scattering.



1. mobility:- The degree of freeness. How much free a electron can move.

$$\mu = \frac{V_d}{E}$$

units : $cm^2/v\text{-}sec$ ($\AA$)
$m^2/v\text{-}sec$.

2. Drift velocity:

when an electron collide with atom the electron will move away from the actual path, it is called

$$V_d = \frac{V_{max} + V_{min}}{2}$$

drift velocity

3 Mean free path: → λ = total distance / no. of collisions (cm or m)

The distance between two successive collisions is called mean free path. T_c = duration of journey / no of collisions → sec

4. Relaxation time:

The time taken between two successive collisions is called Relaxation time.

* If Energy band is greater than 6ev Insulators
* If Energy band is equal to 1 ev semiconductors
* Energy levels in C.B and V.B are multiples of '4'

i) Elemental Semiconductors:

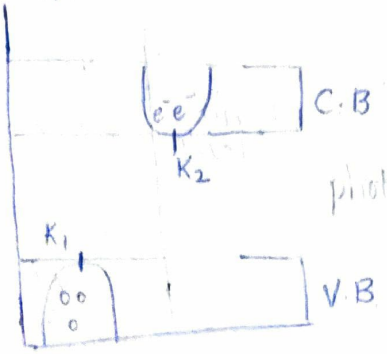
Eg:- Si, Ge, Graphite

* It having only one element.
* These release energy interms of temperature.

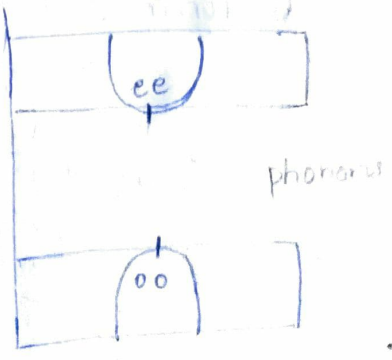
(ii) Compound Semiconductors:

Eg:- GaAs, GaP, GaInP → Direct Band gap Semi. C.

* These semiconductors release energy interms of light.
* mixing of 3rd group element with 5 group element.



elemental semiconductors
I.B.G.S.



Compound Semiconducto
Direct B.G.S.

* In elemental semiconductors. ∴ Indirect band gap
* In compound semiconductors direct band gap is the

19/12/19 **Classification of Semiconductors:**

1) classification of Semiconductors is based on no. of electrons and holes.

1) Intrinsic

(i) four covalent bonds are formed in 1

(ii) No. of electrons in conduction band and is equal to no. of holes in valence band.

(iii) If we supply heat below room temp. there will be no current flow in the

2) Extrinsic:

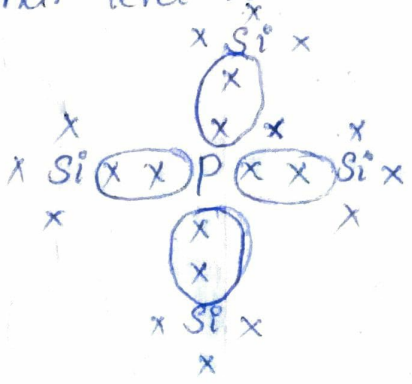
(i) here no. of e^- is not equal to no. of holes.

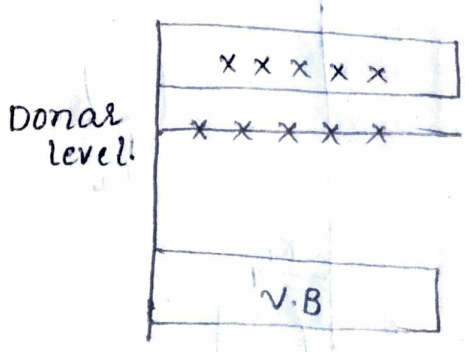
(ii) If we supply heat below room temp. there will be current flow.

(iii) conduction is high in Extrinsic Semiconductors.

(i) n-type:

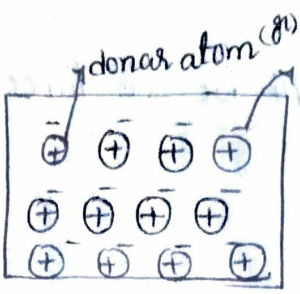
* In n-type e^- are majority carriers and holes are minority carriers.
* donar level is formed in n-type due to free e^-.



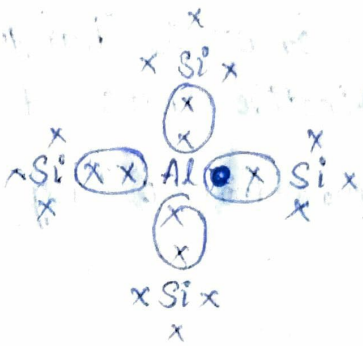


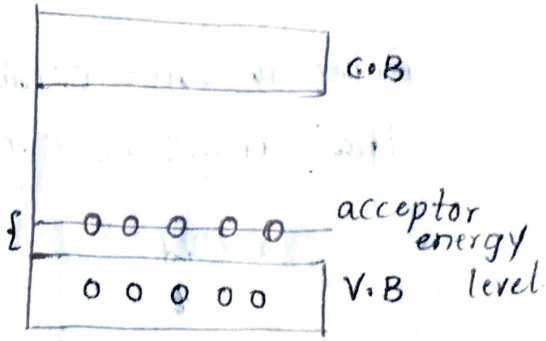
* phosphorus, Arsenic, Antimony

*hole formation is occur when covalently bonded atoms are break.



(ii) p-type: Ga, In, Al



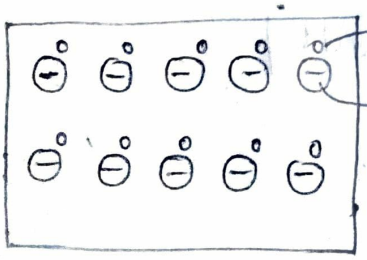


* trivalent impurities are added to Intrinsic to form p-type.

* Here holes are the majority carriers.

* 1 free hole is there in p-type and it forms energy level that is acceptor energy level.

* when we give sufficient energy to holes, they move towards the valence band.



20/12/19

* When e^- move around the nucleus it experience some force.

* due to electric field there will be a force on charge carriers.

$$F = qE \longrightarrow (1)$$

$$F = ma \longrightarrow (2)$$

* due to some collisions mass of e^- is changed and that mass is known as "effective mass of e^-"

$$a = \frac{V_d}{t} \qquad m_0 = 9.31 \times 10^{-31}\ kg.$$

$V_d \rightarrow$ drift velocity

$t \rightarrow$ Relaxation time

$$F = \frac{mV_d}{t} \longrightarrow (3)$$

Volume.

charge density $(\rho) = ne$

$n \rightarrow$ no. of e^-

$e \rightarrow$ charge of the electron.

$$dQ = \rho dv$$

$$dq = \rho A dx \qquad \left[V_d = \frac{dx}{dt} \quad dx = V_d dt\right]$$

$$dQ = \rho A V_d dt$$

$$\frac{dQ}{dt} = (\rho)(A)(V_d)$$

$$I = (\rho)(A)(V_d)$$

$$J = \frac{I}{A} = \rho V_d$$

$$\boxed{J = (ne V_d)} \longrightarrow (4)$$

current density $(J) = ne(at)$

from (1) & (2)

At $T = 300K$: $n = 100n$ $\mu^* = \frac{\mu}{10} = 10ne\mu$

$T = 600K$; $n = 100n$ $\mu^* = \frac{\mu}{20} = 5ne\mu$

* Whether it is a conductor and semiconductor, when we increase temperature above room temperature the mobility will decrease.

for Intrinsic Semiconductor conductivity.

$$\sigma_{intrinsic} = ne(\mu_n + \mu_p)$$

$\mu_p \rightarrow$ mobility of holes

$\mu_n \rightarrow$ mobility of electrons

$n \rightarrow$ mag. of free-e^- concen.

$p \rightarrow$ mag. of holes concen.

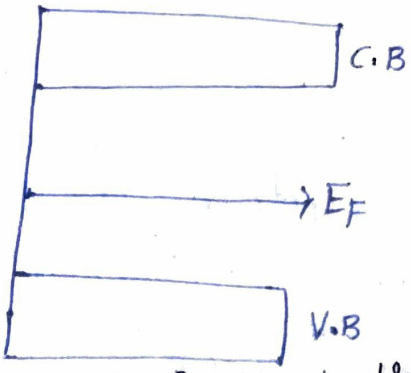
$\sigma \rightarrow$ conductivity.

$$\sigma_{extrinsic} = ne\mu_n + pe\mu_p.$$

Fermi level:

Intrinsic Semiconductor:

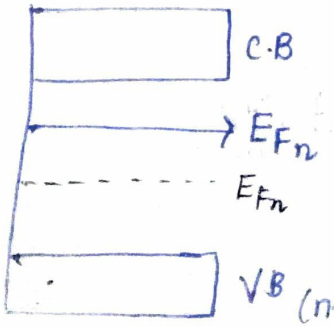
* Fermi level is in the middle of the V.B & C.B
* No. of e^- = No. of holes.



* If we increase the temp in Intrinsic Semi. C. Fermi level is formed at the middle of V.B and C.B.

Extrinsic Semiconductor:-

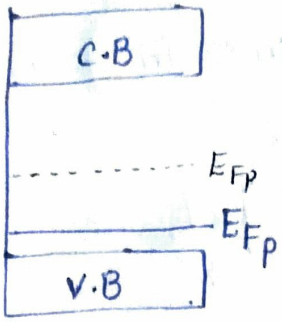
n-type Semiconductor:



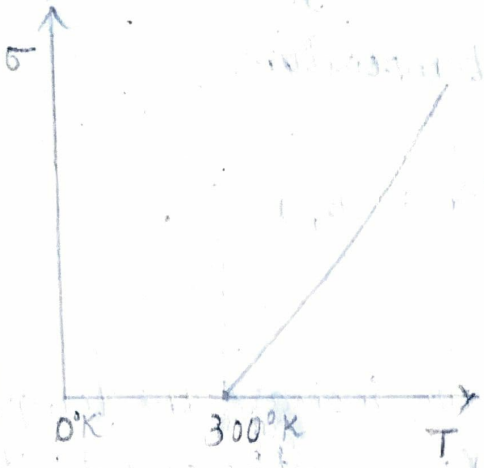
* depending upon the doping concentration Fermi level is formed
* If we increase temperature in n-type Semi-conductor. fermi level will come at the middle

* "Extrinsic Semiconductor, If we increase temperature."

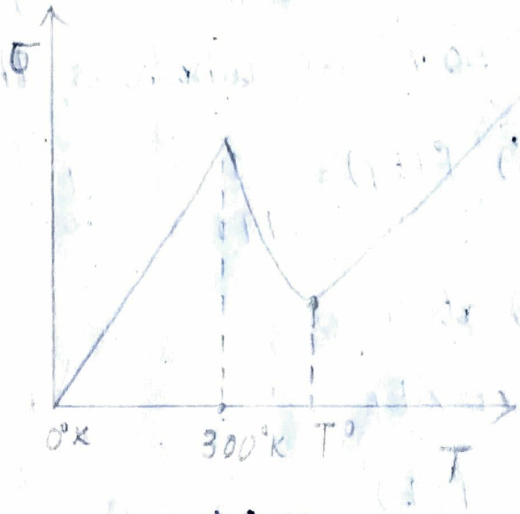
p-type Semiconductor:-



(p-type)



Intrinsic



Extrinsic

$\sigma = ne\mu$

*mobility decreases after room temp. and conductivity also decreases. no. of e^- does not effect the mobility of e^-.

* But at some point of time no. of e^- dominate the mobility of e^-

12/19 Fermi-Dirac Distribution function.

$$f(E) = \frac{1}{1 + e^{\left(\frac{E - E_f}{KT}\right)}}$$ units : No units.

$f(E)$: The probability of finding an e^- in an energy level E (some energy states).

K : Boltzmann constant $\left[1.38 \times 10^{-23}\right] \frac{eV}{K^\circ}$

T : Temperature. ($^\circ K$)

E_f : Fermi energy level (eV)

* When energy level is equal to fermi energy level then the probability of finding an electron is 50% at whatever the temperature.

(i) $f(E_f) = \frac{1}{1+1} = \frac{1}{2}$ (for $E = E_f$)

(ii) at $T = 0$

$E > E_f$

$f(E) = \frac{1}{1 + e^{\infty}} = 0$

* If we increase the temp. when ($E > E_f$) the probability of finding an (e^- increases) an occupied quantum state of energy greater than E_f at absolute zero.

(iii) at $T = 0$

$E < E_f$

$f(E) = \frac{1}{1 + e^{\left(\frac{E - E_f}{KT}\right)}} = \frac{1}{1+0} = 1$

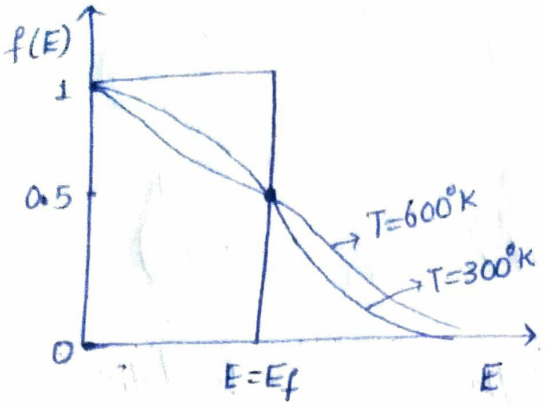
Graphs:

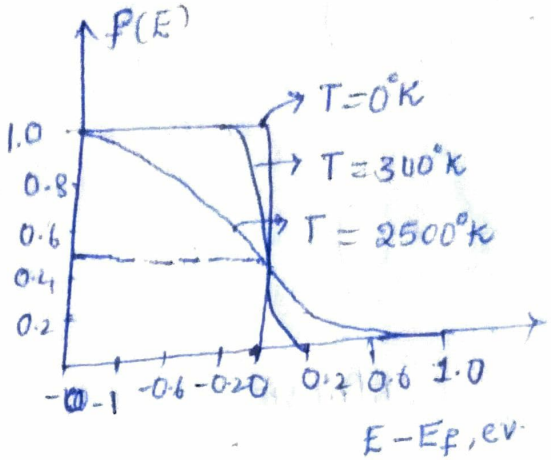
* If we increase the temperatue when $E < E_f$ the probability of an e^- decreases

* The E_f represents the energy state with 50% probability of being filled if no forbidden band exists.

* ($E < E_f$): All quantum levels with energies less than E_f will be occupied at $T = 0^\circ K$ $P_E = \begin{cases} 1 & \text{for } E < E_f \\ 0 & \text{for } E > E_f \end{cases}$

Graph: Energy verses probability.



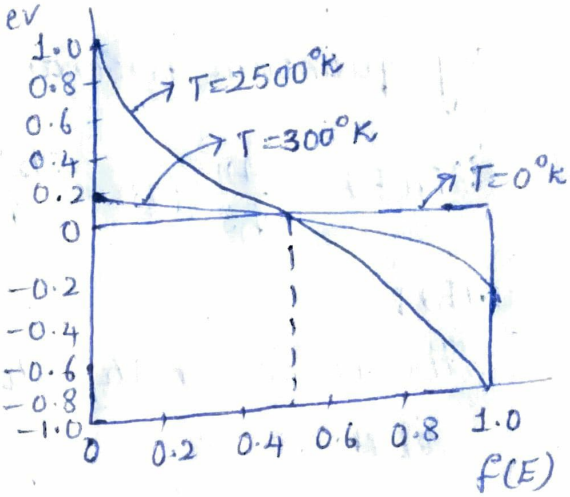


At T=300K

(i) $E = E_f$; $f(E) = 0.5$

(ii) $E > E_f$; $f(E) = 0$

(iii) $E < E_f$; $f(E)$ = decreases.



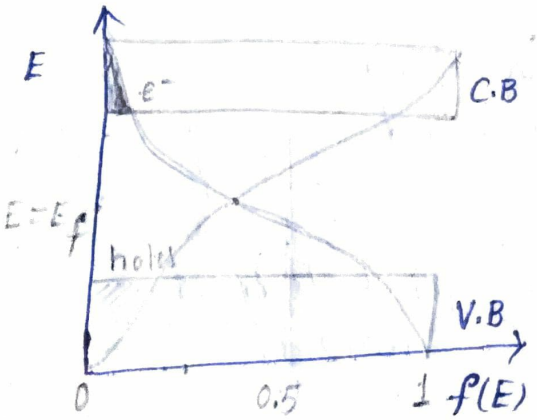
At 600°K:

(i) $E = E_f \Rightarrow f(E) = 0.5$

(ii) $E > E_f \Rightarrow$

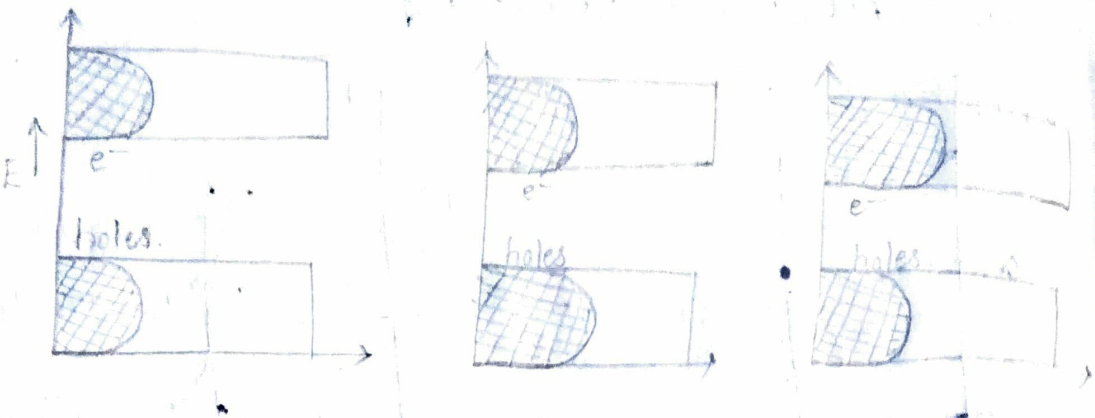
(iii) $E < E_f \Rightarrow$ decreases.

Giraph: probability verses Energy



* When an applied energy is greater the E_f then the probability of finding an electron in conduction band. ($E > E_f$)

* When an applied energy is less than E_f then the probability of finding an e^- in valence band



Intrinsic p-type n-type

By quantum mechanics

(i) $N(E) = \frac{4\pi}{h^3}(2me)^{3/2}\sqrt{E-E_c}$ (in conduction band)

N(E):

The no. of density states per each energy per unit volume.

units: $\frac{\text{No. of density states}}{(E)\ cm^3}$.

(ii) $N(E) = \frac{4\pi}{h^3}(2mh)^{3/2}\sqrt{E_v-E}$ (in Valence band).

$E_c \rightarrow$ energy of conduction band

$E_v \rightarrow$ energy of valence band.

$$n = \int_{E_c}^{\infty} f(E)\,N(E)\,dE \qquad n = \frac{\text{no. of electrons}}{m^3 \text{ (or) } cm^3}$$

$$n = \int_{E_c}^{\infty} \left(\frac{1}{1+e^{\left(\frac{E-E_f}{KT}\right)}}\right)\left(\frac{4\pi}{h^3}(2me)^{3/2}\sqrt{E-E_c}\cdot dE\right).$$

$$n = \frac{4\pi}{h^3}(2me)^{3/2}\int_{E_c}^{\infty} e^{-\left(\frac{E-E_f}{KT}\right)}(E-E_c)^{1/2}\,dE.$$

$$= a \cdot e^{\frac{E_f - E_c}{KT}} \int_{E_c}^{\infty} e^{\frac{E_c - E}{KT}} (E - E_c)^{1/2} dE \qquad \left(a = \frac{4\pi}{h^3}(2m_e)^{3/2}\right)$$

$$x = \frac{E - E_c}{KT}$$

$$dE = (dx)\, KT$$

$$n = a \cdot e^{\frac{E_f - E_c}{KT}} \int_0^{\infty} e^{-x} (x)^{1/2} (KT)^{1/2} dx\, (KT)$$

$$n = a \cdot e^{\frac{E_f - E_c}{KT}} \cdot (KT)^{3/2} \int_0^{\infty} e^{-x} (x)^{1/2} dx$$

$$n = a \cdot (KT)^{3/2} e^{\frac{E_f - E_c}{KT}} \left(\frac{\sqrt{\pi}}{2}\right)$$

$$\boxed{n = N_c\, e^{\left(\frac{E_f - E_c}{KT}\right)}}$$

$$N_c = 2\left(\frac{2\pi m_e KT}{h^2}\right)^{3/2} = 4.7 \times 10^{21} (m_e T)^{3/2}\ m^{-3}.$$

$$4.82 \times 10^{21} \left(\frac{m_e}{m}\right)^{3/2} T^{3/2}\ m^{-3}.$$

n = no. of e^- in conduction band.

No. of holes in valence band:

$$P = \int_{-\infty}^{E_v} N(E) \cdot (1 - f(E))\, dE.$$

$$P = \int_{-\infty}^{E_v} \left(\frac{4\pi}{h^3}(2m_h)^{3/2} \sqrt{E_v - E_e}\right)\left(1 - \frac{1}{1 + e^{\left(\frac{E - E_f}{KT}\right)}}\right) dE$$

$$P = \int_{-\infty}^{E_v} \left(\frac{4\pi}{h^3}(2m_h)^{3/2} \sqrt{E_v - E_e}\right)\left(\frac{1 + e^{\left(\frac{E - E_f}{KT}\right)} - 1}{1 + e^{\left(\frac{E - E_f}{KT}\right)}}\right) dE$$

$$P = \int_{-\infty}^{E_v} \frac{4\pi}{h^3}(2m_h)^{3/2} \sqrt{E_v - E}\left(\frac{e^{\left(\frac{E - E_f}{KT}\right)}}{1 + e^{\left(\frac{E - E_f}{KT}\right)}}\right) dE$$

$$\int_{-\infty}^{E_V} \frac{4\pi}{h^3}(2m_h)^{3/2} \int_{-\infty}^{E_V} (E_V - E)^{1/2} \left(\frac{e^{\left(\frac{E-E_f}{KT}\right)}}{1+e^{\left(\frac{E-E_f}{KT}\right)}} \right) dE$$

$$p = \frac{4\pi}{h^3}(2m_h)^{3/2} e^{\frac{E-E_f}{KT}} \int_{-\infty}^{E_V} (E_V - E)^{1/2}\, dE$$

$$p = a \cdot e^{\left(\frac{-E_f}{KT}\right)} \int_{-\infty}^{\infty} (E_V - E)^{1/2} \cdot e^{\frac{E}{KT}}\, dE$$

$E_V - E = x \Rightarrow E = E_V - x \Rightarrow dE = -dx$

$$p = a \cdot e^{\left(\frac{-E_f}{KT}\right)} \int_{\infty}^{0} \sqrt{x} \cdot e^{\frac{E_V - x}{KT}}\, dx$$

$$p = a \cdot e^{\left(\frac{E_V - E_f}{KT}\right)} \int_{0}^{\infty} x^{1/2} e^{-x/KT}\, dx$$

$$p = a \cdot e^{\left(\frac{E_V - E_f}{KT}\right)} (KT)^{3/2} \frac{\sqrt{\pi}}{2}$$

Hence, $p = \frac{4\pi}{h^3}(2m_h)^{3/2} e^{\left(\frac{E_V - E_f}{KT}\right)} (KT)^{3/2} \frac{\sqrt{\pi}}{2}$

$$p = 2\left(\frac{2\pi m_h KT}{h^2}\right)^{3/2} e^{\frac{E_V - E_f}{KT}}$$

$$\boxed{N_V = 4.82 \times 10^{21} (m_h T)^{3/2}\ m^{-3}} \qquad \boxed{N_c = 4.82 \times 10^{21} (m_e T)^{3/2}\ m^{-3}}$$

~ In a material free electrons have mobility of 1000 $cm^2/V\text{-sec}$ and $m_n = 0.25 m_0$ if thermal velocity of electrons is 10^7 cm/sec. then calculate mean free time and mean free path.

Sol:- given,

$\mu = 1000\ cm^2/V\text{-sec} \qquad V_d = 10^7\ cm/sec.$

$m_n = 0.25 \cdot m_0 = 0.25 \times 9.1 \times 10^{-31} = 2.275 \times 10^{-31}\ kg$

$$\mu = \frac{e T_c}{m_n}$$

$$T_c = \frac{\mu m_n}{e}$$

$$T_c = \frac{1000 \times 2.275 \times 10^{-31}}{1.602 \times 10^{-19}}$$

$$T_c = 1.402 \times 10^{-9}\ sec$$

$l = V_d \times T_c$

$l = 10^7 \times 1.404 \times 10^{-9}$

$l = 0.014$ cm

2) An electric field of 10V/cm moves an e^- a distance of 2cm in 10μsec. What is the mobility of e^-?

Sol:- $V_d = \mu E$

$\mu = \frac{V_d}{E}$

Since,

$l = V_d \times T_c$

$V_d = \frac{l}{T_c} = \frac{2}{10 \times 10^{-6}} = 200000$

$\mu = \frac{V_d}{E} = \frac{2 \times 10^5}{10} = 20000$

$\mu = 2 \times 10^4$ cm²/V-sec.

~ A copper wire of diameter 1mm and length is 300m as a resistance of 10Ω if concentration of free electron in a copper is 8.4×10^{28} per m^3 and a current of 2A. is passing through the wire. Then calculate conductivity mobility of free electrons and drift velocity.

Sol:- $d = 1mm = 1 \times 10^{-3} m$

$l = 300m$

$R = 10\Omega$

$I = 2A$

$n = 8.4 \times 10^{28}/m^3$

(i) conductivity σ, $R = \frac{\rho l}{A}$

$A = \pi r^2$

$A = \pi (0.5 \times 10^{-3})^2$

$A = 7.85 \times 10^{-7} m^2$.

$$\rho = \frac{RA}{l}$$

$$\rho = \frac{10 \times 7.85 \times 10^{-7}}{300}$$

$$\rho = 2.6 \times 10^{-8}\ \Omega/m$$

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

$$\sigma = \frac{1}{2.6 \times 10^{-8}}$$

$$\boxed{\sigma = 3.8 \times 10^{7}\ \mho/m.}$$

(ii) mobility of free electrons

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

$$= \frac{3.8 \times 10^{7}}{8.4 \times 10^{28} \times 1.6 \times 10^{-19}}$$

$$\boxed{\mu = 2.82 \times 10^{-3}\ m^2/V\text{-sec.}}$$

(iii) Drift Velocity (V_d)

$$V_d = \mu E$$

$$V_d = (2.82 \times 10^{-3}) \frac{V}{L}$$

$$V_d = 2.82 \times 10^{-3} \times \frac{IR}{L}$$

$$V_d = 2.82 \times 10^{-3} \times \frac{2 \times 10}{300}$$

$$\boxed{V_d = 1.88 \times 10^{-4}\ m/sec.}$$

(or) $J = neV_d$

$$V_d = \frac{J}{ne}$$

$$V_d = \frac{I}{A \cdot ne}$$

$$V_d = \frac{2}{7.85 \times 10^{-7} \times 8.4 \times 10^{28} \times 1.6 \times 10^{-19}}$$

$$\boxed{V_d = 1.88 \times 10^{-4}\ m/sec}$$

~ In a metal fermi energy is $E_f = 8.8 \times 10^{-19}$ J, and $m_n = 0.02$ cm. The velocity of fastest moving at zero degree Kelvin.

Sol:- Given,

$E_f = 8.8 \times 10^{-19}$ J

$m_n = 0.02$ cm.

$$V_f = \sqrt{\frac{2E_f}{m_n}} \qquad V_f = 3.19 \times 10^{6}$$

Effect of Electric field on Velocity.

$V_d = \mu E$

$\boxed{V_d \propto E}$

(i) If smaller electric field is applied i.e ($< 10^3$ V/cm)

$\Rightarrow V_d$ is increases linearly w.r.t applied field

$\boxed{V_d \propto E}$

(ii) moderate electric field ($10^3 < E < 10^4$)

V_d increases Sublinearly.

$\boxed{V_d \propto \sqrt{E}}$

* When electric field increases drift velocity (V_d) increases then no. of collisions increases the mean free time decreases so it leads to decrease in mobility.

$E \uparrow \rightarrow V_d \uparrow \rightarrow$ no of collisions $\uparrow \rightarrow T_c \downarrow \rightarrow \mu \downarrow$.

$\mu \propto \frac{1}{\sqrt{E}}$.

$\mu = \frac{K}{\sqrt{E}}$ $\quad \frac{V_d}{E} = \frac{K}{\sqrt{E}}$

$V_d = K\sqrt{E}$ $\quad \boxed{V_d = K\sqrt{E}}$

$V_d = \mu E$

$V_d = \frac{K}{\sqrt{E}} E = K\sqrt{E}$

(iii) large electric field ($> 10^4$ V/cm)

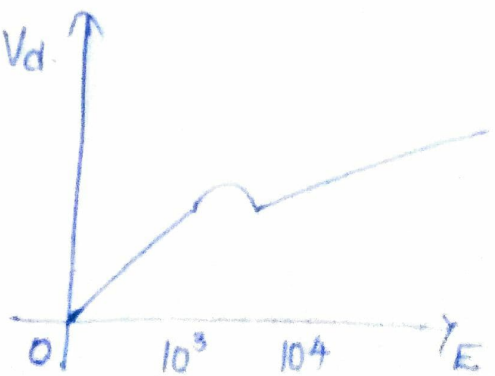
$V_d \propto E$ $\quad \boxed{V_d = K}$

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

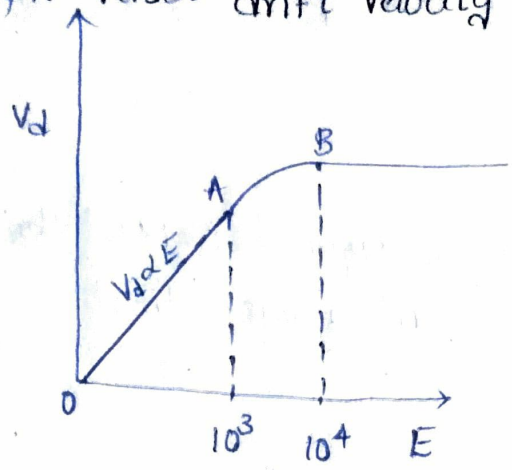
$\boxed{\mu = \frac{K}{E}}$

$V_d = \mu E$

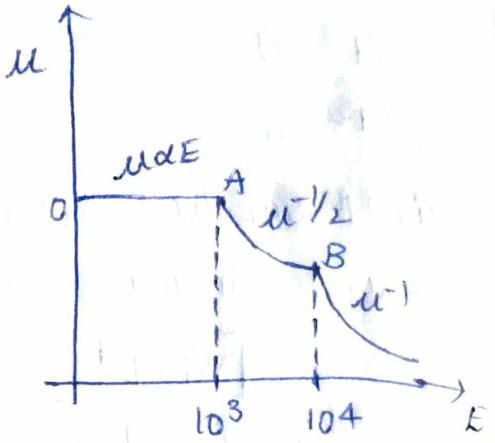
$V_d = \frac{K}{E} \times E$



23/12/19 $\vec{E}$ verses drift velocity



$\vec{E}$ versus mobility.



*Whenever the $\vec{E}$ is upto 10^3 there is linear increase in the drift velocity.

(i) $E \Rightarrow 0 < E \leq 10^3$. $\Rightarrow \boxed{V_d \propto E}$

(ii) $E \Rightarrow 10^3 \leq E \leq 10^4$

* Here in this region drift velocity increases Sublinearly

$$\boxed{V_d \propto E^{1/2}}$$

(iii) $E \Rightarrow 10^4 < E$:

*mobility decreases

Units of N_c & N_v

$$\left[\frac{(Kg)\cdot(J)}{(J\cdot sec)^2}\right]^{3/2}$$

$$\left[\frac{Kg}{J sec^2}\right]^{3/2} = \left[\frac{J\cdot \frac{Sec^2}{m^2}}{J\, Sec^2}\right]^{3/2} = \frac{1}{m^3}.$$

Law of mass Action:

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

$$(n)(p) = \left(N_c e^{\frac{E_f - E_c}{KT}}\right)\left(N_v e^{\frac{E_v - E_f}{KT}}\right)$$

$$n_i^2 = N_c N_v e^{\frac{E_f - E_c + E_v - E_f}{KT}}$$

$$n_i^2 = N_c N_v e^{\frac{E_v - E_c}{KT}}$$

$$n_i^2 = N_c N_v e^{-\frac{E_g}{KT}}$$

$$\boxed{n_i^2 = N_c N_v e^{-\frac{E_g}{KT}}}$$

$n = p = n_i = \frac{\text{no. of } e^-}{cm^3}$

$n_i = A\cdot T^{3/2} e^{-E_g/2KT}$

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

$$\ln\left(\frac{n_i^2}{N_c N_v}\right) = \left(e^{-\frac{E_g}{KT}}\right)\ln$$

$$\ln\left(\frac{n_i^2}{N_c N_v}\right) = -\frac{E_g}{KT}$$

$$E_g = KT \ln\left(\frac{N_c N_v}{n_i^2}\right)$$

$$n_i = \sqrt{A}\, T^{3/2} e^{-E_g/2KT} \qquad A = \left(4.82 \times 10^{21}\right)^2 e^{\frac{p}{K}}$$

P1) A conductor material has electron density of 10^{24} e/m... When voltage is applied a constant drift velocity of 1.5×10^{-2} m/sec. is gained by the electrons if the cross sectional area of materials is $1cm^2$. Find the magnitude of current?

Sol:- Given,

$n = 10^{24}\ e^-/m^3$

$V_d = 1.5 \times 10^{-2}$ m/sec

$A = 1cm^2 = 1 \times 10^{-4}\ m^2$

$I = neV_dA$

$I = (10^{24})(1.6 \times 10^{-19})(1.5 \times 10^{-2})(1 \times 10^{-4})$.

$\boxed{I = 0.24\ A}$

P2) The following data is given for a conductor fermienergy will be equal to 5.5ev, Mobility of e^- is equal to $7.04 \times 10^{-3}\ m^2/V.sec$., No. of conduction e^-/m^3 is equal to 5.8×10^{28} find

(i) Relaxation time

(ii) Resistivity of the conductor

(iii) Velocity of e^- with fermi energy?

Sol:- $E_f = 5.5ev$ $\quad n = 5.8 \times 10^{28}$.

$\mu = 7.04 \times 10^{-3}\ m^2/V.sec$

(i) $\mu m = et$

$t = \frac{\mu m}{e}$

$t = \frac{7.04 \times 10^{-3} \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19}}$

$t = 4.0 \times 10^{-14}$ sec.

(ii) $\sigma = ne\mu$

$\sigma = (5.8 \times 10^{28})(1.6 \times 10^{-19})(7.04 \times 10^{-3})$

$R = 1.522 \times 10^{-8}\ \Omega m$

(iii) $= 1.6 \times 10^{-19} \times 5.5 = \frac{1}{2} \times 9.1 \times 10^{-31} V^2$

$V = 1390706.991$ m/s.

$dn = N(E) f(E) dE$

$dn \rightarrow$ no. of conduction e^- per cubic meter energy lies between E and E+dE.

$N(E) =$

$$f(E) = \frac{1}{[1+e^{(E-E_f)/KT}]}$$

At room temperature,

$KT = 0.03 eV.$

$f(E) = 0 \quad (E-E_f >> 0.03)$

$f(E) = 1 \quad (E-E_f << 0.03)$

* Fermi level lies in the region of the energy gap midway between the valance and conduction bands.

Q. For a particular semiconductor, the effective mass of e^- is $m_n = 1.4m$. If $E_c - E_f = 0.25$ eV, determine the effective density of states in the conduction band and concentration of e^- in the semiconductor at $T = 300°K$.

Sol:- Given,

$m_n = 1.4 m_e$

$E_c - E_f = 0.25 eV$

$N_c = ?$

$T = 300°K$

$$N_c = 2\left(\frac{2\pi m_n KT}{KT h^2}\right)^{3/2}$$

$$= 2\left(\frac{2\pi \times 1.4 \times 9.1 \times 10^{-31} \times 8.62 \times 10^{-5} \times 300°K \times 1.6 \times 10^{-19} C}{(6.626 \times 10^{-34} J\,Sec)^2}\right)^{3/2}$$

$$N_c = 4.15 \times 10^{25} m^{-3}.$$

Concentration of e^- in the semiconductor

$$n = (4.15 \times 10^{25})\, e\left(\frac{-0.25}{0.026}\right) \qquad n = (KT) \cdot C \cdot e^{(E_f - E_c)/KT}$$

$$n = 2.67 \times 10^{21} m^{-3}$$

* (b) At $T = 400^\circ K$

$$N_c = 2\left(\frac{2\pi (1.4\times1.9\times10^{-31}) \times (8.62\times10^{-5}) \times 400 \times 1.6\times10^{-19}}{(6.626\times10^{-34})^2}\right)^{3/2}$$

$$N_c = 6.38\times10^{25}\ m^{-3}$$

concentration of e^- at $T = 400^\circ K$

$$n = (6.38\times10^{25})\, e^{\left(-\frac{0.25}{0.259}\right)}$$

$$n = 4.1\times10^{21}\ m^{-3}.$$

* the concentration of e^- and effective density of states in a semiconductor are increased with the increase in temperature.

The Fermi Level in an Intrinsic Semiconductor:

$$n_i = p_i$$

$$N_c e^{\left(-(E_c - E_F)/KT\right)} = N_v e^{\left[-(E_f - E_v)\right]/KT}$$

$$\ln \frac{N_c}{N_v} = \frac{-E_f + E_v}{KT} + \frac{E_c - E_f}{KT}$$

$$\ln \frac{N_c}{N_v} = \frac{-E_f + E_v + E_c - E_f}{KT}$$

$$\ln\left(\frac{N_c}{N_v}\right) = \frac{E_v + E_c - 2E_f}{KT}$$

$$E_f = \frac{E_c + E_v}{2} - \frac{KT}{2} \ln\left(\frac{N_c}{N_v}\right)$$

$$N_c = N_v$$

$$E_f = \frac{E_c + E_v}{2}$$

$T = 0^\circ K$. Hence the fermi energy level lies in the centre of the forbidden energy band.

The effective masses of electron and hole are $m_n = 0.55m$ and $m_p = 0.37m$ respectively. Find the position of the intrinsic Fermi level in germanium at 300°K

Sol:- $m_n = 0.55m$

$m_p = 0.37m$

$$N_c = 2\left(\frac{2\pi m_n KT}{h^2}\right)^{3/2}$$

$$= 2\left(\frac{2\pi \times 0.55}{6.6\times10^{-34}} \times 1.60\times10^{-19}\right)^{3/2}$$

$$N_c = E_{midgap} = \frac{E_f + E_v}{2}$$

$$E_f - E_{midgap} = -\frac{KT}{2}\ln\left(\frac{m_n}{m_p}\right)^{3/2}$$

$$= -\frac{3KT}{4}\left(\frac{m_n}{m_p}\right)$$

$$= -\frac{3\times0.0259\ ev}{4}\left[\ln\left(\frac{0.55}{0.37}\right)\right]$$

$$= -7.7\times10^{-3}ev$$

fermi level is located at -7.7×10^{-3} ev

* In Intrinsic Semiconductor E_f lies in the middle of the energy gap, indicating equal concentrations of free e^- and holes.

* If a donar type added to intrinsic semiconductor, at a given temp. and assuming all donar atoms are ionized, the first N_D states in the conduction band will be filled.

* Hence it will be more difficult for the e^- from the valence band to bridge the energy gap by thermal agitation. Consequently no. of e^- hole pair thermally.

generated for that temperature will be reduced.

* Since the Fermi level is a measure of the probability of occupancy of the allowed energy states, it is clear that E_f must move closer to the conduction band to indicate that many of energy states in that band are filled by the donor electrons, and fewer holes exist in the valence band. This is n-type material.

* As temp. increases of either n-type or p-type material increases, the Fermi level moves toward the centre of the energy gap.

24/12/19

1) Given $R = 1.73 \times 10^{-8}\ \Omega m$, average time of collision of $e^- = 2.42 \times 10^{-14}$ sec. Calculate no. of e^- per unit volume, also find mobility of e^-.

Sol:- $R = 1.73 \times 10^{-8}\ \Omega m \Rightarrow \sigma = \frac{1}{R} = 5.7 \times 10^{7}\ \Omega^{-1} m^{-1}$

$T = 2.42 \times 10^{-14}$ sec

$\mu = ?$

$n = ?$

$\mu = \frac{et}{m} \qquad \sigma = \frac{ne^2\tau}{m}$

$\frac{\sigma m}{e^2 T} = n \Rightarrow 0.84 \times 10^{29}\ m^3$.

$\mu = \frac{1.6 \times 10^{-19} \times 2.42 \times 10^{-14}}{9.1 \times 10^{-31}} = 4.26 \times 10^{-3}\ m^2/V.sec$

units:

mobility μ : $m^2/V.sec$

2) A conducting wire has $1.5\times10^{-8}\ \Omega m$, at 300°k. It's Fermi Energy is 5ev. It's volume of $1m^3$ contains 6×10^{28} conducting e^- find relaxation time? Also find the drift velocity if the conductor is subjected to an electric field of 100 vols per meter?

Sol:- $R = 1.5\times10^{-8}\ \Omega m$ $\quad \sigma = 6.6\times10^{7}\ \Omega^{-1}m^{-1}$

$E_f = 5eV$ $\quad E = 100\ V/m$

$V = 1m^3$

$n = 6\times10^{28}$

$T_c = ?$

$V_d = ?$

$$\sigma = \frac{ne^2T}{m} \Rightarrow T = \frac{\sigma m}{ne^2} = \frac{6.6\times10^{7}\times9.1\times10^{-31}}{(6\times10^{28})(1.6\times10^{-19})^2}$$

$$\boxed{T = 3.91\times10^{-14}.\ sec.}$$

$V_d = \mu E$

$$V_d = \frac{et}{m}E = \frac{1.6\times10^{-19}\times3.91\times10^{-14}\times8\times10^{-19}}{9.31\times10^{-31}}$$

$$\boxed{V_d = 0.68\ m/s}$$

3) A copper wire of 2mm. diameter with a conductivity of $5.8\times10^{7}\ \Omega m$ and e^- mobility $0.0032\ m^2/V.sec$, is subjected to an electric field of 20mv/m. then calculate

(i) charge density of free e^-

(ii) e^- density of free e^-

(iii) current density

(iv) current flowing in the wire

(v) drift velocity.

Sol:- $d = 2mm = 2\times10^{-3}m$ $\quad E = 20mv/m.$

$\sigma = 5.8\times10^{7}\ \Omega^{-1}m^{-1}$

$\mu = 0.0032\ m^2/V.sec$

$\rho = ne$

$\rho \neq 0$

(i) $\sigma = ne\mu$

$\sigma = \rho\mu$

$$\rho = \frac{\sigma}{\mu} = \frac{5.8\times10^{7}}{0.0032} = 1.8125\times10^{10}\ c/m^3$$

(ii) $\rho = ne$

$$n = \frac{\rho}{e} = \frac{1.812\times10^{10}}{1.6\times10^{-19}} = 1.13\times10^{29}\ e.$$

(iii) $J = ne\mu$

$J = 1.13\times10^{29}\times1.6\times10^{-19}\times0.0032\times20\times10^{-3}$

$J \approx 1.157\times10^{6}\ A/m^2$

(or)

$J = \sigma E$

$J = 5.8\times10^{7}\times20\times10^{-3}$

$\boxed{J = 1.157\times10^{6}\ Amp/m^2}$

(v) $V_d = \mu E$

$V_d = 0.0032\times20\times10^{-3}$

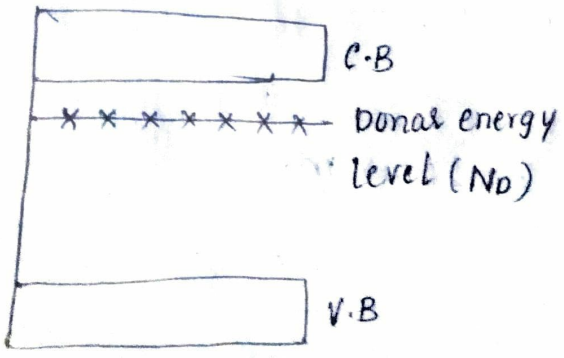
$\boxed{V_d = 6.4\times10^{-5}\ m/s}$

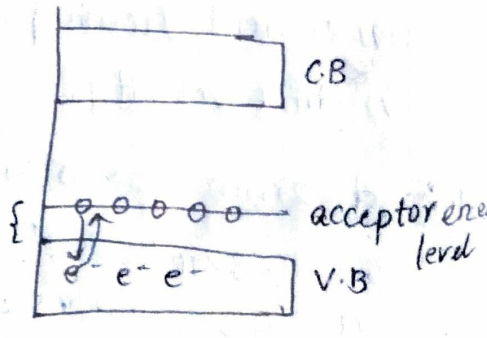
(iv) $I = \frac{J}{A} = \frac{1.157\times10^{6}}{3.14\times10^{-6}}$

$\boxed{I = 3.68\times10^{11}\ A}$

26/12/19

Donar level Ionization :





When the temperature is less than 300°k the electrons in the donar energy level. will move into the C.B. then that energy level is Completely Ionized.

If we increase the temperature above room temperature, acceptor energy level electrons will move into the C.B. then acceptor energy level and holes into the V.B

At 300°K.

for n-type: $P = N_A$ (p-type).

$$\boxed{n = N_c\, e^{\frac{E_f - E_c}{KT}}}$$

$$N_D = N_c\, e^{\frac{E_{FN} - E_c}{KT}}$$

$$\frac{N_D}{N_c} = e^{\frac{E_{fN} - E_L}{KT}}$$

Apply 'log' on b.s.

$$\ln\left(\frac{N_D}{N_c}\right) = \frac{E_{fN} - E_c}{KT}$$

$$KT \ln\left(\frac{N_D}{N_c}\right) = E_{FN} - E_c$$

$$\boxed{E_{FN} = E_c - KT \ln\left(\frac{N_c}{N_D}\right)}$$

for p-type:

$$\boxed{P = N_V e^{\frac{E_V - E_f}{KT}}}$$

$$N_A = N_V\, e^{\frac{E_V - E_{Fp}}{KT}}$$

$$\left(\frac{N_A}{N_V}\right) = e^{\frac{E_V - E_{Fp}}{KT}}$$

$$\ln\left(\frac{N_A}{N_V}\right) = \frac{E_V - E_{Fp}}{KT}$$

$$KT \ln\left(\frac{N_A}{N_V}\right) = E_V - E_{Fp}$$

$$E_{Fp} = E_V + KT \ln\left(\frac{N_V}{N_A}\right)$$

Intrinsic Semiconductor (Fermi Energy level):

$$n = p$$

$$N_c e^{\frac{E_f - E_c}{KT}} = N_V e^{\frac{E_V - E_F}{KT}}$$

$$\left(\frac{N_c}{N_V}\right) = e^{\frac{E_V - E_F + E_F + E_c}{KT}}$$

$$\left(\frac{N_c}{N_V}\right) = e^{\frac{E_V + E_c - 2E_F}{KT}}$$

Apply log on both sides.

$$\ln\left(\frac{N_c}{N_V}\right) = \ln\left(e^{\frac{E_V + E_c - 2E_{Fi}}{KT}}\right)$$

$$\ln\left(\frac{N_c}{N_V}\right) = e^{\frac{E_V + E_c - 2E_{Fi}}{KT}}$$

$$KT \ln\left(\frac{N_c}{N_V}\right) = -2E_{Fi} + E_V + E_c$$

$$E_{Fi} = \frac{E_V + E_c}{2} + \frac{KT}{2} \ln\left(\frac{N_c}{N_V}\right)$$

$$N_V = \left(\frac{m_h}{m}\right)^{3/2} T^{3/2} \qquad N_c = \left(\frac{m_e}{m}\right)^{3/2} T^{3/2}$$

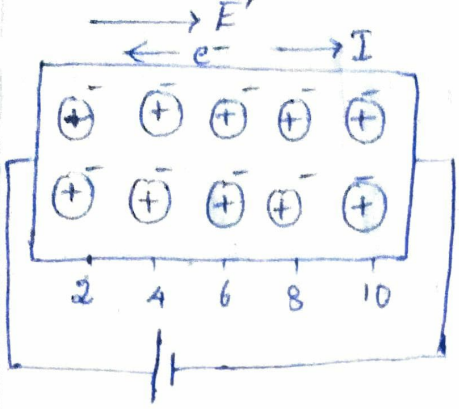
$$E_{Fi} = \frac{E_c + E_V}{2} + \frac{KT}{2} \ln\left(\frac{m_h}{m_e}\right)^{3/2}$$

$$E_{Fi} = \frac{E_c + E_V}{2} + \frac{3}{4} KT \ln\left(\frac{m_h}{m_e}\right)$$

Fermi energy level in Intrinsic Semi. C.

Uniform Doping:

Consider n-type Semiconductor.



* When we apply external electric field, current flow along the $\vec{E}$ and e^- move opposite to the $\vec{E}$.

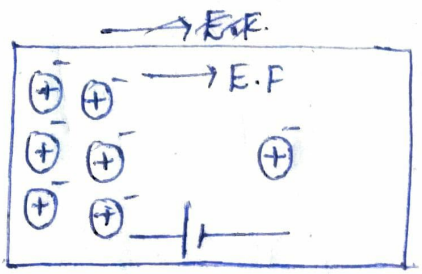
* When we apply external $\vec{E}$, collisions occur and current is produced that current is called "drift current" (I_d).

$$I_d \propto E$$

$$\frac{dn}{dx} = 0$$

* diffusion current is zero in U. doping.

Non-Uniform Doping :-



* When there is no external E.F. the current is zero in Non-Uniform doping.

$$I = 0$$

$\longrightarrow e^-$ (diffuse)

$\longleftarrow I$ (diffuse)

$\longleftarrow e^-$ (drift)

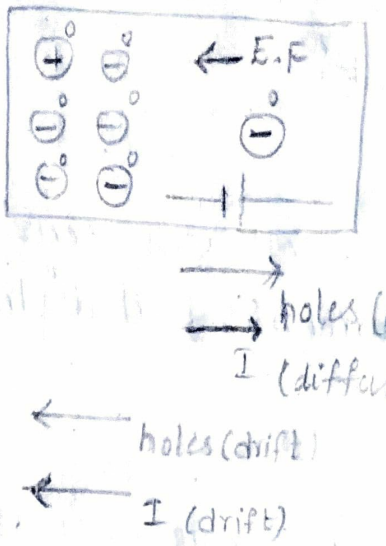
$\longrightarrow I$ (drift).

* elections will move of diffuse from higher concentration gradient to lower concentration gradient. and current will move opposite to the e^- diffusion.

* When we consider electricfield internally, e^- drift will move in the opposite direction to E.F. and current will move along the "E.F."

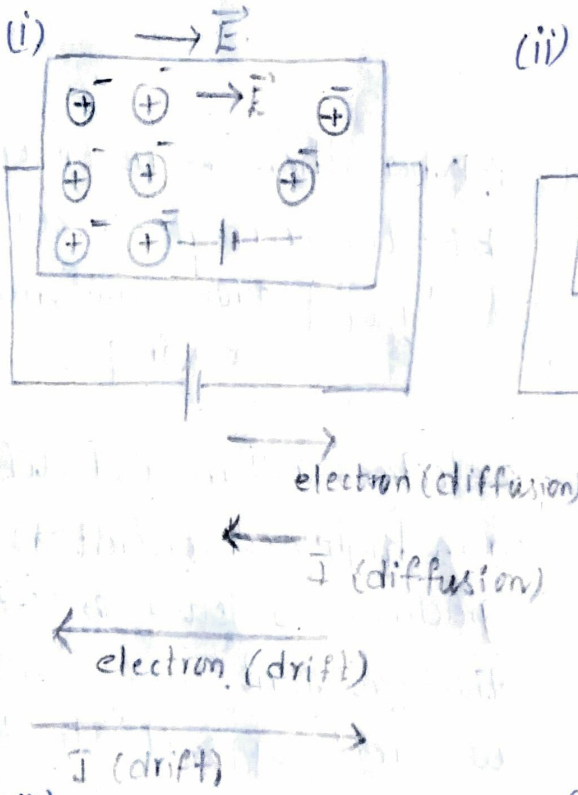
* So, diffussion current and drift current are opposite in direction, so by this we can say that current is zero when there is no external E.F

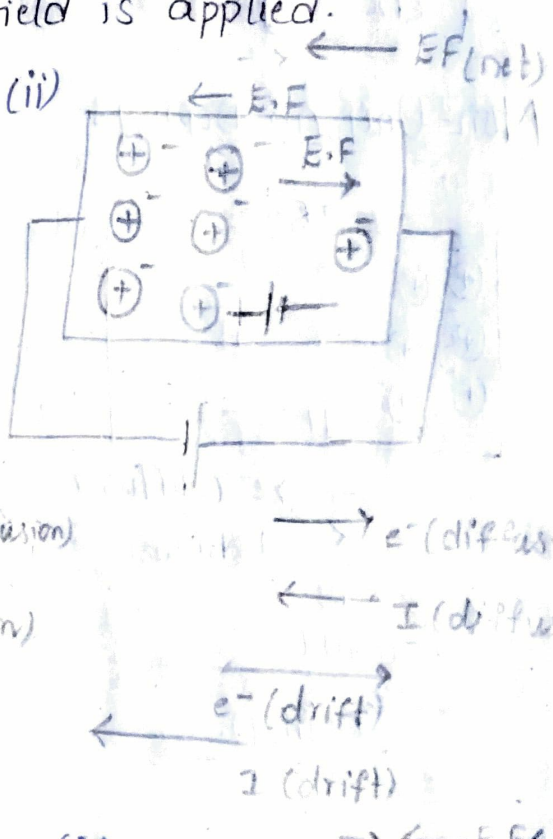
$$I_{(diffuse)} + I_{drift} = 0$$

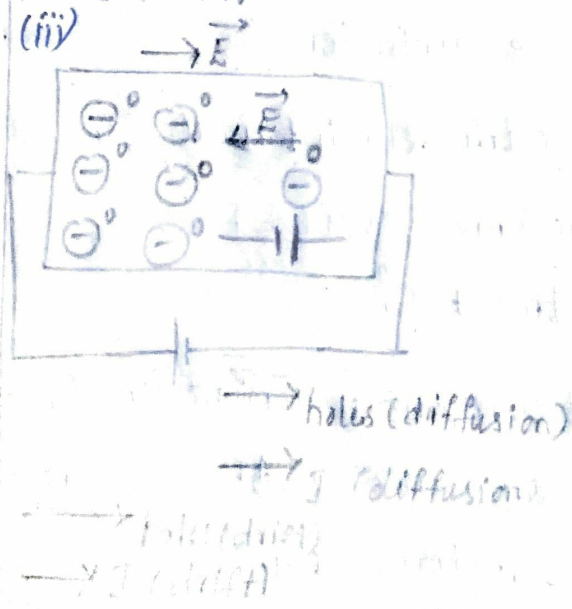


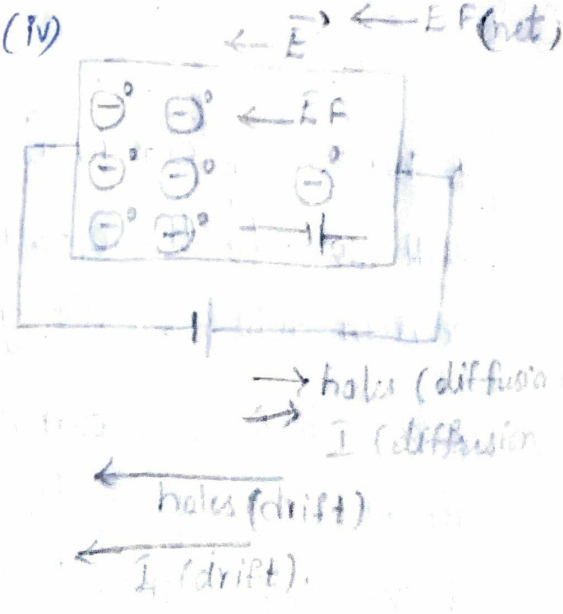
26/12/19 When external electric field is applied.

H.W

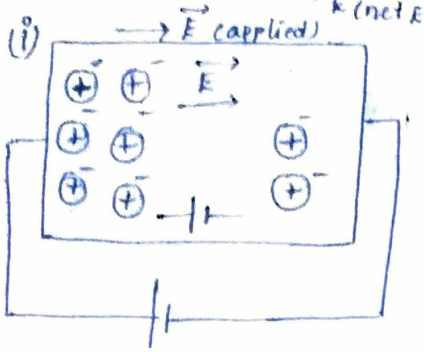








27/12/19 When the applied E.F is greater than internal E.F:-

(i) 

* Whenever we apply external electric field. It doesn't have diffusion current and there will be more drift current.

$I = I_{drift} + I_{diffusion}$

$\boxed{I = I_{drift}}$

(ii). When polarity changes:-

* Whenever we apply external $\vec{E}$ greater than internal $\vec{E}$: The net $\vec{E}$ is along the applied $\vec{E}$.

$$\boxed{I = I_{drift} + I_{diffusion}}$$

(iii) p-type :-

$$\boxed{I = I_{drift} + I_{diffusion}}$$

(iv) p-type : when polarity changes

$\boxed{I = I_{drift}}$

* current diffusion is along the holes diffusion in p-ty
* current diffusion is opposite to the electron diffusion in n-type.

Hole concentration of n-type conductor:

$$n_p = n_i^2$$

$$n_n p_n = n_i^2 \qquad \text{if } N_D >>> n_i$$

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

$$\boxed{p_n = \frac{n_i^2}{N_D}} \Rightarrow \text{minority charge carrier concentration in n-type}$$

electrons concentration of p-type semiconductor

$$n_p = n_i^2$$

$$n_p p_p = n_i^2$$

$$\boxed{n_p = \frac{n_i^2}{N_A}} \Rightarrow \text{minority charge carrier concentration in p-type}$$

$N_D \longrightarrow$ Donar impurity concentration

$N_A \longrightarrow$ Acceptor impurity concentration

$n_i \longrightarrow$ concentration of charge carriers in Intrinsic.

N-type : majority carrier concentration.

When $N_D > n_i$

$$p + N_D = n + N_A$$

$$p_n + N_D = n_n$$

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

$$n_i^2 + N_D n_n = n_n^2$$

$$n_n^2 - N_D n_n - n_i^2 = 0 \longrightarrow (1)$$

(1) is in the form of quadratic eqn, roots are

$$n_n = \frac{-(-N_D) \pm \sqrt{N_D^2 - 4(1)(-n_i^2)}}{2}$$

$$= \frac{N_D \pm \sqrt{N_D^2 + 4n_i^2}}{2}$$

$$n_n = \frac{N_D}{2} \pm \sqrt{\frac{N_D^2}{4} + \frac{4n_i^2}{4}}$$

$$\boxed{n_n = \frac{N_D}{2} \pm \sqrt{\left(\frac{N_D}{2}\right)^2 + n_i^2}}$$

$n_n \rightarrow$ majority charge carrier concentration (electrons) in n-type.

* n_n is always positive.

p-type : majority charge carrier concentration.

When $N_p > n_i$

$$p + N_D = n + N_A$$

$$P_p = n_p + N_A$$

$$P_p = \frac{n_i^2}{P_p} + N_A$$

$$n_i^2 + N_A P_p = P_p^2$$

$$-n_i^2 + P_p^2 - N_A P_p = 0$$

$$P_p^2 - N_A P_p - n_i^2 = 0 \longrightarrow (1)$$

$$P_p = \frac{-(-N_A) \pm \sqrt{N_A^2 - 4(1)(-n_i^2)}}{2}$$

$$= \frac{N_A \pm \sqrt{N_A^2 + 4n_i^2}}{2}$$

$$P_p = \frac{N_A}{2} \pm \sqrt{\frac{N_A^2}{4} + \frac{4n_i^2}{4}}$$

$$P_p = \frac{N_A}{2} \pm \sqrt{\left(\frac{N_A}{2}\right)^2 + n_i^2}$$

$P_p \rightarrow$ majority charge carrier concentration in p-ty
(holes).

When $N_A >>> n_i$

$$P_p = \frac{N_A}{2} + \frac{N_A}{2}$$

$$P_p = N_A$$

30/12/19 Determine the Resistivity of germanium
i) in Intrinsic condition at 300°K
ii) With donar impurity of 1 in 10^7.
(iii) with acceptor impurity of 1 in 10^8
(iv) With both impurities simultaneously. Given that Ge at room temperature $n_i = 2.5 \times 10^{13}/cm^3$, mobility of electrons is equal to 3800 $cm^2/V.sec$, mobility of holes is equal to 1800 $cm^2/V.sec$. and a no. of Ge atoms./cm^3 is equal to 4.4×10^{22}.

Sol:- (i) $\sigma_{intrinsic} = n_i e (\mu_p + \mu_n)$

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

$= 0.0224$

$$\rho = \frac{1}{\sigma} = \frac{1}{0.024} = 44.64\ \Omega cm$$

(ii) $N_D = \frac{4.4 \times 10^{22}}{10^7} = 4.4 \times 10^{15}/cm^3$

$\sigma = n_n q \mu_n$

$= N_D q \mu_n$

$= 4.4 \times 10^{15} \times 1.6 \times 10^{-19} \times 3800$

$\sigma = 2.675\ \Omega^{-1}cm^{-1}$

$\boxed{\rho = 0.37\ \Omega cm}$

(iii) $\sigma = n_p q \mu_p$

$= N_A q \mu_p$

$= \frac{4.4 \times 10^{22}}{10^8} \times 1.6 \times 10^{-19} \times 1800$

$\sigma = 0.126\ \Omega^{-1}cm^{-1}$

$\boxed{\rho = 7.89\ \Omega cm}$

(iv) $\sigma = n_e e\mu_n + p_e e\mu_p = n_n e\mu_n + p_n e\mu_p$

$\sigma = (N_D - N_A) q \mu_n = N_D e\mu_n + \frac{n_i^2}{N_D} e\mu_p$

$\sigma = (3.96 \times 10^{15})$

$\sigma = 2.407\ \Omega^{-1}cm^{-1}$

$\boxed{\rho = 0.415\ \Omega cm}$

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Drift current:

Drift current is due to electrons movement

-for p-type: (current density due to holes)

$\boxed{J_p = pq\mu_p E}$

-for n-type: (current density due to electrons).

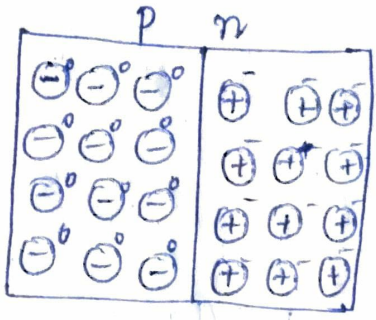
$\boxed{J_n = nq\mu_n E}$

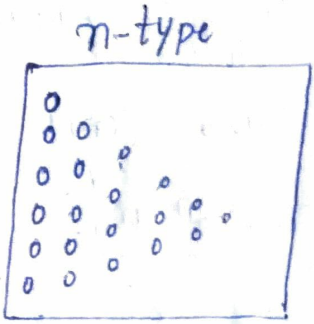
Carrier life time:

The amount of time the electron spend in conduction band it is called carrier life time.

Diffussion current:

The current due to the change in the concentration gradient.





J_p (diffusion) $\propto \frac{dP}{dx}$

J_p (diffusion) $\propto q$

J_p (diffusion) $\propto -q \frac{dP}{dx}$

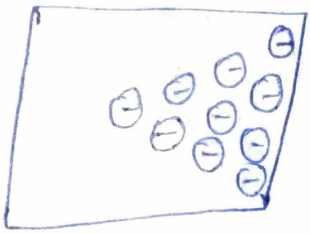
J_p (diffusion) $= -D_p q \frac{dP}{dx}$

$$J_p \text{ (diffusion)} = -D_p q \frac{dP}{dx}$$

Total current due to holes. is -

$$J_p \text{ (diffussion + drift)} = pq\mu_p E + \left(-D_p q \frac{dP}{dx}\right)$$

for p-type



J_n (diffusion) $\propto \frac{dn}{dx}$

J_n (diffusion) $\propto q$

J_n (diffusion) $\propto q \frac{dn}{dx}$

J_n (diffusion) $= D_n q \frac{dn}{dx}$

$$J_n \text{ (drift + diffusion)} = n q \mu_n E + D_n q \frac{dn}{dx}$$

current density due to electrons ↗

current due to electrons:

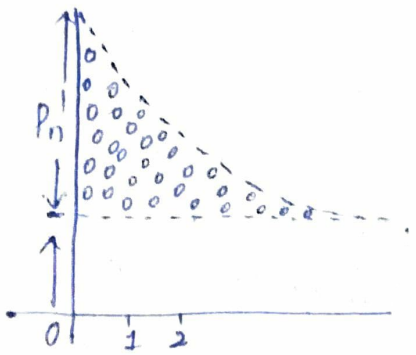
$$I_n = (J_n) A$$

current due to holes:

$$I_p = (J_p) A$$

* The average life time of an electron in conduction band is called carrier life time.

Injected minority charge concentration:



$$P_n(x) = P_{n_0} + P_n' e^{-x/L_p}$$

when $x = 0$

$$P_n(x) = P_{n_0} + P_n'$$

$$n_p(x) = n_{p_0} + n_p' e^{x/L_n}$$

when $x = 0$

$$n_p(x) = n_{p_0} + n_p'$$

(a) Find the concentration of holes and electrons in a p-type germanium at 300°K. If the conductivity is $100 (\Omega m)^{-1}$. Assume that the conductivity due to electrons is negligible as compared to that due to holes.

$\sigma = 100\ (\Omega cm)^{-1}$ $\mu_p = 1800\ cm^2/sec$ for germanium

$T = 300^\circ K$

$$\sigma = p_p \mu_p e$$

$$p_p = \frac{\sigma}{\mu_p e} = \frac{100\ (\Omega cm)^{-1}}{1800\ cm^2/V.sec \times (1.6\times10^{-19} C)}$$

$$= 3.41\times10^{17}\ cm^{-3}$$

$$n_p = \frac{n_i^2}{p_p} = \frac{(2.5\times10^{13} cm^{-3})^2}{3.41\times10^{17} cm^{-3}} = 1.83\times10^{9}\ cm^{-3}$$

b) Determine the position of Fermi level with respect to the edge of the conduction band of the germanium of part (a). Assume $N_V = 6.0\times10^{19}\ cm^{-3}$ and $E_G = 0.72$ at $300^\circ K$

$N_V = 6\times10^{19} cm^{-3}$

$E_g = 0.72$

$T = 300^\circ K$

for p-tye semiconductor

$$p_p = N_A$$

$$E_F - E_V = KT \ln\left(\frac{N_V}{p_p}\right)$$

$$= (3.2\times10^{-23})(300)\ln\left(\frac{6\times10^{19}}{3.41\times10^{17}}\right)$$

$$= 0.134 ev.$$

Fermi Level is located at 0.134ev above the edge of V.B

E_F with respect to conduction B.

$$E_F - E_c = (E_F - E_V) - (E_c - E_V)$$

$$= (E_F - E_V) - E_G$$

$$= 0.134 - 0.72$$

$$= -0.586 eV$$

Thus F.E.L is at 0.586ev below the edge of C.B.

In an n-type silicon the donar concentration is 1 atom per 2×10^8 silicon atoms. Assume that the effective mass of the electron equals the true mass and the density of atoms in the silicon is 5×10^{22} atoms cm^3. At what temperature will the Fermi level coincide with the edge of the conduction band?

Sol:- $N_D = \frac{1}{2\times10^8} = (5\times10^{-9})\times 5\times10^{22} = 2.5\times10^{14}$ atoms/cm^3

$$E_{F_N} = E_C - KT\ln\left(\frac{N_c}{N_D}\right)$$

$$E_F - E_C = KT\ln\left(\frac{N_c}{N_D}\right)$$

$$N_c = N_D = 2.5\times10^{14}$$

Fermi level coincides with the edges of the conduction band.

(b) $m_n = m$

$$T = \left(\frac{2.5\times10^{20}}{4.82\times10^{21}}\right)^{2/3}$$

$$T = 0.14^\circ K.$$

For a particular semiconductor material, $N_c = 1.5\times10^{18} cm^{-3}$ $N_V = 1.3\times10^{19} cm^{-3}$ and $E_G = 1.43$ eV at $T = 300^\circ K$

(a) Determine the position of the intrinsic Fermi level with respect to the centre of the bandgap. What is the position of the Fermi level with respect to the top of the valence band E_V?

(b) Find the intrinsic carrier concentration of the semiconductor at $T = 300^\circ K$

(c) Determine effective masses m_n and m_p of electrons and hole respectively..

position of F level with respect to centre of bandgap Emidgap is obtained from

$$E_F - E_{midgap} = -\frac{0.0259}{2} \ln\left(\frac{1.5\times10^{18}}{1.3\times10^{19}}\right)$$

$$= 0.028 eV.$$

Fermi level is located at 0.028ev above the centre of the bandgap.

position of the fermi level with respect to E_V is

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

$$= \frac{E_C - E_V}{2} + E_V + \frac{KT}{2} \ln\left(\frac{N_C}{N_V}\right) \qquad (E_G = E_C - E_V)$$

$$= \frac{E_G}{2} + E_V - \frac{KT}{2} \ln\left(\frac{N_C}{N_V}\right)$$

$$E_F - E_V = \frac{1.43}{2} + \frac{(1.38\times10^{-23}\times300}{2} \ln\left(\frac{1.5\times10^{18}}{1.3\times10^{19}}\right)$$

$$= 0.715 + 0.028$$

$$\boxed{E_F - E_V = 0.743 eV}$$

Fermi energy level is 0.743ev above the V.B. edge E_V.

Fermi enenergy level w.r.t. C.B edge E_C.

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

$$E_F = \frac{2E_C - E_G}{2} - \frac{KT}{2} \ln\left(\frac{1.5\times10^{18}}{1.3\times10^{19}}\right)$$

$$E_F - E_C = -\frac{E_G}{2} - \frac{KT}{2} \ln\left(\frac{N_C}{N_V}\right)$$

$$= -0.687 eV.$$

Fermi energy level is located at 0.687 ev below E_C

(b). $n_i^2 = N_c N_v e^{\left(\frac{-E_g}{kT}\right)}$

$= (1.5\times10^{18})(1.3\times10^{19})\, e^{\left(\frac{-1.43}{0.0259}\right)}$

$n_i^2 = 2.05\times10^{13}\,cm^{-6}$ //

$n_i = 4.53\times10^{6}\,cm^{-3}$

(c) $N_c = 1.5\times10^{18}\,cm^{-3}$

$1.5\times10^{24}\,m^{-3}$

$N_c = 4.82\times10^{21}\,(m_n T)^{3/2}$

$m_n = \left\{\left(\frac{N_c}{4.82\times10^{21}}\right)^{2/3}\frac{1}{T}\right\} m$

$m_n = \left\{\left(\frac{N_c}{4.82\times10^{21}}\right)^{2/3}\cdot\frac{1}{T}\right\} m$

$= \left\{\left(\frac{1.5\times10^{24}}{4.82\times10^{21}}\right)^{2/3}\frac{1}{300}\right\} m$

$= 0.135m \quad = 0.135\times9.1\times10^{-31} = 1.23\times10^{-31}\,Kg.$

Effective mass of holes

$m_p = \left\{\left(\frac{N_V}{4.82\times10^{21}}\right)^{2/3}\frac{1}{T}\right\} m$

$= \left\{\left(\frac{1.3\times10^{25}}{4.82\times10^{21}}\right)^{2/3}\frac{1}{300}\right\}(9.1\times10^{-31})$

$\boxed{m_p = 5.88\times10^{-31}\,Kg}$

The effective masses of electron and hole in germanium are $m_n = 0.55m$ and $m_p = 0.37m$ respectively. Find the position of the intrinsic Fermi level in germanium at 300°K.

$m_n = 0.55m$

$m_p = 0.37m$

$N_c = 2\left(\frac{2\pi\times m_n kT}{h^2}\right)^{3/2} = 2\left(\frac{2\pi\times0.55\times9.1\times10^{-31}\times0.0259}{(6.626\times10^{-34})^2}\right)^{3/2}\times$

$\times\,(1.6\times10^{-19})^{3/2}$

$= 1.022\times10^{25}\,cm^{-3}$

$$N_V = 2\left(\frac{2\pi m_p KT}{h^2}\right)^{3/2} \times (1.60\times10^{-19})^{3/2}$$

= the position of th F.L w.r.t the middle of the band gap

$$E_{midgap} = \frac{E_c + E_v}{2}$$

$$E_F - E_{midgap} = -\frac{KT}{2}\ln\left(\frac{m_n}{m_p}\right)^{3/2}$$

$$= -\frac{3}{4}KT\ln\left(\frac{m_n}{m_p}\right)$$

$$= -\frac{3\times0.0259}{4}\ln\left(\frac{0.65}{0.37}\right)$$

$$= -7.7\times10^{-3}\text{ eV}.$$

F.L is located at 7.7×10^{-3} eV below the middle of the Forbidden gap of Intgermanium at 300°K

KT =

For a particular semiconductor, the effective mass of e^- is $m_n = 1.4m$, If $E_c - E_F = 0.25$eV, determine the effective density of states in the conduction band and concentration of electron in the semiconductor at T=400°K

$m_n = 1.4m$

$E_c - E_F = 0.25$eV

$$N_c = 2\left(\frac{2\pi \times (1.4\times9.1\times10^{-31})(8.625\times10^{-5})(400^\circ K)\times1.6\times10^{-19}}{(6.626\times10^{-34})^2}\right)^3$$

$$= 6.38\times10^{25} m^{-3}.$$

$$n = N_c e^{\left(\frac{E_f - E_c}{KT}\right)}$$

$$= 6.38\times10^{25} e^{\left(\frac{-0.25}{0.0259}\right)}$$

$$\boxed{n = 4.10\times10^{21}\ m^{-3}.}$$

6) Determine the concentration of free electrons and holes in a sample of germanium at 300°K which has a concentration of donar atoms equal to 2×10^{14} atoms/cm^3 and a concentration of acceptor atom equal to 3×10^{14} atoms/cm^3. Is this p or n-type germanium? In other words, is the conductivity due primarily to holes or to electrons?

$N_D = 2\times10^{14}$ atoms/cm^3.

$N_A = 3\times10^{14}$ atoms/cm^3

$n_i = 2.5\times10^{13}\ cm^{-3}$.

$T = 300°K$.

$$n = \frac{1}{2}\left\{(N_A - N_D) + \sqrt{(N_A - N_D)^2 + 4n_i^2}\right\}.$$

$$= \frac{1}{2}\left\{(2\times10^{14} - 3\times10^{14}) + \sqrt{(3\times10^{14} - 2\times10^{14})^2 + 4\,(2.5\times10^{13})^2}\right\}$$

$$n = 5.90\times10^{12}\ cm^{-3}$$

$$p = \frac{(2.5\times10^{13})^2}{5.90\times10^{12}} = 1.06\times10^{14}\ cm^{-3}.$$

$$\sigma_n = n\mu_n e$$

$$= (5.90\times10^{12})(3800)(1.6\times10^{-19})$$

$$= 0.0036\ (\Omega cm)^{-1}$$

$$\sigma_p = p e \mu_p$$

$$= (1.06\times10^{14})(1.6\times10^{-19})(1800)$$

$$= 0.0305\ (\Omega cm)^{-1}$$

$\frac{\sigma_p}{\sigma_n} = \frac{0.0305}{0.0036} = 8.41$. greater than $\frac{\sigma_{pi}}{\sigma_{ni}} = \frac{\mu_p}{\mu_n} = \frac{1800}{3800} = 0.47$

Hence the sample is p-type.

Diffusion:

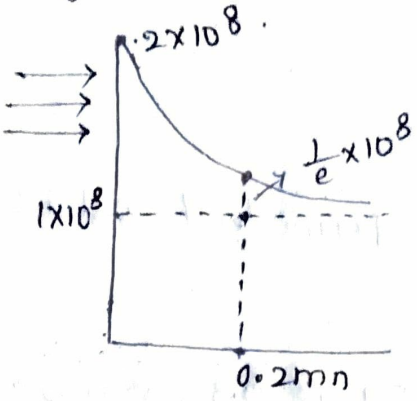
non-uniform concentration of particles in a semiconductor, the concentration of p of holes varies with distance x in the semiconductor, and there exists a concentration gradient dp/dx in the density of carriers. The existence of a gradient implies that, if an imaginary surface is drawn in the semiconductor, the density of holes immediately on one side of the surface is

01/01/2020

$$P_n(x) = P_{no} + P_n' e^{-x/L_p}$$

The average distance that the minority charge carriers cover during its diffusion in its life time is called diffusion length

1) Figure shows an n-type semiconductor illuminated at left end find diffussion concentration and diffussion length.



(i) $P_n(x) = P_{no} + P_n' e^{-x/L_p}$

$P_n(0) = P_{no} + P_n'$

$2\times10^8 = 1\times10^8 + P_n'$

$\boxed{P_n' = 1\times10^8}$

(ii) $P_n(x) = P_{no} + P_n' e^{-x/L_p}$

$P_n(0.2) = 1\times10^8 + 1\times10^8 \cdot e^{-0.2/L_p}$

$P_n(0.2) - 1\times10^8 = 1\times10^8 e^{-0.2/L_p}$

$\frac{1}{e}\times10^8 = 1\times10^8 e^{-0.2/L_p}$

$e^{-1} = e^{-0.2/L_p}$

$\boxed{L_p = 0.2\text{mm}}$

2) In an n-type semiconductor the F.L is 0.24ev below the C.B at 300°k. If temperature is increased to 350°k determine the new position of F.L w.r.t C.B.

$E_F = E_c - E_{Fn} = 0.24\text{eV}$

$T = 300°K$

$E_c - E_{Fn} = ?$ at $T = 350°K$.

$$E_{Fn} = E_c - KT\ln\left(\frac{N_c}{N_D}\right)$$

$$E_c - E_{Fn} = KT\ln\left(\frac{N_c}{N_D}\right)$$

$$\frac{E_c - E_{FN}}{(E_c - E_{FN})_{new}} = \frac{KT\ln\left(\frac{N_c}{N_D}\right)}{KT\ln\left(\frac{N_c}{N_D}\right)}$$

$$\frac{0.24\,eV}{E_c - E_{Fn}} = \frac{300}{350}$$

$$\boxed{E_c - E_{Fn} = 0.28\,eV}$$

If temperature increases the Fermi level will also increases.

3) In a p-type semiconductor the F.L is 0.3 ev above the V.B at room temp. determine the new position of F.L at 350°K and 400°K

$$E_{Fp} = E_v + KT\ln\left(\frac{N_V}{N_A}\right)$$

$$E_{Fp} - E_v = KT\ln\left(\frac{N_V}{N_A}\right)$$

$$\frac{E_{Fp} - E_v}{(E_{Fp} - E_v)_{new}} = \frac{KT\ln\left(\frac{N_V}{N_A}\right)}{KT\ln\left(\frac{N_V}{N_A}\right)}$$

$$\frac{0.3}{E_{Fp} - E_v} = \frac{300}{350}$$

$$\boxed{E_{Fp} - E_v = 0.35\,eV}$$ The F.L is 0.35 ev above the C.B

$$\frac{0.3}{E_{Fp} - E_v} = \frac{300}{400}$$

$$\boxed{E_{Fp} - E_v = 0.4\,eV}$$ The F.L is ~~0.35~~ 0.4 ev above the C.B

4) In ...

c.B. Find the position of Fermi level ... tion of donar atoms is increased by a factor of

(i) 4 times (ii) 8 times.

Sol: $E_{Fn} = E_c - KT\ln\left(\frac{N_c}{N_D}\right)$

$E_c - E_{Fn} = KT\ln\left(\frac{N_c}{4N_D}\right)$

$E_c - E_{Fn} = KT\ln\left(\frac{N_c}{4N_D}\right)$

$$\frac{0.2eV}{E_c - E_{Fn}} = \frac{\ln\left(\frac{N_c}{N_D}\right)}{\ln\left(\frac{N_c}{4N_D}\right)} =$$

(or) $\frac{0.2}{E} = \ln(N_c) - \ln(N_D) - \ln(N_c) + \ln(4N_D)$

$\frac{0.2}{E} = \ln\left(\frac{4N_D}{N_D}\right)$

$\frac{0.2}{\ln(4)} = E \Rightarrow 0.144\ eV$

the .2

$$\frac{0.2}{E_c - E_{Fn}} = \frac{\ln\left(\frac{N_c}{N_D}\right)}{\ln\left(\frac{N_c}{4N_D}\right)}$$

$$E_c - E_{Fn} = 0.2\left[\frac{\ln\left(\frac{N_c}{N_D}\right) - \ln(4)}{\ln\left(\frac{N_c}{N_D}\right)}\right]$$

$$= 0.2\left[1 - \frac{\ln(4)}{\ln\left(\frac{N_c}{N_D}\right)}\right]$$

$$= 0.2\left[1 - \frac{1.386}{\ln\left(\frac{N_c}{N_D}\right)}\right]$$

$$= 0.2\left[1 - \frac{1.386}{7.72}\right]$$

$$= 0.2\,[0.8204]$$

$$\boxed{E_c - E_{Fn} = 0.164\ eV}$$

$0.2 = KT\ln\left(\frac{N_c}{N_D}\right)$

$\frac{0.2}{KT} = \ln\left(\frac{N_c}{N_D}\right)$

$\frac{0.2}{0.0259} = \ln\left(\frac{N_c}{N_D}\right)$

(ii)

$$E_c - E_{Fn} = 0.2\left[1 - \frac{\ln(8)}{7.72}\right]$$

$$= 0.2\,(0.730)$$

$$\boxed{E_c - E_{Fn} = 0.146\ eV}$$

5) In a p-type semiconductor the F.L lies 0.4 eV above the V.B determine the new position of F.L If the acceptor atoms are multiplied by the factor of

(i) 0.5

(ii) 0.4

$$E_F - E_V = KT \ln\left(\frac{N_V}{N_A}\right) \rightarrow (1)$$

$$E_F - E_V = KT \ln\left(\frac{2N_V}{N_A}\right) \rightarrow (2)$$

$$(1) \div (2) \quad \frac{E_F - E_V}{E_F - E_V} = \frac{KT \ln\left(\frac{N_V}{N_A}\right)}{KT \ln\left(\frac{2N_V}{N_A}\right)}$$

$$\Rightarrow \frac{0.4}{x} = \frac{\ln\left(\frac{N_V}{N_A}\right)}{\ln\left(\frac{N_V}{N_A}\right) + \ln(2)}$$

$$x = 0.4\left[\frac{\ln\left(\frac{N_V}{N_A}\right) + \ln(2)}{\ln\left(\frac{N_V}{N_A}\right)}\right]$$

$$0.4 = KT \ln\left(\frac{N_V}{N_A}\right)$$

$$\ln\left(\frac{N_V}{N_A}\right) = 15.44$$

$$= 0.4\left[1 + \frac{\ln(2)}{\ln\left(\frac{N_V}{N_A}\right)}\right]$$

$$= 0.44\left[1 + \frac{\ln(2)}{15.44}\right]$$

$$x = 0.459 \text{ eV}$$

$$\frac{0.4}{x} = \frac{\ln\left(\frac{N_V}{N_A}\right)}{\ln\left(\frac{5N_V}{2N_A}\right)}$$

$$x = 0.4\left[1 + \frac{\ln\left(\frac{5}{2}\right)}{\ln\left(\frac{N_V}{N_A}\right)}\right]$$

$$= 0.4\left[1 + \frac{0.916}{15.44}\right]$$

$$\boxed{x = 0.423 \text{ eV}}$$

02/01/2020 Prove that $E_{Fn} - E_{Fi} = KT \ln\left(\frac{N_D}{n_i}\right)$.

$$E_{Fn} - E_{Fi} = KT \ln\left(\frac{N_V}{n_i}\right)$$

$$E_c - KT \ln\left(\frac{N_c}{N_D}\right) - \left[\frac{E_c + E_V}{2} + \frac{KT}{2} \ln\left(\frac{N_V}{N_c}\right)\right]$$

$$E_c - KT \ln\left(\frac{N_c}{N_D}\right) - \left[\frac{E_c + E_c - E_G}{2} + \frac{KT}{2} \ln\left(\frac{N_V}{N_c}\right)\right]$$

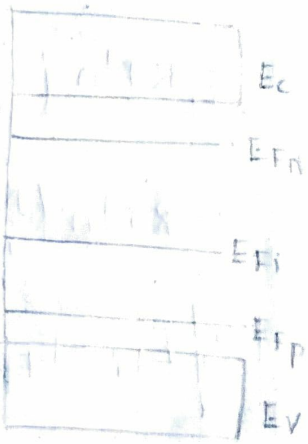
$$E_c - KT \ln\left(\frac{N_c}{N_D}\right) - \left[\frac{2E_c}{2} - \frac{E_G}{2} + \frac{KT}{2} \ln\left(\frac{N_V}{N_c}\right)\right]$$

$$-KT \ln\left(\frac{N_c}{N_D}\right) + \frac{E_G}{2} - \frac{KT}{2} \ln\left(\frac{N_V}{N_c}\right)$$

$$-KT \ln\left(\frac{N_c}{N_D}\right) + \frac{KT}{2} \ln\left(\frac{N_c N_V}{n_i^2}\right) - \frac{KT}{2} \ln\left(\frac{N_V}{N_c}\right)$$

$$-KT \ln\left(\frac{N_c}{N_D}\right) + KT \ln\left(\frac{N_c N_V}{n_i^2}\right)^{1/2} - KT \ln\left(\frac{N_V}{N_c}\right)^{1/2}$$

$$= KT \ln\left[\frac{\left(\frac{N_c N_V}{n_i^2}\right)^{1/2}}{\left(\frac{N_c}{N_D}\right)\left(\frac{N_V}{N_c}\right)^{1/2}}\right]$$



$$KT \ln\left[\left(\frac{N_c N_V}{n_i^2}\right)^{1/2}\left(\frac{N_D}{N_c}\right)\left(\frac{N_c}{N_V}\right)^{1/2}\right]$$

$$= KT \ln\left(\frac{N_D}{n_i}\right)$$

$$\therefore \boxed{E_{Fn} - E_{Fi} = KT \ln\left(\frac{N_D}{n_i}\right)} \quad //$$

$\boxed{E_c - E_V = E_G}$

2) Prove that $E_{Fi} - E_{Fp} = KT \ln\left(\frac{N_A}{n_i}\right)$

$$\frac{E_c + E_V}{2} + \frac{KT}{2} \ln\left(\frac{N_V}{N_c}\right) - \left[E_V + KT \ln\left(\frac{N_V}{N_A}\right)\right]$$

$$\frac{E_c + E_V}{2} + \frac{KT}{2} \ln\left(\frac{N_V}{N_c}\right) - \left[E_V + KT \ln\left(\frac{N_V}{N_A}\right)\right]$$

$$\frac{E_G + E_V + E_V}{2} + \frac{KT}{2}\ln\left(\frac{N_V}{N_C}\right) - \left[E_V + KT\ln\left(\frac{N_V}{N_A}\right)\right]$$

$$\frac{E_G}{2} + \frac{KT}{2}\ln\left(\frac{N_V}{N_C}\right) - KT\ln\left(\frac{N_V}{N_A}\right)$$

$$\frac{KT}{2}\ln\left(\frac{N_C N_V}{n_i^2}\right) + \frac{KT}{2}\ln\left(\frac{N_V}{N_C}\right) - KT\ln\left(\frac{N_V}{N_A}\right)$$

$$KT\ln\left(\frac{N_C N_V}{n_i^2}\right)^{1/2} + KT\ln\left(\frac{N_V}{N_C}\right)^{1/2} - KT\ln\left(\frac{N_V}{N_A}\right)$$

$$KT\ln\left(\frac{\left(\frac{N_C N_V}{n_i^2} \times \frac{N_V}{N_C}\right)^{1/2}}{\left(\frac{N_V}{N_A}\right)}\right)$$

$$KT\ln\left(\frac{\left(\frac{N_V^2}{n_i^2}\right)^{1/2}}{\frac{N_V}{N_A}}\right)$$

$$= KT\ln\left(\frac{N_V}{n_i} \times \frac{N_A}{N_V}\right)$$

$$= KT\ln\left(\frac{N_A}{n_i}\right)$$

$$\therefore \boxed{E_{Fi} - E_{Fp} = KT\ln\left(\frac{N_A}{n_i}\right)}$$

Formulas:

1) $E_{Fn} = E_C - KT\ln\left(\frac{N_C}{N_D}\right)$

2) $E_{Fp} = E_V + KT\ln\left(\frac{N_V}{N_A}\right)$

3) $E_{Fn} = E_{Fi} + KT\ln\left(\frac{N_D}{n_i}\right)$

4) $E_{Fp} = E_{Fi} - KT\ln\left(\frac{N_A}{n_i}\right)$

problem-1:-

1) The mobility of electrons and holes in silicon are 0.125 $m^2/V.sec$ and 0.048 $m^2/V.sec$ respectively. Determine the conductivity of intrinsic silicon at 27°c. If the intrinsic carrier concentration is 1.6×10^{16} atoms $/m^3$. when it is doped with 10^{23} phosphorous atoms$/m^3$ Determine equilibrium hole concentration, conductivity and position of fermi level relative to the intrinsic level.

$\mu_p = 0.048\ m^2/V\,sec$ $\quad n_i = 1.6\times10^{16}$ atoms$/m^3$.

$\mu_n = 0.125\ m^2/V.sec$ $\quad N_D = (10^{23})$

$T = 27°c$

$\sigma_{intrinsic} = nq(\mu_n+\mu_p)$

$= (1.6\times10^{16})(1.6\times10^{-19})(0.048+0.125)$

$= 4.428\times10^{-4}\ \Omega^{-1}m^{-1}$

$P_n = \frac{n_i^2}{N_p}$ $\qquad \sigma = nq\mu_n$

$\sigma = 2000\ \Omega^{-1}m^{-1}$

$= \frac{(1.6\times10^{16})^2}{10^{23}} = 2.56\times10^{9}$

$E_{Fi} = \frac{E_c+E_v}{2} - \frac{KT}{2}\ln\left(\frac{N_c}{N_v}\right)$ $\qquad E_{Fn}-E_{Fi} = KT\ln\left(\frac{N_D}{n_i}\right)$

$= 0.4068eV$

$E_{Fi} - E_{midgap} = -\frac{KT}{2}\ln\left(\frac{N_c}{N_v}\right)$

3/1/20

Einstein relation for Semiconductors:

1) $\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{KT}{q} = V_T$

$V_T \rightarrow$ Thermal voltage.

$D_n \rightarrow$ diffussion constant for electrons.

$D_p \rightarrow$ diffussion constant for holes

$\mu_n \rightarrow$ mobility of electrons.

$\mu_p \rightarrow$ mobility of holes

$\frac{KT}{q} \rightarrow$ 26mV.

$\boxed{V_T = 26mV}$

2) $E_G = E_{G_0} - \beta T$

$E_G \rightarrow$ Energy Gap

$E_{G_0} \rightarrow$ Energy Gap at $T = 0°K \rightarrow$ Si $\rightarrow$ 1.21eV.
Ge $\rightarrow$ 0.785 eV.

$\beta \rightarrow$ for silicon $\rightarrow 3.6 \times 10^{-4}$
for Ge $\rightarrow 2.23 \times 10^{-4}$

$T \rightarrow$ Temperature.

Energy Bandgap at room temperature for silicon & Germanium.

$E_G = 1.21 - (3.6 \times 10^{-4})(300).$

$\boxed{E_{G_{Si}} = 1.1eV}$

$E_{G_{ger}} = 0.785 - (2.23 \times 10^{-4})(300°K)$

$\boxed{E_{G_{ger}} = 0.72eV}$

* For any Semiconductor the ratio of diffussion constant to mobility of carries depends on temperature.

1) Generative Type Semiconductors.

* A semiconductor which obey mass action law is called Generative type semiconductors

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

* If we increase the donar impurity concentration the E_{Fn} will move upward.

* If we dope E_{Fn} very heavily E_{Fn} will move into the C.B (Tunnel diode).

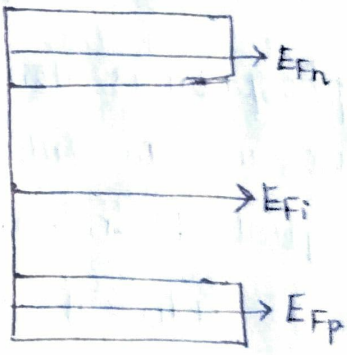
* If we increase the temperature the E_{Fn} will move downward.

2) De-Generative Type Semiconductor:

* A semiconductor which does not obey law of mass action they are called De-Generative type Semiconductor.

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

Eg:- Tunnel diode



Parameters	Silicon	Germanium
1. Atomic number	14	32
2. Lattice co	0.543 nm	0.565nm
3. Relative permitivity (ε_r)	11.8	16.0
4. Energy Gap at 0°K	1.21eV	0.785eV
5. Energy Gap at 300°K	1.12eV	0.72eV
6. Electron mobility (μ_n) $m^2/V\text{sec}$	0.13 $m^2/V\cdot sec$	0.38
7. hole mobility (μ_p) $m^2/V\cdot sec$	0.05 $m^2/V\cdot sec$	0.18 $m^2/V\cdot se$

8. Intrinsic concentration	$1.38 \times 10^{16}/m^3$	$2.5 \times 10^{19}/m^3$
9. Electron diffussion constrant (D_n) m^2/sec	$0.0034\ m^2/sec$	$0.0099\ m^2/$
10. Hole diffussion constant (D_p) m^2/sec	$0.0013\ m^2/sec$	$0.0047\ m^2/sec$ $1 \times 10^{25}\ m^2/sec$
11. Density of states at conduction band (n_c). m^{-3}.	$2.8 \times 10^{25}/m^3$	$1 \times 10^{25}/m^3$
12. Density of states at Valence band (n_v)/m^3	$1 \times 10^{25}/m^3$	$6 \times 10^{24}/m^3$.

problems:-

1) A silicon sample, is uniformly doped with 10^{16} phosphorous atoms/cm^3 and 2×10^{16} boron atoms/cm^3. If all the dopants are fully ionized the material is

Sol:- phosphorous atom 10^{16} will make n-type. Since the dopants are fully ionized the no. of electrons will be equal to no. of donar atoms

$$N_D = n = 10^{16}/cm^3$$

$N_A = p =$ Boran atoms $= 2 \times 10^{16}/cm^3$

$N_A > N_D$

$\therefore$ p-type.

carrier concentration:

$= N_A - N_D$

$= 2 \times 10^{16} - 10^{16}$

$= 10^{16}/cm^3$

2) The intrinsic carrier density at 300°K is $1.5\times10^{10}/cm^3$, in Silicon for n-type silicon doped to 2.25×10^{15} atoms/cm³ the equilibrium election and hole densities are

Sol:- $n_i = 1.5\times10^{10}/cm^3$

$N_D = 2.25\times10^{15}/cm^3 = n$ $\boxed{n >> n_i}$

$n_p = n_i^2$

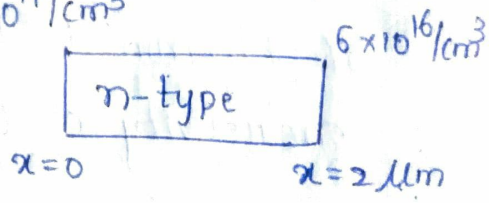
$$P = \frac{n_i^2}{n} = \frac{(1.5\times10^{10})^2}{2.25\times10^{15}} = 10^5/cm^3$$

3) The electron concentration in a sample of uniformly doped n-type silicon at 300°K varies linearly from $10^{17}/cm^3$ at $x=0$ to $6\times10^{16}/cm^3$ at $x=2\mu m$. Assume a situation that electrons are supplied to keep this concentration gradient constant with time. If electronic charge is 1.6×10^{-19} C and the diffussion constant $D_n = 35\ cm^2/s$, the current density in the silicon, if no electric field is present is.

Sol:- $J_n = q\mu_n n E + q D_n \frac{dn}{dx}$

Given $E=0$.

$J_n = D_n \cdot q \frac{dn}{dx}$



$$\frac{dn}{dx} = \frac{6\times10^{16} - 10^{17}}{2\times10^{-4} - 0} = \frac{6\times10^{16} - 10\times10^{16}}{2\times10^{-4}} = \frac{-4\times10^{16}}{2\times10^{-4}}$$

$$= -2\times10^{20}$$

$J_n = D_n q \cdot \frac{dn}{dx}$

$= 35\times1.6\times10^{-19}(-2\times10^{20})$

$= -1120\ A/cm^2$.

4) An n-type silicon bar 0.1 cm long and $100\mu m^2$ in cross-sectional area has a majority carrier concentration of

of $5\times10^{20}/m^3$ and the carrier mobility is $0.13 m^2/V-s$ at 300°K. If the charge of electron is $1.6\times10^{-19}C$, then the resistance of the bar is,

Given,

$l = 0.1 cm = 10^{-3} m$

$A = 100 \mu m^2 = 100\times10^{-6}\times10^{-6}$

$n = 5\times10^{20}/m^3$

$\mu_n = 0.13 m^2/V.sec$

$R = ?$

$$\sigma = nq\mu_n$$

$$\rho = \frac{1}{\sigma_n} = \frac{1}{nq\mu_n} = \frac{1}{(5\times10^{20})(1.6\times10^{-19})(0.13)} = 0.096$$

$$R = \frac{\rho l}{A} = \frac{0.096\times10^{-3}}{100\times10^{-12}} = 10^6 \Omega$$

5) A silicon sample 'A' is doped with 10^{18} atoms/cm^3 of Boron. Another sample 'B' of identical dimensions is doped with 10^{18} atoms/cm^3 of phosphorous. The ratio of Electron to hole mobility is 3. The ratio conductivity of the Sample A to B is

Sol:- A → $10^{18}/cm^3$ of Boron, p-type

B → $10^{18}/cm^3$ of phosphorous n-type

$$\frac{\mu_n}{\mu_p} = \frac{1}{3} \qquad \sigma_p = pq\mu_p$$

$$\sigma_n = nq\mu_n$$

$$\frac{\sigma_p}{\sigma_n} = \frac{pq\mu_p}{nq\mu_n} = \frac{1}{3}$$

6) A heavily doped n-type Semiconductor has the following data.

Hole electron mobility ratio : 0.4

Doping concentration : $4.2 \times 10^8 / m^3$

Intrinsic concentration : $1.5 \times 10^4 / m^3$

The ratio of conductance of the n-type semiconductor to that of intrinsic semiconductor of same material and ~~atha~~ the same temperature is given by

$\frac{\mu_p}{\mu_n} = 0.4$

$N_D = 4.2 \times 10^8 / m^3$

$n_i = 1.5 \times 10^4 / m^3$

$\frac{\sigma_n}{\sigma_i} = ?$ $\quad \sigma_n = nq\mu_n$

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

$$\frac{\sigma_n}{\sigma_i} = \frac{nq\mu_n}{n_i q(\mu_p+\mu_n)} = \frac{n\mu_n}{n_i \mu_n(1+\frac{\mu_p}{\mu_n})} = \frac{n\mu_n}{n_i \mu_n(1+0.4)}$$

$$\Rightarrow \frac{4.2 \times 10^8}{(1.5 \times 10^4)(1.4)} = 2 \times 10^4 = \frac{\sigma_n}{\sigma_i}$$

7) Silicon is doped with boron to a concentration of 4×10^{17} atoms /cm. Assume the intrinsic carrier concentration of Silicon to be $1.5 \times 10^{10} / cm^3$ and the value of $\frac{KT}{q}$ to be 25mV. at 300K. Compared to un-doped silicon, the Fermi level, of doped silicon,

Sol:- boron - p type:

$N_A = 4 \times 10^{17} / cm$

$n_i = 1.5 \times 16^{10}$

$\frac{KT}{q} = 25mV.$

Since the semiconductor is of p-type, the Fermi will go down with respect to intrinsic level.

The expression for quasi Fermi level for p-type Semiconductor in terms of Acceptor concentration

$$E_{Fi} - E_{Fp} = KT \ln\left(\frac{N_A}{n_i}\right)$$

$$= 25\times10^{-3}\left(\frac{4\times10^{17}}{1.5\times10^{10}}\right)$$

$$= 25\times10^{-3} \ln(2.66\times10^{7})$$

$$= 0.425\ eV$$

8) The silicon sample with unit cross-sectional area shown below is in thermal equilibrium. The following information is given: $T = 300°K$, electronic charge = $1.6\times10^{-19}C$, thermal voltage = 26mv. and electron mobility = $1350\ cm^2/V\text{-sec}$

(i) The magnitude of the electric field at $x = 0.5\mu m$ is

Sol:- $x = 0.5\mu m$

$T = 300K$

$V_T = 26mV.$

$q = 1.6\times10^{-19}$

$\mu_n = 1350\ cm^2/V\text{-sec.}$

$$E = \frac{1}{1\mu m} = \frac{1}{1\times10^{-6}} = 10^6\ V/m.$$

$E = 10KV/cm.$

(ii) The magnitude of the electric drift current density $x = 0\mu m$ is,

Sol:- $J = \sigma E = N_D q \mu_n E$

$= 10^{16}\times1.6\times10^{-19}\times1350\times10\times10^3$

$= 1.6\times1350\times10$

$J = 2.16 \times 10^4$ A/cm^2.

drift current is same throughout the sample. at $x = 0.5$.

9) Assume electronic charge $q = 1.6 \times 10^{-19}$C, $\frac{KT}{q} = 25$mV and electron mobility $\mu_n = 1000$ cm^2/V-s. If the concentration gradient of electrons injected into a p-type silicon sample is 1×10^{21}/cm^4, the magnitude of electron diffusion current density (in A/cm^2) is _____

$\frac{KT}{q} = 25$ mV

$\mu_n = 1000$ cm^2/V-s.

$\frac{dn}{dx} = 1 \times 10^{21}$/cm^4

$J_{n(x)} = q \cdot D_n \frac{dn}{dx}$

$D_n = \left(\frac{KT}{q}\right) \mu_n = V_T \mu_n$

$= 25 \times 10^{-3} \times 1000$

$D_n = 25$.

$J_{n(x)} = q \cdot D_n \frac{dn}{dx}$

$= (1.6 \times 10^{-19})(25) \cdot (1 \times 10^{21})$

$= 40 \times 10^2$

$J_{n(x)} = 4000$ A/cm^2 //

10) Consider a silicon sample doped with $N_D = 1 \times 10^{15}$/cm^3 donor atoms. Assume that the intrinsic carrier concentration $n_i = 1.5 \times 10^{10}$/cm^3. If the sample is additionally doped with $N_A = 1 \times 10^{18}$/cm^3 acceptor atoms the approximate number of electrons/cm^3 in the sample, at $T = 300$K, will be

$N_D = 1 \times 10^{15}$/cm^3 $\quad N_A = 1 \times 10^{18}$/cm^3

$n_i = 1.5 \times 10^{10}$/cm^3 $\quad T = 300$ K

$$\eta = \frac{n_i^2}{(N_A - N_D)} = \frac{2.2\,(1.5\times10^{10})^2}{(10^{18} - 10^{15})} = \frac{2.25\times10^{20}}{(1000\times10^{15} - 10^{15})}$$

$$= \frac{2.25\times10^{20}}{999\times10^{15}} = 2.252\times10^{2}$$

$$= 225.2$$

4|1|20

problems:-

1) In Ge Semiconductor material at T=400K the intrinsic concentration is

Sol:- $N_c = 1.04\times10^{19}$

$N_V = 6\times10^{18}$

$E_G = 0.66$

$T = 400K$

$n_i^2 = a_0 T^3 e^{-Eg/KT}$

$= ($

$n_i^2 = (4.821\times10^{21})^2 e^{\frac{\beta}{k}} \cdot \left(\frac{400}{300}\right)^3 e^{\frac{-Eg}{KT}}$

$n_i^2 = N_c N_V e^{-\left(\frac{E_G}{KT}\right)}$

$= (1.04\times10^{19})(6\times10^{18})\, e^{-\left(\frac{0.66}{8.625\times10^{-5}\times400}\right)}$

$n_i = 5.53\times10^{14}\ cm^{-3}$ //

2) The intrinsic carrier concentration in silicon is to be no integer than $n_i = 1\times10^{12}\ cm^{-3}$. The maximum temperature allowed for the silicon is (Assume $E_G = 1.12\ eV$)

Sol:- Silicon → $N_c = 2.8\times10^{19}$; $N_V = 1.04\times10^{19}$

$n_i = 1\times10^{12}$; $E_g = 1.12\ eV$.

$n_i^2 = N_c N_V e^{\left(\frac{Eg}{KT}\right)}$

$\frac{n_i^2}{N_c N_V} = e^{-\frac{Eg}{KT}}$

$$\ln\left(\frac{n_i^2}{N_c N_v}\right) = -\frac{E_g}{KT}$$

$$T = \frac{-E_g}{K \ln\left(\frac{n_i^2}{N_c N_v}\right)}$$

$$= \frac{-1.12}{(8.625\times10^{-5}) \ln\left(\frac{(1\times10^{12})^2}{2.8\times10^{19}\times1.04\times10^{19}}\right)}$$

$$T = 389.89 \text{ K}.$$

5/1 Wal-paper.

1) An n-type Semiconductor has its Fermi level at 0.25 ev below the conduction band edge. If the density of Semiconductor in conduction band at room temperature is $2.51\times10^{25}/m^3$, the majority carrier concentration is.

Sol:- $E_F - E_c = KT \ln\left(\frac{N_c}{N_D}\right)$

$$\frac{E_F - E_c}{KT} = \ln N_c - \ln N_D$$

$$\ln N_D = \ln N_c - \frac{E_F - E_c}{KT}$$

$$= \ln(2.51\times10^{25}) - \frac{0.25}{0.0259}$$

$$= 58.48 - 9.652$$

$$\ln N_D = 48.82$$

$$N_D = 1.605\times10^{21}/m^3$$

2 volts supply is applied to the Semiconductor bar of length 2 μm. Then magnitude of electric field (~~mV~~ mV/m) at $x = 0.5\,\mu m$ is

$l = 2\,\mu m = 2\times10^{-6} m$ $x = 0.5\times10^{-6} m$

$E = ?$ $V = 2V$

$E = \frac{2V}{0.5 \times 10^{-6}} = 4 \times 10^6$ V/m.

3) In a semiconductor sample the electron and hole mobility are $0.15 \frac{m^2}{V\text{-}S}$ and $0.06 \frac{m^2}{V\text{-}S}$ respectively. The diffussion constant for electrons is 3.75×10^{-3} m^2/sec. The diffussion constant for holes is

Sol:- $\mu_n = 0.15$ $m^2/V.S$

$\mu_p = 0.06$ $m^2/V.S$.

$D_n = 3.75 \times 10^{-3}$ m^2/sec

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

$D_p = \mu_p \frac{D_n}{\mu_n} = 0.06 \times \frac{3.75 \times 10^{-3}}{0.15}$

$= 1.5 \times 10^{-3}$ m^2/sec.

4) The current produced in a Ge of area $1cm^2$ and length 0.3mm when a potential difference of 2V is applied across it [Assume $n_i = 2 \times 10^{19}$, $\mu_n = 0.35 \times \frac{m^2}{V\text{-}S}$ and $\mu_p = 0.17 \frac{m^2}{V.S}$].

Area $= 1cm^2$ $\quad n_i = 2 \times 10^{19}$

$l = 0.3mm$ $\quad \mu_n = 0.35 m^2/V\text{-}sec$

$V = 2V$ $\quad \mu_p = 0.17$ $m^2/V.sec$

$J = \frac{I}{A} \Rightarrow I = JA$

$J = \sigma E$

$J = 1.664 \times 6666.67$

$J = 11093.33$

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

$= (2 \times 10^{19})(1.6 \times 10^{-19})(0.35 + 0.17)$

$= 1.664$

$E = \frac{V}{l} = \frac{2}{0.3 \times 10^{-3}} = 6666.66$

$I = JA = 11093.33 \times 1 \times 10^{-4}$

$= 1.109.$

$\boxed{I = 1.11\ A}$

5) The diffussion current in a sample of Ge. given having concentration gradient for electrons of 1.5×10^{22} electrons/m4 is ____ A/m^2 [Assume the diffussion constant for electrons $= 0.00120\ m^2/sec$].

Sol:- $D_n = 0.00120\ m^2/sec.$

$\frac{dn}{dx} = 1.5 \times 10^{22} e^-/m4$

$J_n = D_n q \frac{dn}{dx}$

$= (0.00120)(1.6 \times 10^{-19})(1.5 \times 10^{22})$

$J_n = 2.88\ A/m^2$ //

3) Two Semiconductor material have exactly the same properties that material A has a bandgap of 1.0 ev and material B has a bandgap energy of 1.2ev. The ratio of intrinsic concentration of material A to that of material B is

$n_{iA}^2 = N_c N_v e^{-\frac{E_g}{KT}}$

$n_{iB}^2 = N_c N_v e^{-\frac{E_g}{KT}}$

$\frac{n_{iA}^2}{n_{iB}^2} = \frac{N_c N_v e^{-\frac{E_g}{KT}}}{N_c N_v e^{-\frac{E_g}{KT}}}$

$\frac{n_{iA}^2}{n_{iB}^2} = \frac{e^{\left(-\frac{1.0}{0.0259}\right)}}{e^{\left(-\frac{1.2}{0.0259}\right)}}$

$\frac{n_{iA}^2}{n_{iB}} = 47.5$ (B).

4 In silicon at T = 300K the thermal equilibrium concentration of electron $n_0 = 5 \times 10^4 cm$. The hole concentration is

Sol:- $T = 300K$

$n_0 = 5 \times 10^4 cm = N_D$

$$P = \frac{n_i^2}{N_D} = \frac{(1.5 \times 10^{10})^2}{5 \times 10^4}$$

$P_0 = 4.5 \times 10^{15} / cm^3$ (A)

5. In silicon at T = 300K if the Fermi energy is 0.22 eV above the valence band energy, the value of P_0 is

$T = 300K$ $\quad N_V = 1.04 \times 10^{19}$.

$E_F - E_V = 0.22 eV$.

$P_0 = ?$

$$P = N_V e^{\frac{E_V - E_F}{KT}}$$

$$= (1.04 \times 10^{19}) e^{\left(\frac{-0.22}{0.0259}\right)}$$

$P_0 = 2.128 \times 10^{15}$ (A)

6. The thermal equilibrium concentration of hole p_0 in silicon at T = 300K is $10^{15} cm^{-3}$. The value of n is

$P = 10^{15} / cm^3$ $\quad n_i = 1.5 \times 10^{10}$

$T = 300K$

$np = n_i^2$

$$n = \frac{n_i^2}{P} = \frac{(1.5 \times 10^{10})^2}{10^{15}}$$

$n = 2.25 \times 10^5 / cm^3$.

7. In Germanium Semiconductor at T=300K, the acceptor concentration is $N_a = 10^{13} cm^{-3}$ and donar concentration is $N_d = 0$. The thermal equilibrium concentration P_o is

$T = 300°K$

$N_A = 10^{13}/cm^3$

$N_D = 0$

$$P_o = \frac{N_A - N_D}{2} + \sqrt{\left(\frac{N_A - N_D}{2}\right)^2 + (n_i^2)}$$

$$= \frac{10^{13}}{2} + \sqrt{\left(\frac{10^{13}}{2}\right)^2 + (2.4 \times 10^{13})^2}$$

$$= 2.95 \times 10^{13} /cm^3 \quad (C)$$

8. In Germanium Semiconductor at T=300K, the impurity concentration are

$N_d = 5 \times 10^{15}/cm^3$ and $N_a = 0$

8) The thermal equilibrium electron concentration n_o is

Sol:- $N_d = 5 \times 10^{15}/cm^3$

$N_a = 0$

$$n_o = \frac{N_D - N_a}{2} + \frac{1}{2}\sqrt{(N_D - N_a)^2 + 4n_i^2}$$

$$= \frac{5 \times 10^{15}}{2} + \frac{1}{2}\sqrt{(5 \times 10^{15})^2 + 4(2.4 \times 10^{13})^2}$$

$$n_o = 5 \times 10^{15}/cm^3 \quad (A)$$

9) The thermal equilibrium hole concentration P_o is

$$P_o = \frac{-5 \times 10^{15}}{2} + \sqrt{\left(\frac{5 \times 10^{15}}{2}\right)^2 + (2.4 \times 10^{13})^2}$$

$$P_o = 1.15 \times 10^{11}/cm^3$$

10) A sample of silicon at $T = 300K$ is doped with boron at a concentration of $2.5 \times 10^{13}/cm^3$ and with arsenic at a concentration of $1 \times 10^{13}/cm^3$ The mat...

Sol:- $T = 300K$

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

$N_a = 1 \times 10^{13}/cm^3$

$$n = \frac{N_d - N_a}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 + n_i^2}$$

$n = 1.5 \times 10^{13}/cm^3.$

$$p = \frac{N_a - N_d}{2} + \sqrt{\left(\frac{N_a - N_d}{2}\right)^2 + n_i^2}$$

$p = 1.499 \times 10^{7}/cm^3$

$\therefore$ n-type. (c)

11) In a sample of gallium arsenide at $T = 200K$, $n_0 = 5$ p_0 and $N_a = 0$. The value of n_0 is

Given, $n_0 = 5p_0$

$N_a = 0$

12) Ge at T=300K is uniformly doped with an acceptor concentration of $N_a = 10^{15}/cm^3$ and a donor concentration of $N_d = 0$. The position of fermi energy with respect to intrinsic Fermi level is

Sol:- $N_a = 10^{15}/cm^3$

$N_d = 0$.

$$E_{Fi} - E_{Fp} = KT \ln\left(\frac{N_A}{n_i}\right)$$

$$= 0.0259 \ln\left(\frac{10^{15}}{2.4 \times 10^{13}}\right)$$

$E_{Fi} - E_{Fp} = 0.09\ eV$

13) In Ge at T=300K, the donor concentration are $N_d = 10^4\ cm^{-3}$ and $N_a = 0$. The Fermi energy level with respect to intrinsic Fermi level. is.

Sol:- $N_d = 10^4/cm^3$

$N_a = 0$

$$E_{Fn} - E_{Fi} = KT \ln\left(\frac{N_d}{n_i}\right)$$

$$= 0.0259 \times \ln\left(\frac{10^{14}}{2.4 \times 10^{13}}\right)$$

$$= 0.0369$$

$E_{Fn} - E_{Fi} \simeq 0.04\ eV$

14) A GaAs. is doped with a donor concentration of $3 \times 10^{15}\ cm^{-3}$. For the device to operate properly, the intrinsic carrier concentration must remain less than temperature 5% of the total concentration. The

maximum temperature on that the device may operate is.

$N_d = 3 \times 10^{15}/cm^3$ $\quad n_i = 1.8 \times 10^6$

$n_i = n_i \times \frac{5}{100} n_i \times 100 + n_i \rightarrow 1.8 \times 10^6$.

$T = ?$

15) For a particular Semiconductor at $T = 300°K$ $E_g = 1.5 eV$, $m_p^* = 10 m_n^*$ and $n_i = 1 \times 10^{15} cm^{-3}$. The position of Fermi level with respect to the centre of the bandgap

Sol:- $T = 300°K$

$E_g = 1.5 eV$

$m_p^* = 10 m_n^*$

$n_i = 1 \times 10^{15}/cm^3$

$E_F - E_{midgap} = \frac{3KT}{4} \ln\left(\frac{m_D}{m_p}\right)$

$= \frac{-3}{4}(0.0259) \ln\left(\frac{m_D}{10 m_n}\right)$

$= -(-0.0447)$

$= 0.045 eV$ //

16) A silicon sample contains acceptor atoms at a concentration of $N_a = 5 \times 10^{15}/cm^3$. Donar atoms are added forming and n-type compensated Semicon-

ductor such that Fermi level is 0.215eV below the conduction band edge. The concentration of donors atoms added are

Sol:- $N_a = 5\times10^{15}/cm^3$

$N_d = ?$

$E_c - E_{Fn} = 0.215\ eV.$

$E_c - E_{Fn} = KT \ln\left(\frac{N_c}{N_d}\right)$

$N_d = -\frac{(E_c - E_{Fn})}{KT} + \ln(N_c)$

$\ln(N_d) = \frac{0.215}{0.0259} + \ln(2.8\times10^{19})$

$\ln N_d = 5.15\times10^{15}$

17) A silicon Semiconductor sample at T=300K is doped with phosphorous atoms at a concentrations of $10^{15}/cm^3$. The position of the Fermi level with respect to the intrinsic Fermi level is

Sol:- $N_d = 10^{15}/cm^3.$ $\qquad n_i = 1.5\times10^{10}$

$E_{Fn} - E_{Fi} = KT \ln\left(\frac{N_d}{n_i}\right)$

$= (0.0259) \ln\left(\frac{10^{15}}{1.5\times10^{10}}\right)$

$E_{Fn} - E_{Fi} = 0.287\ eV$ //

18) A Silicon crystal having a cross sectional area of $0.001\ cm^2$ and a length of $20\times\mu m$ is connected to its ends to a 20V battery. At T=300°K, we want a current of 100mA in crystal. The concentration of donar atoms to be added is

$A = 0.001\ cm^2$ $\qquad V = 20V$ $\qquad I = 100\times10^{-3}A.$

$l = 20\times10^{-6}m$ $\qquad T = 300°K$ $\qquad \mu_n = 1350$

$\sigma = n_d q \mu_n$

$R = \frac{V}{I} = \frac{20}{100 \times 10^{-3}}$

$R = 200\ \Omega$

$n_d = \frac{\sigma}{q\mu_n}$

$\sigma = \frac{RA}{l} \Rightarrow$

$\sigma = \frac{200 \times 20 \times 10^{-6}}{0.001 \times 10^{-4}} = 4 \times 10^4\ \Omega m$

$n_d = \frac{4 \times 10^4}{(1.6 \times 10^{-19})(1350)}$

$\rho = \frac{RA}{l}$

$\rho = \frac{200 \times 0.001 \times 10^{-4}}{20 \times 10^{-6}}$

$n_d = \frac{1}{(1.6 \times 10^{-19})(1350)}$

$\rho = 1$

$\sigma = 1$

$n_d = 4.629 \times 10^{15}$

19) The cross sectional area of silicon bar is $100\ \mu m^2$. The length of bar is 1mm. The bar is doped with arsenic atoms. The resistance of bar is.

$A = 100 \times 10^{-6}\ m^2$

$l = 1 \times 10^{-3}\ m$

$R =$

$R = \frac{\rho A}{l}$ $R = \frac{\rho L}{A}$ $R = \frac{L}{A\sigma}$

$\sigma = ne\mu$

20) Six volts is applied accross a 2cm long semiconductor bar. The average drift velocity is 10^4 cm/s. The electron mobility is

Sol:- $V = 6V$

$l = 2 \times 10^{-2}\ m$

$V_d = 10^4\ cm/s$.

$V_d = \mu E$ $E = \frac{V}{l} = \frac{6}{2} = 3$

$10^4 = \mu \times 3$

$\mu = \frac{10^4}{3} = 3333.33\ cm^2/V.s.$