UNIT- I

Diodes

Semiconductor: Material whose conductivity is in between insulator & conductor is said to be "semiconductor"

→ Semiconductors are of two types ① Intrinsic sc
② extrinsic sc.

Intrinsic semiconductor: pure form of semiconductor, whose conductivity at room temperature is zero is said to be "Intrinsic semiconductor".

Extrinsic semiconductor: The semiconductor which is manufactured by adding impurities to instrinsic semiconductor to increase the conductivity at room temperature is said to be "extrinsic semiconductor."

ISC + impurities = extrinsic semiconductor.

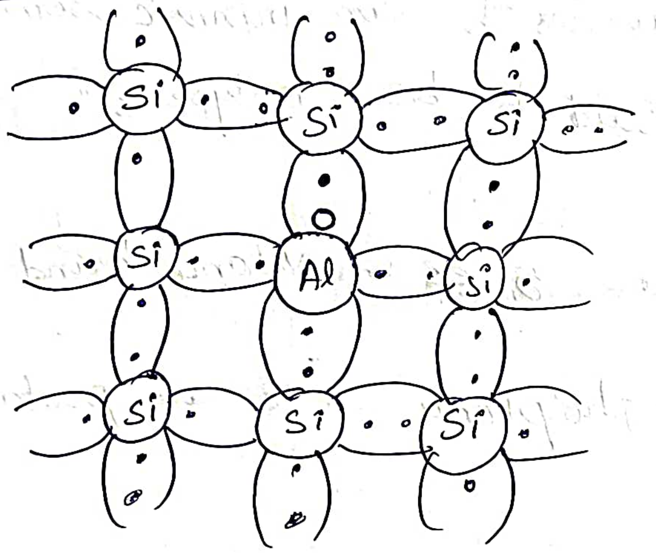
→ Based on type of impurities (or) dopants added to intrinsic semiconductor, Extrinsic semiconductors are classified as
① p-type extrinsic semiconductor
② n-type " "

P-type extrinsic Semiconductors: If trivalent atoms are added as impurities to an intrinsic semiconductor then the resultant is said to be " P-type sc".

→ Trivalent atoms have 3 valance electrons.

→ Aluminium, Boron, galium .. etc are trivalent atoms

structure



→ As Al has 3 valence ēs, all of them are shared with neighbouring silicon atoms.

→ There exist one vacancy in valence band of Al

→ Due to this vacancy A hole is created in the silicon structure. so We can say that every one added 'Al' atom creats one hole. so by increasing the amount of 'Al' impurities. no: of holes in the structure can be increased.

→ Trivalent atoms are known as "acceptor atoms (or) acceptors", as they accept the free ēs to form the bond.

→ To form a covalant bond with is neighbour atom free ēs of silicon starts moving towards the holes of 'Al' atom, as a result there exist flow of current. (Conductivity exists)

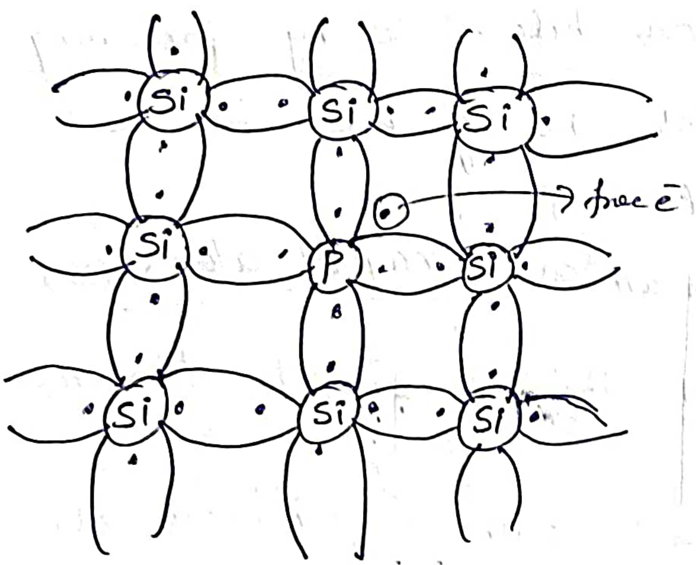
→ If the amount of "Al" ~~add~~ atoms added increases, then the no: of ès moves to form a pair with hole will increase which intern increases the Conductivity of the material.

n-type extrinsic semiconductor : If pentavalent atoms are added as impurities to an intrinsic semiconductor then the resultant is said to be "n-type sc".

→ Pentavalent atoms have 5 ès in valence band.

→ Arsenic, Antimony, phosphorus ..etc are pentavalent atoms.

Structure :



→ 'p' has 5 valence ès out of which, 4 are being shared by the neighbouring silicon atom.

→ so for every added 'p' atom there exist one free electron, which can move randomly in the structure of silicon, can produce current.

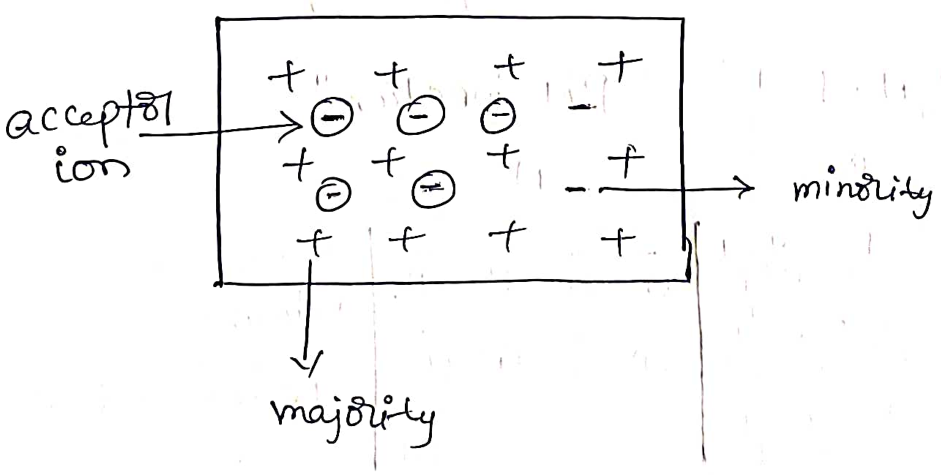
→ so if no: of 'P' atoms to be added increases, then the no: of free electrons in structure increases as a result the conductivity of material increases.

→ As the $\bar{e}$ is of 'negatively charged element, the resultant sc is said to be 'n-type sc'.

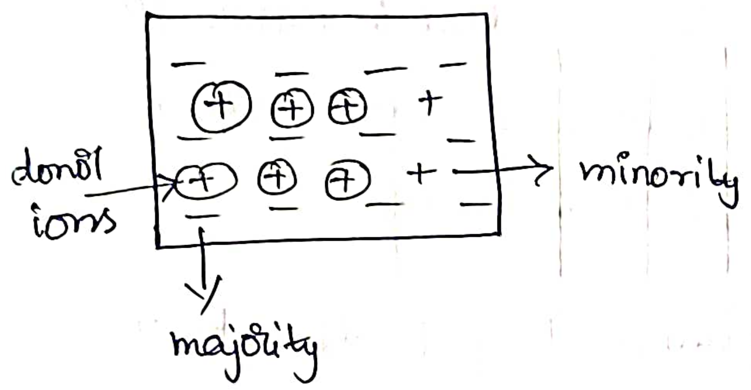
→ pentavalent atoms are said to be 'donor' atoms (or) 'donors' as they donate one free electron to move randomly.

Majority & Minority carriers

P-type : In this type of sc, holes are said to be the majority charge carriers & ēs are minority charge carriers.



n-type: In n-type, electrons are majority charge carriers & holes are minority charge carrier.



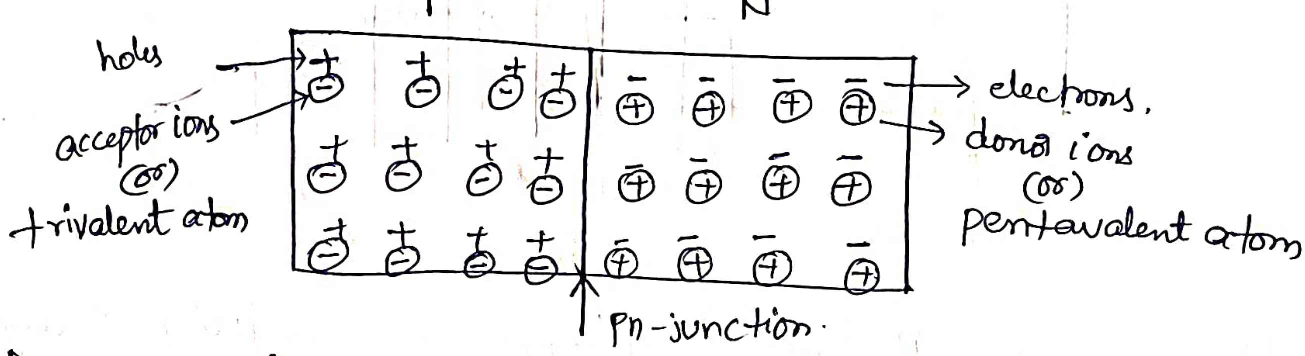
→ In p-type sc, flow of current is due to holes

→ In n-type sc, flow of current is due to electrons

PN Junction ~~Diode~~ :-

→ In p-type semiconductor holes are the majority charge carriers & in n-type semiconductor electrons are the majority charge carrier.

→ By doping one side of silicon crystal with p-type impurities & other side with n-type impurities, silicon crystal is converted to "PN junction."



→ "PN-junction" is the boarder where p-type & n-type sc regions meet each other.

→ Silicon crystal with p-type & n-type impurities is known as "diode".

→ Here p-type & n-type regions act like two electrodes

Unbiased pn junction (or) Formation of Depletion Region.

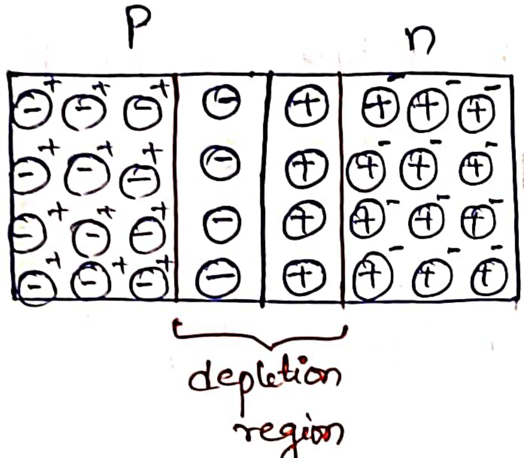
→ When p & n regions are joined then the ēs from n-side starts diffusing towards p-side

→ When ēs diffuses towards p-type from n-type, then they rejoin with holes across the trivalent atom[⊖]

→ When ē & hole rejoin (or) combine across a trivalent at then that trivalent atom becomes an immobile (-ve)

→ Illy when ē & hole rejoin (or) combine across a pentavalent atom, then that atom becomes an immobile (+ve) ion.

→ Due to the recombination of holes & ē near the pn junction, the layers of immobile ions are (is) formed at the pn junction, and these layers doesn't allow the flow of charge carriers i.e these layers deplete the flow of current, Hence the region (or) layers such formed across the pn junction is said to be "depletion region" (or) space-charge region (or) ~~transmission~~ transition region.



$\ominus^{+}$ → trivalent atom with hole (+)

$\ominus$ → immobile (-ve) ion

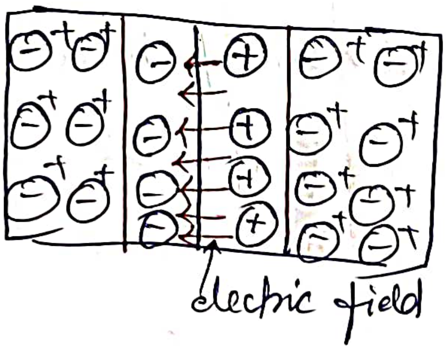
$\oplus^{-}$ → pentavalent atom with $\bar{e}$ (-)

$\oplus$ → immobile (+ve) ion.

→ Depletion region contains +ve & -ve ions which are immobile in nature.

→ Depletion region also contains "thermally generated negligible charge carriers".

→ Ions of the depletion region set up the electric field. This electric field points from (+ve) ion to (-ve) ion



→ Immobile ions creates the barrier potential for the majority charge carriers, so that they can't diffuse through depletion region.

→ barrier potential is alse known as "built-in-potential" (or) "cut-in-voltage"

→ barrier potential represents the height of barrier, that is to be overcome by e⁻s & holes to cross the pn junction.

→ cut-in-voltage for silicon is 0.7V & Germanium is 0.3V.

→ Due to this built in electric field minority carrier can move through depletion region but from p to n & n to p regions not the majority charge carriers.

** → Flow of minority charge carrier due to electric field & flow of majority charge carrier (if exists), due to diffusion gets cancelled, and finally "current flow in unbiased diode is said to be zero". i.e depletion region offers more resistance in unbiased mode of diode.

→ To generate the flow of current in pn-diode, majority charge carriers should cross the depletion region.

→ To move the majority charge carriers "external biasing (provide voltage (or) energy source) is required"

→ If the applied external electric field is in the same direction of built in electric field then the width of depletion region ↑es i.e it offeres highest resistance to flow of majority charge carriers.

(+)

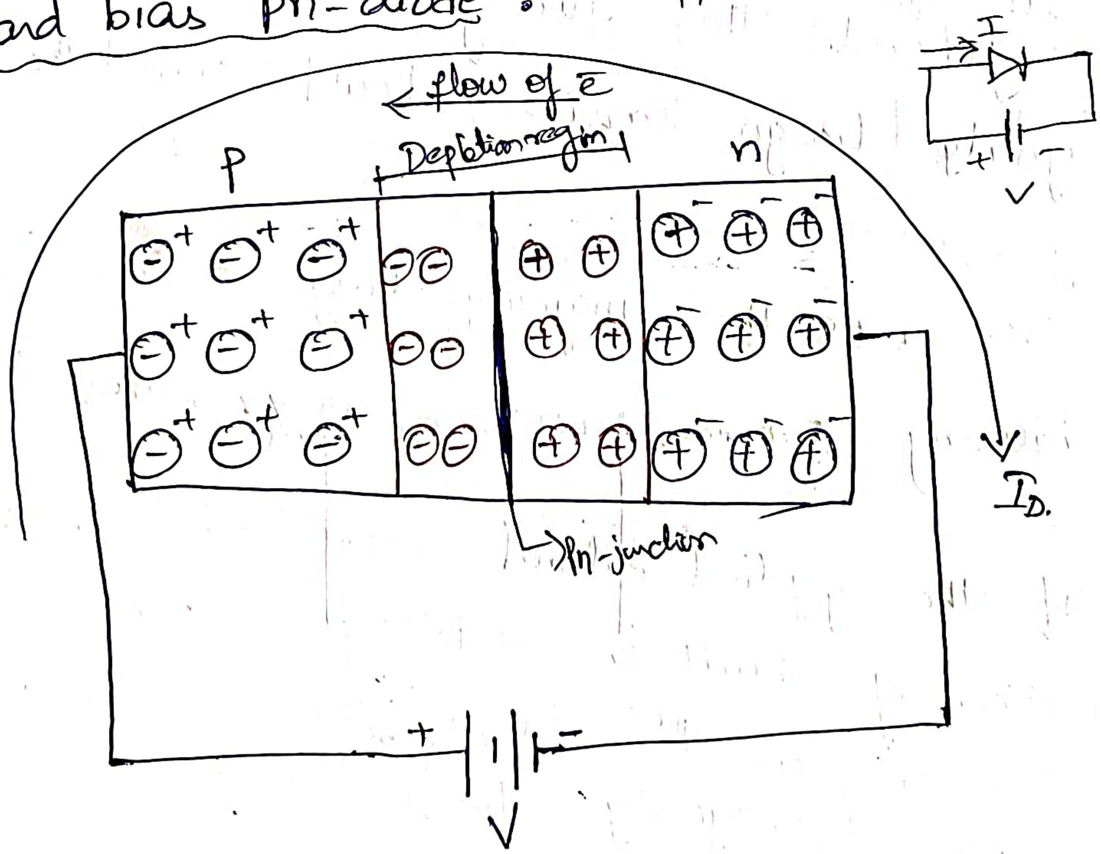
→ If the applied external electric field is in opposite direction of built in electric field then depletion region width ↓es & it offers low resistance to flow of majority charge carriers.

→ Here there exists two types of external biasing to Pn diode.

1. forward biasing
2. Reverse biasing

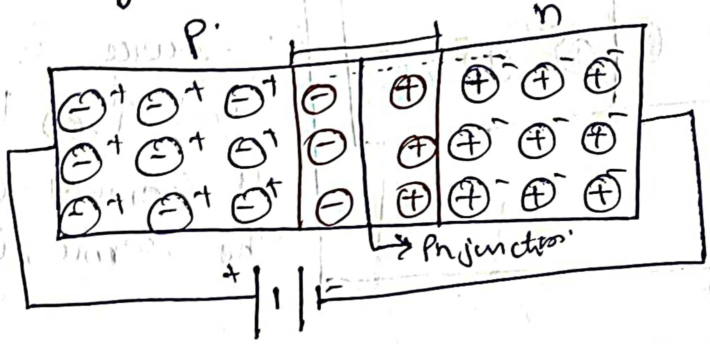
<u>P-n junction as a diode</u> (or)
<u>Operation (or) working of Pn-diode</u>: In general a diode permits the flow of current in one direction but resist the flow in opposite direction.

<u>Forward bias pn-diode</u> :-



→ In forward biasing (+ve) terminal of source is connected to P-type & (-ve) terminal of source is connected to n-type of the semiconductor.

→ In forward biasing external electric field is in the opposite direction of built in electric field. Due to this effective electric field at junction reduces. Hence holes from P-side & ē from n-side start moving towards the junction. then the width of the depletion region decreases.



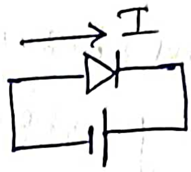
→ If we further increase the external voltage, then the width of the depletion will reduce further

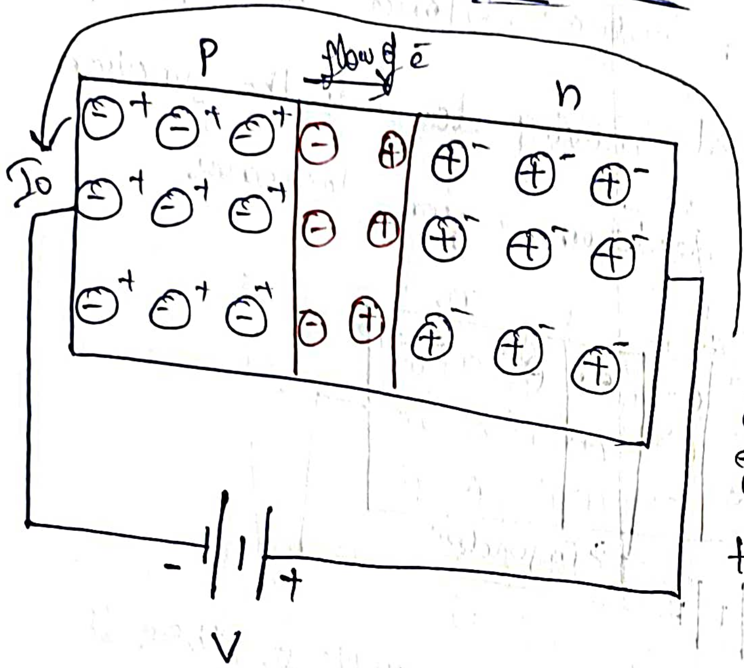
→ If the external voltage is increase to a value which is greater than barrier potential of junction (0.7V for Si & 0.3V Ge) then the resistance offered by depletion region is neglegible.

→ If the external voltage is > barrier potential, then the majority carriers from both P & n cross the depletion region and travel toward the terminals of applied source. Hence there will be flow of current due to majority charge carriers in forward biasing

→ Hence if we increase the external voltage then the flow of current in forward biased diode will increase.

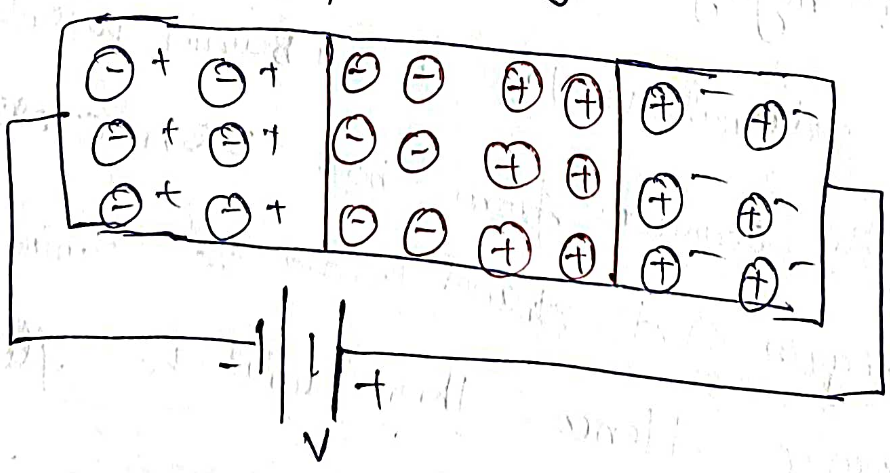
<u>Reverse biased Pn- diode</u> :





In reverse biasing (-ve) terminal of external source is connected to P-side and (+ve) terminal of source is connected to n-side of the semiconductor.

→ electrons from n-side of sc. get attracted towards the (+ve) terminal of source & holes from P-side of sc, get attracted towards the (-ve) terminal of source, as a result more no. of ion layers form at junction. Hence the width of the depletion region increases.



→ If applied reverse voltage is further increased, then the width of the depletion region further increases.

→ As depletion region increases, it offers more resistance t the flow of majority charge carriers. Hence current due to majority charge carriers in reverse bias is zero.

→ But in reverse bias there exist current due to flow of minority charge carriers. As minority charge carriers are less in number, current due to minority carriers will also be very low and is negligible.

→ Curent due to minority carriers in reverse biasing is kno as "reverse saturation current (I_0)". And it will be in the range of μAmps & nA.

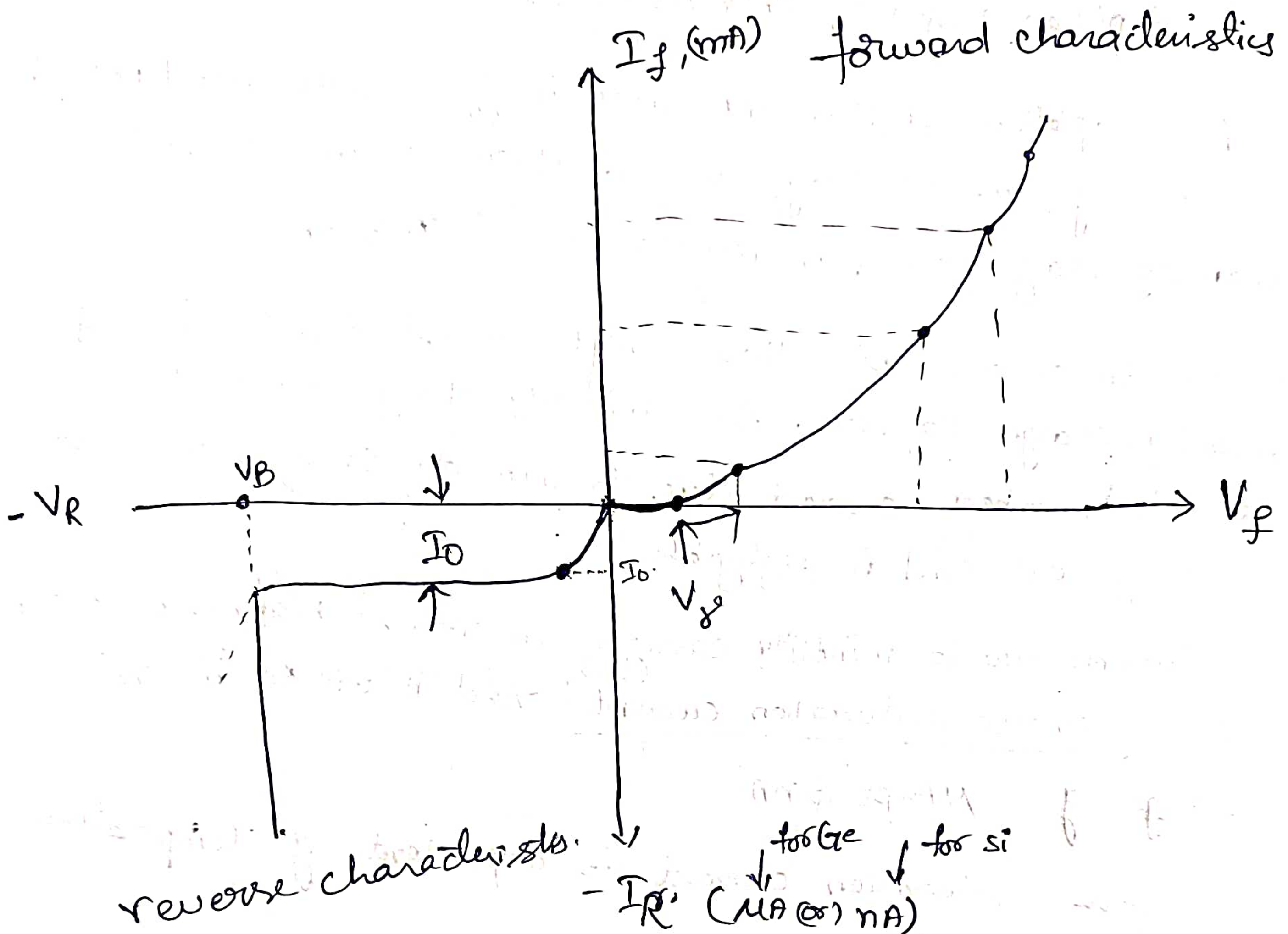
→ reverse saturation current is dependent of temperature

→ If temperature is increased by $10°C$ then reverse saturation current gets doubled.

→ If applied reverse voltage is increased then will not much change in reverse saturation current.

→ If reverse voltage is further increased, then it reache a point known as "break down voltage". At this voltage the current due to minority carriers suddenl increases to an high amount.

V-I characteristics of a Diode:



m - 10^{-3}

µ - 10^{-6}

n - 10^{-9}

→ V_f → forward voltage

I_f → forward current

V_R → reverse voltage

V_B → breakdown voltage

I_R → reverse current.

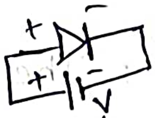
V_γ → Cut-in voltage (or) offset voltage (or) threshold voltage.

$V_\gamma = 0.7$ for silicon

$V_\gamma = 0.2$ for Germaneum.

→ The 1st voltage point at which there is raise in forward current is said to be " cut-in-voltage " (or) offset voltage (or) threshold voltage.

Forward characteristics :



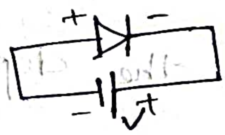
→ As long as V_f is less than V_γ, the current flowing is very small, practically it is said to be zero.

→ when V_f reaches to V_γ, the flow of forward current starts.

→ When $V_f > V_\gamma$ the current I_f increases suddenly and exponentially.

→ The forward current is the conventional current, hence it is treated as (+ve) & forward voltage V_f is also treated positive. Hence forward characteristics are plotted in 1st quadrant.

Reverse characteristics :-



→ As V_R is increased, initially the reverse current increases and is equal to reverse saturation current I_0.

→ Further if V_R is increased, the reverse current remains Constant.

→ Still if V_R is increased, then there will be sharp raise in I_R. Which is due to the damage in diode. The voltage at Which there is a sharp raise in reverse current is called " breakdown voltage (or) reverse breakdown voltage".

Diode Current Equation: The relationship b/w applied voltage 'V' & diode current I (or) I_D is exponentially & mathematically given by the equation called "diode current equation". Also known as Shockley's eqn.

$$I \text{ (or) } I_D = I_0\left[e^{\frac{V_D}{\eta V_T}} - 1\right] \text{ Amps.} \rightarrow (1)$$

$I_0 \rightarrow$ Reverse saturation current in Amperes

$V_D \rightarrow$ Applied voltage. , $\boxed{\begin{array}{l}\eta = 1 \text{ for Ge} \\ \;\;= 2 \text{ for Si}\end{array}}$

$V_T \rightarrow$ Voltage equivalent of temperature (or) Thermal voltage

→ V_T indicates the dependence of diode current on temperature.

η - ideality factor, depends on physical construction

$V_T = KT$ where

$K \rightarrow$ Boltzmann's constant $= 8.62 \times 10^{-5}$ eV / °K

$T \rightarrow$ Temperature in °K.

→ At room temperature of 27°c, T in Kelvin is

$T = 27 + 273 = 300°K$

$\therefore \boxed{V_T \simeq 26 \text{ mV}}$

$$V_T = \frac{K \cdot T}{q}$$

$K = 1.38 \times 10^{-23}$ J/K

T = absolute temperature $= 273 + 27°c = 300°K$

q = charge of $\bar{e}$ $= 1.6 \times 10^{-19}$

$V_T \simeq 26$ mV.

forward current $\quad I_f = I_0 e^{\frac{V_D}{\eta V_T}}$

Reverse current $\quad I_R = -I_0$

Resistance Levels :- As the operating point of a diode moves from one region to another, the resistance of the diode will also change.

→ Based on type of applied voltage (or) signal there exist 3 resistance levels w.r.t diode. They are

1. DC (or) static Resistance
2. AC (or) Dynamic Resistance.
3. Average AC resistance.

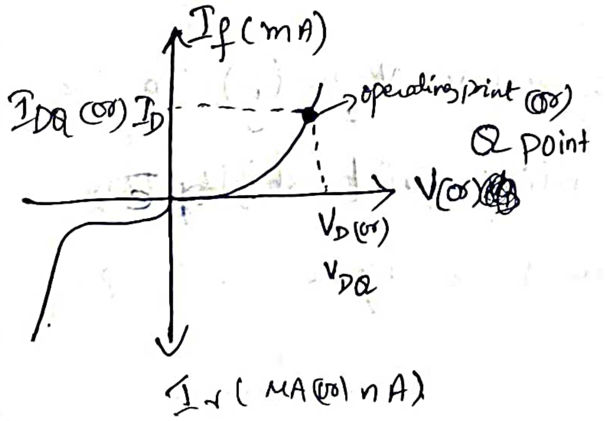
DC (or) Static Resistance :- When we apply dc voltage to a circuit, which contains a semiconductor diode then it results an operating point on characteristic curve of diode. "The resistante of the diode at that particular operating point" is said to be "DC (or) static Resistance".

(or)

"The resistance of the diode when a d.c voltage is applied is said to be DC (or) static resistance". Static resistance is calculated only at particular point on characteristics of diode.

→ DC (or) static Resistance is denoted with R (or) R_D.

And is given as

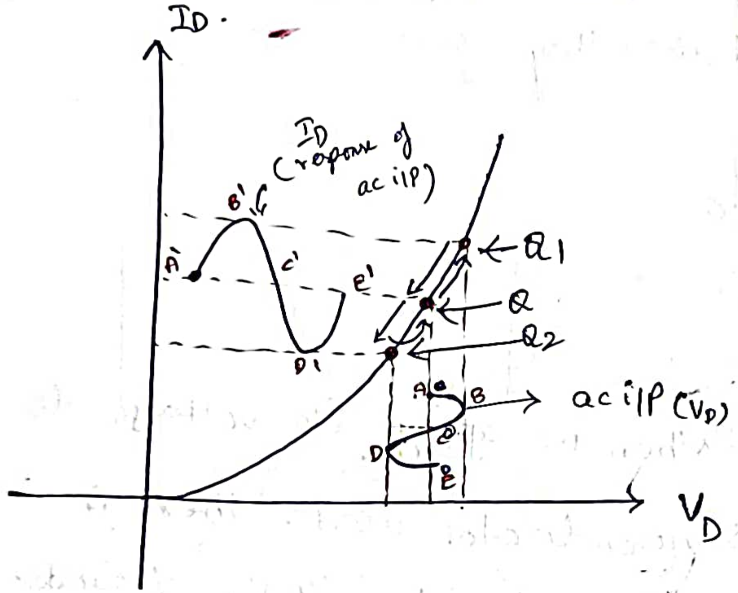


$$R \text{ (or) } R_D = \frac{V_D}{I_D} \text{ (or) } = \frac{V_{DQ}}{I_{DQ}}.$$

→ if $I_D \uparrow$ ses then $R_D \downarrow$ ses.

→ R (or) R_D will be in the range of $\boxed{10\,\Omega \text{ to } 80\,\Omega}$

AC (or) Dynamic Resistance :- If an a.c i/p is applied to the ckt which contains semiconductor diode, then this varying i/p (a.c i/p) will move the operating point up & down on characteristic curve of diode. "The resistance of diode when a.c i/p is supplied is said to be AC resistance".



→ From the graph it can be observed that, with the small change in diode voltage (a.c i/p). Current changes rapidly

→ As there is significant change in current, the operating point moves accordingly.

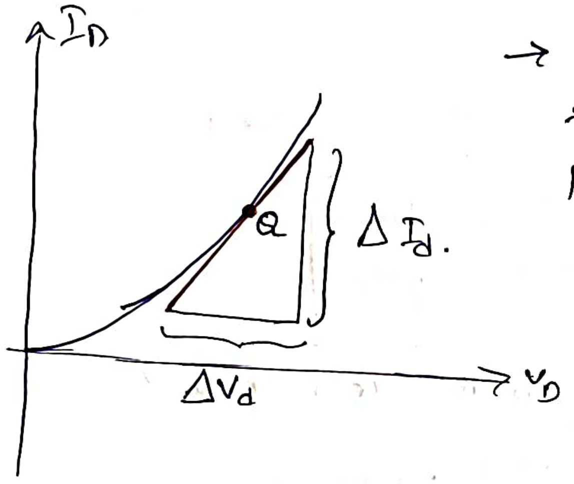
reference purpose only.

→ When ac i/p is zero (A), I_D = 0 (A') and position of operating point is at Q.

→ When ac i/p is increased (B) then I_D also increased (B') and the position of operating point is shifted to Q_1

→ When ac i/p is decreased and reached to zero (c), the I_D also decreases and reaches to zero (c'), operating point shifts from Q_1 to Q.

→ When ac i/p is further decreased to a (-ve) value (D), I_D also decreases to (-ve) value (D'), operating point shifts from Q to Q_2. And the process continues as long as ac i/p is supplied.



→ To calculate AC resistance, draw a st. line tangent to the curve through 'Q' point.

→ A.C resistance is denoted as r_d. And is given by

$$\boxed{r_d = \frac{\Delta V_d}{\Delta I_d.}} \rightarrow (A)$$

→ The dynamic resistance is also defined as "reciprocal of slope of characteristics".

<u>Derivation</u>: WKT diode current is given by

$$\cancel{I_D = I_o(e^{\eta V_T}}$$

$$I_D = I_o\left(e^{\frac{V_D}{\eta V_T}} - 1\right)$$

$$I_D = I_o \, e^{\frac{V_D}{\eta V_T}} - I_o \rightarrow (1)$$

differentiat I_D w.r.t V_D

$$\frac{dI_D}{dV_D} = I_o \frac{d}{dV_D}\left(e^{\frac{V_D}{\eta V_T}}\right) - \cancelto{0}{\frac{d}{dV_D}(I_o)}$$

$$= I_o \cdot \frac{1}{\eta V_T} e^{\frac{V_D}{\eta V_T}} \qquad \left[\frac{d}{dx}e^{2x} = 2e^{2x}\right]$$

$$\frac{dI_D}{dV_D} = \frac{I_o e^{\frac{V_D}{\eta V_T}}}{\eta V_T}$$

from eqn (1) $I_o e^{V_D/\eta V_T} = I_D + I_o$

$$\frac{dI_D}{dV_D} = \frac{I_D + I_o}{\eta V_T}$$

WKT $I_D >> I_o$

$$\therefore \frac{dI_D}{dV_D} = \frac{I_D}{\eta V_T}$$

$$\boxed{\frac{dV_D}{dI_D} = \frac{\eta V_T}{I_D}}$$

WKT $V_T = 26\,mV$

Let $\eta = 1$ then

$$\frac{dV_D}{dI_D} = \frac{26\,mV}{I_D}$$

from (A)

$$\boxed{r_d = \frac{26\,mV}{I_D}}$$

Note: Dynamic ~~resi~~ Conductance

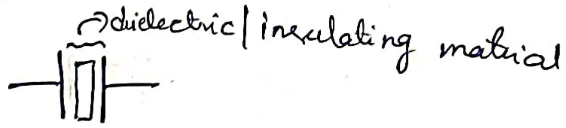
$$\boxed{g = \frac{1}{r_d} = \frac{I_D}{\eta V_T}}$$

→ For small signal operation, r_d is an important parameter.

→ Dynamic resistance is also known as incremental resistance.

Diode capacitance:

We know that "if there is an insulating/dielectric material b/w two conducting parallel plates, then the resultant is said to be Capacitor".



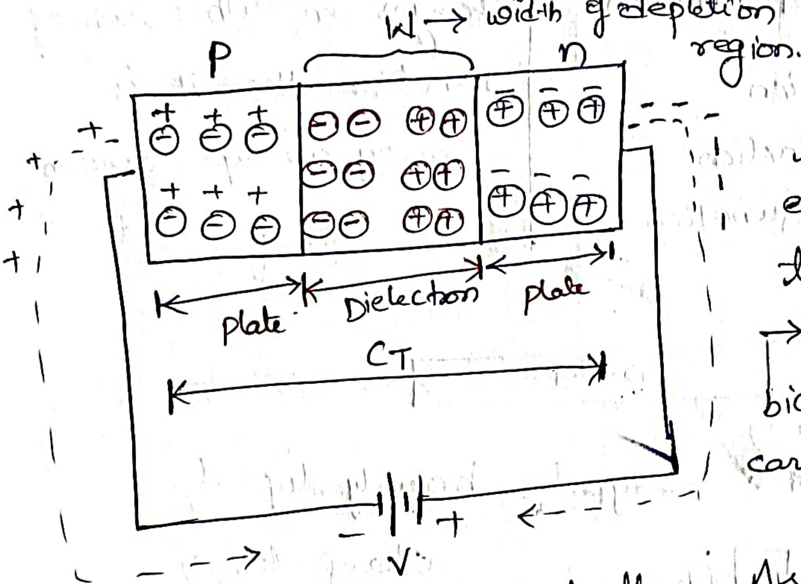
→ Capacitor stores the charge in the form of electric field.

→ Diode capacitances are of two types

1. Transition (or) space-charge capacitance
2. Diffusion capacitance.

Transition capacitance: It is represented with C_T. And is also known as space-charge capacitance.

→ Transition capacitance is observed / obtained in reverse biased pn-diode.



→ In reverse biased Pn-diode holes from P-side are attracted towards (-ve) terminal & electrons from n-side are attracted towards (+ve) terminal of battery

→ If we increase the reverse bias voltage, more and more majority carriers attract towards the opposite terminals of battery. As a result the width of the depletion region (W) increases. Depletion region doesn't conduct as it has immobile ions.

→ Hence from the above diagram it can be observed that P-side & n-side acts as conducting parallel plates & depletion region acts as dielectric. ∴ Pn-diode in reverse bias can (act as a) resemble capacitor.

→ As depletion region is also known as space-charge region (or) transition region, the capacitive effect in reverse bias is known as "Transition capacitance (or) space-charge capacitance"

$C_T = \frac{dQ}{dV}$ (change in charge w.r.t change in applied reverse voltage)

$$\boxed{= \frac{\varepsilon A}{W} = \frac{\varepsilon A}{W}}$$

only for reference.

Derivation : C_T is derived by Considering an alloy junction.

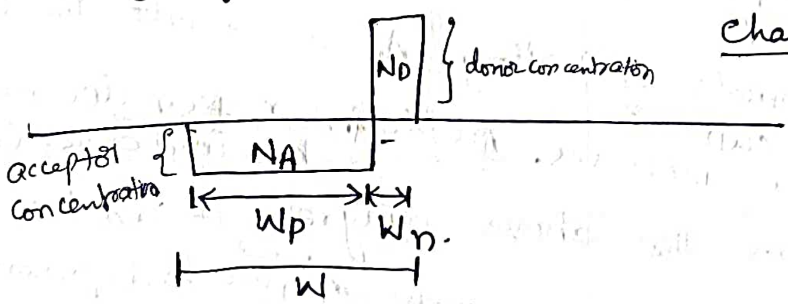
→ For alloy junction doping concentration is unequal.

→ Alloy junction is also known as
i) step-graded junction
ii) Abrupt junction
iii) fusion junction
iv) non linear junction.

If there exists sudden changes in either side of junction. then it is "alloy, abrupt" junction.

→ Let P-type is lightely doped & n-type is heavily doped.

Charge density



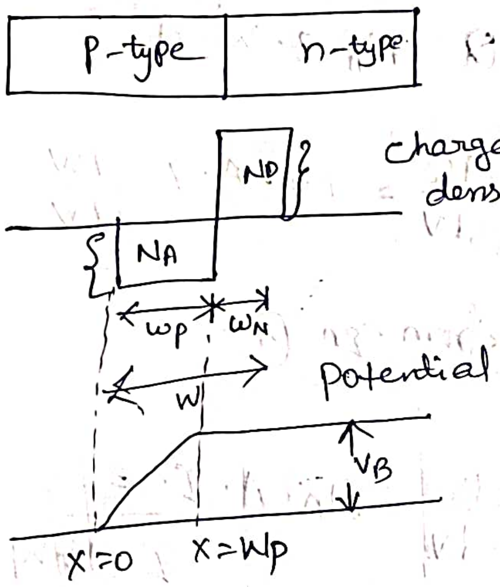
→ As p-type is lightely doped, Acceptor atoms Concentration (N_A) is very low when compared with donor atoms Concentration(N_D) in n-type.

$$N_A << N_D \quad \text{so} \quad W_p >> W_n$$

W_p → width of depletion region in P-type
W_n → " " " " n-type.

→ so we can say that depletion region is more penetrated into p-type s.c. than n-type.

→ Hence we assume that total depletion region is present in p-type



From poissions' eqn

$$\frac{d^2V}{dx^2} = \frac{qN_A}{\varepsilon} \longrightarrow (1) \quad , \varepsilon = \varepsilon_0 \varepsilon_r$$

$\varepsilon_0 \rightarrow$ permitivity of free space

$\varepsilon_r \rightarrow$ relative permitivity of semiconductor.

Integrate eqn (1) w.r.t 'x' twice.

$$\int \frac{d^2V}{dx^2} dx = \int \frac{qN_A}{\varepsilon} . dx \quad \text{— 1st integration}$$

$$\boxed{= \int \frac{d^2V}{dx^2} dx \quad \cancel{\int} \frac{d}{\cancel{dx}} \cancel{(V)} . \frac{d}{dx}(V) . \cancel{dx} \quad = \frac{d}{dx} V}$$

$$\frac{dV}{dx} = \frac{qN_A}{\varepsilon} \int dx$$

$$\frac{dV}{dx} = \frac{qN_A}{\varepsilon} . x$$

$$\int \frac{dV}{dx} . dx = \int \frac{qN_A}{\varepsilon} . x . dx \quad \text{— 2nd integration}$$

$$\cancel{\int} \frac{d}{\cancel{dx}} (V) . \cancel{dx} = \frac{qN_A}{\varepsilon} \int x \, dx$$

$$V = \frac{qN_A}{\varepsilon} . \frac{x^2}{2} \longrightarrow (2)$$

From graph at $x = W$, Wp $V = V_B$ (barrier potential) ✓

$$V_B = \frac{qN_A}{2\varepsilon} W^2 \longrightarrow (3)$$

$$W^2 = \frac{V_B \cdot 2\varepsilon}{q N_A}$$

$$W = \left(\frac{V_B \cdot 2\varepsilon}{q N_A}\right)^{1/2}$$

$$\boxed{W \propto \sqrt{V_B}}$$

diff eqn (3) w.r.t V

∴

$$\frac{dV_B}{dV} = \frac{q N_A}{2\varepsilon} \frac{d}{dV}(W^2)$$

if $V_B = V$

$$1 = \frac{q N_A}{\cancel{2}\varepsilon} \cdot \frac{dW}{dV} \cdot \cancel{2W}$$

$$\left[\frac{dW^2}{dV} = 2W \cdot \frac{dW}{dV}\right]$$

$$\frac{dW}{dV} = \frac{\varepsilon}{q N_A W} \rightarrow (4)$$

if 'A' is the area of cross section of junction.

then Charge

$$\cancel{Q = N_A \cdot A \cdot q \cdot \frac{dW}{dV}} \rightarrow (5)$$

$$Q = N_A \cdot q \cdot W \cdot A$$

$$\frac{dQ}{dV} = N_A \cdot A \cdot q \cdot \frac{dW}{dV}$$

from eqn (4)

$$\frac{dQ}{dV} = \cancel{N_A} \cdot A \cdot \cancel{q} \cdot \frac{\varepsilon}{\cancel{q}\,\cancel{N_A}\,W}$$

$$\boxed{\frac{dQ}{dV} = \frac{\varepsilon A}{W} = C_T}$$

$\varepsilon = \varepsilon_0 \varepsilon_r$

$\varepsilon_0 = 8.849 \times 10^{-12}$ F/m

$\varepsilon_r = 16$ for Ge &

12 for si.

A – Area of cross section

W – width of depletion region.

Diffusion capacitance: (C_D):

→ Diffusion capacitance exists in forward biased PN junction diode.

→ In forward biased condition, the width of depletion region decreases and holes from P-side get diffused into n-side & $\bar{e}$s from n-side get diffused into P-side.

→ If the applied forward voltage increases, the concentration of these injected charge carriers increases. This rate of change of injected charge with applied voltage is defined as "diffusion capacitance".

$$C_D = \frac{dQ}{dV_D} \rightarrow ①$$

WKT $Q = \tau I_D \rightarrow ②$

$\tau \rightarrow$ Life time of charge carrier.

$I_D \rightarrow$ diode current.

Apply differentiation to eqn ②

$\therefore dQ = \tau\, dI_D$

$$\frac{dQ}{dI_D} = \tau \rightarrow ③$$

eqn ① can be written as

$$C_D = \frac{dQ}{dI_D} \times \frac{dI_D}{dV_D} \rightarrow ④$$

Alternate method

diff eqn ② w.r.t V_D

$$\frac{dQ}{dV_D} = \tau \cdot \frac{dI_D}{dV_D} \rightarrow ③$$

WKT

$$I_D = I_0 e^{V_D/\eta V_T} - I_0$$

$\rightarrow ④$

diff eqn ④ w.r.t V_D

$$\frac{dI_D}{dV_D} = I_0 \cdot \frac{1}{\eta V_T} \cdot e^{V_D/\eta V_T} - \cancel{\frac{dI_0}{dV_D}}^{\,0}$$

from ④

$$I_0 e^{V_D/\eta V_T} = I_D + I_0$$

WKT $I_D >> I_0$

$$\therefore \frac{dI_D}{dV_D} = \frac{I_D}{\eta V_T} \rightarrow ⑤$$

Sub ⑤ ④ ③

$$\boxed{\frac{dQ}{dV_D} = C_D = \frac{\tau I_D}{\eta V_T}}$$

Sub eqn ③ in eqn ④

$$C_D = \tau \times \frac{dI_D}{dV_D} \rightarrow ⑤$$

WKT.

$$I_D = I_O\left(e^{\frac{V_D}{\eta V_T}} - 1\right) \rightarrow ⑥$$

for forward biased PN-diode, there exist only forward current, hence eqn ⑥ can be written as $\left[\left(e^{\frac{V_D}{\eta V_T}} >>> 1\right)\right]$

$$I_D = I_O e^{\frac{V_D}{\eta V_T}} \rightarrow ⑦$$

diff eqn ⑦ w.r.t V_D

$$\frac{dI_D}{dV_D} = I_O \cdot \frac{1}{\eta V_T} \cdot e^{\frac{V_D}{\eta V_T}}$$

$$\frac{dI_D}{dV_D} = \frac{1}{\eta V_T} \cdot I_O e^{\frac{V_D}{\eta V_T}}$$

sub ⑦ in above eqn

$$\frac{dI_D}{dV_D} = \frac{1}{\eta V_T} I_D.$$

$$\frac{dI_D}{dV_D} = \frac{I_D}{\eta V_T} \rightarrow ⑧$$

sub eqn ⑧ in eqn ⑤

$$C_D = \tau \cdot \frac{I_D}{\eta V_T}.$$

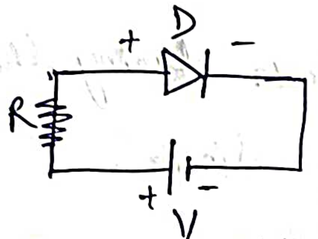
$$\therefore \boxed{C_D = \frac{dQ}{dV_D} = \frac{\tau I_D}{\eta V_T}}$$

$$\rightarrow \boxed{C_D \propto I_D.}$$

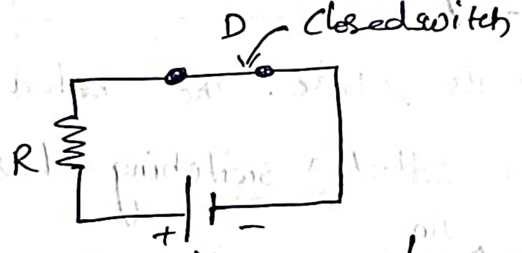
Diffusion Capacitance is directly proportional current through diode.

Diode as a Switch :

① → When a PN-diode is forward biased by connecting (+ve) terminal of the battery to p-type sc & (-ve) terminal of the " " n-type sc, then the diode will act as closed switch (or) 'ON' switch.



ⓐ Forward biased PN diode.

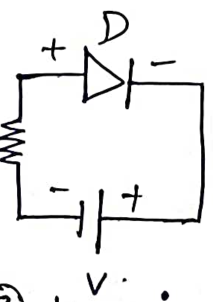


ⓑ diod as closed/ON switch.

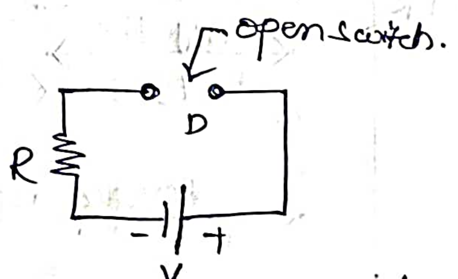
→ When diode acts as closed switch, current will flow through it, as it is forward biased.

→ Diode provides very little resistance, when it acts as closed switch

② → When PN-diode is reverse biased by connecting (-ve) terminal of battery to p-type sc & (+ve) terminal of battery to n-type sc, then diode will act as 'open-switch' (or) 'OFF-switch'.



ⓒ diode in reversebias



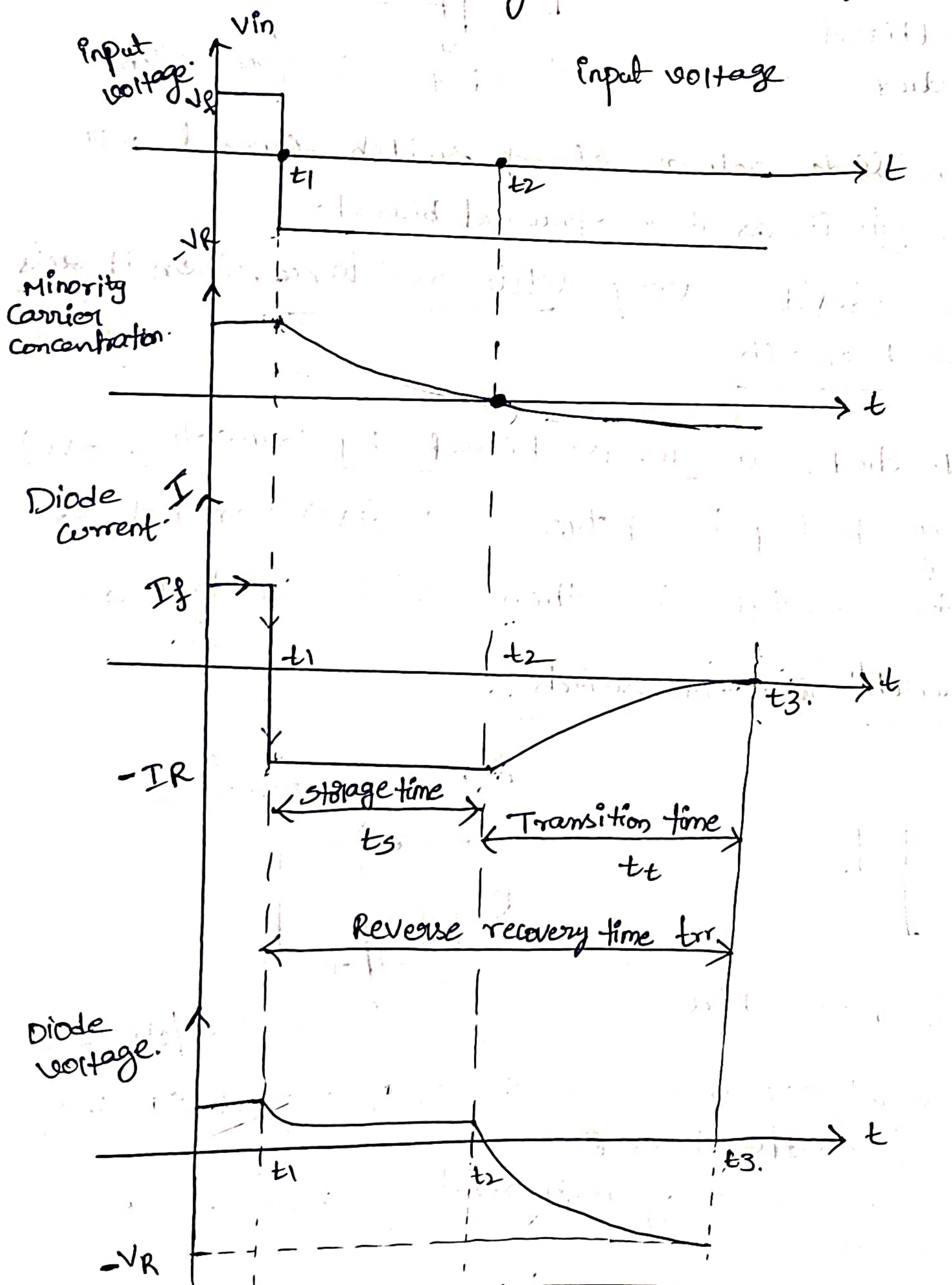
ⓓ diode as open/OFF switch.

→ When diode acts as open switch, current will not flow through it, as it is reverse biased.

→ Diode provides very high resistance, when it acts as open switch

Switching times (or) Switching characterestics of a diode

When the diode is switched from forward biased to reverse biased (or) Vice Versa, then diode should switch from ON state to OFF state (or) viceversa instantly. But practically it takes some finite time for the diode to change its state. The behaviour of the diode during this time is called "switching characteristics of diode".



→ There are '4' time parameters, which are associated with switching characteristics of diode. They are

1. Forward recovery time (t_{fr})
2. Reverse recovery time (t_{rr})
3. Storage time (t_s)
4. Transition time. (t_t)

Forward recovery time (t_{fr}) :- Time required for the diode current to reverse its direction & attain a steady value when forward bias is applied to reverse biased PN diode. (or) time taken by the diode to switch from reverse biase to forward bias.

Reverse recovery time (t_{rr}) :- Time required for the diode current to reverse its direction & attain a steady value when reverse bias is applied to forward biased PN diode. (or) Time taken by diode to switch from forward biase to reverse bias.

Storage time (t_s) : Minority carriers are stored & gradually decreases to zero b/w t_1 & t_2. This time is called "storage time".

(or)

The time duration for which the diode remains in conduction state even if the reverse biase is applied, is called "Storage time".

Transition time (t_t) :- Time taken by the diode current to reach to it's saturation value, is called "transition time".

(or)

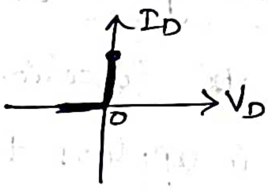
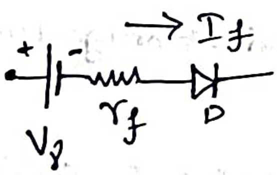
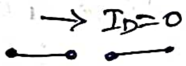
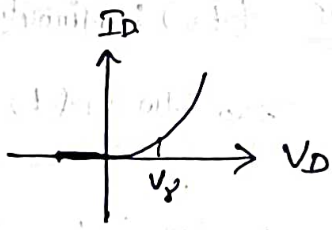
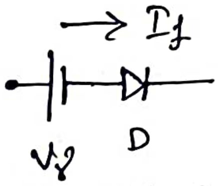
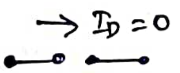
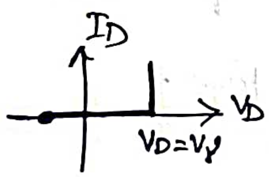
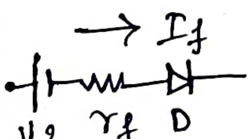
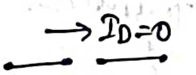
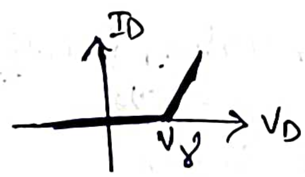
to reduce it's value to zero

Diode Equivalent Circuits :-

The diode is ~~required~~ to be replaced by ~~the~~ its' equivalent circuit in many practical electronic circuits, for the analysis purpose.

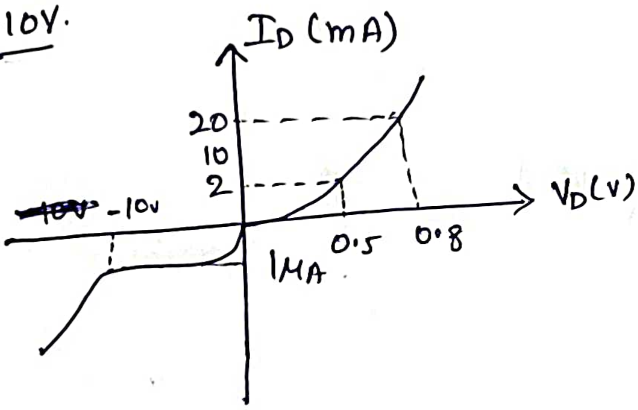
There are 3 types of diode equivalent ckts

1. Ideal diode 2. practical diode 3. piecewise linear model.

Type	Forward biased	Reverse biased	V–I characteristics	Drop across diode
Ideal Diode	 $\rightarrow I_D$ $r_f = 0$	$I_D = 0$		$V_f = 0$
practical diode.		 open ckt		$V_f = V_\gamma + I_f r_f$
Piecewise Linear (a) with $r_f = 0$	 $r_f = 0$	 open ckt.		$V_f = V_\gamma$
(b) with finite r_f		 open ckt.		$V_f = V_\gamma - I_f R_f$

Problems:

1. Calculate DC resistance of the diode for the following Curve at different voltages such as $V_D = 0.5V$, $0.8V$, and $-10V$.



Sol: WKT $R_D = \frac{V_D}{I_D}$.

Case(1): for $V_D = 0.5V$

from graph $I_D = 2mA$

$\therefore R_D = \frac{0.5}{2\times10^{-3}} = 250\Omega$

Case(2): for $V_D = 0.8V$

from graph $I_D = 20mA$.

$\therefore R_D = \frac{0.8}{20\times10^{-3}} = 40\Omega$

Case(3): for $V_D = -10V$

from graph $I_D = -1\mu A$

$R_D = \frac{\cancel{-}10V}{\cancel{-}1\times10^{-6}} = 10M\Omega$

② Determine AC Dynamic resistance of diode, if current varies from 2 to 17mA & voltage changes from 0.65V to 0.725V.

Sol: WKT

$$r_d = \frac{\Delta V_D}{\Delta I_D} = \frac{26mV}{I_D}$$

$\Delta V_D = V_2 - V_1 = 0.725 - 0.65 = 0.075V$

$\Delta I_D = I_2 - I_1 = 17 - 2 = 15mA$.

$\therefore r_d = \frac{0.075}{15\times10^{-3}} = 5\Omega$.

③ Determine the values of forward current in case of PN junction diode with I_0 is $10\mu A$, $V_f = 0.8V$ at $T = 300°k$ and assume silicon diode.

Sol: Given data

$I_0 = 10\mu A$, $V_f = 0.8V$, $T = 300°K$

$$I_D = I_0\left[e^{V_D/\eta V_T} - 1\right] \times$$

for silicon $\eta = 2$

WKT $V_T = 26mV$. $V_D = V_f = 0.8V$.

$$= 10\times10^{-16}\left[e^{0.8/2\times26\times10^{-3}} - 1\right]$$

$I_D \simeq 47.99A$

$\rightarrow I_f = I_0 e^{V_D/\eta V_T}$ ✓ $I_R = -I_0$

④ A Si PN junction under reverse bias has depletion of width 10μm. the relative permittivity of silicon ε_r is 11.7 and permittivity of free space is $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m. Determine depletion capacitance of diode per square meter.

Sol: Given data

$W = 10\mu m$, $\varepsilon_r = 11.7$, $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

$$C_T = \frac{\varepsilon A}{W} =$$

$$\frac{C_T}{A} = \frac{\varepsilon}{W} = \frac{\varepsilon_0 \varepsilon_r}{W} = \frac{8.854 \times 10^{-12} \times 11.7}{10 \times 10^{-6}}$$

$$= 10\mu F$$