Basic Electronics

Electronics is a Subject where we Study about electrons as well as electronic components. In our universe every thing is available in three forms i.e Solid, liquid and gas. We can sense them by feeling, touching and can even seeing as well as they have weight, Size and there three types conductors insulators and Semi conductors.

conductor:- A conductor is a Substance or material that allows electricity to flow through it. In a conductor electrical charge carriers usually electrons or ions move easily from atom to atom when voltage is applied.

Eg: copper, aluminium, gold, silver etc.

Insulator:- The material that donot allow electricity to pass through them are called insulator.

Eg: Glass, air, wood, plastic, rubber etc.

Semi conductor:- semi conductors are materials which have a conductivity between conductors and non conductors (Insulator).

Eg: Silicon, germanium.

Classification of Solids on the basis of energy band theory:

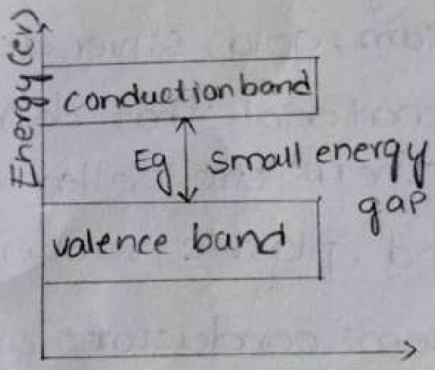
Out of all the bands three bands are important to understand the behaviour Solids.

Valence band:- A set of energy level possesed by valence electrons is known as valence band. It is obviously the highest occupied band as regards occupiency it may be either completely filled or partially filled with electrons but can never be empty.

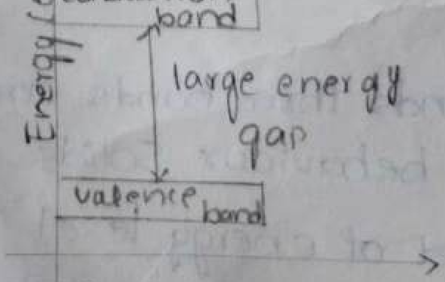
Conduction band:- A set of energy levels possesed by free electrons or conduction electrons is known as conduction band.

→ The electrons which have left the outermost orbit of an atom are called free electrons or conduction electrons.

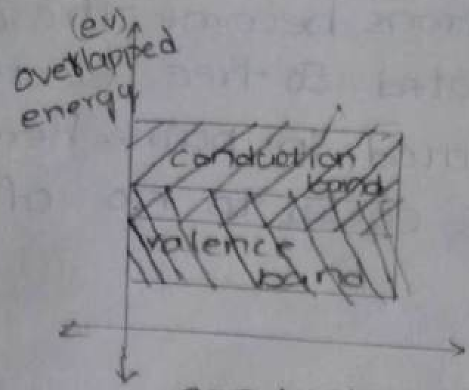
Forbidden energy band (or) energy gap:- Valence band and conduction band are separated by a gap known as energy gap.



eg:- Semiconductor



Insulator



conductor

Types of Semi conductors:-

1. Intrinsic Semi conductor (Pure)

2. Extrinsic Semi Conductor (impure)

Intrinsic Semi conductor:-

→ A Semi conductor in its pure form is called an intrinsic semi Conductor.

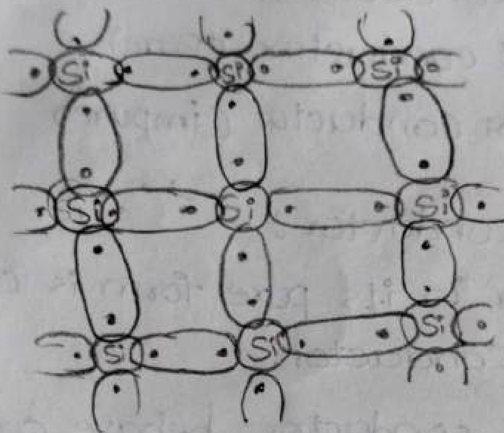
→ Intrinsic Semi conductor behave as a perfect insulator at '0' temparature

→ At room temperature some of the valence electrons absorb the thermal energy due to which they break the bond and drift to conduction band Such electrons become free to move in the crystal.

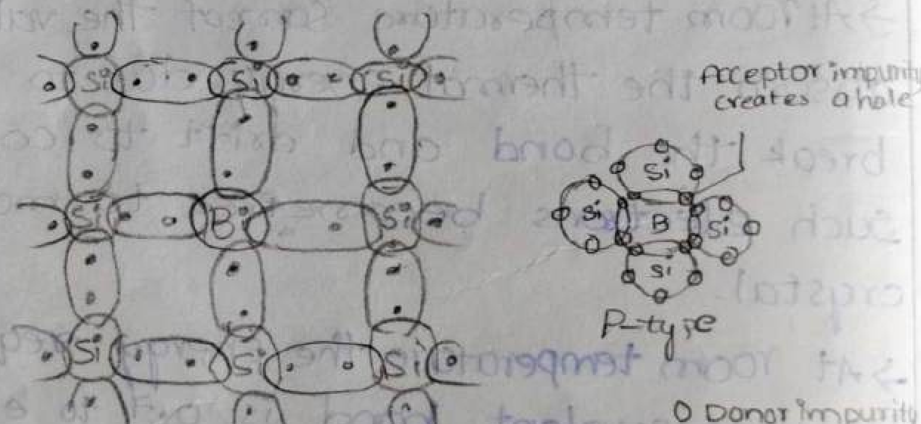
→ At room temperature the energy required to break a covalent bond is 0.7 to ev for germanium and 1.1 ev for Silicon. For every electron jumped from valence band to conduction band breaking a covalent band there will be vacancy is created in the broken band Such vacancy is called hole.

→ Whenever an electrons become the corresponding hole gets generated. So free electrons and holes gets generated in pairs. Here, the number of electrons is equal to no. of holes.

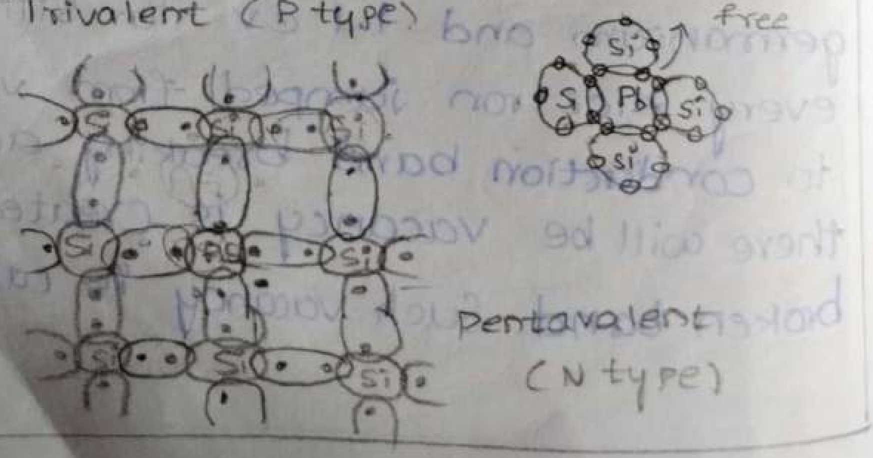
Silicon Crystalline



Extrinsic SemiConductor:-



Trivalent (P type)



Pentavalent (N type)

→ The conductivity of semiconductors can be greatly improved by introducing a small no of suitable replacement atoms called impurities.

→ The process of adding impurity atoms to the pure semiconductor is called Doping. Usually, only one atom in 10^7 is replaced by a dopant atom in the doped semiconductor.

→ An extrinsic semiconductor can be further classified into:

- N-type semiconductor
- P-type semiconductor

Classification of Extrinsic semiconductor.

N-Type Semiconductor

- Mainly due to electrons
- Entirely neutral
- $I = I_n$ and $n_e \gg n_h$. $n_e > n_i$
- Majority - Electrons and Minority - Holes.

→ When a pure semiconductor (Silicon or Germanium) is doped by pentavalent impurity (P, As, Sb, Bi) then, four electrons out of five valence electrons bonds with the four electrons of Ge or Si.

→ The fifth electron of the dopant is set free. Thus the impurity atom donates a free electron for conduction in lattice and is called "Donor".

→ Since the no of free electron increases by the addition of an impurity, the negative charge carriers increase. Hence it is called n-type semiconductor.

→ Crystal as a whole is neutral, but the donor atom becomes an immobile positive ion. As conduction is due to a large no of free electrons, the electrons in n-type semiconductor are the Majority carriers and holes are the minority carriers.

P-Type Semiconductor

- Mainly due to holes
- Entirely neutral
- $S = S_a$ and $p_h >> p_e$
- Majority - Holes and Minority - Electrons

→ When a pure semiconductor is doped with a trivalent impurity (B, Al, In, Ga) then, the three valence electrons of the impurity bonds with three of the four valence electrons of the semiconductor.

→ This leaves an absence of electron (hole) in the impurity. These impurity atoms which are ready to accept bonded electrons are called "Acceptors".

→ With the increase in the no of impurities, holes (the positive charge carriers) are increased. Hence it is called P-type Semiconductor.

→ Crystal as a whole is neutral, but the acceptors become an immobile negative ion. As conduction is due to a large no of holes, the holes in the P-type semiconductor are majority carriers and electrons are minority carriers.

Difference b/w Intrinsic and Extrinsic Semiconductor

Intrinsic Semiconductor	Extrinsic Semiconductor
1. Pure Semiconductor	1. Impure semiconductor
2. Density of electrons is equal to the density of holes.	2. Density of electrons is not equal to density of holes.
3. Electrical conductivity is low.	3. Electrical conductivity is high.
4. Dependence on temparature only	4. Dependence on temp as well as on amount of impurity.

P-N Junction:

A p-n junction is an interface or a boundary b/w two semiconductor material types, namely the P-type and the n-type, inside a semiconductor.

→ The p-side or the positive side of the semiconductor has an excess of holes and the n-side or the negative side has an excess of electrons.

→ In a semiconductor, the p-n junction is created by the method of doping. The process of doping is explained in further detail in the next section.

Formation of P-N Junction:

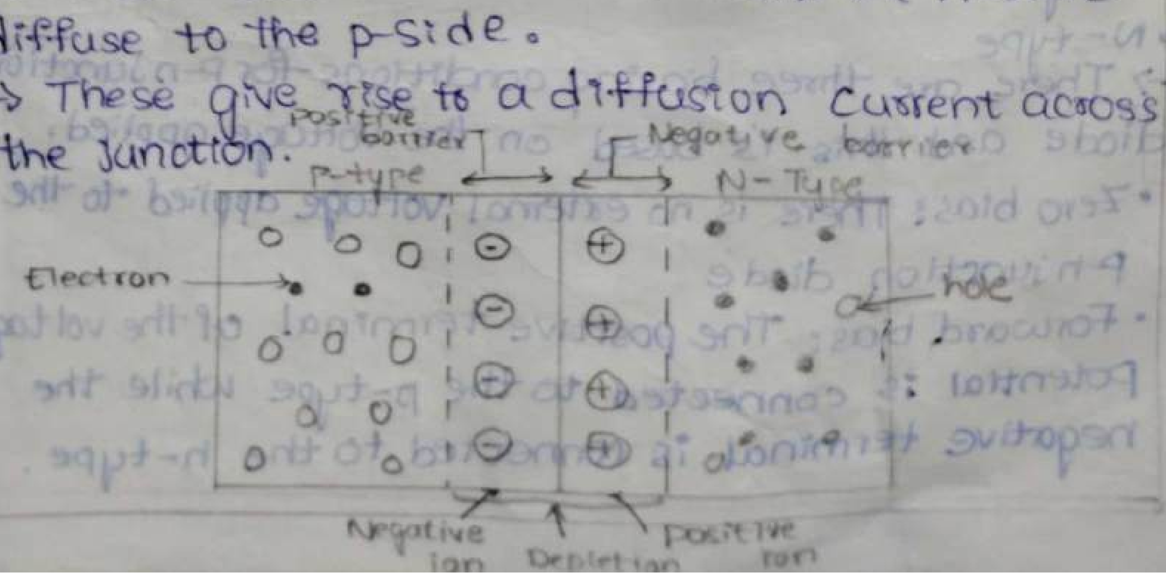
Let us consider a thin p-type silicon semiconductor sheet. If we add a small amount of pentavalent impurity to this, a part of the p-type Si will get converted to n-type silicon.

→ This sheet will now contain both p-type region & N-type region and a junction b/w these two regions.

→ The processes that follow after the formation of a p-n junction are of two types - diffusion and drift.

→ As we know, there is a difference in the concentration of holes and electrons at the two sides of a junction, the holes from p-side diffuse to n-side and the electrons from the n-side diffuse to the p-side.

→ These give rise to a diffusion current across the junction.



When an electron diffuse from the n-side to the p-side, an ionized donor is left behind on the n-side, which is immobile. As the process goes on, a layer of positive charge is developed on the n-side of the junction.

→ Similarly, when a hole goes from the p-side to n-side, and ionized acceptor is left behind in the p-side, resulting in the formation of a layer of negative charges in the p-side of junction.

→ This region of positive charge and negative charge on either side of the junction is termed as depletion region.

→ Due to this positive space charge region on either side of the junction, an electric field direction from +ve charge towards -ve charge is developed.

→ Due to this electric field, an electron on the p-side of the junction moves to the n-side of junction.

→ this motion is termed as the drift, Here, we see that the direction of drift current is opposite to that of the diffusion current.

There are two operating regions in the p-n junction diode:

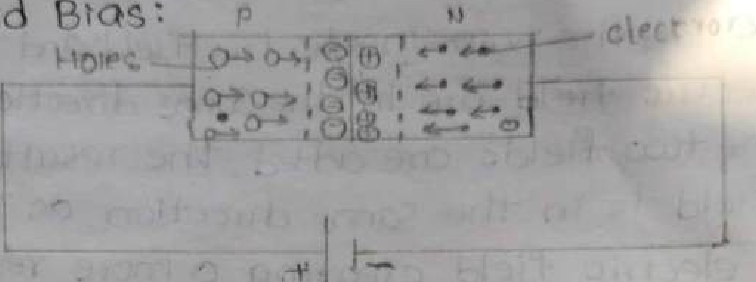
- P-type
- N-type

→ There are three biasing conditions for p-n junction diode and this is based on the voltage applied.

- Zero bias: There is no external voltage applied to the p-n junction diode
- Forward bias: The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type.

• Reverse bias: The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type.

Forward Bias:



Forward Biasing

→ When the p-type is connected to the positive terminal of the battery and the n-type to the negative terminal then the p-n junction is said to be forward biased.

→ When the p-n junction is forward biased, the built-in electric field at the p-n junction and the applied electric field are in opposite directions.

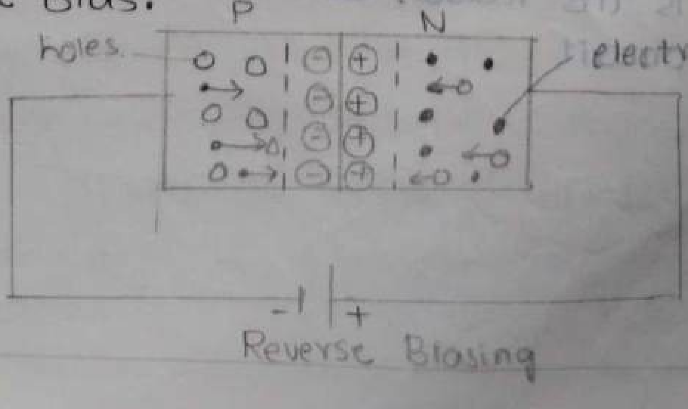
→ When both the electric fields add up the resultant electric field has a magnitude lesser than the built-in electric field.

→ This results in a less resistive and thinner depletion region.

→ The depletion region's resistance becomes negligible when the applied voltage is large.

→ In silicon, at the voltage of 0.6V, the resistance of the depletion region becomes completely negligible and the current flows across it unimpeded.

Reverse Bias:



Reverse Biasing

→ When the p-type is connected to the negative terminal of the battery and the n-type is connected to the positive side then the p-n junction is said to be reverse biased.

→ In this case, the built-in electric field and the applied electric field are in the same direction.

→ When the two fields are added, the resultant electric field is in the same direction as the built-in electric field creating a more resistive, thicker depletion region.

→ The depletion region becomes more resistive and thicker if the applied voltage become larger.

Current flow in PN junction diode

→ The flow of electrons from the n-side towards the p-side of the junction takes place when there is an increase in the voltage.

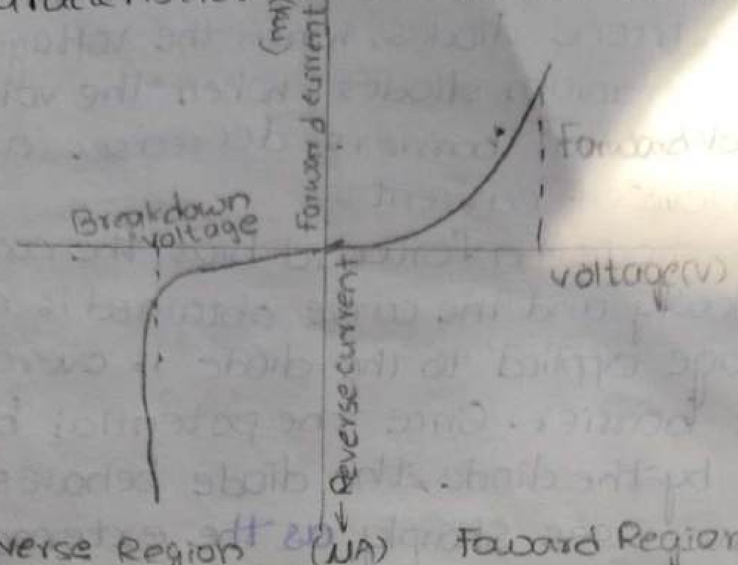
→ Similarly, the flow of holes from the p-side towards the n-side of the junction takes place along with the increase in voltage.

→ This results in the concentration gradient between both sides of the terminals.

→ Because of the formation of the concentration gradient, there will be a flow of charge carriers from higher concentration regions to lower concentration regions.

→ The movement of charge carriers inside the p-n junction is the reason behind the current flow in the circuit.

I-V Characteristics of PN Junction Diode



I-V characteristics of PN Junction diode is a curve b/w the voltage and current through the circuit. Voltage is taken along the x-axis while the current is taken along the y-axis. The above graph is the I-V characteristics curve of the PN Junction diode. With the help of the curve we can understand that there are three regions in which the diode works, and they are:

- Zero bias
- Forward bias
- Reverse bias.

→ When the PN junction diode is under Zero bias condition, there is no external voltage applied and this means that the potential barrier at the junction does not allow the flow of current.

→ When the PN junction diode is under forward bias condition, the P-type is connected to the positive terminal while the n-type is connected to the negative terminal of the external voltage.

-> In this manner, there is a reduction in the potential barrier. For Silicone diodes, when the voltage is 0.7 V and for germanium diodes, when the voltage is 0.3V, the potential barriers decreases and there is a flow of current.

-> When the diode in forward bias, the current increases slowly and the curve obtained is non-linear as the voltage applied to the diode is overcoming the potential barrier. Once the potential barrier is overcome by the diode, the diode behaves normal and the curve rises sharply as the external voltage increases & the curve so obtained is linear.

-> When the PN junction diode is under reverse bias condition, the P-type is connected to the negative terminal while the n-type is connected to positive terminal of the external voltage. This results in an increase in the potential barrier. Reverse saturation current flows in the begining as minority carriers are present in the junction.

-> When the applied Voltage is increased, the minority charges will have increased kinetic energy which affects the majority charges. This is the stage when the diode breaks down. This may also destroy the diode.

Applications of PN Junction Diode

- P-n junction diode can be used as a photodiode as the diode is sensitive to the light when the configuration of the diode is reverse-biased.
- It can be used as a solar cell.
- When the diode is forward-biased, it can used in LED lighting applications.
- It is used as rectifiers in many electric circuits and as a voltage-controlled oscillator in varactors.

Diode Resistance:-

Diode conducts current in forward biased mode whereas reverse biased diode doesnot conduct current So that diode offers low resistance to forward biased when compared to reverse biased resistance. The resistance offered by a diode under forward bias is known as Forward Resistance. It is of two types.

1. DC or static Resistance
2. AC or Dynamic Resistance

DC or Static Resistance:-

The resistance offered by a diode under dc conditions is called DC Resistance.

$$R_{static} = \frac{V}{I}$$

The static resistance under the forward bias is denoted by R_f while under reverse bias is denoted by R_r.

$$R_f = \frac{V_f}{I_f}$$

$$R_r = \frac{V_r}{I_r}\,\Omega = \frac{V_r}{I_0}\,\Omega$$

Ac or Dynamic Resistance:-

The resistance offered by a diode under AC conditions is called AC Resistance.

(or)

It is defined as the ratio of change in forward voltage to change in forward current.

$$r_d = \frac{dV}{dI}$$

From diode current equation $I = I_0(e^{V/\eta V_T} - 1)$

Where I_0 = Inverse Saturation current

V = Applied Voltage

$V_T = \frac{KT}{q}$ = Voltage equivalent of temparature in volts.

T = Absolute temperate

K = Boltzamns constant = $8.62 \times 10^{-5}\ eV/^{\circ}K$

η = constant for germanium (ge = 1) & (Si = 2).

$$I = I_0 \cdot e^{V/\eta V_T} - I_0 \rightarrow (1)$$

$$I + I_0 = I_0 \cdot e^{V/\eta V_T} \rightarrow (2)$$

diff eq^n (1) w.r.t to V

$$\frac{dI}{dV} = \frac{d}{dV}(I_0 \cdot e^{V/\eta V_T} - I_0)$$

$$\frac{dI}{dV} = I_0 \cdot e^{V/\eta V_T} \cdot \frac{1}{\eta V_T} - 0.$$

$$\frac{dI}{dV} = \frac{I_0}{\eta V_T} e^{V/\eta V_T}$$

$$\frac{dI}{dV} = \frac{I + I_0}{\eta V_T} \quad (I_0 << I)$$

$$\frac{dI}{dV} = \frac{I}{\eta V_T}$$

$$r_d = \frac{dV}{dI} = \frac{\eta V_T}{I}$$

$$\boxed{r_d = \frac{\eta V_T}{I}}$$

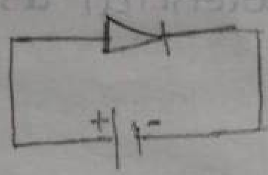
MID-I Imp

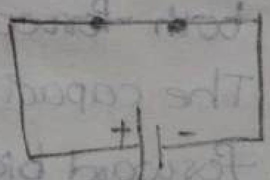
Diode Equivalent Circuit:

An ideal diode offers zero resistance in the forward biased condition whereas it offers infinite resistance in the reversed biased condition. So that ideal diode is replaced by a conductor in forward bias. While in the reverse bias it is replaced by an open circuit.

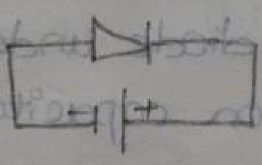
Symbol:

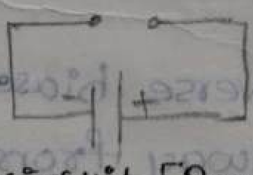
Ideal diode under forward bias



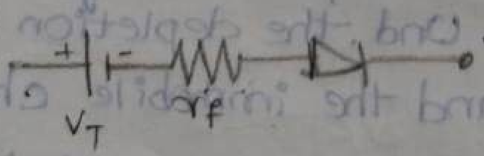


Ideal diode under reverse bias

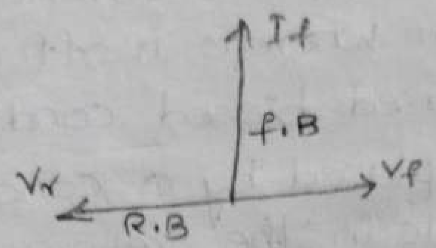




Equivalent circuit [Practical Diode equivalent circuit]



Ideal diode characteristics



Practical diode has Small resistance in forward bias While under reverse bias it has maximum resistance. But not under infinite so that a practical diode is represented with Series resistance and barrier potential as Source "V_T".

Diode Capacitance:

Diode offers capacitance in both forward bias as well as in reverse bias. The capacitance offered by a diode under forward bias is known as Diffusion capacitance. And the capacitance offered by a diode under reverse bias is known as Transition capacitance

Transition capacitance:-

When a P-N junction is reverse biased the majority carriers move away from the junction. As result the depletion region width will be increased. And the depletion region acts as insulator and the immobile charges will like be increases on either side of depletion region. This uncovered incremental charge can be considered as transition capacitance and is given $C_T = \frac{dQ}{dV}$

* It occurs due to majority carriers.

$$C_T = \frac{dQ}{dV} \qquad C_T = \frac{\epsilon A}{W}$$

Where C_T = Transition capacitance

$\frac{dQ}{dV}$ = Increase in charge due to increase in voltage.

If we increase reverse bias the transition capacitance will be decreases as they increase depletion region in reverse bias increase width.

Diffusion Capacitance:

When a PN junction is forward bias the electrons from N side enter the P-side and holes from P side enter into the N-side and gets recombine The density of charge carriers is high near the junction and decays exponetially with distance thus a charge is stored on both sides of the junction. This charge we are considering as diffusion capacitance or storage capacitance

$$C_d = \frac{dQ}{dV}$$

$$I = Q/\tau$$

$$Q = I\tau$$

Where τ is the lifetime of charge

I = diode current.

$$Q = I\tau$$

$$Q = I_0 e^{V/nV_T} \cdot \tau$$

$$C = \frac{dQ}{dV}$$

$$= \frac{d}{dv}\left(I_0 \cdot e^{V/\eta V_T} \cdot \tau\right)$$

$$= I_0 \tau \cdot \frac{1}{\eta V_T} \cdot e^{V/\eta V_T}$$

$$C = \frac{I_0 \tau}{\eta V_T} e^{V/\eta V_T}$$

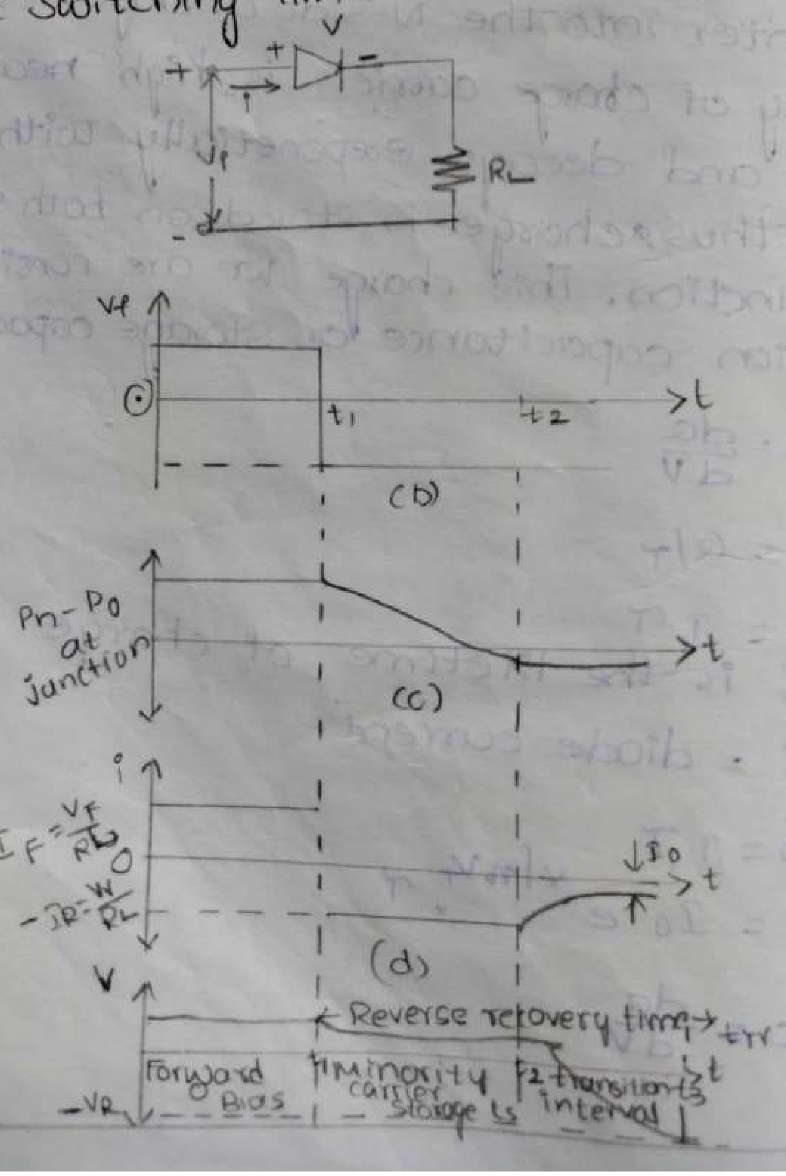
$$C = \frac{\tau}{\eta V_T} \cdot I_0 \cdot e^{V/\eta V_T}$$

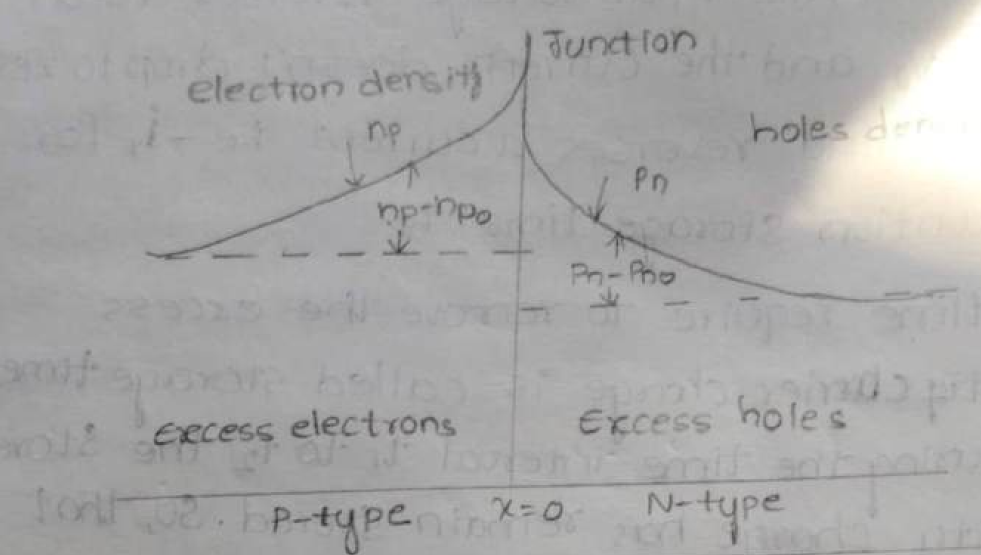
$$= \frac{\tau (I + I_0)}{\eta V_T}$$

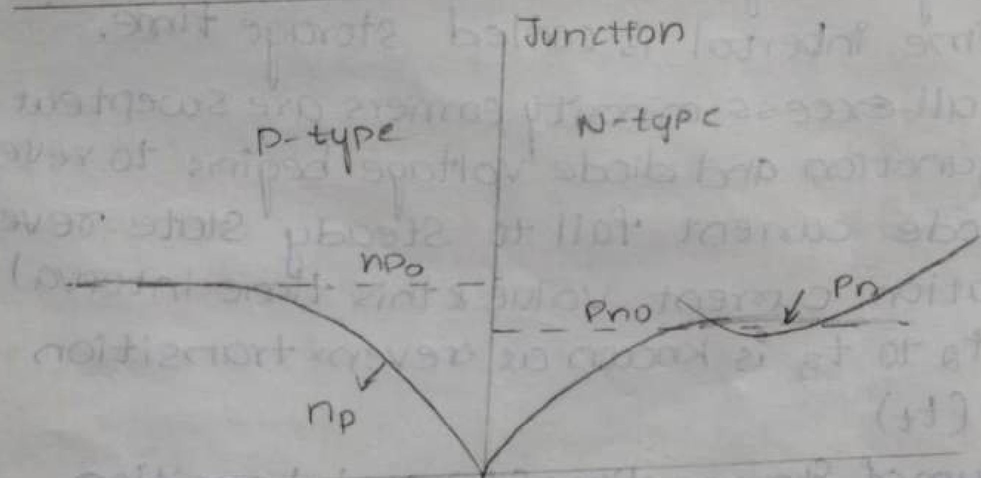
$$I_0 << I$$

$$C_D = \frac{\tau I}{\eta V_T}$$

Diode Switching Times:-







Diode as a Switch
A Diode is two terminal P-N junction. The P-N Junction when forward biased acts as closed circuited and when reversed biased acts as open circuited. Hence, change in state from forward biased to reverse biased makes the diode work as a Switch the forward being on & reverse being off.

Switching times:-
→Upto time t_1 the diode is conducting in forward direction and current flows through the diode and there is a voltage drop across the diode.

→ At time t_1, the input voltage reverses to a value $-V_R$ and the current doesn't drop to zero but instead reverses a current i.e $-i_r$ for the duration storage time t_s.

→ The time require to remove the excess minority carrier charge is called storage time(t_s) (or) during the time interval t_1 to t_2 the stored minority charge has remain stored. So, that this time interval is called storage time.

→ After all excess minority carriers are swept out of the junction and diode voltage begins to reverse and diode current fall to steady state reverse saturation current value & this time interval from t_2 to t_3 is known as reverse transition time (t_t)

→ The sum of storage time (t_s) and transition time (t_t) is called the diode reverse recovery time (t_{rr}).

$$t_s + t_t = t_{rr}$$

→ The time required for the diode to change from forward bias to reverse bias is called as reverse recovery time.

→ The time required for the diode to change from reverse bias to forward bias is called as forward recovery time.

1. In a silicon diode the forward current changes by 2.5 mA when the voltage changes from 0.08 to 0.09 V then find the dynamic resistance of diode.

Given $\Delta V = 0.09 - 0.08\ V$

$\Delta I = 2.5\,mA$

$$r_d = \frac{\Delta V}{\Delta I} = \frac{0.01}{2.5 \times 10^{-3}} = \frac{0.01}{2.5} \times 10^{3}$$

$$= 0.004 \times 10^{3}$$

$$= 4\,\Omega$$

2. The P-N Junction diode voltage is changing from 5V to 15V then the value of current changes from 38 μA to 88 μA. Determine the resistance of junction diode.

Given $\Delta V = 15 - 5 = 10\,V$

$\Delta I = 88\,\mu A - 38\,\mu A = 50\,\mu A$

$$r_d = \frac{\Delta V}{\Delta I} = \frac{10}{50 \times 10^{-6}}$$

$$= \frac{10 \times 10^{6}}{50}$$

$$= \frac{10^{7}}{5 \times 10}$$

$$= \frac{10^{6}}{5}$$

$$= 200000$$

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

$$r_d = 200\,k\Omega$$

3. An ideal germanium diode at room temperature as source resistance of 4.57 Ω at a point where the current flowing is 43.8 mA. Find the dynamic resistance for a forward bias 0.1 volts.

Given $r_S = \frac{V}{I}$

$$4.57 = \frac{V}{43.8\times10^{-3}}$$

$$V = 0.2V$$

$$\Delta V = V_2 - V_1 = 0.2 - 0.1 = 0.1V$$

$$r_d = \frac{\Delta V}{\Delta I} = \frac{0.1}{43.8\times10^{-3}} = \frac{500}{219}$$

$$= 2.28\,\Omega$$

4. Determine the Static and Dynamic resistance of a PN junction germanium diode for an applied forward bias 0.2V if the temperature is 300k under reverse saturation current is 1μA.

Given that,

$V = 0.2V$ $\quad\quad \eta = 1$ for germanium

$I_0 = 1\times10^{-6}A$ $\quad\quad V_T = \frac{KT}{q} = \frac{8.62\times300\times10^{-5}}{1.6\times10^{-19}}$

$I = I_0 \cdot e^{V/\eta V_T} - I_0$ $\quad\quad = 26mV$

$$I = 1\times10^{-6}\, e^{\frac{0.2}{26\times10^{-3}}} - 1\times10^{-6}$$

$$= 1\times10^{-6}\left(e^{0.2/26\times10^{-3}} - 1\right)$$

$$= 1\times10^{-6}\left(e^{100/13} - 1\right) = 1\times10^{-6}\left(e^{7.69} - 1\right)$$

$= 1\times10^{-6}(2186.3 - 1)$

$= 2.18\times10^{-3}\,A$

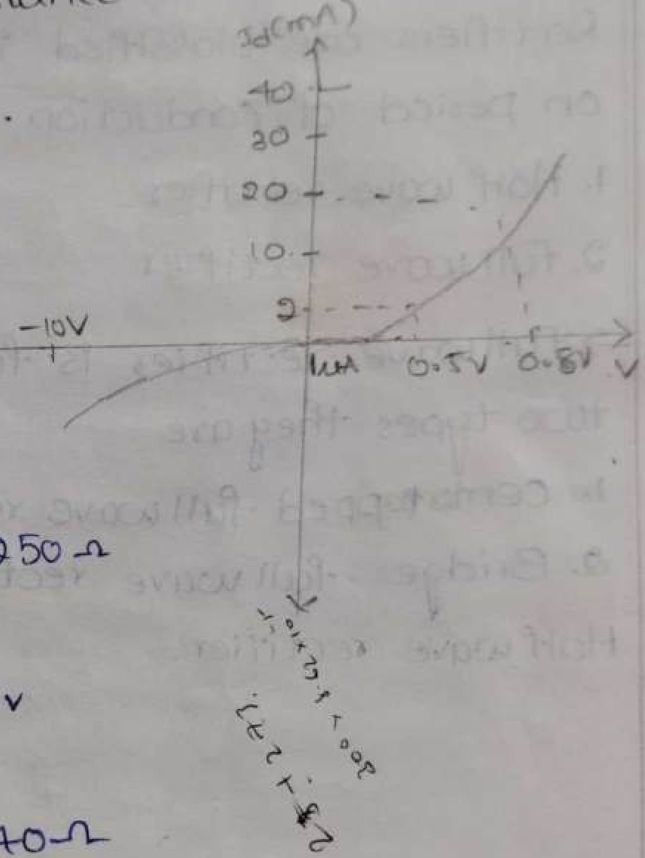
$= 2.18\,mA$

$r_{static} = \frac{V}{I} = \frac{0.2}{2.18\times10^{-3}} = 91.74\,\Omega$

$r_d = \frac{\Delta V}{\Delta I} = \frac{\eta V_T}{I} = \frac{26\times10^{-3}\times1}{2.18\times10^{-3}} = 11.9\,\Omega$

5. Determine the DC resistance levels for the diode at

1. $I_d = 2\,mA$
2. $I_d = 20\,mA$
3. $V_d = -10\,V$



1. $I_d = 2\,mA$

$V_d = 0.5\,V$

$r_d = \frac{V}{I} = \frac{0.5}{2\times10^{-3}} = 250\,\Omega$

2. $I_d = 20\,mA$ $\quad V_d = 0.8\,V$

$r_d = \frac{V}{I} = \frac{0.8}{20\times10^{-3}} = 40\,\Omega$

3. $V_d = -10\,V$ $\quad I_d = 1\times10^{-6}$

$r_d = \frac{V_d}{I_d} = \frac{-10}{1\times10^{-6}} = -10000000$

$= -1\times10^{7}$

$= -10\times10^{6}$

$= -10$ megha ohms