UNIT- I

Semiconductor Devices

* Concept of Electronics :-

→ Electronics may be defined as the science and technology of electronic devices and systems. Electronic devices ~~and~~ are primarily non-linear devices such as diodes and transistors and in general integrated circuits in which small signals (voltages and currents) are applied to them. [The movement of electron is Electronics]

→ The term electronics is derived from the word electrons. Electronics is a branch of physics that deals with theory and use of devices in which the electrons travels through a vaccum, gas or a semi conductor medium.

*→ Father of electronics - Michael Faraday [Motors, transformer, generators]

*→ Father of electronics in India - Prof. Siddeswari Prasad Chakravarthi

*→ Father of Modern electronics - John Ambrose Fleming

→ Father of semiconductors - William bradford shockley

→ First electronic device in India - TIFRAC.
Tata institute of fundamental Research automatic Calculator. was the first computer developed in India at Tata Institute of Fundamental Research in Mumbai. Initially a TIFR.

- The charge of the electron is $e = 1.602 \times 10^{-19}$ coulombs
Mass of the electron is $m = 9.11 \times 10^{-31}$ kg
The radius of electron is $r = 10^{-15}$ m

→ Definition of electronics is the branch of science the deals with the study of flow and control of electronics and the study of behaviour and effects of Vaccums and semi conductor devices.

Applications : Real time applications

1) Mobile phones
2) Television
3) Computers etc.,

Technical applications : 1) Analog circuits
2) Integrated circuits
3) High speed mixed signals systems.

* Basic Electronic Components :-

The basic electronic components that are used for building electronic circuits. without these components circuit designs are never complete or didn't function well. These components have a minimum of two terminals which are used to connect to the circuit. The classification of electronic components can be done based on applications like active, passive and electromechanical.

① Active components
② Passive components

① Active Components :- An active component is an electronic component which supplies energy to a circuit.

Ex :- Voltage sources, Current sources generators, transistors, diodes.

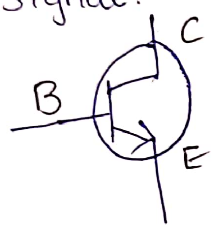
* Voltage source :- When current leaves from the positive terminal of the voltage source, energy is being supplied to the circuit. (it continuously delivers energy to the circuit).

Symbol :-

Voltage Source   Current Source

* Current Sources:- The current supplied to the circuit by an ideal current source is independent of circuit voltage. As a circuit source is controlling the flow of charge in a circuit.

* Transistors :- Transistors are able to amplify the power of signal.



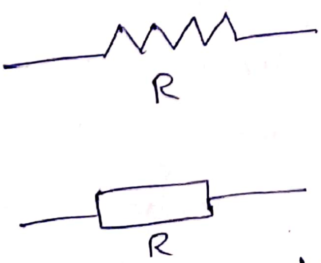
Symbol of transistor

② Passive components :- A passive component is an electronic component which can receive energy, which it can either dissipate, absorb or store it in an electric field or magnetic field.

Ex:- Resistors, Inductors, capacitors, transformers

* Resistors :- Resistor is a passive elements which absorbs the energy. whenever current is passed through it. It is denoted as 'R'.

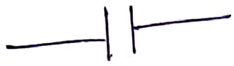
Symbol :-



Units : ohms (Ω) , $k\Omega$, $M\Omega$

* **Capacitor:-** Capacitor is a passive element which stores the energy in the form of electric field. whenever a current is passed through it. It is denoted as 'C'.

units:- f (faradays)
(micro)μf, nf(nano), pf (pico)



C

symbol of capacitor

* **Inductor:-** Inductor is a passive element which stores the energy in the form of magnetic field. It is denoted as 'L'.

units: H, (Henrys)
mH

L

symbol of Inductor

* **Semi conductor devices:-**

- Semi conductor devices are electric components that exploits (exibits) the electronic properties of semi conductor materials. That is silicon, Germenium, Arsenic, Antimony, Boron etc.,
- Semiconductors are two types 1) n-type
  2) p-type

* In n-type semiconductors electrons are the majority carriers and holes are minority carriers.
* In p type semiconductors holes are the majority carriers and electrons are the minority carriers.
* Both electrons and holes are present in any semi-conductors substances. ~~and~~ electrons are flow from -ve to +ve and holes are flow from +ve to -ve.

* classification of solids :-

Based on the energy band structure, the arrangement of electrons and forbidden bands, solid materials are classified into the following

1. conductor
2. Insulator
3. Semi conductor

1. Conductor : conductors are the materials which allow electricity to flow through them.

Ex:- Iron, metals, humans, earth and Animals.

- They conduct electricity because they allow electrons to flow easily inside them from atom to atom.
- Also conductors allow the transmission of heat or light from one source to another.

2. Insulator :- Insulators are the materials in which electric current does not flow freely.

Ex:- plastic, cloth, rubber, wood,

3. Semi conductor :- A substance whose conductivity lies in between insulators and conductors are called semi conductors

Ex:- silicon (Si), Germanium (Ge), tin (Sn), selenium (Se) etc.

* At 0 c of temperature semiconductor can acts as an insulator.

* With increasing of temperature semiconductor can acts as a conductor.

(or)

A material is called a semiconductor if its forbidden band gap is very small ($\approx 1eV$)

* Energy band structure of Insulator :-

- In insulator, the forbidden gap is very large, so that electrons can not move.

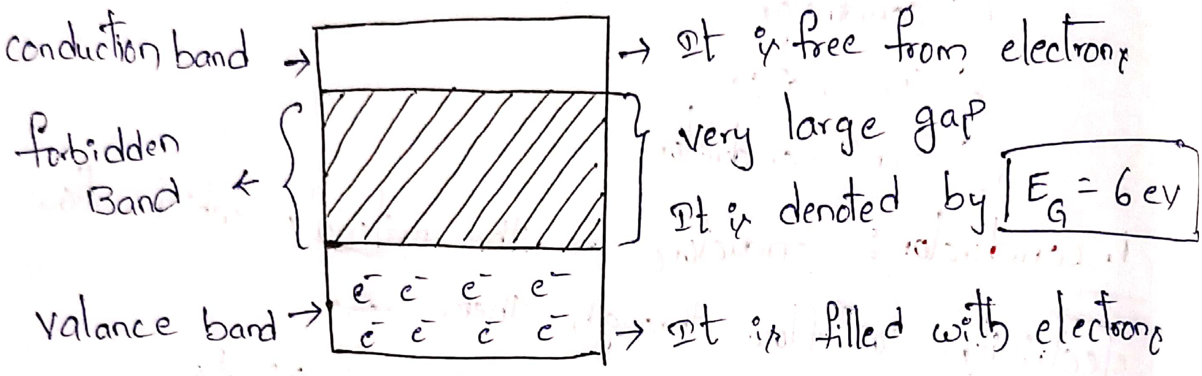


fig:- Energy band structure of a Insulator.

* Energy band structure of a conductor :-

- If the width of the forbidden band in energy band structure is zero, then it is a conductor.

(or)

- The conduction and valence bands overlap then it is a conductor.

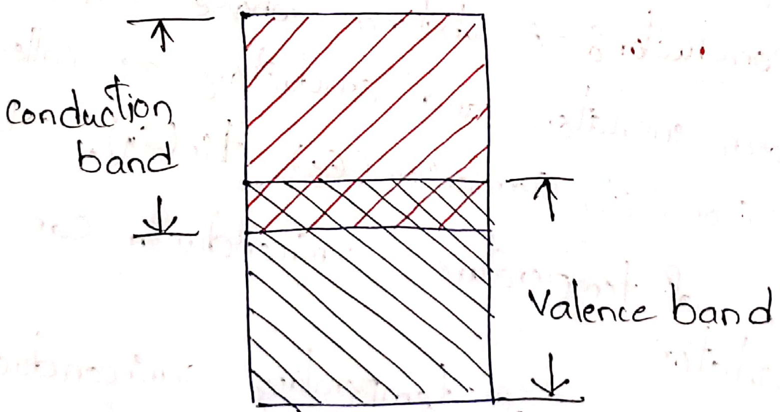


fig:- Energy band structure of a conductor

- Here in energy band structure of a conductor conduction band and valence bands are overlapped, ~~so~~ that electron can move easily from one band to another band.

* Energy band structure of semiconductor :-

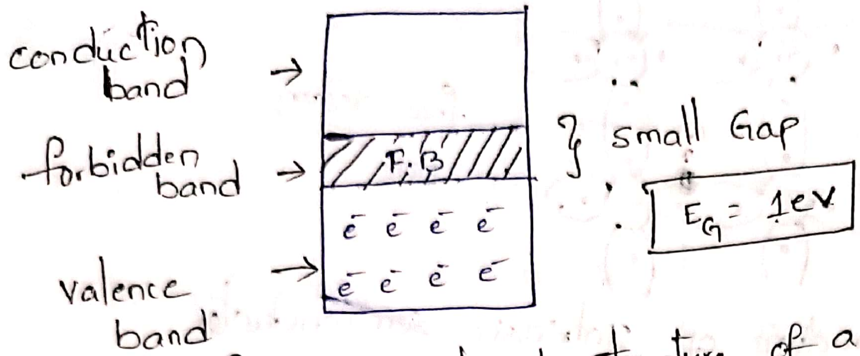


fig:- Energy band structure of a semiconductor

- Now it is very easy to breakup this band (forbidden band) by increasing of temperature or electric field which we are applying to this semiconductor materials.
- Because of this reason semiconductors are more suitable to control the electric current as compared to conductor or insulator.

* Semiconductor Circuit :-

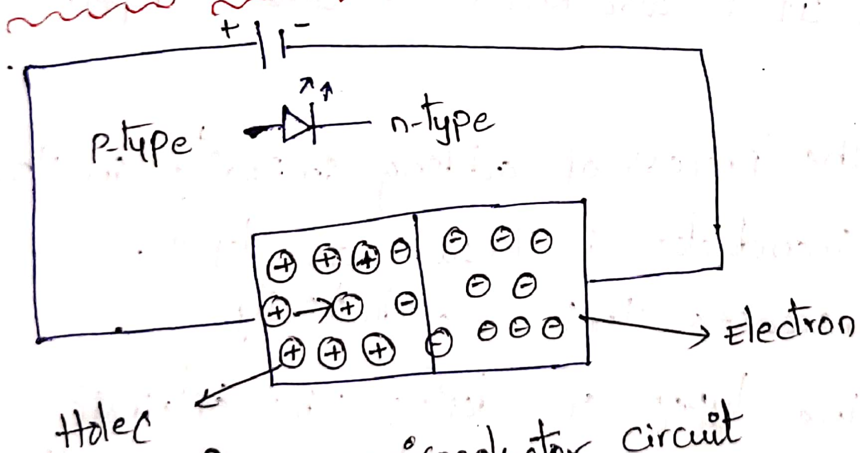


fig:- semiconductor circuit

* Types :-

1. Intrinsic Semiconductor
2. Extrinsic Semiconductor

1. **Intrinsic Semiconductor :-** A pure semiconductor or undoped semiconductor is called Intrinsic semiconductor.

Ex :- Silicon (Si), Germanium (Ge)

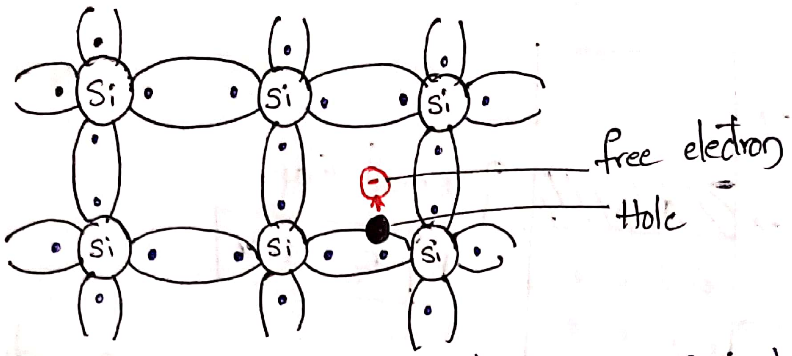


fig:- Structure of Intrinsic semiconductor

- Here the number of charge carriers i.e., holes and electrons are determined by properties of semiconductor material itself instead of the impurity.
- No. of free electrons = no. of holes.

2. Extrinsic Semi conductor :-

When a small amount of chemical impurity is added to an intrinsic semiconductor is known as extrinsic semi conductor. It is also known as ~~adding~~ doped semi conductor.

Doping :- The process of adding impurity in the intrinsic semiconductor is known as doping.

- doping increases their conductivity.
- Based on the types of doping the extrinsic semiconductors are classified into two types, they are

(i) N-type semiconductors (Donor)
(ii) P-Type semiconductors (Acceptor)

→ When a pentavalent ($5\bar{e}$) impurity is added to an intrinsic Semiconductor is termed as N-type Semiconductor. Majority charge carriers are electrons and minority charge carriers are holes.

→ When a trivalent (3e⁻) impurity is added to a pure semiconductor is termed as p-type semiconductor. Majority charges are holes and minority charge carriers are electrons.

Ex:- Pure silicon and Germanium are doped with chemical impurities like Arsenic (As), Phosphorus (P), Bismuth (Bi), Antimony (Sb), In, B, Al etc..
(Indium) (Boron)

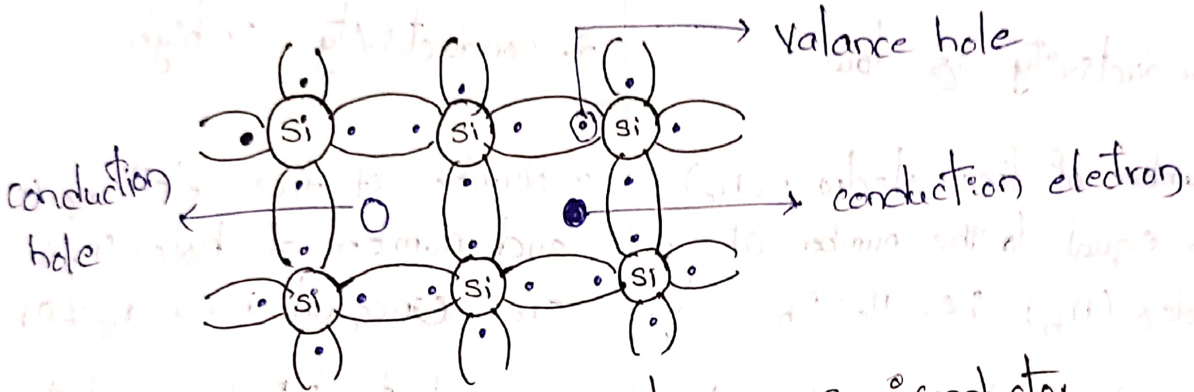


fig: structure of Intrinsic semiconductor

* Properties of semiconductors :-

1. Conductivity lies between that of conductors and insulators.
2. Concentration of free electron (n) lies between that of conductors and insulators.
3. Pure semiconductor behaves like insulator at low temperature.
4. Its conductivity increases with increase in temperature.
5. There are 4 electrons in the outer orbit.

* Applications of semiconductor :-

- Semiconductors are used in
  i) diodes
  ii) Bipolar Junction-transistor construction,
  (iii) JFETS, MOSFETS, UJTs and SCRs.

* Difference between Intrinsic and Extrinsic Semiconductor:

Intrinsic Semiconductor	Extrinsic Semiconductor
1. Pure form of semiconductor is Intrinsic semiconductor (without doping)	1. Impure form of semiconductor is extrinsic semiconductor. (Doping with impurities of chemical)
2. conductivity is low	2. conductivity is high.
3. Number of free electrons (n_e) is equal to the number of holes (n_h) i.e., $n_e = n_h$	3. Number of free electrons (n_e) and number of holes (n_h) are unequal. i.e., $n_e \neq n_h$
4. conductivity depends only on temperature	4. conductivity depends both on temperature and impurity added.
5. Conductivity due to electrons and holes is nearly equal.	5. conductivity is mainly due to majority charge carriers.
6. It does not conduct at zero kelvin.	6. It conducts at zero kelvin.

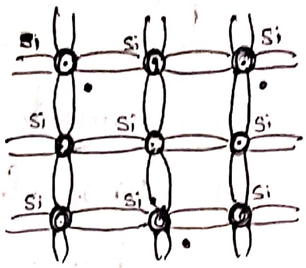
* Doped semiconductors:-

Doping process:-

- Doping is mixing semiconductor with a choiced impurity in a measured quantity.
- Doping is categorized into two types
  1. P-type doping
  2. N-type doping

→ for doping we take an atom of a different material which will replace any atom.

→ The atom should be choosen the neighbourhood of the silicon either one of neighbouring groups. So that there is not much of difference in the size.



→ If there is a difference in the size very large one (or) very small one then symmetry of this lattice will be disturbed and that will make disturbed in motion of an electrons. so we want from the neighbouring side.

→ silicon is having 4 electrons; So we choose an impurity which is either having 3 electrons metal side or 5 electrons non-metal side. (so silicon and Germanium are)

→ when we take 3 electrons type 1 electron is less than that makes p-type dope, because it will be in search of electron and it will behave like a positive material.

→ When we have 5 electron doping that will have 1 extra electron and that will be negative charge i.e., N-type doping.

$$\boxed{\text{doping} \propto \frac{1}{\text{depletion layer}}}$$

Ex:- Aluminium - 3 electrons - p-type
phosphorous - 5 electrons - n-type

→ So, both are neighbours to this 4 electron silicon (Si).

⇒ What is the charge on the doping atom?

The charge on aluminium = zero (0)
phosphorous = zero (0)

∴ charge on any atom = zero (0)

* for flow of electric current we need number of charge Carriers

$$\boxed{I = n.e.A.V_d}$$

where I = Current flowing through the conductor
n = No. of free electrons (or) Density of charge carrier
e = charge on the electrons
A = Area of cross - section.
V_d = Drift - velocity

In Intrinsic $n_e = n_h$
(no. of electrons) (no. of holes)

When we added phosphorous atoms electrons are added.

So $n_e \neq n_h$
(majority $\bar{e}$ no. of $\bar{e}$ increase) (no. of holes decrease) but it will not be zero

Initially in intrinsic we know
$n_e = n_h = n_i$ (no. of intrinsic charge carriers)

if we multiply n_e & n_h
$n_e \times n_h = n_i^2$ (constant; if it converts from I.S.C to E.S.C).

now we are increasing $n_{e_2} \times n_{h_2} = n_i^2$

Suppose initially both $n_e \times n_h = 10{,}000$

$n_{e_2} = 10{,}000$, $n_{h_2} = 10{,}000$ & $n_i^2 = 100000000$

$n_{e_2} = 10^4$ $\quad n_{h_2} = 10^4$ $\quad n_i^2 = 10^8$

$\therefore 10^4 \times 10^4 = 10^8$

Now we have added 30,000 phosphorous

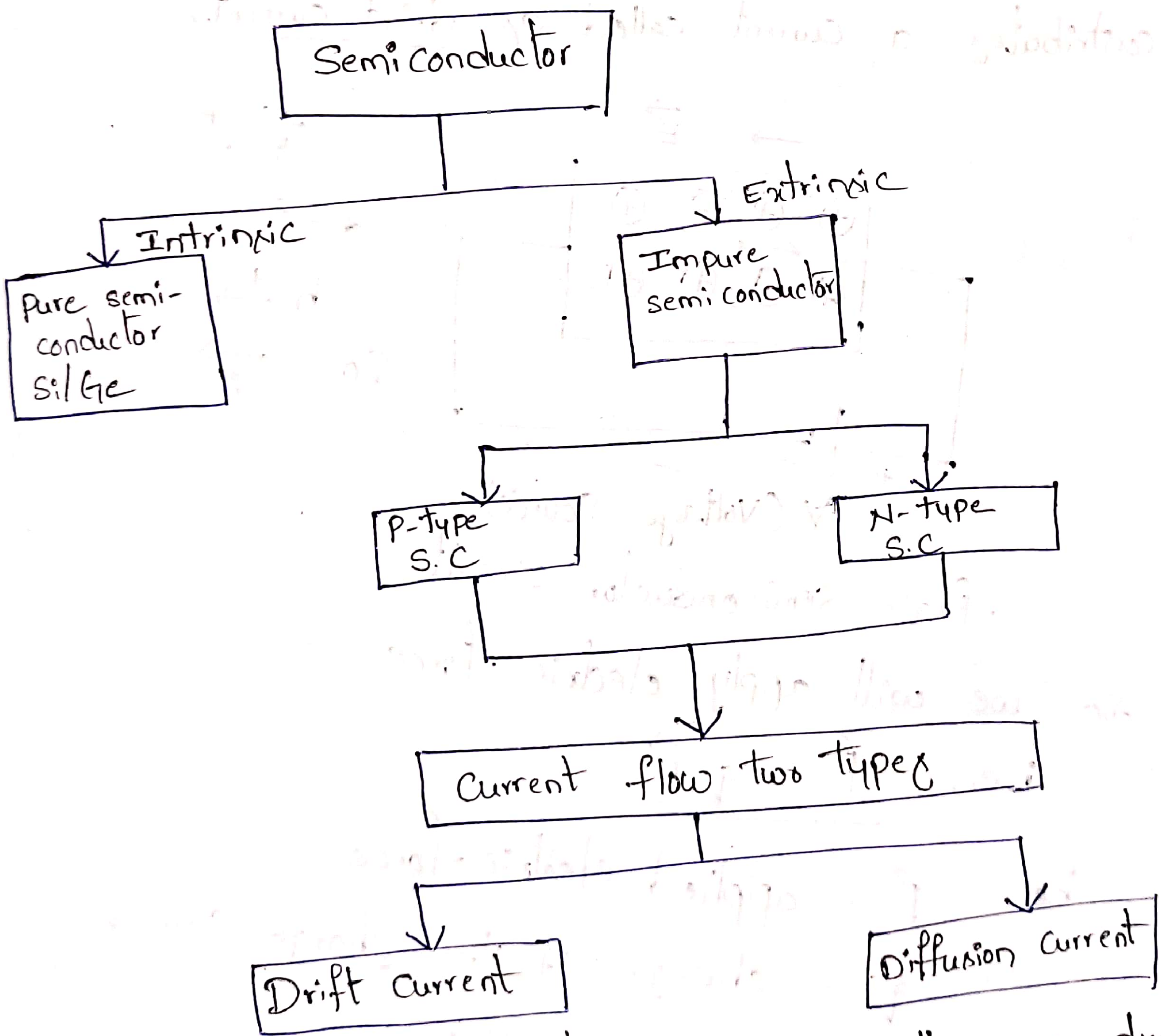
So, $40000 \times n_h = 10^8$

$$n_h = \frac{10^8}{4\times10^4} = \frac{10^4}{4} = \frac{10000}{4} = 2500$$ (this will not be zero)

∴ So, the no. of phosphorous particles can be added in any amount we needed to control the conduction (or) conductivity of this semiconductor.

* Current flow in semiconductors :-

Flow of current in P and N type semiconductors



[This will cause due to external electric field]

Due to majority charge carriers

[This will cause due concentration gradient]

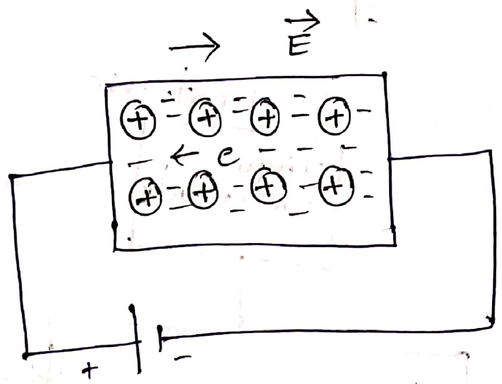
* Drift Current :-

Drift Current can be defined as the flow of electric current due to motion of charge carriers on applying external electric field.

$$\boxed{\text{Drift velocity } (V_d) = \mu E}$$

where μ = mobility of charge carriers
E = Electric field applied at the semiconductor

→ The combined movement of charge carriers (e^- & h) contributes a current called as drift current.



$\vec{E} \xrightarrow{+}$

$\leftarrow e^-$

$h \xrightarrow{+}$

So $\xrightarrow[i]{}$

V (Voltage Source)

fig:- Semiconductor Circuit

So we will apply electric force

i.e., $\vec{F} = q.\vec{E}$

here $\vec{F}$ = applied electric force
q = charge of the charge carrier
$\vec{E}$ = Electric field

→ Electrons will move opposite to the direction of electric field, and holes are moving in same direction of electric field.

- Current in a semiconductor is given by

$$\boxed{I = n.e.A.V_d}$$

where I = Current in a semiconductor
n = density of charge carriers
e = charge on the charge carriers
A = Cross sectional area of the material
V_d = drift velocity

If I divide current in a semiconductor with cross sectional area of the material.

then $\frac{I}{A} = n.e.V_d$ $\quad (\because \frac{I}{A} = J)$

where J = Current density for $\bar{e}$ & h

$$\boxed{J = n.e.\mu E} \quad (\because V_d = \mu E)$$

So, if I want to calculate the current density for both $\bar{e}$ & holes separately.

for $\boxed{\bar{e} = J_n = n.q.\mu_n E \quad A/cm^2}$

for holes $\boxed{J_p = p q \mu_p E \quad A/cm^2}$

$\therefore$ The Combined current density in the semiconductor

$$\boxed{J = nq\mu_n E + pq\mu_p E}$$

Take out common terms $\quad (q = 1.6 \times 10^{-19})$

$$\boxed{J = (n\mu_n + p\mu_p) qE}$$

conductivity σ

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

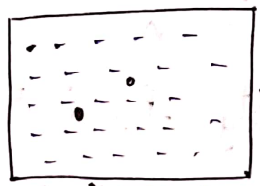
other expression $J = \sigma E$

$J = (n\mu_n + p\mu_p) q.E \quad A/cm^2$

* Diffusion Current :-

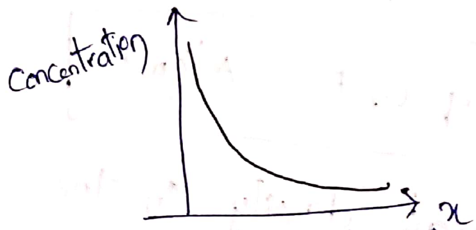
Diffusion current is defined as the movement of charge carriers of same type takes place from a region of higher concentration to lower concentration. Resulting current due to this movement of charge is called as "diffusion current".

- If no. of e^- or holes are greater in one region of a semiconductor in comparision to rest of the region, then we say that concentration gradient exists in the material.


← N-type (holes are ~~maximum~~ minimum)

fig(a).

- In n-type semiconductor minority charge carriers are holes.
- Number of holes are decreasing as I am going towards other region.
- So, there is a concentration difference in the holes, in one region it is higher and other region it is lower.



fig(b) → distance

- The holes have tendency to move towards lower concentration from higher concentration and this will cause the diffusion current to flow.

Diffusion current density due to e^-

$$\boxed{J_n = qD_n \cdot \frac{dn}{dx} \quad A/cm^2}$$

Diffusion current density due to holes

$$\boxed{J_p = -q \cdot D_p \cdot \frac{dp}{dx} \quad A/cm^2}$$

Here $\frac{dn}{dx}$ & $\frac{dp}{dx}$ are concentration gradients (slope) for $\bar{e}s$ and holes respectively.

dn & dp are concentration of charge carriers ($\bar{e}$ & holes)

dx is the direction distance

D_n & D_p are the diffusion constants for $\bar{e}$ & holes.

So, total current present in the semiconductor is equal to sum of drift and diffusion current

$$\boxed{\text{Total current in a semiconductor} = \text{Drift current} + \text{Diffusion current}}$$

for N-type semiconductor total current is

$$\boxed{J_n = q \cdot n \cdot \mu_n \cdot E + q \cdot D_n \frac{dn}{dx}}$$

$||^{ly}$

for P-type semiconductor total current is

$$\boxed{J_p = q \cdot p \cdot \mu_p \, E + q \cdot D_p \cdot \frac{dp}{dx}}$$

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* Resistor colour code :-

- The resistance value and tolerance of carbon resistor is usually indicated by colour coding.
- colour strip or bands are printed on the insulating body. They consists of 4 colour bands and they are read from left to right.
- 1st band represents first digit
  2nd band represents second digit
  3rd band represents Multiplier (no. of zeros)
  4th band represents tolerance in percentage

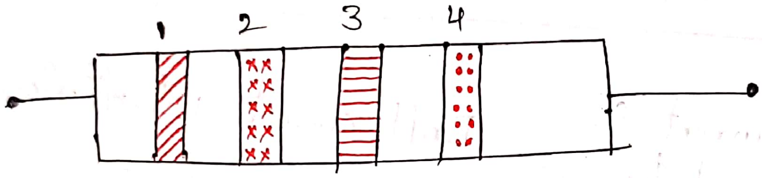

fig:- colour coded resistor

The colour codes are presented in table

Colour	1st digit for 1 band	2nd digit for 2nd band	Multiple digit for 3rd band	Resistance tolarence
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	±2%
Orange	3	3	10^3	±3%
Yellow	4	4	10^4	±4%
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
white	9	9	10^9	
Gold	–	–	10^{-1}	±5%
Silver	–	–	10^{-2}	±10%
[illegible] band	–	–	–	[illegible]

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* Basic difference between the Electronics and Electrical.

Electrical	Electronics
→ Generating of Power in different ways by using electrical equipment with different resources.	→ The controlling mechanism of flow of electrical power (or) flow of current is taking care by the electronics.
→ Electrical deals with the flow of electrical power or charge.	→ Electronics deals with the flow of electrons
→ If there is the involvement of just electricity as energy, then that is called electrical.	→ If there is clear cut manipulation of electrical energy, then that is called electronics.

*Vaccum Tubes to Nano Electronics :-

* Vaccum Tubes :- Vaccum tube also called as Electronic Tube. Device usually consisting of a sealed glass or metal - ceramic enclosure that is used in electronic circuitry to control a flow of electrons.

Common applications of vaccum tubes :

i) amplification of a weak current

ii) Rectification of an alternating current (AC) to direct current (DC).

iii) Generation of oscillating radio frequency (RF) power for radio and radar.

iv) creation of images on a television screen or computer monitor

→ Common types of vaccum tubes include magnetrons, klystrons, gyrotrons, cathode ray tubes, photoelectric cells, fluorescent lamps.

- In 1950s vaccum tubes, were used in virtually every kind of electronic devices like computers, radios, transmitters, components of high fidelity sound systems.

Vaccum Tubes → Transistors → Integrated Circuits

fig:- Main Components in the history of electronics

Vaccum Tube :- A device controlling electric current throught a vaccum in a sealed container. It is used as amplifier, display screen (CRT) and also as on/off switch.

- The diode is the simplest vaccum tube.
- Limitations :- Power consumed even if it is not used and the filament burn out.
- Tubes with 3 electrons are called triodes and 4 electrons are known as tetrode.

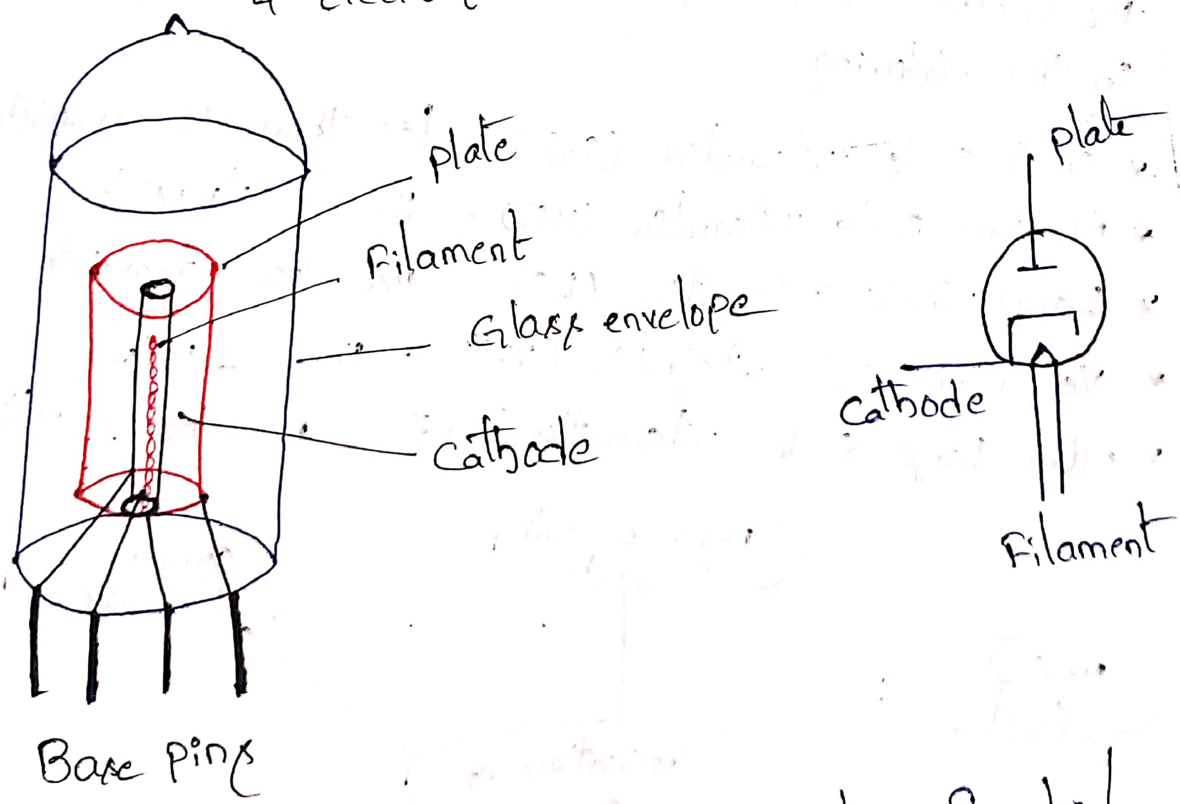


fig:- Vaccum Tube and Symbol

(1948) Transistors:- Transistor is a 3terminal device, that regulates current or voltage flow and acts as a switch or gate for signals.

- Amplication performed when signal strength has be improve.

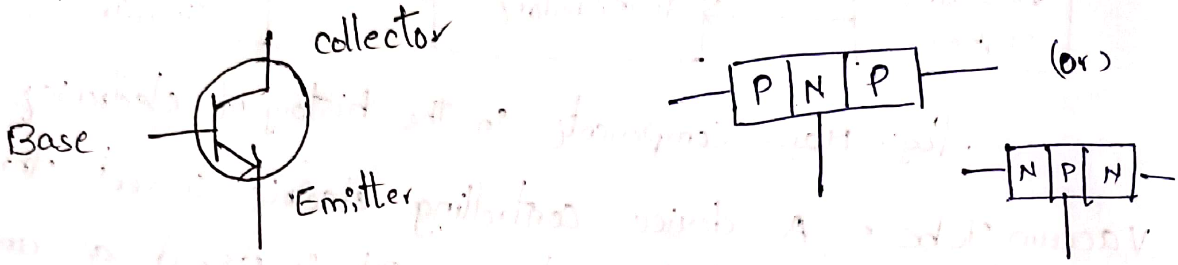
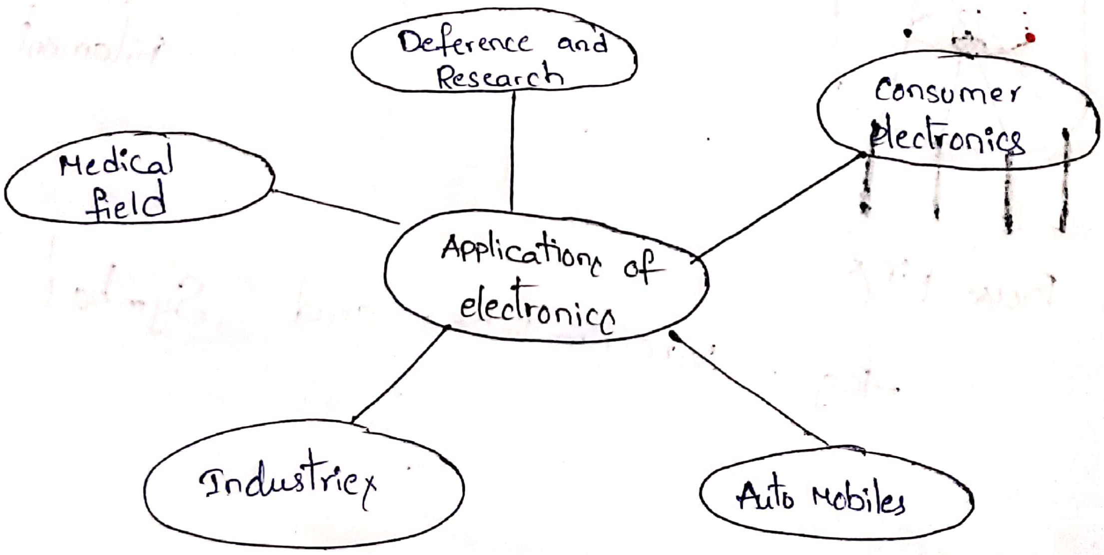


fig: symbol of transistor

Integrated circuits:- (1958)

- A unique components that is built with thousands of other electronic components transistors, resistors, diodes and on a tiny Silicon chip is known as Integrated circuit (IC).
- The IC's with enlarged capabilities of numerous thousands components on a single chip were introduced in the following.

* Small scale Integration (SSI) - less than 100 transistors
* Medium scale Integration (MSI) - 100-1000 transistors
* Large Scale Integration (LSI) - 1000-10000 transistors
* Very Large scale Integration (VLSI) - 10,000 - 1 Million
* Ultra Large Scale Integration (ULSI) - More than 1 Million.



* Diodes :-

A diode is a two-terminal electronic component that conducts current primarily in one direction. It has low resistance in one direction, and high resistance in the other.

(or)

A diode is a semiconductor device that essentially acts as one-way switch for current. It allows current to flow easily in one-direction, but severely restricts current from flowing in the opposite direction.

- Diodes are used to protect circuits by limiting the voltage and also transform AC to DC.
- semiconductors like silicon and germanium are used to make the most of the diodes.

fig:- symbol of diode

→ When the anode voltage is more positive than the cathode voltage, the diode is said to be forward biased, and it conducts low-voltage drop.

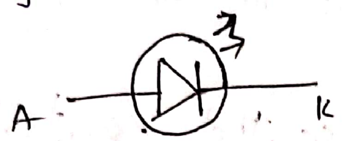
→ when the cathode voltage is more positive than the anode, the diode is said to be reverse biased.

* Types of diodes :- The types of diodes are

1. Light Emitting diode (LED)
2. Laser diode
3. Avalanche diode
4. zener diode
5. schottky diode
6. photo diode
7. PN junction diode

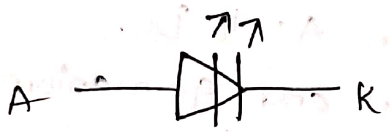
1. Light Emitting Diode (LED) :-

Light is generated when a sufficient amount of forwarding current passes through it.



(a) symbol of LED

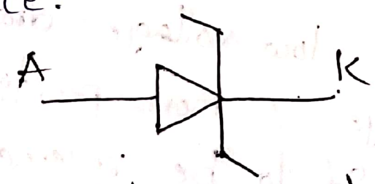
2. Laser Diode :- It produces coherent light, used in CD drives, DVDs etc.,



(b) symbol of laser diode

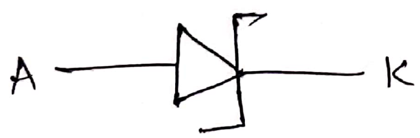
3. Avalanche diode :- This diode belongs to a reverse bias type and operates using the avalanche effect. When voltage drop is constant and is independent of current, the break down of avalanche takes place.

(used in photo detection)



c) symbol of avalanche diode

4. Zener diode :- It is the most useful diode as it can provide a stable reference voltage. These are operated in reverse bias and break down on the arrival of a certain voltage.



Use: Power supplies to provide reference voltage.

d) symbol of zener diode

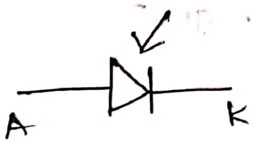
5. Schottky diode :- It has a lower forward voltage than other silicon PN junction diodes. The drop will be seen where there is low current and at that stage, voltage ranges between 0.15 & 0.4V.

Use :- Highly used in rectifier applications.

(e) symbol of schottky diode

6. photo diode :- A photo diode can identify even a small amount of current flow resulting from the light. These are very helpful in the detection of light.

Use :- solar cells, photometers



(f) symbol of photo diode

7. PN junction Diode :-

- The P-N Junction diode is also known as rectifier diodes. These diodes are used for the rectification process and are made up of semiconductor material, two layers are p-type and N-Type.
- It allows the current flow in the forward direction and blocks in the reverse direction.

* Diode Applications :- Diode are used as a

- Rectifier
- clipping circuit
- clamping circuit
- Logical gates
- Reverse current protection.

* What is ideal diode.

- An ideal diode is a diode that acts like a perfect conductor when voltage is applied forward biased.
- And like a perfect insulator when voltage is applied reverse biased.

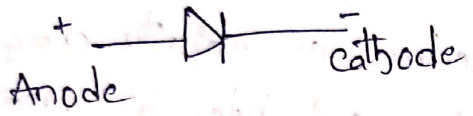
* Difference between p-type and n-type semiconductor.

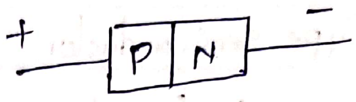
P-Type Semiconductor	N-type Semiconductor
1. Holes are majority charge carriers and electrons are minority charge carriers.	1. Electrons are majority charge carriers and holes are minority charge carriers.
2. The majority of charge carriers move from high potential to low potential.	2. The Majority of charge carriers move from low potential to high potential.
3. An acceptor is a contaminating atom that could produce a p-type semiconductor whenever introduced to a semiconductor	3. An donor is a doping atom that can produce an n-type semiconductor whenever introduced to a semiconductor.
4. Trivalent impurities are added.	4. pentavalent impurities are added.
5. It has acceptor energy levels that are very close to the valence band.	5. It has donor energy levels that are very close to the conduction band.

* PN Junction Diode :-

Definition:- Two types of materials namely n-type and p-type semiconductors are chemically combined with a special fabrication technique then PN Junction diode is formed.

Symbol:





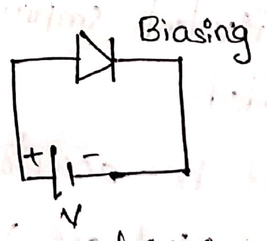
- It allows current in a only one direction.
- It high resistance in one end, low resistance in other end.

* - Diode operated at voltage (or) Barrier voltage is
  0.7 V for silicon
  0.3 V for Germanium.

- The basic characteristics of diodes are V_F, I_F, V_R & I_R

Biasing: To apply voltage to the circuit is called biasing.

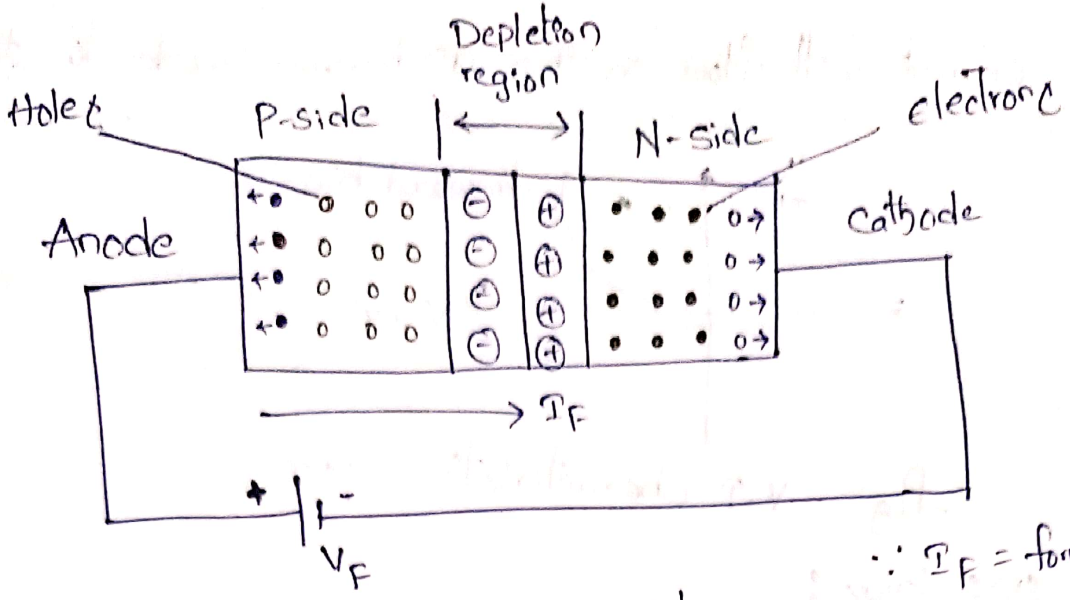
- Diode has two types of biasing
  1. Forward bias
  2. Reverse bias



(a) biasing ckt

1. Forward bias:

- When a positive terminal of an external voltage source is connected to p-side of a diode and a negative terminal of an external voltage source is connected to N-side of the diode then the condition is known as forward bias condition of PN junction diode.



$\therefore I_F$ = forward current
V_F = forward voltage

fig:- Forward biased condition

→ Under this forward bias condition the holes from P-side are repelled from the positive terminal and they are driven towards the junction.

→ And electrons are repelled by the negative terminal and they are driven towards the junction.

→ Due to this the depletion region will become narrow and that will reduce barrier potential.

[immobile - Not moving, non-movable
repelled - force]

depletion Region :-

- Depletion region or depletion layer is a region in a P-N junction diode where immobile charge carriers are present.
- Depletion layer (or) region acts like a barrier that opposes the flow of electrons from n-side and holes from P-side.

→ When the applied voltage is gradually increased the barrier potential will become very less, and the depletion region will disappear.

→ Then the electrons from N-side are attracted towards P-side, and the holes from P-side are attracted towards N-side.

→ The current will flow in the diode from anode to cathode.

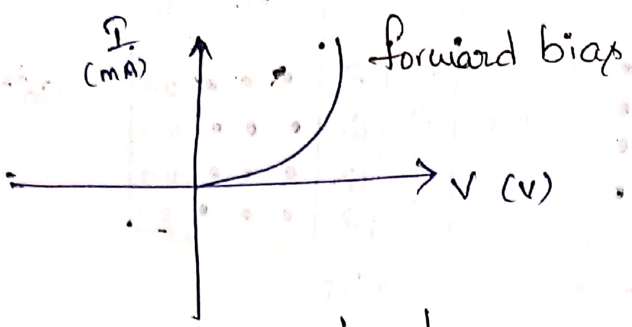


fig: V-I characteristics curve.

2. Reverse Bias :-

- In reverse biased condition the negative terminal of an external voltage source is connected to P-side and the positive terminal of an external voltage source is connected to N-side of the diode then this condition is known as reverse bias condition of PN junction diode.

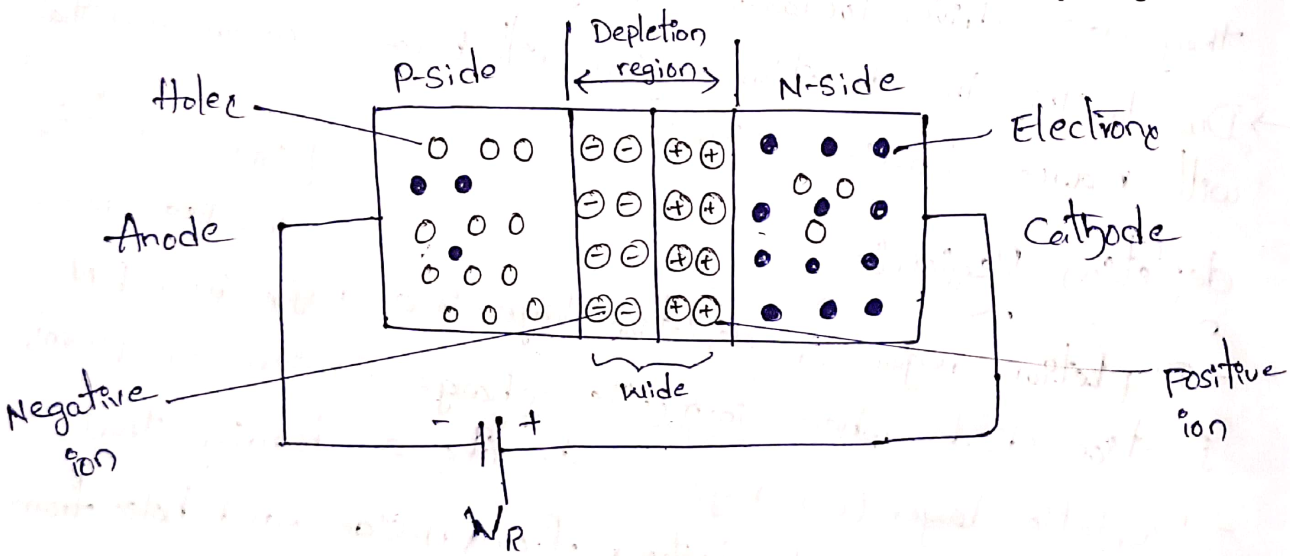


fig: Reverse biased condition

- Under this condition electrons from N-side are attracted towards the positive terminal of an external voltage source and the holes from P-side are attracted towards the negative terminal of an external voltage source.

→ Due to this the width of the depletion region increases and the barrier potential inside the depletion region will also increases.

→ Hence there will be no current flow when the diode is connected in reverse bias condition.

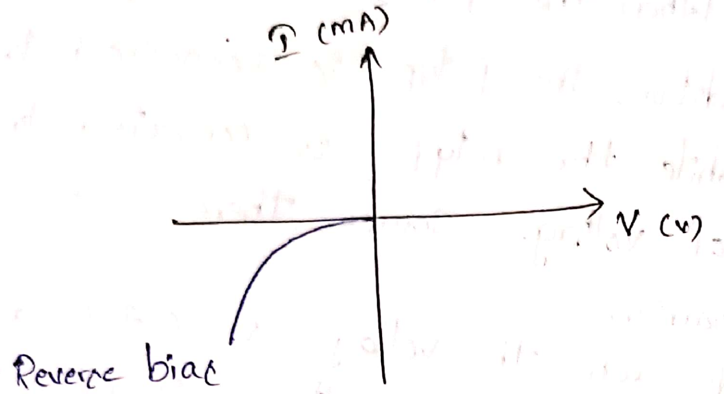


fig:- Reverse biased - VI characteristics

* VI - characteristics of P-N junction diode :-

- VI characteristics of P-N junction diode is a curve between the voltage and current through the circuit. voltage is taken along the X-axis while the current is taken along the Y-axis. The below graph is the V-I characteristics curve of the P-N junction diode. With the help of the curve we can understand that there are three regions in the diode works and they are.

① zero bias (or) No bias
② Forward bias
③ Reverse bias

∵ Si - 0.7
∵ Ge - 0.3

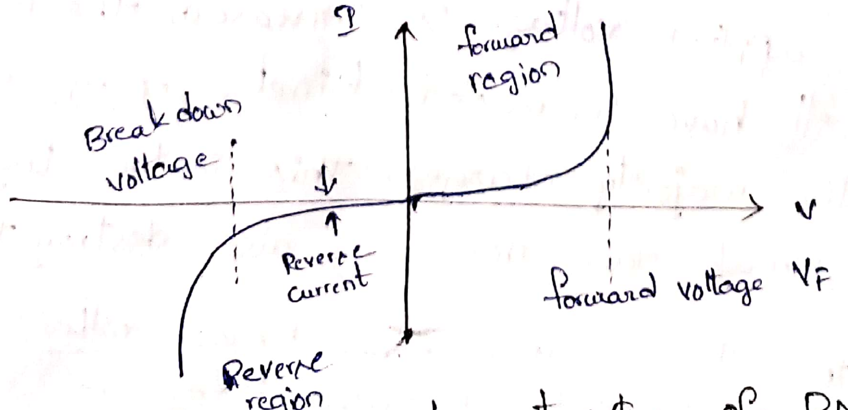


fig: VI - characteristics of PN Diode

① zero bias :- When the P-N junction diode is in 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.

② Forward bias :- When the P-N junction diode is in forward bias condition, the p-type is connected to the Positive terminal while the n-type is connected to the negative terminal of voltage source. there is a reduction in the potential barrier.

- For silicone diodes when the voltage is 0.7V and for Germanium diodes when the voltage is 0.3V the potential barrier decreases, and there is a flow of current.
- Once the diode overcomes the potential barrier the diode behaves normally and the curve rises sharply as the external voltage increases and the curve obtain is linear.

③ Reverse bias :- When the P-N junction diode is in reverse bias condition, the p-type is connected to the negative terminal while the n-type is connected to the Positive terminal of the external voltage. This results in an increase in the potential barrier.

- 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.

NOTE :- V_{th} := The minimum forward bias voltage required for a diode to conduct on ON

* Zener Diode :-

- A zener diode is a semiconductor device that permits current to flow in either a forward or reverse direction.
- The zener diode consists of a special, heavily doped P-N junction, design to conduct in the reverse direction when a certain specified voltage is reached.

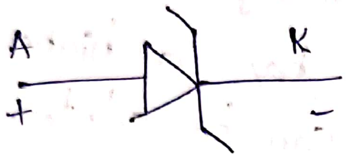


fig:- Symbol of zener diode

- A zener diode can conduct in both directions.
- A zener diode is very useful for creating voltage references, shunt voltage regulators, and over-voltage protection circuits.

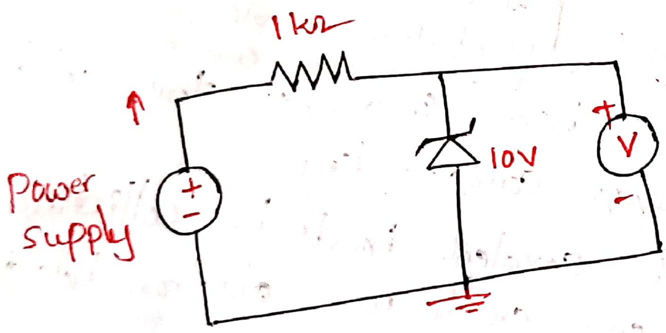


fig: zener diode in a circuit operation

- If we change the supply voltage (Increase), then due to the reverse breakdown voltage of zener diode gives us the same voltage.

⇒ Zener diode characteristics :-

- When the reverse voltage reaches breakdown voltage in normal PN Junction diode, the current through the junction will be high. So diode can get damaged.
- But zener diode is designed with adequate power dissipation capability to operate in the breakdown region.

- The operation of the zener diode is same as PN diode under forward biased condition.
- Where as under reverse biased condition, breakdown of the junction occurs. The breakdown voltage depends upon the amount of doping.
- If the diode is heavily doped, depletion layer will be thin and consequently, breakdown occur at lower reverse voltage, the breakdown voltage is sharp.
- Where as alightly doped diode has a higher breakdown voltage. Thus breakdown voltage can be selected with the amount of doping.
- Increasing current under breakdown conditions are due to the following two mechanisms
  1. Avalanche breakdown
  2. zener breakdown

1. Avalanche breakdown : [it occurs because of the ionisation of electron and hole pair where as the zener breakdown occurs because of heavy doping)

- As the applied reverse bias increases, the field across the junction increases corresponding.
- * These electrons disrupt covalent bonds by colliding with immobile ions and create new electron-hole pairs. These mechanism of carrier generation is avalanche multiplication. This results large amount of current flow in reverse bias.

2. Zener breakdown :

- when the P and N regions are heavily doped, direct rupture ([illegible]) of covalent bonds takes place because of the strong electric field, at the junction.

- The increase in current takes place at constant value of reverse bias typically below 6V for heavily doped diodes.
- The depletion region width becomes very small.
- When the applied voltage reaches constant voltage then zener breakdown occurs.
- Zener breakdown occurs for lower breakdown voltage and avalanche breakdown occurs for higher breakdown voltage.

* Two characteristics of zener diode are
  1. Forward characteristics
  2. Reverse characteristics

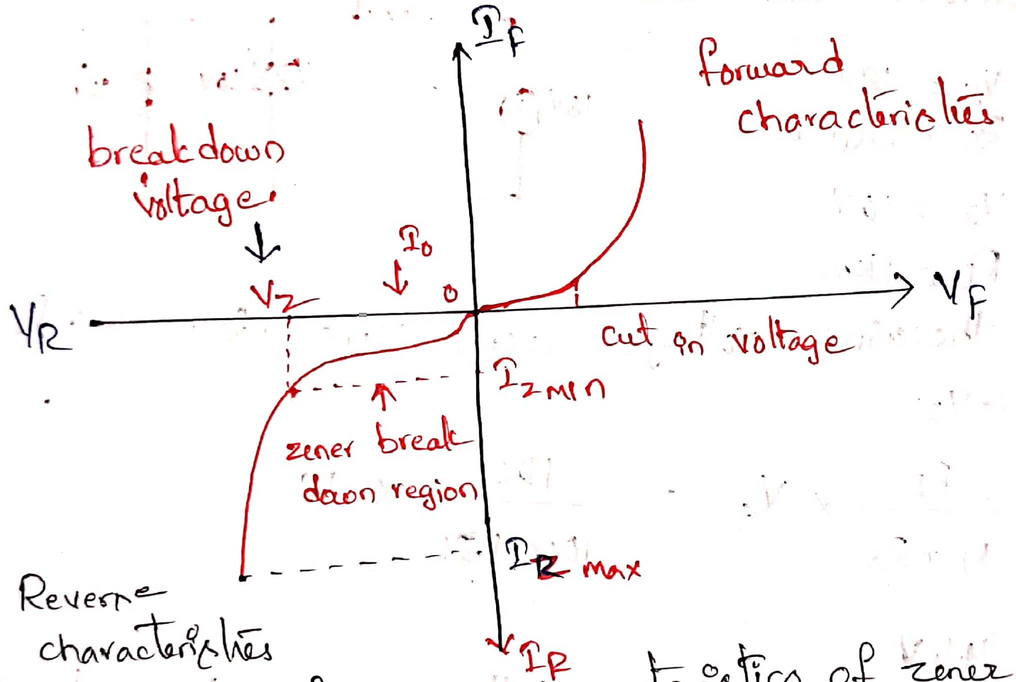


fig: VI characteristics of zener diode

NOTE: (Not in syllabus)

* $V_{th} = \frac{R_L}{R_L + R_S} \times V_S$

$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L}$

$I_S = \frac{V_S - V_Z}{R_S}$

$I_S = I_Z + I_L$

$\boxed{I_Z = I_S - I_L}$

$\boxed{P_Z = V_Z + I_Z}$

Exam

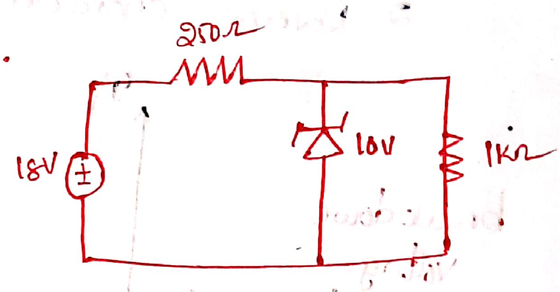
Applications :-

1. It is used in switching operation.
2. It is used in clipping & clamping ckts.
3. It is used in voltage stabilizers (or) voltage regulators.

Advantages:-

1. Power dissipation capacity is very high
2. High accuracy, small size, low cost.

① **Example :-** Find the zener current and power dissipated across zener diode.



Sol:- Given $V_S = 18V$

$R_S = 250\Omega$

$V_Z = 10V$

$R_L = 1k\Omega$

Calculate thevenins voltage across the diode and R_L

i.e., $V_{th} > V_Z$

$$V_{th} = \frac{R_L}{R_L + R_S} \times V_S = \frac{1000}{1000+250} \times 18$$

$$V_{th} = 14.4V$$

Hence $V_{th} > V_Z$, so diode will operate in breakdown voltage

$$I_L = \frac{V_Z}{R_L} = \frac{10V}{1k} = 10mA$$

$$I_S = \frac{V_S - V_Z}{R_S} = \frac{18 - 10V}{250} = 32mA$$

$$I_Z = I_S - I_L$$

$$= 32 - 10 = 22mA$$

$$P_Z = I_Z \times V_Z$$

$$= 22 \times 10^{-3} \times 10 = \underline{220 mV}$$

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