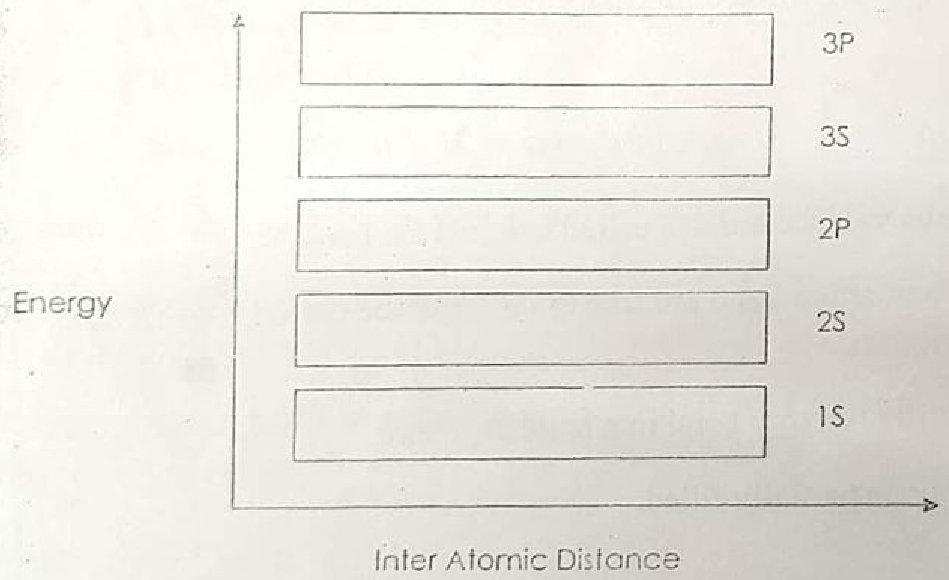
SEMICONDUCTOR PHYSICS

Q. Explain band theory of solids?

1. A single isolated atom has discrete energy level.
2. Solids contain large number of atoms which are very close to each other.
3. These atoms are interacting with each other because of which the energy levels of outer shell are most affected.
4. Hence a single energy level contains large no. of electrons.
5. But according to PAULI'S Exclusive principle, not more than two interacting electrons can have the same energy level.
6. Therefore single energy level splits into many energy levels.
7. Such a group of energy levels splitted from a single energy level and having a small energy difference is called as band.



PHY
semiconductor
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superconductivity
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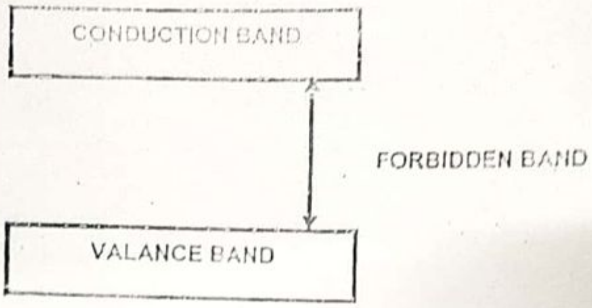
Q. Explain various bands.

In band structure of a solid there are three important bands



1. Valence band

   a) Valence band are formed by splitting up of valence orbital.

   b) It contains valence electrons which are in bound condition.

   c) It is highest occupied energy band in a band structure.

   d) It may be completely filled or partially filled.

2. Conduction band

   a) Any band above valence band is called conduction band.

   b) Electrons in conduction band are free to move hence called free electron or conduction electron.

   c) It is lowest unfilled energy band in a band structure.

   d) It may be empty or partially filled.

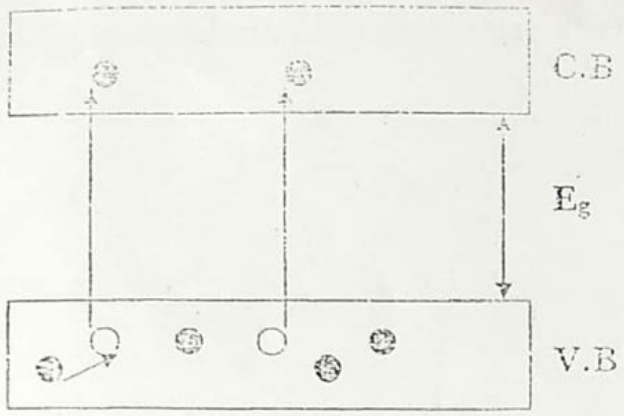
3. Forbidden band

   a) The energy gap between valence band and conduction band is called as forbidden band or forbidden gap

   b) The energy of this band is Eg.

   c) It is amount of energy required to move an electron from valance band to conduction band.

Explain the concept of free electron and hole.



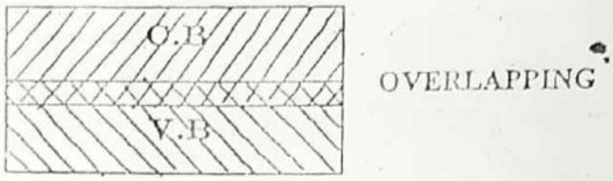
1. Initially the valence band is completely filled with valence electron and conduction band completely empty.
2. When valence electron acquires energy greater than Eg, Then they jump into C.B.
3. These electrons in C.B. are free electrons and are responsible for the conductivity property..
4. Absence of electron in V.B. is called as hole.
5. Hence hole is considered as a positive charge carrier.
6. Electrons from neighboring co-valent bond fill this vacancy (hole) and vacancy shift there.
7. Hence holes move in opposite direction to that of electron in V.B.

Q. Classify solids on basis of band theory.

On the basis of band theory materials are classified into three categories:

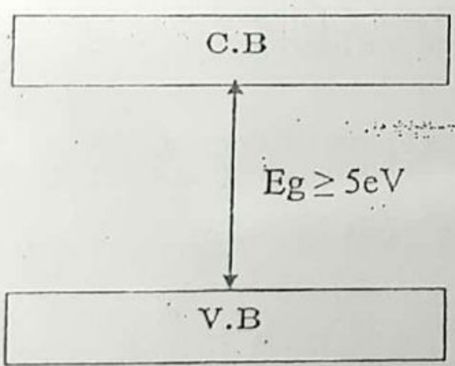
1. Conductors
2. Insulators
3. Semiconductors

1. CONDUCTORS:



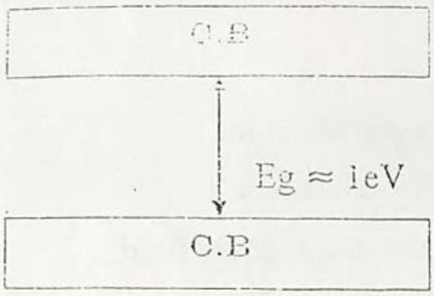
1. Conductor is a solid in which conduction and valence band overlap and there is no energy gap between the two bands.
2. All the electrons present in the bands act as free electrons.
3. The concept of holes does not arise in conductors.
4. No forbidden gap.

2. INSULATORS:



1. They have a full valence band.
2. In these materials the valence electrons are bound very tightly to their parent atom.
3. Empty conduction band.
4. Band gap is very high.
5. Shows small conductivity at high temperature.
6. Eg. Diamond

SEMICONDUCTORS:



1. At absolute temperature conduction band is totally empty and valance band is completely filled. Hence they behave as a perfect insulator.
2. Eg is small
3. At room temperature electrons form V.B moves into C.B, hence they show a small conductivity.
4. Eg. germanium

Q. Write a note on temperature dependence of conductivity.

Conductivity of a material is given by

$$\sigma = n e \mu$$

Hence we can say that conductivity is directly proportional to

1. Charge density (n) i.e Concentration of charge carriers.
2. Mobility (μ) i.e the average drift velocity per unit electric field.

CONDUCTORS

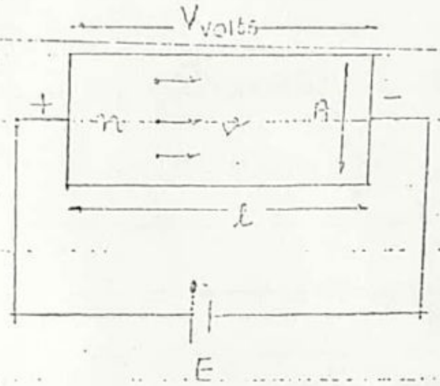
1. With increase in temperature the concentration of charge carriers re constant, hence it does not effect the conductivity.
2. Therefore in conductors with increase in temperature the cond decreases.

SEMICONDUCTORS

1. With increase in temperature the concentration of charge carriers increa electrons from V.B jumps into C.B. Hence conductivity increases.
2. With increase in temperature the collision of electrons with the vibrating a or ions increases hence the mobility decreases.
3. But increase in concentration is very high as compared to decrease in mo Hence overall there is an increase in the conductivity of semiconductor increase of temperature.

Conductivity and Current density in a conductor

Let us consider a conductor of length (l) and Area of cross section (A).



If, n = Concentration of electrons per unit volume (i.e. electron density)

e = Charge of the electron

E = Electric field applied to conductor

V = Voltage developed between two ends of conductor

v_- = drift velocity of electrons

μ_e = mobility of electrons

Then,

∴ Total number of electrons crossing the cross section A

$= n \times$ (volume of conductor)

$= nAl$ (∵ Volume = Area × length)

∴ The total charge crossing the cross section A

$$\boxed{q = nAle}$$

∴ Charge flowing through any cross section per unit time

$$\boxed{\frac{q}{t} = \frac{nAle}{t}}$$

or $I = nAve$ $(\because v = d/t)$

or $I = nA\mu_e E e$ $(\because v = \mu_e E)$ from eq (i)

or $\boxed{I = nA\mu_e \frac{V}{l} e}$ $(\because dE = dV/dx)$

i.e the relation between $\vec{E}$ & V)

Now we know that in a conductor,

$$R = \frac{V}{I}$$

$$\therefore R = \frac{Vl}{nA\mu_e V e}$$

$$\boxed{R = \frac{l}{A} \frac{1}{n\mu e}}$$

Now comparing this equation with,

$R = \frac{\rho l}{A}$, we can write

$$\therefore \boxed{\text{Resistivity } \rho = \frac{1}{n\mu e} \ \Omega m}$$

According to the defination of conductivity,

$$\therefore \boxed{\text{Conductivity } \sigma = \frac{1}{\rho}}$$

$$\therefore \rho = \frac{1}{n\mu e}$$

$$\therefore \sigma = n\mu e \ \Omega^{-1} m^{-1}$$

$$\therefore \boxed{\text{Conductivity} = \sigma = n\mu e \ \Omega^{-1} m^{-1}}$$

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C M Mahajan

Current Density (J)

It is defined as current flowing per unit cross section area.

$$J = \frac{I}{A} = \frac{n A e v}{A}$$

$$J = n e v$$

$$= n e \mu_e E \quad (\because v = \mu_e E)$$

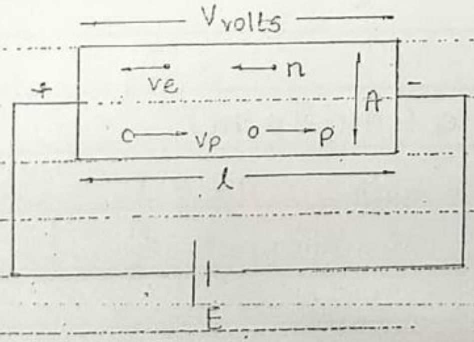
$$\therefore J = \sigma E \quad (\because \sigma = n \mu_e e)$$

or $\sigma = \frac{J}{E}$

$$\boxed{\text{Current density} = J = \sigma E}$$

Conductivity and Current density in a Semiconductor

Consider a semiconductor of length (l) and area of cross section A.



If,

n = no. of electrons per unit volume (i.e electron density).
p = no. of holes per unit volume (i.e hole density).
v_e = drift velocity of electrons
μ_e = electron mobility
v_h = drift velocity of holes

E = Applied electric field
V = potential developed across two ends of semiconductor

We know that in a semiconductor, the total current is because flow of electrons and holes

$$\therefore \quad I = I_e + I_h$$

$$I_{semi} = nAv_e e + pAv_h e$$
$$= Ae\,(nv_e + pv_h)$$
$$= Ae\,(n\mu_e E + p\mu_h E) \qquad (\because v = \mu E)$$
$$= AeE\,(n\mu_e + p\mu_h)$$
$$= Ae\frac{V}{l}\,(n\mu_e + p\mu_h)$$

$$\therefore \quad I_{semi} = Ae\frac{V}{l}\,(n\mu_e + p\mu_h)$$

$\therefore$ Resistance of Semiconductor,

$$R = \frac{V}{I} = \frac{V}{Ae\frac{V}{l}(n\mu_e + p\mu_h)}$$

$$\therefore \quad R = \frac{l}{A} \cdot \frac{1}{e(n\mu_e + p\mu_h)}$$

Comparing this equation with $R = \rho\frac{l}{A}$ we get,

$$\text{Resistivity} = \rho = \frac{1}{e(n\mu_e + p\mu_h)}$$

According to the definition of conductivity,

$$\text{Conductivity} = \frac{1}{\rho}$$

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

$\therefore \sigma = e\,(n\mu_e + p\mu_h) \quad \Omega^{-1} m^{-1}$

$$\boxed{\therefore \sigma_{semi} = \sigma_e + \sigma_h}$$

Current density (J)

It is defined as the current flowing per unit crosssection area.

$$\therefore J = \frac{I_{semi}}{A}$$

$$= \frac{neAv_e + peAv_h}{A}$$

$$= \frac{Ae\,(nv_e + p\,v_h)}{A}$$

$$= e\,(n\mu_e E + p\,\mu_h E)$$

$$= eE\,(n\mu_e + p\,\mu_h)$$

$$J = \sigma_{semi}\,E$$

$$\boxed{\therefore \sigma_{semi} = \frac{J}{E}}$$

Conductivity in intrinsic semiconductor

We know that in intrinsic semiconductor the electron concentration is equal to the hole concentration.

i.e $n = p = n_i$ (i.e concentration of charge carriers in intrinsic semiconductor)

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$$\sigma_{intrinsic} = e\,(n\mu_e + p\mu_h)$$
$$= e\,(n_i\mu_e + n_i\mu_h)$$
$$= e n_i\,(\mu_e + \mu_h)$$

(μ_e & μ_h are different because one is in C.B & other is in V.B)

Conductivity in Extrinsic Semiconductor

i) P-type semiconductor

In p-type semiconductor concentration of holes is very very large as compared to the concentration of electrons.

i.e. $p >> n$

Therefore, neglecting the n-type concentration, the conductivity of p-type semiconductor is,

$$\boxed{\sigma_p = e p \mu_h = a e \mu_h}$$ ($\because a$ = concentration of acceptor...)

ii) N-type semiconductor

In n-type semiconductor concentration of electrons is very large as compared to the concentration of holes.

i.e. $n >> p$

Therefore neglecting the p type conductivity,

$$\boxed{\sigma_n = e n \mu_e = d e \mu_e}$$ ($\because d$ = concentration of donor impu...)

field, the... perpendic... Hall Effec... EXPLA...

1 Co... dir...

2 Ve...

3 He... in...

4 He...

5 Th...

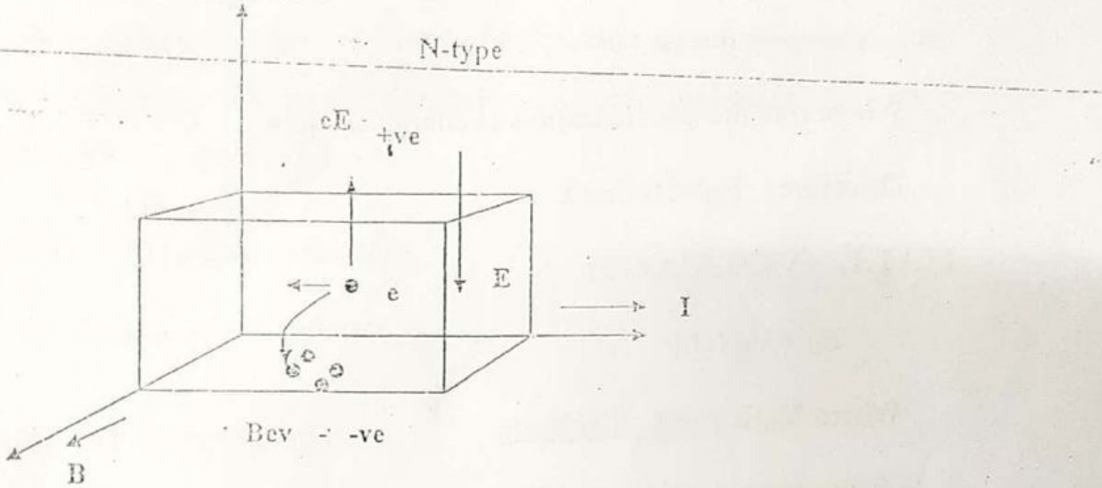
6 At ... for ... ele...

7 Th... as...

State & explain Hall Effect. Obtain expression [illegible] field, coefficient, mobility, charge density? Give its application

When a semiconductor carrying current is placed in a transverse magnetic field, then an electric field, is produced inside the semiconductor in a direction perpendicular to both current and the magnetic field. This phenomenon is known as Hall Effect.

EXPLATION OF THE EFFECT



1 Consider an N-type semiconductor in which the current is flowing in +ve X-direction. Therefore the electron is moving in opposite direction.

2 Velocity, current & magnetic filed are mutually perpendicular to each other.

3 Hence electron experiences a Lorentz's force (Bev) which pulls the electron in downward direction. Hence Face 2 becomes –ve w.r.t Face 1.

4 Hence electric field is generated in the semiconductor.

5 The force (eE) due to electric field pulls the electron in the upward direction.

6 At one stage the upward electrical pull becomes equal to downward Lorentz's force. Hence the accumulation of electrons stops and a constant hall's electrical field is produced.

7 This gives potential difference along the top and bottom faces. This is called as Hall's Voltage.

UNDER EQUILIBRIUM CONDITION upward electrical pull is equal to downwards Lorentz's force.

Thus $eE_H = eBv$

Therefore $E_H = vB$

But current in a semiconductor is given by

$$I = neAv$$

Where n is the concentration of charge carriers.

Therefore $E_H = BI / neA$ .... (1)

HALL VOLTAGE

$$E_H = V_H / d$$

Where V_H is the hall voltage

Substituting this value in (1) we get

$$V_H = BId / neA$$

Or $V_H = BJd / ne$ (Since $J = I / A$)

HALL COEFFICIENT (R_H)

In the expression of hall voltage the factor $1 / ne$ is a constant quantity and it is called as HALL'S COEFFICIENT.

Therefore

$$V_H = BId / neA$$

Or $V_H = R_H BId / A$ (Since $R_H = 1 / ne$)

Therefore

$$R_H = V_H A / BId$$

Or $R_H = E_H dA / BId$ (Since $E = V / d$)

Or $R_H = E_H / BJ$ (Since $J = I / A$)

Hence we define Hall's Coefficient as the halls electric field generated per unit magnetic field and current density.

Since Hall's Coefficient is related to electric field, whose direction specifies the type of semiconductor, hence we can say that hall's coefficient can give us the idea about the type of semiconductor.

When R_H = +ve P- type semiconductor

R_H = -ve N- type semiconductor

CHARGE DENSITY (Φ)

Charge density will be product of electron density and charge of electron

Therefore $\Phi = ne$

Substituting this value in the equation of Hall's voltage we get

$$V_H = BId / neA$$

$$V_H = BId / \Phi A$$

Therefore

$$\Phi = BId / V_H A$$

$$\Phi = BI / V_H w \quad (\text{Since } A = dw)$$

In this expression all parameters can be measured experimentally.

MOBILITY (μ)

We Know that conductivity is given by

$$\sigma = ne\mu$$

Therefore

$$\mu = \sigma / ne$$

But $1/ne = R_H$

Therefore $\mu = \sigma R_H$

$$= \sigma V_H A / BId$$

$$= \sigma V_H w / BI \qquad \text{(Since } A = dw\text{)}$$

In this expression all parameters can be measured experimentally.

APPLICATION OF HALL EFFECT

1 DETERMINATION OF TYPE OF SEMICONDUCTOR

2. CALCULATION OF CHARGE CARRIER DENSITY

3. DETERMINATION OF MOBILITY OF CHARGE CARRIER

C.M.Mahore

Q. Define Fermi level and Fermi energy for conductors and semiconductors. Give its significance.

Fermi level is defined as the highest occupied energy level in the band structure of a solid. The energy corresponding to this level is called as Fermi Energy (E_F).

CONDUCTOR

Fermi level is defined as the highest occupied energy level in the highest energ band of band structure at absolute temperature.

Significance: It gives the value of the maximum energy an electron can have in conductor.

SEMICONDUCTOR

It is that energy level which corresponds to the center of gravity of no. electrons in conduction band and no. of holes in valance band when weigh according to their energies.

Significance: The value of the Fermi level gives us the idea probability presence of an electron in C.B or the presence of hole in the valance band of t material.

C·M·Kale

Q. Explain Fermi Dirac probability distribution function or Fermi Dirac statistik What is it's importance? Obtain the probability of finding an electron in an energy level $E > E_F$, $E < E_F$ when $T = 0\,°K$ and $E = E_F$ when $T = T\,°K$. Represent the results graphically.

Fermi Dirac probability distribution function or Fermi Dirac statistics gives the distribution of electrons over a range of allowed energy levels at therma equilibrium.

$$P(E) = \frac{1}{1+e^{(E-E_F)/KT}}$$

Where, $P(E)$ = Probability of finding an electron in an energy level].

E_F = Fermi Level

K = Boltzman's Constant

T = Temperature at which we are finding the probability

IMPORTANCE

It gives the idea about the presence of electrons in an energy level of conduction b or the absence of an electron (i.e presence of hole) in an energy level of valance b

Using Fermi Dirac statistics the probability of finding an electron in an energy level for three different cases are

1. At $T=0°K$, for $E < E_F$, the term $e^{((E-E_F)/KT)}=0$ and $P(E)=1$

$$P(E < E_F) = \frac{1}{1+0} = 1$$

Hence at $T=0°K$ all energy states below E_F are totally occupied.

2. At $T=0°K$ and $E > E_F$ the term $e^{((E-E_F)/KT)}$ [illegible]

$$P(E > E_F) = \frac{1}{1+\infty}$$

$$P(E > E_F) = 0$$

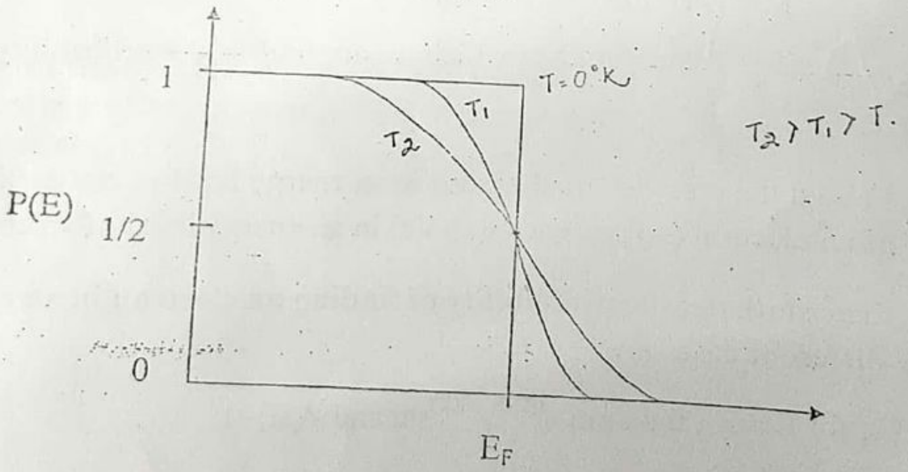
It means that, at T=0°K all the energy states above E_F have zero probability of occupancy and hence are empty.

3. At T>0°K and $E=E_F$, the term $e^{((E-E_F)/KT)}=1$ and $P(E)=1/2$

$$P(E=E_F) = \frac{1}{1+1}$$

$$P(E=E_F) = 1/2$$

i.e. the energy state at the Fermi Level has 50% probability of being occupied by an electron at any finite temperature T> 0°K



From the graph we can conclude that at absolute temperature all level below Fermi are occupied and all level above Fermi are empty and at Fermi level the probability is 50%. As temperature increase some electrons move into higher energy level so probability below Fermi starts decreasing and probability above Fermi starts increasing.

C.M. Mahajan

5) At high temperature, electrons from VB move in CB hence the centre of gravity shifts upwards. So Fermi level is anywhere bet $EF_{intrinsic}$ and E_A. But it can never be $EF_{intrinsic}$ or can go ~~below~~ above it as in P-type number of holes in V.B is greater than number of electrons in CB.

6) So in P-type Fermi-level is near V.B.

7) Nearness to VB depends on doping.

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2) SHOW THAT THE FERMI LEVEL OF INTRISIC SEMICON-DUCTOR LIES IN CENTRE OF FORBIDDEN GAP

→ As in intrinsic semiconductors concentration of holes is equal to concentration of electrons so fermi-level lies exactly at the centre of forbidden gap.

PROOF :- 1) widths of VB & CB are small compared to Eg.

2) All levels in the band have very small energy difference. Hence we can assume single value of energy i.e E_c & E_v.

T°K Let N_c = Number of electrons in CB
N_v = Number of electrons in VB.
$N = N_c + N_v$ = Total no. of electrons in both bands.

It
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i.e.
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Fermi
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level so
increas

By Probability theory
$P(E=E_c) = N_c/N$

By Fermi Dirac Probability distribution function

$$P(E=E_c) = \frac{1}{1+e^{(E_c-E_F)/KT}}$$

$$\therefore \frac{N_C}{N} = \frac{1}{1+e^{(E_c-E_F)/KT}}$$

$$\text{or } N_C = \frac{N}{1+e^{(E_c-E_F)/KT}}$$

similarly $N_V = \frac{N}{1+e^{(E_V-E_F)/KT}}$

As $N = N_C + N_V$.

$$\therefore \cancel{N} = \cancel{N}\left[\frac{1}{1+e^{(E_c-E_F)/KT}} + \frac{1}{1+e^{(E_V-E_F)/KT}}\right]$$

$$\left(1+e^{(E_c-E_F)/KT}\right)\left(1+e^{(E_V-E_F)/KT}\right) = 2+e^{(E_c-E_F)/KT}.$$

$$1+e^{\cancel{(-E_V-E_F)/KT}}+e^{\cancel{(E_c-E_F)}/KT}+e^{1/KT(E_c-E_F+E_V-E_F)}$$

$$= 2+e^{\cancel{(E_c-E_F)}/KT}+e^{\cancel{(E_V-E_F)}/KT}$$

$$e^{(E_c+E_V-2E_F)/KT} = 1.$$

But we know that $e^0 = 1$

$$\therefore \frac{E_c+E_V-2E_F}{KT} = 0.$$

$$\text{or } \frac{E_c+E_V}{2} = E_F$$

. For intrinsic semiconductors Fermi level is at centre of

C.M.Mahaj.

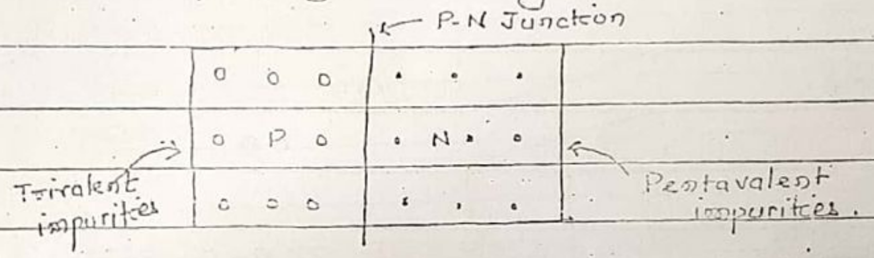
P-N JUNCTION DIODE (ON THE BASIS OF BAND DIAGR

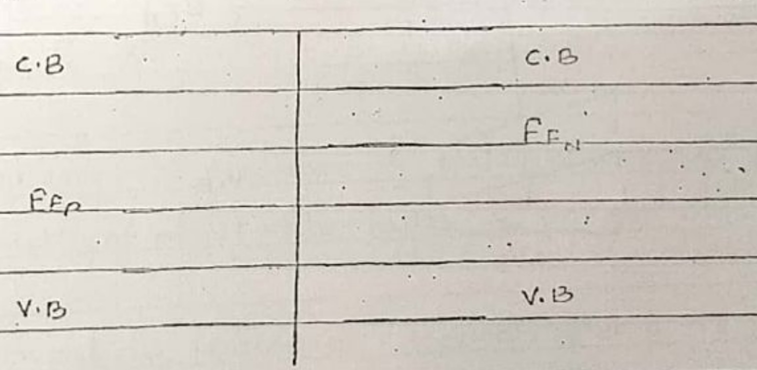
A diode is a semiconductor device which allows curre to flow in a single direction.

CONSTRUCTION (IN EXAM CONST. PART CAN BE NEGLECTED)

1) When in a semiconductor material, from one end triva impurities are added and from other end pentavalent impurities added, then we get a diode.

2) The plane seperating the two regions is called as P-N Jun





EQUILIBRIUM CONDITION (ZERO BIASING)

1) As soon as a diode is formed, diffusion of electrons & ho the junction takes place.

2) Hence a depletion region is created which produces a bar potential V_B.

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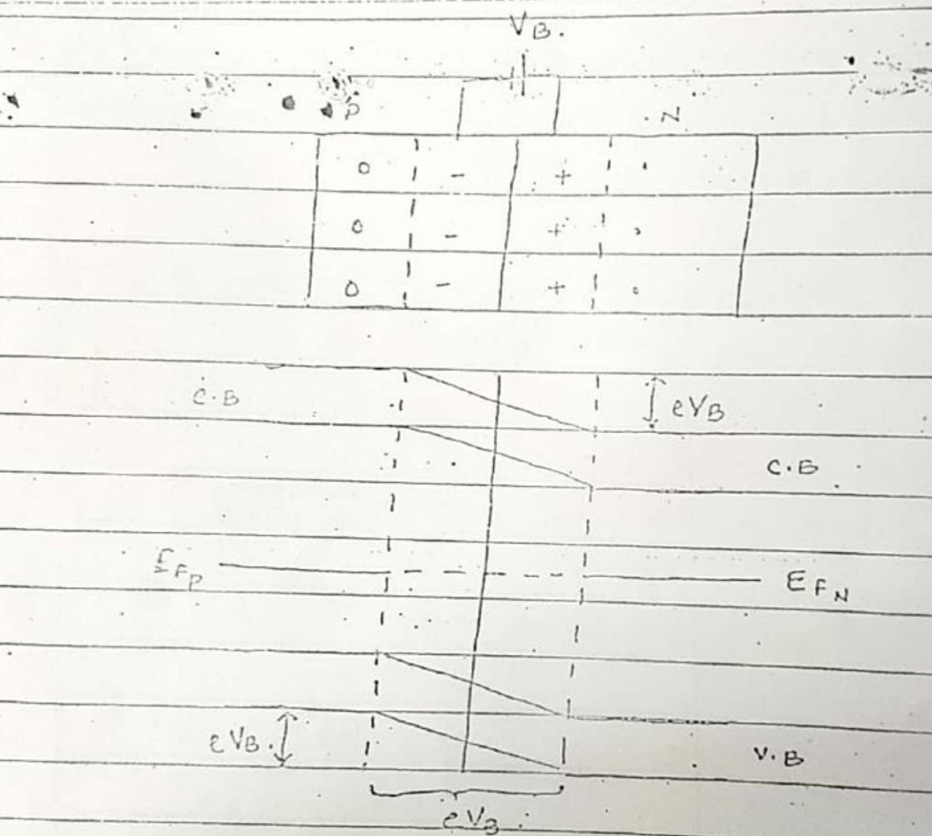
charge carriers.

Due to diffusion the energy of electrons in N-region & holes in p-region decreases, because of which there is a shift in the position of bands.

This is called band bending & because of this there is no flow of charge carriers during equilibrium condition.

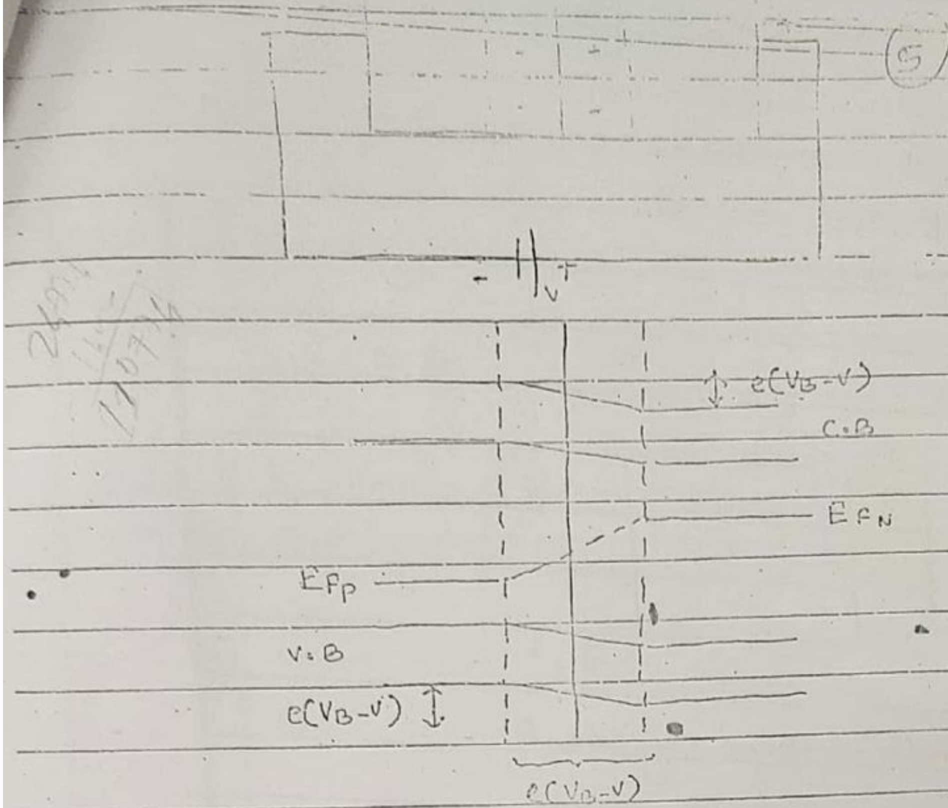


RWARD BIASING

During forward baising an external potential with its +ve to P-type & -ve to N-type is applied.

Due to this the energy of electrons & holes increases. Hence the width of depletion layer and the barrier potential decreases.

Thus the band bending decreases when the external ... $V > V_D$

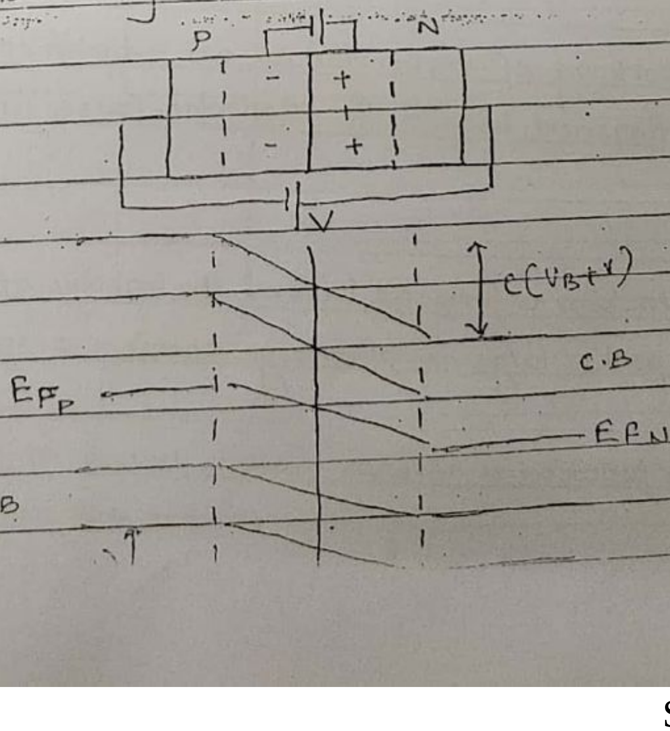


REVERSE BIASING

1) During Reverse biasing an external potential with its +ve to N-type & -ve to P-type is applied.

2) Due to this energy of electrons & holes decreases further. Hence the width of depletion layer & barrier potential

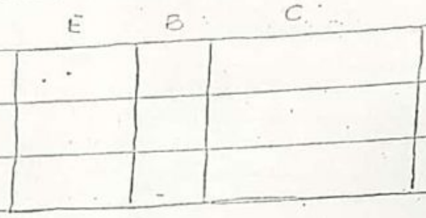
3) Thus band bending increases. Hence there is no flow.



JUNCTION TRANSISTOR

Transistor is a semiconductor device which is used for the Amplification of input Signal.

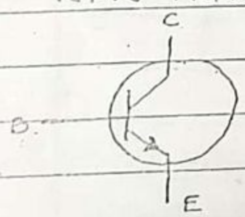
CONSTRUCTION



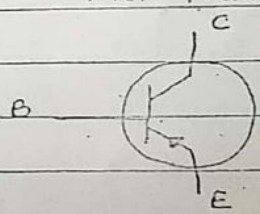
1) Transistor consists of three regions Emitter, Base & C

2) Depending upon the type of semiconductor used in crea emitter, base & collector, transistor are ~~cate~~ classified as

NPN Transistor



PNP Transistor



WORKING (NPN

1) For the working of transistor as an amplifier the Em junction is forward biased & Collector-Base junction reversed biased

2) As E-B junction is forward biased the energy of Majority charge increases and a large no. of charge carriers cross the j

3) Since C-B junction is reverse biased, hence in the bas ... coming from emitter act as Minori

Hence majority of these charge carriers are pulled into the collector region.

$\therefore \quad I_E = I_B + I_C$

But $I_B \ll I_E$

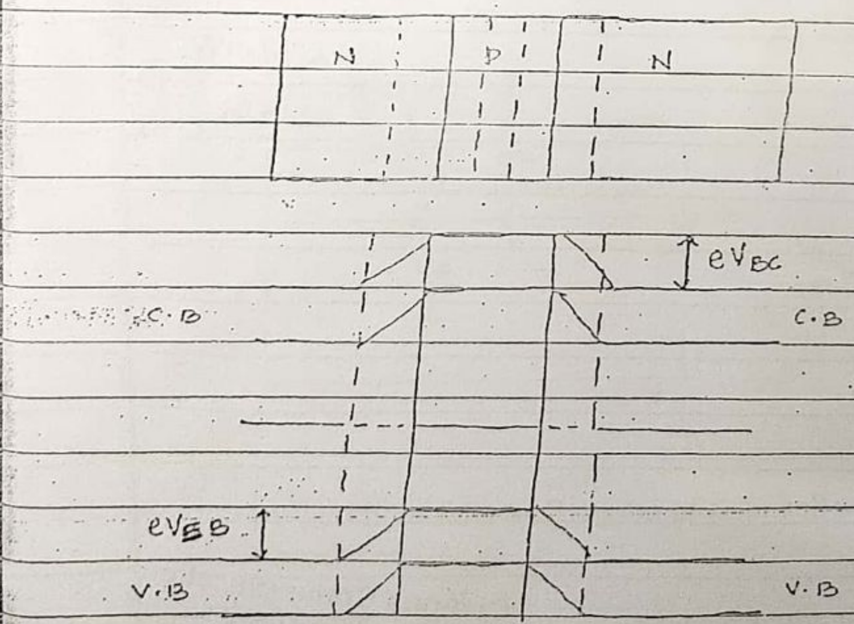
$\therefore \quad I_E \simeq I_C.$

Since E-B junction is forward bias $\therefore$ R_{EB} is small & C-B junction is reverse biased $\therefore$ R_{CB} is large.

Hence Input power $I_E^2 R_{EB} < I_C^2 R_{CB}$ Output power

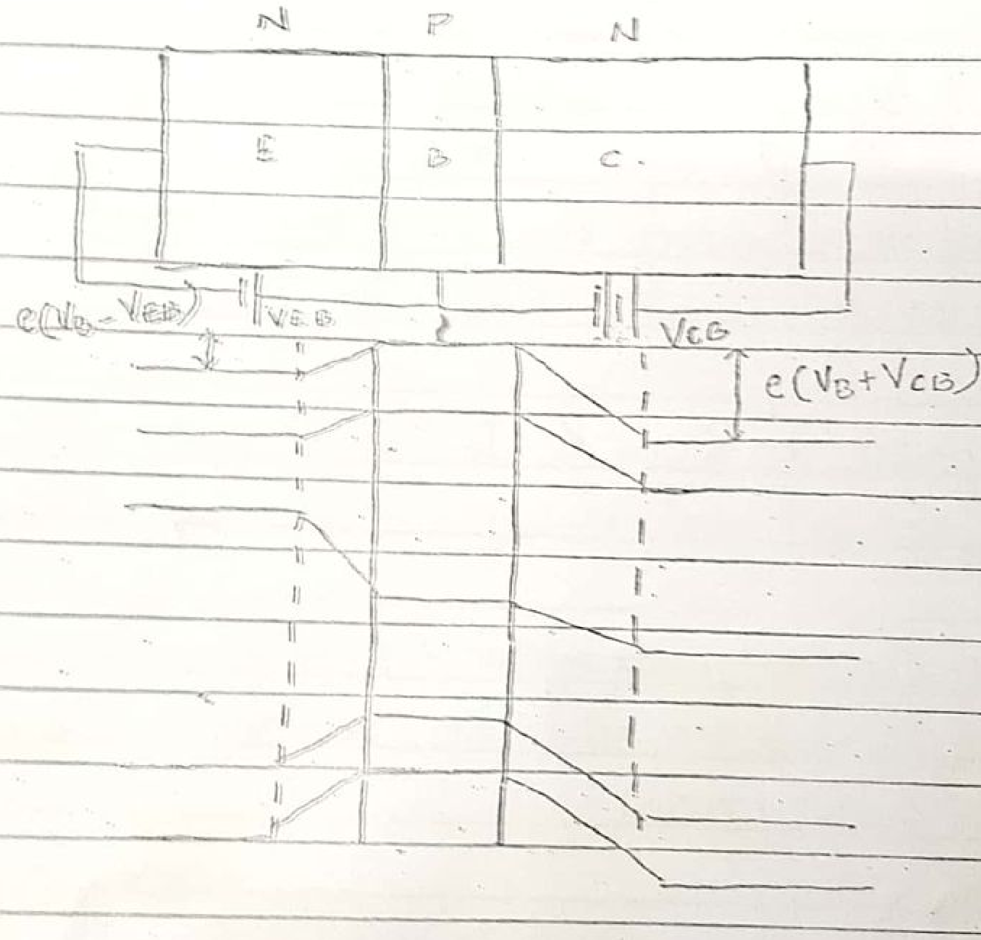
AND DIAGRAM (NPN Transistor)

EQUILIBRIUM CONDITION



1) When transistor is biased E-B junction is forward bias hence band bending decreases

2) C-B junction is reverse biased hence band bending increases.



C.M.Mal

C·M·Nakafu

Q. Describe the principle, construction, working & characteristics of th
solar cell.

Definition : Solar cell is a P-N junction diode having large surface area an
a small P . It converts solar energy into electrical energy

Principle : It is based on photovoltaic effect i.e. conversion of light energ
to potential difference.

Construction :

1) First an N type semiconductor having large surface area & small thickness (i.e. 12 - 18 mm) is taken.

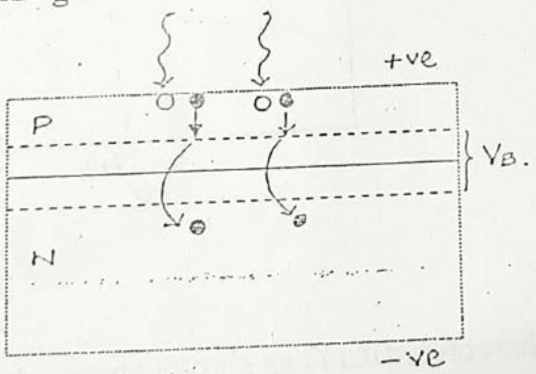
2) Very small amount of trivalent impurities are added so that a thin P Region (0.2 to 0.5μm) is created.

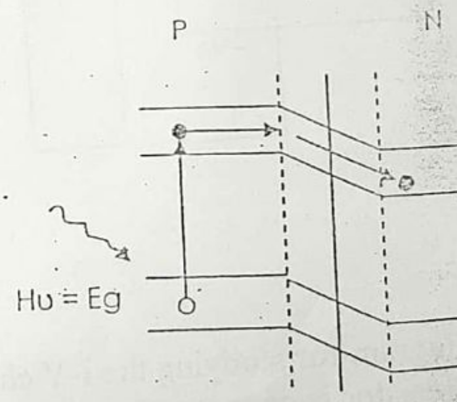
3) Hence a solar cell is formed

4) Antireflection layer is coated on P type material to avoid loss of lig due to reflection.

5) All assembly is covered with glass for protection.

Working :





1) When light falls on P region of solar cell an electron hole pair is produced.

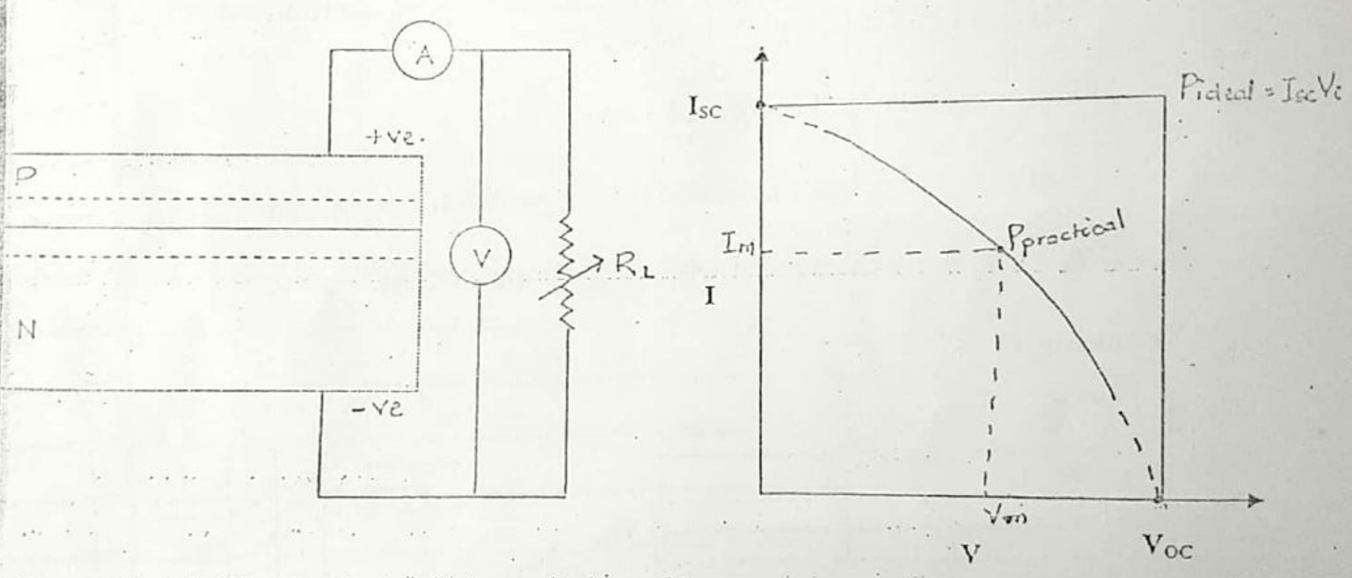
2) Since P region is very thin hence electron immediately moves tow
the junction.

3) Since this electron is in the conduction band of P-type region hence it requires a very small amount of energy to cross the junction.

4) At the junction because of the barrier potential this electron is swept into N region. Hence number of electrons in N region increases and P region contains holes..

5) Thus a potential difference is produced between the two terminals of solar cell.

Q . Explain the characteristics of solar cell. Give significance of the cell parameters Isc, Voc & fill factor.



he Circuit diagram for studying the I-V characteristics is as shown above. A ariable load resistor is connected parallel to the solar cell. The voltage drop across pad resistor gives the voltage drop across solar cell. When voltage drop changes ien the current through solar cell also changes.

a

Applications of solar cell

The sun is most attractive renewable power source and more widely used. It can b applied to many purposes in everyday life and environmental friendly.

1) **Residential homes:** lightning systems, outdoor lighting system (such as garden lights, garage lights and fence lanterns, etc.) electrical equipments, electric gate openers, security systems, ventilators, water pumps, water filters and emergency lights, etc.

2) **Water pumping :** Consumption, public utility, livestock watering, agriculture, gardening and farming, mining and irrigation, etc.

3) **Battery charging systems :** Emergency power system, batteries charging centers for rural villages and power supplies for household use and lighting in remote area, etc.

The various parameters of Solar cell are

1) V_{oc} (OPEN CIRCUIT VOLTAGE)

It is defined as the voltage drop across the solar cell when the impedance or resistance of the solar cell is infinity.

When , V=Voc then I=0

Hence by OHM's law

$R_L = \infty$ This is an ideal value

2) I_{SC} (SHORT CIRCUIT CURRENT)

It is defined as the current flowing through the solar cell when the resistance or the impedance of the circuit is zero.

when I = Isc then V=0

$R_L = 0$ This is an ideal value

3) FILL FACTOR

It is defined as the ration of maximum practical power to that of ideal power.

Ideal power $P_{ideal} = I_{sc}V_{oc}$

Max. Practical Power $P_{Practical} = I_m V_m$

Therefore fill factor = $\dfrac{ImVm}{IscVoc}$

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Q) What is Superconductivity, Superconductors and Transition temperature?

The property of sudden disappearance of resistance of a material below certain temperature is called as **superconductivity**.

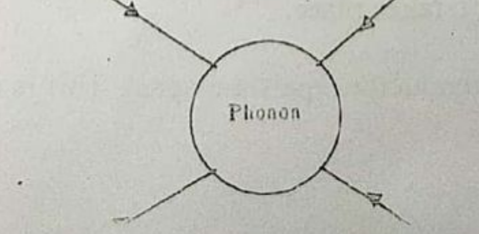
The materials showing this property are called as **superconductors**.

The temperature below which a conductor gets converted into a superconductor is called as **critical temperature** or **transition temperature**.

Q) Explain BCS theory of superconductivity.

The explanation for a material getting converted into a superconductor below critical temperature was given by three scientists Jhon Bardeen, Leon Cooper and Jhon Schriffer. Hence this explanation is called as BCS theory.

1) The layer containing regular arrangement of atoms or ions is called as lattice.
2) The quanta of vibrating ions in the lattice are called as phonon.
3) When an electron is moving through the lattice, because of the coulomb's attractive force between the electrons and the ions there is an interaction between the electrons and the lattice.
4) Due to this interaction the lattice gets distorted. Hence the density of ions in the distorted region increases.
5) Due to this a near by moving electron is pulled towards the distorted region.
6) Hence we say that in the material and electron gets attracted towards another electro through phonon.
7) The attractive force between the electrons is greater than the coulomb's repulsive force between the electrons only when the vibration of lattice is very small.
8) Hence a pair of electron is formed. This pair is called as cooper pair.
9) These cooper pairs are formed at low temperature and they are drifting with the sam velocity over the lattice.
10) Hence the collision of electrons with the lattice minimizes below critical temperatu and the material starts acting as a superconductor.



(11)

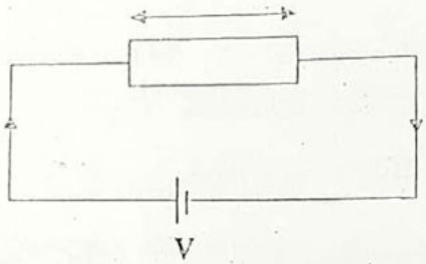
G.M. Mahajan

Q) Write various properties of superconductors.

The various properties of superconductors are as follows

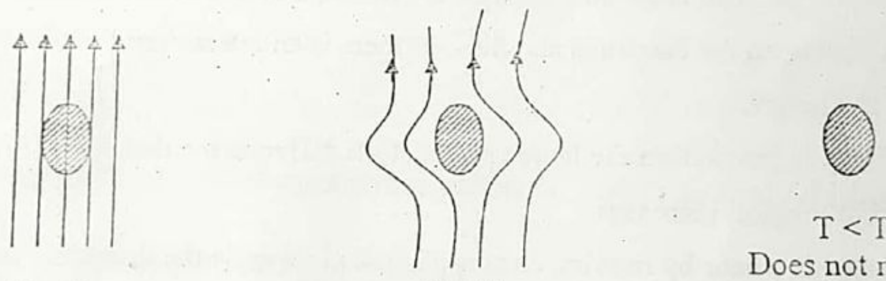
1) ZERO RESISTANCE

A superconductor is characterized by zero resistance. Whether the resistance of superconductor is zero or not can be verified by a simple experiment.



If there is a voltage drop across the object it means it is a conductor, if not then it is a superconductor

2) MEISSNER EFFECT (FLUX EXPULSION)



$T > T_C$ Magnetic Flux Pass

$T < T_C$ Magnetic Flux Expelled

$T < T_C$ Does not retain any Magnetism Perfect diamagnetic Materials .

In 1933 Meissner found out that when a superconductor below critical temperature i placed in a magnetic field. Then the magnetic line of force or magnetic flux is expelle through it. This effect is called as Messner's effect.

When the magnetic field is removed then the superconductor does not retain an magnetization. This suggests that superconductors are perfect diamagnetic materials.

The reason for Meissner effect is that when the superconductor below critical temperature placed in a magnetic field then circulating currents are produced on the surface of th superconductors. Due to this a magnetic field of same magnitude but opposite direction produced hence the flux repulsion takes place.

Due to Meissner effect a superconductor repels a magnet. This is called as Levitation effec or Suspension effect.

C.M. Mahajan

3) ISOTOPE EFFECT

It was found that the critical temperature at which a conductor gets converted into superconductor depends upon the isotopic mass. The critical temperature decreases with increase in the isotopic mass.

4) CRITICAL FIELD

It has been found out that when a superconductor is placed in an expanding magnetic field then the superconductor loses itr superconducting property above certain value of magnetic field.

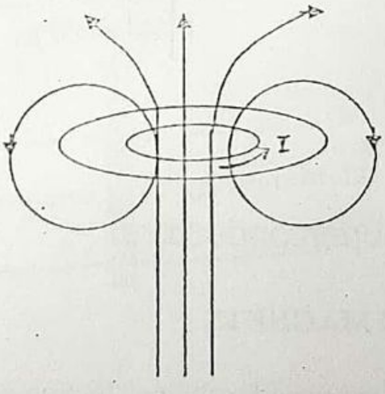
The strength of the magnetic field above which a superconductor loses its property is called as critical field.

5) PERSISTENT CURRENT

If a superconducting ring maintained below critical temperature is placed in a magnetic field then circulating current is produced in the ring (Meissner's effect).

Now even if the magnetic field is removed the current continues to flow on its own because there is no opposition to the flow of current.

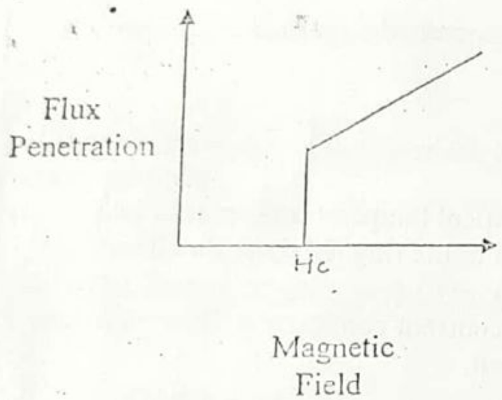
Such a steady current which keeps on flowing is called as persistent current. The persistent current does not require external power to maintain it as there are no I^2R losses. Superconducting coils with persistent currents produce magnetic fields and can therefore serve as magnets.



Q) Differentiate between Type-I and Type-II superconductors.

TYPE - I SUPERCONDUCTORS

1) Superconductors in which transition from superconducting state to conducting state is sharp is called as Type – I superconductors

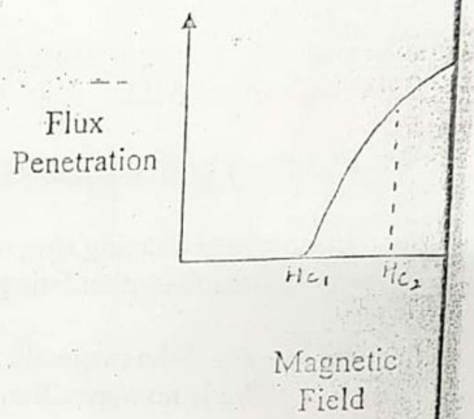


2) These are poor carriers of electrical energy.

3) Hence they cannot be used to produce strong magnetic fields.

TYPE - II SUPERCONDUCTORS

1) Superconductors in which transition from superconducting state to conducting state is gradual is called as Type – II superconductors



2) These are good carriers o electrical energy.

3) Hence they can be used to produc strong magnetic fields.

Q) Write applications of superconductors.

1) SUPERCONDUCTING MAGNETS

Superconductors are used for the production of high magnetic field without a large consumption of electrical power.

Superconducting magnets are used in many areas such as energy storing devices, electric motor windings, and particle accelerators. It is also used in the field of medicine for NMR (Nuclear Magnetic Resonance)

(1h)

2) HIGH POWER TRANSMISION LINES

When electric power is transmitted through ordinary cables a large amont of power is lost due to I^2R losses. Superconducting cables permit high power transmission without any power loss and that to at low voltage.

3) BEARINGS

Meissner effect is used in bearings. The mutual repulsion between two superconductors due to repulsion between the magnetic fields they generate is used in bearings.

The bearings thus operate without power loss and friction.

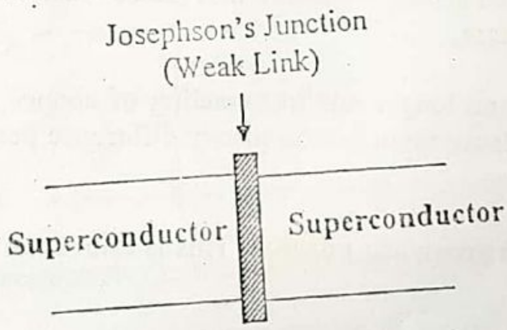
4) Superconductors will drastically change IC fabrication. Currently due to I^2R losses, there is a limit to which components can be placed on a chip. Use of superconductor will make it possible to place large no. of circuits in a given area.

5) Superconductors can be used as a memory device in computers.

Q) What is Josephson's effect? Explain D.C Josephson's effect and A.C Josephson's effect.

JOSEPHSON'S EFFECT

C.M. Mahajan



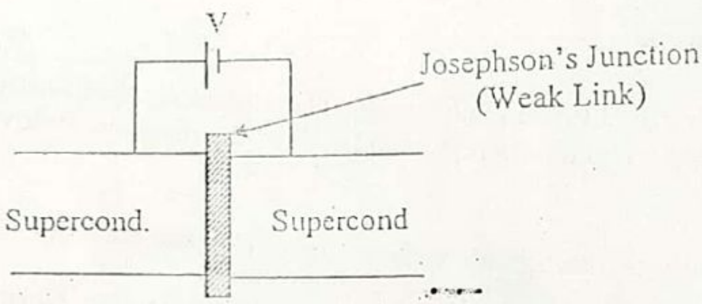
Two superconductors connected by a thin layer of insulating material is cal Josephson's junction (Weak Link). It was found out by Josephson that if the thick the insulating material is very small ie of the order of de-Broglie's wavelength or s ≤ 50 Å), then the electrons in form of cooper pair tunnel through the insulating m into other superconductor and hence a current flows across the junction.

This effect is called as **JOSEPHSON'S EFFECT.**

Depending upon the type of current flowing across the junction Josephson's effect is divided into two categories

1) D.C JOSEPHSON'S EFFECT

Consider two superconductors separated by an insulator having thickness of the order of 10 to 20 Å. This is called as Josephson's Junction.



Let an external voltage V is applied across the junction.

When V is either zero or less than critical voltage V_C then the junction acts a[s a] superconductor. The cooper pairs tunnel from one side to another very easily.

Hence a D.C current flows through the junction without any voltage drop. This is know[n] as **D.C JOSEPHSON'S EFFECT.**

2) A.C JOSEPHSON'S EFFECT

When the voltage applied across the junction is greater than the critical voltage th[en] the junction acts as a conductor.

In such case the current is no longer due to tunneling of cooper pairs. It is dhe to t[he] single electron tunneling. Hence there is a frequency difference between the electrons [of] two sides.

Hence an A.C current flows across the junction. This is known as **A.C JOSEPHSON['S] EFFECT.**

C.M.Mahajan

Q) Give full form of Laser & define Laser.

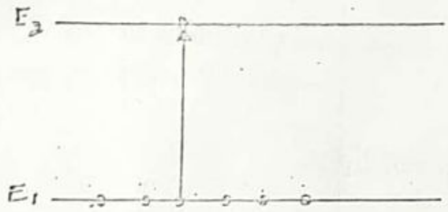
The word laser is acronym for
'LIGHT AMPLIFICATION BY STIMULATED EMISSIONOF RADIATION'.

Laser is quantum electronic device which produce **intense, coherent, highly directional &** monochromatic beam of light.

Q) Explain Stimulated Absorption, Spontaneous emission, Stimulated emission, Metastable state, Population inversion and Active State.

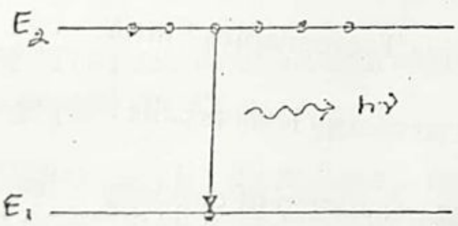
In an atomic system when a photon is incident then three processes can take place

1. **STIMULATED ABSORPTION**



The electrons present in the ground level absorb the energy and move into excited state. This process is called as Stimulated Absorption process.

2. **SPONTANEOUS EMISSION**



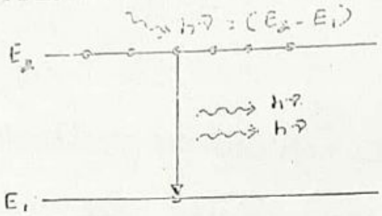
a) The electrons stay in the excited energy level for a short duration of time.

b) This time is called as **LIFE TIME** of excited electron. It is of the order of 10^{-9} sec

c) After its life time the electron by itself returns to the ground state by emitting exce amount of energy (in form of Photon).

d) This process is called as spontaneous Emission process.

3. STIMULATED EMISSION PROCESS



a) Consider an electron present in the excited state.

b) If a Photon having the same energy as that of the excited electron is incident on the excited electron then it forces the electron to move to the lower energy level.

c) While moving downwards this electron emits out two photons, one absorbed while moving up and one received by incident photon.

d) This process is called as stimulated emission process

e) In stimulated emission process due to one photon at the input we get two photons at the out put.

f) Hence we get an amplified form of light.

4. METASTABLE STATES

A Metastable state is an excited state of an electron. The only difference between metastable state and normal state is that the life time of excited electron is greate metastable state as compared to excited state. The life time of an electron in a metast state is of the order of 10^{-3} sec. This is 10^{6} times greater that the excited state.

5. POPULATION INVERSION (Negative Temperature State)

a) Concentration of an electron in an energy level is called as population of that state

b) Under equilibrium condition the population of electrons in lower energy level is greater than higher energy level.

c) The state of an atomic system in which the concentration of electrons is greater th lower energy state is called as population inversion or negative temperature state.

d) Here it should be clearly understood that the negative temperature state is not a physical quantity, but it is a convenient mathematical expression signifying the no equilibrium state of the system.

6. Active State or Active medium

A state or medium in which the condition of population inversion is achieved is ca as Active State or Active medium.

C.M.

Q) Distinguish between spontaneous emission and Stimulated emission.

SPONTANEOUS EMISSION	STIMULATED EMISSION
1) Spontaneous emission is directly proportional to the no of atoms present in excited state.	1) Stimulated emission is directly proportional to the no of atoms present in excited state and the no. of photons incident.
2) The photons, emitted in spontaneous emission moves in random directions.	2) Most of the photons emitted in stimulated emission moves in the same directions.
3) The photons emitted have no definite phase relationship with each other.	3) The photons emitted have a definite phase relationship with each other.
4) Emitted photons do not have the same state of polarisation	4) Emitted photons have the same state of polarisation

Q) Write the properties of LASER. Explain any one property.

The light emitted by Laser source has following properties

1. **INTENSE:** The intensity of the light emitted by lasers is very high. It means that it has a large amount of energy.
2. **MONOCHROMATIC:** As the laser is combination of photons emitted due to stimulated emission between two fixed energy levels hence it has Monochromaticity property.
3. **HIGHLY DIRECTIONAL:** Due to stimulated emission process laser has got directionality property.
4. **COHERENT:** The light emitted by laser has got very high degree of coherency.

Q) Define and explain the terms Pumping.

PUMPING: The process by which atoms are raised from lower energy level E1 to the higher energy level E2 is called as pumping.

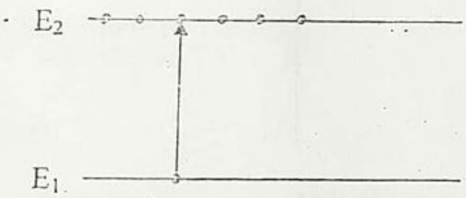
It can be done by supplying sufficient energy from a source. The most commonly used source of energy is light energy. This method is called as optical pumping.

<u>Optical pumping</u>: In Optical pumping Photons are used to excite the atoms in the medium. There are two type of Optical Pumping pumping:

1) Two level pumping

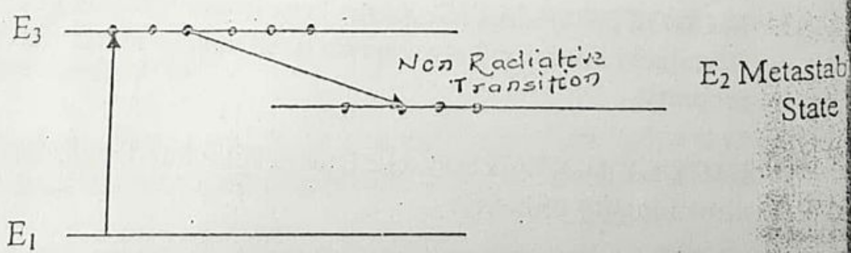
2) Three level pumping.

1) **Two level pumping**: In two level pumping system two energy levels are inv (Ground state & Excited state). When light energy is supplied then electrons from ground level to excited level. Hence a population inversion condit achieved.



The disadvantage of a two level pumping system is that in this case the pumping should be greater than the life time of electron in the excited state (l which is very small. Hence the process is very difficult. So we use a three level pumping system.

2) **Three level pumping**: In three level pumping system three energy levels are us Ground state, excited state and metastable state.



Electrons when supplied with electric energy move to the excited state. excited state they move to metastable state (10^{-3} sec). This transition is a non ra transition.. Since the time period of excited electrons in Metastable state is grea than that of the excited state hence it becomes easier to achieve rate of pumpin greater than the time period of metastable state

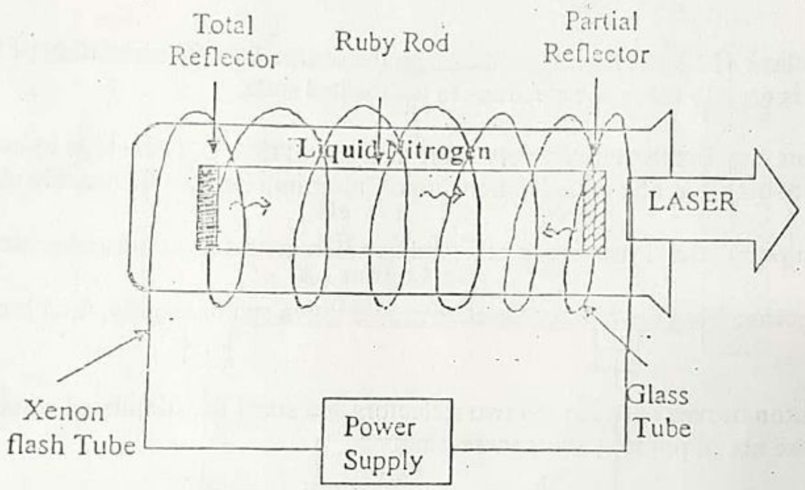
Therefore the population of atoms becomes more in the meta stable state compared to ground state.

C.T.Mahaja

Q) Explain the operation of ruby laser with the help of neat labelled diagram.

Ruby laser is also called as pulsed laser, because it emits laser beam in short pulses and not continuously. It is a three level laser system.

CONSTRUCTION



1) It consists of a Ruby road (Al_2O_3). In this some of the aluminium atoms are replaced by chromium atoms (Cr_2O_3). Chromium atoms act as active atom.

2) Light energy is used as pumping energy. Xenon flash light in the form of a helical tube is used which is wound round the ruby road.

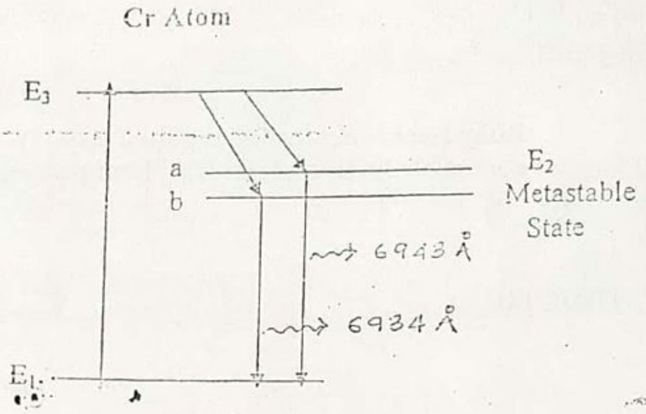
3) The flash of Xenon light is produced for a very short duration of time (300 μsec) and it generates a very large amount of energy (10,000 W).

4) Out of this only a small amount is used for achieving population inversion condition and remaining is converted in the form of heat. This heat can disturb the population inversion condition.

5) Hence ruby rod is immersed in liquid nitrogen which is kept in a glass tube.

6) The two faces of ruby road are polished in such a way that one acts as a full reflector and another acts as a partial reflector.

WORKING



1) First a flash of Xenon light is produced by the source for a short duration of time. This energy is used to move the electrons to the excited state.

2) Electrons stay in this state for very short duration of time and the move to metastable state. This transition is a non radiative transition. Chromium has two Metastable states a & b.

3) Hence a population inversion is achieved between metastable state and ground state.

4) If an electron from the Metastable state moves down spontaneously, then it emits out a photon.

5) This photon moves between the two reflectors and starts the stimulated emission process. Hence the no. of photons starts increasing.

6) These photons move back and forth between the two reflectors and continuously produce the stimulated emission process until the energy of photons increases to a large amount.

7) Once the energy of photons becomes very high then it is emitted in form of laser from the partial reflector side.

8) As the stimulated process continuous the no of electrons in the metastable state goes on decreasing and a stage is reached when the condition of population inversion finishes. Hence the production of laser stops.

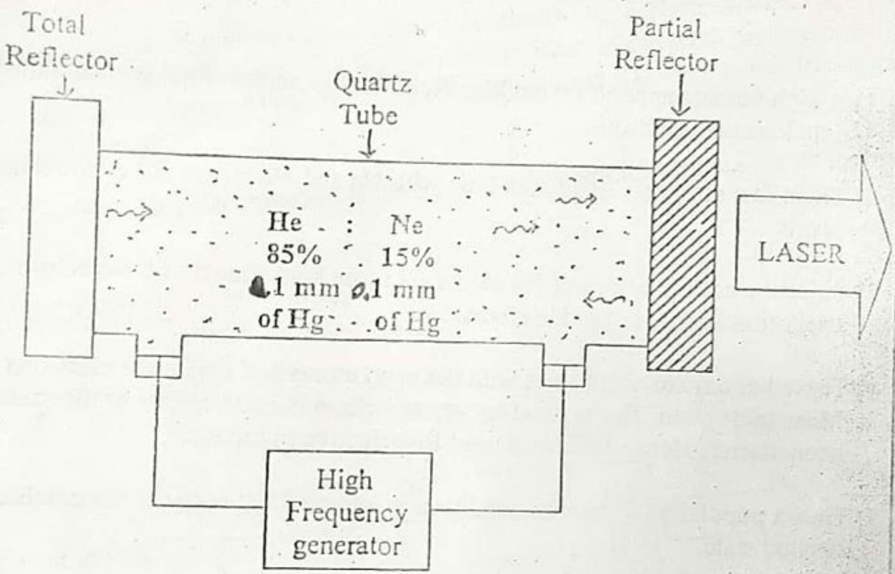
9) Hence ruby laser is also called as **PULSED LASER.**

10) The process again starts when the a new flash of Xenon light is produced.

Q) Explain action of gas laser (Continuous Laser.) How does stimulated emission takes place with exchange of energy between Helium and Neon atoms.

Helium Neon laser uses mixture of He-Ne gas as a medium hence it is also called as gas laser. It produces a continuous beam of laser light.

CONSTRUCTION



1) It consists of a quartz tube having 10-100 cm length and 2-8 mm width.

2) It is filled with a gas mixture of Helium and Neon. Neon atoms are active atoms whereas helium atom acts as buffer for selective pumping of neon atoms.

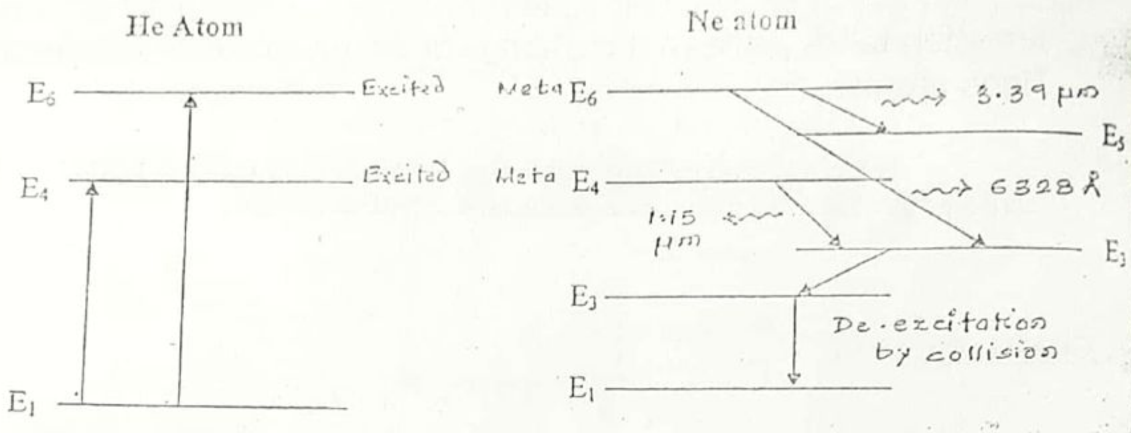
3) The ratio of He and Ne atoms is 85% : 15 %. Helium is filled at a pressure of 1 mm of Hg whereas Ne is filled at a pressure of 0.1 mm of Hg.

4) The pumping energy is supplied in the form of electric energy by a High frequency generator.

5) Two reflectors one totally polished and other partially polished is place inside the tube. This acts as the resonating cavity.

C M Kall

WORKING



1) A high voltage applied by the high frequency generator produces breakdown of the gas into ions and electrons.

2) These fast moving electrons collide with He and Ne atoms and excite them to high energy levels.

3) Since the concentration of He atoms are more hence most of the electrons supply excitation energy to the He atoms.

4) These helium atoms collides with the neon atoms and excite the electrons to the Metastable state. The excited energy of helium is same as that of the metastable energy of neon atoms . Hence helium is used for selective pumping.

5) Thus a population inversion condition is achieved between the Metastable state and the excited state.

6) Now if transition takes place between $E_6 - E_5$, E_6 - E_3 and E_4 - E_3 then a photon is emitted by spontaneous emission process. This photon moves between the two reflectors and start the stimulated emission process. When the energy of photon becomes very high then it is emitted out of partial reflector in the form of LASER.

7) The various wavelength which are emitted during these transitions are 3.39 μm, 6328 Å and 1.15 μm respectively.

Q) Write a note on semiconductor Laser.

It is a heavily doped p-n junction diode which emits coherent radiation when forward biased.

PRINCIPLE

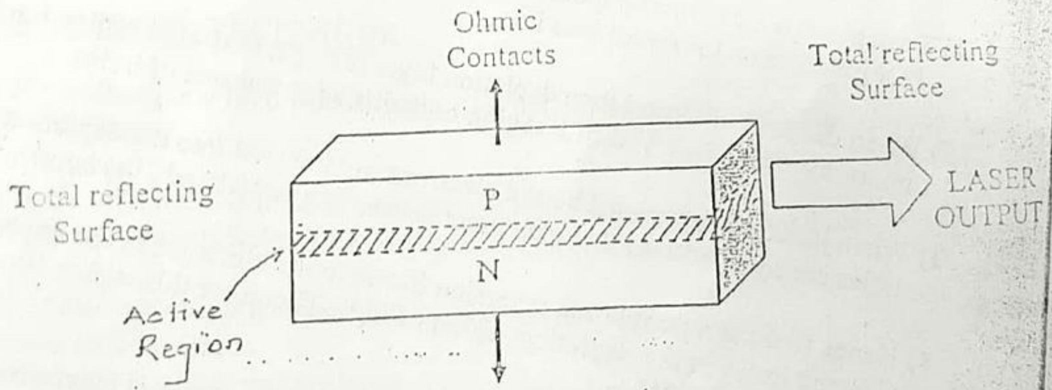
1) Band structure of an intrinsic semiconductor consist of a valence band and conduction band separated by an energy gap Eg.

2) Valance band at lower energy Ev contains holes and conduction band At higher energy Ec containsof electrons .

3) If transition of electron occurs from CB to VB so that electrons recombines with the holes then the energy (Ec-Ev) =Eg is given out. In most of the semiconductors this energy is given in form of heat . In some semiconductors (GaAs) it is released in the form of photon hυ.

4) This electron hole recombination is the basic mechanism involved in the emission of radiation.

CONSTRUCTION



1) Diode is extremely small in size having dimension of the order of 1mm.

2) Junction lies in a horizontal plane through centre while the top and bottom faces metallised and are provided with ohmic contacts so as to forward bias the junct

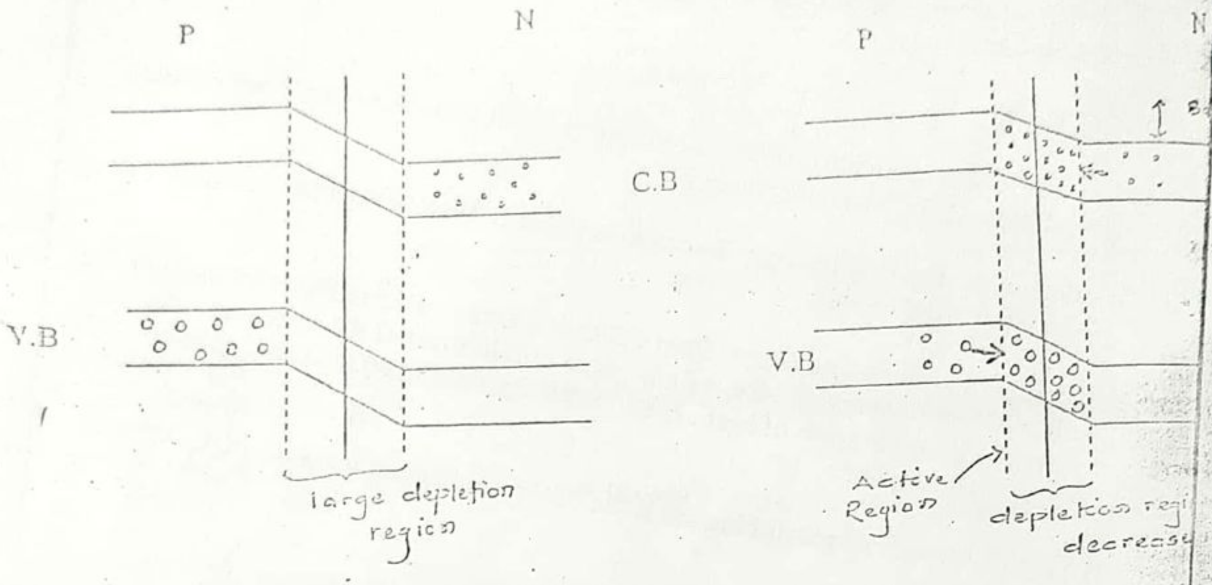
3) Front and rear faces are polished parallel to each other and perpendicular to the of the junction. These polished places constitute the resonating cavity.

4) Other two faces which are opposite are roughened so as to prevent the laser ou that direction.

WORKING

BEFORE BIASING

AFTER BIASING



1) To achieve the required population inversion in semiconductors we use heavily dop P-N junction and forward bias it.

2) When diode is unbiased then depletion layer is large, C.B of N-region contains larg no. of electrons and V.B of P region contains large number of holes.

3) When junction is forward biased electrons are injected into the depletion layer of C holes are injected into the depletion region of valance band , the band width decre

4) Hence there is a population inversion between the electrons in the depletion region C.B and holes in the depletion region of V.B. Therefore this region is called as ACTIVE REGION.

5) This population inversion has been achieved by the forward bias current, hence th current acts as PUMPING AGENT.

6) Now if an electron of C.B combines with a hole of V.B then spontaneous emissi takes place and a photon is emitted.

7) This photon moves between the two reflectors and starts the stimulated emissio process. Hence large number of photons are emitted. When the energy of photo becomes high laser is emitted out from the partial reflector side.

8) Since electrons and holes are injected into the depletion layer for population in condition therefore this lase is also called as INJECTION LASER.

9) Semiconductor diode laser are compact, highly efficient and simple in operatio Power requirement is also low.

C.H.A. Mali

Q) What are different applications of laser? Explain any one.

Laser is an Intense, monochromatic, coherent and highly directional beam of light. Because of these properties laser has a wide range of applications in various fields

1) INDUSTRY

In industry laser is used for welding, cutting drilling. These applications of laser use the property of high energy and high directionality.

2) MEDICAL FIELD

In medical field laser is used for Surgery, Cancer treatment, Dental decay treatment, Skin diseases etc.

3) COMMUNICATION

In communication laser is used in a technique called as Fibre Optic Technique

4) INFORMATION TECHNOLOGY

In IT laser is used in printers, CD writing and reading, Holography.

1) FIBER OPTIC TECHNIQUE

This is a technique which is used to transfer optical energy through thin glass tubes cal as optical fibres.

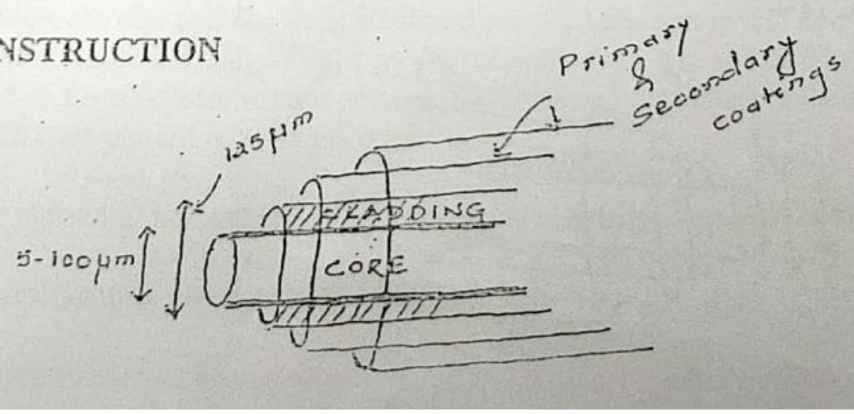
Fibre optic technique is used in communication as a transmitting medium. In this technique we take the help of LASER because of two reasons

1. Laser has very high frequency hence the quantity of message which can be transmitted increases.
2. Laser has very high energy hence it can travel very large distance without much lo of energy. Hence the quality of message increases.

PRINCIPLE

In fibre optic technique messages are transmitted by using the principle of total interna reflection

CONSTRUCTION



C.P.Notes

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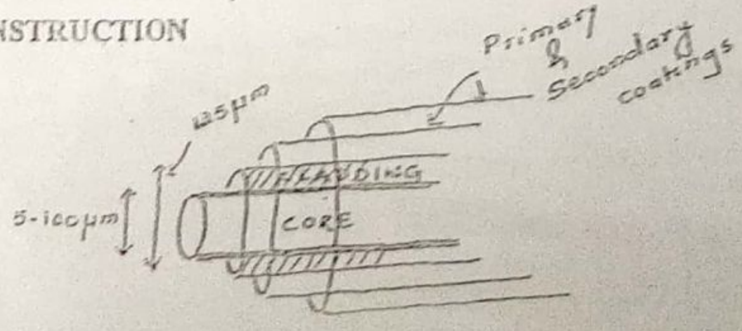
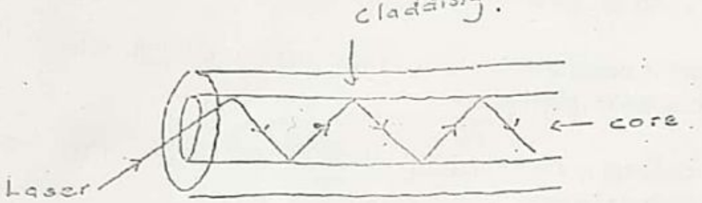


1. The central part of an optical fiber is made up of glass having a diameter of 10-100 μm. This part is called as CORE.
2. CORE is coated with a material having high refractive index.
3. The part surrounding core is called as CLADDING. It is also made up of glass having a diameter of 125 μm.
4. It is coated with a material having low refractive index.
5. In order to protect these glass fibres primary and secondary plastic coatings are provided on it.

WORKING



1. The message which is to be transmitted is superimposed on the laser having high frequency.
2. This laser is made incident on core region of the optical fiber at an angle greater than the critical angle.
3. Since light is travelling from denser medium (CORE) to rarer medium (CLADDING) hence it gets totally internally reflected.
4. In this way laser carrying message is transmitted over long distance through optical fibres.

2) HOLOGRAPHY

Holography is a technique of obtaining a three dimensional image of an object. Such images which are obtained are called as HOLOGRAMS.

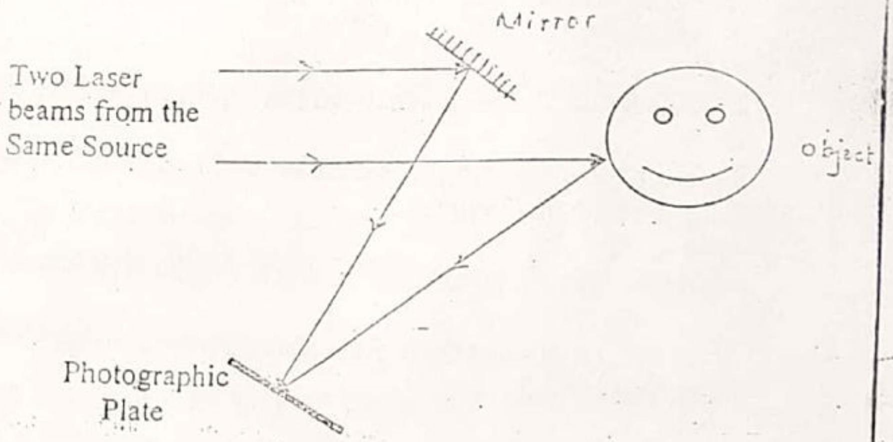
A Hologram contains the information about the variation in INTENSITY as well as variation in the PHASE of light waves reflected from the object. This information is stored in form of interference pattern. Hence in order to observe the image the interference pattern is to be decoded.

Laser is used in holography because it has a very high degree of **coherency**

Thus holography process consists of two parts

1. Construction of Hologram
2. Reconstruction of image from hologram

CONSTRUCTION OF HOLOGRAM



a) A laser beam is first divided into two beams.

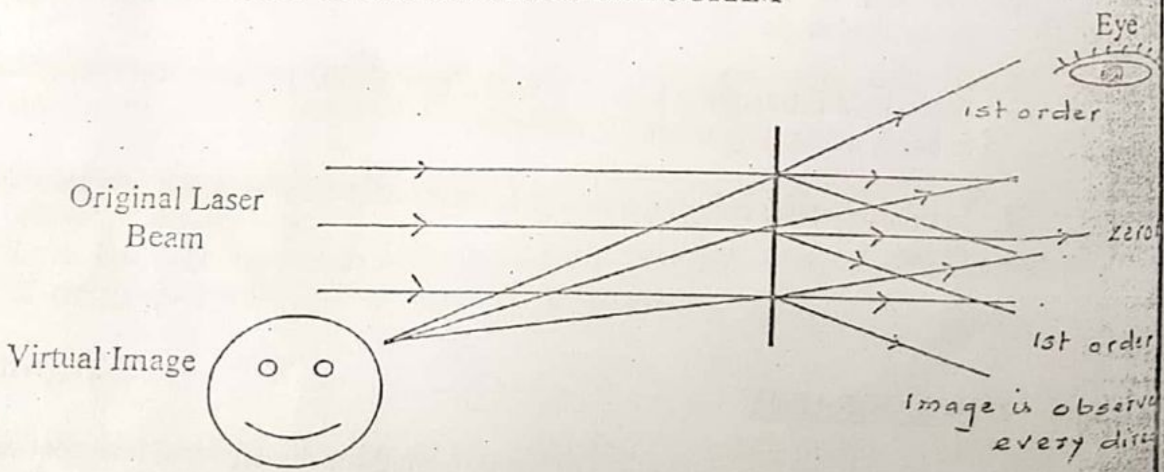
b) One beam is made incident on a mirror and hence it gets reflected. It contains the idea about the original phase.

c) The other beam is made incident on the object. The phase and intensity of the light reflected changes.

d) The two reflected beams are made to interfere and this interference pattern is recorded on a photographic plate.

e) This photographic plate is called as hologram.

RECONSTRUCTION OF IMAGE FROM HOLOGRAM



a) The hologram which is obtained contains interference pattern in the form of dark and bright band.

b) Hence this photographic plate can be used as a diffraction grating. The dark bands of the interference pattern acts as opaque spaces whereas the bright band acts as slits.

c) The diffracted beams from this grating superimpose to produce the image of the object in all directions.

PARTICLE

A particle is called as [illegible] that behaves as a whole unit in terms of its transport and properties.

NANO MATERIALS OR NANO PARTICLES

A material or particle having at least one dimension in the range of 1 to 100 nm

NANO CRYSTAL

If the Nano particles are of single crystalline form then they are called as Nano Crystals.

QUANTUM DOT'S

When the dimensions of nanoparticles is sufficiently small and quantum effects are ~~observed (Process that takes place at atomic level)~~ then QUANTUM DOT'S is the common term used to describe such nanoparticles.

NANOTECHNOLOGY

The research and application of the nanostructured materials into nanoscale devices is called as Nanotechnology

G.M. Mahajan Sir

PROPERTIES OF NANOPARTICLES

1. OPTICAL PROPERTIES

a) Optical properties of Nanomaterials are significantly different from bulk materials.

b) In bulk semiconductors the absorption of light energy is more for longer wavelength of light.

c) But in semiconductor Nanoparticles the absorption of light energy is more for shorter wavelength of light.

d) We know that the observance of colour is an optical property. It has been found out that the colours of nanoparticles changes with their size.

2. ELECTRICAL PROPERTIES

a) Nanoparticles have a very high surface area to volume ratio, as one dimension is very small.

b) Hence there is an increased surface scattering of atoms. Due to this the electrical conductivity decreases.

c) In some Nano materials since the no of atoms are less hence there is a better ordering of microstructures of atoms as compared to that of in a bulk material.

d) Hence conductivity also increases.

3. MECHANICAL PROPERTIES

a) Strength is one of the mechanical property of a material. It has been found out that the strength of Nanomaterials can reach a very high value as compared to that of the bulk material.

b) This is simply due to the reduced probability of defects.

4. STRUCTURAL PROPERTIES

In Nano materials we know that less no. of atoms are present. These atoms are placed in a manner which is different from the arrangements of the atom in the bulk. Hence it has different structural properties.

5. MAGNETIC PROPERTIES

a) We know that magnetic materials have domains. Depending upon orientation of domains magnetic materials are classified into paramagnetic and ferromagnetic materials.

b) Bulk ferromagnetic materials have many domains hence they show hysteresis effect.

c) But in Nanomaterials since the particle size is very small hence many domain formation is not favored and material shows a single domain. Hence they do not show Hysteresis effect.

METHODS OF SYNTHESIS

G.M. Mahajan Sir

1. Physical Methods

Physical methods are divided into two categories

a) Mechanical Method

a) This method is used to make Nano particles in the form of powder.
b) It can be considered as a grinding process.
c) In this method we take help of a ball Mill vessel.
d) It is a container in which hardened steel or carbide ball are present.
e) Material whose Nano particles are to be produced are put in the container. The container is closed with the help of lid.
f) Then it is rotated. Due to this the material is pushed to the walls of the container and it is crushed to fine powder by the steel balls.