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UNIT - 3

SEMICONDUCTORS

Introduction to Semiconductors - Basic Properties of Semiconductors

- The substance whose current conducting properties lies between good conductors and insulators are called "semiconductors" - In the case of semiconductors there exist covalent bond.
- At 0 K semiconductors acts as insulators due to strong covalent bond and at high temperatures they act as conductors due to breaking of covalent bond.
- In the case of semiconductors they have completely filled valence band (CFVB) and completely empty conduction band (CECB).
- They have negative temperature coefficient of resistance because their resistivity decreases with increase in temperature.
- They have two types of charge carriers namely Electrons and Holes.
- Semiconductors are available both in elemental and compound form. Compound semiconductors are formed by adding 3^{rd} and 5^{th} group elements (or) 2^{nd} and 4^{th} group elements.
- Semiconductors are tetravalent in nature i.e., atoms of semiconductors contains 4 valence electrons in their outermost orbital.

- Charge carriers in semiconductors can be moved under the process called drift and diffusion.
- Semiconductors are bipolar in nature, because they contains two types of charge carriers.
- Semiconductors are extensively used in solid state electronic devices.
- Conductivity of semiconductors can be enhanced by adding impurities.

Semiconductors are basically divided into two types

1. Intrinsic Semiconductors
2. Extrinsic Semiconductors

Intrinsic Semiconductors

- The semiconductors in pure form are called Intrinsic semiconductors.

(or)

- The semiconductors in which charge carriers are produced by thermal agitation are called Intrinsic semiconductors.

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- Frequently available elemental semiconductors are silicon and germanium, they belongs to IV th group of periodic table, they are tetravalent. To get stability each of these atoms makes four covalent bonds with surrounding of four neighbouring atoms.
- The two-dimensional representation of silicon intrinsic semiconductor at 0 K along with energy band structure as shown in the below diagram

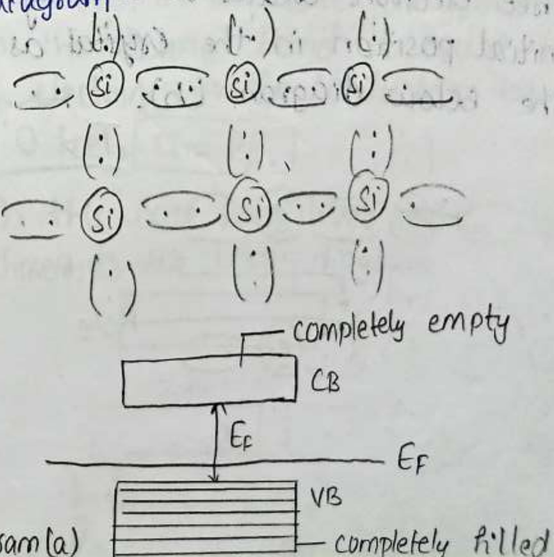
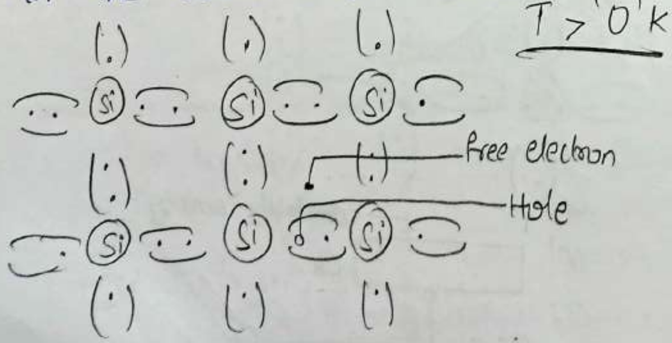


Diagram (a)

- At 'O'K all valence electrons are strongly bound to their atoms and actively participate in the covalent bond formation.
- As a result, there is no free electrons are available for conduction and it acts as insulator.
- Under this situation energy band diagram contains completely filled valence band and completely empty conduction band with fermi level exactly in between them as shown in the above diagram (a).
- At T > 'O'K, the valence electrons acquires sufficient amount of thermal energy. As a result of that breaking of covalent bond takes place releasing free electrons.
- These free electrons creates a vacancy in its initial position in the crystal as shown in the below diagram (b).



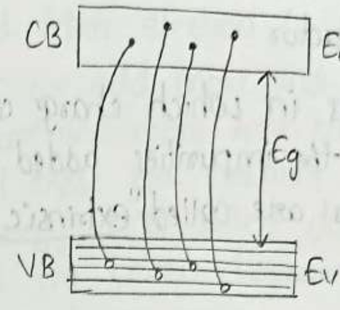
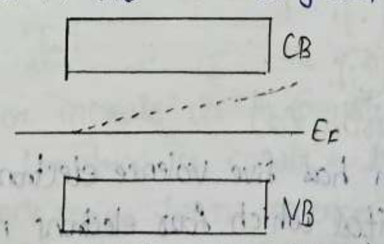


Diagram (b)

- This vacancy is called a hole and is assumed to carry a positive charge equivalent to charge of electron.
- This free electrons due to acquiring sufficient ~~energy~~ thermal energy cross the energy gap enter into the conduction band from valence band.
- Thus valence band has holes and conduction band has electrons.
- Therefore, in this case the number of holes in the valence band is equal to number of electrons in the conduction band.

i.e., $\boxed{n = p}$

- In this case fermi levels slightly shifts as shown in the below diagram



Extrinsic Semiconductor

- The semiconductors in which charge carriers are produced by the impurities added to pure semiconductors are called "extrinsic semiconductors".

- Based on the type of impurities added to extrinsic semiconductors are divided into two types they are:
  1. N- type extrinsic semiconductors
  2. P- type extrinsic semiconductors

N - type Extrinsic Semiconductor

- When small amount of pentavalent impurity (V group elements) such as aresenic is added to the intrinsic semiconductor. Then impurity atoms occupy one of the position of the silicon atoms as shown in the below diagram (a)

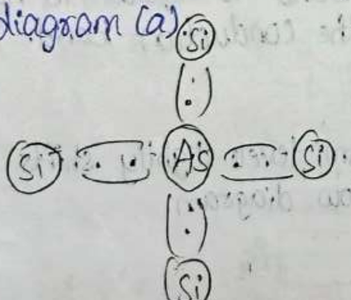
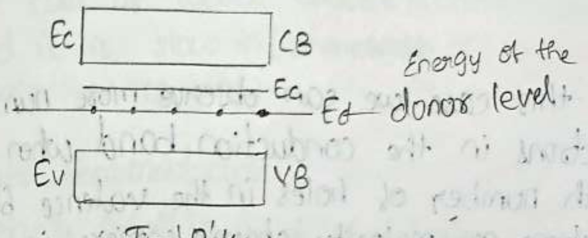


Diagram (a)

- Aresenic atom has five valence electrons in its outermost orbital which four electrons makes a covalent bond with adjacent silicon atoms and fifth electron is becomes free electron.

- If we add more and more arsenic atoms, more and more free electrons are produced. All these free electrons occupies a special energy level called donor level as shown in the below diagram (b).



- This is the case when T = '0'K in this case Fermi level E_F lies exactly in between donor level and conduction band.

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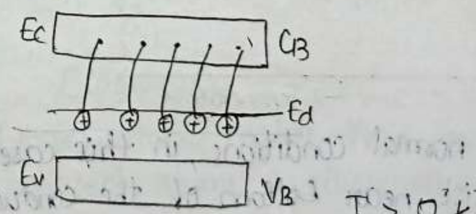
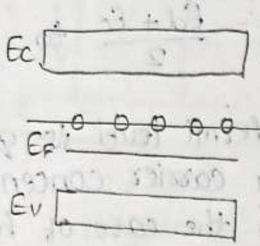
- If temperature is increased above '0'k, by receiving that thermal energy in the donor level makes a transition from donar level (E_d) to Conduction band as shown in the below diagram (c)

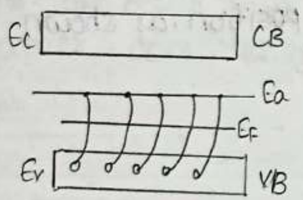


- Further increase in temperature T = 300K, makes breaking of covalent bonds due to this electrons moves from valence band to conduction band as shown in the diagram. (d) energy level is called acceptor level. as shown in the below diagram (b).



Diogrom (b) T = 0'K

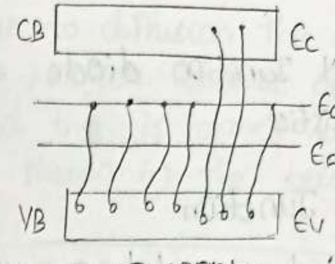
- As a temperature of P-type semiconductor the electrons move from valence band to Ea (acceptor level) as shown in the below diagram (c)



T > 0'k

diogrom (c)

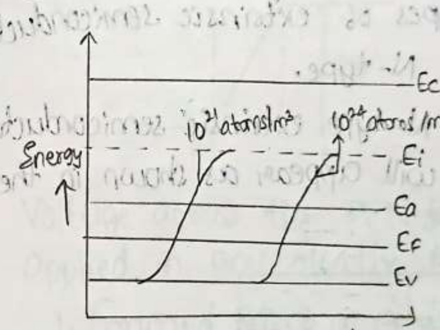
- At high temperature T = 300k due to breaking of covalent bonds more and more electrons move from valence band to conduction band. As a result of that there exist more holes in the valence band than number of electrons in the conduction band i.e., $p > n$ as shown in the diagram (d)



T = 300K

diagram (d)

Variation of fermi level with temperature and carrier conductors in P-type semiconductor



- In this case initially fermi level lies between acceptor level and valence band. When temperature increases above '0'K same of the electrons in the valence band moves to acceptor level.
- At high temperature (T = 300k) due to breaking of covalent bond more and more valence electrons moves from valence band to conduction band.
- Due to this fermi level shifts from $E_F = \frac{E_v + E_a}{2}$ to intrinsic level E_i.
- But for same temperatures shifting of fermi level is quick for low carrier concentration when compared with higher carrier concentration.

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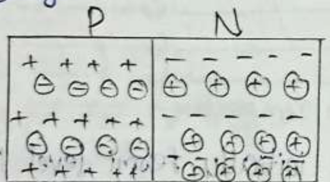
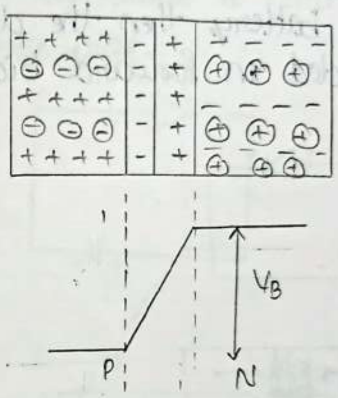
Formation of P-N Junction diode and its V-I Characteristics

Formation of P-N Junction

- When P-type & N-type crystals are used separately conducts just like any poor conductors. Almost all semiconductor devices which are in use today are combination of the two types of extrinsic semiconductors. i.e., P-type and N-type.
- When P-type & N-type extrinsic semiconductors are joined it will appear as shown in the below diagram



- Here, uncircled charge i.e., positive charges on P-side and negative charges on N-side are charge carriers, whereas circled charges i.e., negative charges on P-type and positive charges on N-type are called immobility donors and acceptors.
- On P-side of the junction large number of free holes exist and on N-side of the junction large number of free electron exist.
- Due to diffusion this charge carriers cross the junction because of this potential barrier and this is formed between this region as shown in the below diagram.



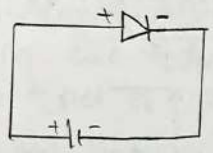
- Voltage across the P-N junction may be applied in any of the following two ways:
  1. Forward Bias
  2. Reverse Bias

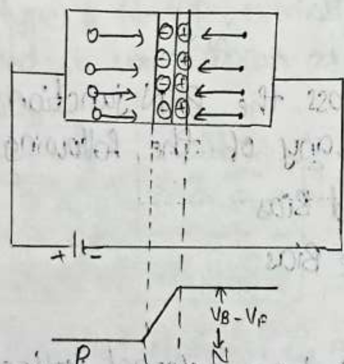
Note:

Biasing - Applying external voltage to the junction diodes is called biasing.

1. Forward Bias

- When P-region of the diode is connected to positive terminal of the battery and N-region of diode is connected to negative terminal of the battery then the diode is said to be connected in forward bias.

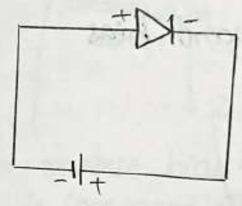


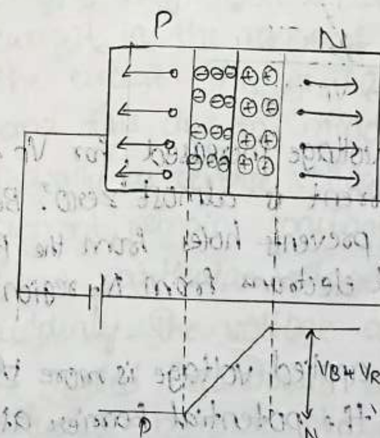


- Under forward bias majority charge carriers from respective regions moves towards the junction and hence '<u>junction thickness decreases</u>'.
- As a result of that barrier height decreases, due to decrease in junction resistance p-n junction diode allows current to flow in the external circuit.

2. Reverse Bias

- When P-region of a diode is connected to negative terminal of the battery and N-region is connected to positive terminal of the battery then the diode is said to be connected in reverse bias.





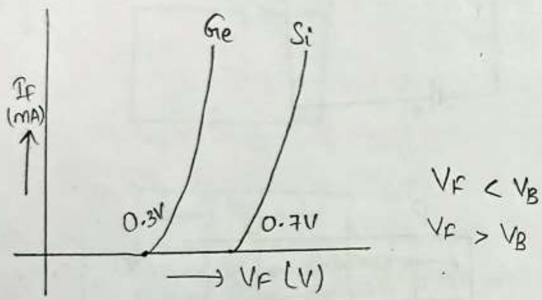
- Under reverse bias majority charge carriers moves away from the junction, and hence '<u>junction thickness increases</u>'.
- As a result of that barrier height ($V_B + V_R$) increases. Due to increase in junction resistance p-n junction diode does not allows current to flow in the external circuit.

Conclusion:

Hence P-N junction diode allows current under forward bias and it does not allows current in the reverse bias.

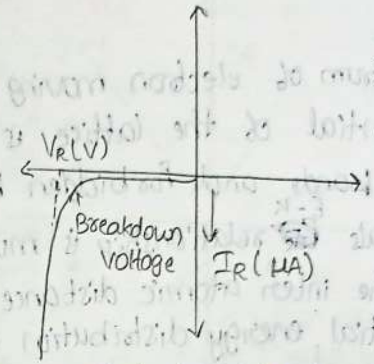
V-I characteristics of P-N junction diode -

1. Characteristics of forward bias



- As the forward voltage increased, for $V_F < V_B$, the forward current is almost 'zero'. Because potential barrier prevents holes from the P-region to N-region and electrons from N-region to P-region.
- for $V_F > V_B$ (if applied voltage is more than the barrier potential) the potential barrier at the junction completely disappears and hence charge carriers flows across the junction. As a result of that current flow is different for different materials as shown in the above diagram. The voltage at which current raises suddenly is called knee voltage (or) threeshold voltage.

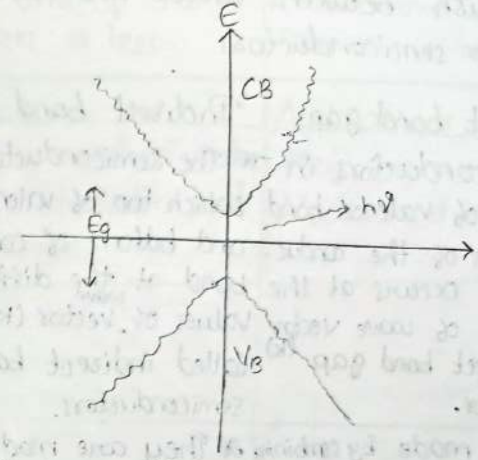
2. Characteristics of Reverse Bias



- Under reverse bias the barrier voltage of the diode is increased. Therefore the diode resistance becomes very high. In practise very small current in the range of micro amps flows in the circuit. This is called Reverse current and this due to minority charge carriers.
- Initially as reverse voltage increases, reverse current remains constant upto certain voltage.
- At a particular voltage reverse current raises suddenly. The voltage at which it happens is called Breakdown voltage. At this situation minority charge carriers gets enough energy to break to the junction. As a result the junction is destroyed.

Direct band gap and Indirect band gap Semiconductors

- Energy spectrum of electron moving in a periodic potential of the lattice is divided into allowed bands and forbidden bands.
- In real crystals E-K relationship is much more complicated. The inter atomic distance and the internal potential energy distribution vary with directions in the crystal.
- Hence the E-K relationship and energy band formation is depends on the orientation of the electron wave vector to the crystalographic axis.
- In few crystals (or) semiconductors like Silicon the maximum of valence band does not occur at the same value of wave vector 'k', as that of minimum of conduction band as shown in the below diagram (b).
- In few crystals like galium, arsenaid (Ga, As) the maximum of valence band occurs at the same value of 'k' (wave vector) as that of minimum conduction band as shown in the below diagram (a).



Diagram(a)

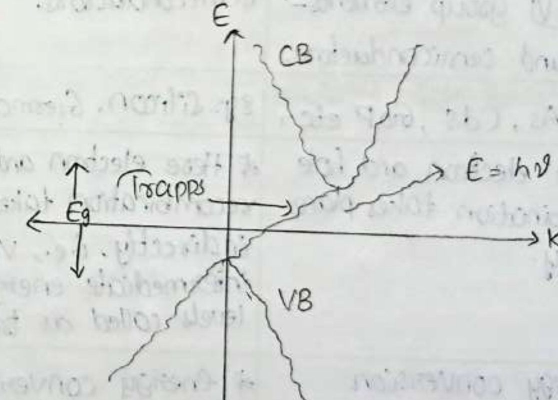


Diagram (b)

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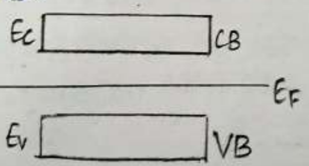
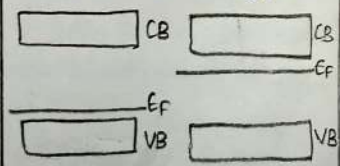
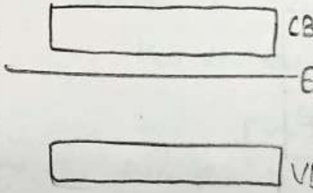
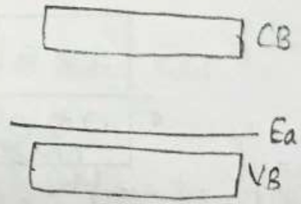
Distinguish between Direct and Indirect band gap semiconductors

Direct band gap	Indirect band gap
* The semiconductors in which top of valence band and bottom of the conduction band occurs at the same value of wave vector (k) is called direct band gap semiconductor.	* The semiconductors in which top of valence band and bottom of conduction band at the different values of wave vector (k) is called indirect band gap semiconductors.
* They are made by combining III & V group elements or II & VI group elements - compound semiconductors.	* They are made of single elements - Elemental semiconductors.
Eg: GaAs (Gallium arsenide), CdS (Cadium sulphide), GaP (Gallium phosphate) etc.,	Eg: Silicon, Germanium.
* Here electron and hole recombination takes place directly.	* Here electron and hole recombination takes place indirectly, i.e., via intermediate energy levels called as traps.
* Energy conversion efficiency is more.	* Energy conversion efficiency is less.
* Here due to direct recombination of electron & holes and releases only photons.	* Here due to indirect recombination phonons (thermal vibrations) are produced along photons.
* Life time of charge carriers is less.	* Life time of charge carriers is more.
Applications: They are used to make LEDs, Photo diodes and laser diodes.	Applications: They are used to make diodes and transistors.

Distinguish between Intrinsic and Extrinsic Semiconductor.

Intrinsic Semiconductor	Extrinsic Semiconductor
* Intrinsic semiconductors are in pure form	* Extrinsic semiconductors are impure form.
* Charge carriers are produced due to thermal agitations.	* charge carriers are produced by added impurities.
* Low electrical conductivity	* High electrical conductivity
* Low operating temperature.	* High operating temperature
* At '0'k, fermi level exactly lies between valence band and conduction band. 	* At '0'k, fermi level lies between E_v & E_g for P-type and between E_d & E_c for N-type.  P-type N-type
Eg: Silicon & Germanium	Eg: Silicon & Germanium doped III & V group elements.

Distinguish between N-type & P-type semiconductor

N-type Semiconductor	P-type Semiconductors.
* N-type semiconductors are obtained by doping intrinsic semiconductor with pentavalent impurities	* P-type semiconductors are obtained by intrinsic semiconductors with trivalent impurities.
* Here electrons are majority charge carriers and holes are minority charge carriers.	* Here electrons are minority charge carriers and holes are majority charge carriers.
* There exist donor level (E_d) nearer to conduction band. 	* There exist acceptor level (E_a) nearer to valence band. 
* At T > '0'k donor level readily donates electrons to conduction band.	* When T is increased acceptor level readily accepts electrons from valence band.

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HALL EFFECT AND ITS APPLICATIONS:

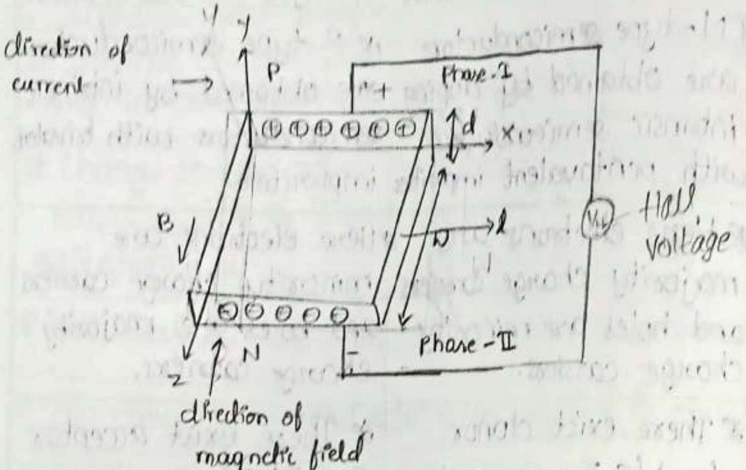
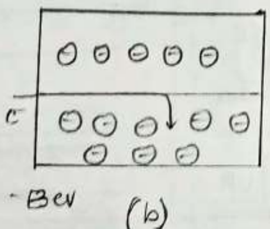


diagram (a)



(b)

When a piece of metal or semiconductor carrying a current is placed in a transverse magnetic field an electric field is produced inside the conductor in a direction normal to both the current and magnetic field. This phenomena is known as Hall effect and the voltage so developed is called "Hall voltage".

→ considering an e^- in n type material to which current is applied allowed to pass along x-direction from left to right and magnetic field applied in Z-direction as a result Hall effect voltage i.e produced as shown in the diagram(a).

→ Since the direction is from left to right, the electrons move from left to right to left in x-direction as shown in the diagram (b). Now due to the magnetic field applied the e^- moves downwards direction with velocity (v) and it cause the -ve charge to accumulate at phase-I of the material.

→ Therefore the potential difference is established between phase I and phase II of this specimen which gives raise to electric field (E_F) in the negative direction

Here the force due to electric field

$$F = -eE_H \quad \text{—} ①$$

→ The force due to magnetic field

$$F = -Bev \quad \text{—} ②$$

* Therefore at equilibrium condition the force due to electric field is equal to the force due to magnetic field i.e ① = ②

$$-eE_H = -Bev \quad \text{—} ③$$

$$E_H = BV \quad \text{—} ④$$

→ Now the current density J_x along the x-axis

$$J_x = -nev \quad \text{—} ⑤$$

$$\frac{-J_x}{ne} = V \quad \text{—} (6)$$

→ substitute eqn (6) in eqn (4)

$$E_H = \frac{-BJ_x}{ne}$$

$$\boxed{E_H = BJ_x \cdot R_H} \quad \text{—} (7)$$

where $\left| R_H = \frac{-1}{ne} \right.$ — (8)

→ Here R_H is called "Hall coefficient"

→ In equation (8) -ve sign indicates that the field is developed along -ve Y-direction

Hall coefficient in terms of Hall voltage.

→ If the thickness of the sample is 't' and the voltage is "V_H"

$$\boxed{V_H = E_H t} \quad \text{—} (9)$$

Substitute eqn (7) in eqn (9)

$$V_H = BJ_x R_H t \quad \text{—} 10$$

→ If 'b' is the width of the sample, then area of the sample is equal to 'bt'

area = bt

→ Therefore current density $J_x = \frac{I_x}{bt}$ — (11)

Substitute eqn (11) in Eqn (10)

$$\Rightarrow V_H = B \cdot \frac{I_x}{bt} \cdot R_H t$$

$$V_H = B \cdot \frac{I_x}{b} \cdot R_H$$

$$\boxed{R_H = \frac{V_H b}{BI_x}}$$

CONCLUSION :

In this equation b, B, I_x are constants, Therefore hall coefficient depends on Hall voltage.

APPLICATIONS

→ Using hall effect one can determine whether a given semiconductor is p-type or n-type.

→ Using Hall effect one can calculate carrier concentration

$$\boxed{n = \frac{-1}{eR_H}}$$

→ It is used to find mobility of the charge carriers

$$\boxed{\mu = \sigma R_H}$$

→ It is used to design magnetic flux meters.

→ It is used to determine sign of the charge carriers

If hall coeff (R_H) is -ve the sample is n-type

If R_H is +ve the sample is P-type.

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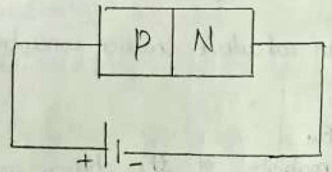
Semiconductor Devices

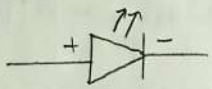
LED - Light Emitting Diode

Introduction

LED is a P-N junction device which emits light when forward bias by a phenomena called "Electro luminescence". LED under forward bias and its symbol is shown in below diagram



LED under forward bias



LED

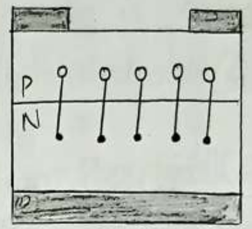
Principle:

When LED is forward biased the electrons and holes moves towards the junction and recombination takes place. As a result of recombination energy releases in the form of light.

$$e^- + e^+ \rightarrow h\nu$$

The brightness of emitted light is directly proportional to the forward biased current.

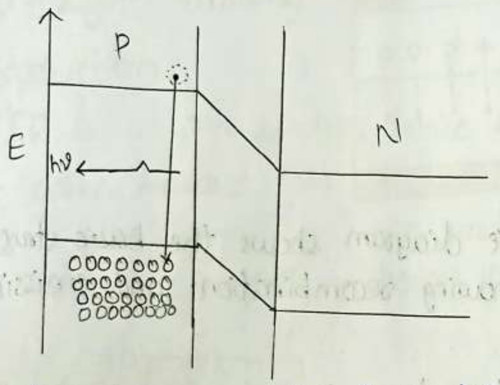
Construction:



The above diagram shows the basic structure of LED showing recombinations and emission of light.

- Here N-type layer is grown on a ~~substraight~~ substrate, a p-type layer is deposited on it by diffusion process. Since carrier recombination takes place in p-layer it is kept upper most, metal anode connections are made at the outer edge of the P-layer.
- So as to allow more central surface area for light to escape.
- A metal film (coated with gold or silver) is applied to the bottom of the substrate, for reflecting as much light as possible to the surface of the device and also to provide cathode connections. LEDs are ~~always~~ always enclosed to protect their delicate wires.
- The efficiency of generation of light increases with the injection current and with a decrease in temperature.

Working principle:



When LED is under forward bias majority charge carriers from both N & P regions moves towards the junction and they will recombine at the junction region as a result of that emission of photons (radiations) takes place as shown in the above energy band diagram.

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Output Wavelength

LEDs radiates different colours such as red, green, yellow, organge and white. Some of the LEDs emit infrared light (invisible).

- The wavelength of the emitted light depends upon the type of material used (i.e., on energy gap) as given by $E_g = h\nu$

$$= \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E_g}$$

where h is planck's constant
C is velocity of light
Eg is energy band gap.

- Gallium Aresnoid (GaAs) - IR radiation (invisible)
- Gallium Phosphide (GaP) - Red (or) Green
- Gallium Aresnoid phosphide (GaAsP) - Red (or) Yellow
- In order to protect LEDs the resistance 1kΩ (or) 1.5kΩ must be connected in series with LED.
- They operate voltage levels from 1.5 to 3.3volts with the current of milli amps.
- Power requirements is typically from 10 to 150 milli watts. LEDs can be switched ON and OFF at the faster rate of the order of 1ms (milli second).

Advantages

1. Life of the LED is more.
2. No heat or ultra voilet emissions are released from LEDs.
3. Instant lightning and ability to withstand for frequent switchings.

Disadvantages

1. High upfront cost.
2. Over heating causes reduced lamp light.
3. Potential colours shifts over lamp lights.

Applications

1. LEDs are used in instrument displays.
2. It is used in calculators.
3. It is used in digital clocks.
4. It is used for indicating power ON and OFF.
5. It is used for optical switching applications.
6. It is used in optical communications.
7. It is used for solid state video display.

03/07/2023

PIN - Photo Diode

For processing the light signals at the receiving end of the communication system we require a device to convert light signals ~~or~~ into electrical signals

The device used for this purpose is called a photo diode.

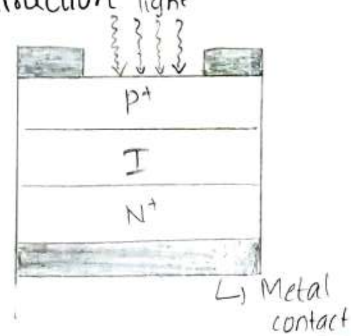
. Photo diode is a reverse biased P-N junction diode which converts light energy into equivalent ~~er~~ electrical energy.

Principle

. This diode works under reverse bias. Under reverse bias, when the light is made to fall on the neutral or intrinsic region (I) electron-hole pairs are generated.

. These electron-hole pairs are accelerated by an external electric field which results in "photo current". Thus the light is converted into electrical signals.

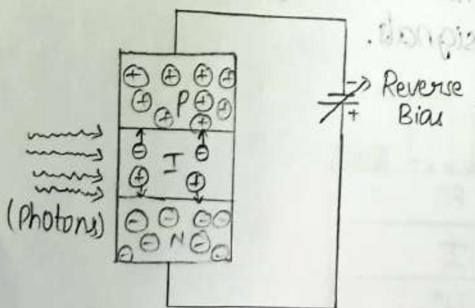
Construction



04/7/23

- The structure of a PIN-photo diode is shown in the above diagram.
- Planar structure of PIN diode consist of a substrate on which N-material is grown above intrinsic layer. Again p-material is grown on intrinsic layer either by diffusion or by an ion implantation.
- In this case both P & N-materials are heavily doped; whereas intrinsic layer is lightly doped.
- Here, P & N-materials made of silicon, the intrinsic layer is made as large as possible in order to absorb more of the incident radiation.
- Since P & N-regions are separated by intrinsic regions, it is also called as "PIN Photo diode"

Working principle



- The PIN Photo diode is connected with reverse bias as shown in the above diagram.
- Now, when a photon of energy having greater than band gap energy of a photo diode ($h\nu > E_g$) electron-hole pairs are created in the intrinsic layer.
- Due to addition of intrinsic layer between P-type & N-type, width of the depletion layer increases as a result of that more photo current will be produced which flows in the external circuit.
- Photo diode acts as a "linear device", because the photo current is directly proportional to the optical power incident on the PIN photo diode.

Applications:

1. They are used in microwave attenuators.
2. Radio frequency attenuators.
3. They are used in photo detector devices.
4. They are used in microwave switching.
5. They are used in radio frequency switching.

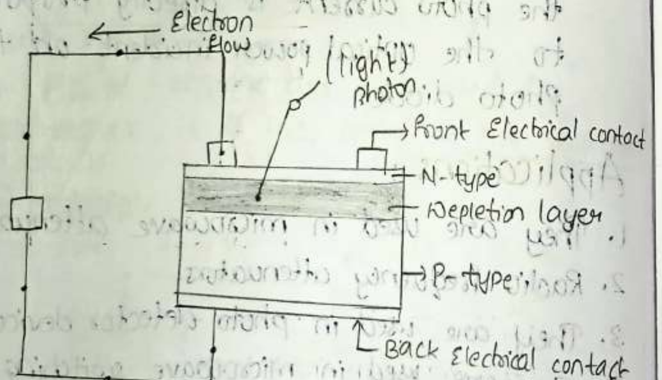
SOLAR CELL

Introduction

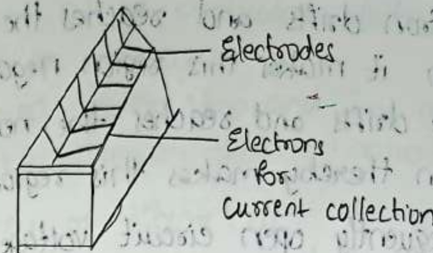
A Solar cell is an electronic device that converts the energy of light directly into electricity by the phenomena called Photovoltaic effect. It is also called Photovoltaic cell.

- Using this effect the generation of voltage and electric current in a material upon explosure to light.

Construction:

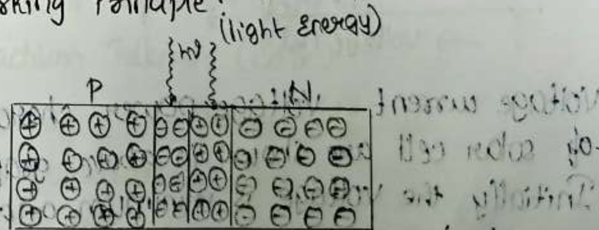


- Very thin layer of N-type semiconductor is grown on a relative thicker P-type semiconducting material, front electrical contacts (electrodes) are made on N-type layer which will not obstruct incident light to reach thin N-layer.



- Below N-type layer there is a P-N junction consist of depletion layer. Also there is a provision of electrodes at the bottom of the P-type layer.
- This entire assembly is encapsulated by thin glass to protect the solar cell from any mechanical shocks.
- Within anti reflecting coating on the surface reduces the reflections and allows more light to enter the device.

Working Principle:

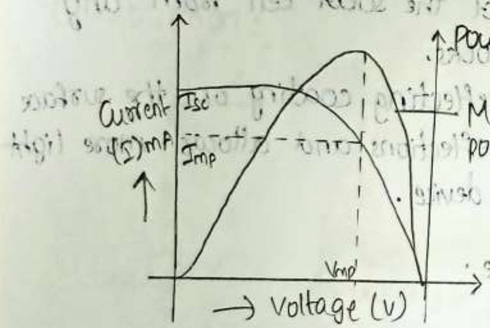


- When exposed to sunlight, the absorption of incident radiation creates electron-hole pairs in the depletion layer.
- Electron-hole pairs are immediately separated by build in field in the depletion layer

which drifts them apart.

- The electron drifts and reaches the neutral, N-region it makes this region negative. Similarly the hole drifts and reaches the neutral, P-region thereby makes this region positive.
- And consequently open circuit voltage is developed. If an external voltage is applied then the excess electrons on N-side can travel around the external circuit, do work and reach P-side to combine with excess holes over there.

Solar cell characterstics:



- Voltage current - Voltage power characteristics of solar cell are shown in above graph. Initially the voltage is minimum and the current is maximum, as voltage increases current remains constant upto certain voltage after that it reaches minimum and decreases. Similarily at low voltage power is minimum as voltage increases, the power also increases and it becomes maximum at a particular voltage, after that it decreases.
- The area under Vmp and Imp gives the amount of power that is generated.

Efficiency of solar cell

$$\text{Fill factor} = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}}$$

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} \times 100$$

$$= \frac{V_{oc} \times I_{sc} \times FF}{P_{in}} \times 100$$

(FF = fill factor)

Where, P_{in} is the power of incident sunlight.

Materials used

1. Silicon
2. Gallium Aresnoid (GaAs)
3. Cadium Telluride (CdTe)

Advantages of Solar cell

1. No pollution
2. Long life
3. Low maintaineance

Disadvantages of solar cell

1. High Installation cost
2. Low efficiency

3. During night time and cloudy days it will not give much output.

Applications

1. It is used to charge batteries.
2. It is used in light meters.
3. It is used in power calculators and smart watches.
4. It is used mainly in space crafts.

07/07/23

UNIT-IV

LASER

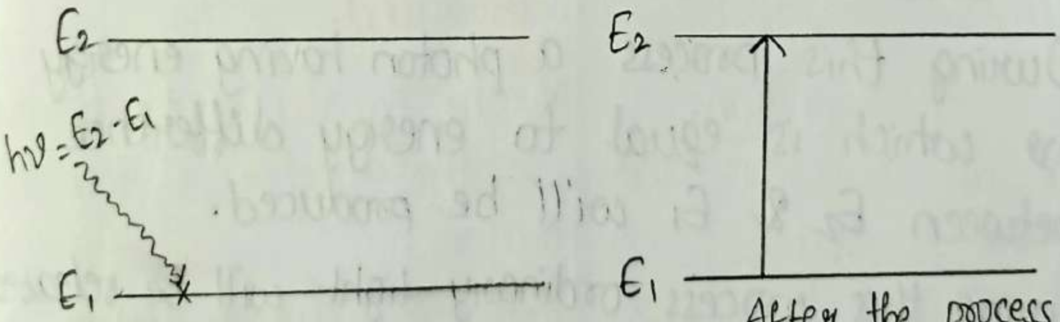
Light Amplification by Stimulated Emission of Radiation — Due to spontaneous Emission

Basic definitions of the laser

1. Stimulated Absorption
2. Stimulated Emission — LASER
3. Spontaneous Emission

Stimulated Absorption:

The process of particle transfer from lower energy level to higher energy level by using external energy is called stimulated absorption and the process is shown in the below diagram

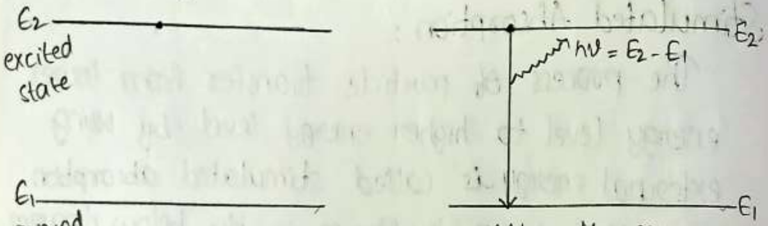


This process takes place when photon of energy $h\nu$ having energy difference between two energy levels $(E_2 - E_1)$ falls on an atom at ground state.

Spontaneous Emission:

The process of particles in an atom transfer from higher energy level to lower energy level without external energy is called "spontaneous emission."

- This process takes place naturally when particle moves from ~~higher~~ excited state to ground state after the lifetime in the excited state (10^{-8} secs) as shown in the below diagram.



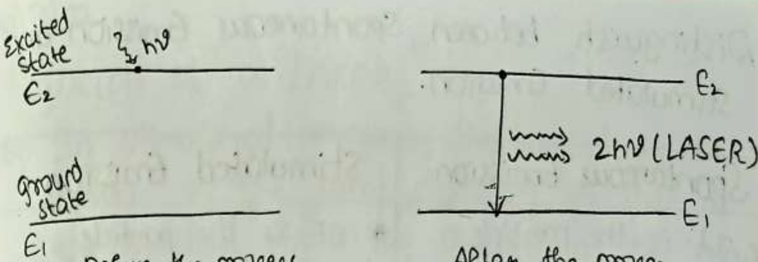
Before the process After the process

- During this process a photon having energy $h\nu$ which is equal to energy difference between E_2 & E_1 will be produced.
- During this process ordinary light will be released.

Stimulated Emission:

The process of particle in an atom from higher level to lower level with the help of external energy is called "stimulated emission."

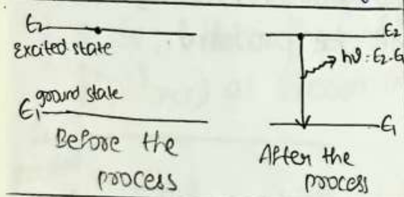
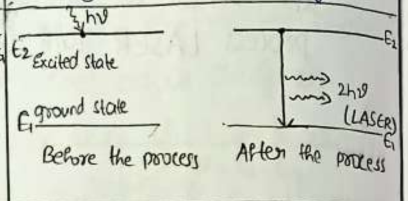
- During this process two photons are produced as shown in the diagram



Before the process After the process

- Out of which one is stimulating photon and the other is stimulated photon. During this process LASER light will be produced.

Distinguish between Spontaneous Emission and Stimulated Emission.

Spontaneous Emission	Stimulated Emission
* It is the particle transfer from higher level to lower level without taking external energy.	* It is the particle transfer from higher level to lower level ~~with~~ by taking external energy.
	
* Single photon released during this process.	* Two photons releases during this process.
* Ordinary light will be produced.	* LASER light will be produced.
* The emitted photons travels all direction and they are random.	* The emitted photon travels in the direction of incident photons.
* The emitted radiation is less intense and is incoherent.	* The emitted radiation is more intense and is coherent.
* The photons are not in phase i.e., there is no phase relation between them.	* The photons are in phase i.e., there is constant phase difference between them.
* It is slow process when compared with stimulated emission.	* It is fast process when compared with spontaneous emission.

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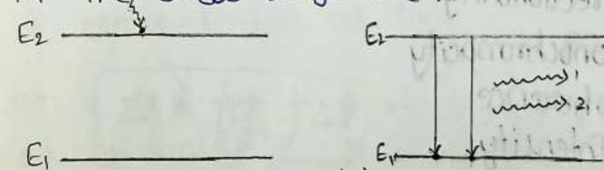
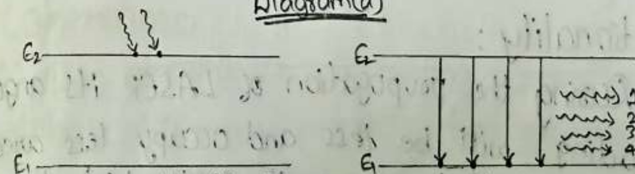
Principle of a LASER:

* In stimulated emission, the emitted light travels in the same direction as that of the incident photon as shown in the below diagram (a). Now these ~~ph~~ emitted two photons stimulate two more atoms (photon) from excited state to ground state as a result of that four photons will be released as shown in the below diagram (b).

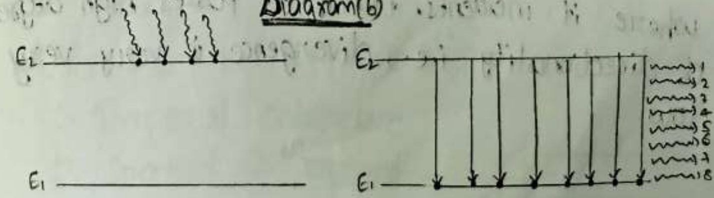
* These four photons again stimulates four more atoms in the excited state as a result of that eight photons will be produced as shown in the below diagram (c).



Diagram(a)



Diagram(b)



Diagram(c)

* Again these 8 photons stimulates 8 more atoms in the excited state as a result of that 16 photons will be released.
* These ~~multication~~ multiplication process continuous till the radiation produced in a laser device gets LASER properties. This process is called principle of LASER.

11/7/23

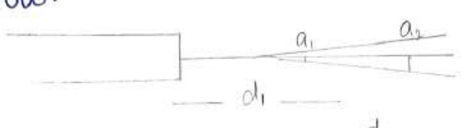
Characteristics of LASER

LASER light is different from conventional light source (ordinary light) in a number of ways. The following are the characteristics of the LASER beam they are:

1. Directionality
2. Monochromacity
3. Coherence
4. Intensity

Directionality:

During the propogation of LASER its angular spreading will be less and occupy less area where it incidents. Hence it posses high degree of directionality i.e., divergence is very very low.



As shown in the diagram if a_1 & a_2 are the diameters of LASER light after travelling a distance of d_1 & d_2, then the angle of divergence can be expressed as

$$\phi = \frac{a_2 - a_1}{2(d_2 - d_1)}$$

Monochromacity:

The property of exhibiting a single wavelength by a light is called "monochromacity".

- When it is sent through a prism then a single line will be appeared in the optical spectrum.
- The degree of a monochromacity of a LASER is expressed with the following equation

$$\Delta\lambda = \left(\frac{-C}{\nu^2}\right)\Delta\nu$$

Coherence:

The property of exhibiting zero (or) constant phase difference between two or more waves is known as "coherence".

- Coherence is of two types
  1. Temporal coherence
  2. Spatial coherence

① Temporal Coherence

If there exist either zero (or) constant phase difference between two light fields measured at two instants at same point then the wave is said to have temporal coherence.

② Spatial coherence

If there exist either zero (or) constant phase difference between two points on a wave front measured at single instant of time then the wave is said to have spatial coherence.

Intensity

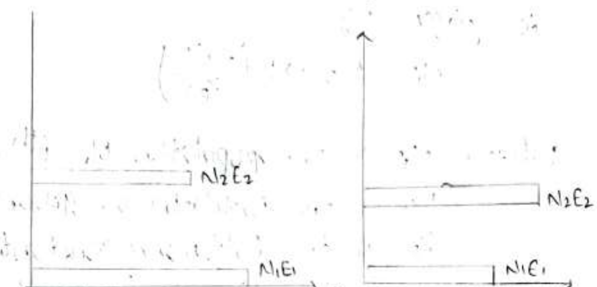
LASER light is highly intense light source and also brighter. This is because of coherence and directionality. Due to negligible divergence LASERs are highly intense and are able to produce high temperatures.

12/7/23

Population Inversion

In general the number of atoms in lower energy level is always larger than the number of atoms in higher energy level i.e., $N_1 > N_2$.

- Actually to get a LASER beam from LASER device their should be more number of atoms in higher energy level when compared with number of atoms in the lower energy level i.e., $N_2 > N_1$.
- For this population of ground state and excited state should be inverted i.e., making more number of atoms in higher energy level when compared with lower energy level is known as population inversion.



$N_1 > N_2$ Before Population Inversion

$N_2 > N_1$ After Population Inversion

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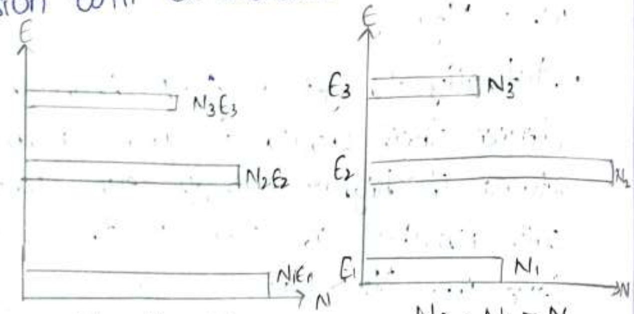
In three level energy scheme is shown in the below diagram, when we supply energy to the atoms it makes a transition from E_1 to E_2 as a result of that population inversion will be acheived.



$N_1 > N_2 > N_3$ $N_3 < N_2 > N_1$

Before Population Inversion After Population Inversion

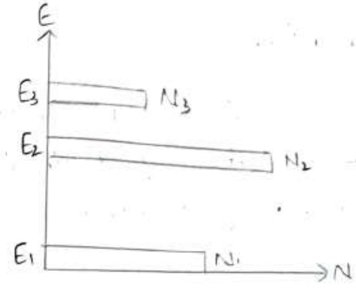
As we move from lower energy level to higher energy level, population decreases as per equation called Boltzmann Distribution law is given by

$$N_i = N_0 \exp\left(\frac{-E_i}{K_B T}\right)$$

where N_i is the population of ith energy level
N_0 is the population of ground state.
K_B is the boltzmann constant
T is the absolute temperature
E_i is the energy of ith energy level

Metastable state

The excited state having longer life time is called "metastable state". It is the energy state which posses a lifelite of the order of 10^{-3} secs.



$N_3 < N_2 > N_1$

- The role of metastable state is very important in achieving population inversion which is essential to get a beam from a LASER device. In the diagram, E_1 is the ground state, E_2 is the first excited state (meta stable state) and E_3 is the second excited state.
- Population inversion is acheived always in metastable state and its lower energy state.
- Because of its longer life time meta stable state accomodates more number of atoms and it recollects the more and more photons.
- At one moment population of metastable state increases when it compares with its lower energy state.

- As soon as population inversion condition is acheived between metastable state and its lower energy state, all the atoms makes transition and emits the LASER beam.

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Pumping Mechanism

The process of raising more number of atoms to excited state by artificial sources is called as pumping process.

(or)

The process of achieving population inversion is called pumping process.

- There are several methods by means of which population inversion can be achieved.
- Some of the most common methods are:
  1. Optical Pumping
  2. Electric Discharge Pumping
  3. Inelastic atom-atom collision
  4. Direct conversion
  5. Chemical reaction

Optical Pumping:

Here the atoms are excited with the help of photons emitted by an external optical source. The atoms absorbs energy from the photons and rises to excited state.

- These types of pumping mechanisms are used in solid state LASERs.

Eg: Ruby LASER, Nd-YAG LASER

Electric Discharge Pumping:

Here the electrons are accelerated to very high velocities by strong electric field and they collides with gas atoms, so that they will raised to excited states.

- These types of pumping mechanisms are generally used in gas LASERs.

Eg: He-Ne LASER, CO_2 LASER

Inelastic atom-atom collision:

In this method a combination of two types of gases are used, i.e., A and B. Both moving nearly coinciding excited states i.e., A^* & B^*.

- During electric discharge method 'A' atoms gets excited due to collision with electrons i.e., $\bar{e} + A \longrightarrow A^*$

- This excited A^* atoms now collides with 'B' atoms, so that B goes to excited states and become B^*.

  i.e., $A^* + B \longrightarrow B^*$

- These type of pumping mechanisms is generally used in gas LASERs only.

  Eg: He-Ne LASER, CO_2 LASER

Direct conversion:

Due to electrical energy applied in direct band gap semiconductors like GaAs etc., the combination of electrons and holes takes place hence electrical energy is converted into light energy directly.

Eg: Semiconductor LASER

Chemical Reaction:

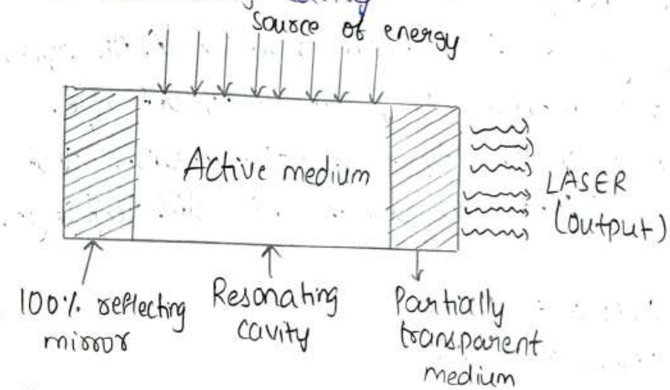
Due to some chemical reactions the atoms may be raised to excited states.

Eg: Dye LASERs

Block Diagram of a LASER

Block diagram of a LASER consist of three parts. They are:

1. Source of Energy
2. Active medium
3. Resonating cavity



Source of energy

In order to send particles from lower energy level to higher energy level i.e., to acheive the process of population inversion, source of energy is required.

- Using source of energy we can supply the energy to the particles (atoms) to the ground state, like this so many ways using different pumping mechanisms.

15/7/23

Active Medium:

The medium in which population inversion takes place is called active medium.

- Active medium provides required energy levels for lasing action. To get the LASER beam from the lasing action.
- To get a LASER beam from a LASER system, active medium plays an important role.
- Based on the type of active medium that is used, LASERs are divided into different types like
  (i) Solid state LASER
  (ii) Liquid state LASER
  (iii) Gas LASERs
  (iv) Semiconductor LASERs
  (v) DYE LASERs

Resonating Cavity (or) Optical Resonator

The optical resonator constitutes an active medium kept in between 100% reflecting mirror and partially reflecting mirror as shown in the diagram.

- The optical resonator acts as a feed back system in amplifying the light which is emitted from the active medium by making it to undergo multiple reflections between 100% reflecting mirror and the partially reflecting mirror.
- Here the light bounces between the two mirrors and hence the intensity of light increases enormously. Finally, the intense amplified light is called LASER, which is allowed to come out through the partially reflecting mirror as shown in the diagram.

18/7/23

Nd - YAG LASER

- Nd - YAG is a Neodinum based LASER. It is called Neodinum - Yitrium Aluminium Garnet ($Y_3 Al_5 O_{12}$). It is a four level solid state LASER.

Principle

The active medium in this case is Nd-YAG material, which is optically pumped by crypton flash tube. The neodinum ions (Nd^{3+}) are raised to excited state with the help of crypton flash tube.

- During the transition from metastable state to ground state a LASER beam of wavelength 1.063μm is emitted.

15/7/23

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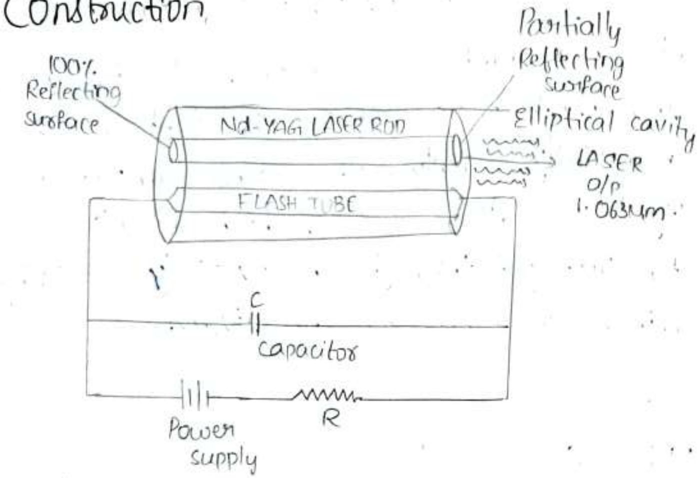
Principle

The active medium in this case is Nd-YAG material, which is optically pumped by crypton flash tube. The neodium ions (Nd^{3+}) are raised to excited state with the help of crypton flash tube.

- During the transition from metastable state to ground state a LASER beam of wavelength 1.063μm is emitted.

Construction



ND-YAG LASER is as shown in the above diagram, small amount of yitrium ions (Y^{3+}) is replaced by neodium in the active element of ND-YAG crystal. The active element is cut into a cylindrical rod, the ends of the cylindrical rod are highly polished and they are made optically flat and parallel to each other.

- This cylindrical rod and pumping source are placed inside an elliptical cavity.
- In this LASER the optical resonator is formed by a Nd-YAG LASER ROD only. Crypton flash tube is connected to power supply.

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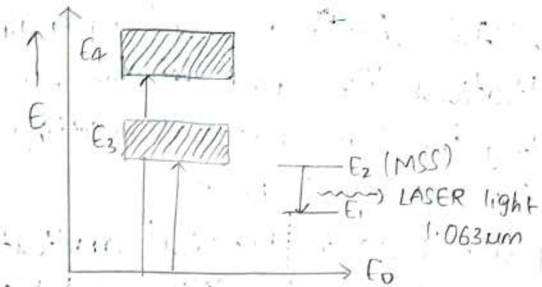
Working



- When crypton flash tube is switch on it emits white colour radiation. By receiving energy from crypton flash tube neodium atoms are raised to energy levels i.e., E_3 & E_4.
- In this case radiation of wavelength 0.73um & 0.8um is ~~observed~~ absorbed, Now Nd^{3+} ions makes a transition from these energy levels (E_3 & E_4) to metastable state E_2 by non-radiative transitions.
- The Nd^{3+} ions are collected in E_2 and population inversion is acheived between E_2 & E_1. LASER transition takes place between E_2 & E_1, that emitting light of wavelength is 1.063um that means after getting sufficient strength in the resonating cavity.

Applications

1. Nd-YAG LASER are used in engineering applications like speed detectors, welding, drilling the hard materials, cutting based on the required shape etc.
2. They are used in medical applications such as endoscopic, ENT, dental surgery and cosmotology etc.

20/7/23 CO_2 LASER

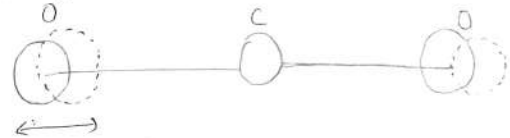
Introduction

- CO_2 LASER is a gas LASER, in this molecular gas LASER transition is acheived between vibrational states of CO_2 molecule.
- It is a four energy level LASER which gives continuous output. This LASER operates at 10.6µm IR region and it is a very efficient LASER.
- This is the first molecular LASER developed by indian born american scientist. professor ~~CKN PILLAN~~ "C.K.N Pillai"

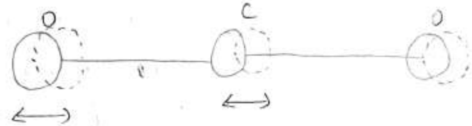
Energy state of CO_2 molecule

- A CO_2 molecule has a carbon atom at the center with two oxygen atoms are attached, one at both sides. This molecule exhibits 3 independent mode of vibrations.

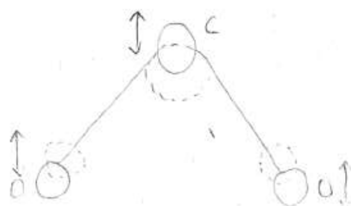
a) Symmetric mode of Vibrations



b) Assymetric mode of vibrations



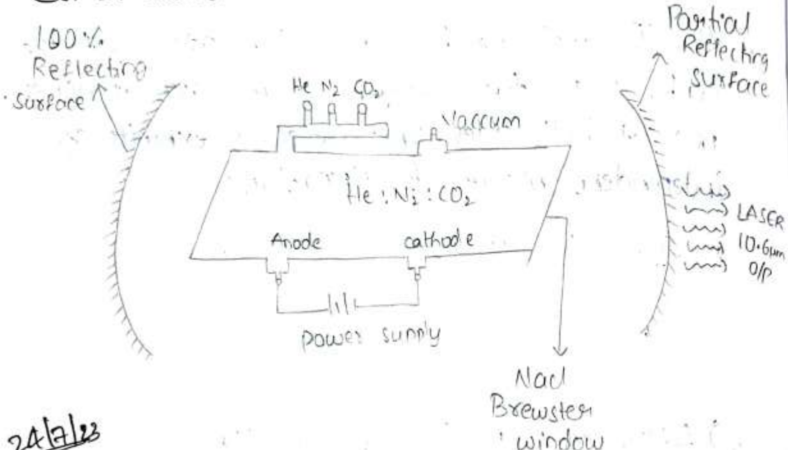
c) Bending mode of vibrations



Principle

The active medium is a gas mixture of CO_2, He and N_2. The LASER transition takes place between the vibrational states of CO_2 molecule.

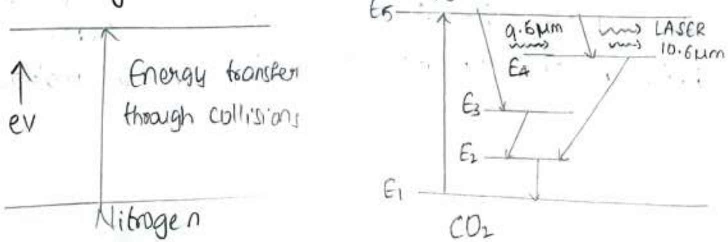
Construction



24/7/23

- It consists of quartz tube of 5m long and 2.5 cm wide in the diameter, the discharge tube is filled with gaseous mixture of CO_2-active medium, He and N_2 with suitable partial pressures.
- The terminal of discharge tube is connected to a DC power supply. The ends of the discharge tube is fitted with Nacl brewster's window, so that the light generated will be polarized, two concave mirrors are (One is fulling reflecting and other one is partially reflecting) form an optical resonator.

Working



- The diagram shows energy levels of nitrogen and carbon dioxide molecules. When discharge occurs in the gas molecule the electrons are moves from cathode to anode and they collide with nitrogen molecule and they are raised to excited state

$$e_1 + N_2 \longrightarrow N_2^* + e_2$$

- Now N_2 molecule in the excited state collides with the CO_2 molecules in the ground state and excites them to higher vibrational states and it can be represented as

$$N_2^* + CO_2 \longrightarrow CO_2^* + N_2$$

- Since the excited ~~state~~ levels of nitrogen is very close to the E_5 level of the CO_2 molecule, which results population in the E_5 level increases
- As soon as population inversion is achieved the transition takes place from E_5 to E_4 and E_5 to E_3 out of these two transitions E_5 to E_4 will produce a LASER beam of wavelength 10.6μm.

Advantages

1. Its efficiency is better than He-Ne LASER and other gas LASERs.
2. Long life of 20,000 hours.

Disadvantages

1. It requires cooling system
2. More cost when compared to other LASER systems.

Applications:

1. High power CO_2 LASERs finds applications in industries, for various purpose like welding, drilling, cutting, soldering.
2. It is used for micro surgery and blood less surgeries.

25/7/23

Applications of LASER in different fields

1. Scientific field

- They are used for isotopes separations.
- They are used to create plasma.
- They are used to produce chemical reactions.
- They are used to study the internal structure of micro-organisms.

2. Medicine

- They are used in bloodless surgery.
- They are used in Angioplastery for removal of blocks.
- They are used in cancer diagonsis and therapies.
- They are used in destroying kidney stones.
- They are used in asthamology, to attach the deattached retina.

3. Industries

- They are used to drill holes in ceramics.
- They are used for heat treatment in the tooling and automotive industries.

4. Communication

- Due to narrow band width LASERs are used in microwave communication systems.
- Due to narrow angular spread they are used in long distance communication.
- By the use of LASERs the storage capacity is gradually improved.

25|6|23

OPTICAL FIBRE

INTRODUCTION

Generally communication is transferred through carrier waves in any communication system. When the frequency of carrier waves are high then the information carrying capacity also enhances.

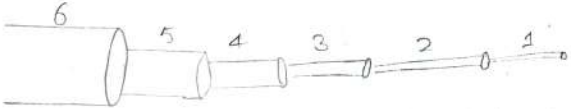
- As the propogation of light takes place in the form of high frequency waves, then these light waves can be used to carry the information i.e., as carrier waves.
- For proper guiding of information with carrying light waves, we need a proper guiding medium (or) material – that material is the optical fibre.

Optical fibre

Optical fibre is a thin and transparent guiding medium (or) material which guides the information carrying light waves.

- A single optical fibre can carry 140MB of information upto 220km in 1 second.

Structure of optical fibre



1. Core
2. Cladding
3. Silicon coating - quality of transmission of light
4. Buffer Jocket - moisture and absorption of external light
5. Strengthen member - toughness and tensil strength
6. Outer Jocket

- Optical fibre consist of central cylindrical layer known as core, surrounded by a second layer called cladding - light is transmitted with in the core.
- The cladding keeps the light with in the core because the refractive index of the cladding is less than that of the core i.e., core acts as denser medium and cladding acts as a rarer medium.
- Silicon coating is provided between buffer jocket and cladding, in order to improve the quality of transmission of light.
- The buffer jocket protects the fibre from moisture and absorption. To provide necessary toughness and tensil strength.
- A layer of strengthen member is arranged surrounding the buffer jocket - finally it is covered with a black poly urethan outer jocket.

Total Internal Reflection - Principle of the optical fibre

- In order to understand the principle of optical fibre let us consider core and cladding having refractive indices are n_1 & n_2. Here core is the denser medium and cladding is the rarer medium.
- Let us consider a ray of light is moving from core to cladding medium with an angle of incidence 'i'. As it is moving from denser medium to rarer medium, it deviates away from the normal. Here the angle of refraction is 'r'.
- As the angle of incidence increases, angle of refraction also increases. At a particular angle of incidence i.e., at $\boxed{i = \theta_c}$, the refracted ray simply grazes along the boundary as shown in the diagram '2', in this case angle of refraction is 90°.

• When the angle of incidence is greater than critical angle i.e., $\boxed{i > \theta_c}$, in that case the light beam simply reflects into the same medium as shown in the below diagram '3'.

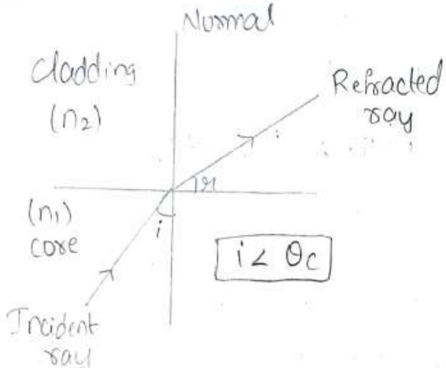


diagram (1)

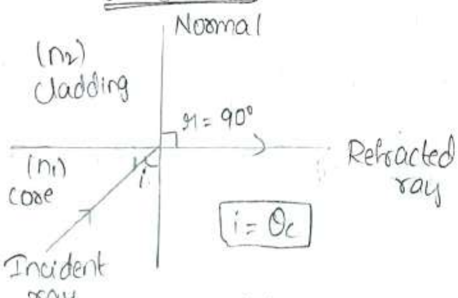


diagram (2)

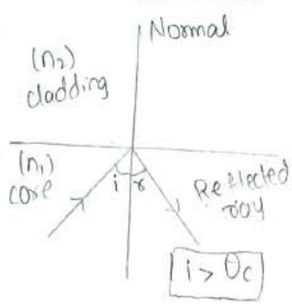


diagram (3)

where n_1 is the refractive index of the core, n_2 is the refractive index of the cladding.

Now applying snell's law of refraction for the second case (diagram 2)

i.e., $$\frac{n_1}{n_2} = \frac{\sin r}{\sin i}$$

$$n_1 \sin i = n_2 \sin r$$

from the above diagram 2, $i = \theta_c$ and $r = 90°$

using this condition, the above equation can be written as

$$n_1 \sin \theta_c = n_2 \sin 90°$$

$$n_1 \sin \theta_c = n_2$$

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$\boxed{\theta_c = \sin^{-1} \frac{n_2}{n_1}}$$

Where θ_c is critical angle

Critical angle : The angle of incidence for which angle of refraction is 90° is called "critical angle" (θ_c)

Conclusion

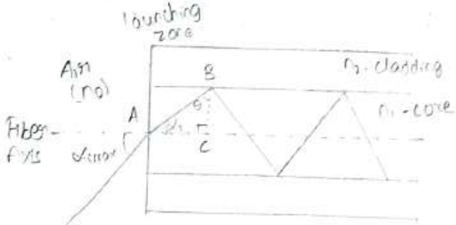
Hence for a light beam to ~~understand~~ undergo total internal reflection the following two conditions are required:

1. Refractive index of core should be greater than refractive index of cladding
   i.e., $\boxed{n_1 > n_2}$
2. Angle of incidence at core-cladding boundary should be greater than critical angle.
   i.e., $\boxed{i > \theta_c}$

31/7/23 **Acceptance angle and Acceptance Cone**

Acceptance angle:

The maximum angle of launch (α_{imax}) at one end of the optical fibre for which total internal reflection takes place at core-cladding boundary is called acceptance angle.



The above diagram shows longitudinal crossection of launch at an end of a optical fibre with a ray of light entering into it. The light is launched from a medium of refractive index n_0 ($n_0 = 1$ for air medium) to the core of refractive index n_1. The ray enter with an angle of incidence α_i to the fibre end phase. This particular ray entering the core at its optic axis point 'A' and proceeds after refraction at the angle of α_r from the axis. It then undergoes total internal reflection at 'B' on core and cladding boundary; at an internal incident angle 'θ'.

- Let us now find upto what value of α_i at 'A', total internal reflection at 'B' is possible.
- From right angled triangle ΔABC

$$\boxed{\alpha_r = 90 - \theta} \rightarrow (1)$$

Using Snell's law of refraction at air-core interface

i.e., $$\frac{\sin\alpha_i}{\sin\alpha_r} = \frac{n_1}{n_0}$$

$$\boxed{\sin\alpha_i = \frac{n_1}{n_0}\sin\alpha_r} \rightarrow (2)$$

Using the value of α_r from eq (1) substitute in eq (2)

$$\sin\alpha_i = \frac{n_1}{n_0}\sin(90-\theta)$$

$$\boxed{\sin\alpha_i = \frac{n_1}{n_0}\cos\theta} \rightarrow (3)$$

If $\alpha_i = \alpha_{imax}$ and $\theta = \theta_c$

Now eq (3) becomes

$$\sin\alpha_{imax} = \frac{n_1}{n_0}\cos\theta_c \rightarrow (4)$$

$$= \frac{n_1}{n_0}\sqrt{1-\sin^2\theta_c} \quad \left[\because \sin\theta_c = \frac{n_2}{n_1}\right]$$

$$= \frac{n_1}{n_0}\sqrt{1-\left(\frac{n_2}{n_1}\right)^2}$$

$$= \frac{n_1}{n_0}\sqrt{\frac{n_1^2-n_2^2}{n_1^2}}$$

$$= \frac{n_1}{n_0} \cdot \frac{\sqrt{n_1^2-n_2^2}}{n_1}$$

$$\sin\alpha_{imax} = \frac{\sqrt{n_1^2-n_2^2}}{n_0}$$

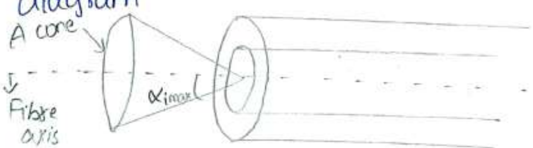
$$\alpha_{imax} = \sin^{-1}\left(\frac{\sqrt{n_1^2-n_2^2}}{n_0}\right)$$

If $n_0 = 1$

$$\alpha_{imax} = \sin^{-1}\sqrt{n_1^2-n_2^2}$$

This maximum angle is called "acceptance angle".

Rotating acceptance angle about the fibre axis will get acceptance cone as shown in the below diagram



Conclusion:

Light launched into the optical fibre end within this acceptance cone alone will be accepted and propagated to other end of the optical fibre by "total internal reflection".

Larger acceptance angle makes launching easier.

Numerical Aperature (NA)

Light collecting capacity of an optical fibre is called numerical aperature.

(or)

Sign of the acceptance angle is called numerical aperature.

i.e., $NA = \sin\alpha_{imax}$

$$= \sin\left[\sin^{-1}\frac{\sqrt{n_1^2-n_2^2}}{n_0}\right]$$

$$= \frac{\sqrt{n_1^2-n_2^2}}{n_0}$$

if $n_0 = 1$

$$NA = \sqrt{n_1^2-n_2^2}$$

From these we can say that the numerical aperature is effiectively dependent only on the refractive indices of the core and cladding materials and it is not a function of a fibre dimensions.

Numerical aperature in terms of a 'Δ'

Delta (Δ) is the fractional difference in the refractive index, it defines

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \rightarrow (1)$$

$$\Delta = \frac{(n_1 + n_2)(n_1 - n_2)}{2n_1^2} \quad [\because n_1 \cong n_2]$$

$$= \frac{2n_1(n_1 - n_2)}{2n_1^2}$$

$$\boxed{\Delta = \frac{n_1 - n_2}{n_1}} \rightarrow (2)$$

$$\boxed{\Delta = 1 - \frac{n_2}{n_1}}$$

from eqn (1)

$$\Delta 2n_1^2 = n_1^2 - n_2^2$$

Square root on both sides

$$\sqrt{\Delta 2n_1^2} = \sqrt{n_1^2 - n_2^2}$$

$$n_1\sqrt{2\Delta} = \sqrt{n_1^2 - n_2^2}$$

$$n_1\sqrt{2\Delta} = NA$$

$$\Rightarrow \boxed{NA = n_1\sqrt{2\Delta}} \rightarrow (3)$$

01/8/23

Types of Optical fibres

Optical fibres are divided into different types based on different parameters

a. Based on the number of modes -
   1. Single Mode Optical Fibre (SMOF)
   2. Multi Mode Optical Fibre (MMOF)

b. Based on the refractive index profile -
   1. Step Index Optical Fibre (SIOF)
   2. Graded Index Optical Fibre (GIOF)

c. Based on the material used -
   1. Glass fibre
   2. Plastic Fibre

a. Based on the number of modes

'MODE' is the one which describes the nature of propogation electromagnetic waves in a waveguide. ~~(or~~

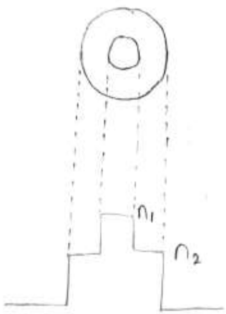
(or)

It describes about the number of light paths travelling in a waveguide.

. Based on the number of modes of propogation optical fibres are classified into two types, they are :

1. Single Mode Optical Fibre (SMOF)

- This fibres are made from doped silicon materials, it has very small core diameter. So that it can allow only one mode of propogation. The cladding diameter is very large when compared to core.
- Thus in the case of single mode optical fibres optical loss is very much reduced. The structure of single mode optical fibre is shown in the below diagram, it is available only for step index only.



Core Diameter - 5-10 μm

Cladding Diameter - 125 μm

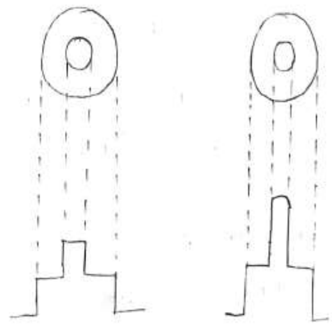
NA - 0.08 to 0.1

Band width > 50MHZ

- Because of their higher bandwidth they are used in long distance communication.

2. Multi Mode Optical fibre (MMOF)

- Here the core diameter is very large when compared with single mode optical fibres, so that it allows many modes to pass through it. The cladding diameter is very large when compared with single mode optical fibre.
- It is available for both step index and graded index optical fibre. The structure of multi mode optical fibre is shown in the below diagram



Core Diameter - 50-350 μm

Cladding Diameter - 125 μm to 500 μm

NA - 0.12 to 0.5

Band width < 50MHz

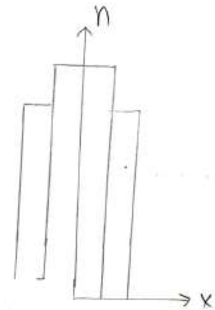
- Because of the less bandwidth multi mode optical fibres are used for short distance communication.

Distinguish between Single Mode Optical Fibre and Multi Mode Optical fibre

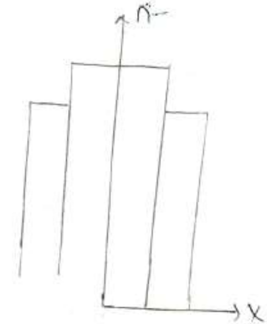
Single Mode Optical fibre	Multi Mode Optical Fibre
* They allows only one light ray path	* They allows more number of light ray paths
* They have small core diameters.	* They have more core diameters.
* $n_1 \cong n_2$ is small	* $n_1 \cong n_2$ is large
* No dispersion	* Dispersion is more
* Used for long distance communications.	* Used for short distance communications.
* Fabrication is difficult and more installation cost.	* Fabrication is easy and less installation cost.
* Launching of light and connecting to fibres is very difficult.	* Launching of light and connecting ~~...~~ to fibres is very easy.

b. Based on the refractive index profile.

1. Step Index Optical Fibre



RI profile for SMSIOF



RI profile for MMSIOF

- In step index optical fibre the entire core has uniform refractive index n_1, which is slightly greater than refractive index of the cladding n_2. Since index profile is in the form of a step, these fibres are called "Step Index Optical fibre".

Transmission of signal in Step Index Optical Fibre

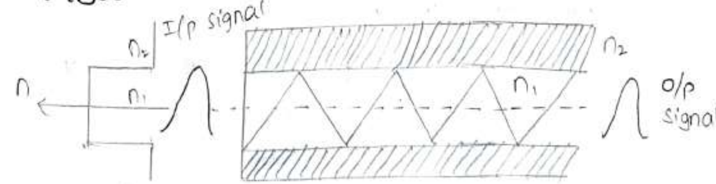
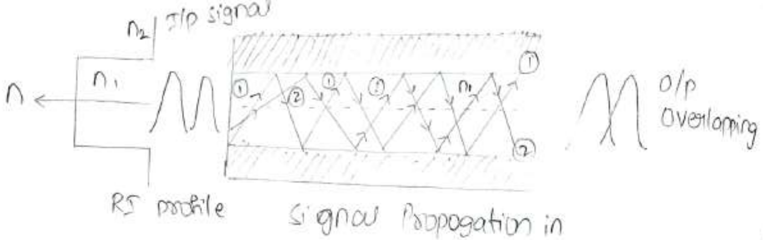


diagram (a)



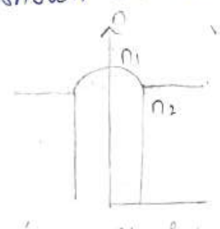
Signal Propogation in MMSIOF

diagram (b)

- In this case transmission of information will be in the form of signals and pulses for a SMSIOF a single light ray from a signal enters into the fibre and travels a single path and forms the output signal. In this case two signals match each other as shown in the above diagram(a).
- In a MMSIOF due to large bandwidth of the core which allows number of light rays from input signals enters into the core and takes multiple internal reflections as shown in the above diagram (b).
- The light ray ① which makes greater angle with the fibre axis suffers more reflections through the fibre and takes more times to travel in the optical fibre. Whereas the light ray ② makes less angle with the fibre axis suffers less number of reflections as a result of that it travels in the optical fibre.
- At the output end the light ray ② reaches first and light ray ① reaches later. Due to the path difference between the two light rays when they superimpose to form the output signal, this signals are overlapped. This overlapping is named as "intermodel dispersion". Due to this problem it is difficult to retrieve the information carried out by output signal.

2. Graded Index Optical Fibre

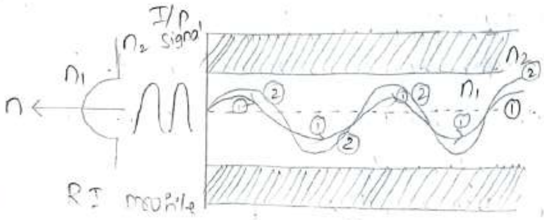
- In graded index optical fibres the refractive index of the core is maximum in the middle of the core and decreases from the fibre axis interface in a parabolic manner and it matches with refractive index of cladding as shown in the below diagram(a).



RI profile for MMGIOF

diagram(a)

Signal propogation in MMGIOF



Signal Propogation in MMGIOF
diagram(b)

- As shown in the above diagram (b) in this case the light rays are moving in the core medium whose refractive index is varying in a parobolic manner. Near fibre axis refractive index is more. As we move away from the core axis towards core cladding boundary the refractive index is decreases.
- The light rays which are moving away from the axis moves fast and the light rays which are moving near the fibre axis moves slow in reaching the other end of the optical fibre.
- So all these light rays are adjusts their velocity in such a way that they will reach simultaneously at the receiving end.
- In this case there is no overlapping of the output signals i.e., no intermodel dispersion and the output signals match with in the input signals.
- In this fibre we get a focusing effect of light rays.
- The number of possible modes through graded index optical fibre is $\frac{\nu^2}{4}$

Therefore, $\nu = \frac{2\pi}{\lambda} a \cdot NA$

where λ is the wavelength of the light ray
a is the radius of the core
NA is the numerical aperature of the given optical fibre

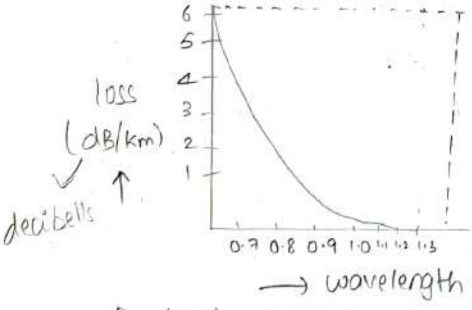
2/8/23

Losses in Optical Fibre

- The power of the light at the output end is found to be always less than intense, the power launched at the input end. The attenuation is found to be a function of fibre material, wavelength of lights and length of the fibres.
- The attenuation loss of optical fibre is divided as below
  1. Scattering loss
  2. Absorption loss
  3. Bending loss

1. Scattering loss :

- Actually the glass which is used to make a optical fibre is a amorphous solid. During its manufacturing sub microscopic variations in the density of the glass are frozen into the glass.
- Dopends added to vary the refractive indices also cause fluctuations in refractive index profile. These optical fibres acts as reflecting and refracting index to scatter a small portion of light passing through the glass contributing further losses



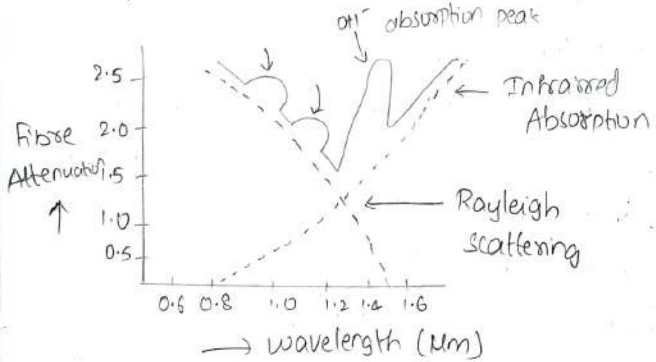
Rayleigh scattering losses in a silica fibre

- The losses induced because of scattering rayleigh inversekly with the 4th power of the light wavelength is used. Hence at 1.3um wavelength scattering losses are very less means about 0.3dB/km while at a wavelength 0.7um they are about 5dB/km as shown in the diagram.

2. Absorption loss :

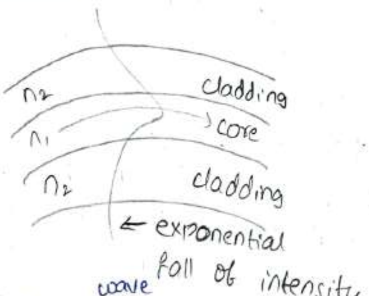
- Three different mechanisms contribute to absorption losses in optical fibres they are
  - (a) Ultravoilet absorption
  - (b) Infrarred absorption
  - (c) Ion resonance absorption
- In pure fused silica absorption of UV radiation arount 0.14um in ionization of valence electron into conduction band. Thus there is a loss of light due to ionization.
- Also during the fabrication of fibre to change the refractive index of glass to any desired value GeO_2 is doped.
- This causes shift in the UV absorption band.
- Absorption of infrarred photon by atoms with in the glass material results in the increase of random mechanical vibrations and hence heating.
- OH^- ions are present in the material due to trapping of minute quality of water molecule during manufacturing of these ions absorb energy (dB/km) at peaks of 0.815, 1.25, 1.39, and with the main peak at 1.3, 1.39um
- The presence of other impurities such as iron, copper, chromium may also create

unacceptable losses within the spectrum.



3. Bending loss:

- The distortion of optical fibre from the ideal straight line configuration may also results in fibre losses



- Consider a wave front travelling to direction of propogation in order to maintain this, the part of the mode which is on outside of the optical fibre bend as to travel faster than that of the inside the optical fibre.
- Because of this the energy associated with this particular part of mode loss by radiation

- The loss is represented by

$$\alpha_B = C \exp\left(-\frac{R}{R_e}\right)$$

where C is the constant
R is the radius of curvature of optical fibre

$$R_e = \frac{a}{(NA)^2}$$ (where a is the radius of the optical fibre)

Loss of Bending

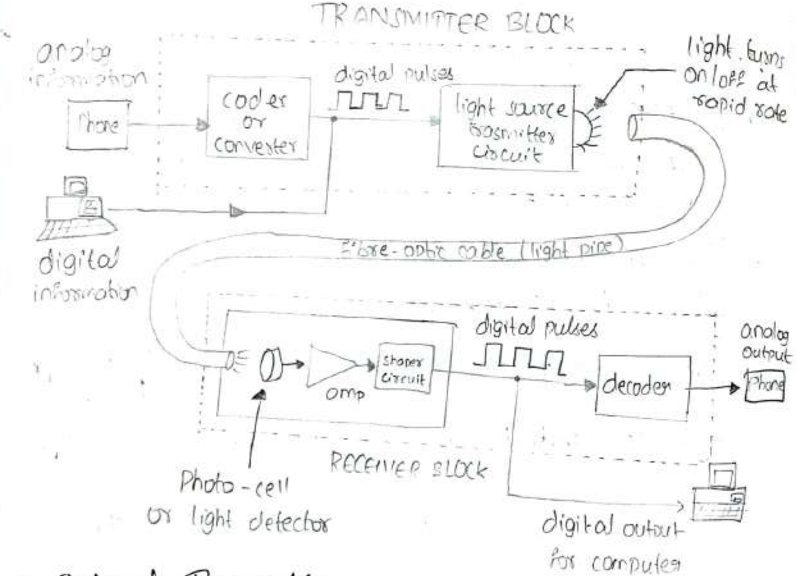
- Attenuation loss in optical fibre generally measured in terms of decibels (dB) which is a logarithm unit.
- The decibel loss of optical power in a fibre is measured through the formula
- Loss of optical power $= -10 \log \left[\frac{P_{out}}{P_{in}}\right]$ dB

where Pout is the output power from the optical fibre
Pin is the power launched in the optical fibre

3/8/23 Optical Fibre Communication System

Fibre optic communication system consist of three important components they are

1. Optical Transmitter
2. Fibre Repeater
3. Optical Receiver



1. Optical Trasmitter

An optical transmitter converts analog to digital signal into the optical form. It consists of an encoder, light source and modulator, the input analog signal is converted into a digital signal by means of an encoder. The converted digital signal is enter into the source which can be LED (or) LASER diode - which converts digital signals into optical signals.

- These optical signals from the source is modulated either based on intensity, amplitude (or) frequency with the help of modulator. The optical signal from the modulator is coupled to the optical fibre by means of couplers. These couplers launch the optical signal into fibre without any distortion (or) loss.
- The optical signal through the fibre is properly connected to a repeaters with the help of connectors.

2. Fibre Repeaters

The optical signals while travelling through very long optical fibres through long distances can suffer transmission losses. As a result, we get weak optical signal at the output end of the optical fibre, to minimize these losses repeaters are kept at regular intervals between the fibres. The repeaters consist of an amplifier and regenerators. The amplifier amplifies the weak optical signal and it is reconstructed to original signal with the help of regenerators. At the last stage these optical signals are going to be received by the receiver.

3. Optical Receiver

The receiver unit consist of photo detectors, amplifier, demodulator and decoder. The photo detector converts optical signals into electrical signals. Then these electrical signals are going to be amplified by the amplifier and demodulated to digital signal, finally these digital signals are going to convert into analog signals with the help of decoders.

Conclusion

This is how optical fibre plays a important role in transmitting information through optical fibre communication system.

Advantages of optical fibres:

1. Extremely large bandwidth - ICC (Information Carrying Capacity) of a wave depends on its frequency. In the case of optical fibres light passes through them have very high frequency 10^{14} to 10^{15} hertz. From this we can say that optical signal carries information at a high rate.

i) Small in size - diameter and weight

Due to small size and less weight optical fibres can be handled very easier than copper cables.

ii) lack of cross talking

In ordinary cables signals are passed from one cable to another capable results in cross talking, but in optical fibre it is very negiliable.

Immune to Inductive Interference:

Fibre cables are immune to interface caused by lightning and other equipments.

Much safer than copper cable:

There is no effects (electrical or optical effects) in the case of optical fibres because they are made of insulating materials.

Long life span:

ⓐ High temperature resistance

ⓑ Easy Maintaineance

4/8/23

Applications of optical Fibres

1. Optical Fibres are used in communication system.
2. Optical Fibres are used in exchange of information between different terminals in a network of computers
3. They are used to exchange of information in Cable telvisions, space vehicles, submarines.
4. They are used in industrial automation and in industry security alarm system.
5. Optical fibres are used in electronic fields - to provide the required delays in delay lines.

6. Optical fibres are used in making sensors. pressure sensors, temperature sensors.

7. They are used in pressure sensors in biomedical and engine control applications.

8. They are used in medicine, in the fabrication of fibrescope in endoscopi for the visualization of internal portions of the human body, fibreoscopi is used for selective condensation of tissues using a LASER beam.

04/08/23

UNIT- 5

PHYSICS OF QUANTUM COMPUTING AND QUANTUM GATES

Classical Bit versus Quantum Bit

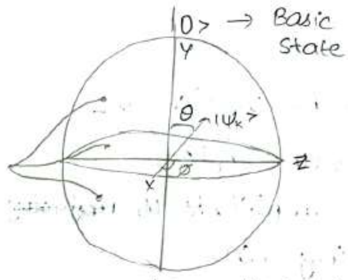
- A classical bit is represented by either '0' (or) '1', which means it possess only two states. This is used by large scale multipurpose computers and devices.
- Quantum bit (or) Q-Bit is the basic unit of the quantum information, Q-Bits are represented by '<u>Ket vectors</u>' as $|0\rangle$ & $|1\rangle$ also their exist large number of Q-Bits between $|0\rangle$ & $|1\rangle$

Difference between classical computing and quantum computing

Classical Computing	Quantum computing
* Information is stored in bits.	* Information is stored in Q-Bits.
* A classical computer has a memory made up of bits where each bit holds either '0' (or) '1'.	* A Q-Bit holds 1, 0 (or) super-position of these two.

* The device computers by manipulating these bits with the help of classical logic gates like AND gate, OR gate, NOR gate.	* The device computers by manipulating these quantum gates.
* In classical computers information is stored in bits which takes more space.	* Here the information is stored in Q-Bits. As Q-Bit can be in states are represented by $\|0\rangle$, $\|1\rangle$ but it can also be a superposition of these two states. $a\|0\rangle + b\|1\rangle$, where a, b are complex numbers.
* Classical Bits are slow	* Quantum Bits are fast (like CSE-C students)
* Its circuit behaviour is based on classical physics.	* Its circuit behaviour is based on quantum physics.

BLOCH SPHERE



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- In Quantum computation, superposition of states is represented on "Bloch sphere". In Quantum mechanics, the block sphere is a geometrical representation of the pure state space of a two-level quantum mechanical system (Q-Bit).

: Assuming the space in the shape of sphere it also called Hilbert space.

- The north and south poles of the block sphere are corresponds to the standard basic vectors $|0\rangle$ & $|1\rangle$.
- If spin up represented by $|0\rangle$ then spin down is represented by $|1\rangle$
- The points on the surface of the sphere correspond to the pure state, the interior points corresponding to the mixed state (Superposition states).

- Superposition states can be represented by -

$a_1 |0\rangle \; a_2 |1\rangle$

- Mixed states can be written as -

$$|\psi_K\rangle = a_0 |0\rangle \; a_1 |1\rangle$$

where a_0 is the amplitude of ~~[illegible]~~ measuring $|0\rangle$

a_1 is the amplitude of measuring $|1\rangle$

- The superposition state of a Q-Bit is represented as -

$$|\psi\rangle = e^{i\vartheta}\left[\cos\theta/_2 |0\rangle + e^{i\phi} \sin\theta/_2 |1\rangle\right] \rightarrow (1)$$

$$|\psi\rangle = a_0 |0\rangle + a_1 |1\rangle \rightarrow (2)$$

where $a_0 = e^{i\vartheta}\cos\theta/_2$ - amplitude of measuring $|0\rangle$

$a_1 = e^{i\phi}\sin\theta/_2$ - amplitude of measuring $|1\rangle$

- The value of $e^{i\vartheta}$ is a overall phase factor which can be neglected

$$\Rightarrow |\psi\rangle = \cos\theta/_2 |0\rangle + e^{i\phi}\sin\theta/_2 |1\rangle \rightarrow (3)$$

where $0 \leq \theta \leq \pi$

- Thus any state $|\psi\rangle$ can be represented interms of $|0\rangle$ & $|1\rangle$ in the above eqn (3)

Quantum Gates

The quantum computing gates are represented by matrix i.e., $\sum_i |a_0\rangle\langle a_i|$

- Quantum gates are logic circuits which takes Q-Bits as input and delivers output.
- Quantum circuits are consist of gates and wires. The wires carries the information and gates manipulate that information.
- There are two types of logic gates
  1. Single Q-Bit logic gates
  2. Two Q-Bit logic gates

Single Q-Bit logic gates

These are the logic gates which takes one Q-Bit as the input and one Q-Bit as output.

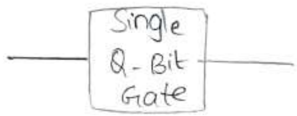
- They are four types

(a) Pauli X - Gate - Quantum NOT Gate.

(b) Pauli Y - Gate - Quantum Y - Gate

(c) Pauli Z - Gate - Quantum Z - Gate

(d) Hadmard Gate.



Two Q-Bit logic gates

These are the logic gates which takes two Q-Bits as input and gives two Q-Bits as output.

- They are two types:
  - i) CNOT Gate
  - ii) SWAP Gate

7/8/23 **Representation of Quantum Gates in Matrix Form**

The matrix representation of Quantum Gates are given by summation of input, output.

$$\sum_i |input\rangle\langle output|$$

Notation for computational basis

1. Single Q-Bit basis

Input	Output
$\|0\rangle = \begin{bmatrix}1\\0\end{bmatrix}$	$\langle 0\| = [1\ 0]$
$\|1\rangle = \begin{bmatrix}0\\1\end{bmatrix}$	$\langle 1\| = [0\ 1]$

2. Two-level Q-Bit basis

Input	Output
$\|00\rangle = \begin{bmatrix}1\\0\\0\\0\end{bmatrix}$	$\langle 00\| = [1\,0\,0\,0]$
$\|01\rangle = \begin{bmatrix}0\\1\\0\\0\end{bmatrix}$	$\langle 01\| = [0\,1\,0\,0]$
$\|10\rangle = \begin{bmatrix}0\\0\\1\\0\end{bmatrix}$	$\langle 10\| = [0\,0\,1\,0]$
$\|11\rangle = \begin{bmatrix}0\\0\\0\\1\end{bmatrix}$	$\langle 11\| = [0\,0\,0\,1]$

Single Q-Bit Logic Gates

1. Pauli X-Gate - Quantum NOT Gate

Quantum NOT Gate in matrix form

$|0\rangle$ —[X]— $\langle 1|$

$|1\rangle$ —[X]— $\langle 0|$

$$= |0\rangle\langle 1| + |1\rangle\langle 0|$$

$$= \begin{bmatrix}1\\0\end{bmatrix}[0\ 1] + \begin{bmatrix}0\\1\end{bmatrix}[1\ 0]$$

$$= \begin{bmatrix}0 & 1\\0 & 0\end{bmatrix} + \begin{bmatrix}0 & 0\\1 & 0\end{bmatrix}$$

$$= \begin{bmatrix}0 & 1\\1 & 0\end{bmatrix}$$

In Quantum NOT Gate if input is 'zero' then output is 'one' and if input is 'one' then output is 'zero'.

2. Pauli Y- Gate - Quantum Y-Gate

Pauli Y- Gate acts on a single Q-Bit.

- It equates to a rotation around the Y-axis of the bloch sphere by π radians...
- It maps from $|0\rangle$ to $i\langle 1|$ & $|1\rangle$ to $-i\langle 0|$

$|0\rangle$ —[Y]— $i\langle 1|$

$|1\rangle$ —[Y]— $-i\langle 0|$

Truth Table

input	output
$\|0\rangle$	$i\langle 1\|$
$\|1\rangle$	$-i\langle 0\|$

Matrix Representation of Y-Gate

$$Y = \sum_i |input\rangle\langle output|$$

$$= \sum_i |0\rangle i\langle 1| + |1\rangle(-i)\langle 0|$$

$$= \begin{bmatrix}1\\0\end{bmatrix} i \begin{bmatrix}0 & 1\end{bmatrix} + \begin{bmatrix}0\\1\end{bmatrix}(-i)\begin{bmatrix}1 & 0\end{bmatrix}$$

$$= \begin{bmatrix}1\\0\end{bmatrix}\begin{bmatrix}0 & i\end{bmatrix} + \begin{bmatrix}0\\1\end{bmatrix}\begin{bmatrix}-i & 0\end{bmatrix}$$

$$= \begin{bmatrix}0 & i\\0 & 0\end{bmatrix} + \begin{bmatrix}0 & 0\\-i & 0\end{bmatrix}$$

$$Y = \begin{bmatrix}0 & i\\-i & 0\end{bmatrix}$$

3. Pauli Z- Gate - Quantum Z-Gate

It inverts sign of $|1\rangle$ to give $-\langle 1|$ and leaves $|0\rangle$ unalternate.

$|0\rangle$ —[Z]— $\langle 0|$

$|1\rangle$ —[Z]— $-1\langle 1|$

- For $|0\rangle$ input the output $\langle 0|$ and for $|1\rangle$ input the output is $-1\langle 1|$

Matrix Representation of Z-Gate

$$Z = \sum_i |input\rangle\langle output|$$

$$= |0\rangle\langle 0| + |1\rangle(-1)\langle 1|$$

$$= \begin{bmatrix}1\\0\end{bmatrix}\begin{bmatrix}1 & 0\end{bmatrix} + \begin{bmatrix}0\\1\end{bmatrix}\begin{bmatrix}0 & -1\end{bmatrix}$$

$$= \begin{bmatrix}1 & 0\\0 & 0\end{bmatrix} + \begin{bmatrix}0 & 0\\0 & -1\end{bmatrix}$$

$$Z = \begin{bmatrix}1 & 0\\0 & -1\end{bmatrix}$$

4. Hardmard Gate in Matrix Form

- In Hardmarid Gate if the input is $|0\rangle$ and the output is $\frac{|0\rangle + |1\rangle}{\sqrt{2}}$ and if the input is $|1\rangle$ and the output is $\frac{|0\rangle - |1\rangle}{\sqrt{2}}$

$|0\rangle$ — [Hadmard] — $\frac{|0\rangle + |1\rangle}{\sqrt{2}}$

$|1\rangle$ — [Hadmard] — $\frac{|0\rangle - |1\rangle}{\sqrt{2}}$

Hadmard Gate $= \sum_i |input\rangle\langle output|$

$= |0\rangle\langle \frac{|0\rangle |1\rangle}{\sqrt{2}}| + |1\rangle\langle \frac{|0\rangle - |1\rangle}{\sqrt{2}}|$

$= \frac{1}{\sqrt{2}}[|0\rangle\langle 0| + |0\rangle\langle 1| + |1\rangle\langle 0| - |1\rangle\langle 1|]$

$= \frac{1}{\sqrt{2}}\left[\begin{bmatrix}1\\0\end{bmatrix}[1\ 0] + \begin{bmatrix}1\\0\end{bmatrix}[0\ 1] + \begin{bmatrix}0\\1\end{bmatrix}[1\ 0] - \begin{bmatrix}0\\1\end{bmatrix}[0\ 1]\right]$

$= \frac{1}{\sqrt{2}}\left[\begin{bmatrix}1 & 0\\0 & 0\end{bmatrix} + \begin{bmatrix}0 & 1\\0 & 0\end{bmatrix} + \begin{bmatrix}0 & 0\\1 & 0\end{bmatrix} - \begin{bmatrix}0 & 0\\0 & 1\end{bmatrix}\right]$

$= \frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$

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Two-level Q-Bit Gates in matrix form

Input	Output
$\|00\rangle = \begin{bmatrix}1\\0\\0\\0\end{bmatrix}$	$\langle 00\| = [1\ 0\ 0\ 0]$
$\|01\rangle = \begin{bmatrix}0\\1\\0\\0\end{bmatrix}$	$\langle 01\| = [0\ 1\ 0\ 0]$
$\|10\rangle = \begin{bmatrix}0\\0\\1\\0\end{bmatrix}$	$\langle 10\| = [0\ 0\ 1\ 0]$
$\|11\rangle = \begin{bmatrix}0\\0\\0\\1\end{bmatrix}$	$\langle 11\| = [0\ 0\ 0\ 1]$

Controlled NOT Gate - CNOT Gate

- CNOT Gate has two input Q-Bits knows as controlled Q-Bit and target Q-Bit.
- The circuit representation of CNOT Gate is shown in the below diagram

- The top line represents the '<u>controlled Q-Bit</u>' while the bottom line represents '<u>target Q-Bit</u>'.
- The action of the CNOT Gate is as follows -
  - → If the controlled Q-Bit is set to '0' then the target Q-Bit is left alone.
  - → If the controlled Q-Bit is set to '1' then the target Q-Bit is flipped.

Truth Table of CNOT Gate

Input	Output
$\|00\rangle$	$\langle 00\|$
$\|01\rangle$	$\langle 01\|$
$\|10\rangle$	$\langle 11\|$
$\|11\rangle$	$\langle 10\|$

Matrix representation of the CNOT Gate

$$CNOT = \sum_i |input\rangle\langle output|$$

$$= |00\rangle\langle 00| + |01\rangle\langle 01| + |10\rangle\langle 11| + |11\rangle\langle 10|$$

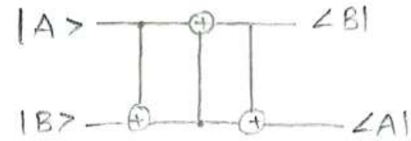
$$= \begin{bmatrix}1\\0\\0\\0\end{bmatrix}[1000] + \begin{bmatrix}0\\1\\0\\0\end{bmatrix}[0100] + \begin{bmatrix}0\\0\\1\\0\end{bmatrix}[0001] + \begin{bmatrix}0\\0\\0\\1\end{bmatrix}[0010]$$

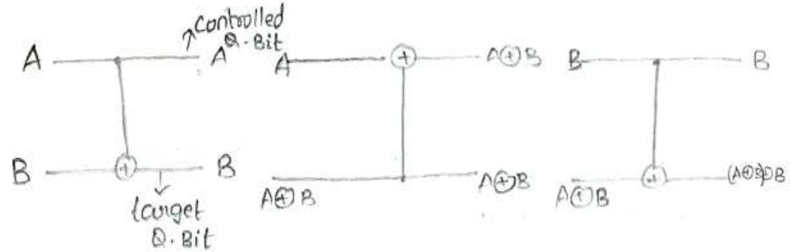
$$= \begin{bmatrix}1&0&0&0\\0&0&0&0\\0&0&0&0\\0&0&0&0\end{bmatrix} + \begin{bmatrix}0&0&0&0\\0&1&0&0\\0&0&0&0\\0&0&0&0\end{bmatrix} + \begin{bmatrix}0&0&0&0\\0&0&0&0\\0&0&1&0\\0&0&0&0\end{bmatrix} + \begin{bmatrix}0&0&0&0\\0&0&0&0\\0&0&0&0\\0&0&0&1\end{bmatrix}$$

$$= \begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&0&1\\0&0&1&0\end{bmatrix} = \begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&0&1\\0&0&1&0\end{bmatrix}$$

SWAP Gate in matrix form

SWAP Gate swaps the states of the two Q-bits, it is prepared by using 3 CNOT Gates, the sequence of the SWAP Gate is represented below





Truth Table

Input	Output
$\|00\rangle$	$\langle 00\|$
$\|01\rangle$	$\langle 10\|$
$\|10\rangle$	$\langle 01\|$
$\|11\rangle$	$\langle 11\|$

Matrix representation of SWAP Gate

$M_{SWAP} = \sum_i |input\rangle\langle output|$

$= |00\rangle\langle 00| + |01\rangle\langle 10| + |10\rangle\langle 01| + |11\rangle\langle 11|$

$= \begin{bmatrix}1\\0\\0\\0\end{bmatrix}[1000] + \begin{bmatrix}0\\1\\0\\0\end{bmatrix}[0010] + \begin{bmatrix}0\\0\\1\\0\end{bmatrix}[0100] + \begin{bmatrix}0\\0\\0\\1\end{bmatrix}[0001]$

$= \begin{bmatrix}1&0&0&0\\0&0&0&0\\0&0&0&0\\0&0&0&0\end{bmatrix} + \begin{bmatrix}0&0&0&0\\0&0&1&0\\0&0&0&0\\0&0&0&0\end{bmatrix} + \begin{bmatrix}0&0&0&0\\0&0&0&0\\0&1&0&0\\0&0&0&0\end{bmatrix} + \begin{bmatrix}0&0&0&0\\0&0&0&0\\0&0&0&0\\0&0&0&1\end{bmatrix}$

$M_{SWAP} = \begin{bmatrix}1&0&0&0\\0&0&1&0\\0&1&0&0\\0&0&0&1\end{bmatrix}$

Advantages of Quantum Computation over Classical Computation.

* Classical computers gradually approaching their limits, the Quantum computers promises to deliver a new level of computational power.
* It is a new theory of computation that incorporates the strategy effects of Quantum mechanics.
* Encode the more information.
* Easily crack secrete codes.
* Fast in searching database.
* Hard computational problems becomes trackable.
* It supports Artificial Intelligence.

Quantum Teleportation

Teleportation is a process which involves scanning of objects, dematerialization and transmitted to another location which results the object rematerialization i.e., back to original state.

Teleportation - (Telecommunication + Transportation)

This concept was first given by "Charles Bennet" and his co-workers / team from IBM. They confirmed that ~~transport~~ Quantum Teleportation was possible, but only if the original object being teleportated was destroyed.

Quantum Teleportation

* It is a process by which quantum information (i.e., the exact state of an atom or photon), by which quantum information can be transmitted.
* Quantum teleportation is making of an object (or) person disintegrate at one place by a perfect replica appears somewhere else.
* Quantum teleportation involves entangling two things like photons (or) ions. so their states are dependent on one another and each can be effected by the measurement of the others state.

Steps involved in the Quantum Teleportation

- Scanning the object completely at the source side.
- Deassembling the scanned data and sending it to the destination.
- Assembling the object from the data, which was sent to destination.

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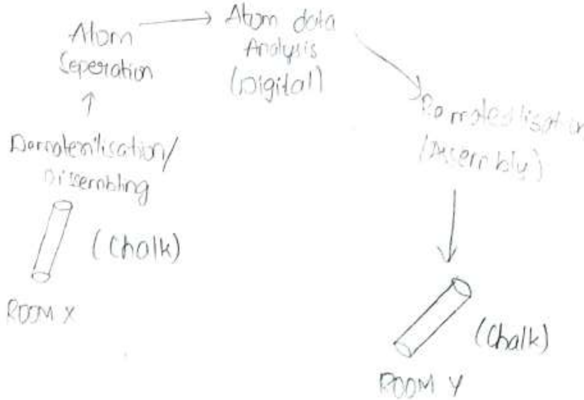
- For example - In Quantum Teleportation an object send the image chalk piece from room X to room Y, the following process is the required steps.



Classification of Teleportation

Basically there are two types of teleportation.

1. Classical Teleportation
2. Quantum Teleportation

Classical Teleportation

In Classical Teleportation the exact replica of the source object is obtained at the destination, where as in Quantum Teleportation the exact copy of the source object at the destination and the source object is destroyed.

Quantum Entanglement

- The two particles of the system are said to be entangled, if any change in one particle brings a change in the other particle irrespective of the distance between two particles.
- In entangled state both particles remains the part of the same quantum system. So whatever you do to the one of the particle its effects another particle in a predictable way.
- Quantum entaglement transforms information around three trillion m/s (or) four orders of magnitude faster than light.

Heisenberg Unceartainity Principle

This principle states that one cannot measure accurately and simultaneously the position and the momentum of a quantum particles.

- The measurement of one value changes the other particle value accordingly.
- This law makes it impossible to measure the exact quantum state of any object with certainity.
- In order to teleport a photon without violating heisenberg unceartainity principle, a phenomena is used known as entaglement.

Advantages of Quantum Teleportation

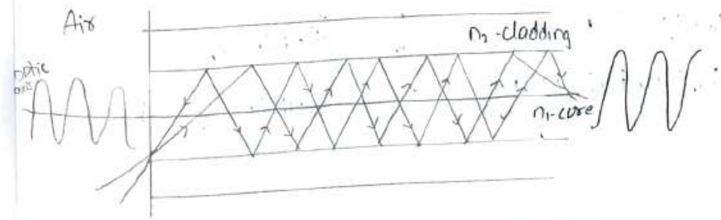
* Transmission of data at higher rates.
* Secure data transmission.
* Transportation becomes much easier.
* Reduced cost of transportation.

Dispersion

- During the transmission of information through optical cables several effects results in spreading of pulse width. This spreading of pulse width at the receiving end is called **dispersion**, which is considered as fibre loss.
- Spreading of output pulse may result in overlapping of adiacent pulses at the receiving end of the fibre.
- As a result of this transmission rate of signal is gradually decreases.
- Dispersion is divided into two types:
  1. Inter model dispersion
  2. Intra model dispersion

Intermodel Dispersion

→ In multimode step index optical fibre each mode enters the fibre at different angles and travels at different parts. Thus the ray arise at the different time at fibre output as shown in the diagram



Intramodel Dispersion

- Based on the refractive index of the core material and also due to material properties dispersion takes place.

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BB84 Protocol

In 1984 the first protocol for quantum cryptography was proposed by Charles. H. Bennit and Giller. Brassard. Therefore the name BB84 is given.

- This concept is purely dependence on Quantum mechanics, this protocol used pulse of "polarized light" where each pulse (light ray) contains a ~~sig~~ single photon.

Working

- To provide a secure communication sender can choose between 4 non-orthogonal states, receiver has two basis with polarized photons

The horizontal vertical bases ✥

- Vertical polarized ↕ Qubit = 0
- Horizontal polarized ⟷ Qubit = 1

The diagonal bases ✕

- Diagonal 45° polarization ⤢ Qubit = 0
- Anti-Diagonal 135° or -45° ⤡ Qubit = 1

Two bases with polarized photos

Type of polarization / Value	0	1
Rectilinear +	|	—
Diagonal ✕	/	\

The process of BB84 protocol

The sender (Alice) choose randomly both the basis and polarization of each photon and sends corresponding polarization state to the receiver.

- Independently and randomly for each photon, receiver chooses one of the two basis, he either measures in the same basis as Alice and gets a perfectly corelated result or the exact opposite, he measures in the different basis than Alice and gets an uncorelated results.
- Sometimes it happens that receiver does not register anything because of the error in the detection (or) in the transmission.

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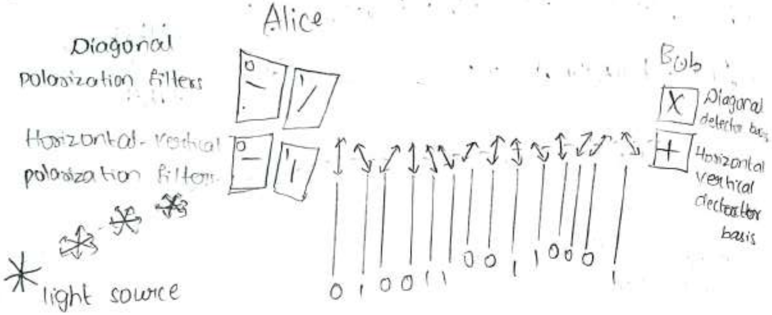

- Receiver obtains a string of all received bits, also called 'raw key'
- For each bit receiver announces through the public channel which basis was used and which photon was registered. and he does not reveal which result he obtained.
- After comparing the selected bases, sender and receiver keep only the bits corresponding to the same bases because both are randomly choosen the bases they get corelated results with equal probability therefore 50% of raw key is discarted, this shorted key is called 'shifted key'
- Sender and receiver choose at random some of the remainings bits which they discart later to check the error rate. There are two main reasons why the error rate can differs from the expected value which gives technical imperfections in the setup and their arrangements.
- only receiver has this key
- To ensure a secret key, sender & receiver must correct the errors. With the help of this procedure they reduce eve's knowledge of the key. The remaining string of the is the secret key.

Now, the actual process of securely encrypting a message can began

- "Note that the secret key is truly random neither sender nor receiver can decide which key results, because they choose randomly between the bases."

Example : The following example is given to illustrate the process of BB84 protocol. In this case |↔> and |⤡> for '1' and |↕> and |⤢> (code) for '0'

Transmitting end	Transmitted bits	0	0	1	0	1	0	1	0	1
	Transmission basis	⊗	⊕	⊗	⊕	⊗	⊕	⊕	⊗	⊕
	Transmitted information	⤢	↕	⤡	↕	⤡	↕	↔	⤢	↔
Receiving end	Measuring basis	⊕	⊕	⊕	⊕	⊗	⊗	⊗	⊗	⊕
	Received results	↔	↕	↔	↕	⤡	↔	⤢	⤢	↔
	Received bit	1	0	1	0	1	1	0	0	1
	Bases match	NO	YES	NO	YES	YES	NO	NO	YES	YES
	Derived key	-	0	-	0	1	-	-	0	1

NO-CLONING THEOREM

The theorem states that "It is impossible to make copy of an unknown quantum state".

- It was first proven in 1982 by Zurek and Wooters. In Quantum key distribution, this means that eve cannot make a copy of sender of photon and send it to receiver. Suppose if we want to clone an unknown quantum state, $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$
- We use some operators Vcopy as shown in the following diagram

$$V_{copy}|\psi\rangle_1|0\rangle_2 = |\psi\rangle_1|\psi\rangle_2$$

- The left hand side of the above equation is

$$V_{copy}|\psi\rangle_1|0\rangle_2 = V_{copy}(\alpha|0\rangle + \beta|1\rangle)_1|0\rangle_2$$
$$= V_{copy}(\alpha|0\rangle_1|0\rangle_2 + \beta|1\rangle_1|0\rangle_2)$$

- Note that the result is an entangled state
- Therefore equation on left side is not equal to equation on right side unless $\alpha = 1$ & $\beta = 0$ (or) viceversa, only $|0\rangle$ (or) $|1\rangle$ states can be copied but not a general quantum state

with superposition. An alternative viewpoint is that the matrix corresponding to V_{copy} is not unitary and therefore cannot be implemented. Therefore it is impossible to make a copy of unknown quantum state.