4. LASERS AND FIBRE OPTICS

Introduction :- We know that light from a Source comes as the Sum of total of radiations by billions of atoms (or) molecules in the source. The phase is ~~at different~~ at different times i.e incoherent source.

In recent years, some sources are developed which are highly coherent. These coherent sources are called LASERS. The word stands for light amplification by stimulated emission of radiation.

=> The theoretical basis for the development of lasers was provided by Einstein in 1917. In 1954, The prediction of Einstein was put to practical use by C.H Townes and his co-worker's. In 1960, The first laser device was developed by T.H Maiman. It is often called as Ruby laser. The Ruby laser emits red light of wavelength 694.3nm

=> A Javan developed the first gas laser using He & Ne gas. It is called Helium-Neon laser. it emits visible light at wavelength 632.8nm and also infrared region at 1150 nm

=> The most important features of lasers are [Characteristics of LASER]

1) Directionality   2) mono chromacity

3) Intensity   4) Coherence.

1) Directionality :-

⇒ During the propagation of a laser its angular spreading will be Less and occupiy less area where it incidente, hence it possess high degree of directionality.

2. Monochromacity :-

⇒ The property of exhibiting a single wavelength by a light is called monochromacity i.e When it is sent through a prism then a single line will be appered in The optical spectrum.

3. Brightness :- [Intensity]

⇒ Due to its directionality many beams of light incident in a Small area therfore The intensity of light is high. hence its brightness is more. So it is used for The welding.

4. Coherence :-

⇒ The two waves which maintain zero (or) constant phase difference between themselves are known as coherent waves. this phenomenon is known as coherence. if The phase difference changes with time, The two sources are known as incoherent.

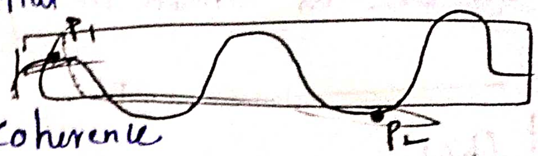
⇒ There are two types of coherences :-

1. Spatial Coherence

2. Temporal Coherence.

1. Spartial Coherence :- (or) transverse Coherence

⇒ If The phase difference between any two fined points in a plane i.e constant normal to The Wave propagation does not vary With time, Then The Wave is said to enhibit spatial coherence



2. Temporal Coherence :- (or) longitudinal Coherence

⇒ If The phase difference between two points along any wave remains Constant during period. The Coherence is called temporal Coherence.

Interaction of Radiation with matter :-

⇒ An Atomic System is characterized by discreate energy states and weally The atoms occupy The lowest energy state known as ground state. An atom in a lower energy state may be encited to a higher energy state through a number of processes. One process being absorption of electromagnetic radiation of proper frequency.

⇒ When Radiation interact with matter there are three actions takes place

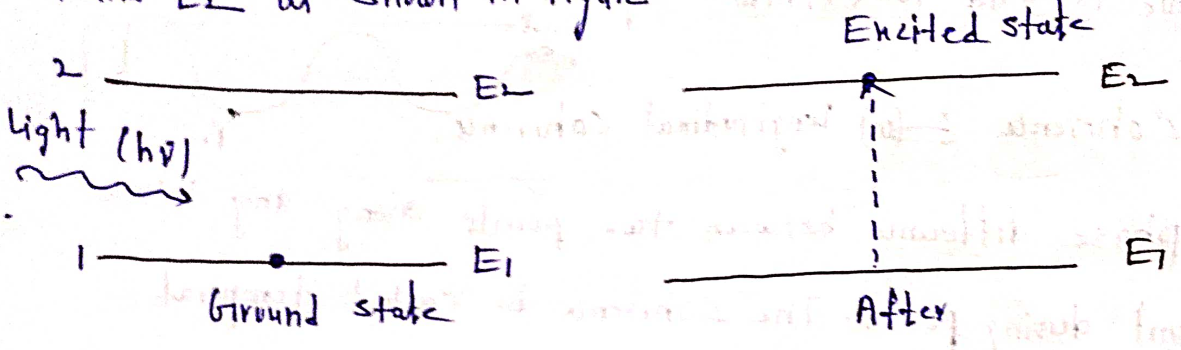
1. Stimulated absorption (or) Absorption of Radiation

2. Spontaneous emission

3. Stimulated emission (or) Induced emission.

1. Stimulated absorption:

⇒ Let us consider two energy levels 1 and 2 of an atom with energies E_1 and E_2 as shown in figure



⇒ Let The atom be exposed to light radiation i.e a stream of photons with energy $h\nu$. Suppose The atom is initially in Lower state 1. The process of atom transfer from normal state (1) to higher energy state is termed as excitation. In this process The absorption of energy from external field takes place. $h\nu = E_2 - E_1$

$$\nu = \frac{E_2 - E_1}{h}$$

⇒ The process is called stimulated absorption (or) simply absorption The particle Can remain in excited state for a Limited time taken as life time i.e order of 10^{-8} sec.

Emission :-

⇒ The atoms coming from higher state to Lower state then that process in known as emission

There will be two types of emission occur

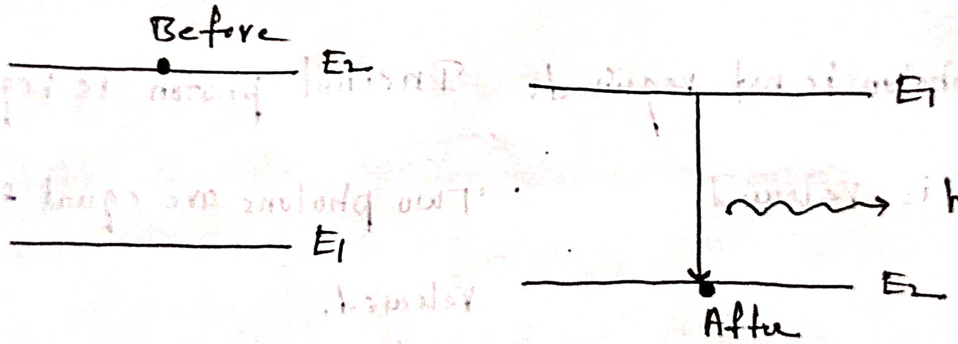
2. Spontaneous emission

3. Stimulated emission.

2 Spontaneous emission :-

=> The excited atom does not remain in The excited state for a Long time After 10^{-8} sec it comes to The ground state by emitting a photon.

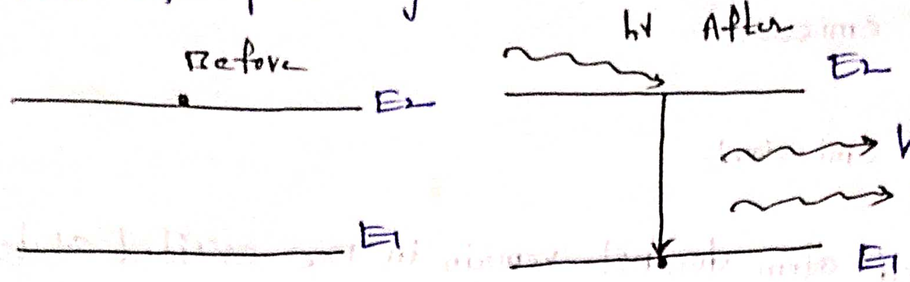
=> The emission Which take place Without any external energy is called Spontaneous emission. The emitted photon in The spontaneous emission is incoherent this was explained by Bohr.



3. Stimulated Emission :-

=> Suppose an atom is in The excited state of energy is E_2 Whose ground level energy is E_1, if a photon of energy $h\nu = E_2 - E_1$ incident on The excited atom there incident photon Stimulate The emission of similar photon from The excited state. Now The atom return to ground state by emitting two photons. The emission which take place under The influence of external energy is called

Stimulated emission. The emited photon radiation is coherent it has The Same wavelength and same phase as that of incident radiation. this was explained by Einstein.



Spontaneous emission	Stimulated Emission.
1. transition occurs from higher Energy state to Lower energy state	In this emission transition occurs from higher state to Lower energy state.
2. Incident photon is not required.	Incident photon is required
3. one photon is released	Two photons are equal energy are released.
4. photons released in this emission are not coherent	photons released in This emission is coherent
5. The energy of emitted photon is equal to The energy difference of two Levels.	The energy of emitted photons is double The energy of stimulated photons.
6. This was explained by Bohr	this was explained by Einstein.
7. Low intense and less directional	high intense & more directional.

Einstein Coefficients & Their Relations :-

=> Einstein mathematically expressed the statistical nature of the three possible radiative transition routes [spontaneous emission, stimulated emission, and absorption] is called Einstein coefficients and quantified the relations between the three processes.

=> Let N_1 be the number of atoms per unit volume with energy E_1 and N_2 be the number of atoms per unit volume with energy E_2, let n be the number of photons per unit volume at frequency ν such that $E_2 - E_1 = h\nu$ then. The energy density of photons $E = h\nu$

i) Stimulated absorption :-

=> When the photons interact with the atoms it leads to absorption transition which is called as stimulated absorption. Stimulated absorption rate depends upon the number of atoms avaible in the lowest energy states as well as the energy density of photons

$$\text{Stimulated absorption rate} \propto N_1$$

$$\propto u(\nu)$$

$$= B_{12} N_1 u(\nu)$$

Where B_{12} is the Einstein coefficient of stimulated absorption.

2 Spontaneous emission :-

⇒ The atom in the excited state returns to ground state emitting aphoton of energy $(E) = E_2 - E_1 = h\nu$ without applying an external energy spontaneously is known as spontaneous emission. The spontaneous emission rate depends up on the number of atoms present in the excited state

$$\text{Spontaneous emission rate} \propto N_2$$

$$= A_{21} N_2$$

Where A_{21} is the Einstein cofficient of spontaneous emission.

3. Stimulated emission :-

⇒ The atom in the excited state can also returns to the ground state by applying external energy (or) inducement of photon energy there by emitting two photons which are having same energy as that of incident photon. this process is called as stimulated emission. Stimulated emission rate depends upon the number of atoms available in the excited state as well as the energy density of incident photons

$$\text{Stimulated emission rate} \propto N_2$$

$$\propto u(\nu)$$

$$= B_{21} N_2 u(\nu)$$

Where B_{21} is the Einstein Coefficient of stimulated emission if The System is in equillibrium The rate of absorption transitions are equal to The emission transitions

The rate of Absorption = The rate of spontaneous + Stimulated emission.

$$B_{12} N_1 u(\nu) = A_{21} N_2 + B_{21} N_2 u(\nu)$$

$$B_{12} N_1 u(\nu) - B_{21} N_2 u(\nu) = A_{21} N_2$$

$$u(\nu) \{ B_{12} N_1 - B_{21} N_2 \} = A_{21} N_2$$

$$u(\nu) = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}$$

$$u(\nu) = \frac{A_{21} \cancel{N_2}}{B_{21} \cancel{N_2} \left[\frac{B_{12}}{B_{21}} \times \frac{N_1}{N_2} - 1 \right]}$$

$$u(\nu) = \frac{A_{21}}{B_{21}} \times \frac{1}{\left[\frac{N_1}{N_2} \times \frac{B_{12}}{B_{21}} - 1 \right]}$$

According to Boltzman distribution Law

$$N_i = N_0 e^{-E_i/k_B T}$$

$$N_1 = N_0 e^{-E_1/k_B T}$$

$$N_2 = N_0 e^{-E_2/k_B T}$$

$$\frac{N_1}{N_2} = \frac{\cancel{N_0} e^{-E_1/k_B T}}{\cancel{N_0} e^{-E_2/k_B}} = e^{\frac{E_2 - E_1}{k_B T}}$$

$$u(\nu) = \frac{A_{21}}{B_{21}} \times \frac{1}{\left[e^{\frac{h\nu}{K_B T}} \left(\frac{B_{12}}{B_{21}} \right) - 1 \right]} \quad \text{--- (1)}$$

According to planck's radiation formula The energy density of photon is given by

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \times \left[\frac{1}{e^{\frac{h\nu}{K_B T}} - 1} \right] \quad \text{--- (2)}$$

Comparing (1) & (2) we get

i) $\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$ (or) $\frac{A_{21}}{B_{21}} \propto \nu^3$

ii) $\frac{B_{12}}{B_{21}} = 1$ (or) $B_{12} = B_{21}$

population Inversion :-

⇒ The number of atoms present in The excited (or higher) state is greater than the number of atoms present in The ground state (or Lower state) is called population inversion.

⇒ Let us consider two Level energy systems of energies E_1 & E_2 Let N_1 and N_2 be The population (means number of atoms per unit volume) of E_1 & E_2 respectively.

According to Boltzman's distribution The population of energy E at temperature T is given by

$$N_i = N_0 e^{\left(\frac{-E_i}{K_B T}\right)} \quad \text{Where } i = 1,2,3 \text{ --- } N_i$$

Where N_0 is The number of atoms in ground (or) Lower energy state

K is The Boltzman Constant

From The above equation The population of energy Levels E_1 and E_2 are given by

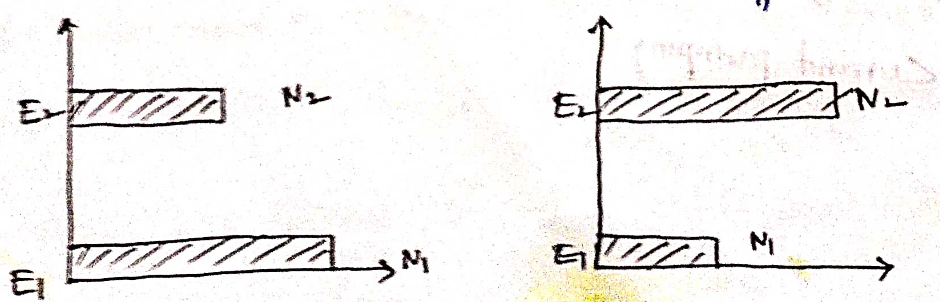
$$N_1 = N_0 e^{\left(\frac{-E_1}{K_B T}\right)}$$

$$N_2 = N_0 e^{\left(\frac{-E_2}{K_B T}\right)}$$

⇒ At ordinary Conditions $N_1 > N_2$ i.e The population in The ground (or) Lower state is always greater than The population in The excited (or) higher state.

⇒ The state of making population of higher energy level greater than population of Lower energy Level is called population inversion i.e $N_2 > N_1$

$$\boxed{\text{population inversion} = N_2 > N_1}$$



At Normal Condition $N_1 > N_2$ — After population inversion is achived $N_2 > N_1$

Meta Stable State :-

⇒ In general The number of excited particles in system is smaller Than The non excited particles, The time during Which a particle can exist in The ground state is unlimited, on The other hand. The particle can remain in The excited state for a limited time known as life time. The life time of The excited hydrogen atom is of The order of 10^{-8} sec. However there exist Such excited states in which The life time is greater than 10^{-8} sec. These states are Called as Meta stable state.

Pumping Mechanics [or Techniques] :-

Pumping :- The process of raising more no. of atoms to The excited state by artificial means is called pumping

⇒ A system in which population inversion is achieved is called as an active system. The method of raising The particles from lower energy state to higher energy state is called pumping. this Can be done by number of ways. The most commonly used pumping methods are,

i) optical pumping

ii) Electrical discharge pumping

iii) Chemical pumping

iv) Injection current pumping

(i)

i) optical pumping :-

⇒ Optical pumping is used in solid laser. Xenon flash tubes are used for optical pumping.

⇒ Since these materials have very broad band absorption, sufficient amount of energy is absorbed from the emission band of flash lamp and population inversion is created

Examples of optically pumped laser's are ruby, Nd : YAG Laser [$Y_3 Al_5 G_{12}$]

[Neodymium Yttrium Aluminium Garnet], Nd : Glass Laser

ii) Electrical discharge pumping :-

⇒ Electrical discharge pumping is used in gas lasers. Since gas laser's have very narrow absorption band pumping them any flash lamp is not possible. Examples of Electric discharge pumped lasers are He-Ne Laser CO_2 Laser, argon-ion laser etc.

iii) Chemical pumping :-

⇒ Chemical reaction may also result in excitation and hence creation of population inversion in few systems. Examples of such systems are HF and DF Laser's

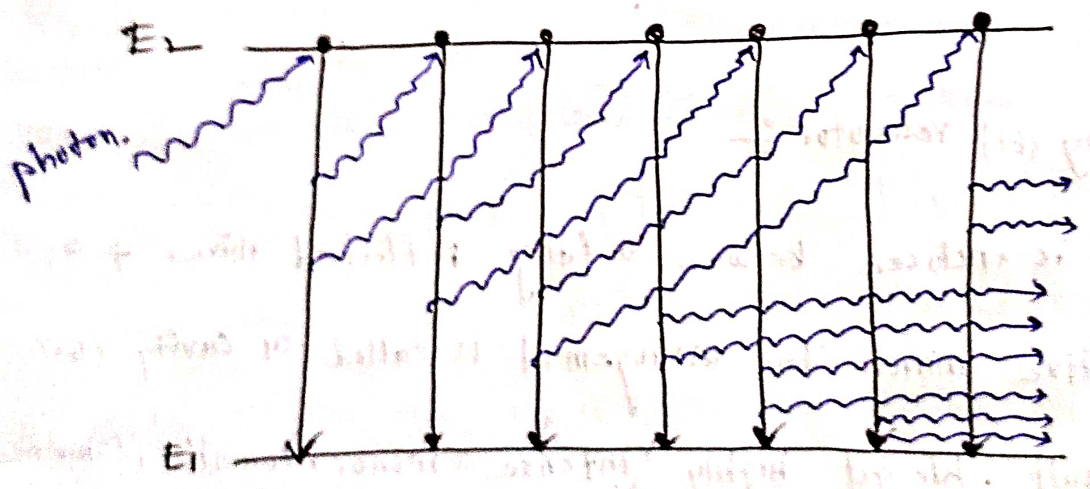
iv) Injection Current pumping :-

⇒ In Semiconductor injection of current through the Junction results in creates of population inversion among the minority charge carrier's

Examples of few systems are InP and GaAs

* Principle of LASER / LASINh Action :-

=> let us Consider many no. of atoms in The excited state. Now The The stimulating photon interacts with any one of The atoms in The excited state. The stimulated emission will occur. it emits two photons. having same energy & same frequency move in The same direction. these two photons will interact with another two ~~pAtoms~~ Atoms in excited state & Emit 8-photons. In a similar way chain reaction is produced this phenomenon is called principle of Lasing Action. We get a monochromatic, coherent, directional & Intense beam is obtained. this is called Laser beam. this is The principle of Working of a Laser.



Components of a LASER :-

=> Any laser System Consists of 3-important Components. they are

i) Source of energy (or) pumping Source

ii) Active medium (LASER material)

iii) Optical Cavity (or) resonator

i) Source of Energy :-

⇒ it supply energy & pumps The atoms (or) molecules in The active medium to excited state. As a result we get population inversion in The active medium which emits Laser.

Ex: Xenon flash lamp, electric field

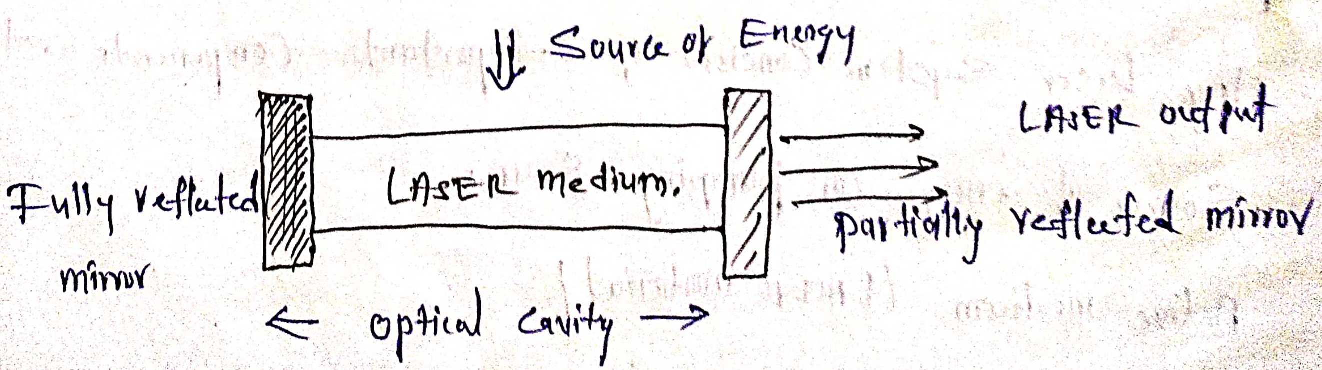
ii) Active Medium :-

⇒ The medium in which The population inversion takes place is called as Active medium.

Active ~~Centre~~ : Centre :- The material in which The atoms are raised to excited state to achieve population inversion is called as active Centre

iii) optical cavity (or) resonator :-

⇒ The active is enclosed between a fully reflected mirror & a partially reflective mirror. The arrangement is called as cavity (or) resonator. As result, We get highly intense monochromatic, coherence Laser light through The non-reflecting portion of The mirror.



Different types of LASERS :-

=> On The basis of active medium used in The Laser Systems. Lasers are classified into several types.

1. Solid Lasers : Ruby Laser, Nd : YAG Laser, Nd ; Glass.
2. Liquid lasers : Europium chelate Laser, $SeOCl_2$
3. Gas Lasers : CO_2, He - Ne, Argon-Ion laser
4. Dye Lasers : Rhodamine 6G
5. Semiconductor Lasers : InP, GaAs.

Ruby LASER :-

=> Ruby Laser is a three level solid state laser and was developed by Maiman in 1960. Ruby (Al_2O_3 + Cr_2O_3) is a crystal of Aluminium oxide, in Which 0.05% of Al^{+3} ions are replaced by The Cr^{+3} ions. The Colour of The ruby rod is pink. The Active medium in The ruby rod is Cr^{+3} ions

principle (or) characteristics of a ruby laser :-

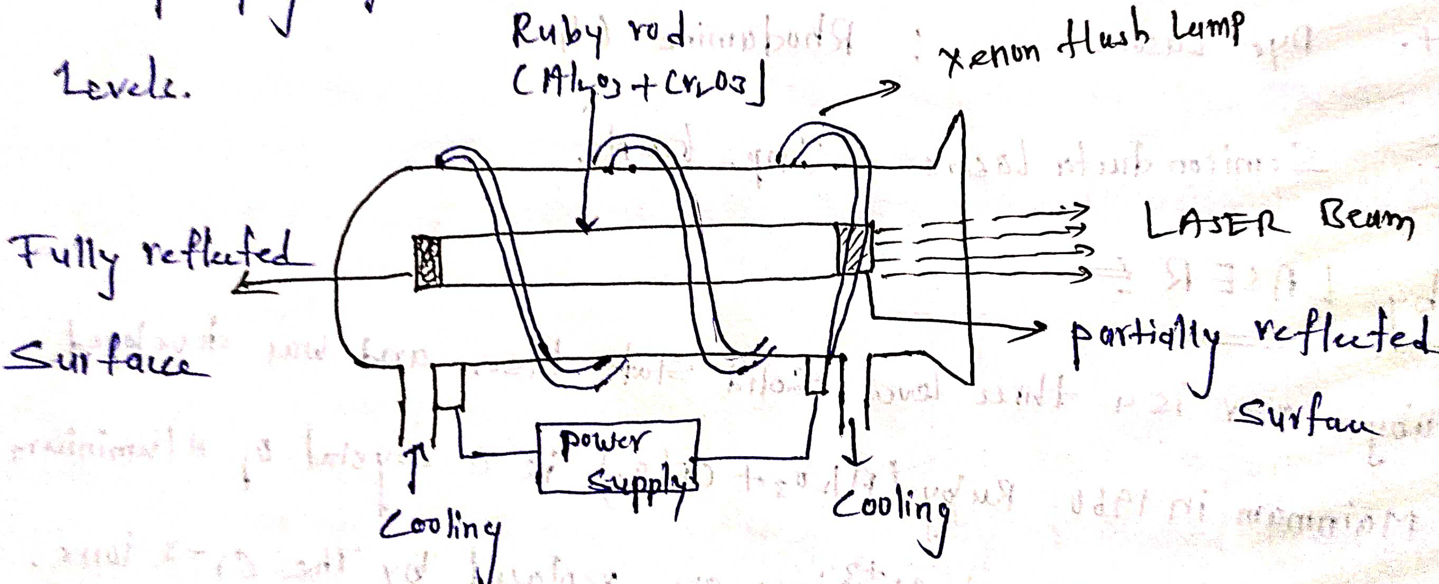
=> Due to optical pumping, The chromium atoms are raised to excited states Then The atoms come to metastable state by non-radiative transition. Due to Stimulated emission The transition of atoms take place from metastable state to ground state and gives LASER beam.

Construction :-

⇒ In ruby laser 4 cm length and 5 mm diameter rod is generally used.

⇒ Both The ends of The rods are highly polished and made stricly parallel. The ends are silvered in such away, one becomy partially reflected and The other and fully reflected.

⇒ The ruby rod is surrounded by xenon flash tube, which provides The pumping light to excite The chromium ions into upper energy Levels.



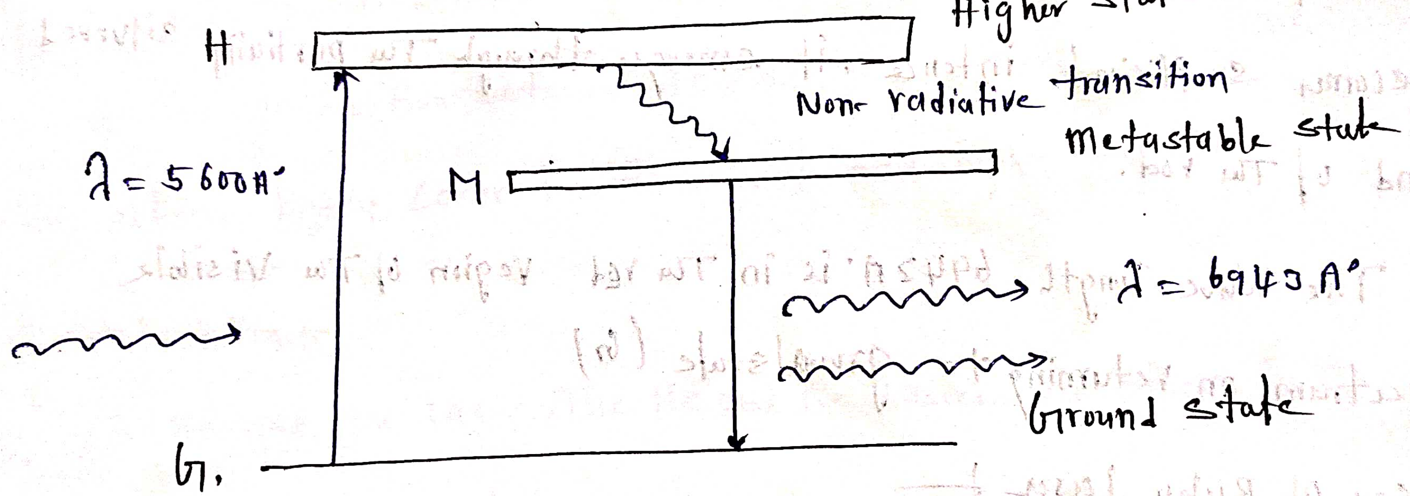
⇒ Xenon flash tube emits thousands jouls of energy in few milli seconds. but only a part of that energy is utilized by The chromium ions while The rest energy heats up the apparatus

⇒ A cooling arrangement is provided to keep The experimental set up at normal temperatures.

Working :-

⇒ The energy level diagram of chromium ions is shown in figure.
The chromium ions get excitation into higher energy levels by absorbing of 5600 A° of Wave length radiation. The excited chromium ions stay in The level H for short interval of time (10^{-8} sec)

⇒ After their life time most of The chromium ions are de-excited from H to G and a few chromium ions are de-excited from H to M



⇒ The transition between H and M is non radiatiative transition ie
The chromium ions gives this energy to The lattice in The form of heat
In The meta stable state The life time of chromium ions is 10^{-3} sec

⇒ Due to The continuous Working of flash lamp, The chromium ions are excited to higher state H & returned to M Level. After few milli sec The Level M is more populated than Level G and hence The desired population inversion is achieved. ∴ The state of population inversion is not a stable one. The process of spontaneous transition is very high.

⇒ When The excited chromium ions passes spontaneously from H to M it emits one photon of wave length 6943 A°.

⇒ The photon reflects back and forth by The silver ends and until it stimulates an excited chromium ion in M state and it to emit fresh photon in phase with The earlier photon.

⇒ The process is repeated again and again until The laser beam intensity is reached to sufficient value. When The photon beam becomes sufficient intense, it emerges through The partially silvered end of The rod.

⇒ The wave length 6943 A° is in The red region of The visible spectrum on returning to groundstate (G)

Uses of Ruby Laser :-

⇒ In distance measurement using pulse echo technique

→ for measurement of plasma properties such a electron density and Temp

→ To remove The melanin of The skin

→ For recording pulsed holograms

Draw backs of Ruby Lasers :-

→ Requires high pumping power

→ The Efficiency of ruby Laser is very small. It is a pulse Laser !

× × ×

He-Ne LASER :-

⇒ it was discovered by A. Javan & his co-workers in 1960, it is Continuous wave gas Laser. it Consists of mixture of He-Ne in 10:1 ratio as a active medium.

principle | Characteristics of He-Ne LASER:

⇒ this LASER is based on The principle of stimulated emission, produced in The He & Ne. The population Inversion is achieved due to The interaction between He & Ne gases. Using gas lasers we Can achieve highly Coherent, directional and high monochromatic beam.

Construction :-

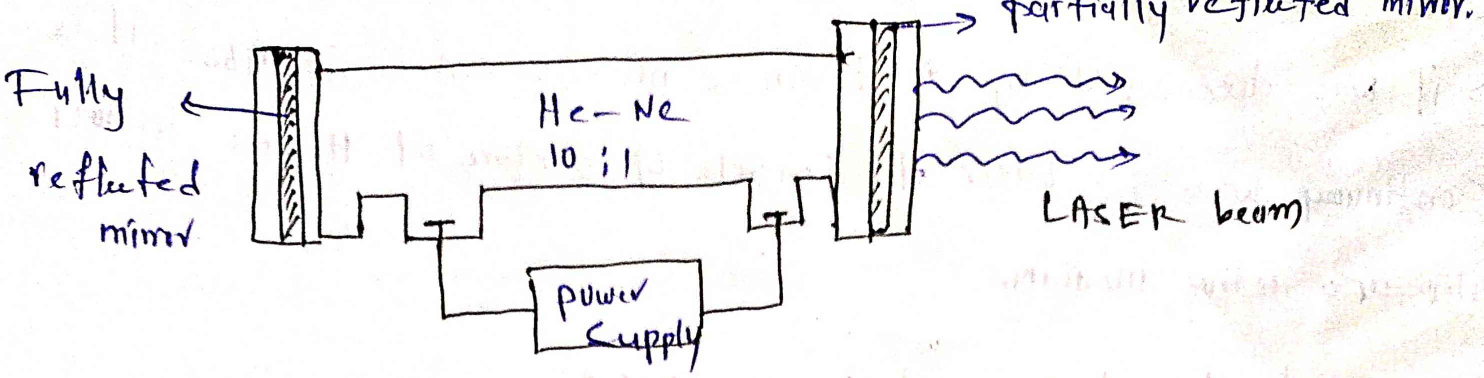
⇒ In He-Ne gas Laser, The He and Ne Lasers are taken in The ratio 10:1 in The discharge tube

⇒ Two reflecting mirrors are fixed on either ends of The discharge tube in That one is partially reflecting and other is fully reflecting.

⇒ In He-Ne Laser 80cm Length and 1cm diameter discharge tube is generally used

⇒ The output power of These lasers depends on The length of The discharge tube and pressure of The gas mixture.

⇒ Energy Source of Laser is provided by an electrical discharge of around 1000V through an anode and Cathode at each end of



Working :-

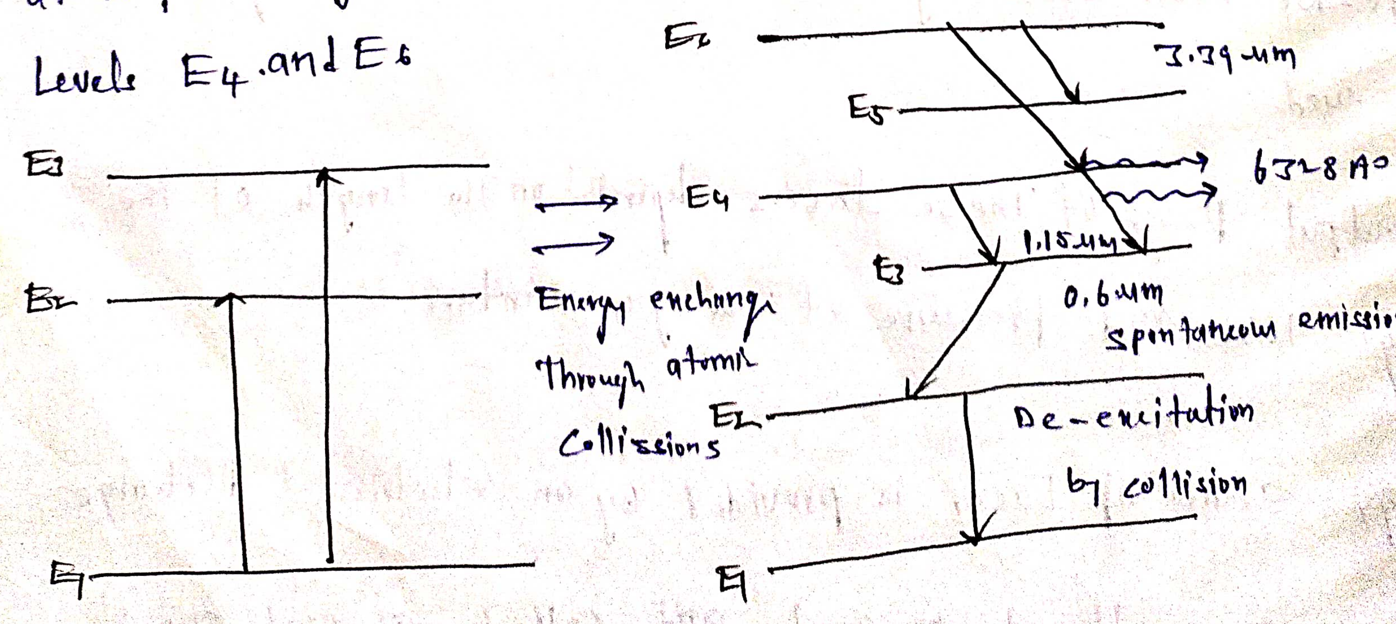
⇒ When The electric discharge is passing through The gas mixture The electrons accelarated towards The positive Electrode

⇒ During their passage, they collide with He atoms and excite Them into higher Levels

⇒ E_2 and E_3 form E_1. In higher Levels E_2 and E_3, The life time of He atoms is more

⇒ So there is a maximum possibility of Energy transfer between He & Ne atoms through atomic Collisions

⇒ When He atoms present in The Levels E_2 and E_3 Collide with Ne atoms present ground state E_1, The Ne atoms gets excitation into high Levels E_4 and E_6



Semiconductor LASER's :-

⇒ The first Semiconductor Lasers were made by hall and Nathan in 1962 using Gallium Arsenide (GaAs). The Semiconductor laser is also called as diode LASER. it has Same principle like light Emitting diode (LED) on The basis of recombination, Semiconductor lasers classified into two types they are.

1. Homojunction Semiconductor laser Ex: GaAs
2. Heterojunction Semiconductor laser Ex: GaAl As

1. Homojunction Semiconductor Laser :-

type : Homojunction Semiconductor laser

Active medium : PN Junction diode

Active Centre : Recombination of electrons & holes

pumping Source : Direct pumping

optical resonator : Junction of diodes - polished

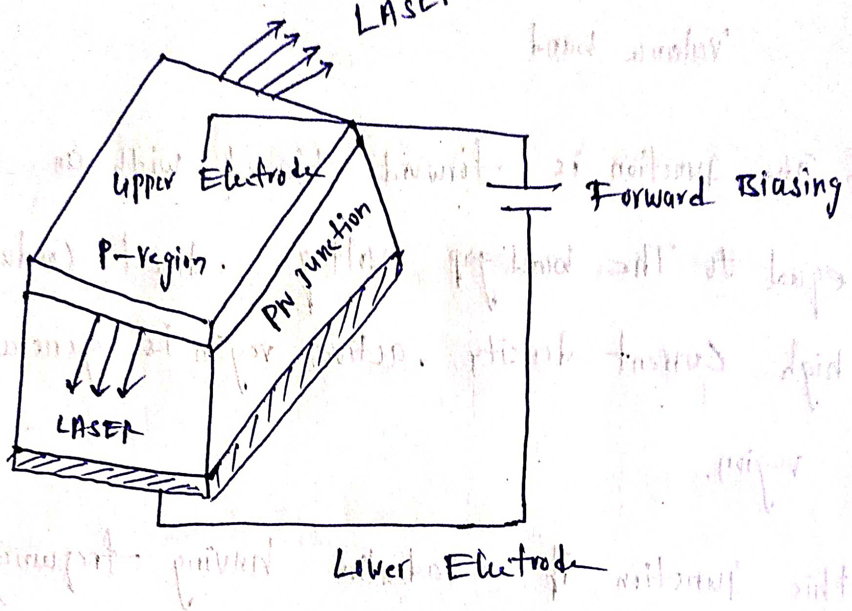
power output : 1mW

Nature of output : pulsed (or) Continuous wave form

Wave length : 8400 A° - 8600 A°

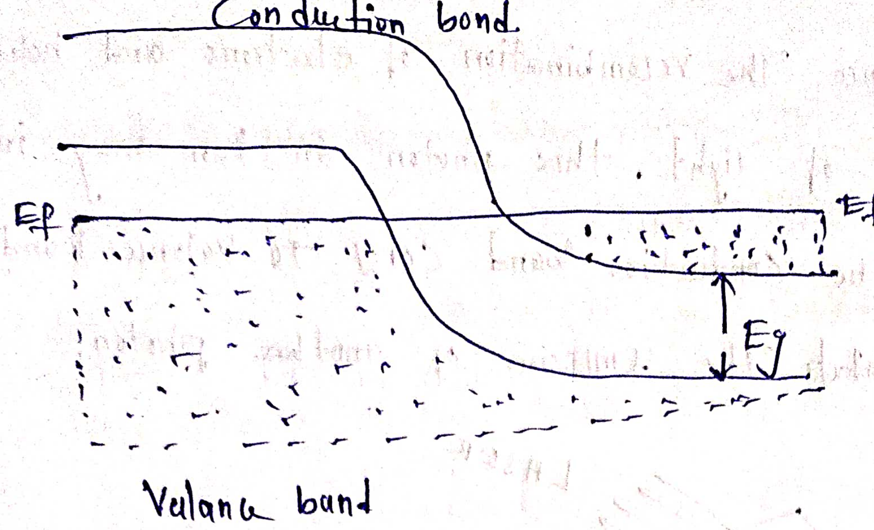
Band Gap : 1.44 eV

Principle :- The electron band combing with a hole in the Valance band and hence The recombination of electrons and holes produces energy in The form of light. this photon in turn may induce another electron in The Conduction band (CB) to Valance band (VB) and there by stimulate The emission of another photon.



Construction :- The Active medium is P-N junction diode made from Crystalline material i.e Gallium Arsenide. in Which P-region is doped with Germanium and N-region with tellurium. The thickness Of The p-N junction layer is very narrow So that The emitted laser radiation has large divergence The junctions of The P and n are well polished and are parallel to each other as shown in figure.

Working :- i) The population inversion in a p-n junction is achieved by heavily doping p and n material. so that The fermi level lies within The Conduction band of n-type and within The valance band of p-type as shown in fig.

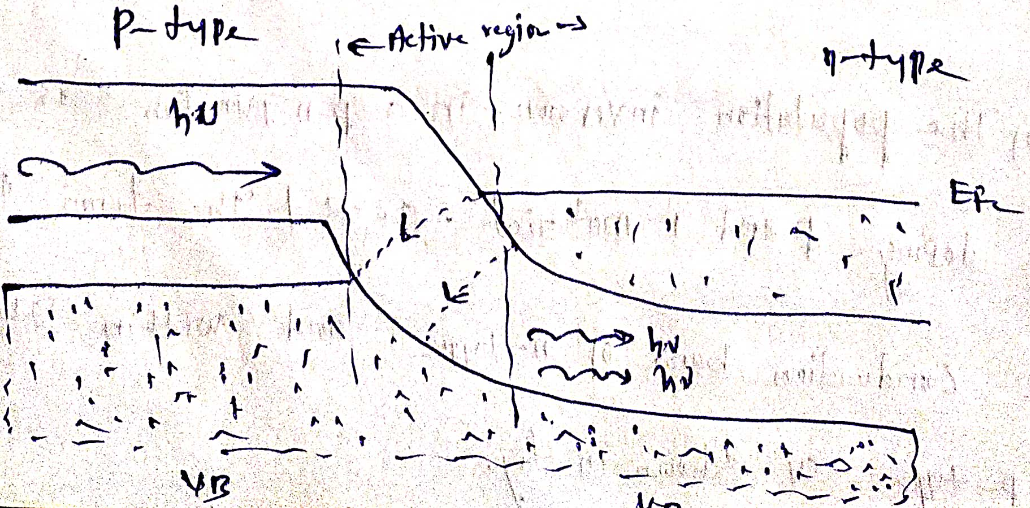


ii) If The junction is forward biased with an Applied voltage nearly equal to The band gap voltage. direct Conduction takes place Due to high Current density, active region is generated near The depletion region.

iii) At this junction if a radiation having frequency (ν) is is made to incident on The p-n junction. then The photon emission is produced as show in fig.

iv) Thus The frequency of The incident radiation should be in The range

$$\boxed{\frac{E_g}{h} < \nu < \frac{(E_{Fc} - E_{Fv})}{h}}$$



v) Further The emitted photons increases The rate of recombination of injected electrons from The n-region and holes in p-region by including more recombinations.

vi) hence The emitted photons have The Same phase & frequency as That of original inducing photons and will be amplified to get intense beam of LASER.

vii) The Wavelength of The emitted radiations depends on The band Gap The Concentration of donor & accepter atoms in GaAs.

Advantages :-

1) it is easy to manufacture The diode

2) The Cost is Low.

Dis Advantages :-

1. it produces Low power output
2. The beam has Large divergence
3. They have high threshold current density.

2. Heterojunction Semiconductor LASER (GaAlAs) :-

Type : Heterojunction Semiconductor LASER

Active medium : p-n junction (with various layer's)

Active Centre : Recombination of electrons & holes

pumping process : Direct pumping

optical resonator : polished junctions of diode

power output : 10mW

Nature of output : Continuous Wave form

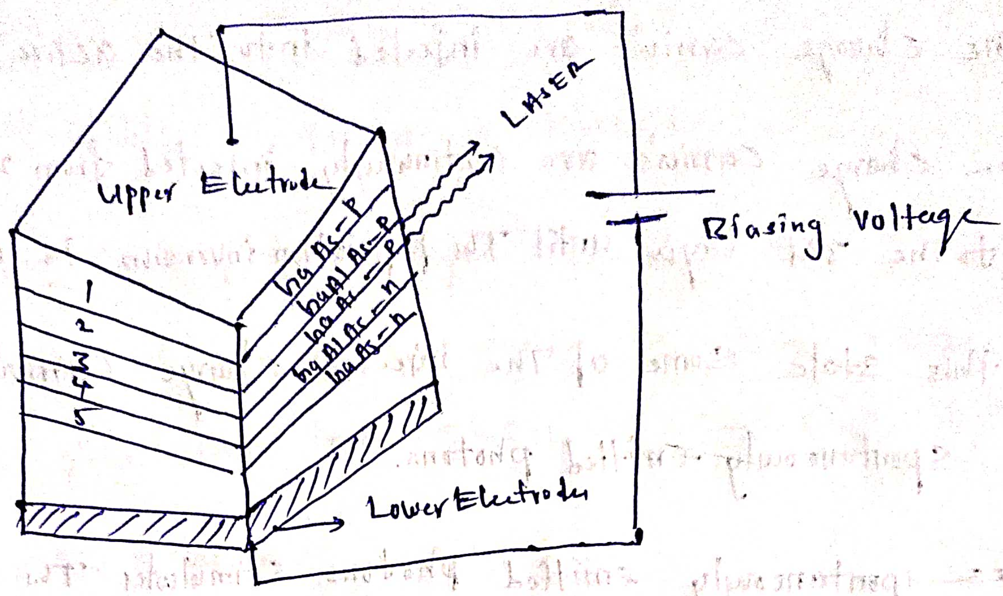
Wave length of output : 8000A°

Band Gap : 1.55eV.

Principle :- The electron in conduction band combines with a hole in the valance band and hence the recombination of electron and hole produces energy in the form of light. This photon in turn may induce another electron in the conduction band (CB), to valance band (VB) and thereby stimulate the emission of another photon.

Construction :-

⇒ it consists of five layer's as shown in fig. A layer of GaAs type (3rd layer) which has a narrow band gap will act as the active region. This layer (3rd layer) is sandwitched b/w the two layer's having width of band Gap viz GaAlAs - p-type (2nd Layer) and GaAlAs - n-type (4th)



⇒ A contact Layer made of GaAs - p-type (1st Layer) is made to form at the top of the 2nd layer for necessary biasing. All these four Layers are grown over the substrate (5th layer) made of GaAs - n-type

→ The Junctions of GaAs - p-type (3rd Layer) & GaAlAs n-type (4th Layer) are well polished and hence it act as an optical resonator. The upper and Lower electrodes helps in forward biasing the diode.

Working :-

⇒ The Working of a heterojunction layer is similar to that of the Working of a homojunction Layer.

i) The diode is forward biased with the help of upper and Lower electrodes

ii) Due to forward biasing The charge carrier's are produced in The Wide band Gap layer's (2 & 4)

iii) The charge carrier's are injected into The active region (Layer 3)

iv) The charge carrier's are continuously injected from 2nd and 4th Layer to The 3rd Layer until The population inversion is achived.

v) At this state some of The injected charge carrier's recombine and produce spontaneously emitted photons.

vi) These spontaneously emitted photons stimulates The injected charge carrier's to emit photons

vii) these photons are reflected back and forth at The Junction and hence an intense, coherent beam of LASER energy out from The PN Junctions of active region i.e b/w Layer-3 and Layer-4

* this Wavelength Lies in IR Region.

CO_2 LASER :-

type : molecular Gas LASER

Active medium : mixture of CO_2, N_2 and helium (or) Water vapour

Active Centre : CO_2

pumping Method : Electric discharge method

Optical Resonator : Metallic mirror of gold

power output : 10kw

Nature of output : Continuous (or) pulsed

Wave length of output : 96000 A° & 106000 A°

Introduction :- C.K.N patel desinged The CO_2 Laser We know in The Case of atoms electrons can be excited to higher energy levels The distribution of electrons in The shells and sub-shells define The electronic rate of The molecule

principle :- The transition b/w these Vibrational and rotational energy levels leads to The Construction from LASER here initially Nitrogen atoms are initially raised to excited state. The nitrogen atom delivers's The energy to CO_2 atoms which has Closest energy level to it. Then transition takes place b/w The vibrational & Energy levels of The CO_2 atoms and hence laser beam is emitted.

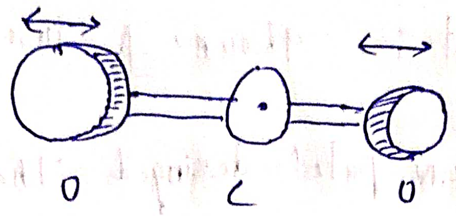
→ CO_2 laser of satisfies The first condition (i.e) here The laser transition occurs b/w vibrational energy levels of The same electronic state

* Fundamental modes of vibrations of The CO_2 molecule. there are Three fundamental modes of vibrations.

1. Symmetric stretching modes of vibrations ($10^{\circ}0$)
2) Bending mode ($01^{1}0$, $02^{0}0$)
3) Asymmetric stretching mode ($00^{\circ}1$, $00^{\circ}2$)

i) Symmetric stretching mode (1 0 0)

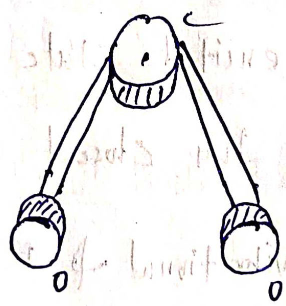
→ here the Carbon atom is stationary and the oxygen atoms oscillate (or) vibrate along the axis of the molecule as shown in fig.



Symmetric mode.

ii) Bending mode

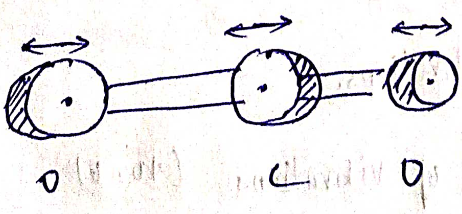
→ here the atoms will not be linear rather the atoms will vibrate ⊥r to the molecular axis as shown in fig this gives rise to two quanta of frequency.



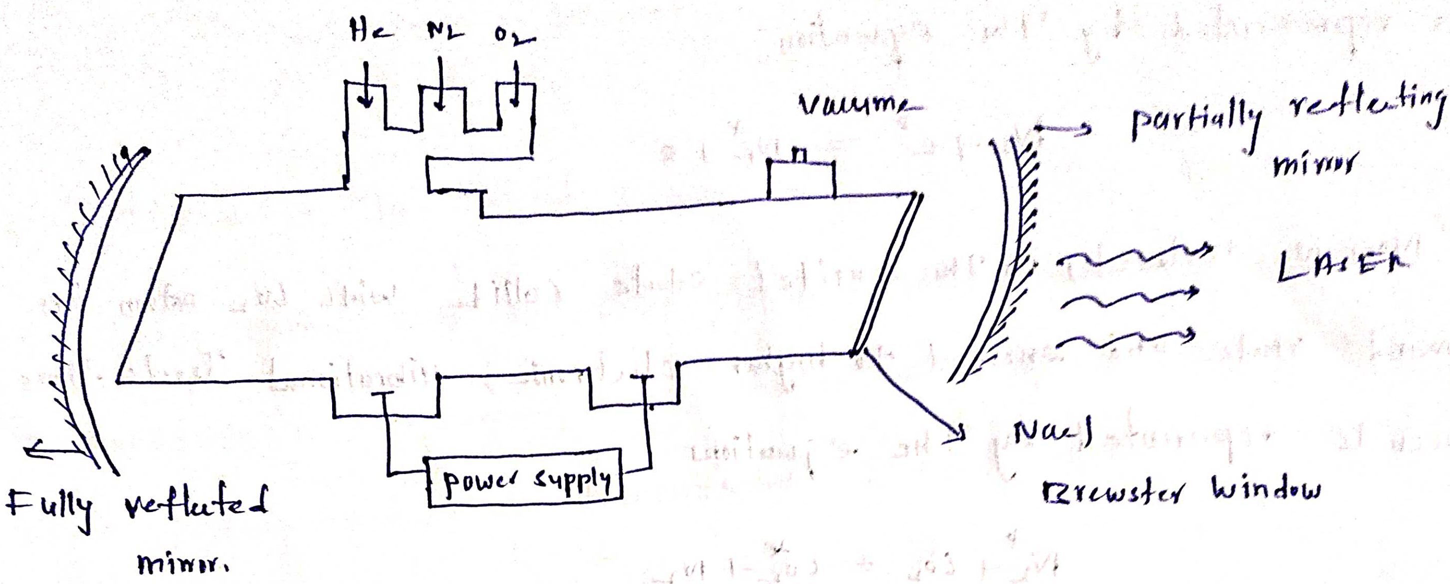
Bending mode

iii) Assymmetric mode :-

→ here all the three atoms will vibrate, here the oxygen atoms vibrate in the opposite direction to the vibration direction of Carbon atom as show.



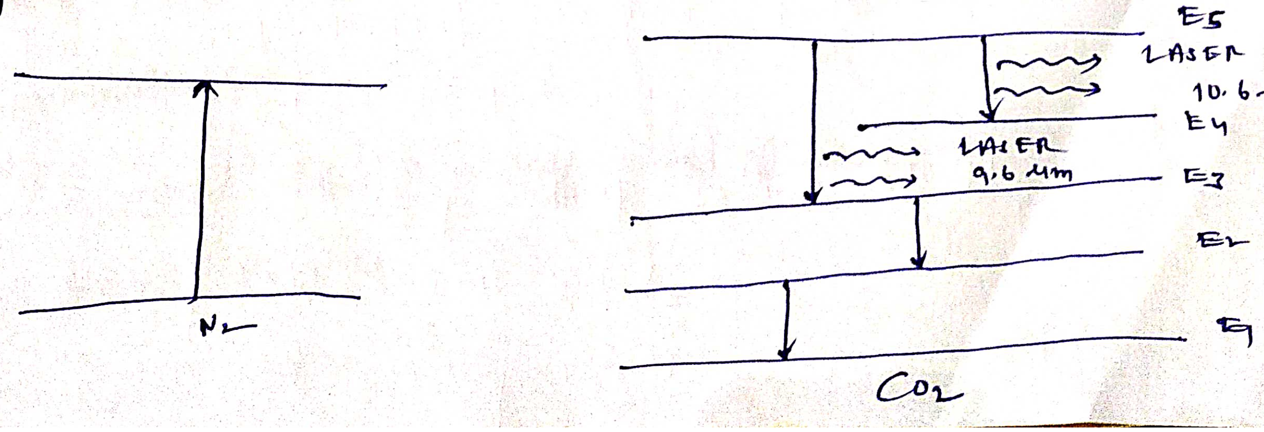
Construction :-



⇒ It consist of a quartz tube 5m along and 2.5 m diameter this discharge tube filled with mixture of CO_2 (Activemedium) He & N_2 with suitable pressure. The terminals of the discharge tube are connected to a DC power supply. The one end of discharge tube with Nacl Brewster window so that laser light generated will polarised two concave mirror's one fully reflecting and other the partially form an optical resonater.

Working :-

Figur shows energy levels of nitrogen and CO_2 molecule.



→ When an electric discharge occurs in the gas, The electrons collide with N_2 molecules and they are raised to excited states this process is represented by The equation.

$$N_2 + e^* = N_2^* + e$$

→ Now N_2 molecules in The excited state collide with CO_2 atom in ground state and excited to higher electronic, Vibrational levels. This process is represented by The equations

$$N_2^* + CO_2 = CO_2^* + N_2$$

→ Since The excited levels of N_2 is Verry close to The E_5 level of CO_2 atoms population of E_5 levels increases.

E_5 to E_4 ← this will produce a Laser beam of Wavelength 10.6 um

$E_5 \rightarrow E_3$, ←

→ this transition will produce a laser beam of wavelength 9.6 um

normally 10.6 um transition is more intense than 9.6 um transition

The output power from this layer is 10kw.

Applications of Lasers:-

Industrial and Engineering Applications:-

(i) **Welding:** the two metals plates to be welded to held in contact at their Edges and a high power laser is focussed on the line contact. the metal at line contact melts and solidifies on cooling which causes the two plates to stick together

(ii) **cutting:** cutting of metal sheets is achived using high power lasers like NdYAG (or) CO_2 lasers. lasers cutting produces higher quality of the cut Edges.

(iii) **Drilling:-** Holes can be drilled in to materials using high power pulsed lasers of 10^{-4} to 10^{-3} sec duration. laser drilling has a very high degree of precision and holes can be drilled in any direction.

(iv) **Measurement of atmospheric. pollution levels.**

Pollution of atmosphere is due to suspended particulate matter like dust, smoke, flash, aerosols Etc. using laser, we can get real time data by transmitting the laser beam in atmosphere and then observing either reflecting or transmitted mean.

v) lasers are used in laser printers. they are also used in CD read and write devices.

(vi) Lasers are used in fibre optics communication systems.

vii) lasers are used in holography

viii) lasers are used in surveying and ranging. Very long distances can be measured using lazers.

Medical Applications:

i) Lasers are used in Eye Surgeries as they can be focussed to very fine spot. It uses to weld detached retinas.

ii) lasers are used in bloodless detached retinas.

iii) lasers are used in pain less dental surgeries.

iv) lasers are used in plastic surgeries for treating skin diseases.

Military Applications:

→ Due to high Energy density, a laser beam can be used to destroy very big objects like aircrafts, missiles, Etc. in a few second by directing the laser beam in to the target. As such it is called 'death ray" or ray weapon.

→ Laser beam can be used in laser gun, highly converge beam is focussed on Enemy targets at a short range.

4. OPTICAL FIBER

Introduction To optical Fiber :-

⇒ Fiber optics is a branch of physics which deals with the transmission & reception of light waves using optical fibers which acts as a guiding media. The transmission of light waves by fiber optics was first demonstrated by "John Tyndall" in 1870.

Optical Fiber :-

⇒ optical fiber is a thin & transparent guiding medium or material which guides The information carrying light waves. it is a cyllindrical wave-guide system which propagates The data & speed signals in The optical frequency range.

⇒ A Light beam acting as a carrier wave is capable of carrying more information than radio waves & microwaves because of its high frequency

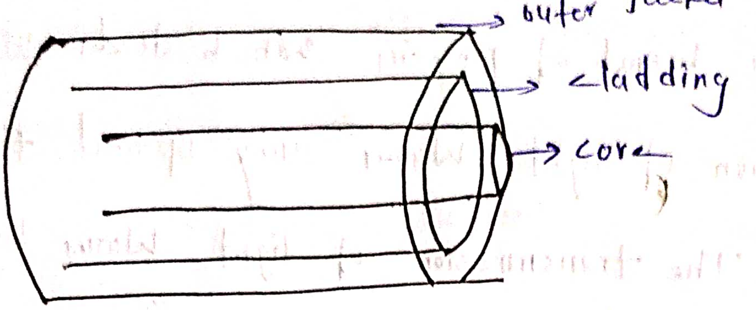
Radio waves $-10^4 Hz$, Micro waves $-10^{10} Hz$, Light waves $-10^{15} Hz$

Construction :-

→ An optical fiber is a very thin, flexible transparent made with plastic (or) glass

→ it has cylindrical shape consisting of three layers of sections

1. The core
2. The cladding
3. The outer Jacket (or) Buffer jacket



1. The core :-

→ It is The central layer surrounded by another layer called cladding. Which has refractive Index (n_1). Light transmitted within The core. core is made of silica (SiO_2). It is a denser medium.

2. The cladding :-

→ it is The second layer, surrounded by a third layer called The outer Jacket. it has refractive index n_2 which is less than refractive index of core ($n_1 > n_2$). it acts as a rarer medium. It keeps The light with in core because $n_1 > n_2$ to Lower The refractive index of cladding The silica is doped with phosphorus or bismuth material.

3. The outer or Buffer Jacket :-

→ It is The third Layer it protects The fiber from moisture & abrasion. To provide necessary toughness & tensile strength, a Layer of strength

→ a layer of strength member is arranged surrounding buffer jacket it is made of polyurethane material.

Working principle of optical fiber :-

Total Internal reflection :- The principle of optical fiber is total Internal reflection.

Condition for total internal reflection :-

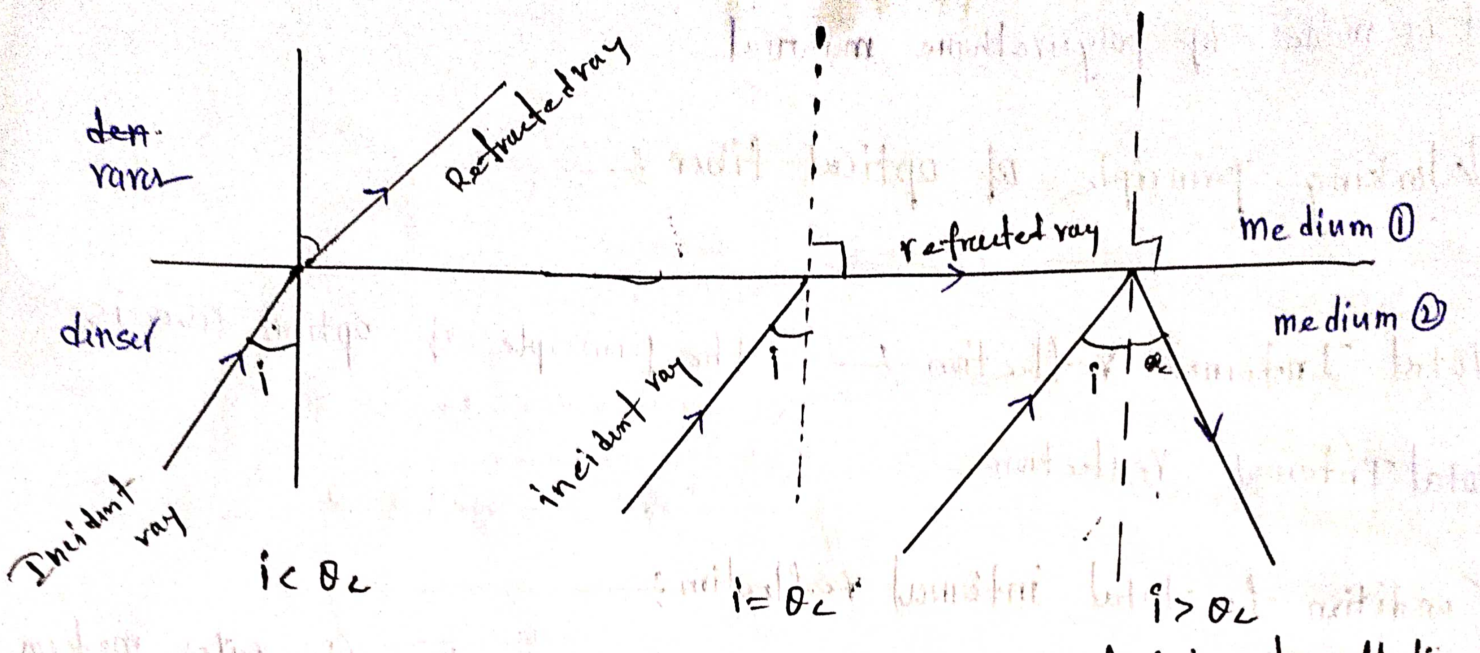
1. The light ray should move from denser medium to rarer medium.
2. The refractive index of core must be greater than cladding ($n_1 > n_2$)
3. The angle of incidence (i) must be greater than the critical angle (θ_c)

   $i > \theta_c$

4. The critical Angle $\theta_c = \sin^{-1} \frac{n_2}{n_1}$

Explanation :-

→ Let us consider a denser medium & rarer medium of refractive indices n_1 & n_2 respectively and $n_1 > n_2$. Let a light ray move from denser to rare medium with "i" as the angle of incidence & "r" as angle of refraction. The refracted ray bends away from the normal as it travel from denser to rarer medium with increase of angle of incidence "i"



In this we get three cases.

Case i :- When $i < \theta_c$ then the light ray refracts rarer medium as shown in figure

Case ii :- When $i = \theta_c$ then the light ray traverse along the two media as shown in figure. For the two media, Applying Snell's Law.

From Snell's Law

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

$$(\because i = \theta_c \ \& \ r = 90)$$

$$n_1 \sin \theta_c = n_2 \sin 90$$

$$n_1 \sin \theta_c = n_2$$

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

Where $n_1 > n_2$

For air $n_2 = 1$

$$\boxed{\theta_c = \sin^{-1}(1/n_1)}$$

Case 3 :- When $i > \theta_c$ then the light ray reflected back into the medium as shown in figur

Acceptance Angle & Acceptance Cone :-

Defination :- Acceptance angle is the maximum angle of incidence at the core of an optical fiber so that the light can be guided through the fiber by total internal reflection. this angle is called as Acceptance angle. it is denoted by αi

⇒ Consider a cross-sectional view of an optical fiber having core & cladding of refractive indices n_1 & n_2

⇒ Let the fiber be in air medium (n_0). The incident light while entering into the core at 'A' makes an incident angle of 'αi' with the fiber axis.

⇒ In core it travels along AB and is incident at part B on cladding interface. let αr be the angle of refraction at part 'A' and θ be the angle of incidence at 'B'

⇒ When 'θ' is greater than the critical angle θ_c then the total internal reflection takes place into the core & light takes the path BP

⇒ Due to multiple total internal reflections the propagation of light ray takes place through the fiber

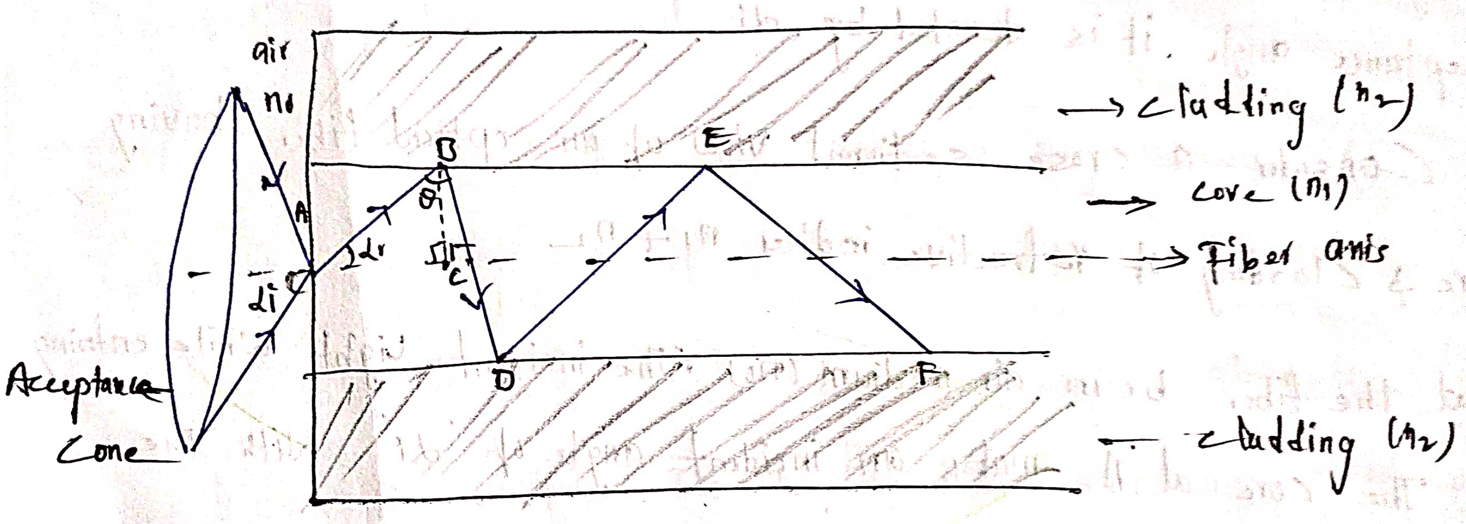
→ Applying Snell's Law at the core-air interface

$$\frac{\sin \alpha_i}{\sin \alpha_r} = \frac{n_1}{n_0}$$

$$n_0 \sin \alpha_i = n_1 \sin \alpha_r \quad \text{—— (1)}$$

→ Let a normal BC be drawn from the point 'B' to the fiber axis. then the ΔABC We get

$$\alpha_r = 90^\circ - \theta \quad \text{—— (2)}$$



Sub^n eq^n (2) in eq (1)

$$n_0 \sin \alpha_i = n_1 \sin (90^\circ - \theta)$$

$$n_0 \sin \alpha_i = n_1 \cos \theta \quad \text{—— (3)}$$

→ to get total internal reflection at B $(\theta > \theta_c)$

→ Let the maximum angle of incidence at poin A be α_i

From eq^n (3) We get

$n_0 \sin \alpha_i = n_1 \cos\theta$ ----- (4)

$\alpha_i(mx) = \alpha_i$, When $\theta = \theta_c$, $\sin \alpha_i(mx) = \frac{n_1}{n_0} \cos\theta_c$ ----- (5)

We know that $\sin\theta_c = \frac{n_2}{n_1}$

$$\cos\theta_c = \sqrt{1-\sin^2\theta_c} = \sqrt{1-\frac{n_2^2}{n_1^2}}$$

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

$$\cos\theta_c = \frac{\sqrt{n_1^2-n_2^2}}{n_1} \quad \text{----- (6)}$$

Sub eqn (6) in (5) We get

$$\sin\alpha_i(mx) = \frac{\cancel{n_1}}{n_0} \frac{\sqrt{n_1^2-n_2^2}}{\cancel{n_1}}$$

$$\sin\alpha_i(mx) = \frac{\sqrt{n_1^2-n_2^2}}{n_0}$$

$$\alpha_i(mx) = \sin^{-1}\frac{\sqrt{n_1^2-n_2^2}}{n_0} \quad \text{----- (7)}$$

$$\alpha_i(mx) = \sin^{-1}\sqrt{n_1^2-n_2^2} \quad \text{----- (8)}$$ [Acceptance Angle]

[$\because$ For air medium $n_0 = 1$]

Fractional Index change (Δ) :-

→ it is The ratio of refractive index difference in core & cladding to The refractive index of core

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

$$n_1 - n_2 = \Delta n_1 \quad \leftarrow (1)$$

Numerical Aperture (N.A) :-

⇒ It is defined as light accepting efficiency of The fiber and is equal to sine of The acceptance angle of The fiber

i.e $N.A = \sin \alpha_i (max)$

$$N.A = \sin \alpha_i (mx) = \sqrt{\frac{n_1^2 - n_2^2}{n_0}}$$

We know that $\Delta = \frac{n_1 - n_2}{n_1}$

$$\Delta n_1 = n_1 - n_2 \quad \text{—} (2)$$

for air $n_0 = 1$

We know $N.A = \sin \alpha_i (max) = \sqrt{n_1^2 - n_2^2}$

$$N.A = \sqrt{(n_1 + n_2)(n_1 - n_2)}$$

if $n_1 = n_2$ then $N.A \quad \sqrt{2 n_1 (\Delta n_1)}$

$$N.A = n_1 \sqrt{2 \Delta}$$

Types OF Optical fibers :-

Optical fibers

- Based on mode
  - Single mode
  - multimode
- Based on refractive Index profile
  - Step index
  - Graded index
- Based on material of fiber
  - Glass fibers
  - plastic fibers

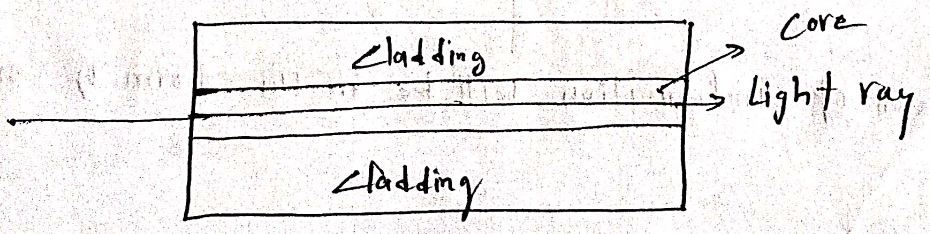
Based on mode :-

→ The rays travelling in The fiber by total internal reflection are called modes.

1. Single mode fiber :-

→ If The thickness of The fiber is so small that it supports only one mode then the fiber is called single mode fiber (or) mono-mode fiber.

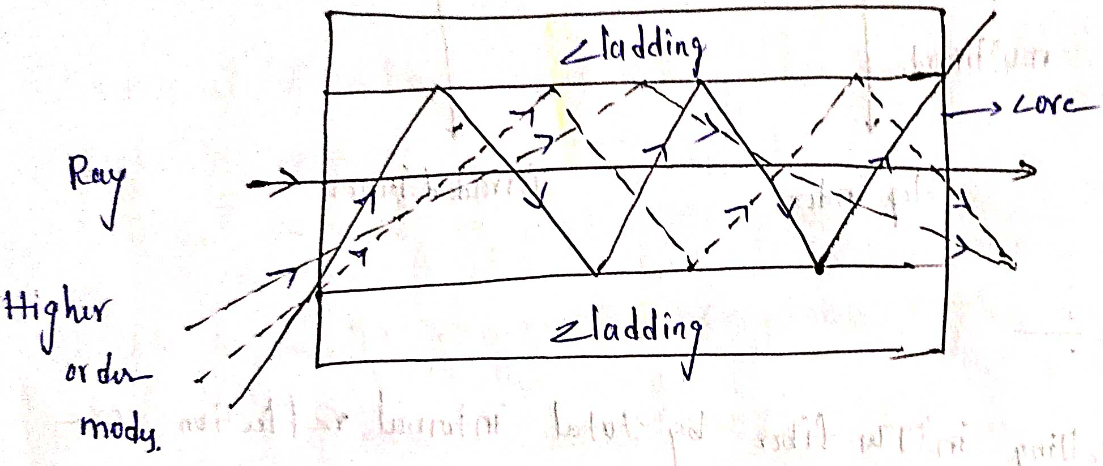
→ The core diameter of this fiber is about 8 to 10 μm and The outer diameter of cladding is 60 to 70 μm.



2. Multi mode fibers :-

→ If The thickness of The fiber is Very Large that it Supports more than one mode than The fiber is Called multi mode fiber.

→ The core diameter of This fiber is about 50 to 200 μm and The outer diameter of cladding is 100 to 250 μm.



Based on refractive index profile :-

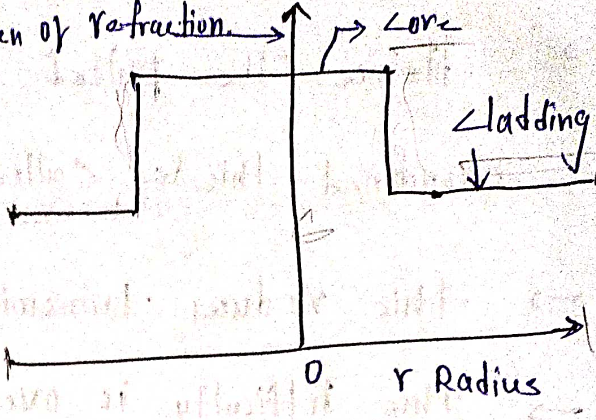
1. Step-index optical fiber :-

→ In a step-index optical fiber, The entire core has uniform refractive index n_1 slightly greater than The refractive index of The cladding. n_2

→ Since The index profile is in The form of a step, these fibers are called step-index fibers

→ The transmission of information will be in The form of signals (or) pulses.

→ these are extensively used because distortion and transmission Losses are very less.



→ Step-index optical fibers are of two types they are

i) Single mode step-index fiber

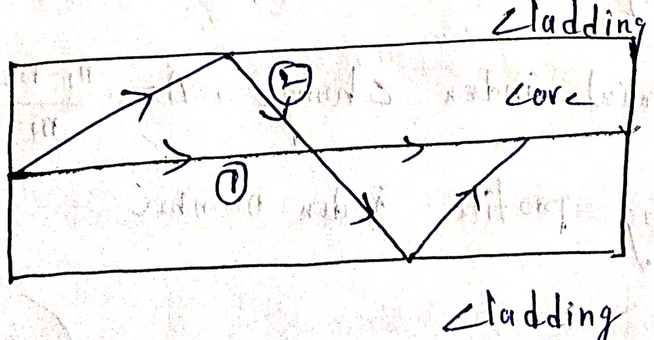
ii) Multi-mode step-index fiber.

propagation of signal in step-index fibers :-

→ Generally the signal is sent through the fiber in digital form i.e in the form of pulses.

→ The same pulsed signal travels in different paths.

→ let us now consider a signal pulse travelling through step index fiber in two different paths ① & ②



→ At the receiving end only the pulse (1) which travels along the fiber axis reaches first while the pulse ② reaches after some time delay.

→ Hence The pulsed signal received at The other end is broadened. this is called internal dispersion.

→ this reduces transmission rate capacity of The signal

→ this difficulty is overcome by graded index fiber's

2. Graded index optical fiber :-

→ in this fiber. The refractive index of of The Core vary radially.

→ It has maximum refractive index at its Centre Which gradually falls with increase of radius and at The core-cladding interface matches with refractive index of cladding.

→ Variation of refractive index of core with radius is given by

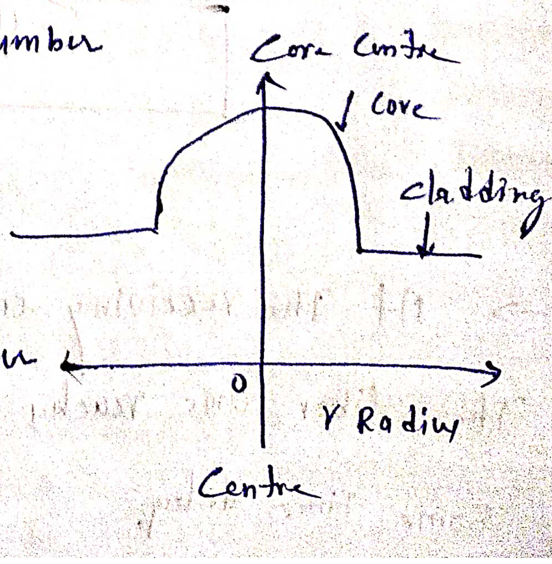
$$n(x) = n_1\left[1-2\Delta\left(\frac{x}{a}\right)^P\right]^{\frac{1}{2}}$$

Where $n_1 \rightarrow$ refractive index at The Centre of The Core

$a \rightarrow$ radius of The Core

$\Delta \rightarrow$ Fractional index change $\Delta = \frac{n_1-n_2}{n_1}$

$P \rightarrow$ Grating profile index number



→ this fiber divided in to two types

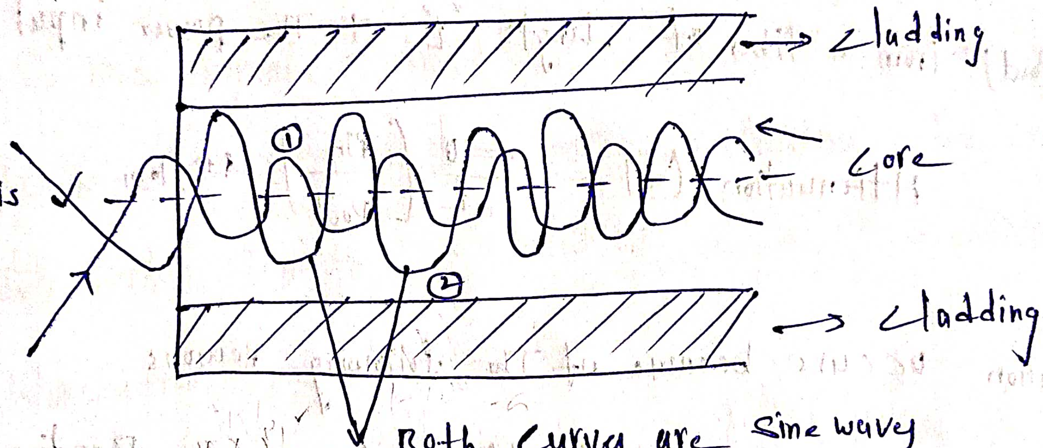
i) Single mode Graded index fiber

ii) Multimode graded index fiber

transmission / propagation of signal in step index fiber's :-

→ let us now consider a signal pulse travelling through graded index fiber in two different paths ① & ②

→ The pulse ① travelling along the axis of the fiber though travels along shorter route it travels through higher refractive index.



Both curves are sine waves

→ The pulse (2) travelling a way from the axis undergo refraction and bend as shown in fig. though it travels longer distance, it travels along lesser refractive medium.

→ Hence both the pulses reach the other end simultaneously

→ Thus the problem of inter model dispersion can be overcome by using graded index fiber's

Based on type of the materials

1) Glass - Glass optical fiber's
2) Glass - plastic optical fiber's
3) plastic - plastic optical fiber's

* Attenuation (power-Loss) in Optical Fibers :-

→ When Light propagates through an optical fiber, then The power of The light at The output end is found to be always less Than The power lanched at The input end. The loss of power is called Attenuation. it is measured in terms of decibles per kilometer

Attenuation :- It is defined as The ratio of The optical power output (Pout) from a fiber of length 'L' to The power input (Pin).

$$\text{Attenuation } (\alpha) = \frac{10}{L}\left(\frac{P_{in}}{P_{out}}\right) \text{ dB/km}$$

→ Attenuation occurs because of The following reasons

1. Absorption 2. Scattering Loss 3. Bending loss

1. Absorption :-

→ it occurs in two ways. i) Absorption by impurity (or) impurity absorption
ii) Intrinsic absorption (or) internal absorption.

i) Impurity absorption : The impurities present in The fiber are transition metal ions, Such as iron, chromium, cobalt & copper. During signal propagation when photons interact with these impurity atoms, then The photons are absorbed by atoms. hence loss occurs in light power

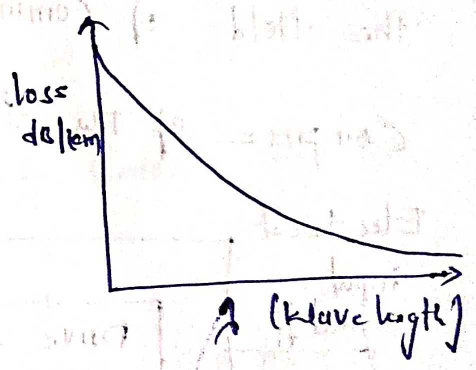
ii) Intrinsic absorption (or) internal absorption :

→ the fiber itself as a material has a tendency to absorb light energy however small it may be. The absorption that takes place in fiber material assuming that there are no impurities in it, is called intrisic absorption.

2. Scattering loss :-

→ When The signals travels in The fiber, The photons may be Scattered due to Variations in The refractive index inside The fiber. this Scattering is called as Rayliegh Scattering. it is also a Wavelength dependent loss.

Rayleigh Scattering loss $\propto \frac{1}{\lambda^4}$



3. Bending losses :-

⇒ these losses occur due to a) Macroscopic bending.
b) Microscopic bending

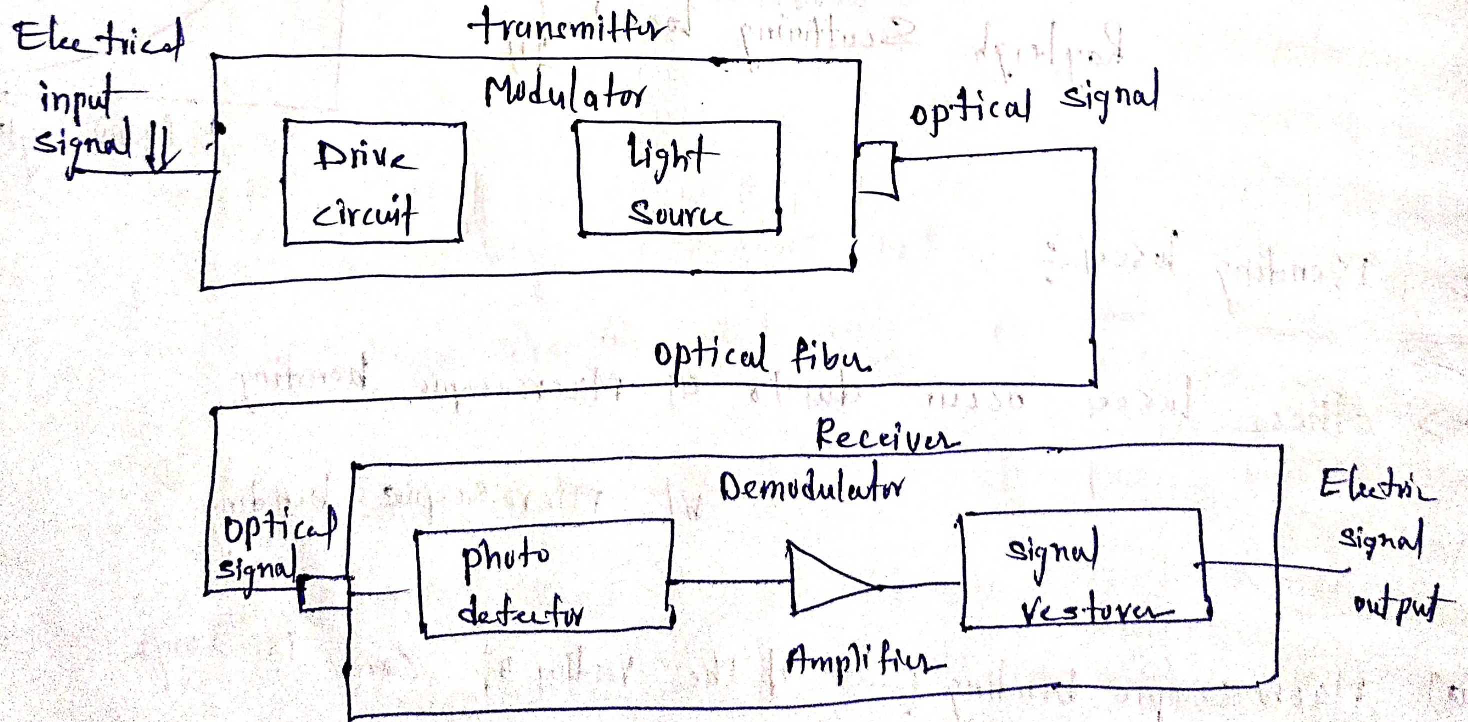
a) Macroscopic bending :- if The radius of Core is large Compared to fiber diameter causes large curvature at The bends. At these bends, The light will not satisfy The Condition for total internal reflection & light escape out

→ it is Called as macroscopic bending

b] Microscopic bending :- these are caused due to non-uniform pressurs created during the cabling of the fiber (or) during the manufacturing the fiber. It causes irregular reflections, this lead to lose of light by leakage through the fiber.

* Optical Fiber in Communication System :- (Imp)

→ The most important application of optical fibers occurs in the field of communication fiber optic communication systems comprise of the following units



Information signal Source :-

→ The information signal to be transmitted may be voice Video or Computer data

Applications of optical Fibers :-

1. Due to high band-width, light can transmit at a higher rate up to 10^{14} to 10^{15} Hz. than radio (or) micro-frequency.

2. Long distance signal transmission

3. they are used for exchange of information in cable television. Space Vehicles sub-marines

4. optical fibers are used in industry in security alarm systems process control & industrial automation.

5. they are used in pressure sensors in biomedical & engine Control applications.

problems :-

1. Estimate The critical Angle When The core refractive index is 1.48 and The relative refractive index is 2%.

Given :- The relative refractive index $\Delta = \frac{n_2 - n_1}{n_1} = 2\%$.

The refractive index of core $n_1 = 1.48$

The relative refractive index $\Delta = \frac{n_2 - n_1}{n_1}$

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

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

We know $\Delta = 2\% = 0.02$

$= 1.002$

$\frac{n_2}{n_1} = 0.98$

We know that The critical Angle $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

$\theta_c = \sin^{-1}(0.98)$

$\boxed{\theta_c = 78.52^\circ}$

2. Find The numerical aperture of an optical fiber having core refractive index of 1.55 and cladding refractive index 1.50

Given :- The refractive index of core $= 1.55$

The refractive index of cladding $= 1.50$

The numerical aperture is $NA = \sqrt{n_1^2 - n_2^2}$

$$= \sqrt{(1.55)^2 - (1.50)^2}$$

$$NA = 0.391$$

3. Find the numerical aperture of an optical fiber having a core refractive index of 1.6 and cladding refractive index of 1.50

Given:

$n_1 = 1.6$

$n_2 = 1.5$

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

$$= \sqrt{(1.6)^2 - (1.5)^2}$$

$$NA = 0.53677$$

4. Calculate the refractive indices of the core and cladding of a fiber from the following data. The numerical aperture is 0.27 and relative refractive index is 0.015

Sol:

$\Delta = 0.015$

$NA = 0.27$

The refractive index of core $n_1 = \frac{NA}{\sqrt{2\Delta}}$

$$n_1 = \frac{0.27}{\sqrt{2 \times 0.015}}$$

$$n_1 = 1.558$$

The refractive index of cladding $\Delta = \frac{n_1 - n_2}{n_1}$

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

$$\boxed{\Delta n_1 = (n_2 - 1)}$$

$$n_2 = n_1 (1 - \Delta)$$

$$= 1.55 \times (1 - 0.015)$$

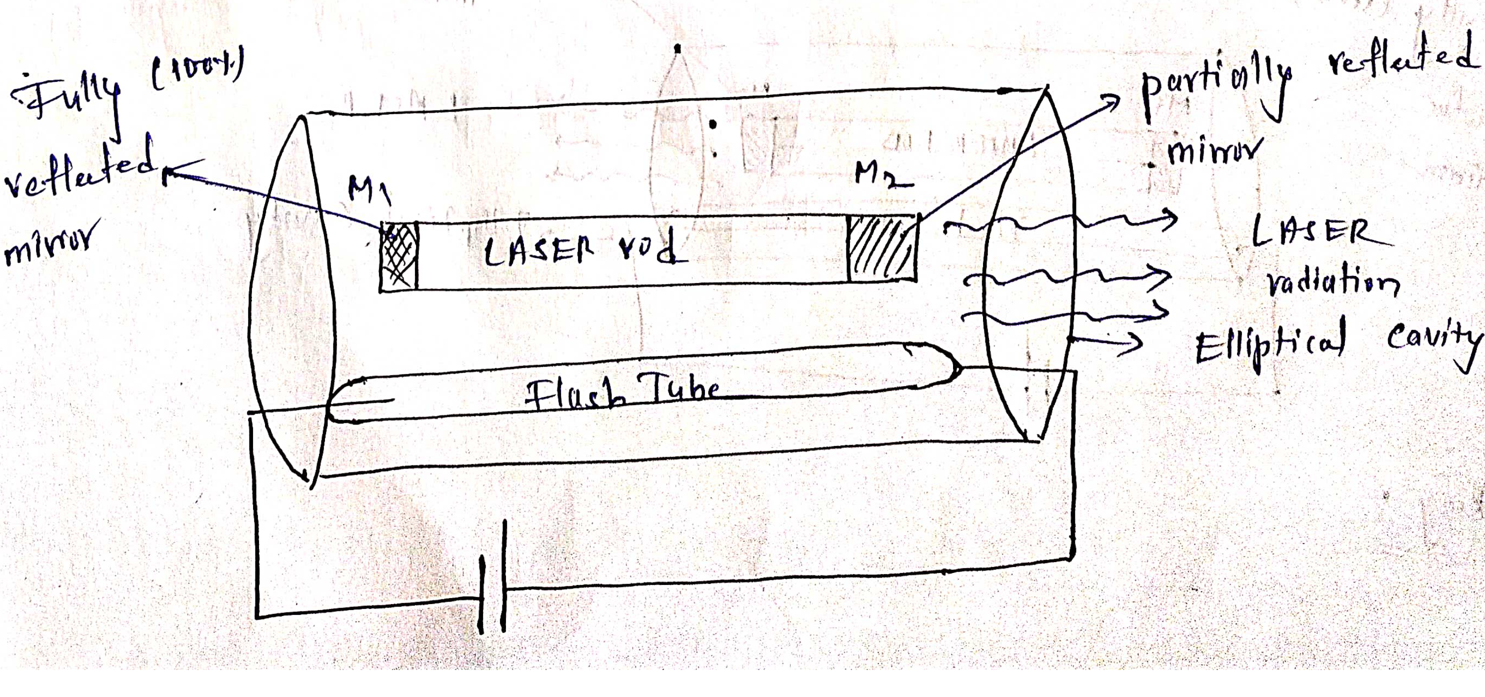
$$n_2 = 1.534$$

Nd-YAG LASER :-

1. type : Four Level solid state laser
2. Active medium : Nd-YAG laser
3. pumping method : optical pumping
4. pumping Source : Xenon (or) krypton flash tube
5. power output : 70 watt
6. Nature of output : Continuous beam of light

⇒ Nd:YAG laser is a neodymium based laser. Nd stands for Neodymium and YAG – Yttrium Aluminium Garnet ($Y_3Al_5O_{12}$).

Principle :- The active medium Nd:YAG rod is optically pumped by krypton flash tube. The neodymium ions (Nd^{3+}) are raised to excited levels. During the transition from meta stable to ground state, a laser beam of wavelength 1.064 μm is emitted.

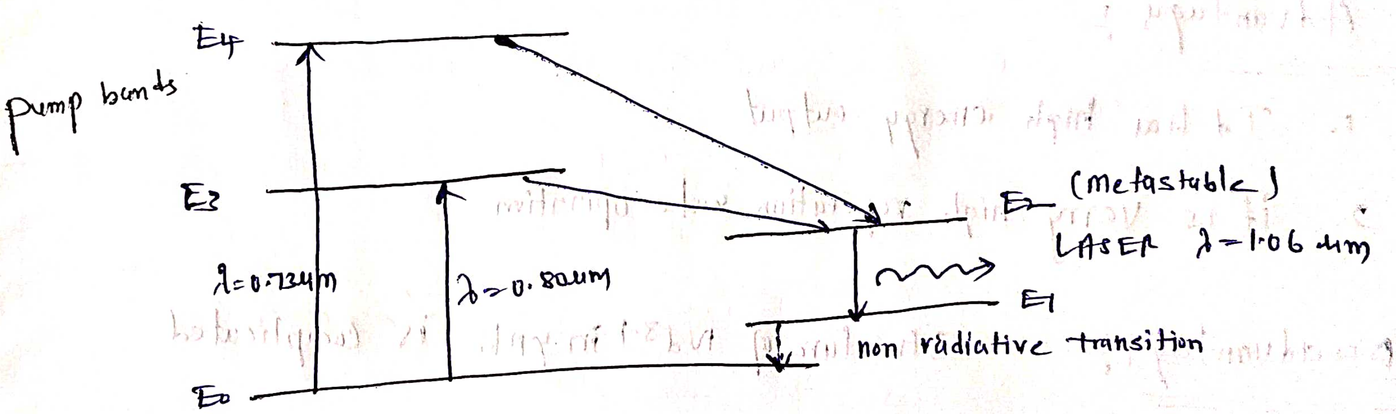


Construction :-

The construction of Nd : YAG laser is as shown in the figure. A small amount of (Y^{3+}) is replaced by (Nd^{+3}) in the active element of Nd : YAG crystal.

⇒ This 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. this cylindrical rod and a pumping source are placed inside a highly elliptical reflector cavity.

Working :-



1. When The krypton flash lamp is switched on by The absorption of light radiation of wavelength 0.73 μm and 0.8 μm. The (Nd^{3+}) atoms are raised from ground level E_0 to upper levels E_3 & E_4 (pump bands)

2. The Neodymium ions atoms make a transition from these energy levels E_2 by non-radiative transition. E_2 is a metastable state

3. The Neodymium ions are collected in The level E_2 and The population inversion is achieved b/w E_2 and E_1

4. An ion makes a spontaneous transition from E_2 to E_1, emitting a photon of energy $h\nu$. ~~emitting a photon of energy~~ The emitted photon will trigger a chain of stimulated photons b/w E_2 & E_1

5. The photons thus generated travel back and forth between two mirrors and grow in strength. After some time the photon number multiply more rapidly.

6. After enough strength is attained, an intense laser light of wave length 1.06 um is emitted through the partial reflector. it corresponds to the transition from E_2 to E_1.

Advantages :-

1. It has high energy output
2. it is very high repitation rate operation

Disadvantages :- Structure of Nd^{3+} in YAG is complicated

Applications :-

1. it find many applications in range finders and illuminators
2. it is widely used in engineering applications.

⇒ Due to The Continuous excitation of Ne atoms. We can achieve The population inversion between the higher Levels $E_4 (E_6)$ and Lower Levels $E_3 (E_5)$.

⇒ The Various transitions $E_6 \rightarrow E_5$, $E_4 \rightarrow E_3$ and $E_6 \rightarrow E_3$ Leads To The emission of Wavelengths 3.39 µm, 1.15 µm and 6328 Å

⇒ The first two Corresponding to The infrared region While The Last Wavelength is Corresponding to The Visible region.

⇒ The Ne atoms present in The E_3 Level are de-excited into E_2 Level. by spontaneously emission of photons

⇒ When a narrow discharge tube is used. The Ne atoms present in The level E_2 Collide with The walls of The tube and get de-Excited to ground level E_1.

Uses of He-Ne LASER :-

→ Used in laboratory for all interferometric Experiments

→ Widley in metrology in Surveying, alignment

→ To read barcodes and He-Ne laser Scanner's also used for optical Character recognition.