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Unit II
Laser and Optic Fibre.

LASER: Light Amplification by Stimulated Emission of Radiation.

LASERS are the light amplifier and the kind of artificial light sources which produces light beams of special characteristics

- Charactoristics of LASER lights

1. It is a highly coherent light source
2. lasers produces monochromatic light
3. Intensity of laser light is very large
4. Laser beam shows very small divergence
5. Laser shows strong directional characteristics

* Energy Levels of Atoms and Molecules

1. Ground State

- It is the lowest possible energy state of a system (of atoms & molecules).
- Ground state is the most stable state of a system and its life time is infinite.
- It means atoms & molecules will remain in ground state as long as we can not disturb them by providing some external energy.

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② Excited State.

- These are the possible higher energy states whose life time are very small of the order of 10^{-5} to 10^{-8} seconds.
- Atoms and molecules will feel highly unstable in the excited states and they will remain in these states only upto their lifetimes.

③ Meta-Stable state

- These are the higher energy states with relatively longer lifetime of the order 10^{-3} sec.
- Generally their life time is thousand times more than that of the life time of excited state.

★ Gain medium OR Active medium

A medium containing metastable state (at least one state) is known as gain/active medium.

- This is the medium, where laser light will be produced by stimulate emission of radiation

★ Stimulated emission

Stimulated emission is the process by which an incoming photon of specific frequency can interact with an excited electron causing it to drop to a lower energy level.

* Population of energy state

The number of particles present in a given energy state is known as its population

- According to the Boltzmann's eqn, population of a state is a function of its energy and temperature of the medium

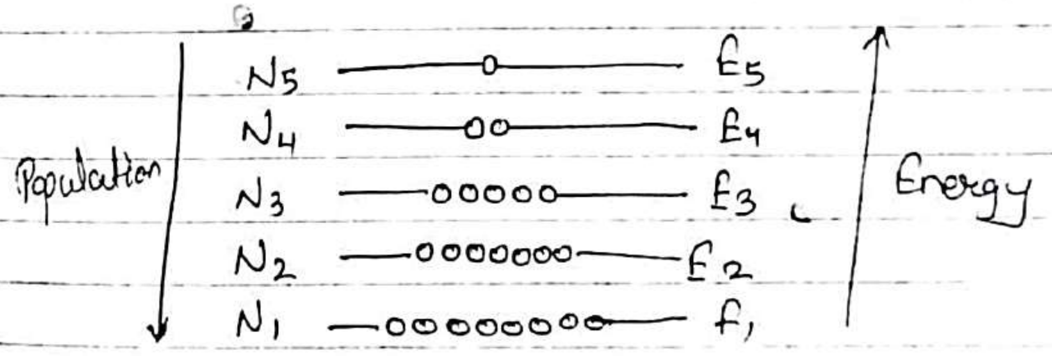
- If 'No' is the total number of particles (atoms, molecules or ions). in a medium having various energy states like $E_1, E_2, E_3, \dots E_N$ and their respective population are given by $N_1, N_2, N_3, \dots$ etc.

Then

$$N_1 = N_o e^{-E_1/kT}$$
$$N_2 = N_o e^{-E_2/kT}$$

Here, $E_2 > E_1$ so $N_1 > N_2$

- Under equilibrium, population of lower energy state will be more than that of the higher energy states



$$\text{Population} \propto \frac{1}{\text{Energy}}$$

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* Population Inversion

When population of higher energy state is more than that of the adjacent lower energy states, then it is said to be population inversion

N_2 oooooooo E_2

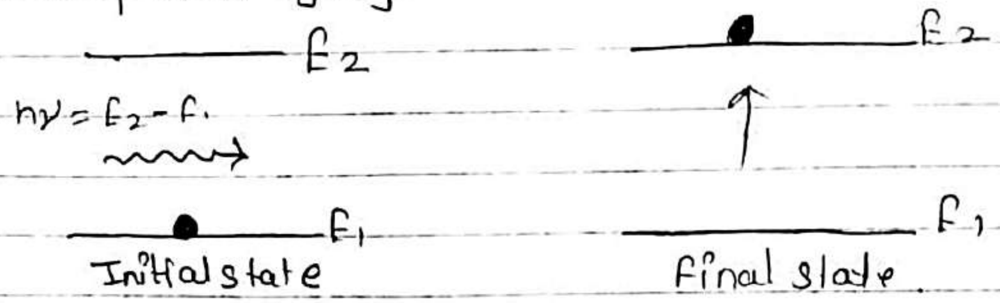
N_1 ooooo E_1

Here $N_2 > N_1$ and $E_2 > E_1$. This is the state of population inversion.

- Population inversion always builds between meta-stable state and adjacent lower energy state.
- Therefore, gain medium is the only suitable medium where we can get population inversion during the continuous energy supply.

* Absorption and Emission of light by the materials.

(1) Absorption of Light

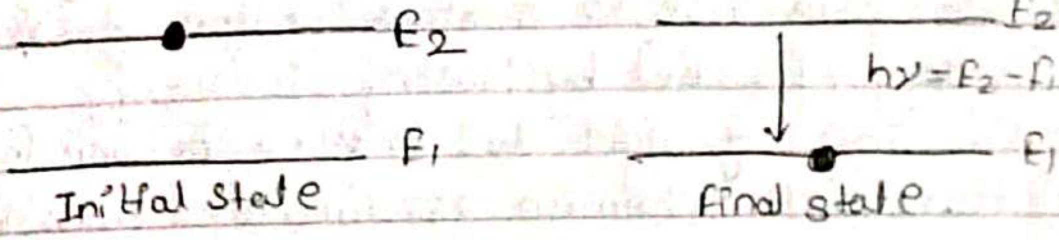


- Initially, a particle will be in its lower energy state.
- When a photon of energy equal to the energy

difference between these two states i.e. $E_2 - E_1$ falls on the system, a particle of lower energy stat will absorb its energy and photo will disappear
- The particle will make transion from lower state energy state (E_1) to higher energy state (E_2)
- This process of raising a particle from lower to higher energy state by a photon is known as absorption.
- It is also known as induced absorption.

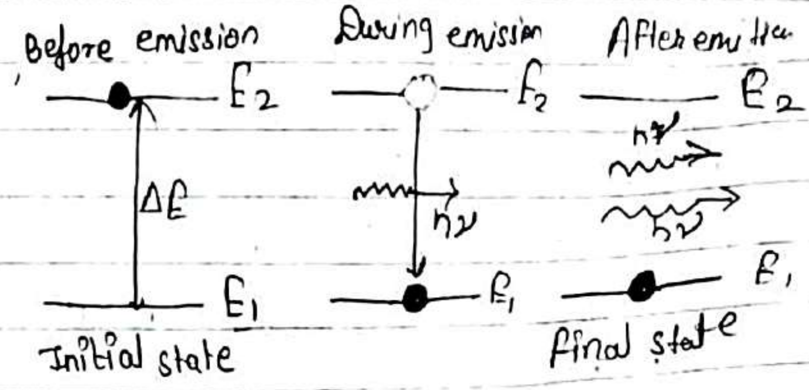
(2) Emission of Light.

i] Spontaneous Emission



- For spontaneouse emission to take place, particles must be there in higher energy state.
- Once the particle completes the life time of higher energy state, it naturally comebacks to the lower energy state.
- During this transition it looses its excess energy ($E_2 - E_1$) in the form of photon.
- This is known as spontaneous emission of light.

ii] Stimulated Emission.



- When photon of energy $(E_2 - E_1)$ interacts with an atom/particle which is initially in the higher energy state.
- This photons forces the particle to undergo transition to the lower energy state E_1 even before completing the life in the higher energy state E_2 &
- This gives rise to another photon of same energy $(E_2 - E_1)$ by loosing its energy.
- Emission of light due to ~~state~~ to such forced transition is known as stimulated emission.

Note:

- In spontaneous emission
  Photon emitted
  (1) In coherent nature
  (2) Random direction
  (3) State of polarization is not same

- In stimulated emission
  Photon emitted
  (1) Highly coherent
  (2) In prefferred direction
  (3) Same state of polarization.

* Pumping

The process of supplying the energy, so that large number of particles can be raised from lower energy state to higher energy state is known as pumping.

• Examples of pumping

① Optical pumping : where intense light flashes can be used as a source of energy

② Electrical pumping : Where electrical energy can be used as source of energy.

③ Chemical pumping : Where chemical reactions can be used as a source of energy

④ Thermal Pumping : Where heat can be used as a source of energy.

■ Note

Rate of sitmulated emission

- depends on intensity of external field
- depends on number of atoms in excited state

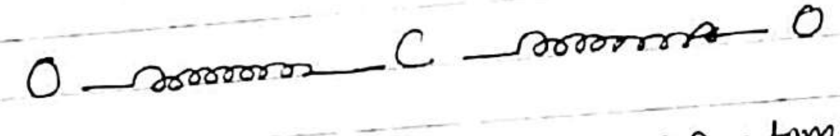
* CO_2 LASER :

- CO_2 is a first molecular gas laser, developed by Indian born American scientists Prof. CKN Patel in the year 1964.
- It's one of the most high power gas laser that uses vibrational energy level changes of CO_2 molecule to amplify intensity of light from far IR region (9.6 µm & 10.6 µm wavelength)

- Vibrational energy states of CO_2 molecules arises due to the relative oscillations of two oxygen atoms surrounded by central carbon atom.

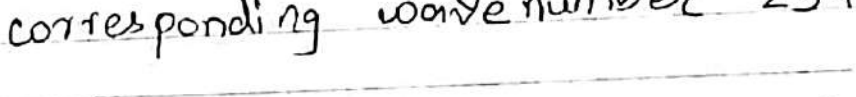
- There exists three distinct modes of vibrations in CO_2 molecule.

(1) Symmetric stretching Mode
(corresponding wavenumber $1388 cm^{-1}$)



Carbon atom is at rest & both oxygen atoms are oscillating in such a way that their distance from carbon atom is always same.

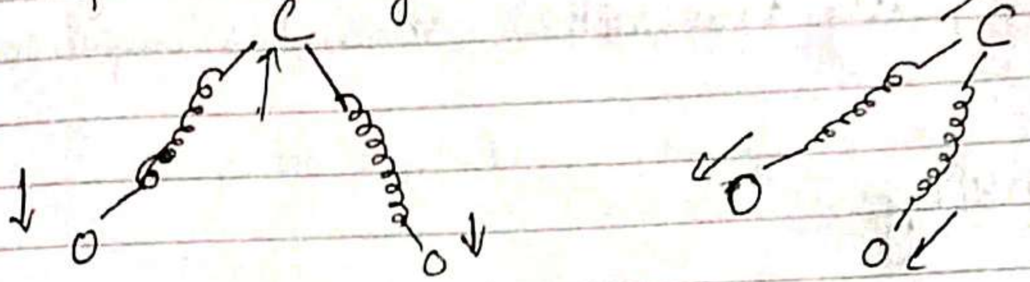
(2) Asymmetric Stretching Mode
(corresponding wavenumber $2349 cm^{-1}$)



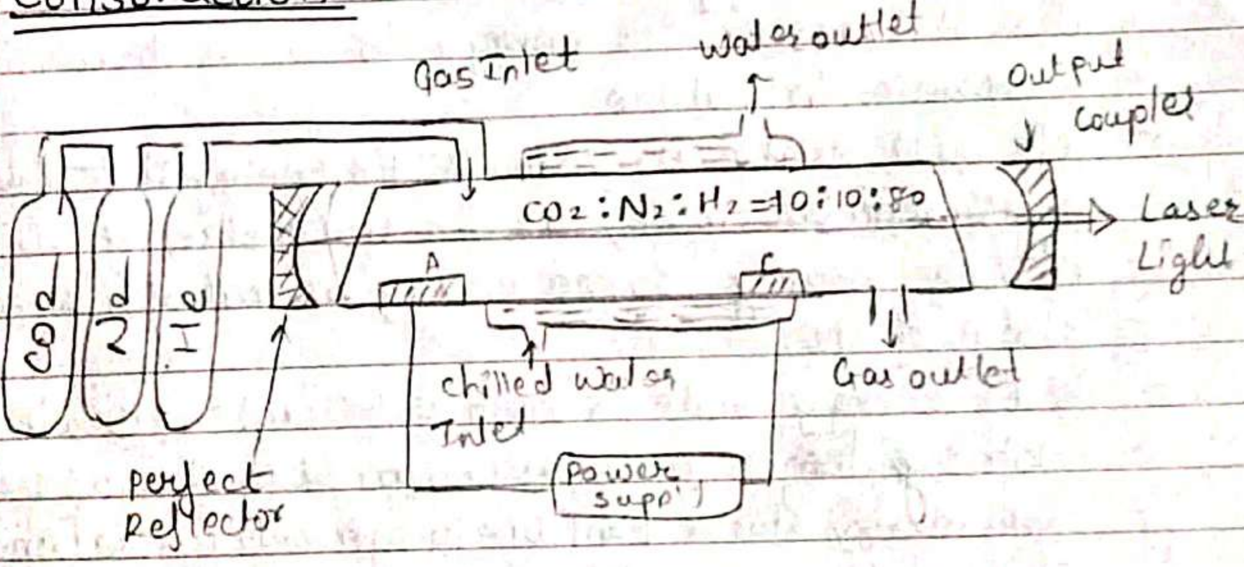
Both oxygen atoms are moving in one direction and carbon is moving in opposite direction

(3) Bending Mode {
(Corresponding Wavenumber 667 cm^{-1})

in plane bending — out of plan bending



☆ Construction



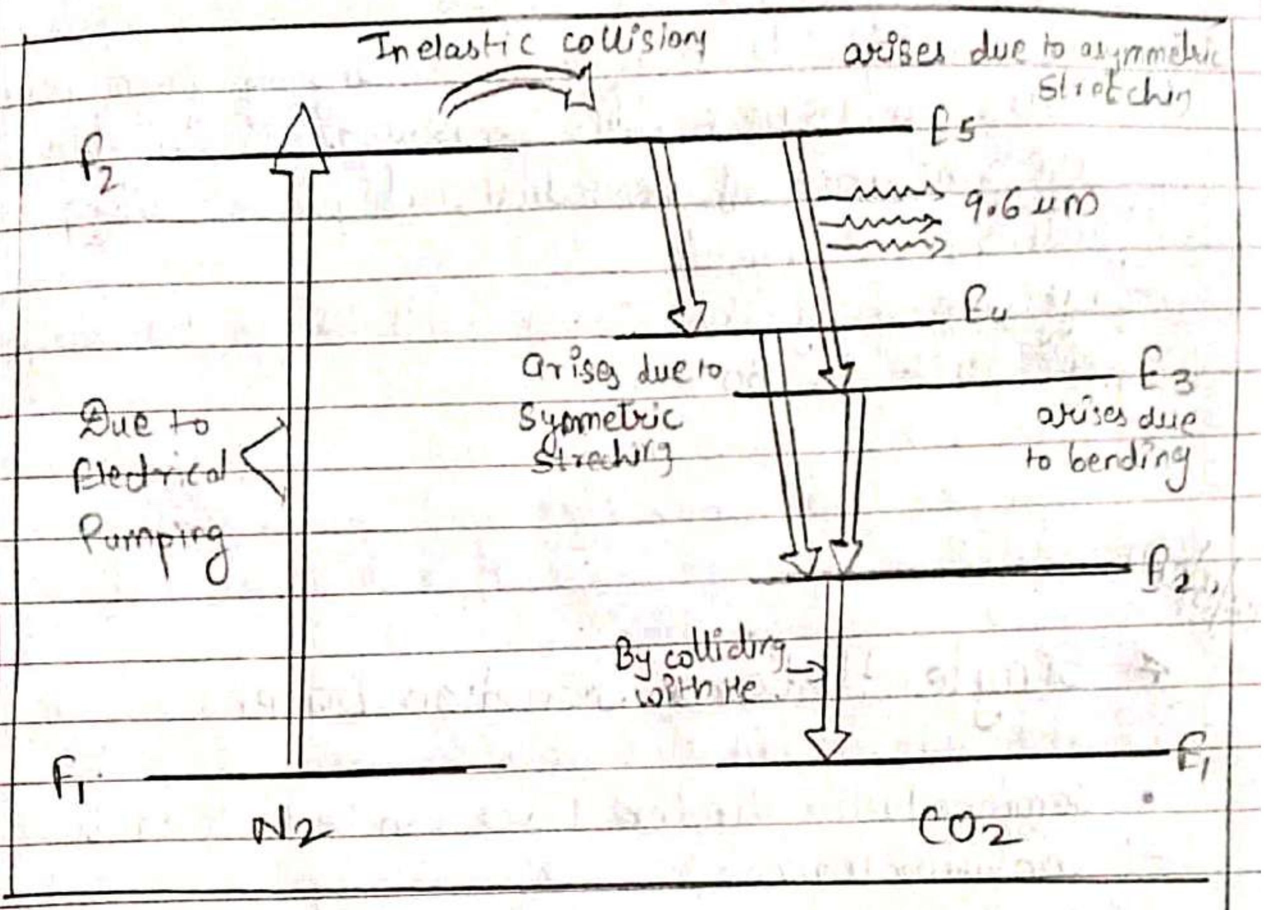
- CO_2 gas laser is consisting of a discharge tube fitted with 2 metallic electrodes for electrical pumping and having an arrangement of inlet & outlet to continuously tube.
- from outside a chilled water circulation is provided in the tube

- Typical length of the tube is of the order of 5 cm & diameter is 2.5cm.
- Two mirrors are placed at the two ends of the tube to form resonating cavity.
- Mirror at the back end is prefect reflector where as front mirror is partly reflector and partly transmitter known as output coupler.

Working.

- When power supply is switched ON, the energy of this source will excite N_2 molecules into the vibrational energy state E_2.
- Now this energetic ~~CO_2~~ N_2 when collides with CO_2 it will transfer its energy to CO_2 as the collision is inelastic in nature.
- This will excite CO_2 into its E_5 energy state (due to asymmetric mode) as E_5 state staes of CO_2 & having nearly same energy as that of E_2 energy state of N_2.
- As E_5 energy state is meta-stable state, CO_2 will stay relatively longer in E_5 as compared to two adjacent lower energy states E_4 (due to symmetric mode) and E_3 (due to bending mode) of CO_2.
- When CO_2 makes transitions from the pairs of energy states, it results in stimulated emission of radiation and emits two laser beams of wavelengths 10.6µm & 9.6µm corresponding to the transition of CO_2 from E_5-E_4 & E_5-E_3 respectively.
- Finally all CO_2 molecules from E_4 & E_3 rapidly

decays to E_2 energy states, where they stay relatively longer as E_2 is also a kind of meta stable state.



- But for continuous lasing action & to increase the efficiency of laser, CO_2 molecules must be rapidly brought to down to ground state E_1.
- This is insured by keeping large concentrations of He in gas mixture, so that it can extract the energy of CO_2 molecules when they are in E_2 state by inelastic collisions.
- Therefore this will increase the temperature of He.
- Hence, to maintain the temperature of gas mixture at room temperature a chilled water is continously circulated around the tube.

- Features

- This laser can be operated in continuous as well as in pulse mode.
- It can yields high power ranging from few watts to 15,000 watts makes them suitable for use in most of the industrical process like cutting, welding etc.
- Efficiency of this laser will be in the range of 10% to 30%.

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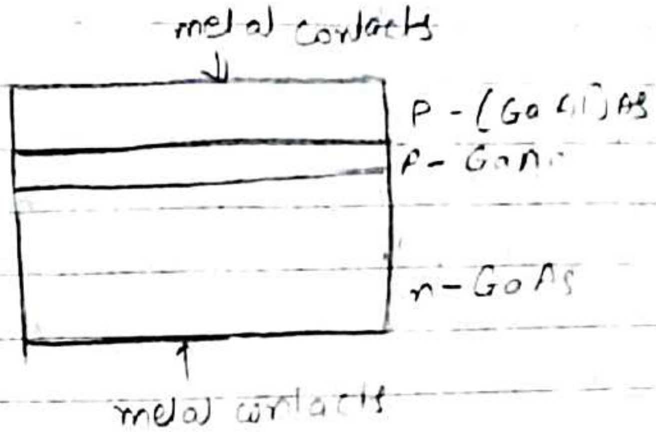
★ Single Hetero Junction Laser:

- semiconductor diodes lases can be built in two configuration.
  1. Homo-Junction Semiconductor laser (made up of extrinsic semiconductor of same materials.)
  2. Hetero-Junction Semiconductor Laser (made up of extrinsic semiconductor of different materials)

A single hetero-juction semiconductor laser is having more advantages over homo-junction semi-conductor laser. It is made up of two different extrinsic semi-conductor of different materials on either side of the junction. eg: GaAsAl & GaAs hetero junction

* **Construction**



- In this single hetro-junction laser, a layer of two energy bandgap semi-conductor P-GaAs is sandwiched between a high energy band-gap P-(GaAl)As and n-GaAs semiconductor
- These layers are having different refractive indices.
- The middle layer P-GaAs is usually having layer refractive index as compared to two outer layers.
- Therefore light is always confined in the middle layer which is also acting as an active region of the junction.
- Resonant cavity is formed by coating the two opposite side surface with thin metal films.
- Electrical contacts are provided for pumping the energy into junction at two extreme layers of the laser.

* **Working**

- The basic principle of working of homo-junction and hetero-junction semiconductor diode laser is same.
- When ~~di~~ forward biasing is provided to the hetro-junction

diode, electrons & holes are getting injected in the active region of P-GaAs from n-GaAs & p-(GaAl)As respectively.

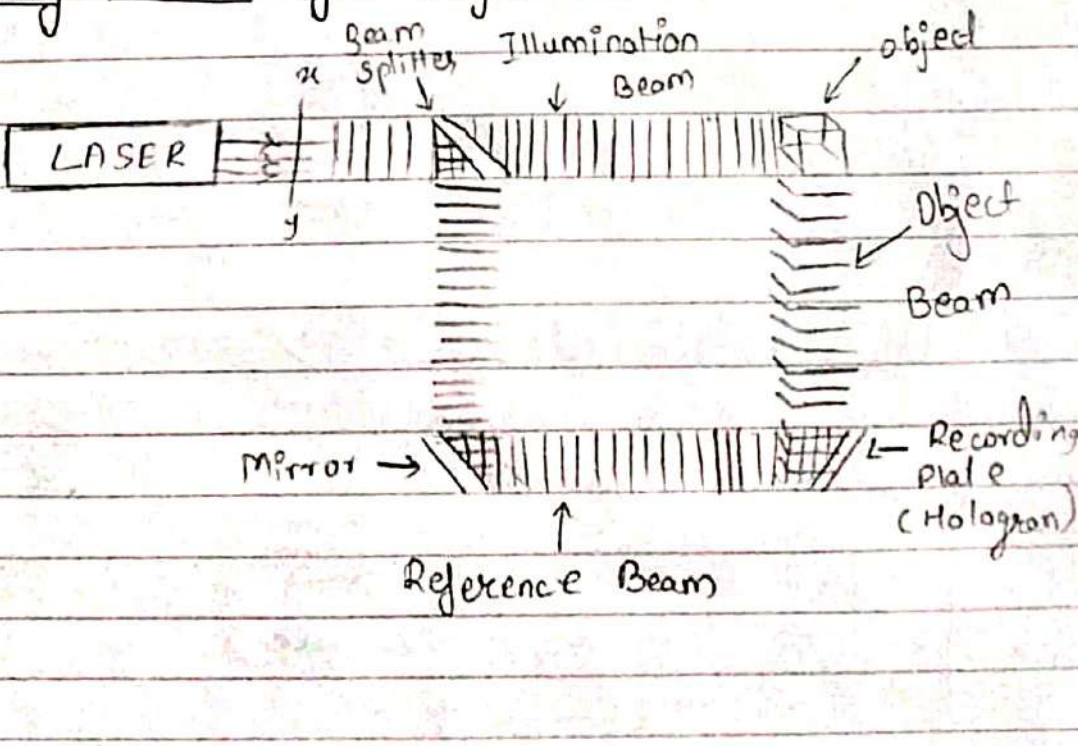
- When diode current during forward biasing reaches a threshold value it builds a huge carrier concentration in the active layer.
- Thus a larger number of electrons are there in conduction band and large number of holes will be there in the valance band of the active ~~ite~~ layer.
- Due to this population inversion, initialy when some electrons from conduction band jumps into the vacant states of valence band it will produce photons due to their recombination.
- Now, these spontaneous photons, travels through the active layer stimulates ther rest of the conduction electrons to jump into the vacant states of valance band and sets up a stimulated emission.
- The intensity of layer lights builds alongs the axis of resonating cavity and the laser light can pass through the partially silvered end of the active layer region.
- The middle layer of active region has layer refractive index of active region has larger refractive index that of the two outer layer, therefore light is getting confined in the middle layer due to total internal reflection.
- Hetero-junction laser can provide high efficiency at room temperature and requires less operating current.

* HOLOGRAPHY

'Holography' is a composite word made up of two Greek words, 'holos' meaning 'whole' and 'grapho' means 'write'.

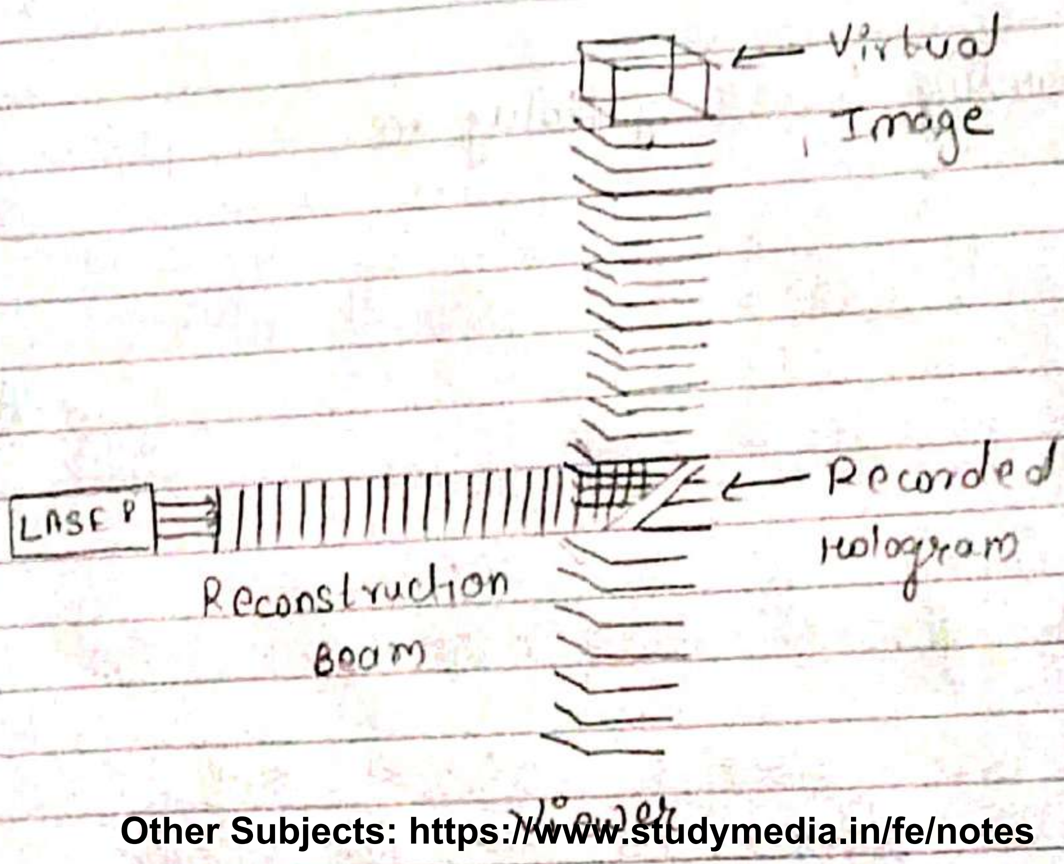
- Thus holography means a complete record of an image which is identical in all respect to the real objects.
- It is a kind of 3 dimensional laser photography, which records the information of intencity as well as phase difference of the reflected light rays coming from the object.
- Where as in conventional photography, which produces 2 dimensional images, only records the information of intensity of reflected light ray/coming from the object.

• Recording Process of Holograms



- With the help of a 'Beam Splitter' and a reflecting 'Mirror', two identical coherent beams of laser lights are producted from a single LASER source
- Out of these two beams, one beam illuminates on object known as 'Illumination Beam' and the other will be used as a 'Reference Beam' to record the interference pattern of this reference beam and the 'Object Beam' on recording plate.
- This interference pattern contains the information of intensity as well as phase difference between the reflected light rays coming from an object with reference to the 'Reference Beam'.

• Reconstruction Process of Holograms



- When this recorded hologram is illuminated with a laser light identical to the one used during recording the interference pattern recorded on plate acts as a diffraction grating and diffracts the incident light.
- This differaction produces a light field identical to the one that was produced in the object beam during recording and helps to construct the 3 dimensional image.
- When observed from behind the plate, a virtual 3 dimensional will be observed on the recording poistion of an object

- <u>Application</u>

1. Optical computing
2. Data storage
3. Interferometry
4. Microscopy
5. Security
6. friction
7. Art.

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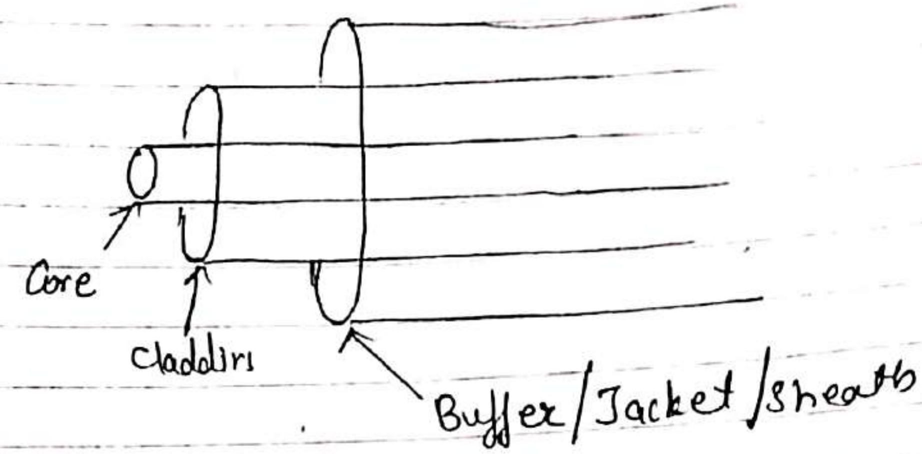
* Optic fibre



- An optical fibre is a very thin and a flexible medium of multi-layer structure having cylindrical shape
- The layers of the optical fibre are made up of transparent dielectrics like glass, clear plastic, polymers etc.

* Core

The innermost co-axial region of the optical fibre is known as the core.

- This is the main portion of the optical fibre through which; the information can be carried out in the form of light signals.

Cladding

- The next co-axial region to the core of the optical fibre is known as cladding.

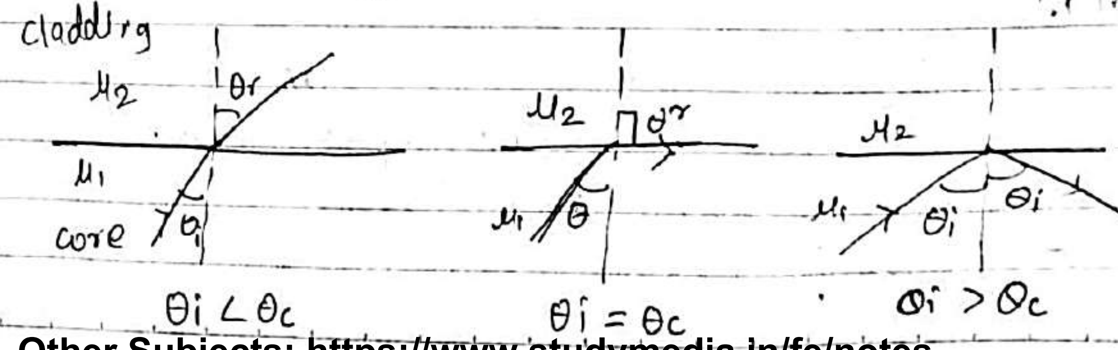
- The diameter of the cladding region is 125 μm.
- The role of the cladding is to create the necessary condition at core-cladding inteface, so that light will be confined within the core of the fiber by following total internal reflection.
- For this the R I of the core medium is slightly (by 1%) greater than the RI of cladding region.

* Buffer / Jacket / Sheath

The next co-axial region to the cladding of the fibre is known as buffer or jacket or sheath

- It's diameter is of the order of 250 um
- The basic role of this region is to protect the core-cladding structure of optical fibre from the external impacts, temperature moisture etc.

* Total Internal Reflection



- When light strikes at core cladding interface at an angle of incidence equal to is greater than the critical angle then all the light will completely reflect back into the core region. This condition is known as total internal reflection.

★ Classification of Optical fibres:

Based on the number of modes transmitted

① Single Mode.

- It is having lower core diameter about 10 μm
- Supports only one singnal/mode at a time
- These fibres will be preferred for long distance communication as losses are relatively less.
- It will support for high bandwidth
- There there is high rate of data transfer
- There is no intermodal dispersion.
- This type of fibres will be generally available in step index form.

② Multi-Mode.

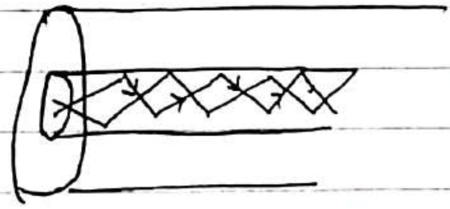
- It is having larger core diameters generally 50 μm and above. ~~and supports many~~
- Supports many modes at a time.
- These fibers will be preferred for short distance

communications usually inside the organization to build local area network.

- It can carry the information without any appreciable loss only upto 1 km. Hence, losses are relatively large.
- It also suffers internodal dispersion means some modes will travel faster as compared to other
- It will support lower bandwidth
- The rate of data transfer is low

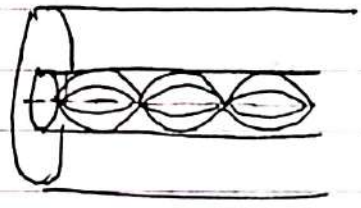
Types

Step Index Multimode Optic fibre



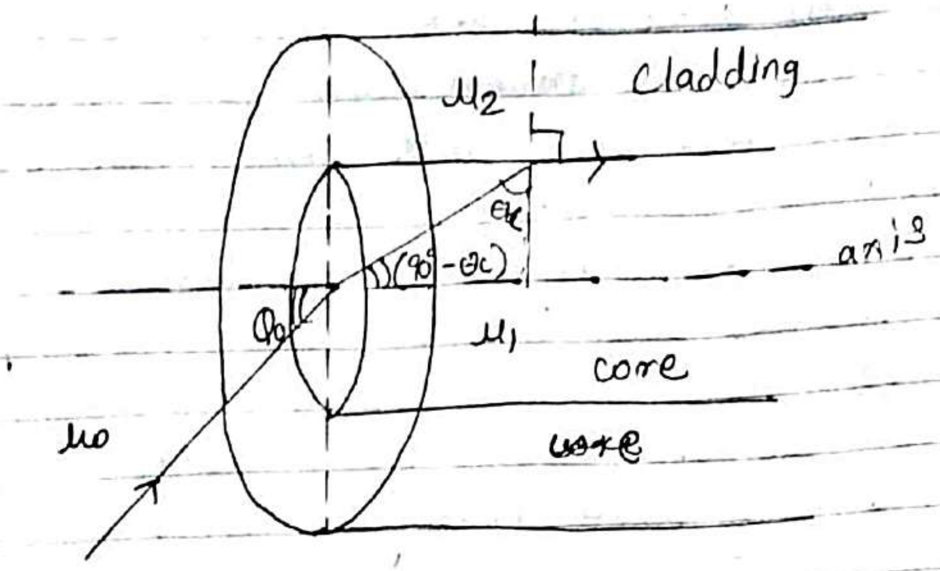
R.I of value is same throughout the fibre

Graded Index Multi-Mode optical fibre.



R.I of outer fibre is higher as we move further R.I will decrease gradually

* Acceptance Angle and Numerical Aperture:



- θ_0 is known as the angle of acceptance
- The minimum angle with respect to the axis of fibre at which light will travel along the core cladding interface is known as angle of acceptance.
- If the angle made by light rays with axis of the fibre is less than the θ_0 then all such light ray follows total internal reflection & it will be confined within the core of the optical fibre.
- In three dimension (3D) the cone traced out by acceptance angle is known as acceptance cone

According to Snell's law applied at point 'A' and point 'B', we get.

$$\mu_0 \sin\theta_0 = \mu_1 \sin(90-\theta_c) \quad \text{——— (1)}$$

$$\mu_1 \sin\theta_c = \mu_2 \sin 90° \quad \text{——— (2)}$$

$$\therefore \mu_1 \sin\theta_c = \mu_2$$

$$\therefore \sin\theta_c = \frac{\mu_2}{\mu_1}$$

From eq^n(1)

$$\mu_0 \sin\theta_0 = \mu_1 \cos\theta_c$$

$$\therefore \mu_0 \sin\theta_c = \mu_1 \sqrt{1-\sin^2\theta_c} \quad \text{--- (4)}$$

Let's substitute the value of $\sin\theta_c$ from equation (3) into equ^n (4)

$$\therefore \mu_0 \sin\Phi_0 = \mu_1 \sqrt{1 - \frac{\mu_2^2}{\mu_1^2}}$$

$$\therefore \mu_0 \sin\theta_0 = \sqrt{\mu_1^2 - \mu_2^2}$$

$$\therefore \sin\theta_0 = \frac{1}{\mu_0}\sqrt{\mu_1^2 - \mu_2^2} \quad \text{--- (5)}$$

For air medium $\mu_0 - 1$

$$\therefore \sin\theta_0 = \sqrt{\mu_1^2 - \mu_2^2}$$

$$\therefore \theta_0 = \sin^{-1}\left(\sqrt{\mu_1^2 - \mu_2^2}\right) \quad \text{--- (6)}$$

$\therefore$ The term $\sqrt{\mu_1^2 - \mu_2^2}$ is known as numerical aperture (light gathering abilities) i.e; N.A.

$$\therefore N.A. = \sqrt{\mu_1^2 - \mu_2^2} = \sin\theta_0\,(max) \quad \text{--- (7)}$$

$$\therefore NA = \sqrt{(\mu - \mu_2)(\mu_1 + \mu_2)}$$

$$\cong \sqrt{2\mu_1(\mu_1 - \mu_2)} \qquad \text{As } \mu_1 \cong \mu_2$$

$$= \sqrt{2\mu_1^2 \frac{(\mu_1 - \mu_2)}{\mu_1}}$$

$$= \mu_1 \sqrt{2\Delta}$$

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where,
$$\Delta = \frac{\mu_1 - \mu_2}{\mu_1} \quad -(8)$$
knao as fractional change in the refractive idex.

$$\therefore N.A. \cong \mu_1 \sqrt{2.\Delta} \quad -(9)$$

- For the fibres used in short distance communication the value of N.A is in the range of 0.4 to 0.5 (multi mode)

- And for the fibres used in longer distance communications (single mode), N.A will be in the range of 0.1 to 0.3.

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* Attenuation and Reasons for Losses in Optic Fibres

Attenuation in optical fibre is defined as the ratio of the optical output power to the optical input power of fibre of length 'L':

i.e., $\text{Attenuation} = \frac{10}{L} \log \frac{P_i}{P_o}$ dB/km.

where, "L" is the length of optical fibre in km
P_i = Input power at launch.
P_o = output power at emerging end:

The basic region for attenuation/ losses is
(1) Absorption
(2) Dispersion
(3) Bending

1] Losses due to absorption involes

- Rayleigh's scattering (arises due to core irregularities of the order of wavelength)
- Intrinsic absorption in the material
- Electron absorption
- Absorption due to impurities

2] Losses due to dispersion involves

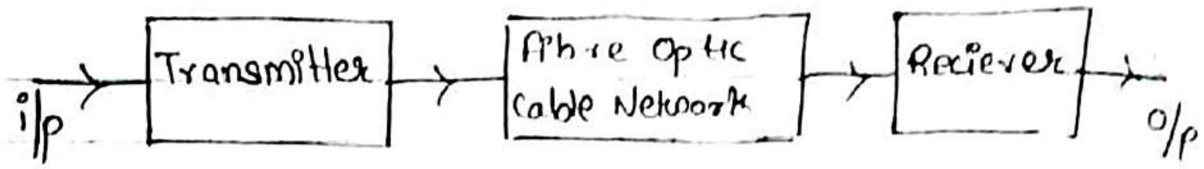
- Internodal dispersion causes broadening of pulse.
- Waveguide dispersion (arises due to diff. effective resfractive indices for different modes)
- Material dispersion.

3] Losses due to bending involves

- Micro - bending losses
(light can leak into cladding)
- Macro - bending losses
(can be minimised by carefull handling and installation)

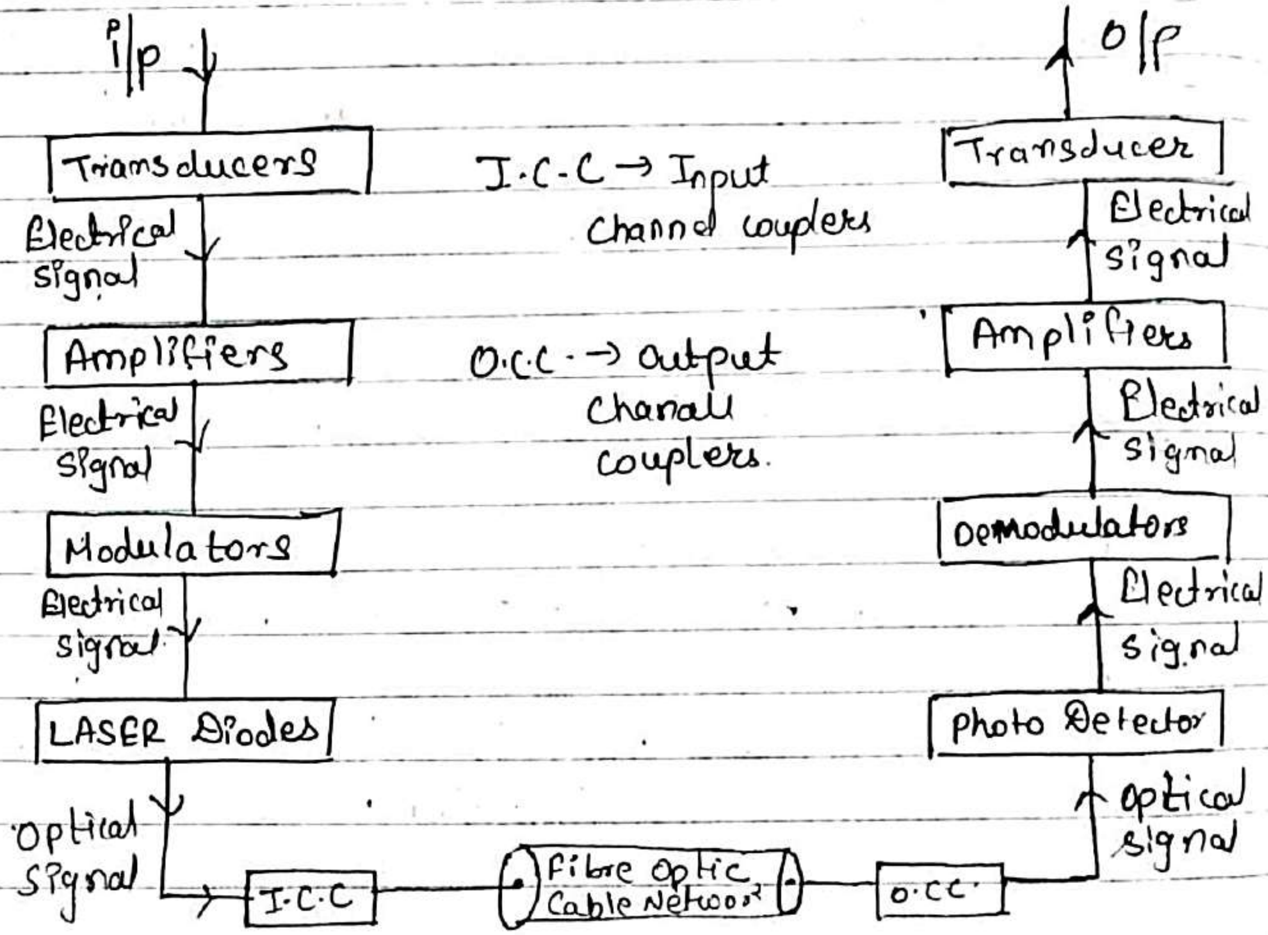
* Generalised Fibre Optic Communication System

The basic structure of generalised fibre optic communication system is a follows



- This system is consisting of three basic building blocks as transmitter, optical fibre network & receiver.
- It can be used for the communication of any kind of information.

The detail structure indicating various sub-sections of these basic building blocks are as follows



Process

In the transmitter section

(1) In transmitter, the first sub-section converts the input signal into electrical signal known as transducers.

(2) Then these signals are amplified by amplifiers which is next section.

(3) These amplified are then passed to the modulators which will superimpose input signal on standard operating singnal.

(4) Then this modulated signal can be finally converted into light signal with the help of suitable laser diodes.

(5) The laser light signal is then effectively coupled into the core of an optic fibre by using input channel connectors.

(6) Fibre optic cable network can be used to carry the signal to desired places. ~~and~~

(7) At the other end, the signal will be extracted into reciever with the proper output channel couplers.

In the reciever section

(8) The photo detectors will be used to convert the optical signal into electrical signals.

(9) In demodulators, the main signal is effectively extracted from modulated signals.

(10) Now this effective signals are then amplified by suitable amplifiers.

(11) Finally then the signal will be processed and converted into the required form at the output end.

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* Advantages of the generalised communication system is as follows.

① We can carry the information in the form of light signal having higher frequencies of the order of 10^{14} Hz

② It supports too larger bandwidths

③ Gives higher data transfer rate.

④ Losses are very less.

⑤ Quality of communication is much better as signal present in one fibre can not effect the signals in adjacent fibre.
i.e, no cross-talking will result.