* LASER: Light Amplification by Stimulated Emission of Radiation

LASERS are the light amplifiers and the kind of artifitial light sources which produces light beams of special characteristics.

Characteristics of LASER lights are
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 and molecules). Ground state is the most stable state of a system and its life time is infinite. It means atoms and molecules will be remain in ground state as long as we can not disturbe them by providing some external energy.
2. Excited state: These are the possible higher energy states whose life times 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 be remain in these states only upto their life times.
3. Meta-stable states: These are the higher energy states with relatively longer lifetime of the order of 10^{-3} second, generally, there life time is thousand times more than that of the life time of excited states.

Scanned by CamScanner

Gain medium OR Active medium:

A medium containing meta-stable state (at least one state) is known as gain/active medium. This is the medium, where laser light will be produced by stimulated emission of radiation.

Population of an energy state:

The number of particles present in given energy state is known as its population. According to the Boltzmann's equation, 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 $E_1, E_2, E_3, \ldots, E_N$ and their respective populations are given by $N_1, N_2, N_3, \ldots$ etc.

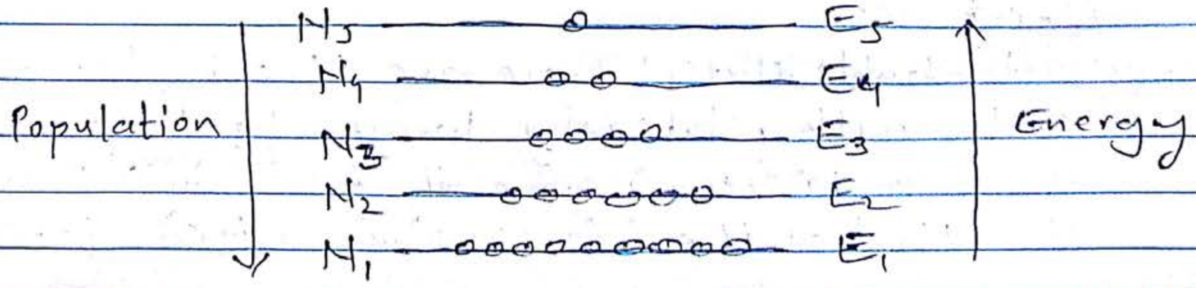
Then

$$N_1 = N_o e^{-E_1/KT}$$

$$N_2 = N_o e^{-E_2/KT}$$

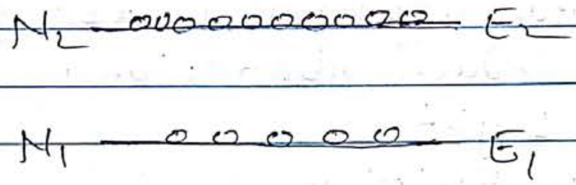
Here, $E_2 > E_1$ therefore $N_1 > N_2$

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



Population Inversion:

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

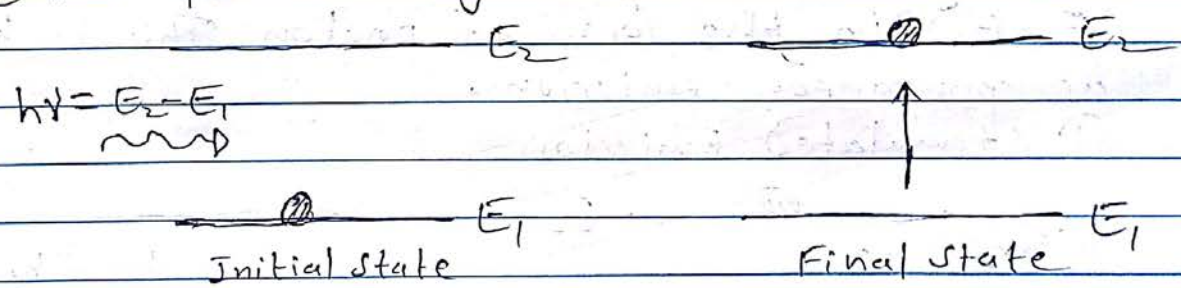


Here $N_2 > N_1$ and $E_2 > E_1$. This is the case of population inversion.

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:

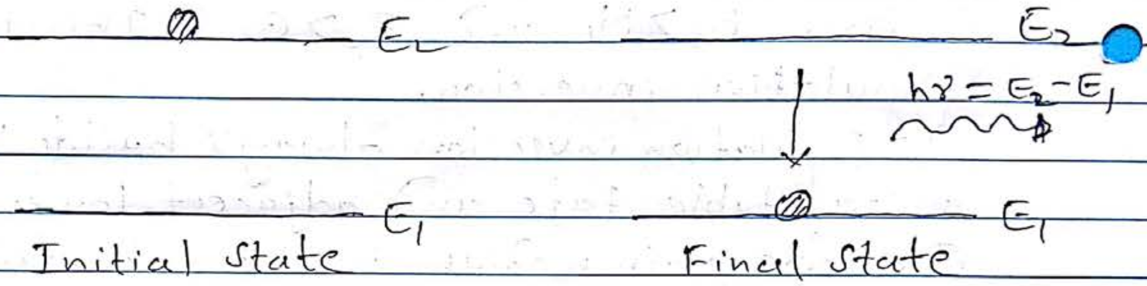
① Absorption of Light:



Let us consider a simplest system of two energy states and a single particle (atoms, molecules or ions). 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 state will absorb its energy and photon will disappear and the particle will make transion from lower energy state (E_1) to higher energy state (E_2). This process of raising a particle from lower energy state to higher energy state by a photon is known as absorption. It is also known as induced absorption.

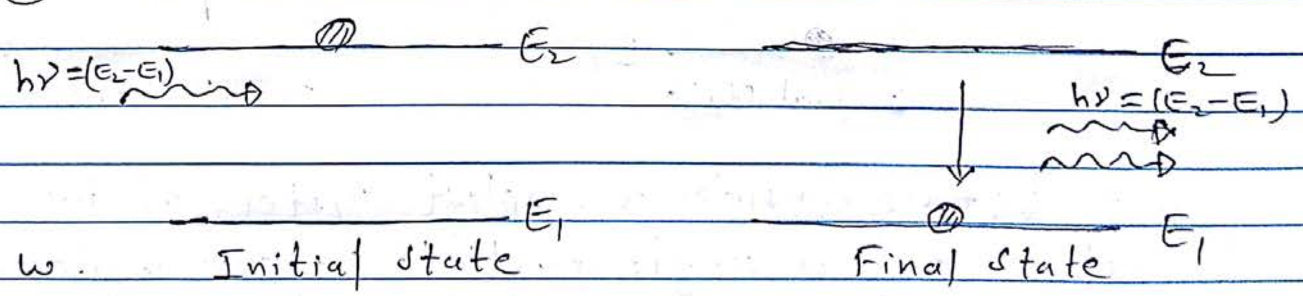
② Emission of Light

(i) Spontaneous Emission



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

(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 photon forces the particle to undergo transition to the lower energy state E_1 even before completing the life time in the higher energy state E_2.

giving rise to another photon of same energy (E_2-E_1) by loosing its energy. Emission of light due to such forced transition is known as stimulated emission.

If we compare the characteristics of photons emitted during spontaneous emission and stimulated emission. Then we observe that, in spontaneous emission, photons emitted are of incoherent nature, getting emitted in random directions and their state of polarization is not same.

Whereas in stumuled emission, photons emitted are highly coherent, they are getting emitted in prefered direction and their state of polarization is also same.

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 by used as a source of energy.
3. Chemical Pumping: where chemica reactions can be used as a source of energy.
4. Thermal Pumping: where heat can be used as a source of energy

etc.

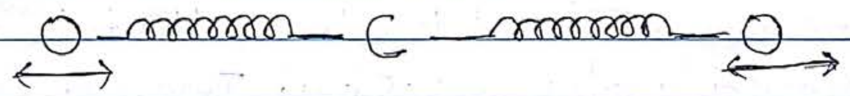
CO_2 LASER:

CO_2 is a first molecular gas laser, developed by Indian born American scientist Prof. C.K.N. Patel in the year 1964. It is 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 and 10.6 μm wavelengths)

Vibrational energy states of CO_2 molecule arises due to the relative oscillations of two oxygen atoms surounded by central carbon atom.

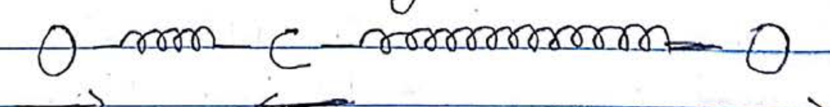
There exists three distinct modes of vibrations in CO_2 molecules

(i) Symmetric stretching Mode



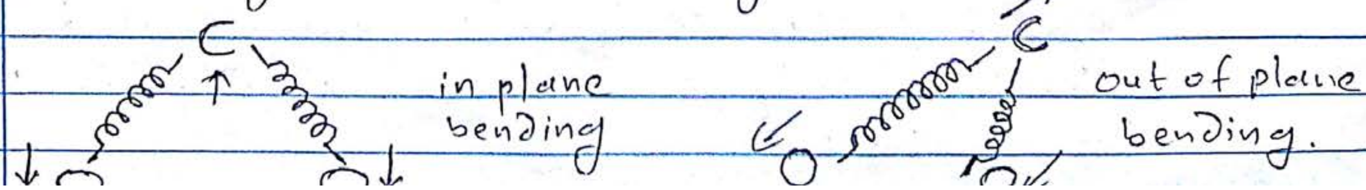
In this mode, central carbon atom is at rest and both oxygen atoms are oscillating in such a way that their distance from carbon atom is always same on both the sides and corresponding wavenumber of this mode of oscillation is 1388 cm^{-1}.

(ii) Asymmetric stretching Mode

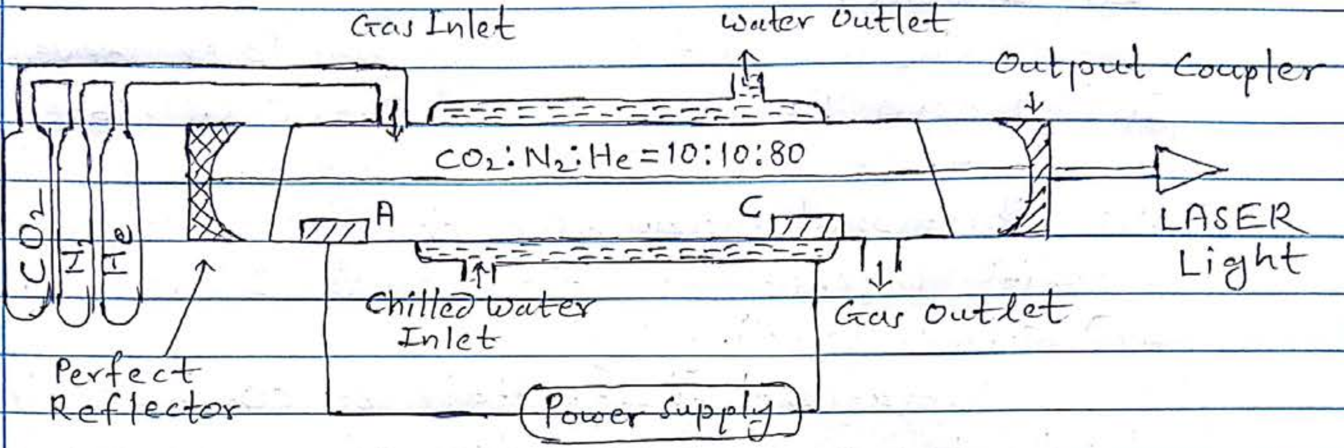


In this mode, both oxygen atoms are moving in one direction and carbon is moving in oposite direction. Corresponding wavenumber of this mode of oscillation is 2349.

(iii) Bending Mode (Corresponding wavenumber is 667 cm^{-1})



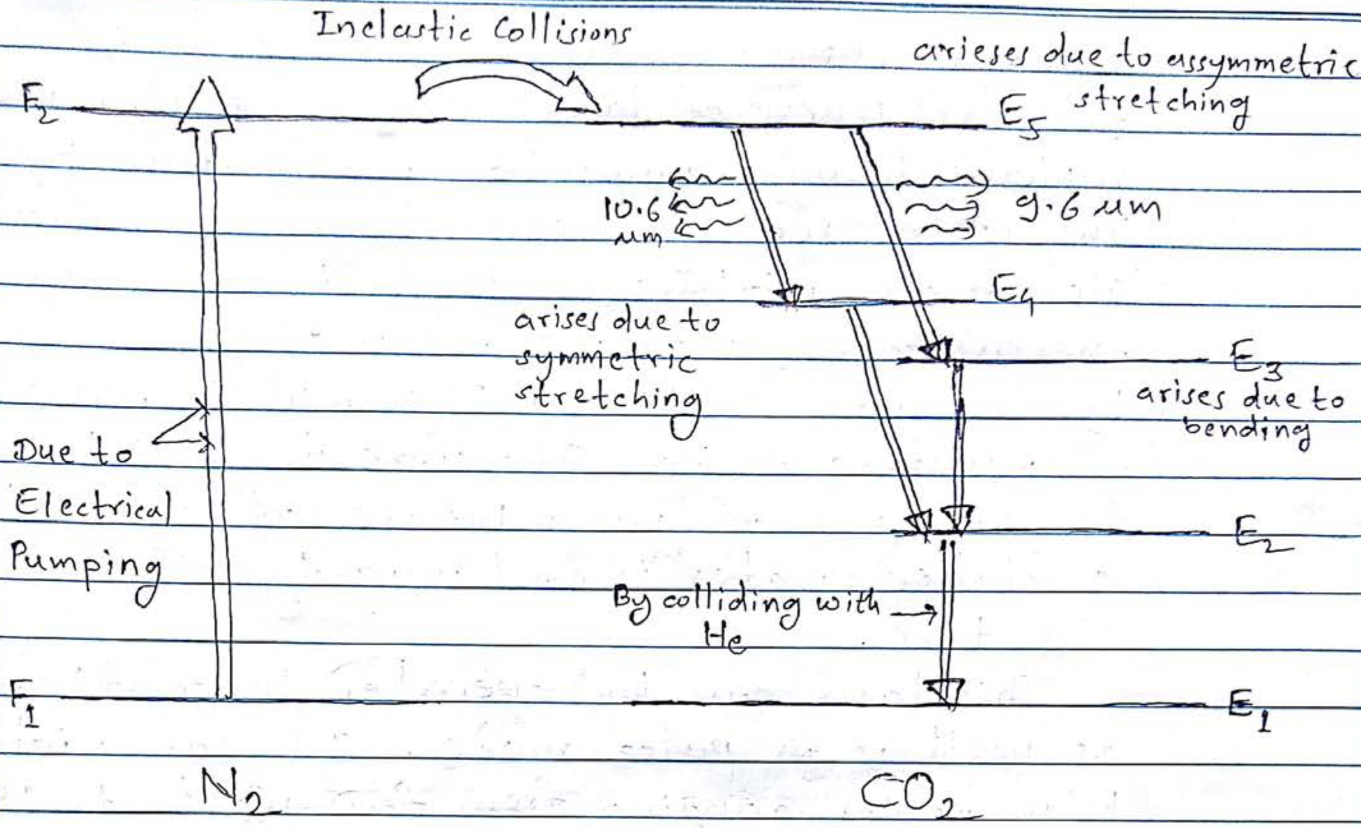
Construction:



CO_2 gas laser is consisting of a discharge tube fitted with two metalic electrodes for electrical pumping and having an arrangement of inlet and outlet to continuously pass the gas mixture of CO_2, N_2 and He throughout the tube. From outside, a chilled water circulation is provided to the tube. Typical length of the tube is of the order of 5 cm & diameter is 2.5 cm. Two mirrors are placed at the two ends of the tube to form resonating cavity. Mirror at the back end is perfect reflector whereas 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 its vibrational energy state, E_2. Now this energetic 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 (arises due to assymmetric stretching modes of vibrations in CO_2) as E_5 energy state of CO_2 is having nearly same energy as that of E_2 energy state of N_2.



As E_5 energy state is a meta-stable state, CO_2 will stay relatively longer in E_5 as compared to two adjacent lower energy states E_4 (arises due to symmetric stretching modes of vibrations) and E_3 (arises due to bending modes of vibrations) of CO_2. Therefore it builds a population inversion between the pairs of energy states $E_5 - E_4$ and $E_5 - E_3$. When CO_2 makes transitions from these pair of energy states, it results in stimulated emission of radiation and emits two laser beams of wavelengths 10.6 um and 9.6 um corresponding to the transitions of CO_2 from $E_5 - E_4$ and $E_5 - E_3$ respectively. Finally all CO_2 molecules from E_4 and E_3 rapidly decays to E_2 energy state, where they stay relatively longer as E_2 is also a kind of meta-stable state.

But for continuous lasing action and to increase the efficiency of laser, CO_2 molecules must be rapidly brought down to ground state E_1.
This is insured by keeping larger 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. This will increase the temperature of He. Therefore to maintain the temperature of gas mixture at room temperature a chilled water is continuously circulated around the tube.

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 industrial processes like cutting, welding etc. Efficiency of this laser will be in the range of 10% to 30%.

Single Hetero Junction Laser:

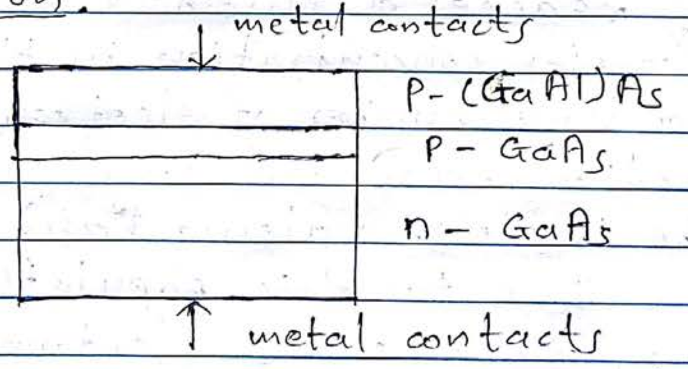
Semi-conductor diode laser can be built in two configuration.

(1) Homo-Junction Semiconductor Laser (madeup of extrinsic semiconductors of same material.)

(2) Hetero-Junction Semiconductor Laser (madeup of extrinsic semiconductors of different materials.)

A single hetero-junction semiconductor laser is having more advantages over homo-junction semi-conductor laser. It is made up of two different extrinsic semi-conductors of different materials on either side of the junction, e.g. Gallium Arsenide Aluminium and Gallium Arsenide hetero junction.

Construction:



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

Working:

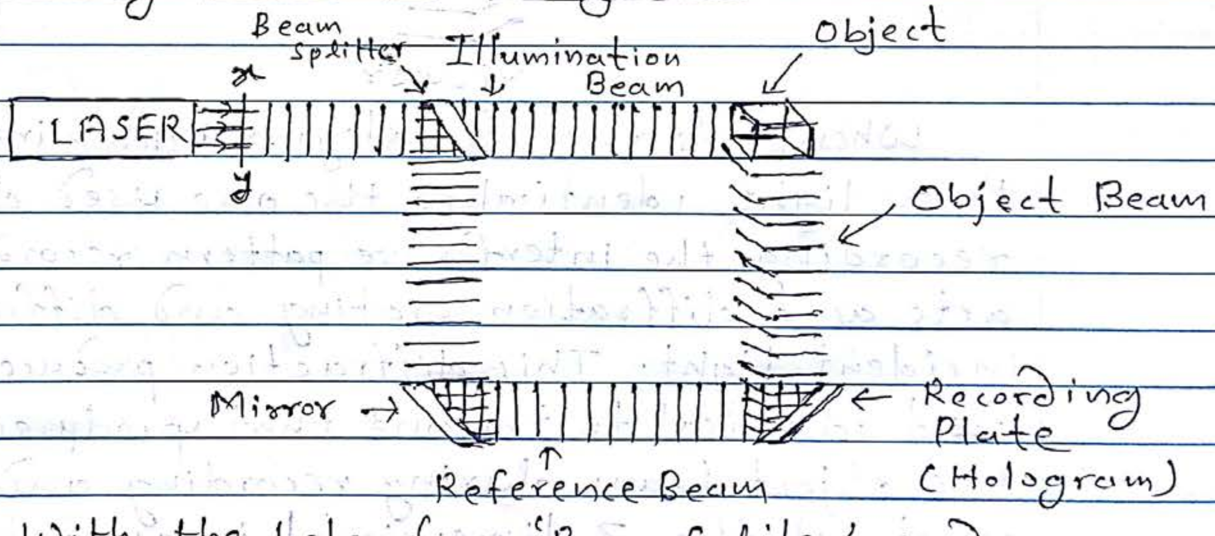
The basic principle of working of homo-junction and hetero-junction semiconductor diode laser is same. When forward biasing is provided to the hetero-junction diode, electrons and holes are getting injected in the active region of p-GaAs from n-GaAs and p-(GaAl)As respectively. When diode current during forward biasing reaches a threshold value it builds a huge carrier concentration in the active layer. Thus, a large number of electrons are there in conduction band and large number of holes will be there in valence band of the active 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 there recombination. Now, these spontaneous photon's, travels through the active layer stimulates the rest of the conduction electrons to jump into the vacant states of valence band and setups stimulated emission. The intensity of laser lights buids along 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 larger refractive index than that of the two outer layers, therefore light is getting confined in the middle layer due to total internal reflection.
This light will acquire directional characteristic.
Hetero-junction laser can provide high efficiency at room temperature and requires less operating current.

* Holography :

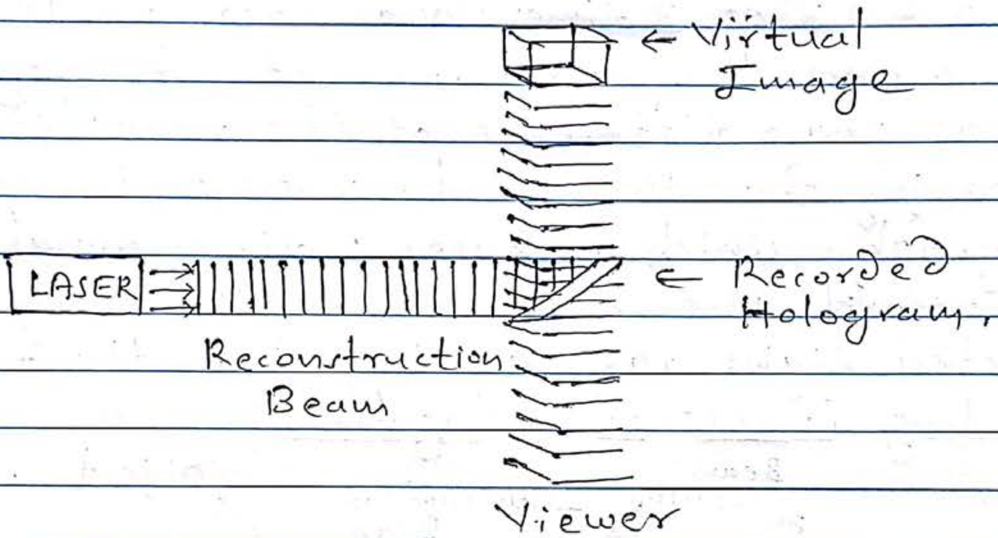
'Holography' is a composite word made up of two Greek words; 'holos' meaning 'whole' and 'grapho' means 'write'. Thus, holography means a complete record of an image which is identical in all respect to the real objects. It is a kind of 3 dimensional laser photography, which records the information of 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 rays coming from the object.

Recording Process of Holograms:



With the help of a 'Beam Spliter' and a reflecting 'Mirror', two identical coherent beams of laser lights are produced from a single 'LASER' source. Out of these two beams one beam illuminates an 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'.

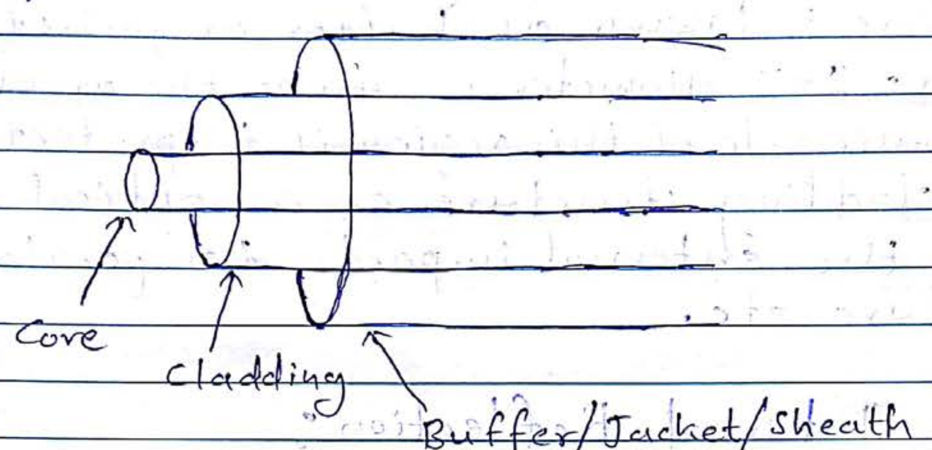
Reconstruction Process of Holograms:



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 diffration grating and diffracts the incident light. This diffraction 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 position of an object.

Applications: In ① optical Computing, ② Data storage, ③ Interferometry, ④ Microscopy ⑤ Security, ⑥ Fiction, ⑦ Art. etc.

* Optical Fibre :



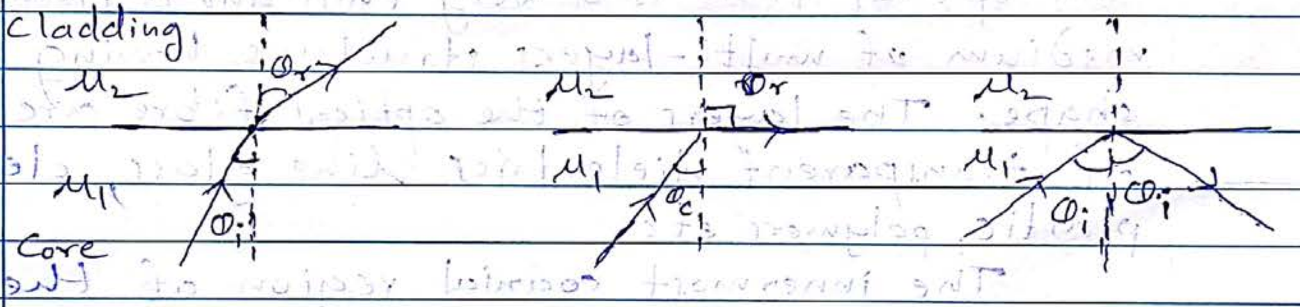
An optical fibre is a very thin and a flexible medium of multi-layers structure having cylindrical shape. The layers of the optical fibre are madeup of transparent dielectrics like glass, clear plastic, polymers etc.

The innermost coaxial 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 signal.

The next coaxial 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 interface, so that light will be confined within the core of the fibre by following total internal reflection. For this, the refractive index of the core medium is slightly (by 1%) greater than that of the refractive index of cladding region.

The next coranial region to the cladding of the fibre is known as buffer or jacket or cheath. It's diameter is of the order of 250μm. The basic role of this region is to protect the core-cladding structure of an optical fibre from the external impacts, temperature, moisture etc.

* Total Internal Reflection:



$\theta_i < \theta_c$ $\theta_i = \theta_c$ $\theta_i > \theta_c$

when light strikes at core cladding interface at an angle of incidence equal to critical angle θ_c, then no portion of light will enter into cladding or core region, instead it travels along the boundary between core and cladding. And when angle of incidence θ_i is smaller than critical angle θ_c light can leak into cladding region as refracted beam.
But if angle of incidence is greater than critical angle then all the light will completely reflects back into the core region. This is known as total internal reflection.

Classification of Optical Fibres:

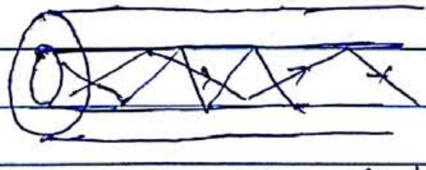
Based on the number of modes transmitted

① Single Mode:

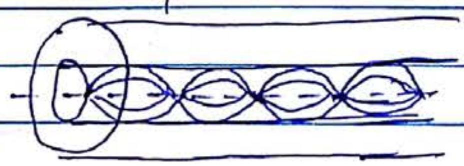
Having lower core diameters about 10 µm and supports only one signal / mode at a time. These fibres will be preferred for long distance communication as losses are relatively less. It will support for high band width. This type of fibres will be generally available in step index forms.

② Multi-Mode:

Having larger core diameters generally 50 µm and above. and supports many modes at a time. These fibres 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. Therefore losses are relatevely large. It also suffers internodal dispersion meaning some modes will travel faster as compaired to other modes. This difficulty will be overcomed in graded index multi-mode optical fibres.

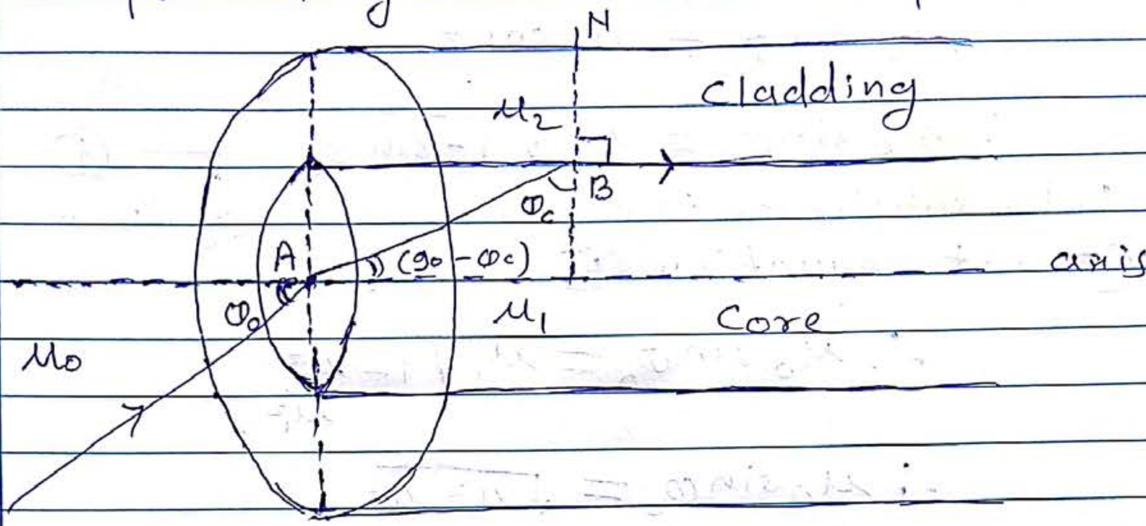


Step Index Multi Mode Optical Fibre



Graded Index Multi Mode Optical Fibre.

Acceptance Angle and Numerical Aperture:



θ_0 is known as the angle of acceptance, it is the maximum angle with respect to the axis of fibre at which light will travel along the core cladding interface. If the angle made by light rays with axis of the fibre is less than the θ_0 then all such light rays follows total internal reflection and 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

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

$$\mu_1 \sin\theta_c = \mu_2 \sin 90^\circ \quad \text{--- (2)}$$

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

$$\therefore \sin\theta_c = \frac{\mu_2}{\mu_1} \quad \text{--- (3)}$$

From equation (1)

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

$$\therefore \mu_0 \sin\theta_0 = \mu_1 \sqrt{1-\sin^2\theta_c} \longleftarrow (4)$$

Let's subtitute the value of $\sin\theta_c$ from equation (3) into equation (4)

$$\therefore \mu_0 \sin\theta_0 = \mu_1 \sqrt{1-\frac{\mu_2^2}{\mu_1^2}}$$

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

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

For air medium $\mu_0 = 1$.

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

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

The term, $\sqrt{\mu_1^2-\mu_2^2}$ is known as numerical aperture. i.e, N.A.

$$\therefore N.A. = \sqrt{\mu_1^2-\mu_2^2} = \sin\theta_{0(max)}. \longrightarrow (7)$$

$$\therefore N.A. = \sqrt{(\mu_1-\mu_2)(\mu_1+\mu_2)}$$

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

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

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

Where, $\Delta = \frac{\mu_1 - \mu_2}{\mu_1}$ —— (8)

Known as fractional change in the refractive index

$$\therefore N.A. \simeq \mu_1 \sqrt{2 \cdot \Delta} \quad —— (9)$$

For the fibres used in short distance communications the value of N.A. is in the range of 0.4 to 0.5. It is the case of multi mode optical fibres. And for the fibres used in longer distance communications (single mode optical fibres), N.A. will be in the range of 0.1 to 0.3.

* 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 this 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 and
- Abcorption due to impurities.

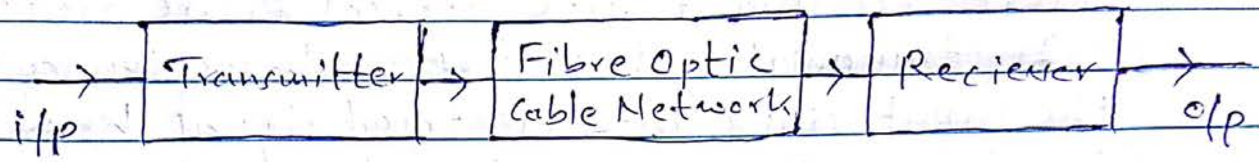
(2) Losses due to dispersion involves

- Internodal dispersion causes broadening of pulse.
- Waveguide dispersion (arises due to diff. effective refractive 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.

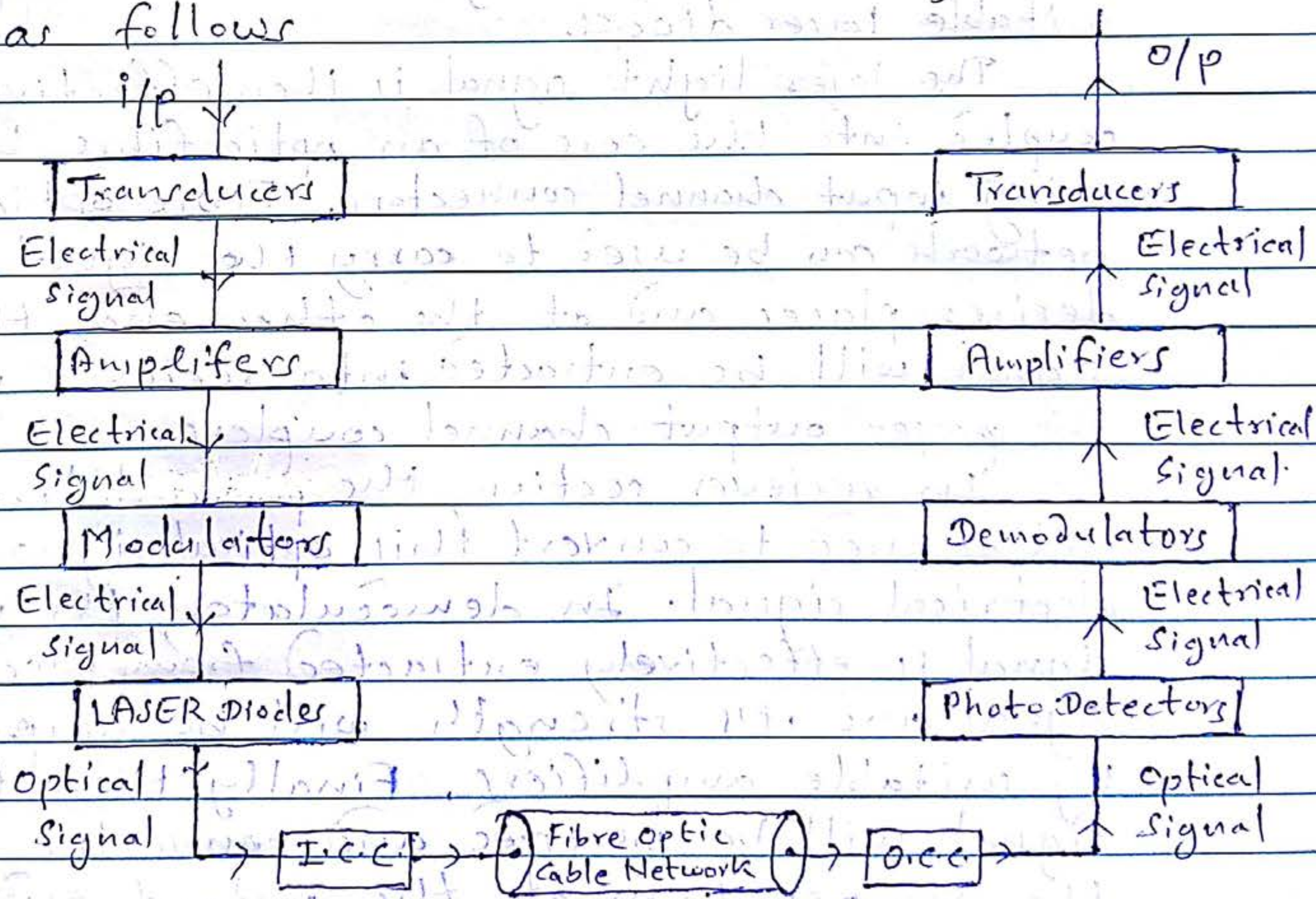
Generalised Fibre Optic Communication System

The basic structure of generalised fibre optic communication system is as follows.



This system is consisting of three basic building blocks as transmitter, optical fibre network and reciever. 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



I.C.C. → Input Channel Couplers

O.C.C. → Output Channel Couplers

The transmitter section of the communication system accepts the signal of any form containing information & process the signal into its various subsections before feeding it into optical fibre network.

In transmitter, the first sub-section converts the input signal into electrical signal known as transducers. Then in next section, it is amplified by amplifiers.

A communication system works on a standard operating signal. The modulators will superimpose input signal on standard operating signal and then this modulated signal can be finally converted into light signal with the help of suitable laser diodes.

The laser light signal is then effectively coupled into the core of an optic fibre by using input channel connectors. Fibre optic cable network can be used to carry the signal to desired places and at the other end, the signal will be extracted into reciever with the proper output channel couplers.

In reciever section, the photo detectors will be used to convert this optical signal into electrical signal. In demodulators the main signal is effectively extracted from modulated signal and it's strength will be amplified by suitable amplifiers. Finally then the signal will be processed and converted into the required form at the output end.

Advantage 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 to 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 affect the signals in adjacent fibre. i.e; No cross-talking will result.

* Numericals based Unit-II:
There will be no numericals on LASER.
In Unit-II, numericals will be based Fibre Optics.

(1) Calculate the fractional index change for a given optical fibre if the refractive indices of core and cladding are 1.563 and 1.498 respectively.

Sol^n: Given: $\mu_1 = 1.563$
$\mu_2 = 1.498$.

Formula: Fractional Index Change Δ is

$$\Delta = \frac{\mu_1 - \mu_2}{\mu_1} = \frac{1.563 - 1.498}{1.563}$$

$$\therefore \Delta = 0.0416.$$

(2) Calculate the numerical aperture (N.A.) and acceptance angle of an optical fibre having $\mu_1 = 1.49$ and $\mu_2 = 1.44$.

Sol^n: Given: $\mu_1 = 1.49$
$\mu_2 = 1.44$

Formula for N.A. is

$$N.A. = \sqrt{\mu_1^2 - \mu_2^2}$$

Angle of Acceptance, $\theta_0 = \sin^{-1}(N.A.)$

$$\therefore N.A. = \sqrt{1.49^2 - 1.44^2} = 0.38275.$$

$$\theta_0 = \sin^{-1}(0.38275) = 22.5^\circ.$$

(3) A fibre has an acceptance angle of 30° and a core index of refraction is 1.4. Calculate the refractive index of the cladding.

Solⁿ: Given:

$\theta_0 = 30°$.

$\mu_1 = 1.4$.

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

$\therefore \sin 30 = \sqrt{1.4^2 - \mu_2^2}$

$\therefore \sin^2 30 = 1.4^2 - \mu_2^2$.

$\therefore \mu_2^2 = 1.4^2 - \sin^2 30$

$\mu_2 = 1.3077$

Thus, refractive index of cladding is 1.3077.

* Keywords / Guidlines for the preparation of MCQ based examination:

- Interference defⁿ and understanding
- Monochromatic
- Coherent - division of amplitude & wavefront
- General condⁿ for C.I. and D.I.
- Final equation of optical path difference for the case of uniform thickness thin film and wedge shaped thin film & condⁿˢ.
- Logic of testing of optical flatness
- Meaning of anti-reflection and thickess equation and refractive index condition.

- Diffraction defⁿ and understanding
- Fresnell and Fraunhofer diffraction types and comparision (like distance between source slit and screen, use of lenses, mathematical formulation, ~~etc~~ wavefronts etc.)
- Single slit Fraunhofer diffractions final equation of amplitude and intensity & and various conditions of maxima and minima.
- In grating, final equation for resultant amplitude and intensity and only the equation for condition of minima i.e; $(a+b)\sin\theta = n\lambda$.
- Resolving Power (R.P.) defⁿ and equation of R.P. of Telescope and Grating.

- ✓ Rayleigh's Criteria for resolution like, just resolved, well resolved and not resolved.
- ✓ Equation for Circular Aperture Diffraction.

- ✓ Polarization, def^n and understanding
- ✓ Meaning of plane polarized/linearly polarized, circularly polarized and elliptical polarized light.
- ✓ Malus Law equation ($I = I_0 \cos^2\phi$) and its various cases of intensities.
- ✓ Working principle of liquid crystal display (LCD), ON state and OFF state of LCD.