LASERS &

4.4 characteristics of Laser :-

The most striking features of a laser beam are (i) High Monochromaticity ✓ (ii) high degree of coherence, (iii) high directionality (iv) high brightness.

4.4.1 (i) Monochromacity :-

The light which consist of single wavelength called "Monochromatic light." To speak more about monochromaticity of light source, we make use of "Line width" ($\Delta\nu$) of the source, which is related to wavelength spread "$\Delta\lambda$" source.

Let us ~~consider~~ compare wavelength spread of whit light, light from commercial lamp and a laser light. For white light source $\Delta\lambda \simeq 300$ nm for gas discharge line $\Delta\lambda \simeq 0.01$ n.m, For a laser $\Delta\lambda \simeq 0.001$ n.m

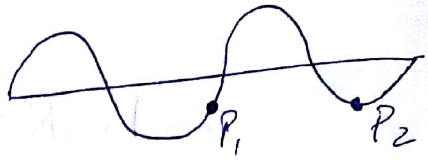
4.4.2 (ii) Coherence :-

A Predictable correlation of the amplitude and phase at any one point with any other point is called "coherence". Laser light is highly coherent. There are two types of coherences.

(a) Temporal coherence.

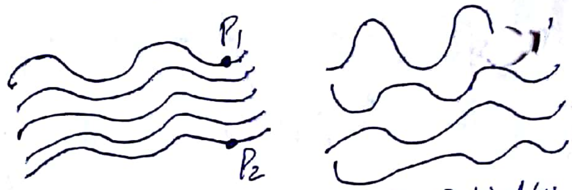
(b) Spacial coherence.

(a) Temperal coherence :- A predictable correlation of the amplitude and phase between any two points on a wave train is called "Temperal coherence".



(b) Spatial coherence :-

Let us consider the cross section of the output beam of a laser. The maximum separation between any two points on the cross section of the wavefront which maintain correlation between them is called "Spatial coherence (or) transverse coherence".

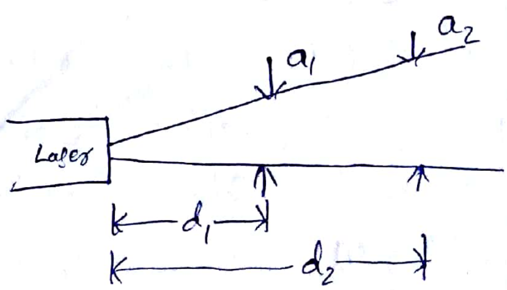


(a) spatially coharent (b) spatially incoherent.

4.4.3 (iii) Directionality :-

In the case of laser the active medium is mostly cylindrical cavity which placed between two reflecting mirrors. Thus the beam drawn from the output mirror it is highly parallel and directional. The degree of directionality is expressed in terms of "divergence". The divergence tells how rapidly the beam spreads when it is emitted from the laser.

At d_1, d_2 distences from laser the diameters of spots are measured to be a_1, a_2. Then the angle of divergence (ϕ) is



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

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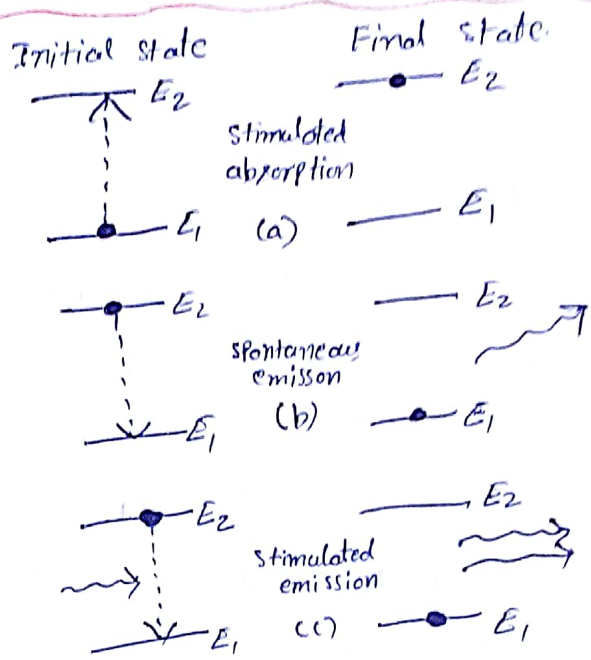
4.4.4 (iv) Brightness :- Lasers are bright and intense light sources. An one milliwatt He-Ne laser is brighter than the sun.

4.4.5 Spontanious and Stimulated Emission of Radiation



when radiation interacts with matter, it emits photons. first of all the energy of the interacting photon ($h\nu$) must match with the energy difference b/w the two states.

When interaction occurs atoms in ground level "E_1" by absorbing the energy they get excited to the higher energy state "E_2" by process called "Stimulated absorption". Then the de-excitation of those atoms to the lower energy state "E_1" occurs with emission of Photon of energy '$h\nu$'. This process called "Spontanious emission"

By interacting with photons we are de-exciting the atoms to ground energy level "E_1" from "E_2" by emitting two photons this process is called "Stimulated emission".

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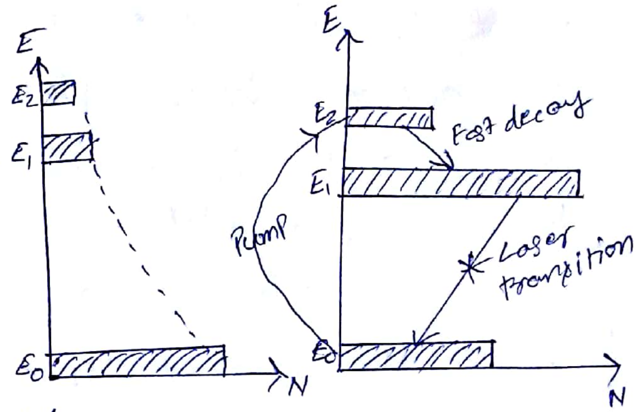
4.5 Population Inversion :-

Population inversion condition required for light amplification. It is a non-equilibrium distribution of atoms among the various energy levels of atomic system.

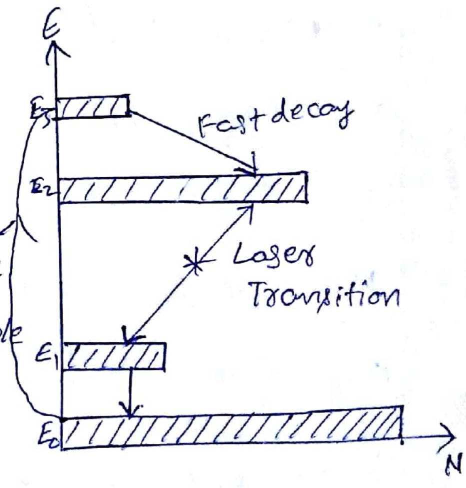
In a atomic system by absorbing energy atoms are excited to higher energy level E_1 from ground level E_0. By direct pumping population inversion is not possible. Population inversion is achived in two stages (i) Three level (ii) Four level Scheme.

(i) Three level Scheme :-



By absorbing energy atoms are excited to higher energy level E_2 from low energy level E_0. In E_2 atoms are having less lifetime. The atoms decay fast to the 'E_1' level. 'E_1' has long life time so it is also called metastable state. So atoms are gathering at energy level 'E_1'. So $(N_1 > N_0)$ population inuention is achived in three level schem.

(ii) Four level Scheme :-



In pumping process atoms are lifted from ground state to the highest level. In this four levels are involved. In this "E_2" is the metastable state Laser transision occurs at $(2 \to 1)$ transision.

4.5.1 Laser Action :-

For continuous stimulated chain reaction of laser population inversion or population reversal should be maintained. This can be done by electrical, optical, and chemical pumping. Population inversion is the main mechanism in laser emission.

4.5.2 Einstein's coefficients :-

In collection of atoms three transitions occur simultaneously. Let "N_1, N_2" be the number of atoms per unit volume with energy "E_1, E_2". "n" no. of photons per unit volume at frequency "ν" such that "$h\nu = E_2 - E_1$".

$\therefore$ The energy density of photons, $\rho(\nu) = nh\nu \rightarrow (1)$

when the photons interact with atoms, both upward and downward transitions occurs. At equilibrium these transitions must be equal.

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upward transitions :-

Stimulated absorption rate depends on the no. of atoms available in the lower energy state and photon density.

$B_{12} \Rightarrow$ Einstein coefficient of stimulated absorption

$$\text{stimulated absorption rate} \propto N_1$$
$$\propto \rho(\nu)$$
$$= N_1 \rho(\nu) B_{12}$$

Downward transition :-

In downward transition spontaneous emission rate depends on no.of atoms in excited state.

$\therefore$ Spontaneous emission rate $\propto N_2$

$$= N_2 A_{21}$$

$A_{21} \rightarrow$ Einstein coefficient of spontaneous emission.

Stimulated emission rate depends on no.of atoms in higher energy level and photon density.

Stimulated emission rate $\propto N_2$

$$\propto \rho(\nu)$$

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

$B_{21} \rightarrow$ Einstein coefficient of stimulated emission.

For a system in equilibrium upward and downward transitions are equal.

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

$$\rho(\nu) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}} = \frac{A_{21}/B_{21}}{\frac{B_{12}}{B_{21}}\frac{N_1}{N_2} - 1} \rightarrow (2)$$

Population of various energy levels of a system in thermal equilibrium by Boltzmann distribution law.

$$N_i = g_i N_0 \exp\left[\frac{-E_i}{KT}\right] \longrightarrow (3)$$

$\therefore N_1 = g_1 N_0 \exp\left(\frac{-E_1}{KT}\right)$

$N_2 = g_2 N_0 \exp\left(-E_2/KT\right)$

$\therefore \frac{N_1}{N_2} = \frac{g_1}{g_2} \exp\left(\frac{E_2 - E_1}{KT}\right)$

$\frac{N_1}{N_2} = \frac{g_1}{g_2} \exp\left(\frac{h\nu}{KT}\right)$

$\therefore$ (2) $\Rightarrow$

$$\rho(\nu) = \frac{A_{21}/B_{21}}{\left[\frac{g_1}{g_2}\frac{B_{12}}{B_{21}}\exp\left(\frac{h\nu}{KT}\right) - 1\right]} \rightarrow (4)$$

From planck's law of black body radiation, the radiation density is given by

$$\rho(\nu) = \frac{8\pi h\nu^3}{c^3}\left[\frac{1}{\exp\left[\frac{h\nu}{KT}\right] - 1}\right] \rightarrow (5)$$

from (4)(5) $\Rightarrow$ $\frac{g_1}{g_2}\frac{B_{12}}{B_{21}} = 1$

$$\boxed{g_1 B_{12} = g_2 B_{21}} \rightarrow (6)$$

$$\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}} \rightarrow (7)$$

eqs (6), (7) are called Einstein's coefficients.

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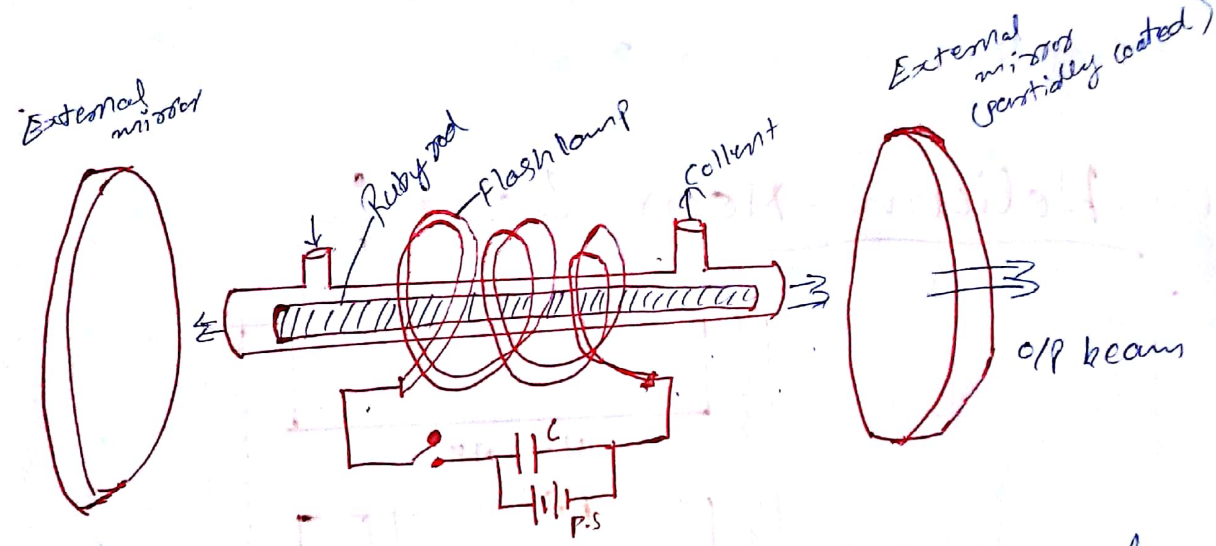
4.6 **Ruby laser** :- The first laser in which laser action was demonstrated by T. Miman in 1960 is Ruby. The active laser particles are Cr^{+3} ions present as impurities in Al_2O_3 crystal. Typical Cr^{+3} ions percentage is around 0.05% by weight. The emission wavelength of Ruby laser is 0.6943 μm or 694.3 nm. In this laser optical pumping using by flash lamps. Recently they are replaced by laser diodes.



Ruby rod is cylindrical rod, nearly 10cm long and 0.5 cm in diameter. The helical Xenon flash lamp surrounds the ruby rod. The flash excitation is provided by the ~~damage~~ discharge of the charge stored in a capacitor bank across the lamp. Two external mirrors are provided both sides of the ruby rod. One is 100% coated with silver and another is 90% partially coated with silver. To avoid the damage of crystal in the ~~crystal~~ experiment ruby rod was circulated around the collent arrangment.

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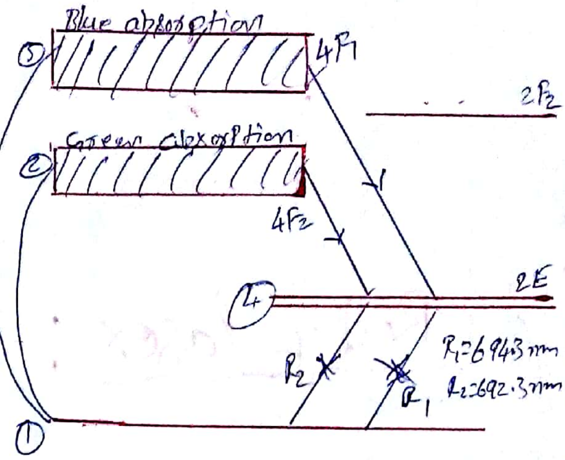
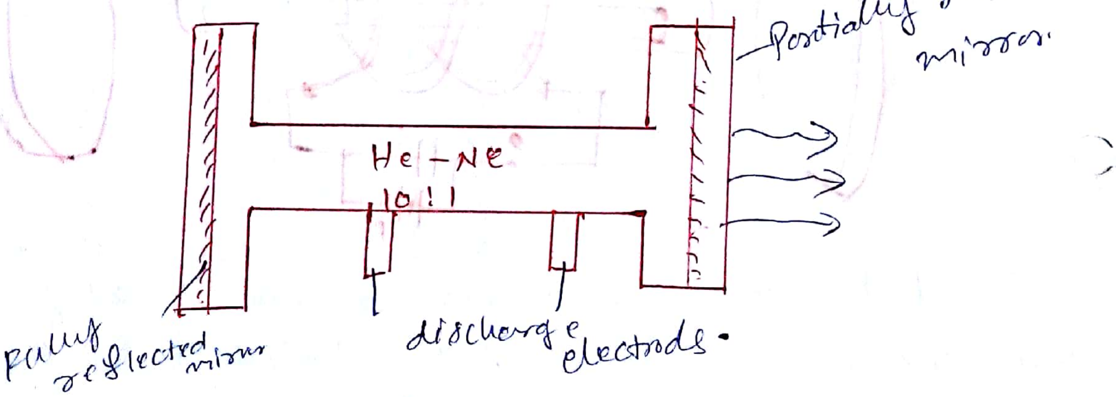
The Pumping of Ruby is usually performed by subjecting it to the light of flashlamp. The Cr^{+3} ions in Ruby rod absorb strongly in the blue and green portions of the visible spectrum. Thus the ions from "$4F_1$", "$4F_2$" undergoes nonradiative transitions to metastable state "2E". Population inversion achived here, From "2E" energy state to ground state the ions will deexcite by emitting R_1, R_2 with intensities 694.3 nm and 692.3 nm. Here 694.3 nm usually dominates laser beam and after amplification by external mirrors laser beam emitted by partially coated mirror. Ruby laser can be operated in pulsed mode.



4.6.1 Helium-Neon Laser :-



He-Ne laser is a gas laser. The o/p beam is a continuous laser beam. It is a four level laser system.

Active material :-

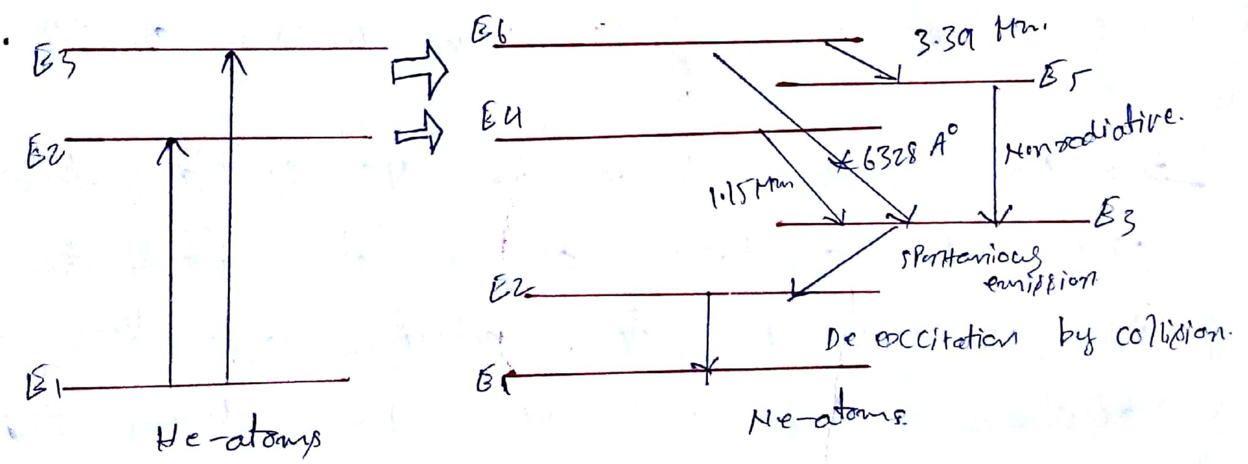
In He-Ne laser active medium consist of mixcure of He-Ne is about 10:1 ratio.

Resonant cavity :-

The set of parallel mirrors forming a resonant cavity one is completly reflective and the other is partially reflective.

Pumping system :-

Electrical discharge is the pumping system. the electrons from the discharge coloid with the helium atoms ~~and excites with the Helium atoms~~ and excites them to higher energy levels.



Working :- During electrical discharge, the electrons by impact with atoms excite them to one of the two metastable states E_2 & E_3 in energy levels diagram of He

$$e_1 + He \rightarrow He^* + e_2$$

where e_1, e_2 are the electron energies before and after collision.

→ The two higher states of 'Ne' have almost exactly the same energy as two of the metastable He- states.

→ collision of excited He-atoms with ground state Ne- atoms results energy transfer. and He-atoms in E_2 & E_3 states return to the ground state and Ne-atoms to the excited states E_4 & E_6 respectively.

$$He^* + Ne \longrightarrow He + Ne^*$$

∴ Population inversion thus created b/w (E_6, E_5) (E_6, E_3) also b/w (E_4, E_3) levels in 'Ne'. So there are three possible oscillations in He-Ne system.

i) $E_6 - E_5$ transition will give 3.39 μm wavelength

ii) E_6 to E_3 transition will give 6328 A° wavelength

iii) E_4 to E_3 transition will give 1.15 μm as o/p.

→ E_2 energy levels of Ne is a metastable state De- excitation of Ne-atom from E_2 to S_1 is achived by the collisions with the discharge tube walls and to enhance this the discharge tube diameter is kept small.

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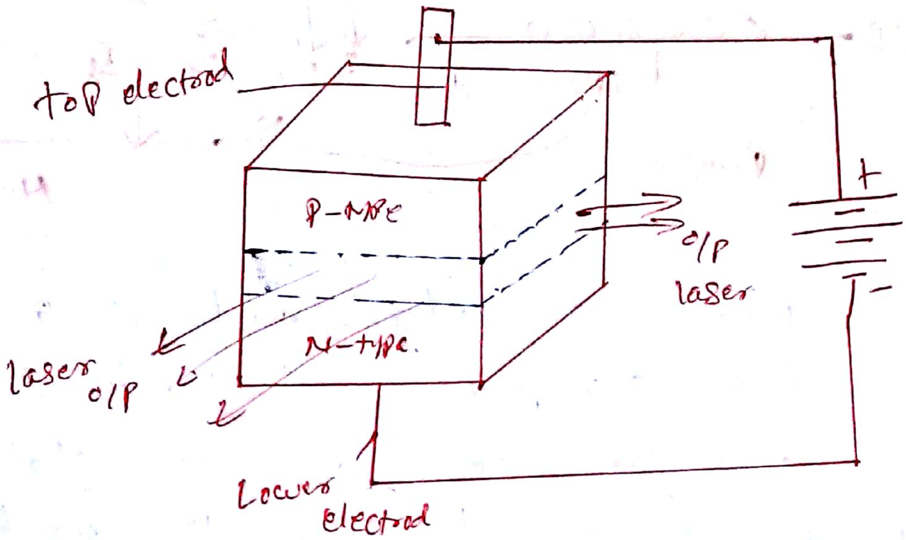
4.7 Semiconductor diode laser :-

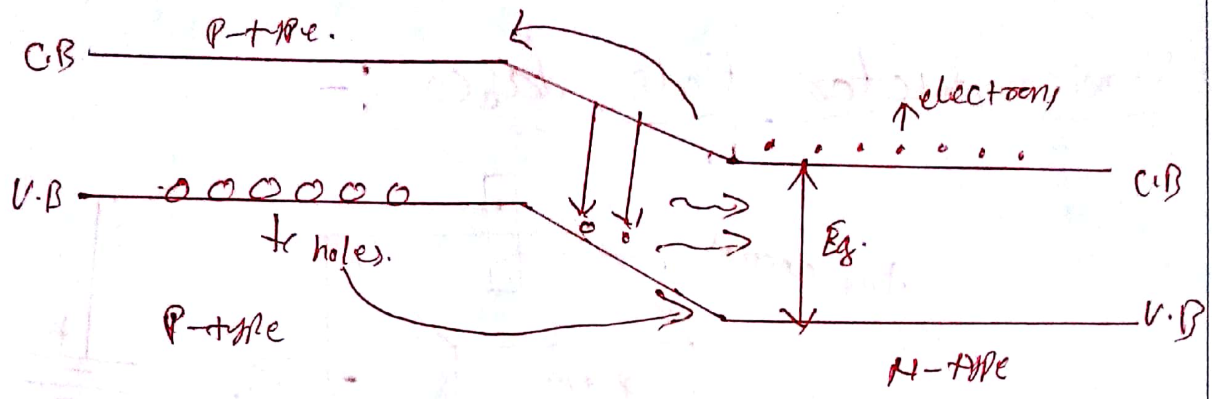


Active medium :- In Semiconductor diode the active medium is Ga-As. Direct band gap Semiconductor which was properly doped with 3rd and 5th group elements to make a P-n junction diode.

Pumping System :- electrons discharge in the P-n junction diode in the forwared bias. Due to recombination taking place b/w electrons and holes at the junction we will get laser light.

Resonating cavity :-

In Semiconductor lases no need of special Construction of resonating cavity this is because of high refractive index of these materials. the critical angle b/w air and diode interface is very less so, the light rays whose angle is greater than this critical angle will reflect back into material to stimulate more electrons. to recombine with holes thus light is going to amplify.



when a P-type material is combined with n-type semiconductor at the junction deplection of charge will takes place and only stationary +ve and -ve ions will present across the junction. These will creat some potential barrier. For farthere diffusion of charges the PN-Junction diode must be connected to voltage source in forwared bias. During the movement of charges i.e electrons from n-type to P-type and holes from P-type to n-type. They will recombine at the junction to liberate light.

4.7) Applications of Lasers :-

1) Lasers are usefull in treating cancer
2) For cataract removal lasers are used.
3) Laser stabels are used for bloodless surgery.
4) High power lasers such as CO_2-lasers are used to cut the metal sheets - and to drill holes for fixing bolts.
5) Lasers are used in destroying kidney stones & gall stones

lasers. Unquestionably this laser ranks first from the stand point of potential industrial applications.

The active medium is CO_2 gas. As He is used for excitation of Ne atoms in He–Ne laser, in CO_2 laser for efficient excitation of CO_2 molecules N_2 molecules are used. Addition of He to the gas mixture enhances the efficiency. The ratio of pressures of CO_2:N_2:He is 1:4:5, optimum value of pressure–tube diameter product is around 33 torr mm.

Excitation process

CO_2 molecules have a more complicated structure and have energy levels that correspond to rotating or vibrating motions of the entire molecular structure. The CO_2 molecule, composed of two oxygen atoms and a carbon atom between them, undergoes three different types of vibrational oscillations, as shown in Fig.16.

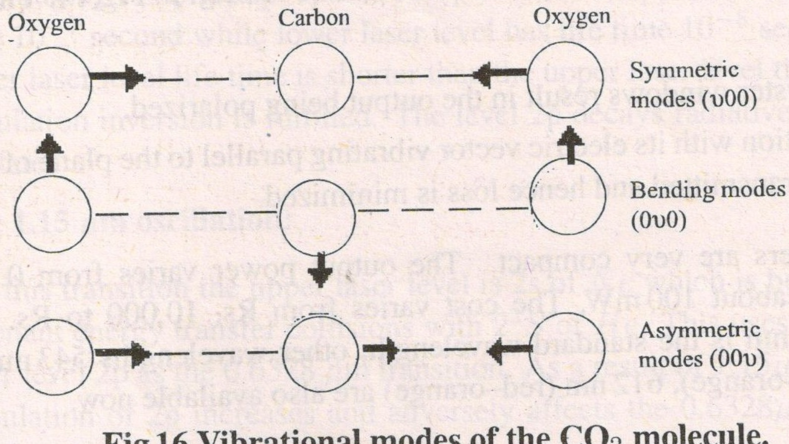


Fig.16 Vibrational modes of the CO_2 molecule.

Simplified energy level diagram for the CO_2 laser is given in Fig.17.

In CO_2 laser, the excitation is provided by electric discharge. Excited N_2 molecules transfer energy to the CO_2 molecules in resonant collisions, exciting them to the (001) levels which are metastable levels with relatively longer life time. With

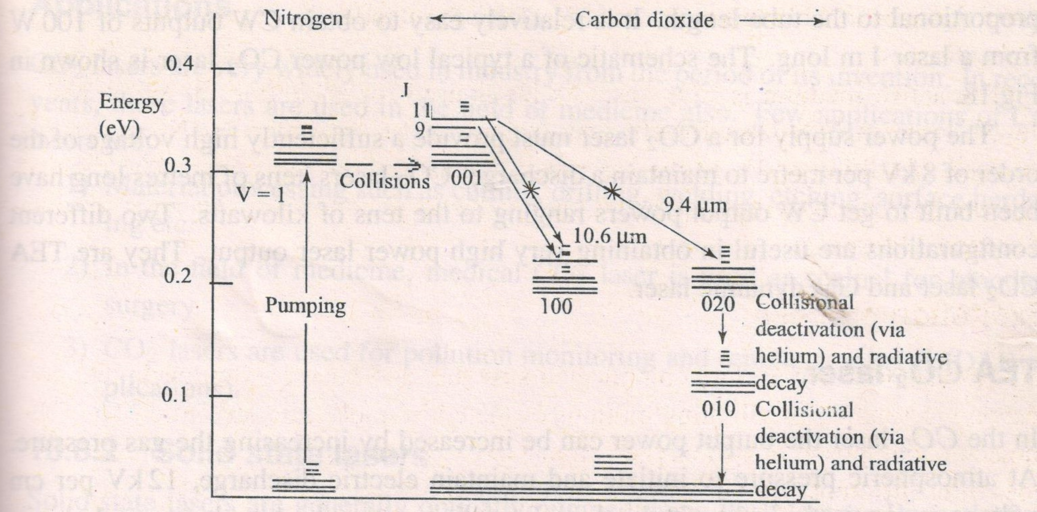


Fig.17 Simplified energy level diagram for the CO_2 laser. Each vibrational level has many rotational levels associated with it, $J = 1, 2, \ldots$ The 10.6μm line is the strongest

sufficient pumping, a population is produced between the (001) state and the (100) and (020) states and laser oscillations begin. The strongest line of the CO_2 laser is at a wavelength of 10.6μm, in the infrared. A weaker line at 9.4μm competes with the 10.6μm line for the available excited molecules. The He increases the laser efficiency at 10.6μm by speeding up the transition from the lower laser level of 10.6μm viz. the (100) energy level to the ground level, thereby maintaining a large population inversion.

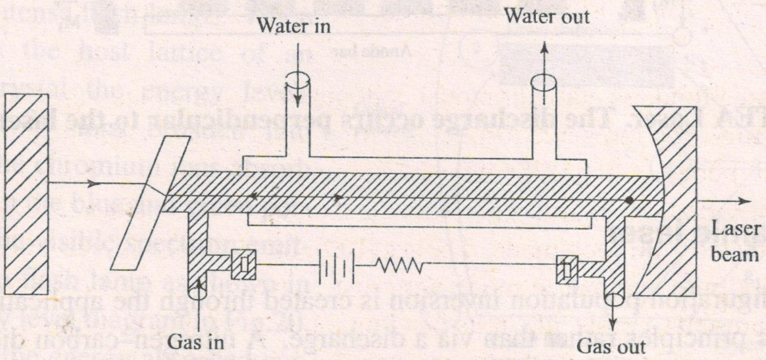


Fig.18 A schematic of a typical CO_2 laser.

CO_2 lasers are capable of producing very high output powers because of the high efficiency up to about 30%. Since operating in high power infrared region, special materials must be used for windows, mirrors and other laser components. Germanium, gallium arsenide, zinc sulphide, zinc selenide and various alkali halides are used as optical materials. The power output of the CO_2 laser is approximately proportional to the tube length. It is relatively easy to obtain CW outputs of 100 W from a laser 1 m long. The schematic of a typical low power CO_2 laser is shown in Fig.18.

The power supply for a CO_2 laser must provide a sufficiently high voltage of the order of 8 kV per metre to maintain a discharge. CO_2 lasers, tens of metres long have been built to get CW output powers ranging to the tens of kilowatts. Two different configurations are useful in obtaining very high power laser output. They are TEA CO_2 laser and Gas dynamic laser.

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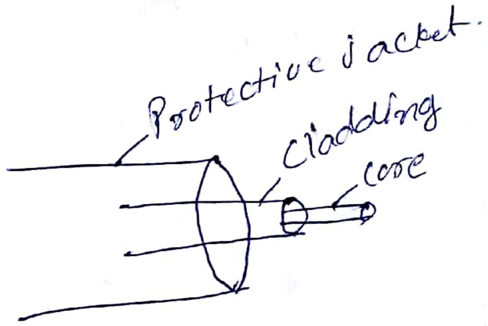
UNIT-III

Principles of optical Fibers

4.8 Construction of optical Fiber :-

Optical fiber is very thin and flexible medium made from dielectric substance such as glass (or) plastic having a cylindrical shap.

- It consist of three sections.
  1) The core material
  2) The cladding material
  3) The outer jacket.

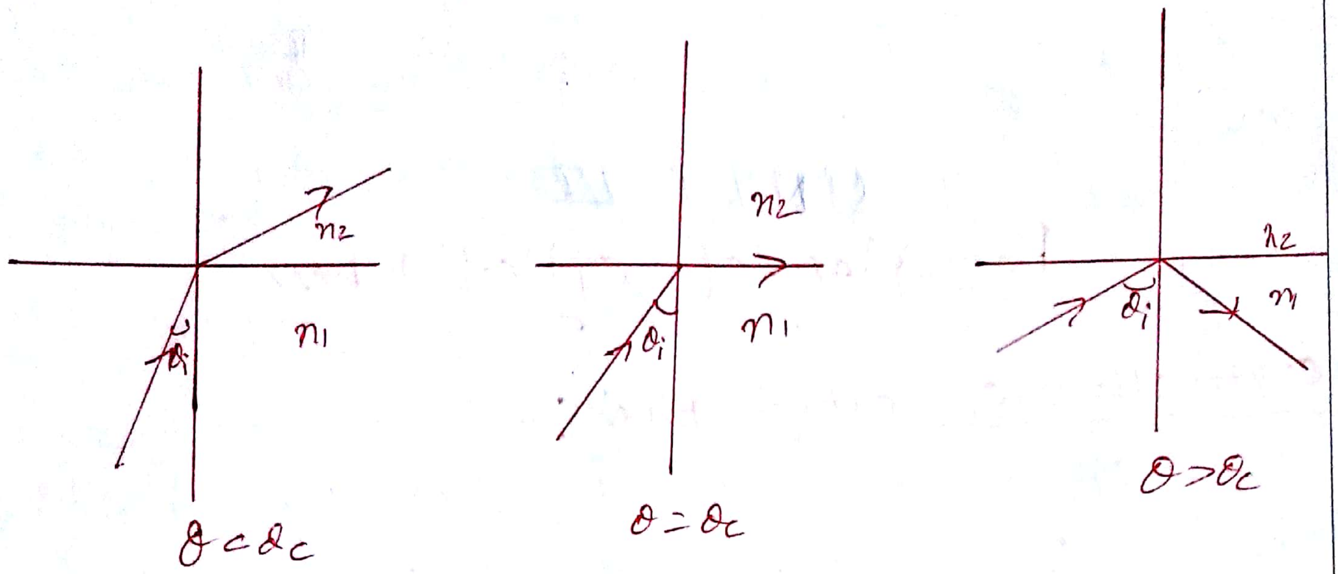


The fiber has a core surrounded by a cladding material whose refractive index is slightly less than that of the core material to satisfy the condition for total internal reflection.

- To protect the fiber material and also to give mechanical support there is a protective cover called outer jacket. Let n_1, n_2 be the refractive index of core & cladding so, $n_1 > n_2$

4.9 Principle of optical fiber :-

→ optical fiber is cylindrical, transparent dielectric material, designed to guide visible and infrared light over long distances.



Optical fiber works on the principle of "total internal reflection."

→ When light of travels from a denser medium into a rarer medium and if the angle of incidence is greater than the critical angle then the light gets totally reflected.

The light launched at one end of the fiber has to travel through the entire length and reach the other end without much loss.

A/c to Snells law.

$$n_1 \sin\theta_i = n_2 \sin\theta_r$$

for $\theta_i = \theta_c$, $\theta_r = 90^\circ$

$$\therefore n_1 \sin\theta_c = n_2 \sin(90^\circ)$$

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

$$\therefore \theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

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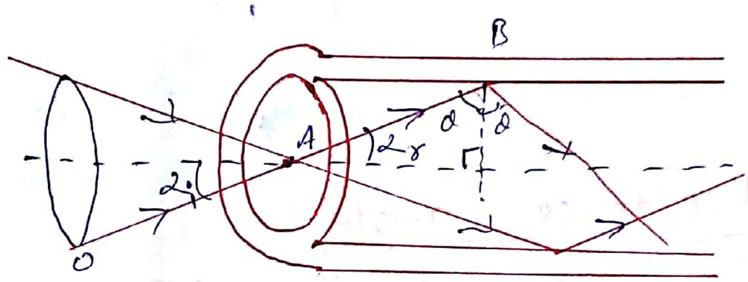
4.9 Acceptence angle :-

" This is the maximum angle at which light ray can have with the axis of the fiber and propagates through the fiber".



The light is entered from medium of refractive index n_0 (air) into the core of refractive index n_1.

The ray (OA) enters with an angle of incidence 'α_i' to the fiber end face.

Let the refractive index of the cladding be n_2

Here, $n_1 > n_2$. the light ray refracts at an angle 'α_r' and strikes the core-cladding interface at angle 'θ'.

If the angle 'θ' is greater than its critical angle 'θ_c', the light rays undergoes total internal reflection

reflection at the interface

A/c to Snell's law

$$n_0 \sin \alpha_i = n_1 \sin \alpha_r$$

From the light angled triangle ABC

$$\alpha_r + \theta = 90^\circ \Rightarrow \alpha_r = 90 - \theta$$

$\therefore n_1 \sin\alpha_i = \frac{n_1}{n_0} \cos\theta_c$

From the condition of total internal reflection

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

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

$$\therefore \sin\alpha_i = \frac{n_1}{n_0} \times \frac{\sqrt{n_1^2-n_2^2}}{n_1} = \frac{\sqrt{n_1^2-n_2^2}}{n_0}$$

$$\therefore \sin\alpha_i = \sqrt{n_1^2-n_2^2}$$

$$\Rightarrow \alpha_{i(max)} = \sin^{-1}\left(\sqrt{n_1^2-n_2^2}\right) \quad (\because n_0 = 1) \text{ (air R.I)}$$

Acceptence angle :-

" Rotating the acceptence angle about the fiber axis describes the acceptence cone of the fiber."

4.9.) Numerical Aperture :-

" Numerical appertune is a measure of the amount of light that can be accepted by a fiber"

" Numerical aperture is defined as the sine of the maximum acceptence angle."

$$\text{Numerical Aperture (NA)} = \sin\alpha_m$$

But we know, $\alpha_m = \sin^{-1}\left(\sqrt{n_1^2-n_2^2}\right)$

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

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

fractional difference in refractive indices n_1 & n_2 is $\Delta = \frac{n_1-n_2}{n_1} \Rightarrow n_1-n_2 = n_1\Delta n$

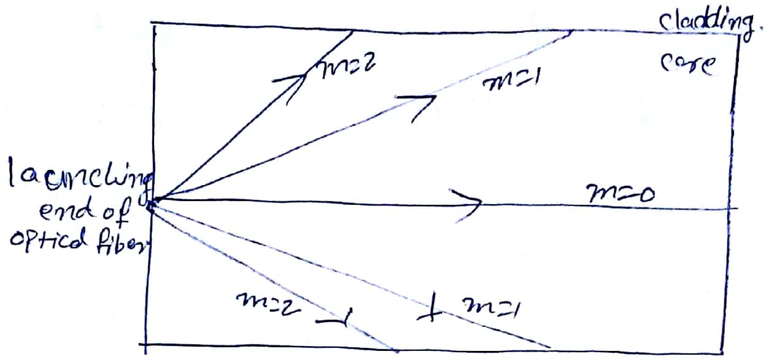
$$\therefore NA = \sqrt{(n_1+n_2)\, n_1\Delta}$$

But $n_1 \approx n_2$ we can take $n_1+n_2 = 2n_1$

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

Types of optical Fibers :-

optical fibers can be classified based on either the modes they support or the refractive index profile of the fiber. Another classification is based on the material of the fiber either plastic or Glass.

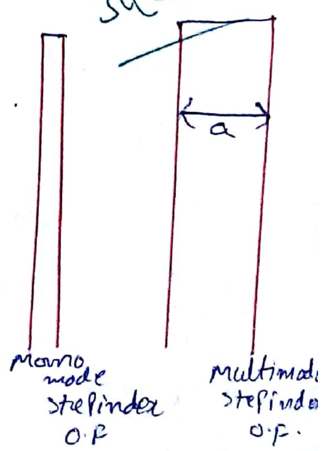


The light launched at one end of optical fiber with in the acceptance angle propagates through optical fiber in specified directions called "modes". as shown in above figure.

The thickness of optical fiber is so small that it supports only one mode then the fiber called "Monomode (or) Single mode optical fiber". Insted if it allows more than one mode then it is called "multimode optical fiber".

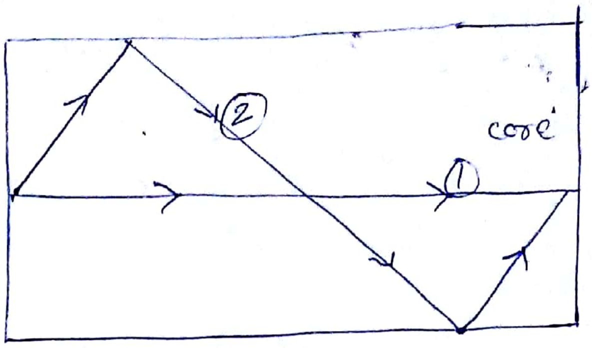
Monomode optical fiber has small diameter around 2-8 μm. The core diameter of multimode fiber is around 50 μm.

(1) Step - Index optical Fiber :-



In these fibers the entire core has uniform refractive index (n_1) slightly grater than cladding Refractive index (n_2). since the index profile is in the form of a step, these fibers are called "step-index optical fibers".

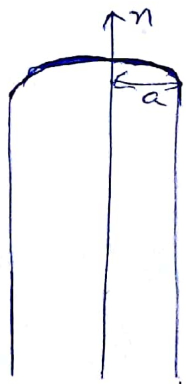
Transmission of Signal in Step-index fiber :-



Let us consider propogation of signal through multimode fiber. It travels in different paths. Hence at the receiving end only the ray ① which travels along the fiber axis reaches first while the rays taking longer path ② reaches after some time delay. Hence the pulsed signal received at the other end. This is called Internal dispersion. This difficulty is overcome by manufacturing of graded index fiber.

(2) Graded - Index fiber :-

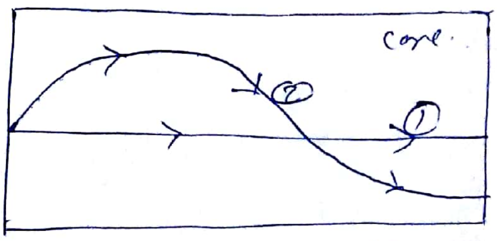
In this fiber refractive index of the core varies radially. It has maximum refractive index at the centre, which gradually falls with increase of radius and at the core-cladding interfaces matches with the refractive index of cladding.



Multimode Graded index optical fiber.

Transmition of Signal in Graded index Fiber :-

Let us consider signal pulse travelling through graded index optical fiber in two different paths ①, ②. Pulse ① travelling ~~through~~ along the axis of fiber where refractive index is high. Pulse ②, travelling away from the axis under go reflection and bend, it travels along the path possessing relatively lesser refractive index and hence bothe the pulses reach the other end simultaneously.



Attenuation in optical fibers :-

Attenuation is one important property of optical fiber.

"The power of light at the output end is found to be always less than the power launched at the input end. It is called Attenuation in optical fiber. It decreases light transmittance these losses are as follows.

$\alpha = \frac{10}{L} \log \frac{P_i}{P_o}$ dB/km L→length of O.F

(1) Scattering losses :- Glass which we are using to fabricate optical fiber is a Amorphous solid, is formed by allowing the glass to cool from its melten state at high temperature. During this process Doapants added to silica to modify the refractive index from core to cladding. These impurities act as reflecting and scatter a small portion of the light passing through the glass, contributing for the losses.

(2) Absorption losses :- During the fabrication of the fiber, to change the refractive index of the glass to any desired value, GeO_2 is doped. This cause shift in the UV-absorption band towards longer wavelength region. The presence of other impurities such as iron, copper and chromium ~~be~~ may also create unacceptable losses within the ~~un~~usable portion of the spectrum.

(3) Bending losses :- The distortion of the fiber from the ideal straight-line configuration may also result in fiber losses. These are called Bending losses.

~~Applications~~ Advantages of optical Fiber :-

optical fibers have number of attractive features

i) Enormous band width

ii) Electrical isolation

iii) Immunity to interference and cross talk.

iv) Signal security

v) Low transmission losses.

→ optical fibers are useful in medical field for endoscopy.

→ Endoscopic examination of the gastrointenstial tract for diagnosis and treatment of ulcer, cancer, bleeding sites and so on.

→ The heart, respiratory system ~~and~~ can ~~be~~ be investigated.

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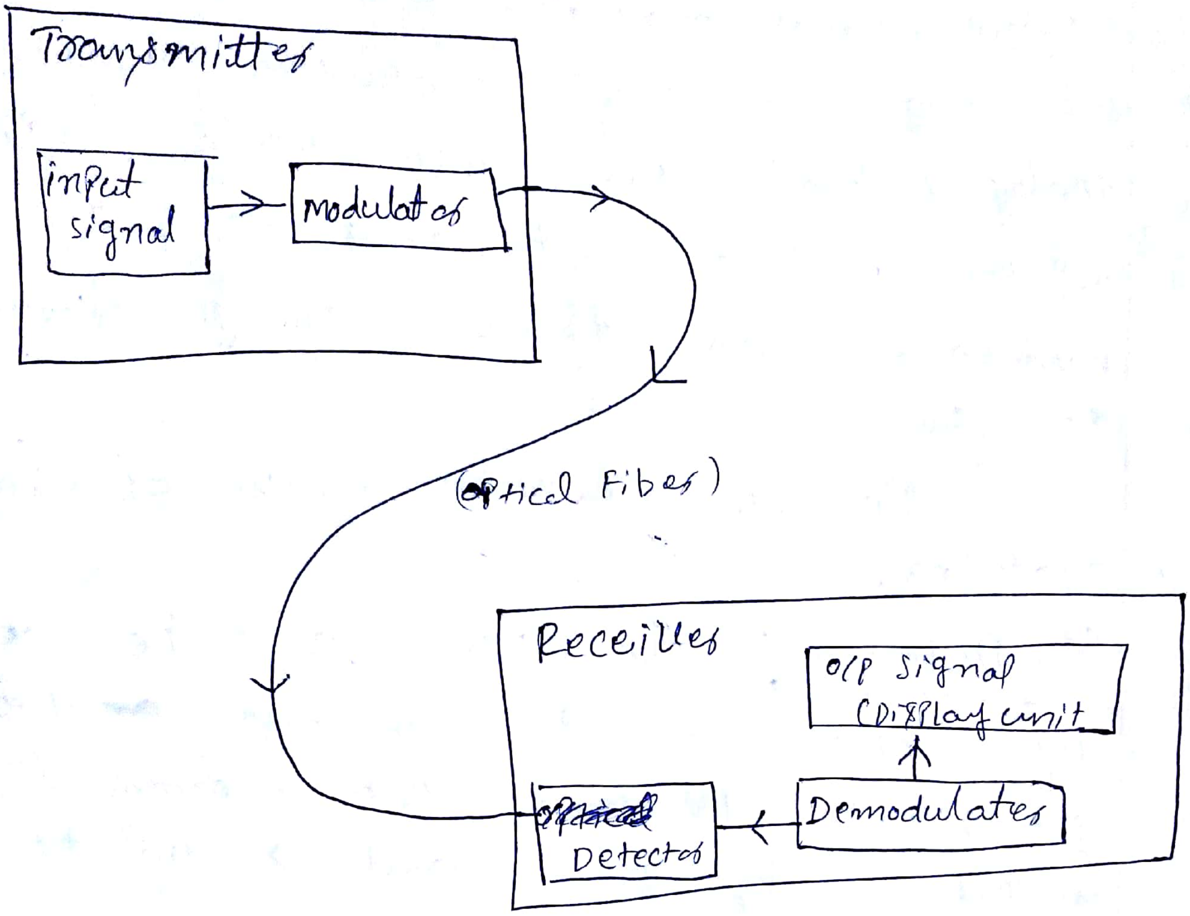
Fiber optic communication system:-



optical fibers are very attractive alternatives to twisted wire or coaxial cables in communi--cation links.

optical fiber communication system consist of two sections. ① Transmitter section, ② Receiver section.

Transmitter section consist of following modules.

(a) Signal generator :- It is usually LED or semico-
-nductor laser for light signal.

(b) Modulator :- The light signal from signal generated sended to the modulater. Here the oregenal signal modulated with carrier signal by using different modulation techniques like Analog modulation, Pulse width modulation, Binary digital modulation techniques etc. This modulated signal transmit through optical fiber to the receiver.

Receiver section consist of following modules.

(a) Detector :- The signal can be detected by Detector in Receiving end. The signal is transmiting through optical fiber Detected by Dector and sended to Demodu-
-later

(b) Demodulater :- The detected signal from detecter sended to Demodulater. Here Demodulater section, Demodulates the oreginal signal with carrier signal.

(c) output device :- Demodulated oreginal signal given to output device as a output.