EI 8075. FIBER OPTICS AND LASER INSTRUMENTS

UNIT-I Optical Fibers and their properties.

Introduction:-

An optical fiber is a glass or plastic fiber that carries light along its length. Fiber optic is the overlap of applied Science and Engineering concerned with the design and application of optical fibers. Optical fibers are widely used in fiber optic Communications, which permits transmission over long distances at higher bandwidths because light has high frequency than anyother forms of Communications. Light is kept in the core of the optical fiber by total internal reflection. This causes the fiber to act as a waveguide. Fibers are used instead of metal wires because Signals travel along them with less loss, and they are also immune to electromagnetic interference, which is caused by thunderstorm. Fibers are also used for illumination and are used for carrying images. The fibers are wrapped in bundles so they can be used to carry images, thus allowing viewing in tight spaces. Specially designed fibers are used for a variety of other applications, including Sensors and fiber lasers.

HISTORY:

1961 - Industry reseseaarchers Elias Snitzer and will hicks demonstrate a laser beam directed through a thin glass fiber. The fiber's core is small enough that the light follows a single path; but most scientists still consider fibers unsuitable for communications because of the high lost of light across long distances.

1970 - Researchers find a way to super purify glass fibers.

1980 - At &T instals first set of fiber opticsables in major cities.

1988 - First transatlantic cable.

1996 - First transpacific cable.

1997 :- First fiber optic Link Around the Globe. (FLAG).

The General System :

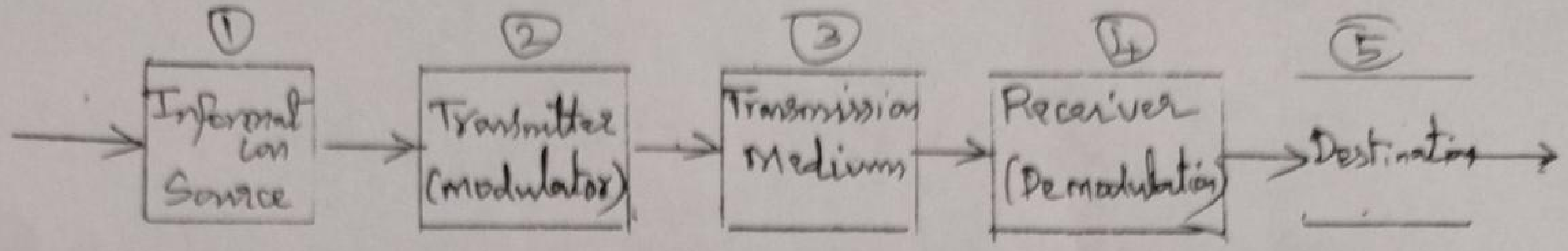


Fig 1. General block diagram of Communication System.

The funtion is to convey the signal from the informa -tion source over the transmission medium to the testination The general block diagram is shown in Fig 1.

The Communication System therefore consists of.

① Information source:-

It provides an electrical signal, usually derived from a message signal to a transmitter.

②. Transmitter:-

Output of Information source is not electrical, ex. (sound) ~~to a~~ comprising electrical and electronic components which converts the signal to a suitable form for propagation over transmission medium.

③. Transmission medium:

It consists of a pair of wires, a co-axial cable or a radio link through free space down which the signal is transmitted to the receiver.

④. Receiver:

The signal received at receiver is transformed into original electrical information signal (demodulated) before being passed to the destination.

⑤ Destination

The destination is the final stage in the communication system. Generally, humans at some place are considered as the destination.

Optical Fiber Communication System:

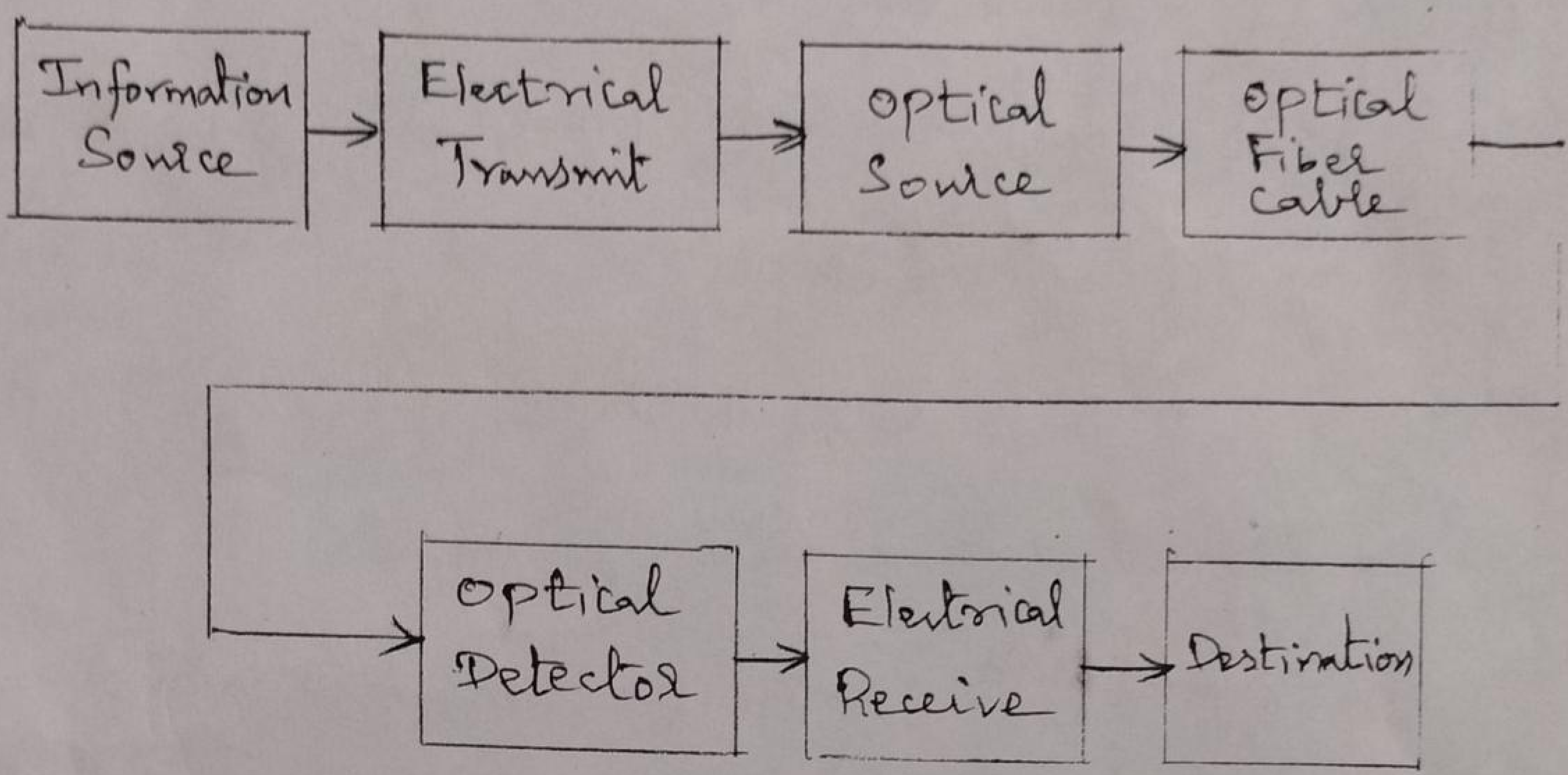


Fig: 2. General block diagram of optical Fiber Communication - System.

The block diagram of communication system using optical fiber is shown in figure 2.

An optical fiber is a very thin strand of silica glass in geometry quite like a human hair. when light enters one end of the fiber it travels until it leaves the fiber at the other end.

Principle of operation:-

① A serial bit stream in electrical form is presented to a modulator, which encode the data appropriately for fiber transmission.

(2) A light source is driven by the modulator and the light focused into the fiber.

(3) The light travels down the fiber (during which time it may experience dispersion and loss of strength).

(4) At the receiver end the light is fed to a detector and converted to electrical form.

(5) The signal is then amplified and fed to another detector, which isolates the individual state changes and their timing.

(6) It then decodes the sequence of state changes and reconstructs the original bit stream.

(7) The timed bit stream so received may then be fed to a using device.

Construction of Fiber Optic Cable.

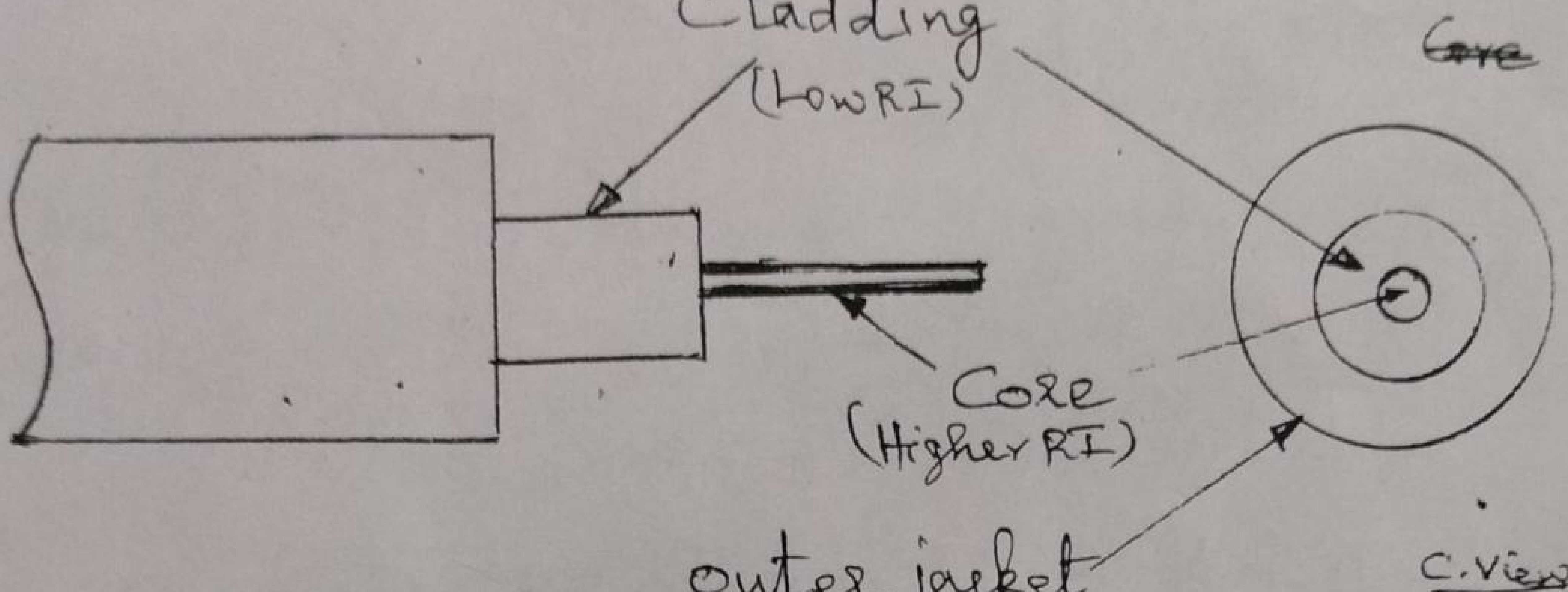


Fig. 3. Construction of Fiber.

① In reality, the Fiber is a very narrow, very long glass cylinder with special characteristics.

② An optical fiber consists of 3 parts the core and the cladding with outer jacket.

③ The Core:

The Core is a narrow cylindrical strand of glass. when the light enters one end of the core it travels until it leaves the core at the other end.

The core has a higher Refractive Index (RI) than the cladding. Light travelling along the core is confined by the mirror to stay within it even when the core/fiber bends around a corner.

④ The Cladding:

The cladding is a tubular jacket surrounding the core. The cladding has a lower (slightly) Refractive Index (RI) than the Core.

The role of cladding is to protect the core and from shocks.

The cladding helps in: (i) Reducing scattering losses. (ii) Adds mechanical strength to the fiber (iii) Protects the core from absorbing unwanted surface contaminants.

⑤ Outer Jacket:

A fiber optic cable has an additional coating around the cladding called jacket. The jacket usually consists of one or more layers of polymer.

Its role is to protect the core and cladding from ~~Sot~~ shocks, that might affect their optical or physical properties.

The jacket does not have any optical properties that might affect the propagation of light within the fiber optic cable.

Guiding Mechanism in optical Fiber:-

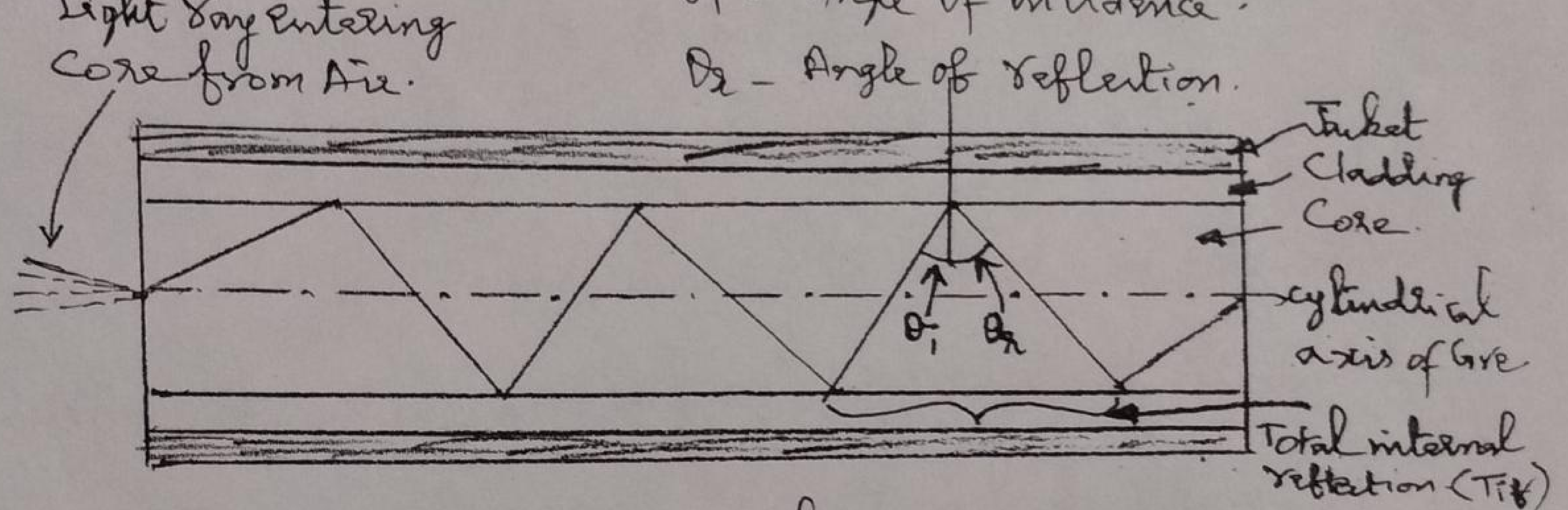


Fig. 4. Mechanism of light wave guide in Fiber.

1. Light ray is injected into the fiber optic cable on the right. If the light ray is injected and strikes the core-to-cladding interface at an angle greater than an entity called the critical angle then it is reflected back into the core. Since the angle of incidence is equal to the angle of reflection, the reflected light will again be reflected.

2. The light ray will then continue this bouncing path down the length of the fiber optic cable.

3. If the light ray strikes the core-to-cladding interface at an angle less than the critical angle then it passes into the cladding where it is attenuated very rapidly with propagation distance.

(4) It is to be noted that a light ray enters the core from the air outside, to the left of Fig. 4. The refractive index of the air must be taken into account in order to assure that a light ray in the core will be at an angle less than the critical angle. This can be done fairly simply.

(5) Suppose a light ray enters the core from the air at an angle less than an entity called the external acceptance angle. It will be guided down the core.

Principles of light propagation through a fiber :-

(1) Total Internal Reflection:

(i) Index of refraction:

This the measuring Speed of light in respative medium.

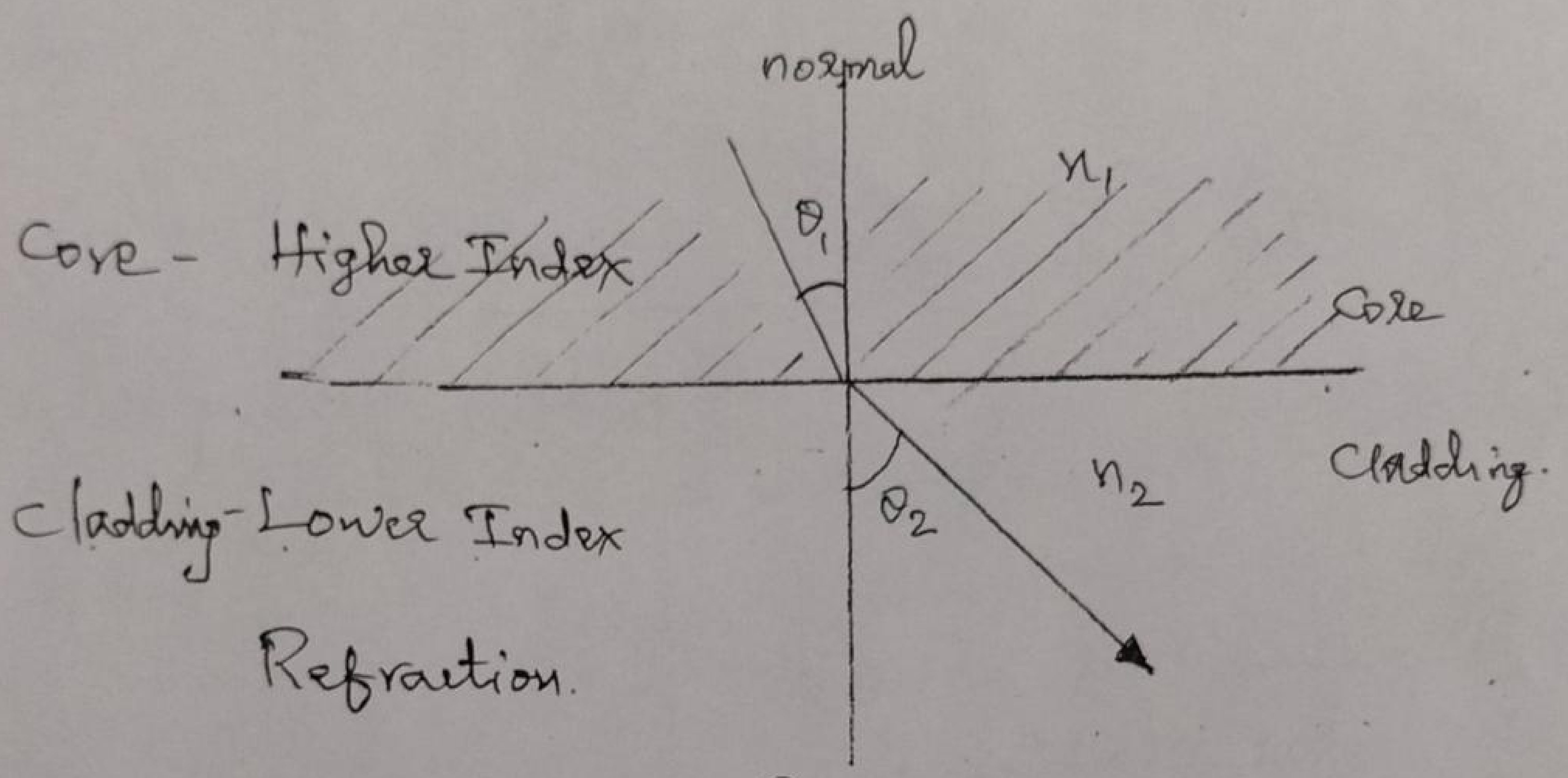
Refrative Index (RI) = $\frac{\text{Speed of light in Vacuum}}{\text{Speed of light in material}}$

RI for Vaccum	= 1
RI for fiber	= 1.48
RI for cladding	= 1.46.

It means Signal will travel around 200 million meters per Second, it will 12000 km in only 60 Seconds, other delay in communication will be due to Communication equipment switching and decoding, encoding the voice of the fiber.

(ii) Snell's Law:-

Inorder to understand ray propagation in a fiber. This is called Snell's Law.



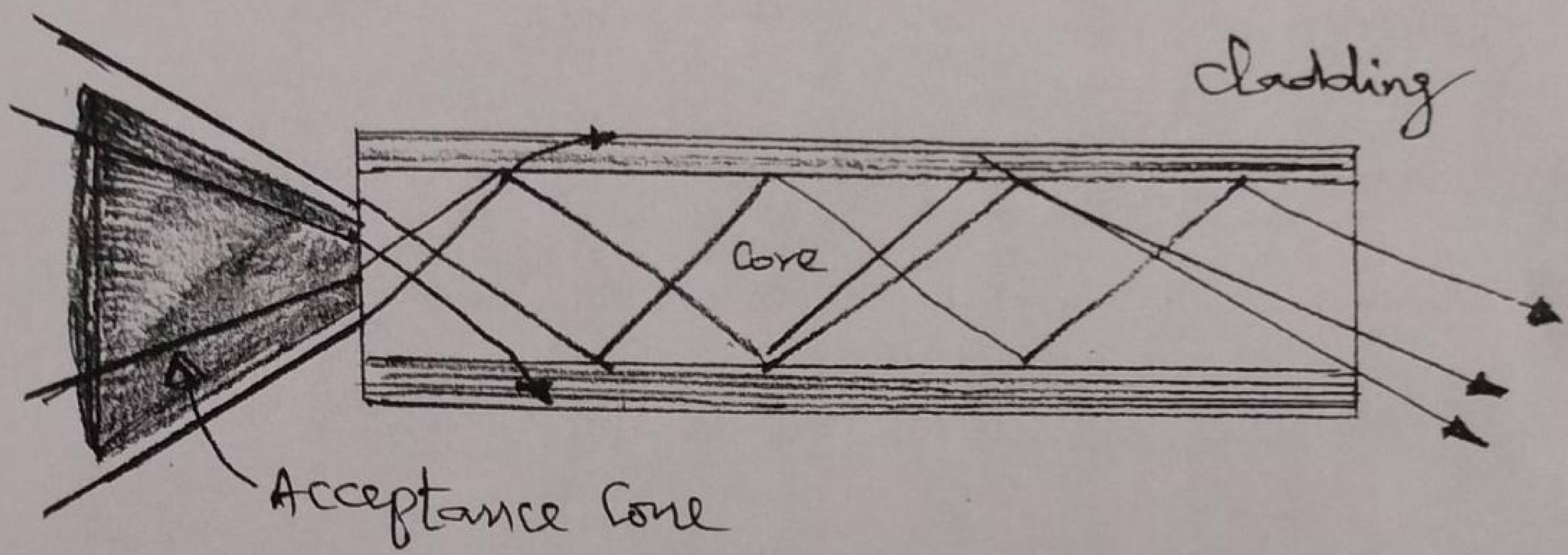
$\theta_1 < \theta_2$.

Snell's Law $\Rightarrow$ $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

where $n_1 \rightarrow$ RI of material ; θ_1 & θ_2 - angles in respective medium

* when light enters in lighter medium from denser medium it inclines towards normal.
* when light enters in denser medium from lighter medium it inclines to normal.

2. Acceptance Angle:



① The maximum incident angle below which the ray undergoes the total internal reflection is called an acceptance angle. The cone is referred as acceptance cone.

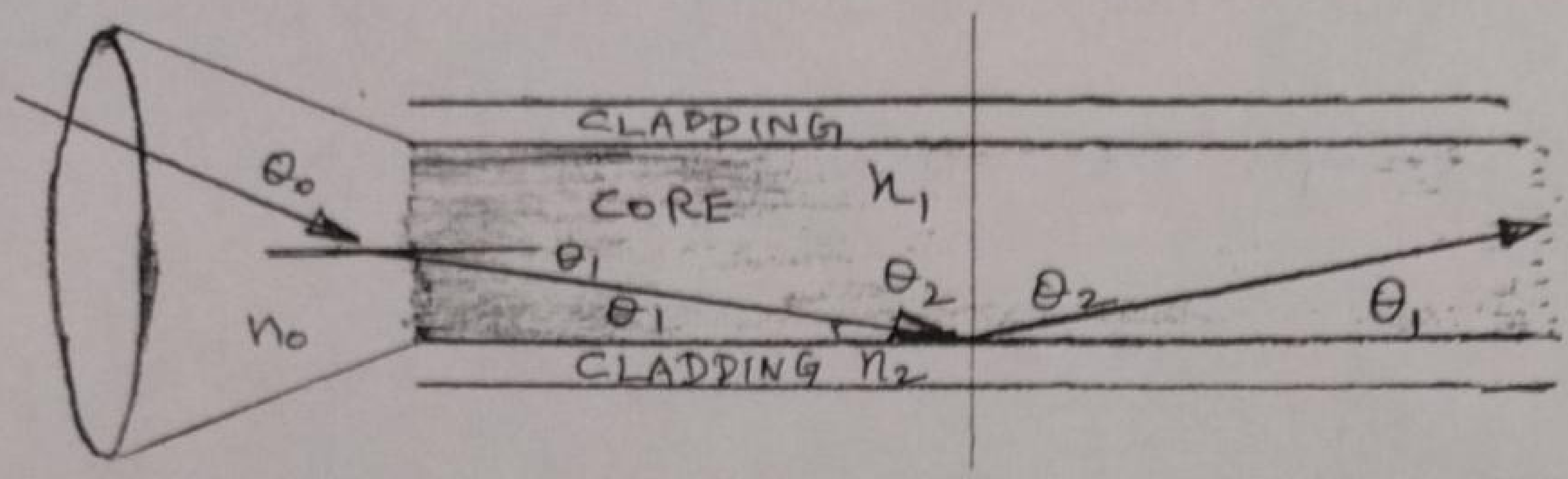
② When we consider rays entering the fiber from the outside (into the end face of fiber) we see that there is a further complication. The refractive index difference between the fiber core and the air will ~~be~~ cause any arriving ray to be refracted.

③ This means that there is max. angle for a ray arriving at the fiber end face at which the ray will propagate. Rays arriving at an angle less than this angle will propagate but rays arriving at greater angle will not.

(4) This angle is not a "critical angle" as that term is reserved for the case where light arrives from a material of higher RI to one of lower RI (In this case, the critical angle ~~is~~ is the angle within the fiber). Thus there is "cone of acceptance" at the end face of a fiber.

(5) Rays arriving within the cone will propagate and once arriving outside of it will not. The acceptance cone is function of difference of RI of core and cladding.

3. Numerical Aperture (NA):-



n_0 = RI of air (=1)
n_1 = RI of Core
n_2 = RI of cladding

NA is defined as the Sine of acceptance angle of the fiber.

ie $NA = \sin i_{max}$.

* one of the most often quoted characteristics of an optical fiber is its "Numerical Aperture". It is intended as a measure of the light capturing ability of the fiber. However it is used for many other purposes.

* For example it may be used as a measure of the amount of loss that we might expect on a bend of a particular radius etc. This ray will be refracted and later will encounter the core-cladding interface at an angle such that it will be reflected. This is because the angle θ_2 is greater than the critical angle. The angle is

greater because we are measuring angle from a normal to the core-cladding boundary not a tangent to it.

* This one will reach the core-cladding interface at an angle smaller than the critical angle, it will pass into the cladding. This ray will eventually be lost.

* If ray enters the fiber at angle within the core, then it will be captured and propagates as a bound mode.

* If a ray enters the fiber at an angle outside the core then it will leave the core and eventually leave the fiber itself.

* The NA is the sign of the largest angle contained within the ~~core~~ cone of acceptance.

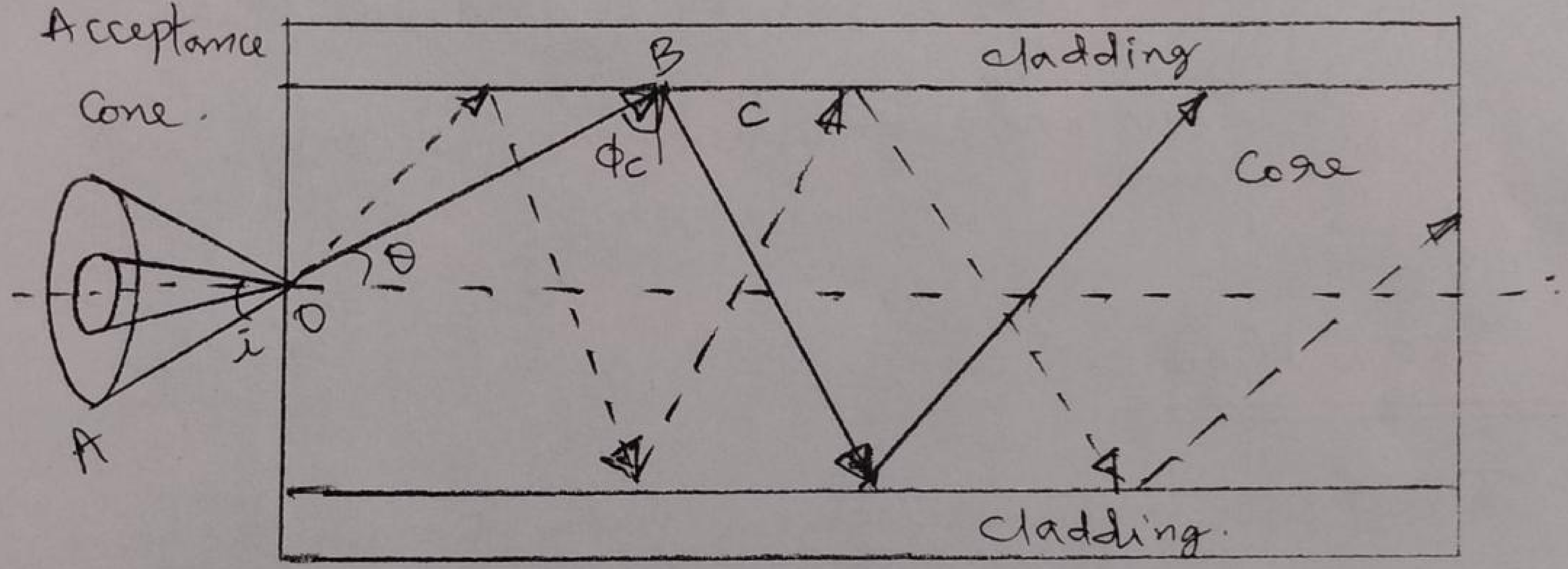
An expression for an Acceptance angle and NA :-

Let us consider an optical fiber, and

n_0 - Refractive Index (RI) of air

n_1 - RI of core

n_2 - RI of cladding.



* The ray 'AO' enter from air into core at an incident angle 'i' refract thro 'OB' at angle θ.

Finally, it is incident from core to cladding interface at an angle ϕ_c

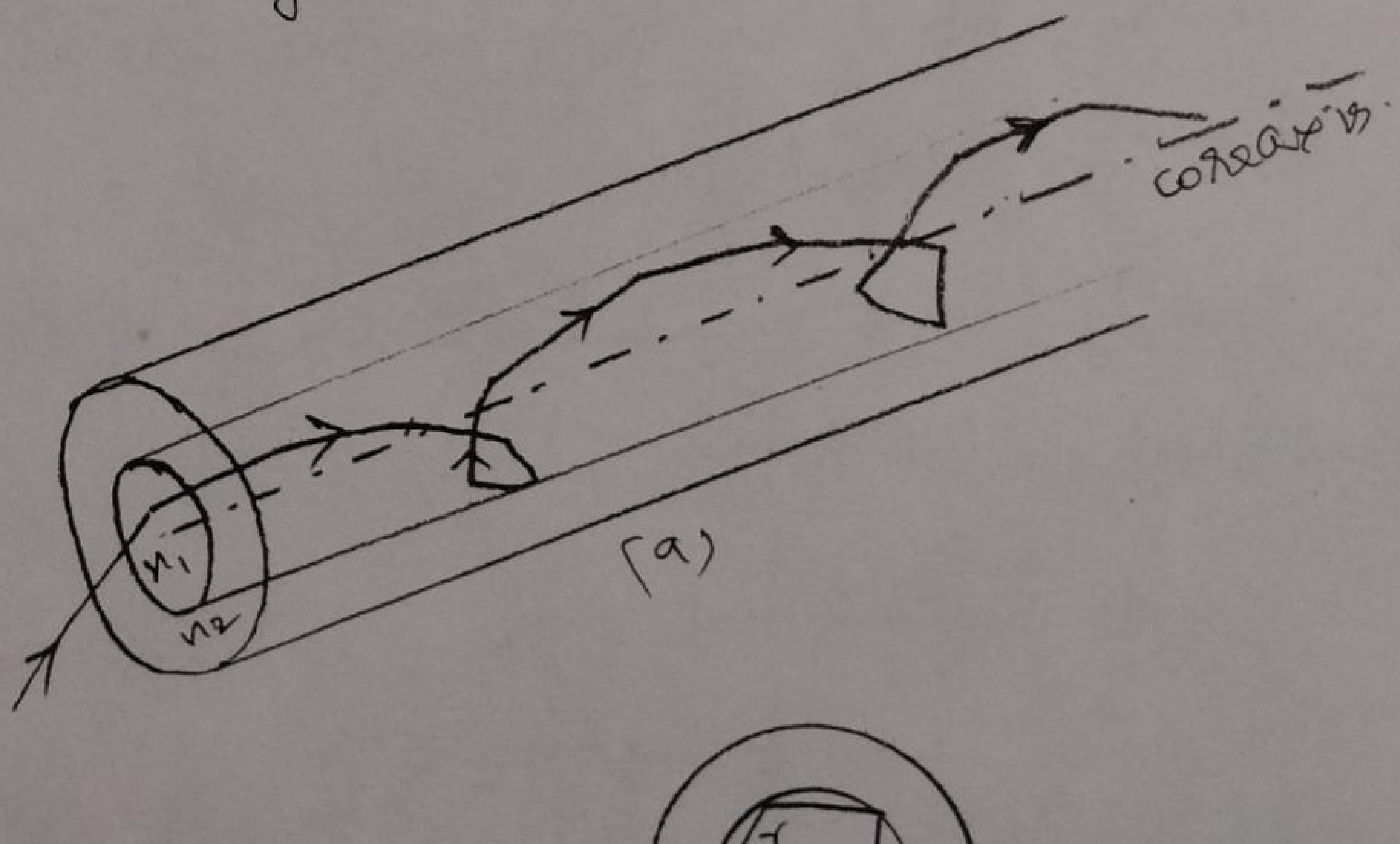
* At the incident angle is critical angle (ϕ_c), the ray just moves along interface BC.

Hence the angle of incidence ($\phi_c = 90 - \theta$) at the interface of core and cladding will be more than the critical angle. Hence the ray is totally internal reflected ray.

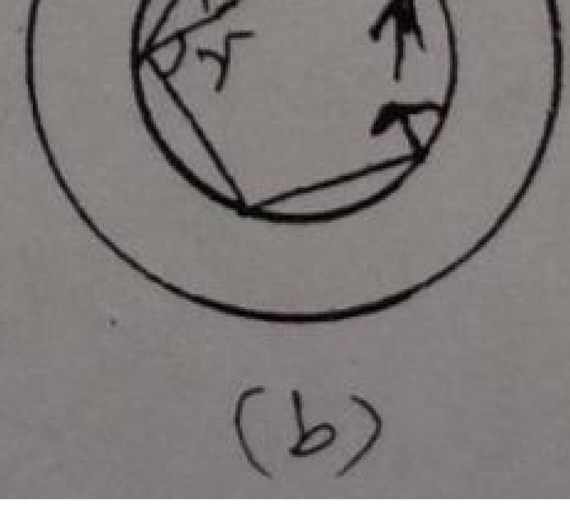
* Thus, only those ray which passes within the acceptance angle will be totally internally reflected. Therefore, the light incident on the core within this maximum external incident angle can be coupled into the fiber to propagate. This angle is called as an acceptance angle.

4. Skew Mode:-

The rays follow a helical path through the fiber is called skew ray.



(a)



(b)

Skew Rays:-

* Another category of ray exists which is transmitted without passing through the fiber axis. These rays, which greatly outnumber the meridional rays, follow a helical path through the fiber and are called Skew rays.

* The light travelling down the fiber is a group of Electromagnetic waves occupying a small band of frequencies within the electromagnetic spectrum, so it is a simplification to call it a ray of light. However, it is enormously helpful to do this, providing an easy concept, some framework to hang our ideas on.

* Magnetic fields are not really lines floating in space around a magnet, electrons are not really little black ball bearings flying round a red nucleus.

* Light therefore, is propagated as an electromagnetic wave along the fiber.

* The two components, the electric field and magnetic field forms patterns across the fiber. These patterns are

called modes of transmission. Modes means methods-hence methods of transmission.

Different types of fibers and their properties:-

Types of Fibers

- Based on material composition
  1. Glass Fiber
  2. Plastic Fiber
- Based on no. of Modes
  1. Single Mode Fiber
  2. Multi mode Fiber.
- Based on RI profile
  1. Step Index fiber
  2. Graded Index fiber

GLASS FIBER

If the fibers are made up of mixture of metal oxides and silica glasses are called Glass Fiber.

example:-
1. Core: SiO_2 & Cladding: $P_2O_3-SiO_2$.
2. Core: GeO_2-SiO_2 & Cladding: SiO_2.

Plastic Fibers:-

If the fibers are made up of plastics which can be handled without any care due to its toughness and durability, it is called plastic fiber.

Example:-

1. Core: Polymethyl methacrylate.

   Cladding: Co-Polymer

2. Core: Polystyrene

   cladding: Methyl methacrylate.

Single mode Fiber:

* It has very small core diameter so that it can allow only one mode of propagation and hence called single mode fibers.
* The cladding diameter must be very large compared to the core diameter.
* Thus, the optical loss is verymuch reduced.

Core diameter - 5 – 10 μm.

cladding diameter - Around 125 μm.

Multimode Fibers:

These are excited with Light Emitting Diode (LED) so here the optical dispersion may occur. They are made by multicomponent glass materials. The core diameter is larger than the diameter of the Single mode fibers, so that it can allow many modes to propagate through it and hence called as multimode fibers.

Core diameter - 50 to 350 μm.

cladding diameter - 125 to 500 μm.

Step Index Fiber:

The refractive indices of air, cladding and Core vary step by step and hence it is called Step index Fiber.

The Step Index Fibers are of two types.

(1) Step Index Single mode fiber
— there is dispersion will occur.

(2) Step Index Multimode Fiber.
— there is intermodal dispersion will occur.

Graded Index Fiber:

* Here the refractive Index of the core varied radially from the axis of the fiber. The refractive Index of the core is large along the fiber axis and its gradually decreases thus it is called as graded index fiber.

* Here the refractive Index becomes small at the core-cladding interface. It has very less intermodal dispersion compared to multimode step index fiber.

FIBER OPTIC CHARACTERISTICS:

(1) Mechanical charateristics
(2) Transmission charateristics.

Mechanical charateristics	Transmission charateristics
1. Strength	1. Attenuation.
2. Static Fatigue	2. Absorption losses. (i) Intrinsic absorption (ii) Extrinsic absorption.
3. Dynamic Fatigue.	3. Scattering losses. (i) Linear Scattering losses (ii) Non-Linear Scattering losses.

(i) Linear Scattering losses

(a) Rayleigh Scattering.

(b) Mie Scattering.

(ii) Non-Linear Scattering.

(a) Stimulated Brillouin Scattering

(b) Stimulated Raman Scattering.

Mechanical characteristics:-

(1) Strength:-

The cohesive bond strength of the constituent atoms of a glass fiber governs its theoritical intrinsic strength.

Max. tensile strength of 14 GPa is observed in short length glass fibers. This is closed to the 20 GPa is tensile strength of steel wire. The difference between glass and metal is that, under an applied stress, glass will extend elastically up to its breaking strength whereas metal can be stretched plastically well beyond their elastic range.

Example: Copper wires can be elongated plastically.

2. Static Fatigue :-

It refers to the slow growth of the existing flaws in the glass fiber under humid conditions and tensile stress This gradual flaw growth causes the fiber to fail at a lower stress level thath that which could be reached under a strength test. The flaw shown propagates through the fiber because of chemical erosion of the fiber material at the flaw tip.

3. Dynamic Fatigue :-

when an optical cable is being installed on a duct, it experiences repeated stress owing to surging effects The surging is caused by varying degrees of friction between the optical cable and the duct or guiding tool on a curved route. Theoritical and experimental investigation have shown that the time to fail under these conditions is related to the maximum allowable stress by the same life time parameter that are in the cases of static stress that increases at a constant rate.

TRANSMISSION CHARACTERISTICS:

1. Attenuation:-

Attenuation in Fiber optics, also known as transmission loss, is the reduction in intensity of the light beam with respect to distance travelled through a transmission medium.

2. Absorption Losses:-

Imperfections in the atomic structure of the fiber material properties. An absorption is also induced by diffusion of hydrogen molecules into the glass fiber.

(i) Intrinsic Absorption:-

Intrinsic absorption is caused by basic fiber material properties.

(ii) Extrinsic Absorption:-

Extrinsic absorption is caused by impurities introduced into the fiber material.

3. Scattering Losses:-

Basically scattering losses are caused by the interaction of light with density fluctuations within a fiber. Density changes are produced when optical fibers are manufactured. Light travelling through the fiber interacts with the density areas in light is then partially scattered in all direction.

(i) Linear Scattering losses:-

(a) Rayleigh Scattering:-

It occurs because the molecules of Silicon dioxide have some freedom when adjacent to one another. Thus, set up at irregular positions and distances with respect to one another when the glass is rapidly cooled during the final stage of the fabrication process. Those structural ariations are seen by the light as variations in the refractive index, thus causing the light to reflect – that is to scatter – in different directions.

Raleigh scattering is a scattering of light by particles much smaller than the wavelength of the light, which may be individual atoms are molecules.

(b) Mie Scattering:-

Non perfect cylindrical Structure of the fiber and imperfections like irregularities of light by particles in the core-cladding interface, diameter fluctuations, Strain and bubbles may create linear Scattering which is termed as Mie Scattering.

Mie Scattering is a scattering of light by particles approximately equal to the wavelength of the light, which may be individual atoms or molecules.

(ii) Non-Linear Scattering:

Non Linear Scattering losses Specially at high optical power levels scattering causes disproportionate attenuation, due to Non-Linear behavior.

(a) Stimulated Brillouin Scattering.

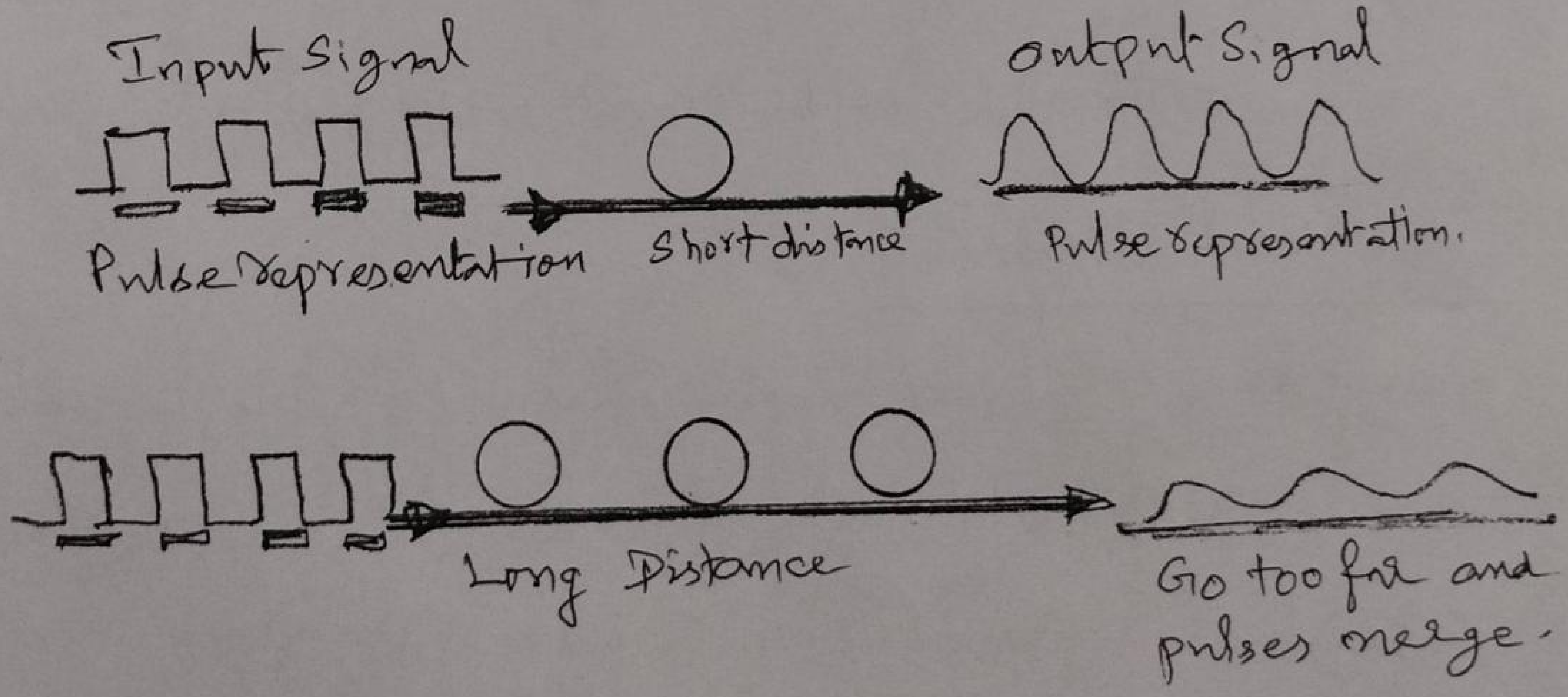
This is defined as the modulation of the light through thermal molecular vibration within the fiber. The Scattered light contains upper and lower Side bands alongwith incident light frequency. An incident photon produces a Scattered Photon as well as Photon of acoustic frequency. The threshold optical power for Brillion Scattering is proportional to $d^2 \lambda^2 \alpha_B$.

(b) Stimulated Raman Scattering:-

Here, the Scattered light consists of a Scattered Photon and a high frequency optical photon. Further, this occurs both in the forward and backward direction in the optical fiber. The threshold optical power for Raman Scattering is proportional to $d^2 \lambda^2 \alpha_R$

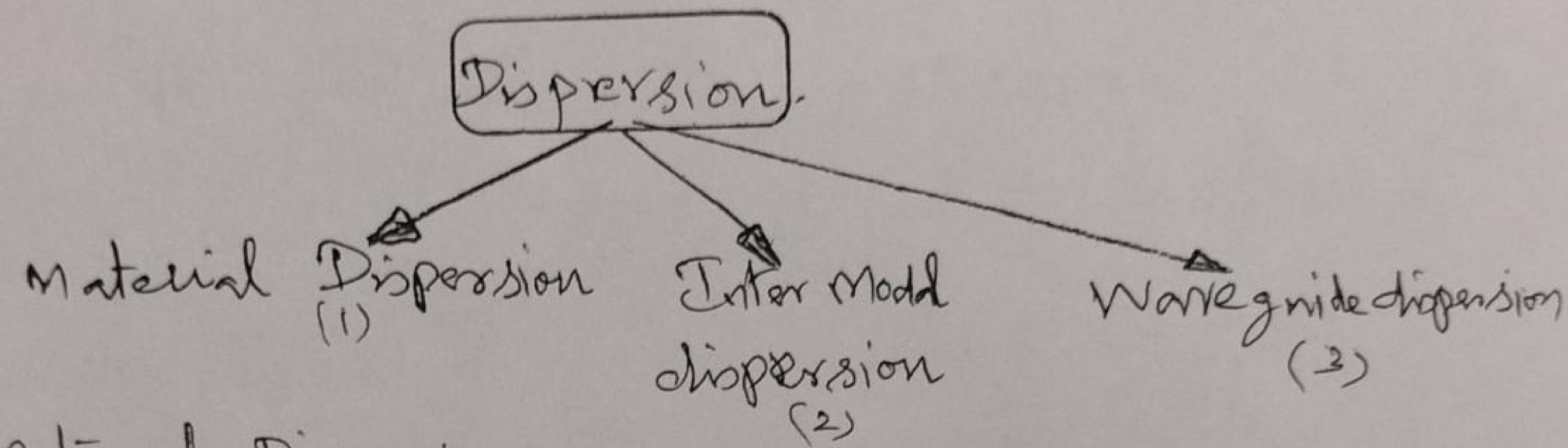
The threshold optical power for Raman Scattering is about three orders of magnitude higher than the Brillion threshold for the given fiber.

DISPERSION:-



Effect of Dispersion.

Dispersion occurs when a pulse of light is spread out during transmission on the fiber. A short pulse becomes longer and ultimately joins with the pulse behind, making recovery of a reliable bit stream impossible.



Material Dispersion:

Both Lasers and LEDs produce a range of wavelengths rather than a single narrow wavelength. The fibre has different refractive index characteristics at different wavelengths arrive before others and signal pulses disperse.

Intermodal dispersion:

When using multimode fiber, the light is able to ~~make~~ take many different paths or modes as it travels in the fiber. Therefore, some components of the pulse will arrive before others. The difference between the arrival times of light taking the fastest mode versus the slowest obviously gets greater as the distance gets greater.

Scanned by TapScanner

Waveguide dispersion:

Waveguide dispersion is a very complex effect and is caused by the shape and index profile of the fiber core. However, this can be controlled by careful design and, in fact, waveguide dispersion can be used to counteract material dispersion.

Splicers and its types:

- Splicers (for permanent connections)
  - (A) Mechanical splices
    - [1] Elastomeric splice.
    - [2] Four rod splices.
  - (B) Fusion splicers.
- Connectors (for temporary connections)
  - (a) Butt joint connectors.
  - (b) Extended Beam connectors.

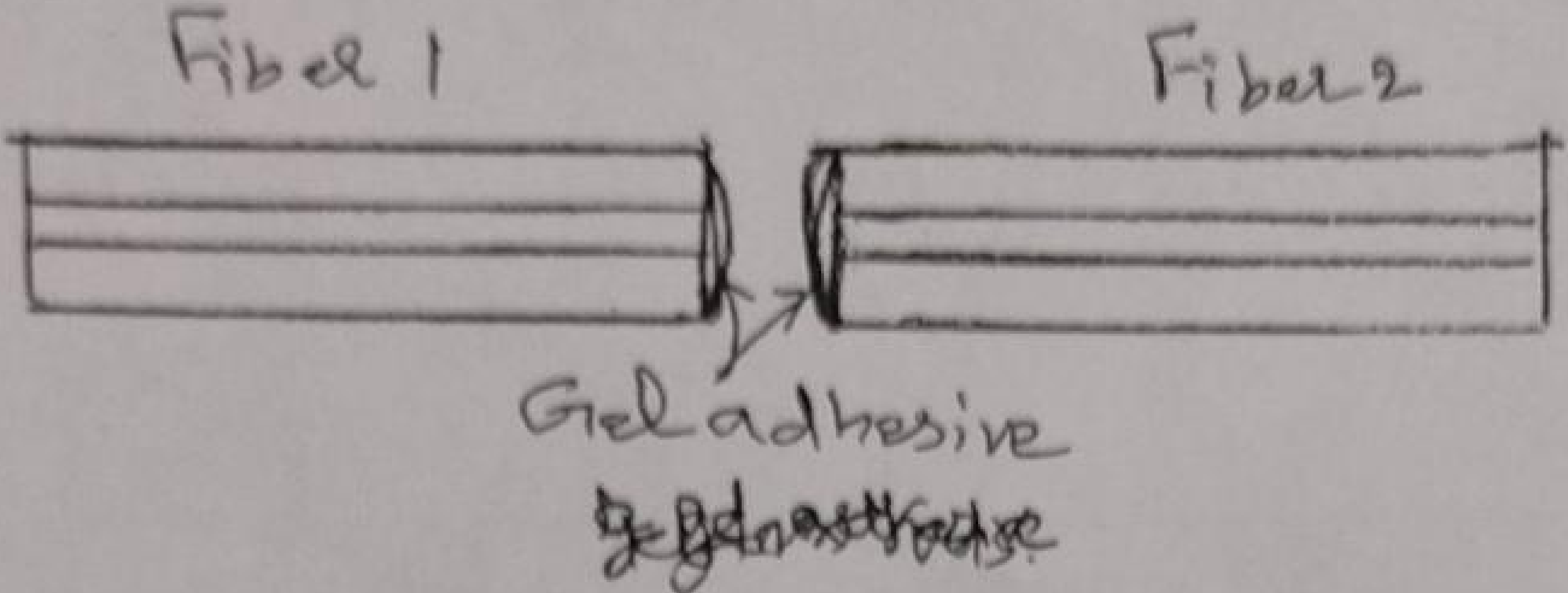
Connectors and its types

SPLICERS.

For longer distance communication, we have to connect one fiber with other fiber and meanwhile the losses must be minimized. The process of connecting the two fibers for permanent requirement is called splicing.

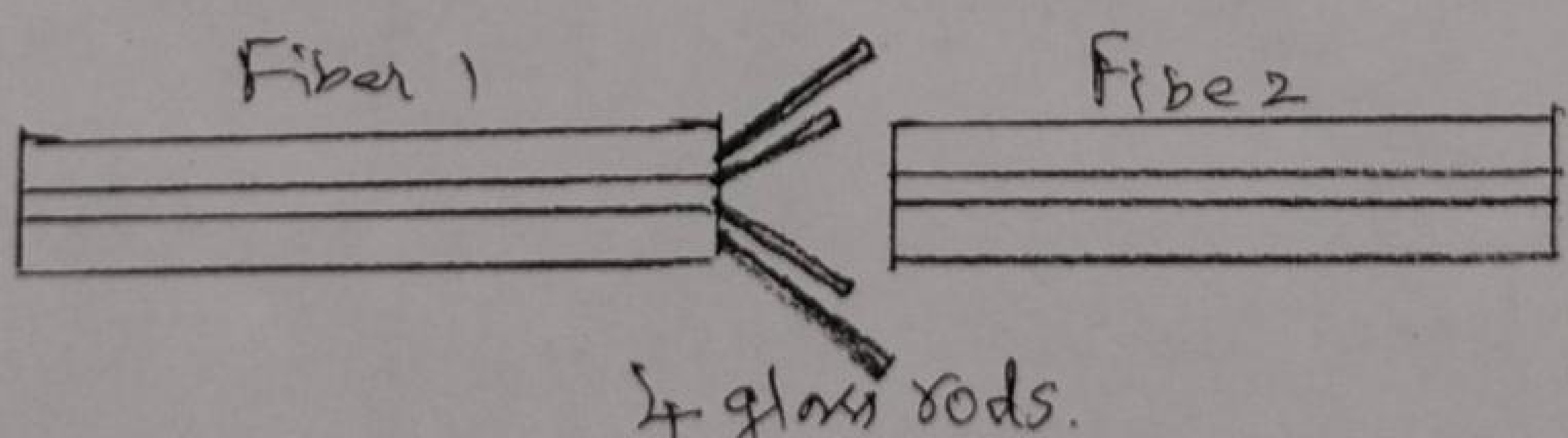
A. Mechanical Splices

(1) Elastomeric splice.



It is made by an elastomer material. It consists of a hole, so that we have to insert the two fibers from two ends for rigid hold. The elaster is covered by a glass sleeve with ends in such a way that it aligns the fibers into the elastomeric splice. The gel has the same RI is used as an adhesive. Thus the fibers are connected.

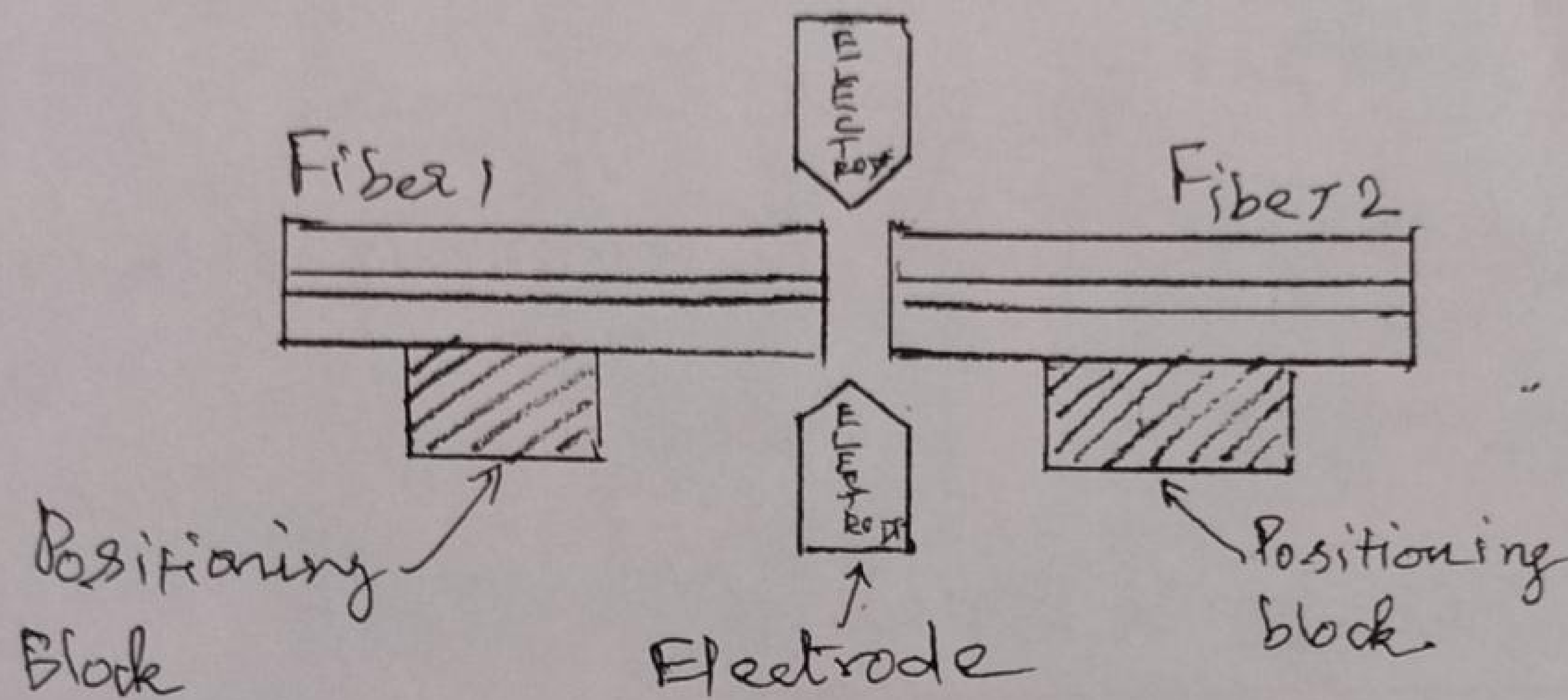
(2) Four rod Splices:-



① The four glass rods are attached with one end of the fiber to hold another fiber firmly.

② Initially the rods curve slightly outward, so that the fiber can be easily inserted into it. By a suitable mechanical pressure, the rods are made to be tightly clamping the two fibers. Here also gel is used for adhesion.

B. Fusion Splices:



① Here two ends of the fiber is fused together with the help of a special equipment, using a high voltage electric arc.

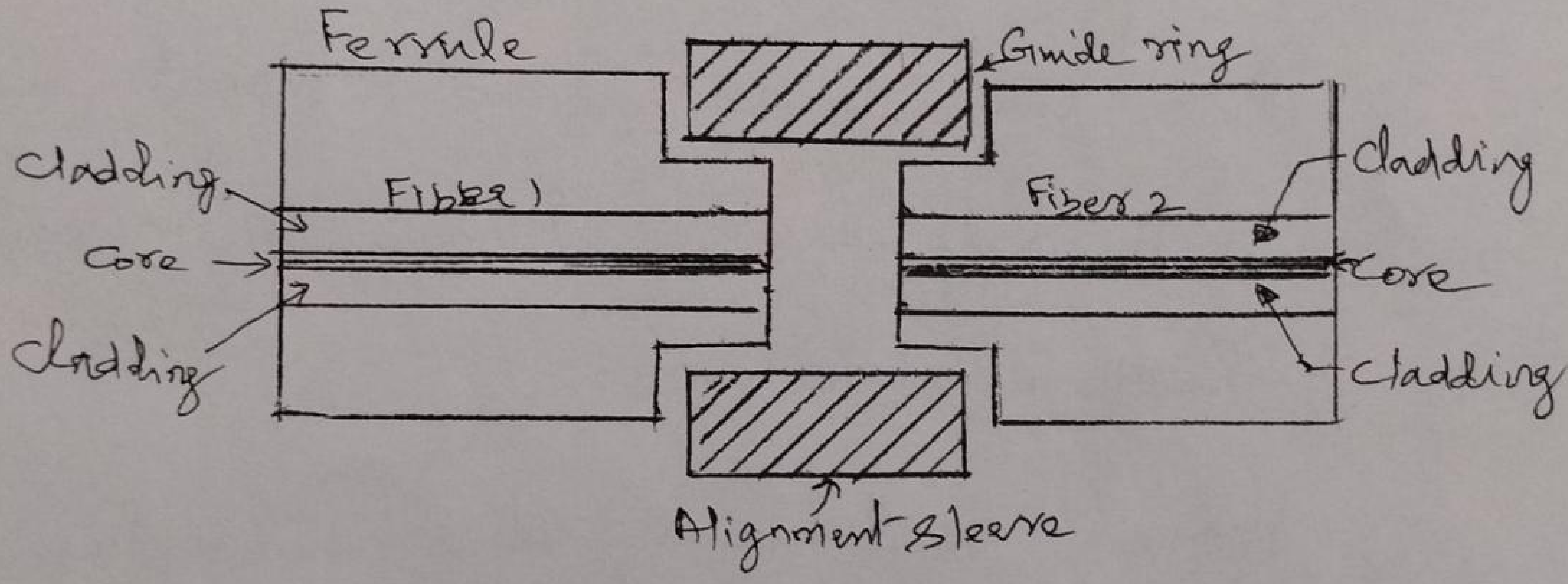
② Hence, these splices are called fusion splices. Here the losses are minimized due to self-alignment system. So it provides better performance.

③ Fusion splicess with stand extreme high temperature changes. It also prevents dust and other contaminants from entering the optical parts.

CONNECTORS AND FIBER TERMINATION:

For longer distance Communication, we have to connect one fiber with other fiber & to minimize the losses, connecting the two fibers for temporary requirement is called Connectors.

(a) Butt-joint Connectors.

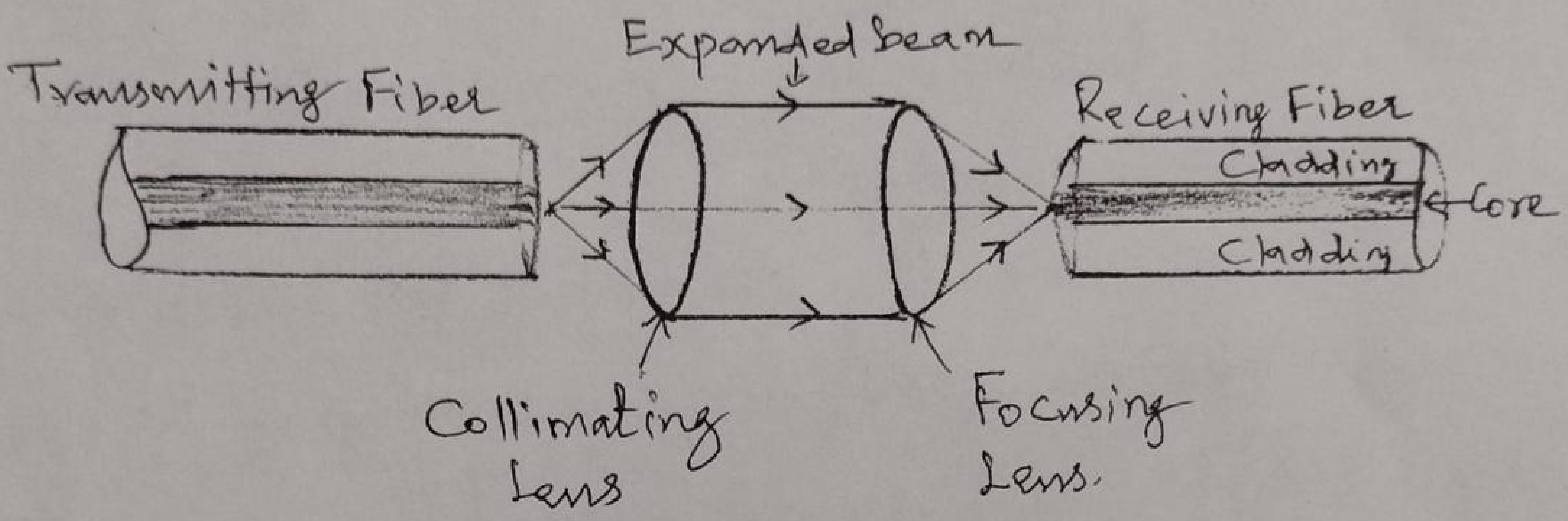


1. It is made up of a special type of material called ferrule, composing of metal / glass / plastic materials.

2. The fiber is send into the drilled hole of the ferrules and is aligned properly with the help of the alignment sleeve which is used to minimize the distance between two fiber ends.

③ once the matching was done, the light from one fiber canbe easily coupled to the other fiber with minimum losses.

(b) Expanded Beam Connectors:



① It consists of collimating lens at the end of transmitting fiber and focusing lens at entrance of the receiving fiber.

② Light coming out from the transmitting fiber is made to fall over the Collimating lens. The collimating lens makes the beam parallel and is focussed into the focusing lens

③ After passing through the focusing lens, the light is coupled into the receiving fiber without any loss. Thus the loss is minimized.

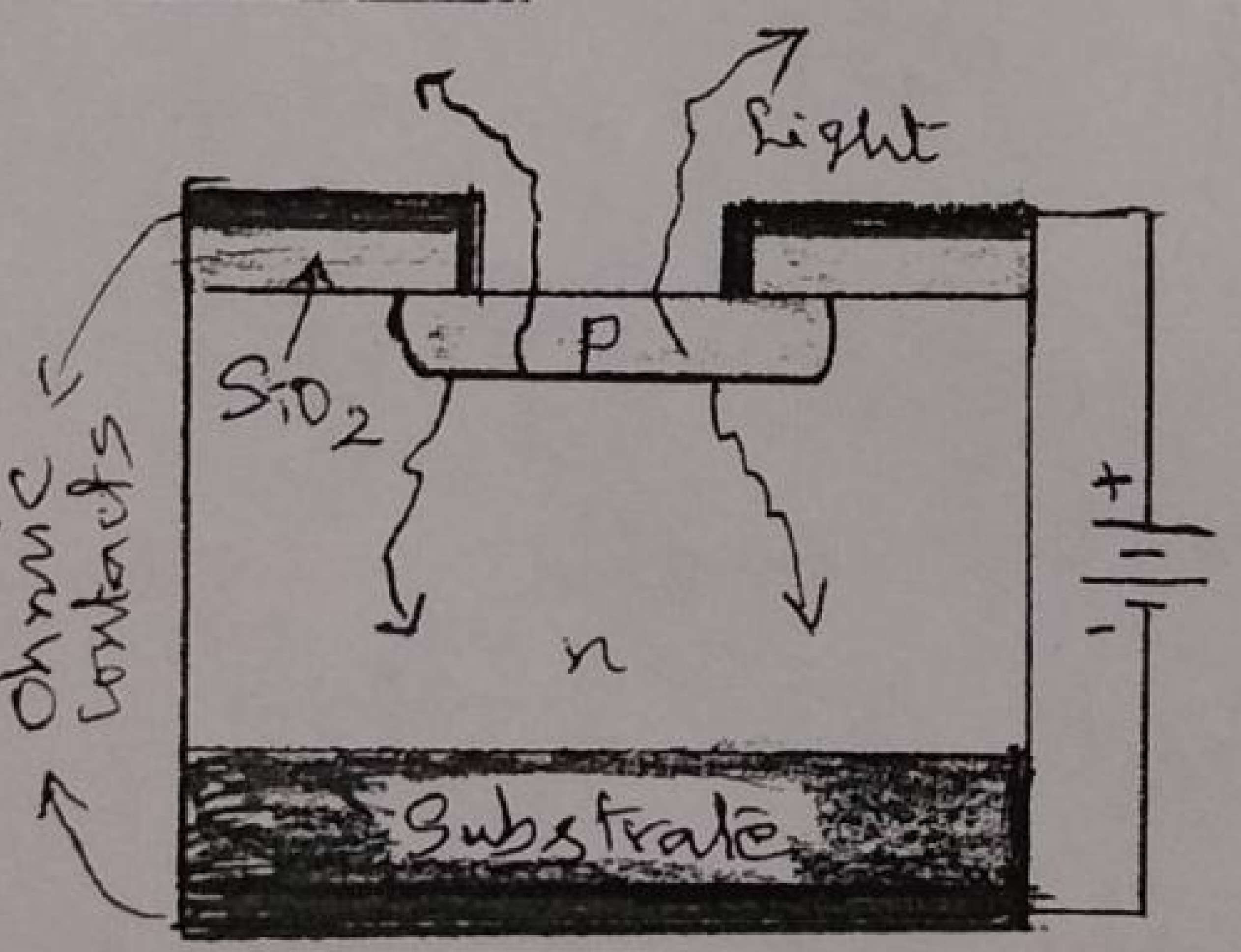
LIGHT EMITTING DIODE: (LED): - (Optical Sensors:)

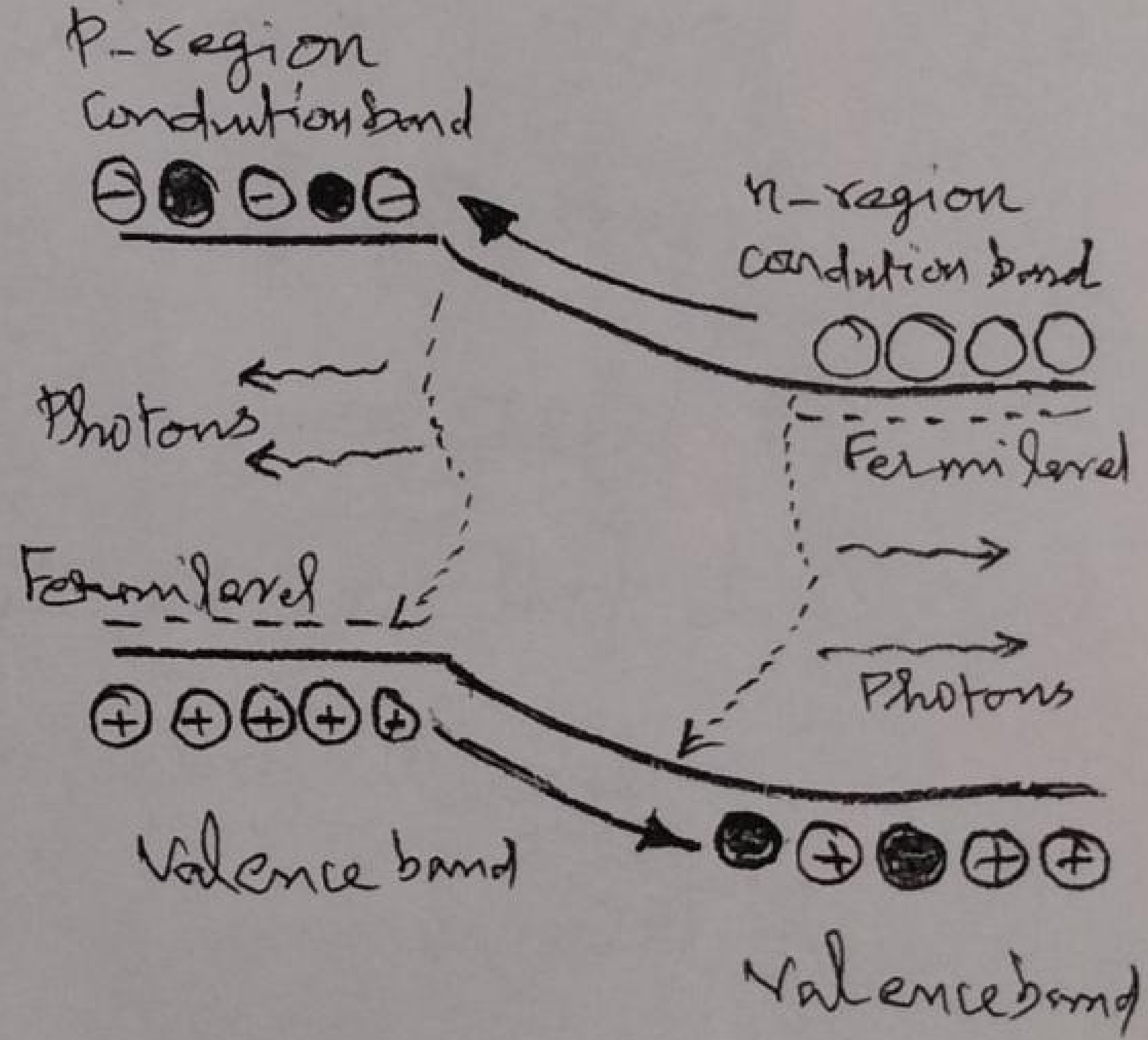
① It is a device used to convert the electrical energy into light energy.

② when it is forward biased, the majority charge carriers of electrons from n-type and holes from p-type are diffuse into each other.

③ At the junction, the electron hole recombination process takes place and energy is emitting in the form of visible light and IR region.

Construction:-





(i) The LED is made by Gallium Arsenide semi Conductors. First PN junction is formed by epitaxial growth technique.

For, n-type - Si + Ga

for P-type - Si + As.

(ii) The thickness of the n-layer is always larger than the p-layer, because of increasing the radiative recombination.

(iii) In forward bias, ie proper electric connection given to the semiconductor through aluminium contact. P-jn is slightly open for out coming light rays.

WORKING PRINCIPLE:-

(1) When the p-n junction is forward biased, the barrier width is reduced, raising the potential energy on the n-side and lowering that on the p-side

(2) The free electrons and holes have sufficient energy to move into the junction region. If a free electron meets a hole, it recombines and release a photon.

(3) Thus, light radiation from the LED is caused by the recombination of holes and electrons that are injected into the junction by a forward bias voltage.

Advantages:-

Very small in size, Less cost and long life time.
It needs less voltage for operate.

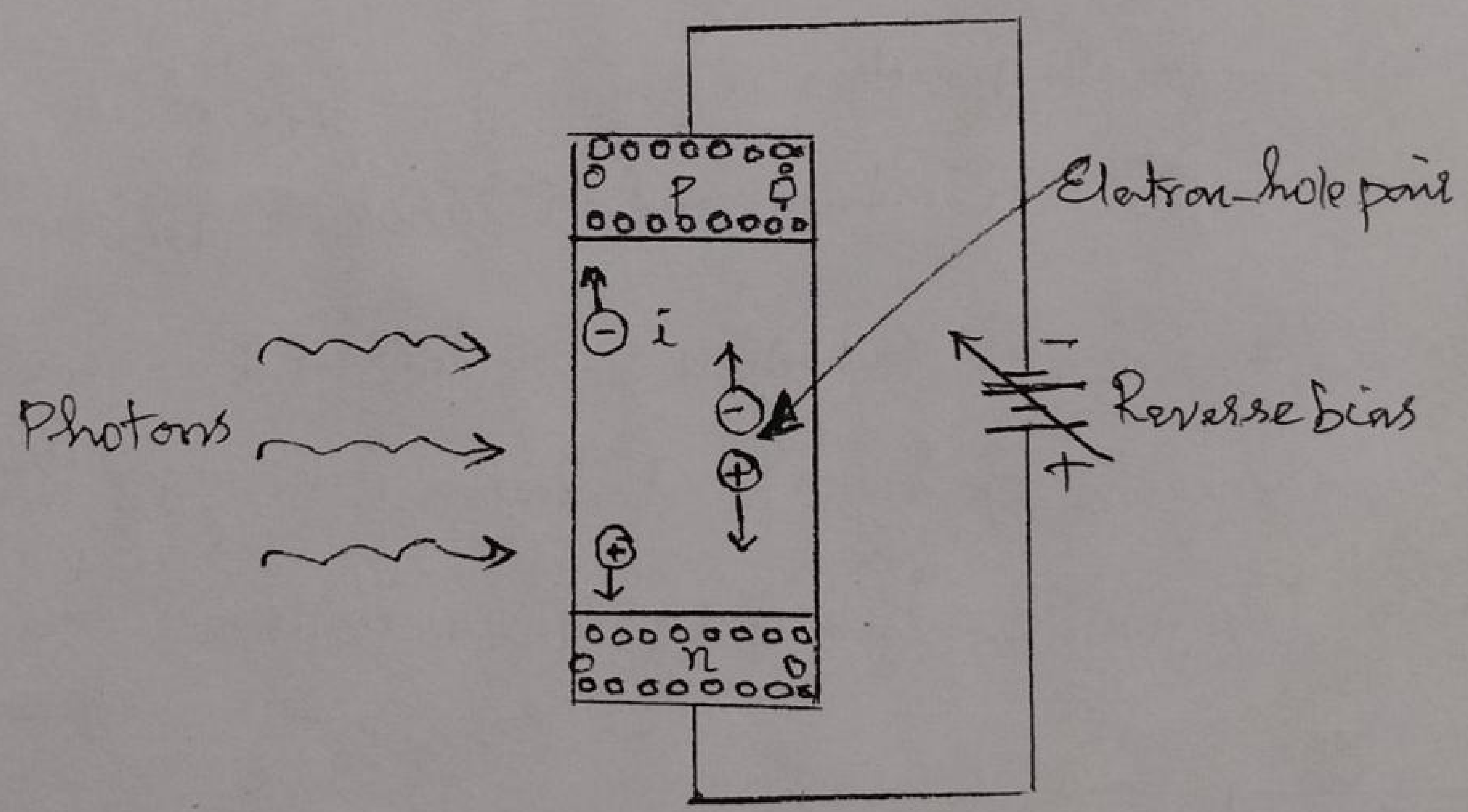
Dis-advantages:-

It requires high power, Its preparation cost is high

PIN DIODE - (Optical Detectors).

* This is a device used to convert the light energy into electrical energy.
* Under the reverse bias condition, if the light rays is incident over the intrinsic region, then it will produce the electron hole pair.
* The accelerated electron-hole pair charges carrier produce the photo-current.

Construction:-



(i) It consists of P, n and intrinsic region with proper biasing.
(ii) The P and n-region are heavily doped.
(iii) The intrinsic layer (i) is slightly larger than the P-type and n-type for receive the light photons.

Working Principle:

(1) The PIN diode is heavily reverse biased when a photon of higher energy is incident over the larger width intrinsic semiconductor layer, then the electron hole pairs are created.

(2) The mobile charges are accelarated by the applied voltage, which gives rise to photo current in the external circuit.

(3) PD is a linear device because the photo current is directly proportional to the incident optical power on the PIN photodiode.

Advantages:-

Low noise, Low bias voltage, High speed response, Low junction capacitance, Large depletion region.

Dis-advantages:-

Less sensitivity, No internal gain, Slow response time, High reverse recovery time due to power loss are significant.

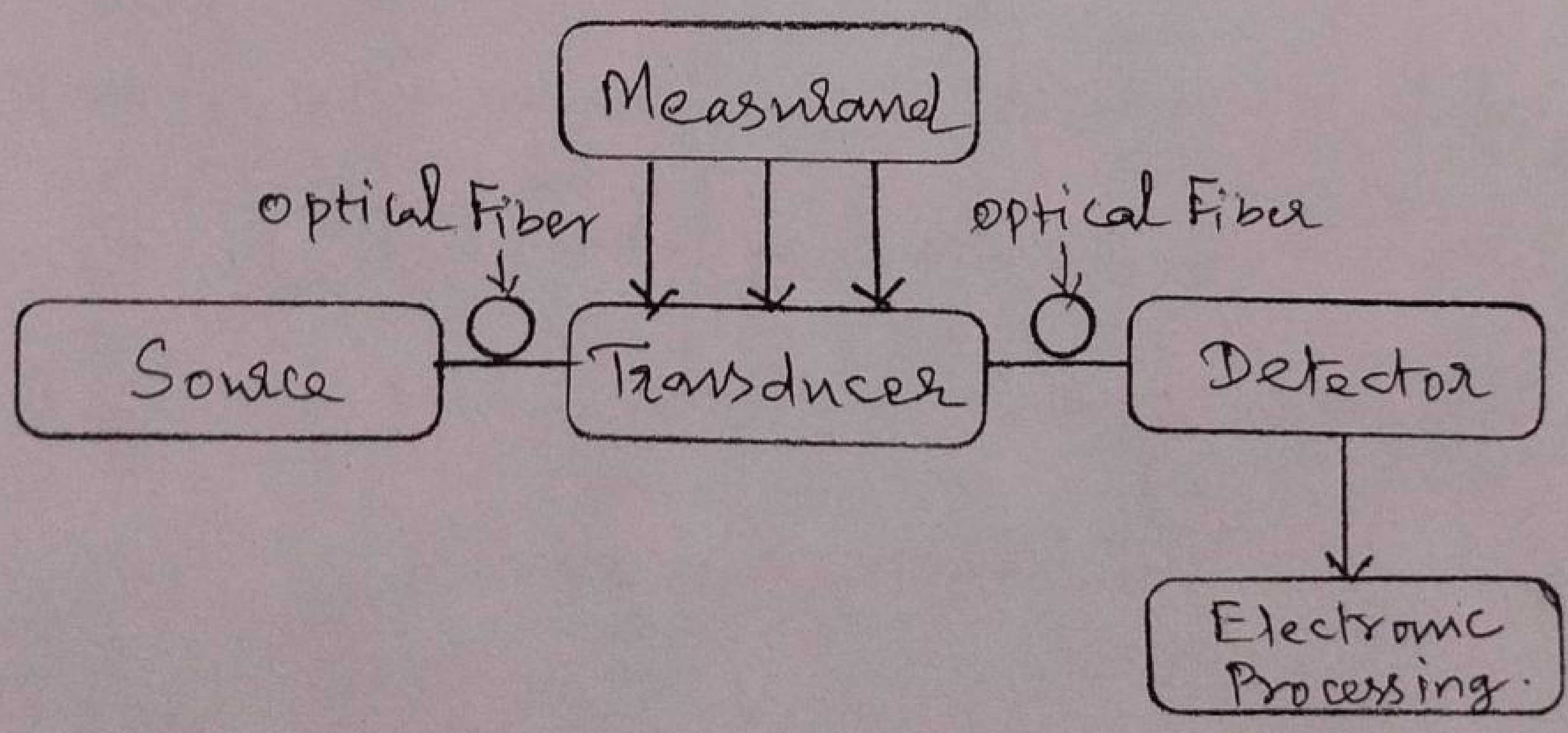
UNIT-II INDUSTRIAL APPLICATION OF OPTICAL FIBERS

Fiber optic Sensors:-

A Sensor that measures a physical quantity based on its modulation on the intensity, Spectrum, Phase or Polarisation of light travelling through an optical fiber.

An optical sensor is a device that converts light rays into electronic signals.

Similar to a photo resistor, it measures the physical quantity of light and translate it into a form read by the instrument. optical Sensors have a variety of uses. They can be found in everything from Computer to motion detectors.



Basic Components of an optical Fiber Sensor System.

* The general structure of an optical fiber sensor system is shown in figure. It consists of an optical source (Laser, LED, Laser diode etc), optical fiber, sensing or modulator element (which transduces the measurand to an optical signal), an optical detector and processing electronics (oscillo-scope, optical spectrum analyzer etc.).

* Fiber optics sensors can be classified under 3 categories. The sensing location, operating principle, and the application. Based on the sensing location, a fiberoptic sensors can be classified as Extrinsic or Intrinsic.

* In an Extrinsic fiber optic sensor the fiber is simply used to carry light to and from an external optical device where the sensing takes place. In this cases, the fiber just acts as a means of getting the light to the sensing location.

A fiber optic sensors can be classified as

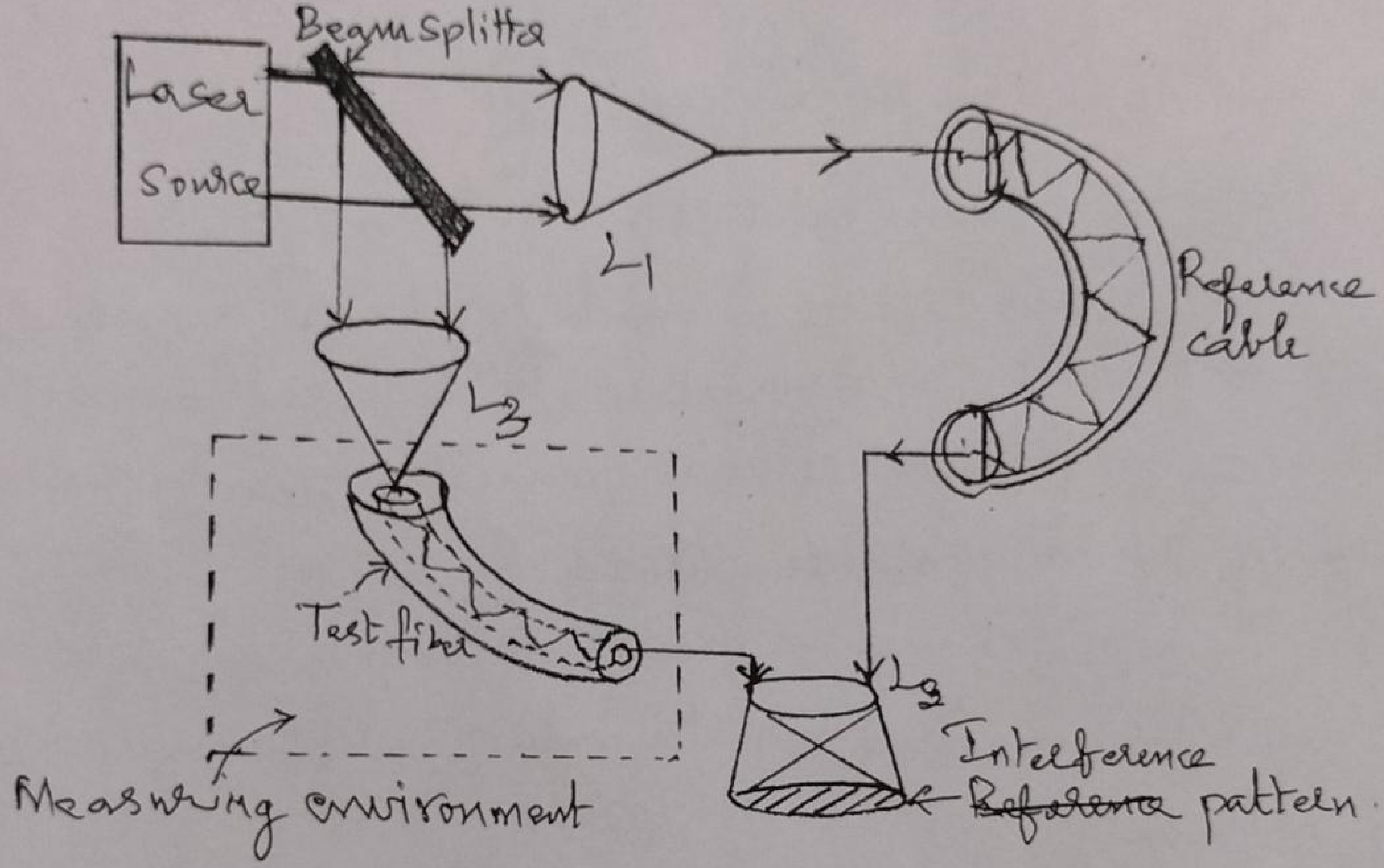
(1) Intrinsic Sensor.

(2) Extrinsic Sensor.

INTRINSIC SENSOR

It is based on the principle of interference between the beams emerging out from the reference fiber and the fiber kept in the measuring environment.

Construction:



1. A monochromatic source of light is emitted from the laser. (Ref. above fig.).
2. It consists of a Laser source to emit light. A beam splitter, made of glass plate is inclined at an angle 45° used to split the single beam into two beams.
3. The main beam passes through the lens L_1 and is focused on to the reference fiber which is isolated

from the environment to be sensed. The beam after passing through the reference fiber then falls on the lens L_2. The splitted beam passes through the lens L_3 and is focussed onto the test fiber kept in the environment to be sensed.

(4) The splitted beam after passing through the test fiber is made to fall on the lens L_2.

(5) The two beams after passing through the fibers, produces a path difference due to the change in parameters such as pressure, temperature etc. in the environment. Therefore a path difference is produced between the two beams causing the interference pattern.

(6) Thus the change in pressure or temperature can be accurately measured with the help of interference pattern obtained.

(7) And other quantities by modifying a fiber so that the quantity to be measured modulates the intensity, Phase, polarization, wavelength or transit time of light are the simplest, since only a simple source and detector are required.

(8) A particularly useful feature of intrinsic fiber optic sensors is that they can, if required, provide distributed sensing over very large distances.

EXTRINSIC SENSORS.

① Extrinsic Fiber optic Sensors use an optical fiber cable, normally a multimode one, to transmit modulated light from either a non-fiber optic sensor, or an electronic sensor connected to an optical transmitter.

② The major benefit of extrinsic sensors is their ability to reach places which are otherwise inaccessible.

③ An example is the measurement of temperature inside aircraft engines by using a fiber to transmit radiation into a radiation pyrometer located outside the engine.

④ These sensors can also be used in the same way to measure the internal temperature of electrical transformers, where the extreme electromagnetic fields present make other measurement technique impossible.

⑤ These sensors provide excellent protection of measurement signal against noise corruption. Unfortunately, many conventional sensors produce electrical output which must be converted into an optical signal for use with fiber.

⑥ Extrinsic sensors are used to measure vibration, rotation, displacement, velocity, acceleration, torque and twisting.

Application:

① optical fiber sensors for temperature and pressure have been developed for down hole measurement in oil wells. The fiber optic sensor is well suited for this environment as it functions at temperatures too high for semiconductor sensors (distributed temperature sensing).

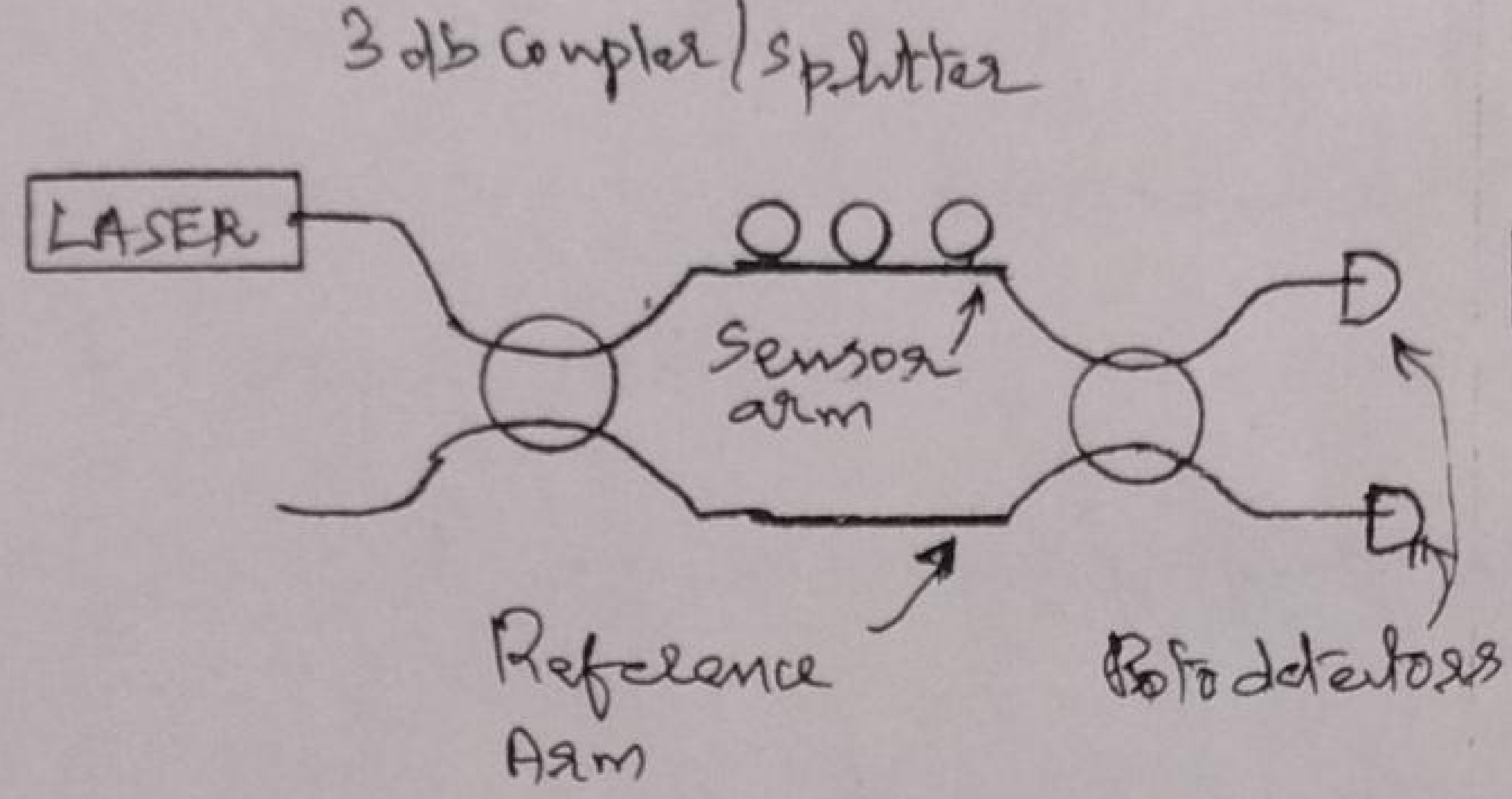
② optical fibers can be made into interferometric sensors such as fiber optic gyroscopes, which are used in the Boeing 767 and in some car models (for navigation purposes).

③ They are also used to make hydrogen sensors.

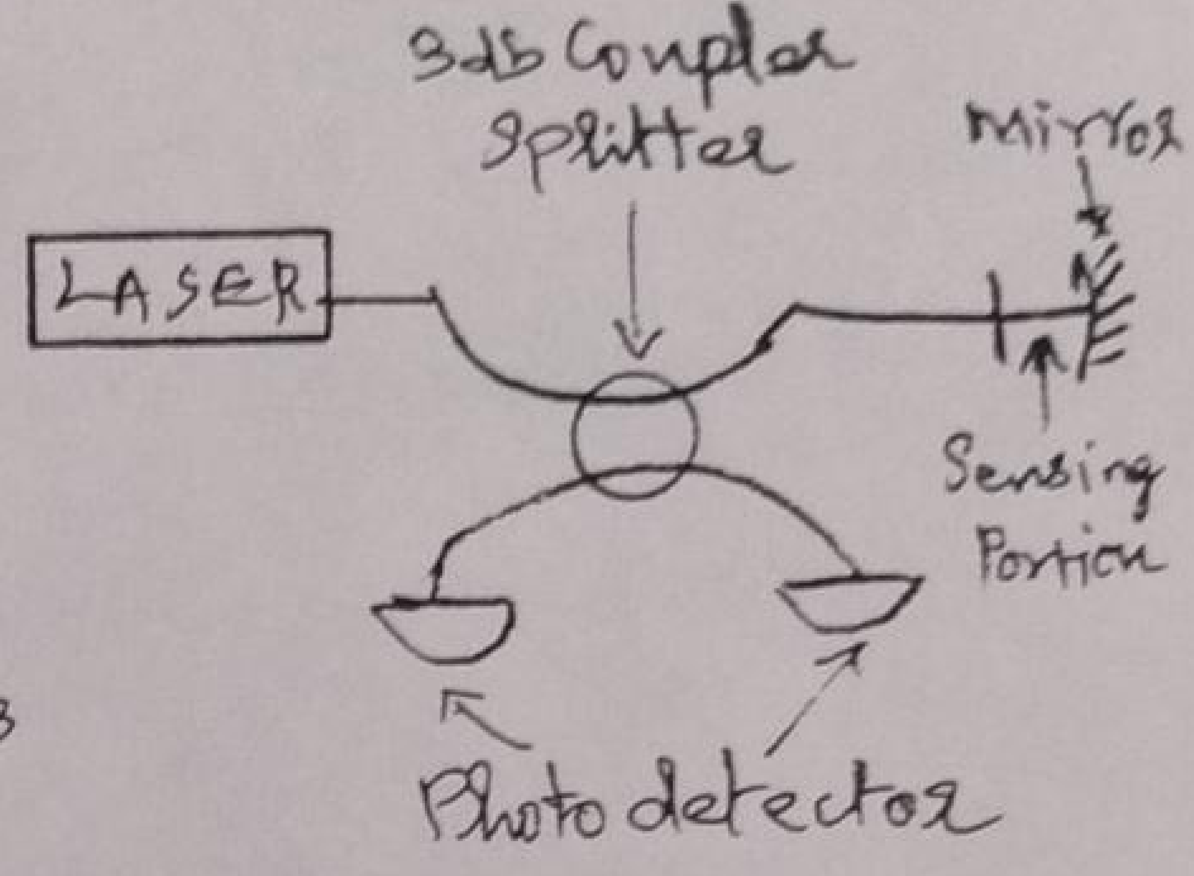
④ Electrical power can be measured in a fiber by using a structured bulk fiber ampere sensor coupled with proper signal processing in a polar metric detection scheme.

⑤ Fiber optic sensors are used in electrical switch gear to a digital protective relay to enable fast tripping of a breaker to reduce the energy in the arc blast.

Phase modulated Fiber optic Sensors;



(a)



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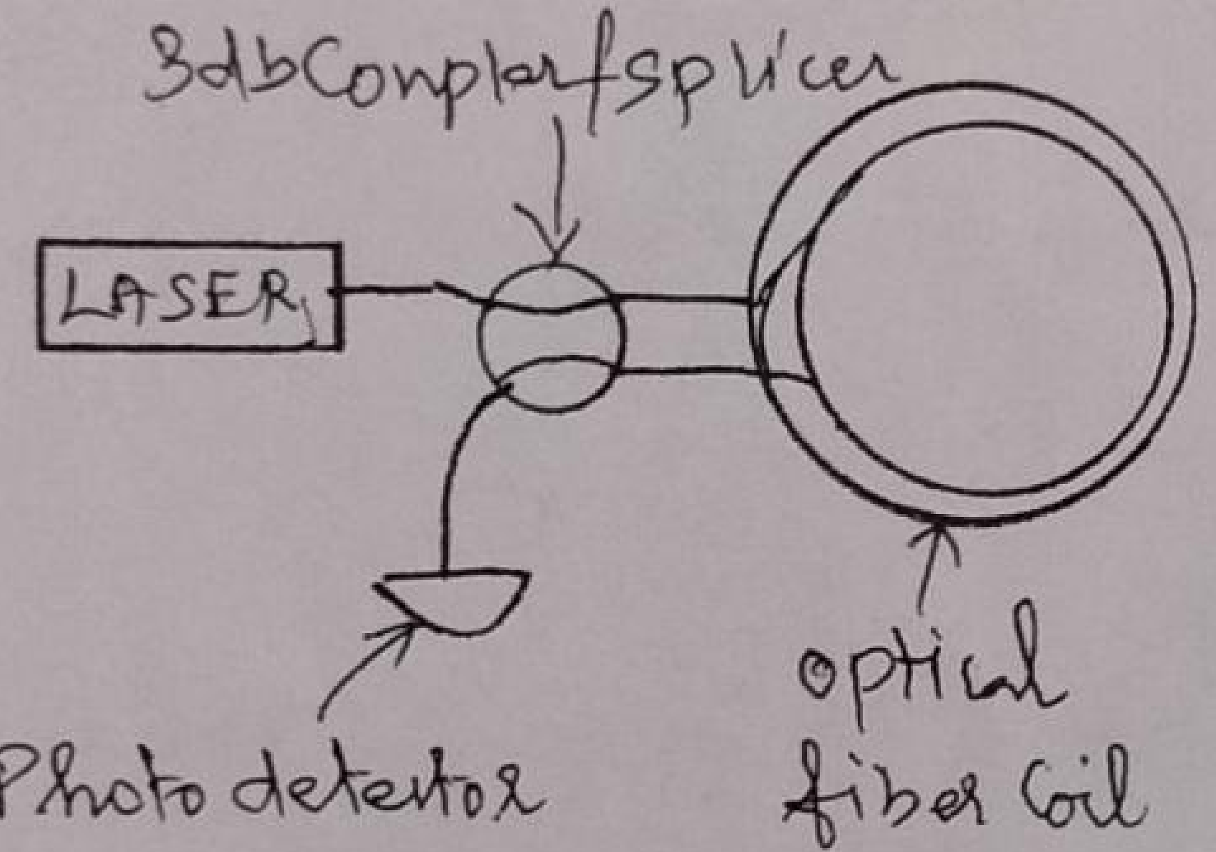

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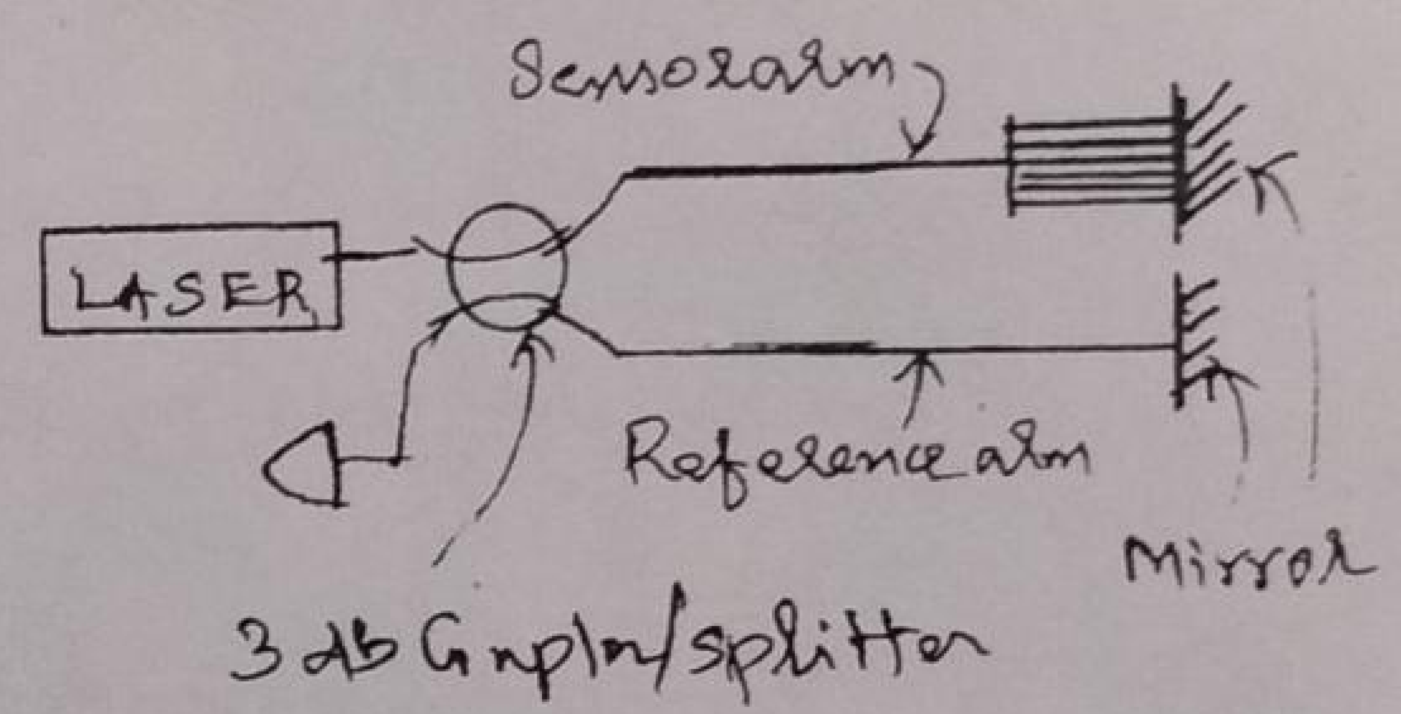


(d)

① The most sensitive fiber optic sensing method is based on the optical phase modulation. The total phase of the light along an optical fiber depends on the properties like the physical length of the fiber, traverse geometrical dimension of the guide; RI, and index of the profile of the waveguide.

② If we assume that index profile remains constant with environmental variations, then the depth of pulse modulation depends on the other remaining parameters.

(3) The total physical length of the optical fiber may be modulated by the perturbations like thermal expansion, application of longitudinal strain and application of a hydrostatic pressure causing expansion via Poisson's ratio.

(4) The RI varies with temperature, pressure and longitudinal strain via photo elastic effect. waveguide dimensions vary with radial strain in pressure field, longitudinal strain in pressure field and by thermal expansion.

(5) The phase change occuring in an optical fiber is detected using optical fiber interferometric techniques that convert phase modulation into intensity modulations.

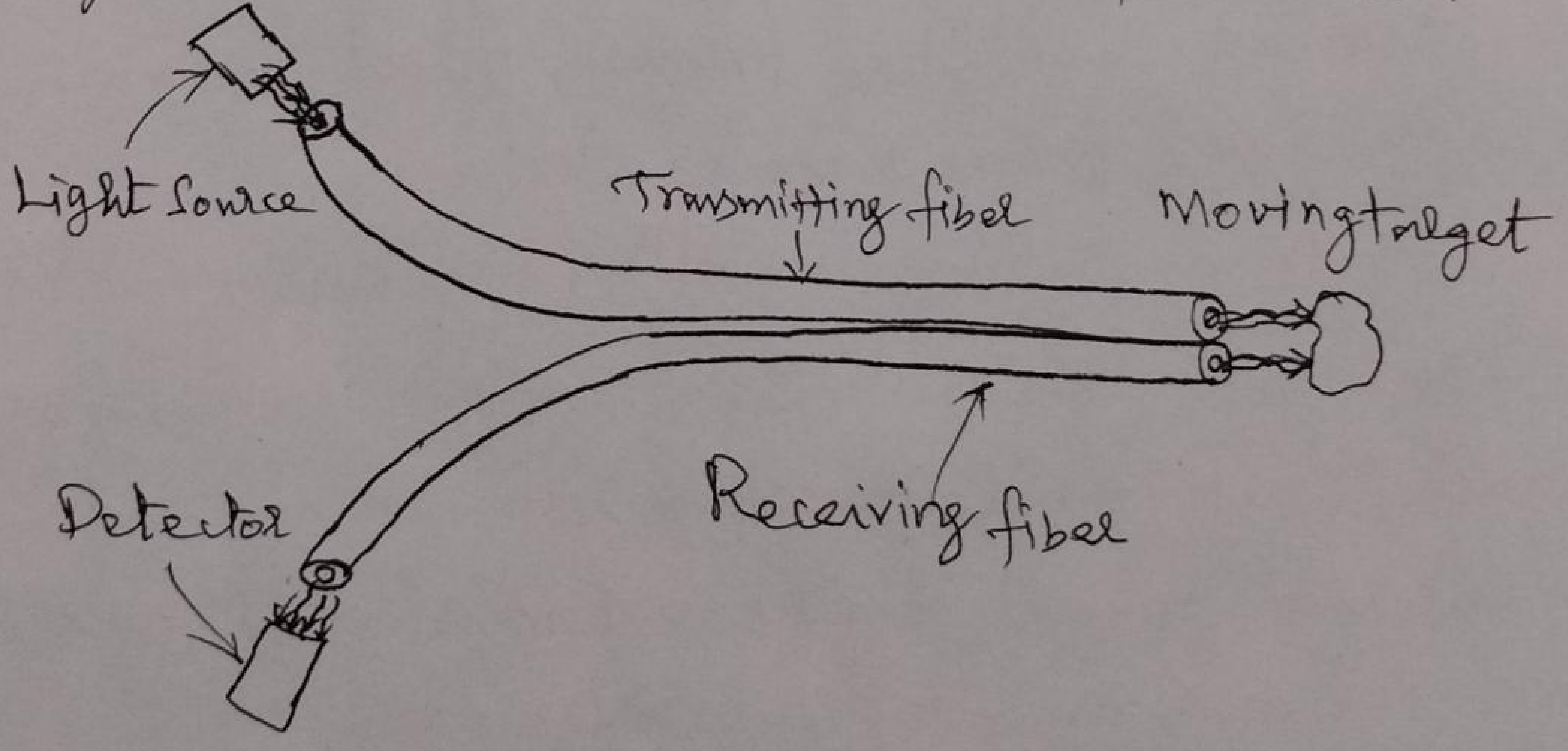
Displacement Sensors:-

Principle:

Light is sent through a transmitting fiber and is made to fall on a moving target. The reflected light from the target is sensed by a detector with respect to intensity of light reflected and the displacement of the target is measured.

Description:

It consists of a bundle of transmitting fibers coupled to the laser source and a bundle of receiving fibers coupled to the detector. The axis of the transmitting fiber and the receiving fiber with respect to the moving target can be adjusted to increase the sensitivity of the sensor.



Construction of Displacement Sensor:

Working principle:

a) Light from the source is transmitted through the transmitting fiber and is made to fall on the moving target. The light reflected from the target is made to pass through the receiving fiber and the same is detected by the detector.

(b) Based on the intensity of the light received, the displacement of the target can be measured, (ie). if the received intensity is more, then we can say that the target is moving towards the sensor and if the intensity is less, we can say that the target is moving away from the sensor.

Applications:

① Measurement of physical properties such as strain, displacement, temperature, pressure, velocity and acceleration in structures of any shape or size.

② Monitoring the physical health of structures in real time.

③ Building and Bridges:- Concrete monitoring during setting, crack (length, propagation speed) monitoring, Prestressing monitoring, spacial displacement measurement, neutral axis evolution, Concrete-steel interaction.

④ Dams:- Foundation monitoring, joint expansion monitoring, spacial displacement measurement, Leakage monitoring, etc.

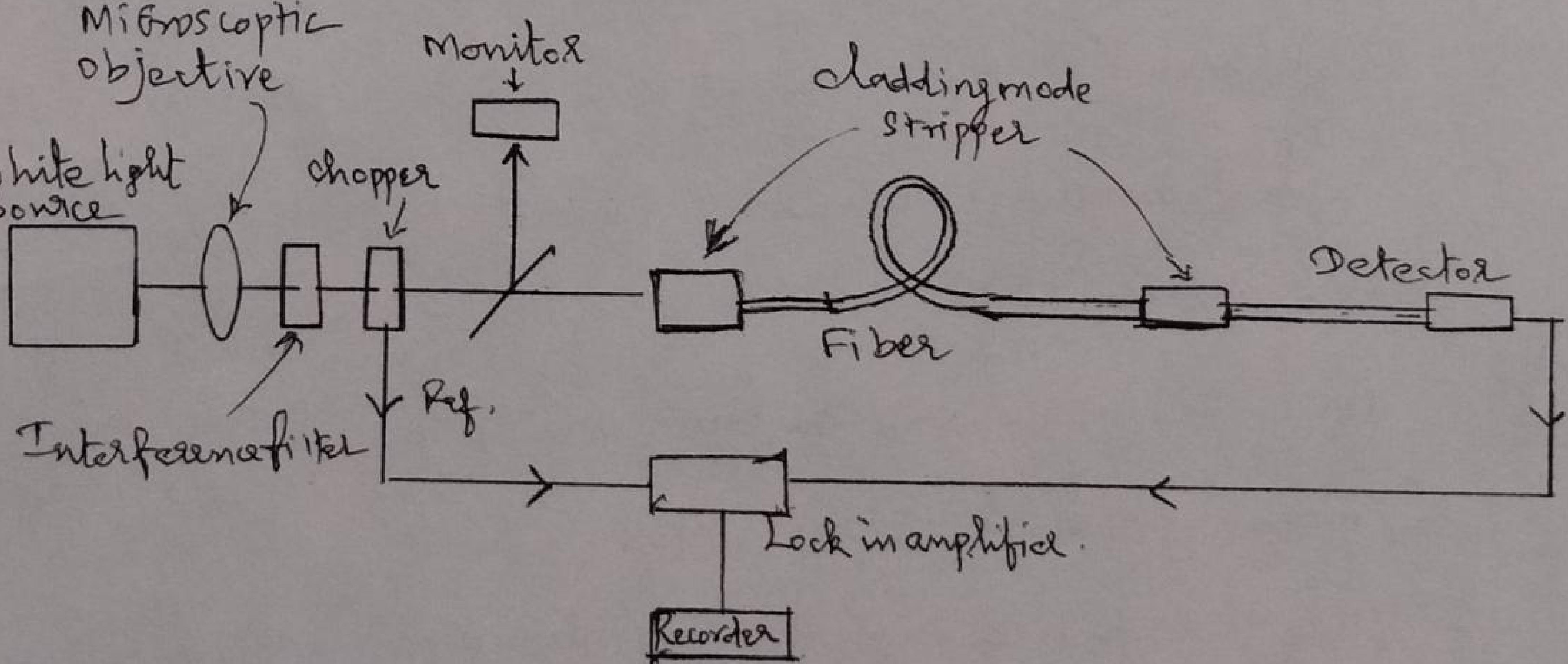
⑤ Tunnels:- Convergence monitoring, prefabricated vaults evaluation, and joints monitoring damage detections

FIBER OPTIC INSTRUMENTATION SYSTEM:

Introduction:-

* The communication engineers need the fiber characteristics to design the optical fiber link with an efficient wave guide without any loss or dispersion.
* Similarly, the fiber manufacturers need, the fiber characteristics for further development.
* Generally, the fiber attenuation measurement are used to determine repeaters spacing and light source power dispersion measurements are used to determine the maximum bit rate.
* RI profile, measurement are to know the number of modes progating the fiber and to determine its Numerical Aperture (NA).

Measurement of Attenuation (by cut back method).



1. Light from a halogen lamp or white light source is couple into the experimental fiber having length about 1Km. The lens placed in front of the source focuses the light on to the interference filter or monochromatic prism or grating.
2. The light with a given wavelength is incident on the chopper which is used to convert dc light into square pulses of light (ac). It also sends the reference signal to the lock in amplifier.
3. Monitor is used to view the intensity of the optical beams.
4. The cladding mode strippers are connected at the input and output end of fiber. These are used to remove the cladding light or cladding modes.
5. Then the jacket fiber is placed in an index matching liquid whose refractive index is slightly higher than that of cladding. This arrangement is called cladding mode stripper which will attenuate the light propagating through the fiber of 1Km length, the given height reaches the index matched photo detector whose output is given to the lock amplifier.
6. The lock amplifier delivers a output to the recorder or nanovoltmeter. Then the fiber is cut back, leaving typically 2m of the fiber and the experiment is repeated. In this case, the output power $P_r(\lambda)$ is noted.
7. This procedure is repeated for other wavelength also.

Thus the fiber attenuation at a given wavelength 'λ' is given by

$$\alpha_{dB} = \frac{10}{L_1 - L_2} \times \log_{10} \frac{P_{o2}}{P_{o1}}$$

L_1 & L_2 - original lengths and cut back lengths.

P_{o1} & P_{o2} - output power from original and cut back lengths.

Where L is the length of fiber cut back in Km. In case of multimode fibers, there are mode scrambler used to get the uniform intensity distribution among all the modes and order sorting filter acting as a mode selector to determine the fiber loss for each mode.

DisAdvantages:

(i) This method cannot be utilized to find the fiber attenuation in a working fiber optic link.

(ii) It is a destructive testing method.

Advantages:

(i) This method is very accurate and

(ii) Very simple.

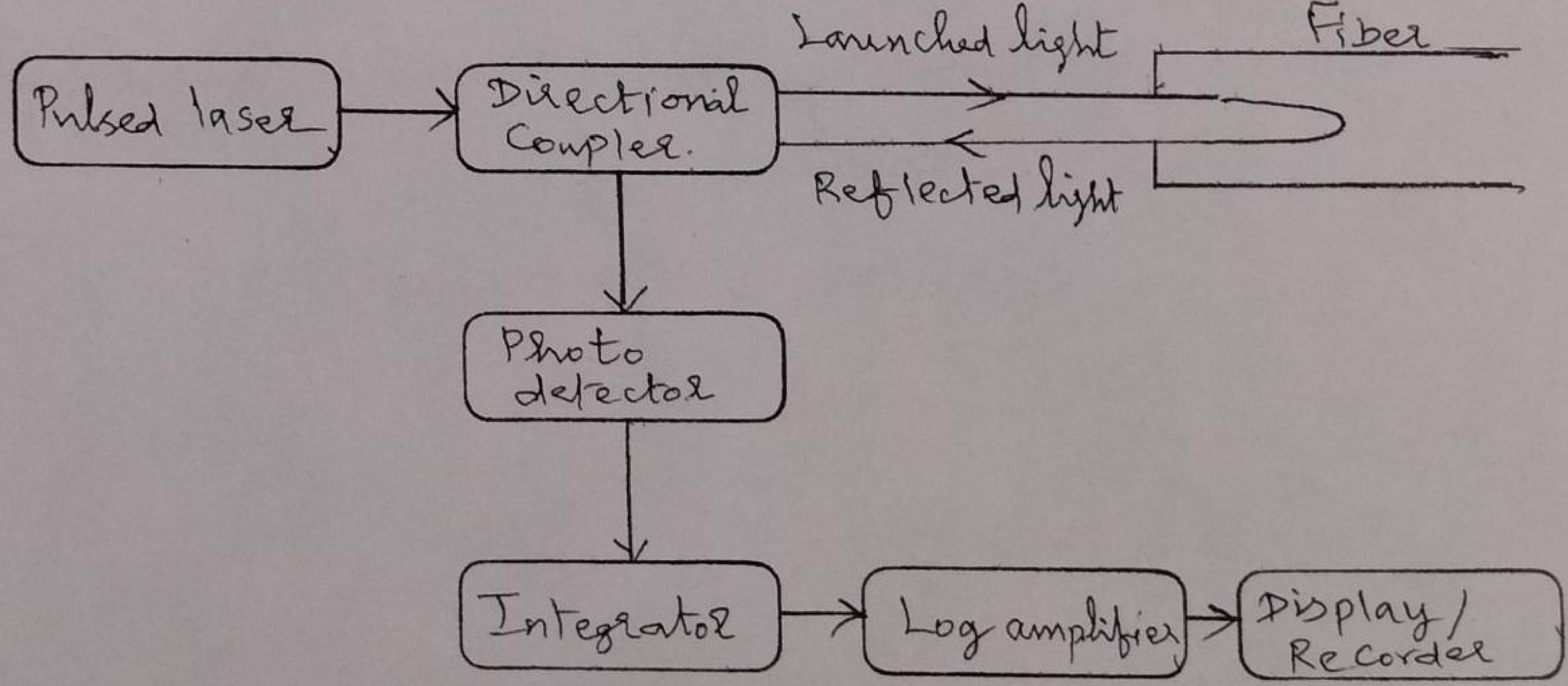
optical domain reflectometers:- (OTDR):

* The OTDR is the instrument which is used in both Laboratory and field measurement for determining fiber attenuation, joint losses and detecting fault losses.

* When the fiber attenuation varies with distance, then OTDR is the only instrument which can measure the fiber attenuation along the fiber optic link.

* The OTDR measurement is a non-destructive measurement.

Construction:-



Working Principle:-

This method is often called the both scatter method. It is based on the measurement and analysis of the fraction of light which is reflected back within the numerical aperture of the fiber due to Raliegh Scattering.

* A light pulse from a pulsed laser is launched into the fiber through a directional coupler. The back scattered light from the fiber is received by a photodetector like APD, through the directional coupler.

* A box car integrator is mainly used to improve S/N ratio by taking arithmetic average over a number of measurements taken at one point within the fiber.

* The signal from the integrator is fed to the logarithmic amplifier and its output is given to the recorder in DB.

* The recorder will display the averaged measurements for successive points within the fiber. The initial peak is caused by the reflection from the input coupler is as small increase in the reflected power.

* There is a long tail caused by Rayleigh scattering of the input pulse as it travels through the fiber link in the forward direction.

* Due to fault presence in the fiber link, there is sudden decrease of reflected power.

* Next peak is caused by splice or joint. Finally there is a peak due to Fresnel reflection of the fiber end where the reflected power is more than that of splice.

Fiber Scattering Loss Measurement:-

① Usually a power laser source like He-Ne laser or Nd-YAG laser is used to provide sufficient input optical power to the fiber.

② The focusing lens focuses the light into the input end of the fiber having short length. Before and after the scattering cell or integrating sphere, the cladding mode strippers are used to avoid the light propagating in the cladding so that the scattering measurement is taken only for the light guided by the fiber core.

③ Further the output end of the fiber is in index matched liquid to avoid reflections contributing to the optical signal within the integrating sphere.

④ The light scattered from the fiber core is detected by the series solar cell in the integrating sphere which also contains the index matching liquid surrounding the fiber.

⑤ The detected signal by series of solar cell gives the measurement of the scattered signal. The detected signal is given to lock in amplifier and then to the recorder or nano voltmeter.

Fiber Absorption Measurement:

* Fiber absorption measurement will give the impurity level in the filter.

Filter Absorption loss (db/Km) = Fiber attenuation loss (db/Km) − Fiber Scattering loss (db/Km)

* Thus the fiber absorption loss is the difference between fiber attenuation loss and Scattering loss.

Principle:

Amount of light energy absorped by the fiber = Heat energy developed in the calorimeter.

Construction:

① Here there are two fibers, one is the fiber under measurement and other is the dummy fiber. The dummy fiber is meant for compensation of any radiation loss of heat energy developed. These two fibers are mounted seperately in silica capillary tubes surrounded by the low refractive index liquid like methonal in the calorimeter for good electrical contact.

② The light from the laser source is well focused on the fiber under measurement.

③ The dummy fiber is not connected with light input. Then the fiber guided light is inserted into the cladding mode

Stripper which removes the light propagated in the cladding of the fiber. After passing through the capillary tube, the fiber with light is immersed in the index matching liquid to avoid reflections contributing to the optical signal within the capillary tube.

Procedure;

1. When the light enters the fiber under measurement is a temperature rise in the capillary tube containing the fiber with light. The temperature rise due to absorption tube containing the fiber with light.
2. The temperature rise due to absorption of energy by the fiber is measured for every 10 seconds by a thermocouple which is spirally around the silics tubes.
3. The hot junction of the thermocouple are connected with a nanovoltmeter.
4. Electrical calibration is done by placing a thin wire instead of fiber such that and passing known amount of current such that

$$mST = I^2RT = VIt.$$

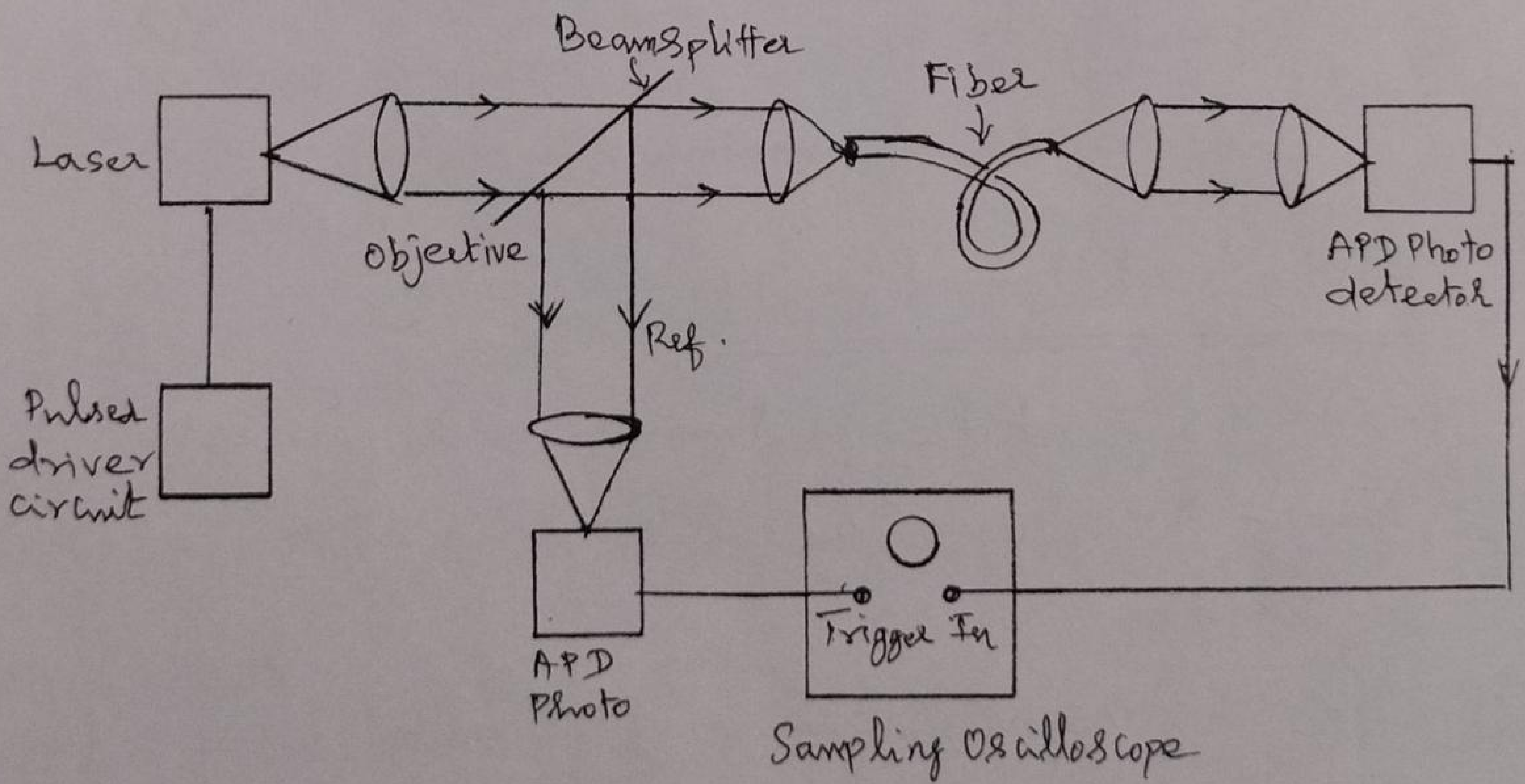
Fiber dispersion Measurements:

* Dispersion is measured interms of pulse broadening.
* There are two types of fiber dispersions.
  (i) Intermodal dispersion.
  (ii) Intra nodal (or) chromatic dispersion

Both can be performed using the same except the light source.

* **Inter modal dispersion:-** It is dominant in the multimode fibers.
* **Intra Nodal (or) chromatic dispersion:-** This measurement is made by the injection laser whose frequency or line width increases with respect to time.

Construction:-



Principle of operation:

(1) The laser with driver circuit gives short narrow pulses of light. The laser light is focussed onto the beam splitter.

(2) The beam splitter is used for triggering the oscillos-cope and for input pulse with measurement.

(3) One of the beams passing through the beam splitter is again focussed into the fiber under measurement. Normally its length is 1 km.

(4) The focused output laser beam is incident on the avalanche photo diode and it gives the output pulses.

(5) The input pulse and output pulse are displayed separately on the screen of sampling oscilloscope and they are in Gaussian shape.

End Reflection Method:

(1) The light from the lambertian source is focused onto the entrance end of the fiber having a length 2 metre.

(2) The magnified image of the output end of the fiber is obtained by a lens arrangement and is then passed through chopper. The near field of the output of chopper is scanned transversely by a p-i-n detector.

(3) The detector output is amplified by a pre-amplifier. The chappa and pre-amplifier are linked with the lock in amplifier.

(4) So the phase sensitive detected signal is further amplified and plotted directly on a X-Y recorder.

(5) For a graded index fiber, the display appears in the form of a Gaussian Curve and for a step index fiber, it appears in the form of a rectangular shape curve.

Limitation of this method:

(i) There should not be any contamination on the fiber surface.

(ii) The fiber surface should be optically plane.

(iii) During scanning, proper alignment of the fiber is necessary.

Near field scanning Techniques:

When a Lambertian source like tungsten filament lamp or LED is used to excite all the guided modes then P(r) is the near field optical power at a distance 'r' from the core axis and P(0) is the optical power at the centre of the core.

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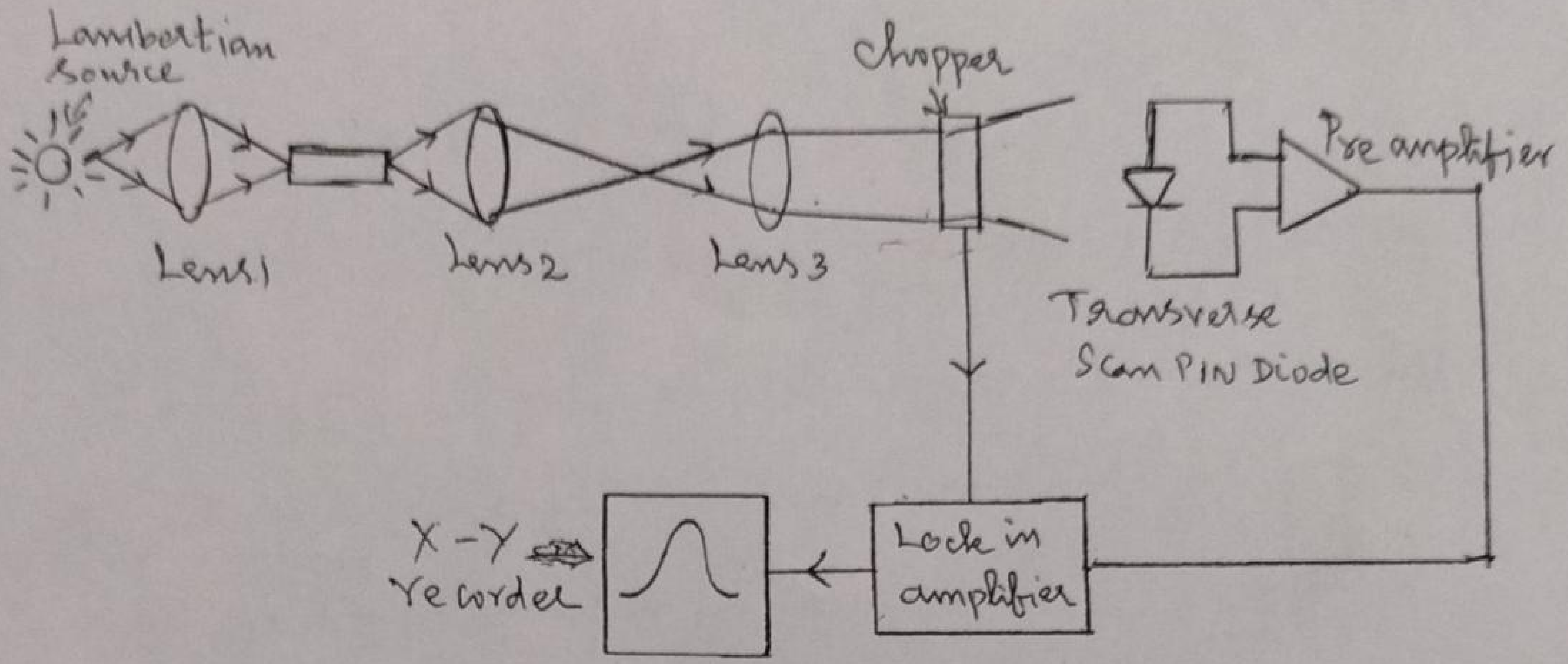


Measurement of NA of the fiber:

① The Lambertian, the Numerical Aperture (NA) of the fiber from the far end pattern. The Lambertian Source gives the angled visible light. It is then focused onto the test fiber of length 1 metre.

② The far field pattern from the fiber is displaced on the screen which is at distance 'D' from the output end of the fiber.

③ The test fiber is aligned so that there is maximum intensity of light on the screen. The pattern size on the screen is measured as A metre.

For a graded index fiber,

$$N.A(r) = \sin\theta_a(r) = (n_1^2(r) - n_2^2)^{1/2}.$$

Different types of modulators:

* According to the properties of the material that are used to modulate the light beam, modulators are divided into 2 groups.

1. **Absorptive modulators:**

   In absorptive modulators, absorption co-efficient of the material is changed.

2. **Refractive modulators:**

   In refractive modulators, refractive index of the material is changed.

* The absorption co-efficient of the material in the modulator can be manipulated by the Franz-Keldysh effect, the Quantum-Confined Stark effect, excitonic absorption, changes of fermi level, or changes of free carrier concentration.

* Usually, if several such effects appear together, the modulator is called an Electro-Absorptive Modulator.

* Refractive modulators most often make use of an electro optic effect. Some modulators utilize an acousto-optic effect or magneto-optic effect or take advantage of polarization changes in liquid crystals.

* The refractive modulators are named by the respective effect: i.e. electro optic modulators, acousto-optic modulators etc.

* The effect of a refractive modulator of any of the types mentioned above is to change the phase of a light beam. The phase modulation can be converted into amplitude modulation using an interferometer or directional coupler.

* Separate case of modulators are spatial light modulators (SLMs). The role of SLM is modification two dimensional distribution of amplitude and/or phase of an optical wave.

ELECTRO-OPTIC MODULATOR (EOM):-

① EOM is an optical device in which a signal controlled element exhibiting the electro optic effect is used to modulate a beam of light.

② The modulation may be imposed on the phase, frequency, amplitude, or polarization of the beam.

③ Modulation band widths extending into the gigahertz range are possible with the use of laser-controlled modulators.

(4) The electro optic effect is the change in the refractive index of a material resulting from the application of a DC or low frequency electro field. This is caused by forces that distort the position, orientation, or shape of the molecules constituting the material.

(5) Generally, a non-linear optical material (organic polymers have the fastest response rates, and thus are best for this application) with an instant static or low frequency optical field will see a modulation of its refractive index.

(6) The simplest kind of EOM consists of a crystal, such as lithium niobate, whose RI is a function of the strength of the local electrical field. That means that if Lithium niobate is exposed to an electric field, light will travel more slowly through it.

(7) But the phase of the light leaving the crystal is directly proportional to the length of time it takes that light to pass through it.

(8) Therefore, the phase of the laser light exciting an EOM can be controlled by changing the electric field in the crystal.

Pockels effect :-

The pockels effect is an electro-optic effect, produces birefringence in an optical medium induced by a constant or varying electric field.

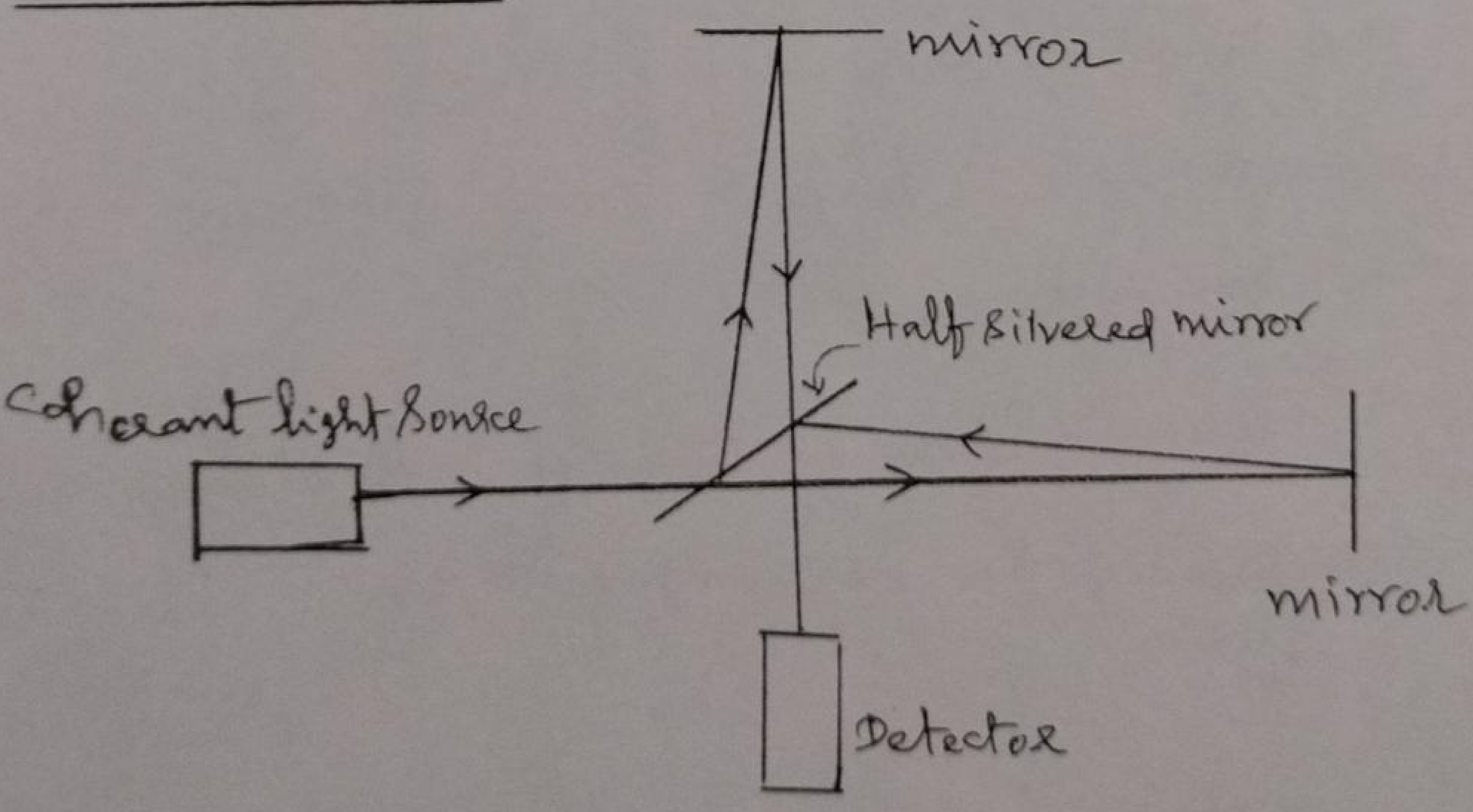
It is fact that the birefringence is proportional to the electric field.

The Pockels effect occurs only in crystals.

Pockels cells :

Pockels cells are voltage controlled wave plates. The Pockels effect is the basis of Pockels cells operation. Pockels cells may be used to rotate the polarization of a passing beam.

Interferometry :



① Interferometry is a family of techniques in which waves, usually electromagnetic, are superimposed in order to extract information about the waves.

② It is an important investigative technique in the fields of astronomy, fiber optics, engineering metrology, optical metrology, oceanography, seismology, spectroscopy (and its application to chemistry), quantum mechanics, nuclear and particle physics, plasma physics, remote sensing, Bio-molecular interactions, micro fluidics, mechanical stress/strain measurement and velocimetry.

③ Interferometers are widely used in science and industry for the measurement of small displacements, refractive index changes and surface irregularities.

④ An astronomical interferometer consists of two or more separate telescopes that combine their signals, offering a resolution equivalent to that of a telescope of diameter equal to the largest separation between its individual elements.

⑤ The light path through a michelson interferometer is shown in above figure. The two light rays with a common source combine at the half-silver mirror to reach the detector.

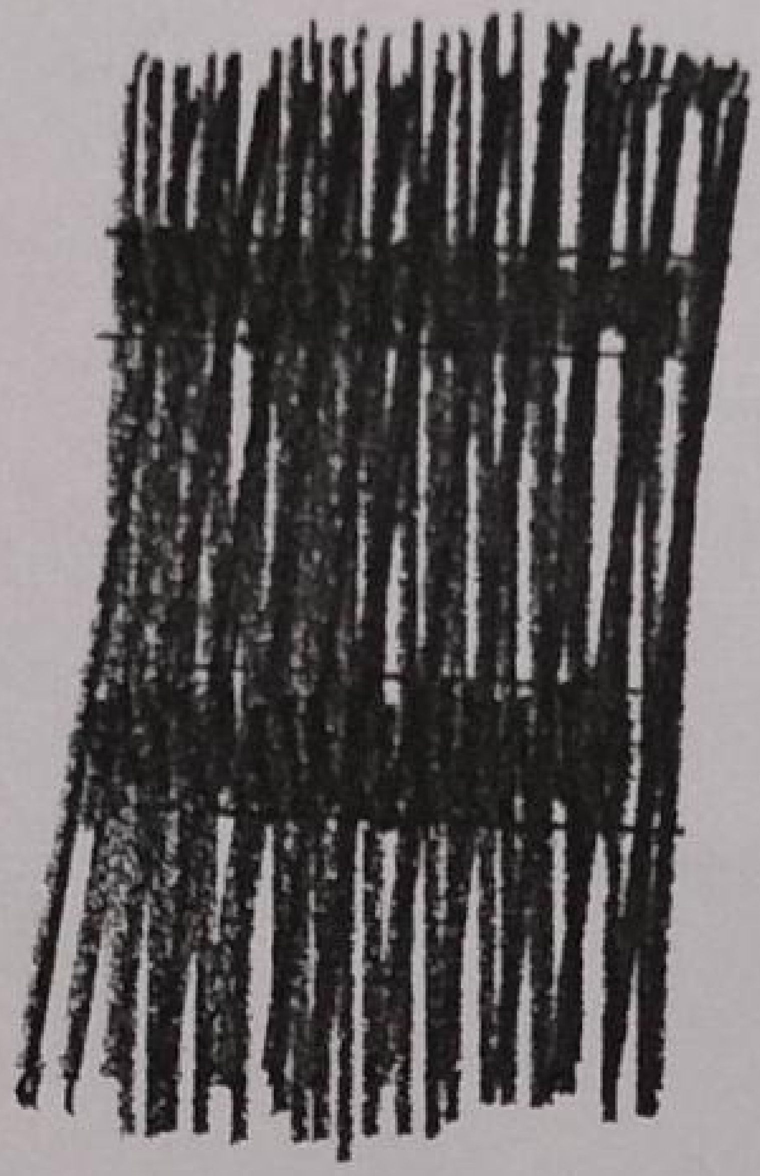
(6) Interferometry makes use of the principle of superposition to combines waves in a way that will cause the result of their combination to have some meaningful property that is diagnostic of the original state of the waves.

(7) Most interferometers use light or some other form of electromagnetic wave.

MOIRE FRINGES:-

* The French term "moire" originates from a type of textiles traditionally of silk textile, traditionally of silk, with a grained or watered appearance.
* The mathematical description of moire patterns resulting from the and grid lines. The moire effect is therefore often termed mechanical interference.
* The mathematical description of moire patterns resulting from the superposition of sinusoidal gratings is the same as interference patterns formed by electromagnetic waves.

Moire Fringes:



① when two periodic geometric patterns of nearly same pitch/period are super imposed, optical interference occurs. This is generally referred to as "Moire Phenomenon" and the resulting interference patterns called the "Moire Fringes".

② This French word is used to describe wavy patterns seens when sheets of shiny woven silk or wool are superposed.

③ Other examples of Moire Fringes often seen include:

(a) when a subject on TV wearing clothes with a regular geometric pattern (say, a shirt with a striped or Grid pattern) or period closed to that of pixels/scan-lines of the screen.

(b) when two spatially displaced picket fences in the direction of observation are viewed together. In these instances, the Moire Patters seen are generally considered an optical noice and undesirable.

Measurement using Fiber optics Sensor :

Measurement of Pressure :

① All the displacement Sensors can be used to measure pressure.

② Here the pressure is Converted first into displacement and the change in intensity is reflected or transmitted light is measured interms of displacement.

③ The pressure sensor based on reflective concept.

④ Depending upon the Value of pressure, the radius of curvature of the diaphragm is changed.

⑤ Hence, the intensity of the reflected light is changed.

⑤ with increase of pressure, the intensity of reflected light is decreased and hence the output voltage decreases.

Measurement of Temperature:

The bimetallic strip acts as a sensing element. It consist of steel and brass which are welded together to form a strip. ~~is attached to a~~ The brass has higher linear expansively compared to steel.

The strip is attached to a bifurcated reflective fiber optic probe The Strip is designed to move continuosly and is movement is directionally proportional to temperature. The amount of reflected light is converted into voltage by a Photodiode.

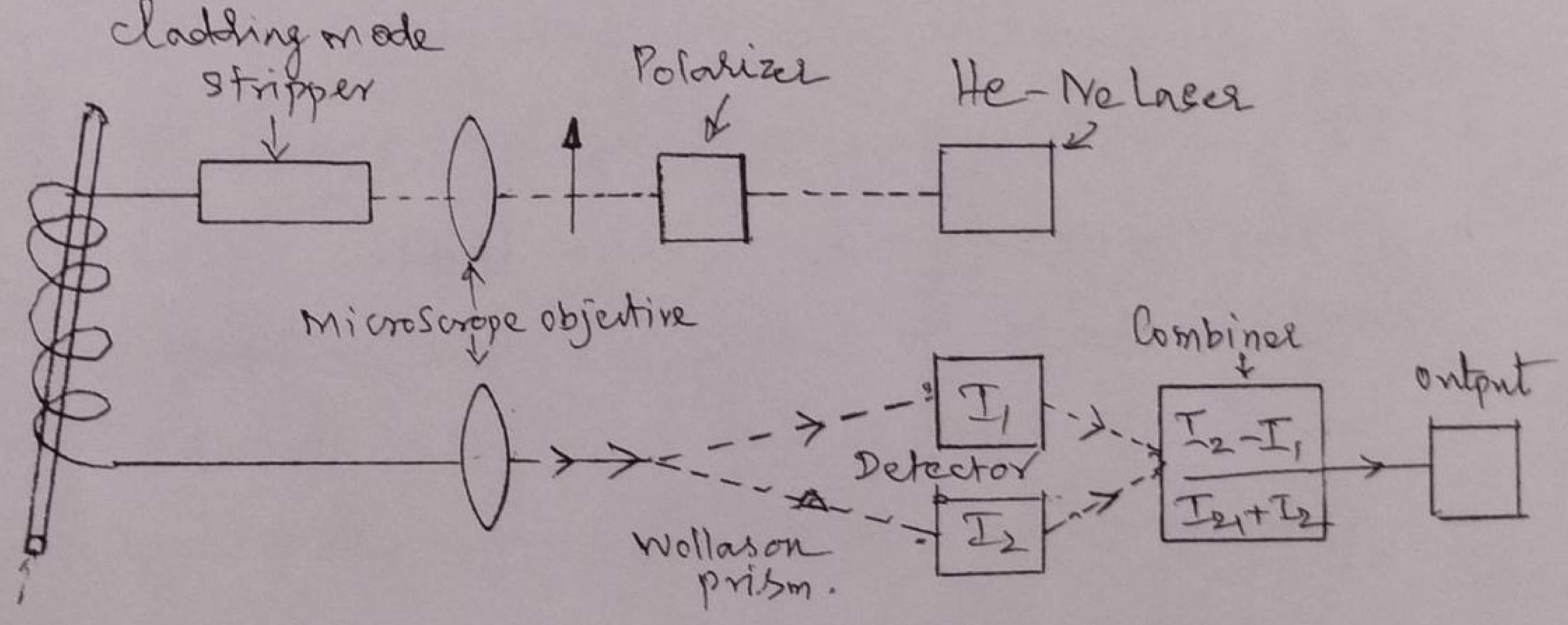
The amount of light reflected decreases with increase of temperature so that output of photodiode decreases with increase of temperature.

Phase modulated Temperature Sensor :-

* Here, the phase shift produced in the sensing relative to reference fiber is a function of temperature.
* The arrangement is called Mach-Zender.
* The semiconductor laser acts as a light source.
* A 3db Splitter acts as the beam splitter which sense the light through the sensing and reference fiber.
* Another 3db Coupler acts as a combiner of these two beams.
* A series of light and dark fringes are formed when light form two fiber interface on the display screen.
* A phase changes of 2ϕ radians causes a displacement of 1 fringe.
* By counting the fringe displacement, the magnitude of temperature is determined.
* It is negligible. By placing a photodetector to measure the intensity of the fringes, we can get sensitivity.

This is called quadrature condition and sensitivity is zero when the phase shifts are π, 2π, 3π, 4π etc. By taking the difference between the two output signals from the sensing fiber and reference fiber, sensitivity of the sensor is doubled.

Measurement of Current:



① The linearly polarized laser light from the negative laser is launched into fiber. Cladding mode stripper removes cladding modes.

② The direction of polarization of light in the fiber rotated by the longitudinal magnetic field around the current carrying conductor.

③ The returning light from the fiber loop is passed through the wallaston prism which is used to sense the resulting rotation and it resolves the emerging light into two orthogonal components I_1 and I_2, these components are separately detected by photodiode detectors and the difference and sum of these signals are obtained.

Measurement of Voltage :-

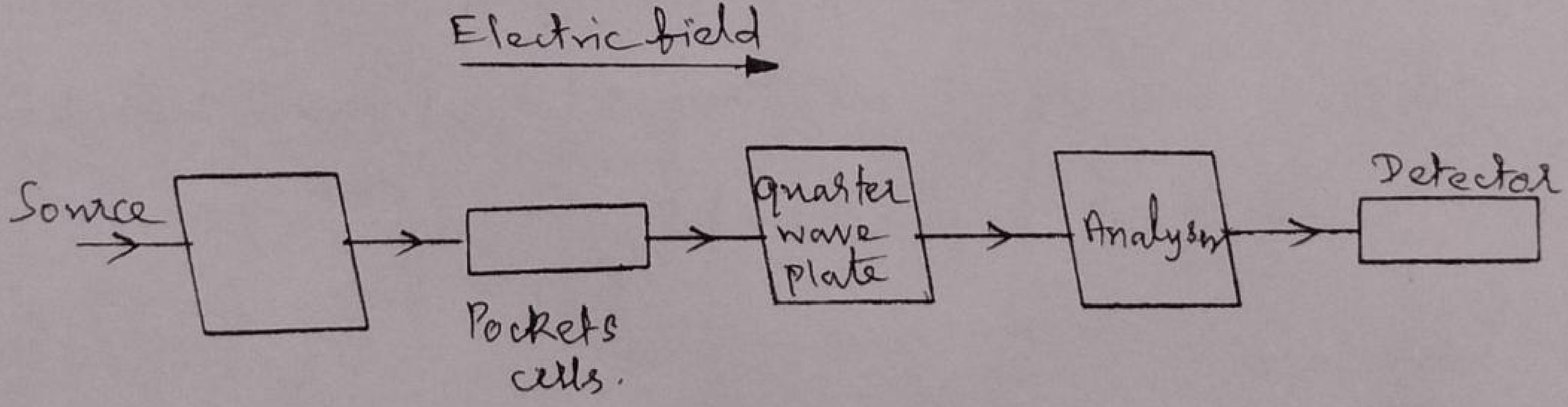
The variation of refractive index with respect to electric field 'E' is written as, $E = RE^2 + rE$.

n_0 - refractive index before the application of electric field.

r - linear electro optical co-efficient.

R - quadratic electro optic co-efficient.

In this crystal, when we apply electric field / voltage along Z-axis, the light which is linearly polarized at an angle 45° with respect to X axis undergoes a phase shift or phase retardation.



If I_0 be the incident light intensity, then the intensity of the transmitted light through crystal is $I = I_0 \sin 2$. Thus, phase produced in the linearly polarized wave is directly proportional to applied field (electric field) / voltage.

The polarizer converts the incident ordinary light into a linearly polarized light.

When there is applied voltage across the pockel cell, phase shift is produced for the transmitted polarized beam. Quarter wave plate produces a phase shift of $\theta/2$. The transmitted light is then analyzed through a Analyser.

Measurement of Liquid Level:-

① Liquid level sensor consists of two fibers which are connected at the base of a glass microprism.

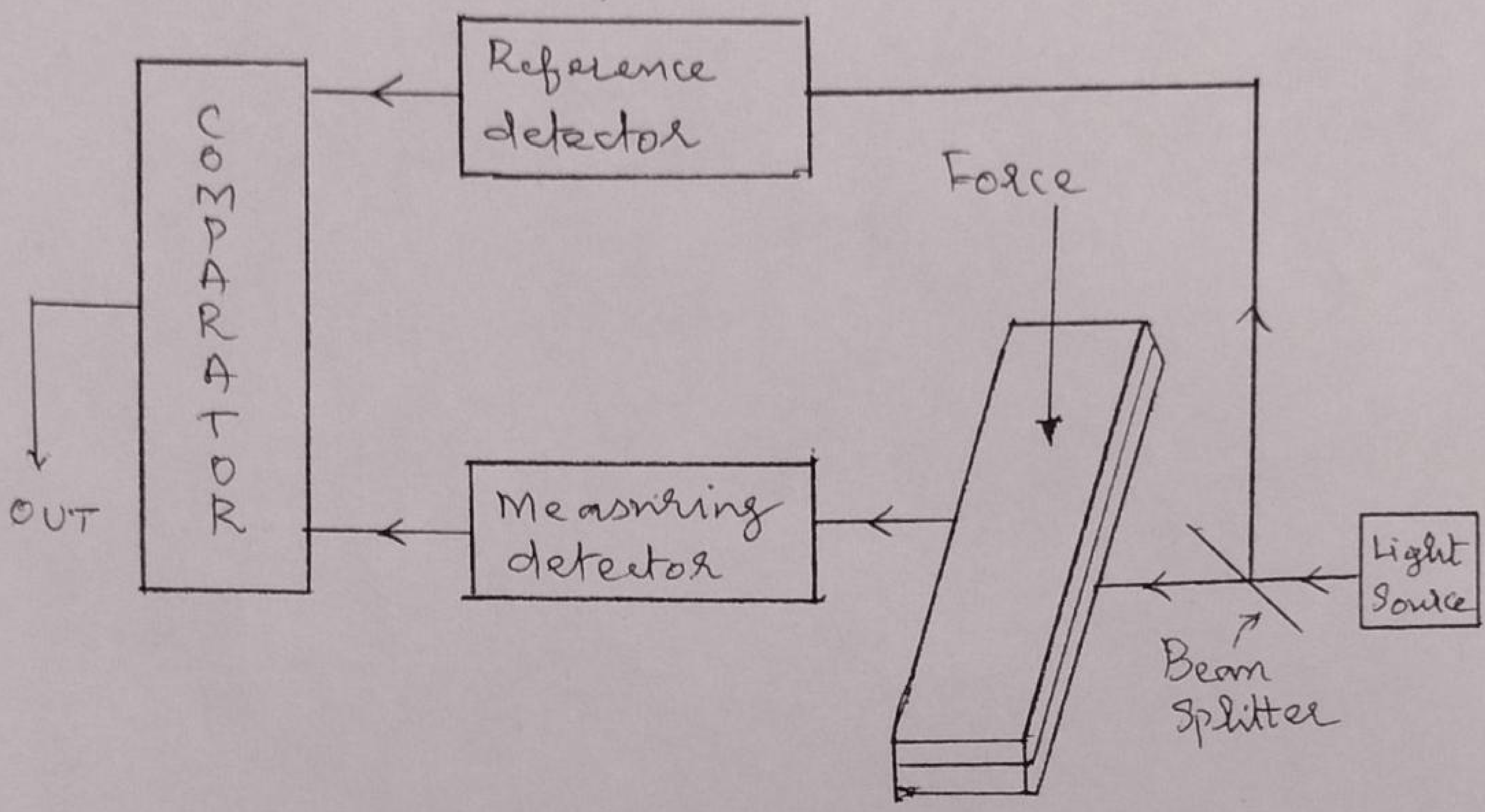
② When the tip of the prism is immersed in the liquid, there is no output at the detector.

③ When the tip of the prism is just above the liquid level, due to contact with air, there is total internal reflection and output is got in the detector.

Disadvantages:-

Not useful for sensing multi liquid level since it operates in digital mode.

Measurement of Strain:-



* Microbending losses are produced in the fiber when the top block presses the fiber by the applied external force.
* The Microbend losses are found to increase in force applied to the top block.
* The intensity changes produced by the applied force are measured with reference to a direct unmodulated Signal from the light Source.
* The comparator compares these two values and gives the value of strain produced.

UNIT-III . LASER FUNDAMENTALS.

FUNDAMENTAL CHARACTERISTICS OF LASERS.

LASER - Light Amplification by Stimulated Emission of Radiation.

* Laser technology is one of most rapidly developing areas in modern technology.
* when the laser was invented in 1960, it was classified as a Solution in Search of a problem, and
* Today laser technology is applied in many different areas such as medicine, communication, daily use, military and Industry.

Principle of operation:

The laser is a device which transforms a signal from high energy orbits to low energy orbits; followed by the collision with excited atoms.

A laser emits a beam of electromagnetic radiation that is always monochromatic, collimated and coherent in nature.

Laser characteristics:-

- The 3 characteristics of laser are:

(1) Superior mono-chromatism:

Laser lights are single wavelength light.

(2) Super Directivity:-

Laser beam is emitted in a specific direction.

(3) Superior Coherance:-

Laser lights have the same phase difference.

LEVEL LASERS:-

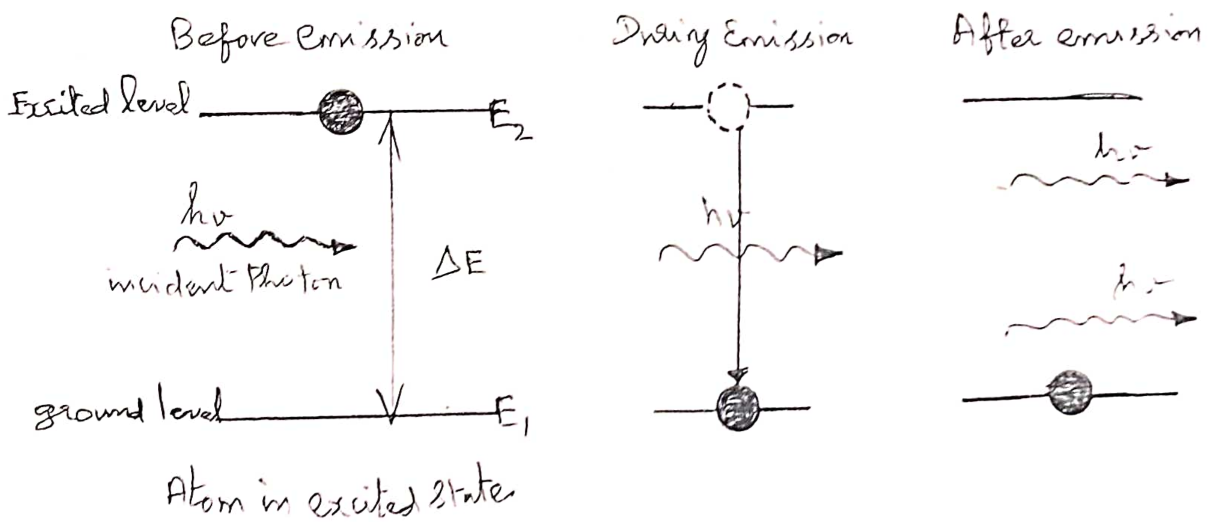
* Every atom or molecule in nature has a specific structure for its energy levels. The lowest energy level is called the ground state; which is the naturally preferred energy state. As long as no energy is added to the atom, the electron will remain in the ground state. When the atom receives energy (electrical energy, optical energy or any form of energy), this energy is transferred to the electron, and raises it to a higher energy level (further away from the nucleus). So, the atom is then considered to be in an excited state.

* The electron can stay only at the specific energy state (levels) which are unique for each specific atom.

* The electron cannot be inbetween these "allowed energy states", but it can "jump" from one energy level to another, while receiving or emitting specific amounts of energy.

* These specific amounts of energy are equal to the difference between energy levels within the atom. Each amount of energy is called a "Quantum" of energy (The name "Quantum Theory" comes from these discrete amounts of energy). Energy transfer to and from the atom can be performed in two different ways.

(1) Two level Laser :-



$$E_2 - E_1 = \Delta E = h\nu.$$

Above Figure : Stimulated emission in a two-level transition.

① Let's consider a laser medium whose atoms have only two energy states: a ground state and one excited state. In such an idealised atom the only possible transitions are excitation from the ground state to the excited state, and deexcitation from the excited state back into ground state.

② There are several important conditions that our laser must satisfy. First of all, the light that it produces must be coherent. That is to ~~stay~~ say, it must emit photons that are in-phase with one another. Secondly, it should emit monochormatic light, ie photons of the same frequency (or wave length). Thirdly, it would be desirable if our laser's output were collimated, producing a sharply ~~designed~~ defined "pencil-like" beam of light. Lastly, it would also be desirable for our laser to be efficient, i.e the higher the ratio of output energy-to-input energy, the better.

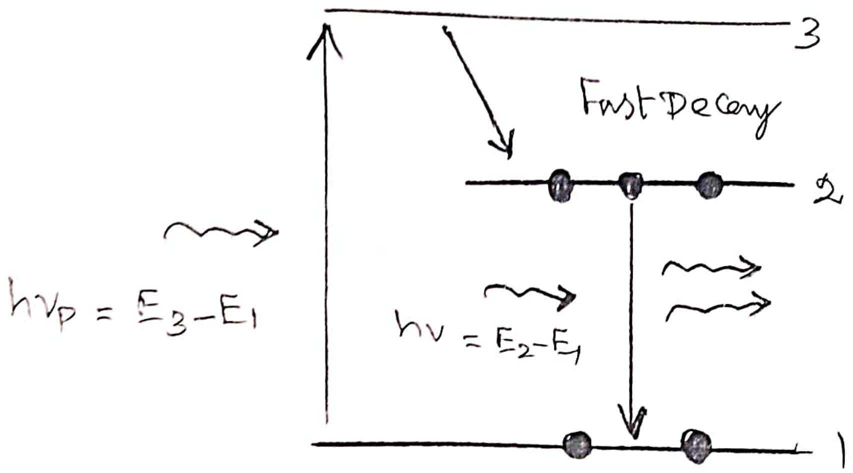
③ Stimulated emission produces identical photons that are of equal energy and phase and travel in the same direction. But for stimulated emission to take place a "passer-by" photon whose energy is just equal to the de-excitation energy must approach the excited atom before it de-excites via spontaneous emission. Typically, a photon emitted by the spontaneous emission serves as the seed to trigger a collection of stimulated emissions.

(4) So to satisfy this requirement, we need to produce a population inverse: creates more atoms in the excited state than those in the ground state.

(5) Achieving population inversion in a two-level atom is not very practical. Such a task would require a very strong pumping transition that would send any decaying atom back into its excited state. This would be similar to reversing the flow of water fall. It can be done, but is very energy costly and inefficient. In a sense, the pumping transition would have to work against the lasing transition.

(6) Once the population reverse is achieved, the laser would lase. But immediately it would end up with more atoms in the lower level. Such two-level lasers involve a more complicated process, and laser used here is pulsed laser. For a continuous laser action we need to consider other possibilities, such as a three-level atom.

(2) Three Level laser:-



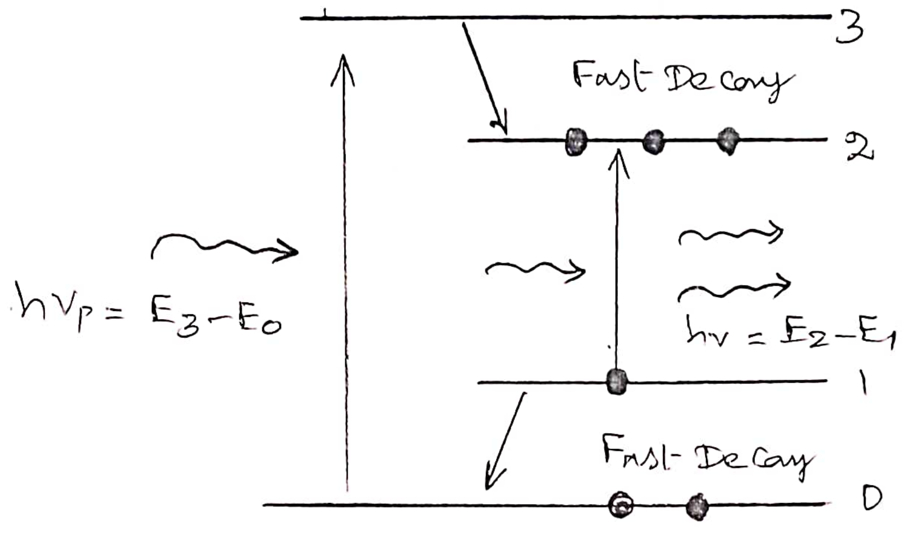
Example:- Ruby Laser.

* In a 3 level System the terminal level for the ~~flou~~ fluorescence process is the ground level (ie) the level with the lowest energy. Here the population inversion is produced by raising electrons to the high energy level by the process of pumping with an auxiliary light source. It is observed to excite electrons from level 1 to level 3. Then, a very fast radiation less transition accomplished by thermal vibrations of the atom will drop the electrons to level 2.

* The difference in energy between level 3 and 2 appears as heat. Stimulated emission occurs between level 2 and 1 at frequency. If substantial power at frequency f_3 is supplied, the transition rate from level 1 to 3 will be large.

3. Quasi Three Level Laser:-

(Better → easier to get a large inversion)



Example :- Nd : YAG Laser.

(1) Collisions with other atoms, and the transfer of kinetic energy as a result of the collision. This kinetic energy is transferred into internal energy of the atom.

(2) Absorption and emission of electromagnetic radiation. Since we are now interested in the lasing process, we shall concentrate on the second mechanism of energy transfer to and from the atom (The first excitation mechanism is used in certain lasers, like Helium-Neon) as a way to put energy into the laser.

(3) The interactions between electromagnetic radiation and matter cause changes in the energy states of the electrons in matter.

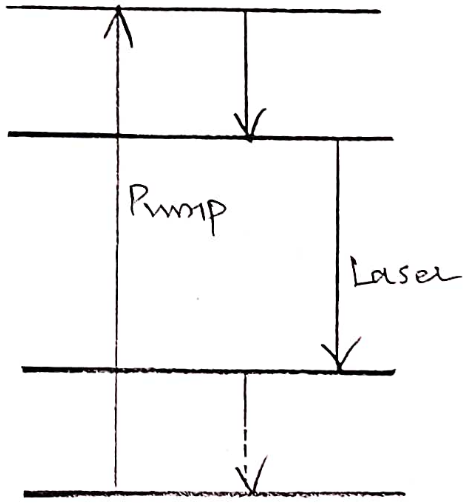
(4) Electrons can be transferred from one energy level to another, while absorbing or emitting a certain amount of energy. This amount of energy is equal to the energy difference between these two energy levels $(E_2 - E_1)$.

(5) When this energy is absorped or emitted in a form of electromagnetic radiation, the energy difference $(E_2 - E_1)$ determines uniquely the frequency (ν) of the electromagnetic radiation : $(\Delta E) = E_2 - E_1 = h\nu = h(\text{bar})\,\omega$

Example:-

The laser is a System that is Similar to an electronic osillator. An Osillator is a System that produces oscillation's' without an external driving mechanism.

4) Four Level Laser:-



* A far lower threshold pump power can be achieved with a four-level laser medium, where the lower laser level is well above the ground state. (Ref. above figure) and is quickly depopulated example: by multi-photon transition (in case of a solid-state medium) or by collisions (in a gas).
* Ideally, no appreciable population density in the lower laser level can occur even during laser operation, since the lower laser level is very short-lived. In that way, reabsorption of the laser radiation is largely avoided. This means that there is no absorption of the gain medium in the unpumped state, and a positive net gain is achieved already for a

rather low population in the upper laser level. The gain usually rises linearly with absorped pump power.

* The most popular four-level solid state gain medium is Nd-YAG. All lasers based on neodymium-doped laser gain media, except those operated on the ground-state transition around 0.9 - 0.95 μm, are four-level lasers.

* Neodymium ions can also be directly pumped into the upper laser level, ex: with pump light around 880 nm for Nd:YAG. While this reduces the quantum defect and thus possibly increases the laser efficiency, it also opens the possibility of stimulated emission of pump radiation reducing the upper state population. The latter is not necessarily a problem, since a quite low upper laser level population is sufficient.

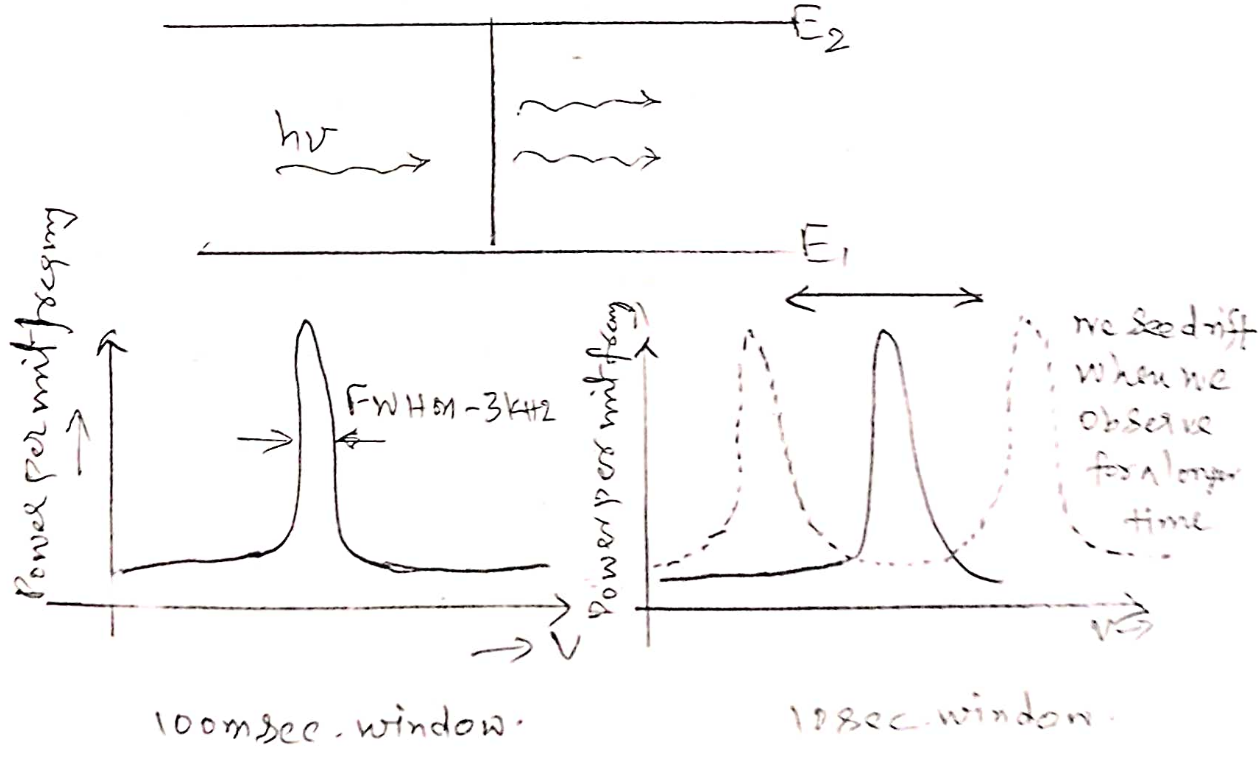
* Even though effectively only three levels are involved, the term three-level system would not be used here.

PROPERTIES OF LASERS:-

1. Monochromaticity:-

(i) First, only an EM wave of frequency $\nu_0 = \frac{E_2 - E_1}{h}$ can be amplified, ν_0 has a certain range which is called line width, which is decided by homogeneous broadening factors, the result line width is very small compared with normal lights.

(ii) Second, the laser cavity forms a resonant system, oscillation can occur only at the resonance frequencies of this cavity. This leads to further narrowing can be as large as 10 orders of magnitude. So laser light is usually very pure in wavelength, we say it has the property of monochromaticity.



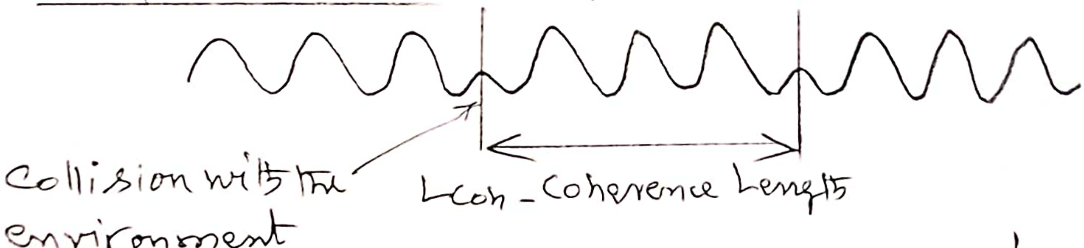
2. Coherence:-

* For any EM wave, there are two kinds of Coherence. Let's consider two points that, at time $t=0$, lie on the same wave front of some given EM wave, the phase difference of EM wave at the two points $t=0$ is k_0. If for any time $t>0$ the phase difference of EM wave at the two points remains k_0, we say the EM wave has perfect coherence between the two points.

* If this is true for any two points of wavefront, we say the wave has perfect spatial Coherence. ~~exists only in a~~

* In practical the spatial coherence occurs only in a limited area, we say it is partial spatial coherence.

Temporal Coherence:-



$$\text{Coherence Time}, \tau_{coh} = \frac{L_{coh}}{c}$$

$$\tau_{coh} = \frac{1}{\Delta\nu}$$

Fig. a.

Spatial Coherence :

We can define a phase front for a laser beam.

→ Causes Laser Speckle.

Fig. b.

* Now we consider a fixed point on the EM wave front. If at any time the phase difference between time 't' and time 't+dt' remains the same, where 'dt' is the time delay period, we say that the EM wave has temporal coherence (Fig a.) over a time 'dt'.
* If 'dt' can be any value, we say the EM wave has perfect temporal coherence. If this happen only in a range $0 < dt < t_0$, we say it has partial (Fig b) temporal coherence, with a coherence time equal to t_0. We emphasise here that spatial and temporal coherence are independent.
* Laser light is highly coherent, and this property has been widely used in measurement, holography etc.

3. Divergence and Directionality:

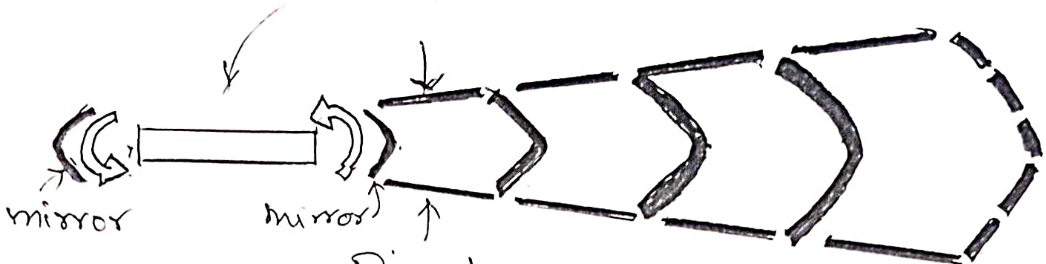


Fig. C.

* Laser beam is highly directional, which implies laser light is of very small divergence. This is a direct consequences of the fact that laser beam comes from the resonant cavity, and only waves propagating along the optical axis can be sustained in the cavity. The directi-onality is described by the light beam divergence angle.

* Fig. C. shows the relationship between divergence and optical systems. for perfect spatial coherent light, a beam of aperture diameter 'D' will have unavoid-able divergence because of diffraction.

From diffraction theory, the divergence angle,

$$q_d = \frac{bL}{D}$$; where, L - wavelength, D - diameter

b - Co-efficient whose value is around unity.

* If the beam is partial spatial coherent, its divergence is bigger than the diffraction limited divergence (θ_d). For this case, the divergence becomes,

$$\theta = \frac{bL}{(S_c)^{\frac{1}{2}}}$$ where, S_c is coherence area.

4. Brightness :-

The brightness of a light source is defined as the power emitted per unit surface area per unit solid angle.

A laser beam of power P, with a circular beam crossection of diameter 'D' and a divergence angle 'θ' and the result emission solid angle is $P\theta^2$, then the brightness of laser beam is

$$B = \frac{4P}{(PD\theta)^2}$$

The maximum brightness is reached when the beam is perfect spatial coherent.

$$B_{max} = \frac{4P}{(PLb)^2}$$

LASER MODES :-

* Surely laser cavity is also very important for a laser in many other aspects, for example, it dimension decides the longitudinal laser modes. Generally speaking light modes means possible standing EM waves in a system. The number of modes in this meaning is huge. Laser mode means the possible standing waves in laser cavity.

* We ~~say~~ see that stimulated lights are transmitted back and forth between the mirrors and interfere with each other, as a result only light whose round trip distance is integer multiples of the wavelength 'l' can become a standing wave. ie

$$m = \frac{2L}{(c/f)} = \frac{2L}{l}, \text{ (or) } f = \frac{mc}{2L}, \quad Df = \frac{c}{2L}$$

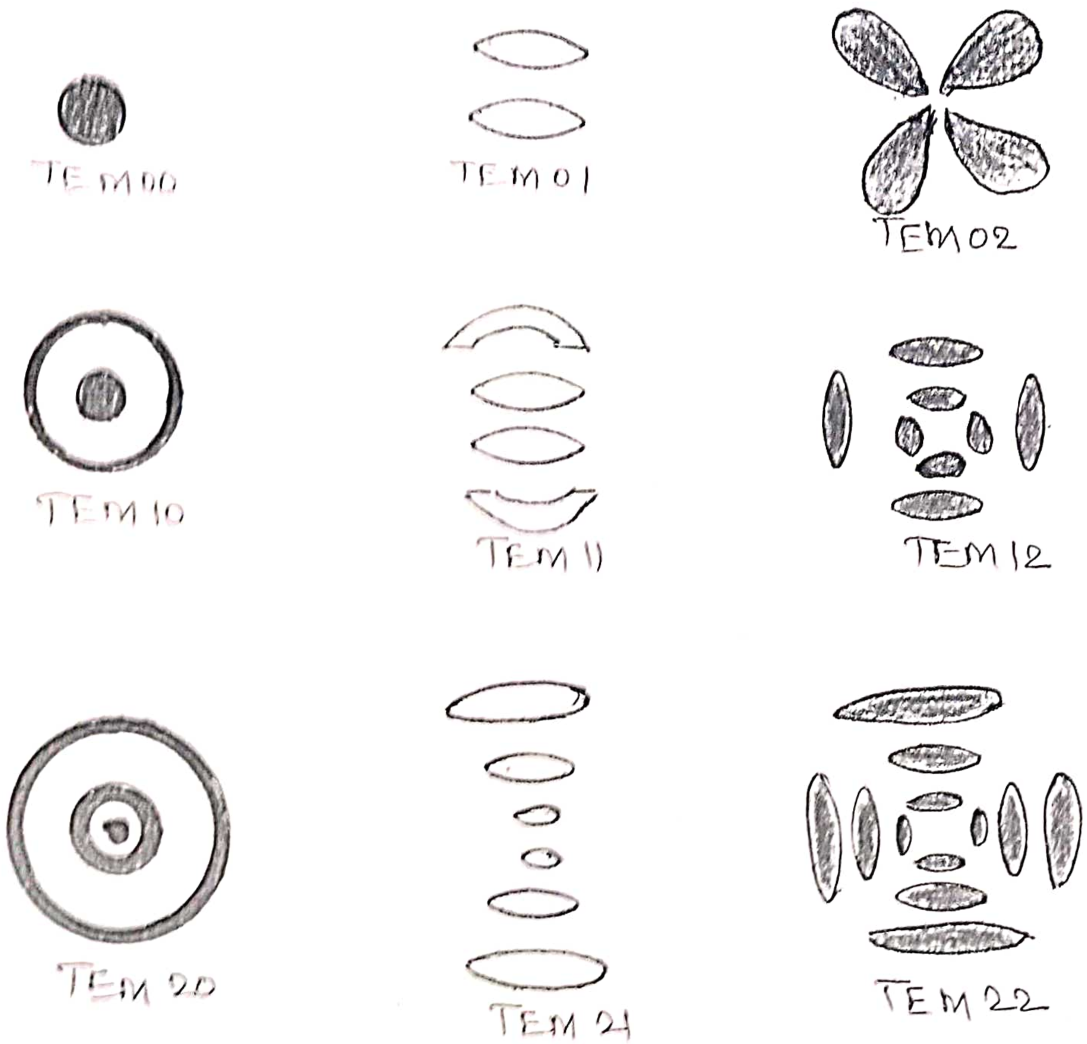
L → length of cavity
c → speed of light in laser cavity
f → frequency of standing wave.
l → wavelength
m → is an integer
Df → is the frequency difference between two consecutive modes.

The number of longitudinal modes may be very large, it can also be a small as only a few (below 10). If we intersect the output laser beam and study the transverse beam cross section, we find the light intensity can be of different distributions (patterns). These are called Transverse Electromagnetic Modes (TEM).

* Three index are used to indicate the TEM modes. TEM_{plq}, P is the no. of radial zero fields, l is the no. of angular zero fields, q - is the no. of longitudinal fields. We usually use the first two index to specify a TEM-mode, like TEM 00, TEM 10, etc.
* Clearly, the higher the order of the modes, the more difficult it is poor to focus the beam to a fine spot. That is why sometimes TEM 00 mode or Gaussian beam is preferred.

* When these modes oscillate, they interfere with each other, forming the transverse standing wave pattern on any transverse intersection plane. This mechanism decides the Transverse Electromagnetic Modes (TEM) of the laser beam, which is the wave pattern on the output aperture plane.

TEM PATTERNS



* The higher order of the mode, the more difficult it is to focus the beam to a fine spot, since the beam of higher order is not from a virtual point, but from patterns as those in the figure shown above.

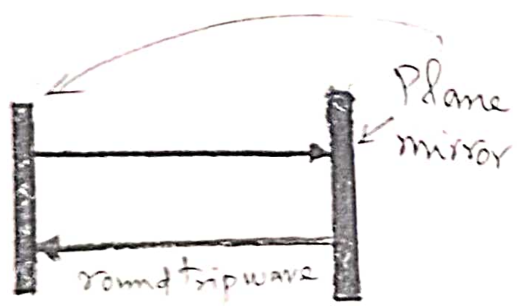
Focal spot size:-

Focus spot size determines the maximum energy density that can be achieved when the laser beam power is set, so the focal spot size is very important for material processing. When a beam of finite diameter 'D' is focussed by a lens on to a plane, the individual parts of the beam striking the lens can be imagined to be point radiators of new wavefront. The light rays passing through the lens will converge on the focal plane and interfere with each other, thus constructive and destructive superposition take place.

RESONATOR CONFIGURATION:

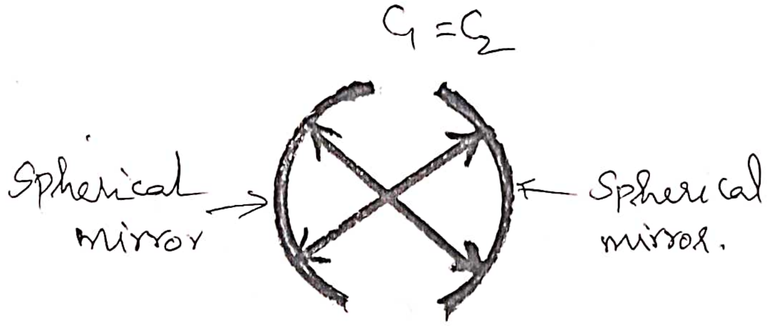
The most widely used laser resonators or cavities have either plane or spherical mirrors of rectangular or circular shape, separated by some distance L.

(i) Plane Parallel Resonators:-



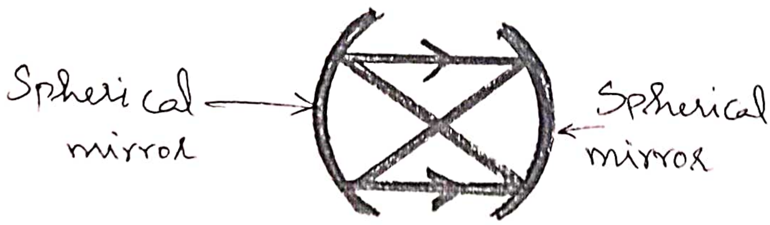
Plane parallel Resonator consists of two plane mirrors set parallel to each other, as shown above. The one round trip of wave in the cavity should be an integral number times 2λ, the resonant frequency is $\lambda = Kc/(2L)$, K-is an integral number, c-is the speed of light in the medium, L is the cavity length. The frequency difference between two consecutive modes (possible standing wave in the cavity) is $c/2L$. This difference is referred to as the frequency difference between two consecutive longitudinal modes; the word longitudinal is used because the number 'K' indicates the number of half wavelengths of the mode along the laser resonator, i.e. in the longitudinal direction.

(ii) Concentric Resonator:



Concentric resonator consists of two spherical mirrors with the same radius R separated by a distance $L = 2R$, so that the centres are coincident. The resonant frequencies use the same equation as above (Ref. (i)).

(iii) Confocal Resonator:-

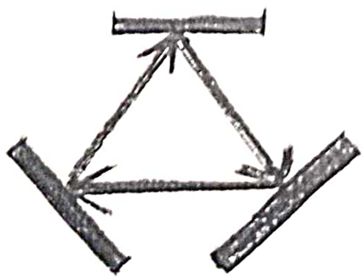


Confocal resonator consists of two spherical mirrors of the same radius of curvature 'R' separated by a distance 'L' such that their foci F_1 and F_2 coincident. In this case, the centre of curvature of one mirror lies on the surface of another mirror, L = R. The resonant frequency cannot be readily obtained from geometrical optics consideration.

(iv) Generalized Resonator:-

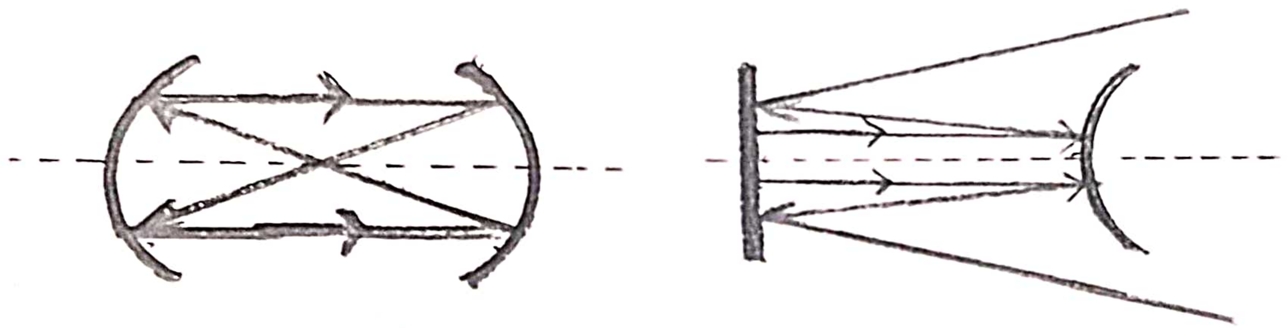
Resonators formed by two spherical mirrors of the same radius of curvature 'R' and separated by a distance 'L' such that R < L < 2R, ie, in between confocal and concentric, are called Generalized Spherical Resonators, which is also often used.

(v) Ring Resonators:-



Ring resonator is a particularly important class of laser resonators. The path of optical rays is arranged in a ring configuration or more complicated configurations like folded configurations. We can compute the resonant frequencies by imposing the constraints that the total phase shift along the ring path or the closed loop path must be equal to the integral numbers of 2π. Then the resonant frequencies are $\nu = Kc/PL$, where K is an integral number, Lp is the loop path length.

STABLE and UNSTABLE RESONATORS.



Stable resonator　　　　Unstable resonator.

* Cavity can be identified as stable or unstable according to whether they make the oscillating beam coverage into the cavity or spread out of the cavity.

* The output mirror of the laser resonator is finely coated to reach the required reflection into the cavity, if the beam is too ~~wal~~ intense, the mirror may suffer breakage. Breakage is serious because it causes shutdown of the production.

* So for powers upto 2KW, lasers mainly use stable cavity

design laser output is from the centre of optical axis.

* Stable cavity design allows the beam to oscillate many times inside the cavity to get high gain, the focal property and directionality are improved. For higher powered lasers, unstable cavities are often used laser output comes from the edge of the output mirror, which is often a totally reflecting metal mirror.

* The ring shaped beam reduces the intensity of the beam, thus reduces the risk of breakage. In the same time, ring shaped beam is poor for focusing.

* Unstable cavities are suitable for high gain per round trip laser systems, which don't require large numbers of osillation between the mirrors.

Q-SWITCHING AND MODE LOCKING:-

Q-Switching:-

Q-Switching is a technique for obtaining energetic short (but not ultrashort) light pulses from a laser by modulating the intracavity losses and thus the Q factor of the laser resonator.

The technique is mainly applied for the generation of nanosecond pulses of high energy and peak power with solid-state bulk lasers.

Mode Locking:-

Mode locking is a technique in optics by which a laser can be made to produce pulses of light of extremely short duration, on the order of picoseconds (10^{-12} s) or femtoseconds (10^{-15} s).

Laser operated in this way is sometimes referred to as a femtosecond laser, for example, in modern refractive surgery.

Q-switching technique:

① Pocket cells act as a quarter wave plate producing a phase difference. When there is no voltage given to cell, there is no phase shift for linearly polarized light from the polarizer. Let the light photon travel from mirror M_1 to M_2. When m = n, the voltage is given to the cell, there is a phase shift.

② Therefore the linearly polarized light is converted into circularly polarized light. Reflection at the mirror M_2 changes the direction of the rotation of circularly polarized light. So, the polarizer does not allow the light to pass through it.

③ Now, the cavity is switched off. Thus, when the voltage given to the cell is zero, the cavity is Q-switched and if there is voltage, the cavity is inactive to produce laser osillation. The changes of voltage from zero to a non-zero, the cavity is Q-switched, and if there is voltage, the cavity is inactive to produce laser osillations.

④ The change of voltage from to zero to a non-zero value should take place within 1nsec.

MODE LOCKING TECHNIQUE :-

① Mode locking is a technique in optics by which a laser can be made to produce pulses of light of extremely short duration, on the order of picoseconds ie (10^{-12} seconds) or femtoseconds ie (10^{-15} seconds).

② The basis of the technique is to induce a fixed phase relationship between the modes of the laser's resonant cavity. The laser is then said to be phase-locked or mode-locked.

③ Interference between these modes causes the laser light to be produced as a train of pulses. Depending on the properties of the laser, these pulses may be of extremely brief duration, as short as a few femtoseconds.

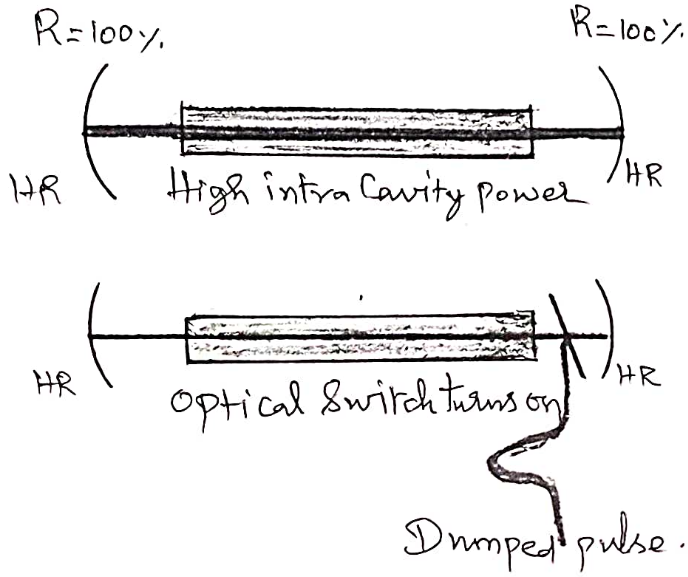
④ Methods for producing mode locking in a laser may be classified as either active or passive

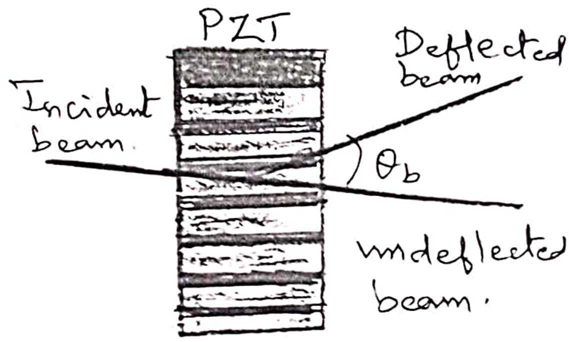
⑤ Active methods typically involve using an external signal to induce a modulation of the intra cavity light.

⑥ Passive methods do not use an external signal, but rely on placing some element into the laser cavity which causes self-modulation of the light.

Cavity Damping:-

Cavity damping is a technique for pulse generation which can be combined either with Q-switching or with mode locking, or sometimes even with both techniques at the same time.





* We replaced the output coupler with a High Reflector (HR) to allow high intracavity power. When intracavity power peaks, an optical switch is gated on to extract the circulating power within a few round trips, creating a pulsed output.
* After excitation the optical switch is gated off to allow intracavity power to build up again.
* The optical switch is usually an acousto-optic modulator (AOM).

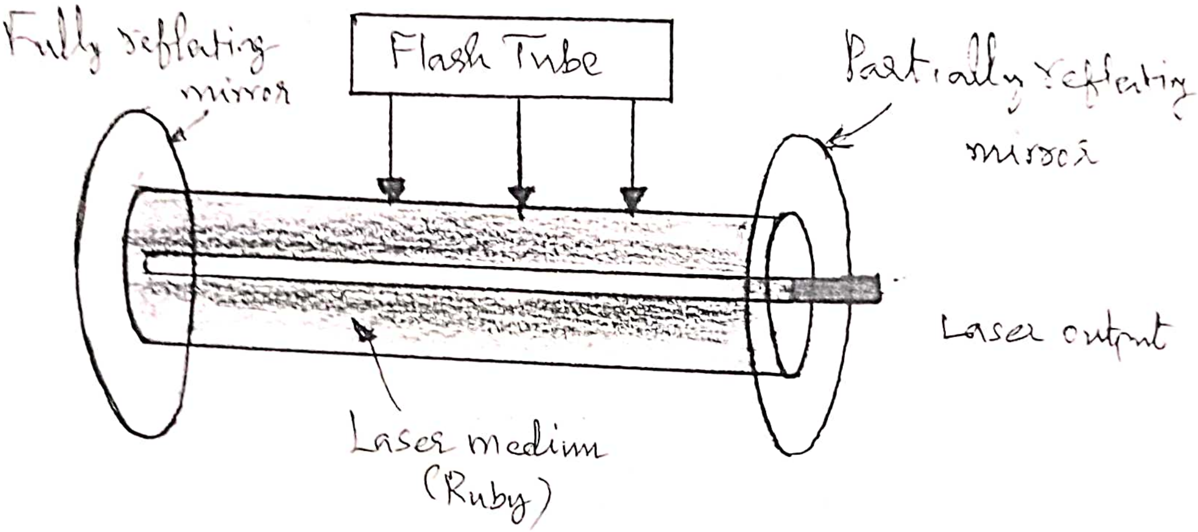
* A piezoelectric transducer bonded to a crystal sends acoustic waves through the crystal when excited by a RF signal. The spatially varying index of refraction create an optical grating which deflects the pulsed beam out of the cavity.

* The repetition rate of the optical switch must be slow enough to allow the cavity to at least partially rebuild power. The RF must be gated on for long enough to allow a pulse to be dumped.

TYPES OF LASERS:

Lasers are classified into 4 types based on the type of laser medium used.

1. Solid State Laser :-



* A solid laser is a laser that uses solid as a laser medium. In these lasers, glass or crystalline materials are used. Ions are introduced as impurities in host material which can be a glass or crystalline. The process of adding impurities to the substance is called doping. Rare earth elements as cerium (Ce), erbium (Er), terbium (Tb) etc. are most commonly used as dopants.

* Materials such as sapphire (Al_2O_3), neodymium-doped yttrium aluminium garnet (Nd: YAG), Neodymium-doped glass (Nd: glass) and ytterbium-doped glass are used as

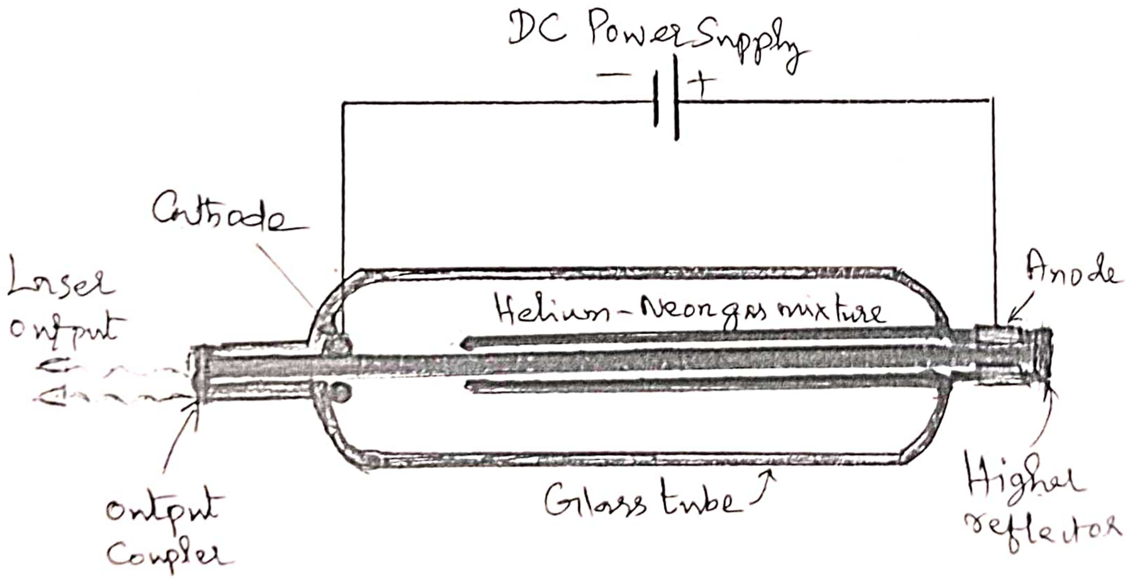
Host materials for laser medium.

* The first solid state laser, a ruby crystal is used as a laser medium.

* In solid state lasers, ~~laser~~ light energy is used as pumping source. Light sources such as flash tube, flash lamps, arc lamps, or laser diodes are used to achieve pumping.

* Semiconductor lasers do not belong to this category because these lasers are usually electrically pumped and involve different physical processes.

GAS LASER :-



* A Gas laser is a laser in which an electric current is discharged through a gas inside the laser medium to produce laser light. In gas lasers, the laser medium is in the gaseous state.

* Gas lasers are used in applications that require laser light with very high beam quality and long coherence lengths.

* In gas laser, the laser medium is made up of the mixture of gases. The mixture is packed up into a glass tube. The glass tube filled with the mixture of gases acts as an active medium or laser medium.

* A gas ~~laser~~ laser is the first laser that works on the principle of converting electrical energy into light energy. It produces a laser light beam in the infrared region of the spectrum at 1.15 μm.

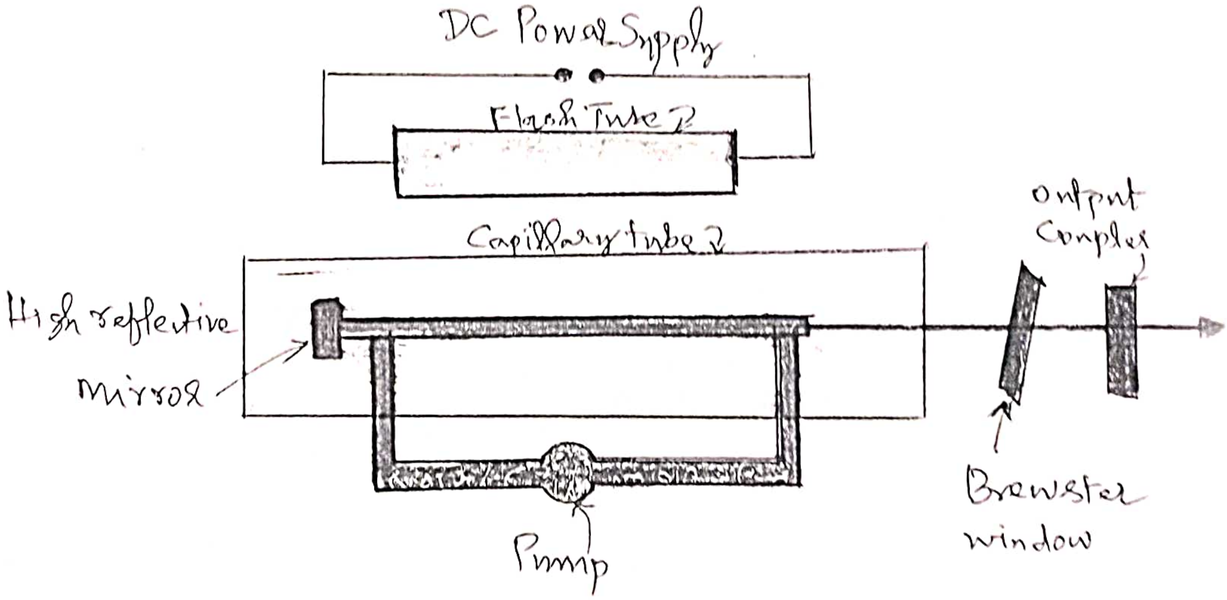
Types of Gas lasers:

(i) Helium (He) - neon (Ne) lasers
(ii) Argon ion lasers.
(iii) Carbon dioxide lasers (CO_2 lasers).
(iv) Carbon Monoxide lasers (CO lasers)
(v) Excimer lasers
(vi) Nitrogen lasers., etc.

LIQUID LASERS:

1. A Liquid laser is a laser that uses the liquid as laser medium. In liquid lasers, light supplies energy to the laser medium.

2. A dye laser is an example of the liquid laser. A dye laser is a laser that uses an organic dye (liquid solution) as the laser medium.



3. In the figure shown above, the dye is pumped through the Capillary tube from a storage tank. While in Capillary tubes it is optically excited by flash lamp. The output of the laser passes through a Brewster window to the output Coupler which is 50% reflective mirror.

(4) We know that active medium used in a dye laser can be one of the organic dyes. The medium is dissolved in a solvent such as water, alcohol or ethylene glycol.

(5) The organic dye such as rhodamine B, sodium ~~fluor fluo~~ fluorsin for example chemical formula for one of these dyes rhodamine-B is C28H31. It is therefore very difficult to determine the element that actually lases. For this reason we ~~s~~ will simply say that some organic dye will lase.

(6) By using birefringent, it is possible to tube the laser to specific output frequency. This makes it possible to tube the laser with great deal of accuracy.

Applications:-

Dye lasers are mostly used in medical applications.

Advantages:-

It is available in visible form.
Beam diameter is very less and construction is simple.
It gives high output power.

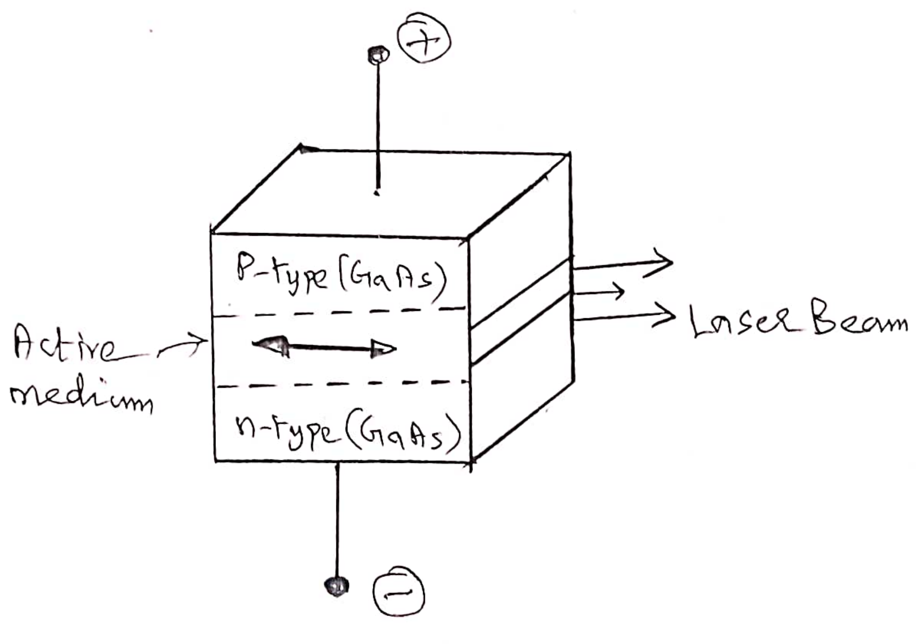
Disadvantages:-

Cost of dye lasers ~~are~~ is very high.
In dye lasers it is very diffcult to determine the element that actually lases, because dye has complex chemical formula.

Semi Conductor Laser :-

Semi Conductor lasers play an important role in our everyday life. These lasers are very cheap, Compact size and consume low power. Semi conductor lasers are also known as laser diodes.

Semi Conductor lasers are different from Solid-state lasers. In Solid-state lasers, light energy is used as the Pump Source, whereas, in Semiconductor lasers, electrical energy is used as the pump Source.



① The Semi Conductor lasers is made up of different materials like, gallium arsenide (GaAs), Indium Phosphide (InP), Gallium nitride (GaN), etc. The band gap of the semi conductor laser is different and hence light of different wavelengths is emitted by these laser

(v) The band gap of InP is 1.35 eV and this material is used to produce laser light of wavelength 1.5 μm. Similarly, GaN has a band gap equal to 3.36 eV. A laser made of GaN is used to emit blue light and ultraviolet rays.

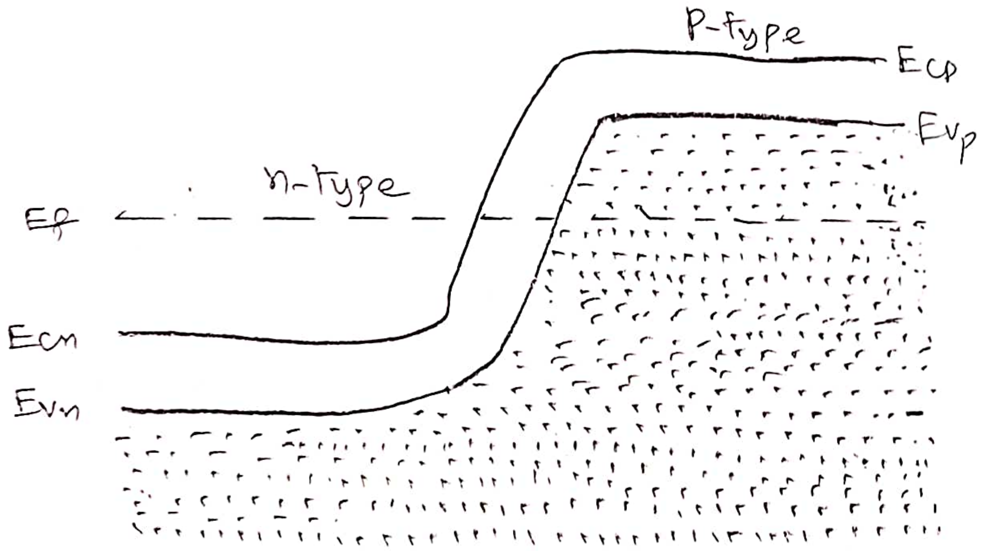
Working of Semi Conductor diode Laser:-

* The active medium of Semi conductor laser is a PN junction. In this laser, mirror is not used as in other resonator or cavity for optical feedback to sustain laser oscillation.
* In this case, the reflectivity due to the refractive indices of two layers of a Semiconductor laser is used for optical feedback. The end faces of two types of Semiconductors (i.e. P-type and n-type) are cleaved and are perfectly parallel to each other for achieving optical feedback.
* If the active medium or junction is made of a single type of Semi Conductor material, then the Semi conductor laser is also known as "homo junction Laser". On the other hand if the junction is made of different types of Semiconductor material, then the Semi Conductor laser is known as a "heterojunction Laser".

* The forward bias voltage causes the carrier pairs (i.e electron in n region and hole in p-region) to inject into the junction region, where they recombine by means of stimulated emission.

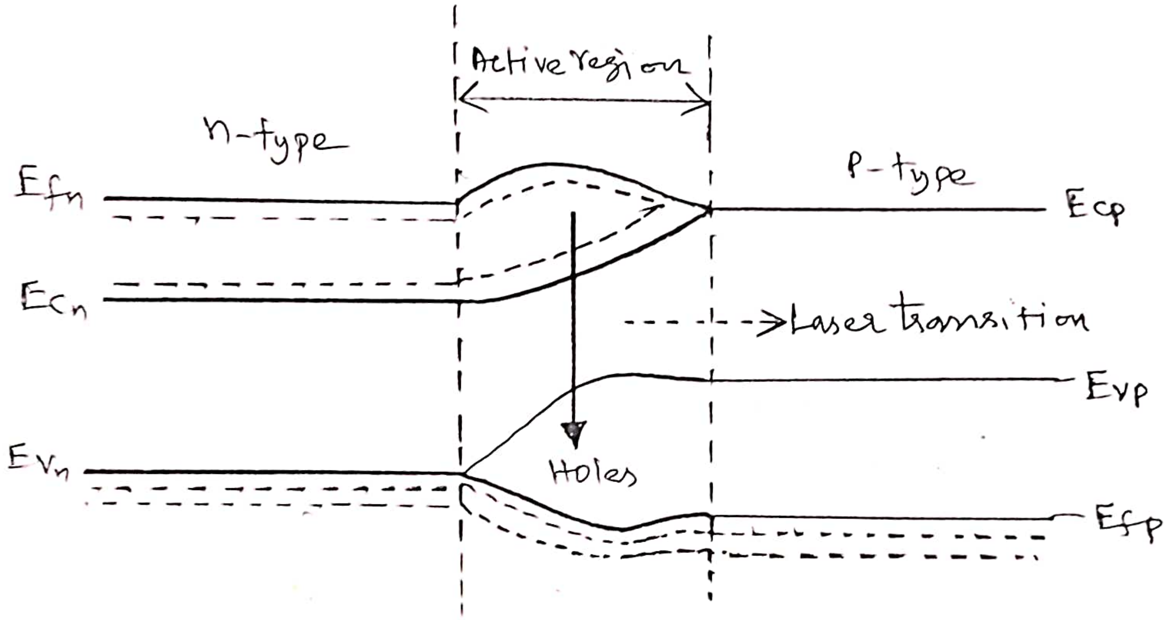
Process:-

At the equilibrium, the fermi level is inside the conduction band of n-type semiconductor and it is inside the valance band of P-type semiconductor.



When P-n-junction is forward biased, the electrons will be injected into conduction band along and side, and the number of holes are produced in the valence band along the P-side of the junction.

Thus, there will be more electrons in the conduction band than that in the valence band. Hence population inversion is achieved.

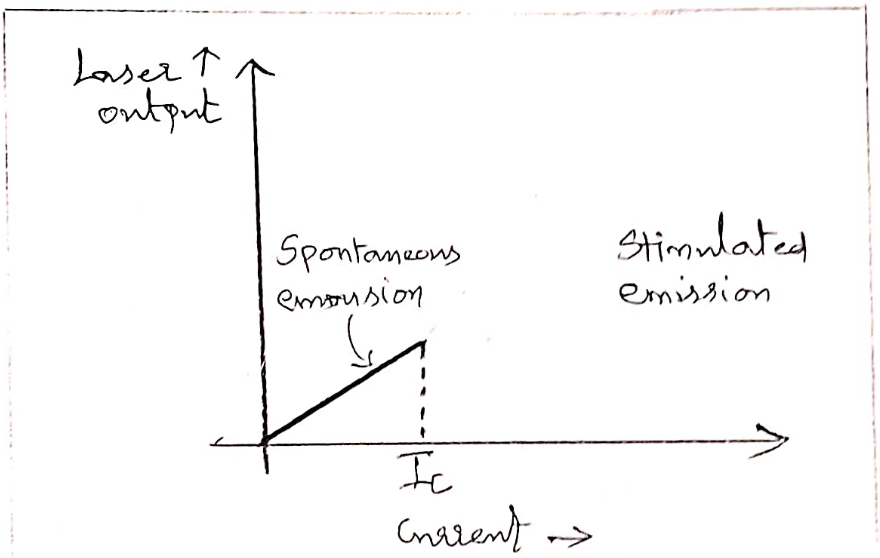


If the forward voltage is low ie forward current is small, the electron jumps from the conduction band to the valence band where, they recombine with hole and emit incoherent light. This is the function of the light-emitting diode.

However, if the forward voltage is high ie forward current is large, the electron jumps from the conduction band to the valence band, then due to the recombination of electron and holes, a photon of energy equal to the forbidden energy gap (E_g) is emitted by 'spontaneous emission' in the junction region of GaAs semiconductor.

This photon stimulated the laser action near the junction. The laser action takes place in the narrow region and the laser oscillation (ie. optical feedback) is done due to the repeated reflection between the cleaved end surfaces.

Laser output Vs Current:-



* When the forward current is low, the population inversion built compensate losses in the system. ie absorption exceeds the gain and hence no lasing action takes place. In this case, laser out varies linearly with current.
* When the current exceeds the critical value (I_c) called "threshold current," the gain exceeds the losses in the system and lasing action takesplace. In this case, laser output increases dramatically with an increase in the current.

Comparison of various types of Lasers

	Solid Lasers	Gas Lasers	Liquid Lasers	Semiconductor Laser.
Advantages	1. Both Continuous and Pulsed output is possible 2. It has high effiency 3. Construction is Simple 4. output power ranging from 0.04 to 600 Watts 5. Cost is economical.	1. cheap gain medium 2. Difficult to damage the gain medium. 3. A gas medium is more uniform with less loss. 4. Larger laser output 5. Less Cost.	1. Low power Consumption 2. operation may be either in Continuous or Pulsed mode.. 3. Available in visible form. 4. Construction is Simple 5. Beam diameter is Very less	1. It requires Low Power for its operation. 2. Compact and lightweight 3. Long life. 4. output of this laser can be easily increased by controlling the junction current. 5. Arrangement is Simple.
Dis-Advantages	1. Great disadvantage of Solid State lasers is the divergence. 2. output power is also not very high. 3. Due to thermal lasting in Solid State laser power loss occurs.	2. It requires high Power. 2. Bulky and Complex 3. output power is low. 4. Very Sensitive in nature. ~~5 Used in Sending bar Codes~~	1. Sensitive to temperature 2. Simple & no complex 3. Beam diameter is very less so much affected by Electromagnetic Interference 4. Short life time. 5. Potentially toxic	1. A large current is needed to operate and they may be damaged if this large current is made to flow to glow continuously to the p-n junction. 2. Radiation is more 3. It dependent on temperature
Application	1. Usually used when drilling holes in metal 2. Used in medical applications such as in endoscopy 3. Military application	1. Used in Semiconductor Photolithography 2. Used in LASIK eye surgery. 3. Used in sending bar codes	1. Bio medical Sensing. 2. Medical procedures as cutting during Surgeries. 3. Used in LCD based display 4. Used in Microscopy.	1. Used in optical Fiber Communication to provide high frequency waves for modulating low frequency Signal. 2. Medical usage

UNIT-IV INDUSTRIAL APPLICATIONS OF LASER

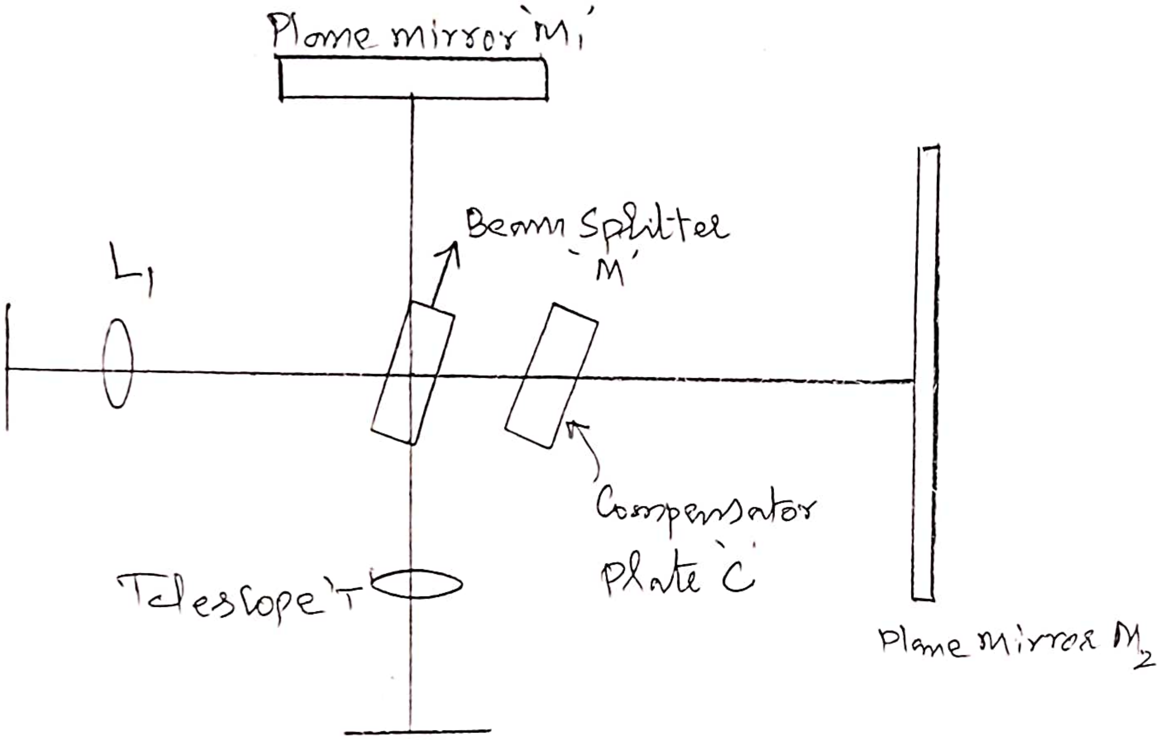
Introduction:-

① There are literally thousands of references on the theory and practical uses of lasers. They are used in everything from portable CD players to sophisticated weapons systems.

② The term laser is an acronym for "Light Amplification by Stimulated Emission of Radiation," and is defined as any of several devices that emit highly amplified and coherent radiation of one or more discrete frequencies.

③ The Nd: yag (Neodymium-Doped Yttrium-Aluminum-Garnet) rod, when stimulated by a flash lamp, emits light in the ultraviolet range with a wave-length of 1.06 microns. The light is then focused and delivered to the workpiece, where the high efficiency and energy density beam is used to weld.

LASER FOR MEASUREMENT OF DISTANCE:



Laser based distance measurements can be done using interferometric principles. Measurements of length using optical interferometry have been performed since 19th century.

Lasers have allowed interferometer to develop into a fast, highly accurate and versatile technique for measuring longer distance.

Operation:-

The beam from the laser falls on the beam splitter that reflects half the beams in one direction and transmits the other half. The two beams are each reflected by mirrors, a stationary mirror in the reference arm and a movable mirror in the measurement arm. In practice, the mirrors are often cube corner reflectors which offer better stability against vibrations than conventional flat mirrors.

Schematic diagram (Ref. figure) of the application of a Michelson interferometer to measurement of distance. The two reflected beams are recombined at the beam splitter to form an interference pattern that is viewed by an observer or measured by a recorder such as a photo detector.

The character of the fringes is related to the different optical path lengths travelled by the two beams before they are recombined.

Suppose, for example, that the detector is viewing a bright fringe in the interference pattern when the movable mirror is at a certain position. If the movable mirror move a distance equal to $\frac{1}{4}$ of the wavelength of light, the round-trip distance travelled by the light in the measurement arm will change by ½ wave length, and the fringe pattern will change so that the detector now views a dark fringe. The distance measurement thus consists of counting the number of fringe variations as the mirror moves. Each complete fringe corresponds to a phase variation equal to 2P. The variation in phase d is determined by,

$$d = \frac{4P\,Dx}{l} \;;$$

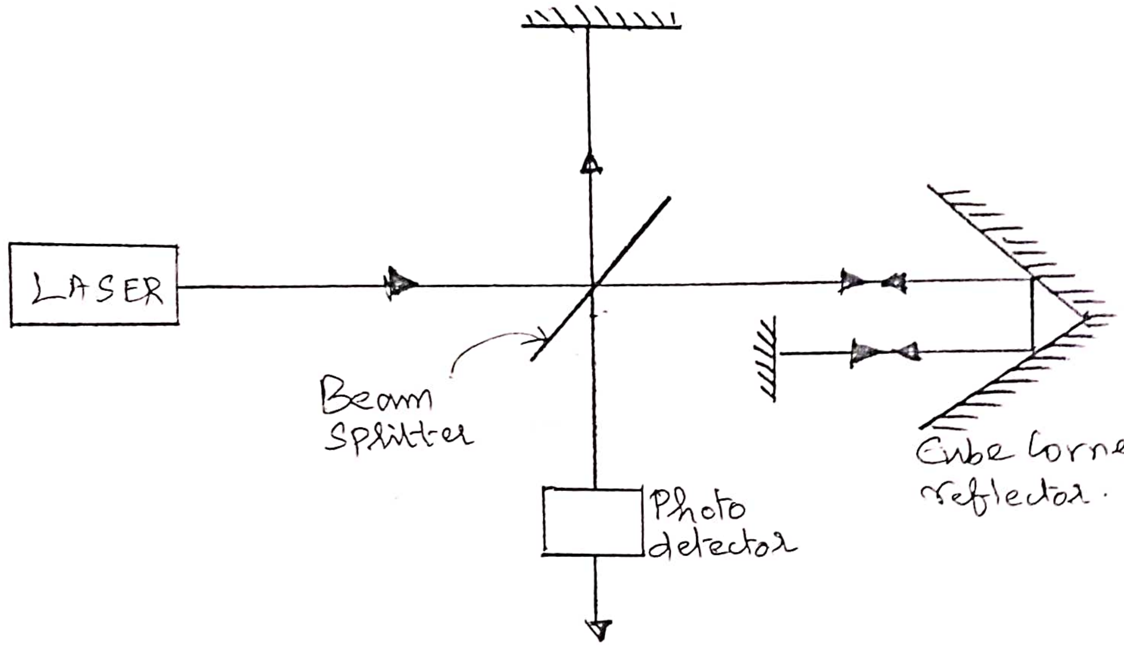
l → wave length of light

Dx → is the distance that movable mirror has moved.

It is apparent that this method offers high precision, allowing measurements of Dx to be made with an accuracy of the order of a friction of the wave length of light. The maximum distance Dx that can be measured in this way, $Dx_{max} = C/Dv$.

where, C = velocity of light, Dv = line width of laser

LASER FOR MEASUREMENT OF LENGTH.



* The large coherence length and high output intensity coupled with a low divergence enables the laser and find applications in precision length measurements, using interferometric techniques.
* Here the laser beam is split into two parts, and they are made to interfere after transversing two different paths. One of the beam emerging from the beam splitter is reflected by a fixed reflector and the other by a cube corner reflector.
* The two reflected beam interfere to produce either constructive or destructive interference.

* As the reflecting surface is moved, one would get alternatively constructive and destructive interference which can be detected with the help of a photo detector.

* Since the change from a constructive to a constructive and destructive interference corresponds to a change of a distance of half a wavelength.

* One can measure the distance transverse by the surface on which the reflector is mounted by counting the number of fringes which have crossed the photo detector.

Applications:-

(1) This technique is used for accurate positioning of aircraft components.

(2) On a machine tool, for calibration and testing of machine tools, for comparison with standards.

LASER FOR MEASUREMENT OF VELOCITY

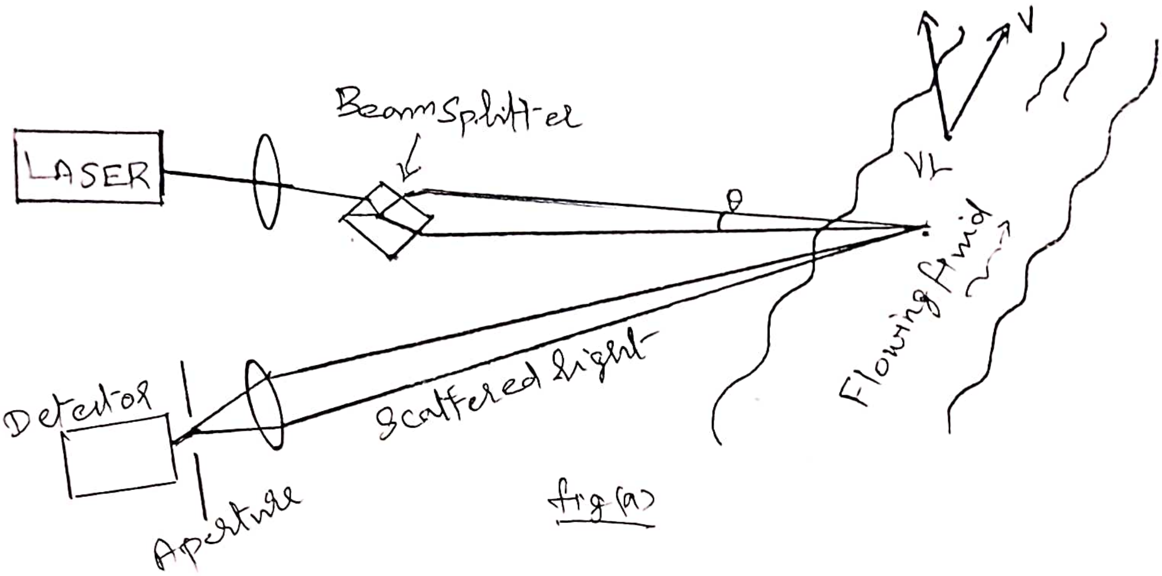


fig (a)

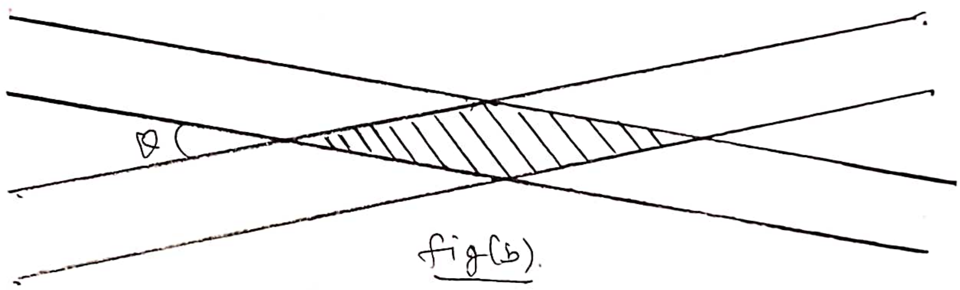


fig (b).

Principle :-

(1) Measurement of the velocity of fluid flow can be performed by scattering a laser beam from a liquid (or) gas.

(2) The laser beam interacts with small particles carried along by the flowing fluid. The particles scattered light is slightly shifted by the "doppler effect".

(3) The magnitude of the frequency shift is proportional to the velocity of the fluid. Measurement of the frequency shift directly gives the flow velocity.

Construction:-

(i) The measurement techniques basically consist of a focusing laser light at a point within the flowing fluid.

(ii) Light scattered from the fluid or from particles entertained within the fluid flow is collected and focused on an optical detector.

(iii) Signal processing of the detector output yields the magnitude of the Doppler frequency shift and hence the velocity of flow.

Working:-

a) The approach towards measurement is called 'Dual beam approach'.

b) Light from a continuous laser is split into two equal parts by a beam splitter. The lens focuses the beam to the same position in the fluid. The place where the two beams crosses in the fluid, they interefere to form fringes consisting of alternating regions of high and low intensity.

c) When the particle transverse the fringe pattern, it will scatter light when it passes through regions of high intensity.

d) The scattering will be reduced when a particle is passing through regions of low intensity. Light scattered by a particles in the fluid and arriving at the detector will produce a varying output, the frequency of which is proportional to the rate at which particle traverses the interferences fringes.

Advantages:-

1) No critical contacts with a fluid and flow is not disturbed.

2) Hot or corrosive fluids can be measured without problems.

3) Measurement is very accurate.

4) Speed of response is high.

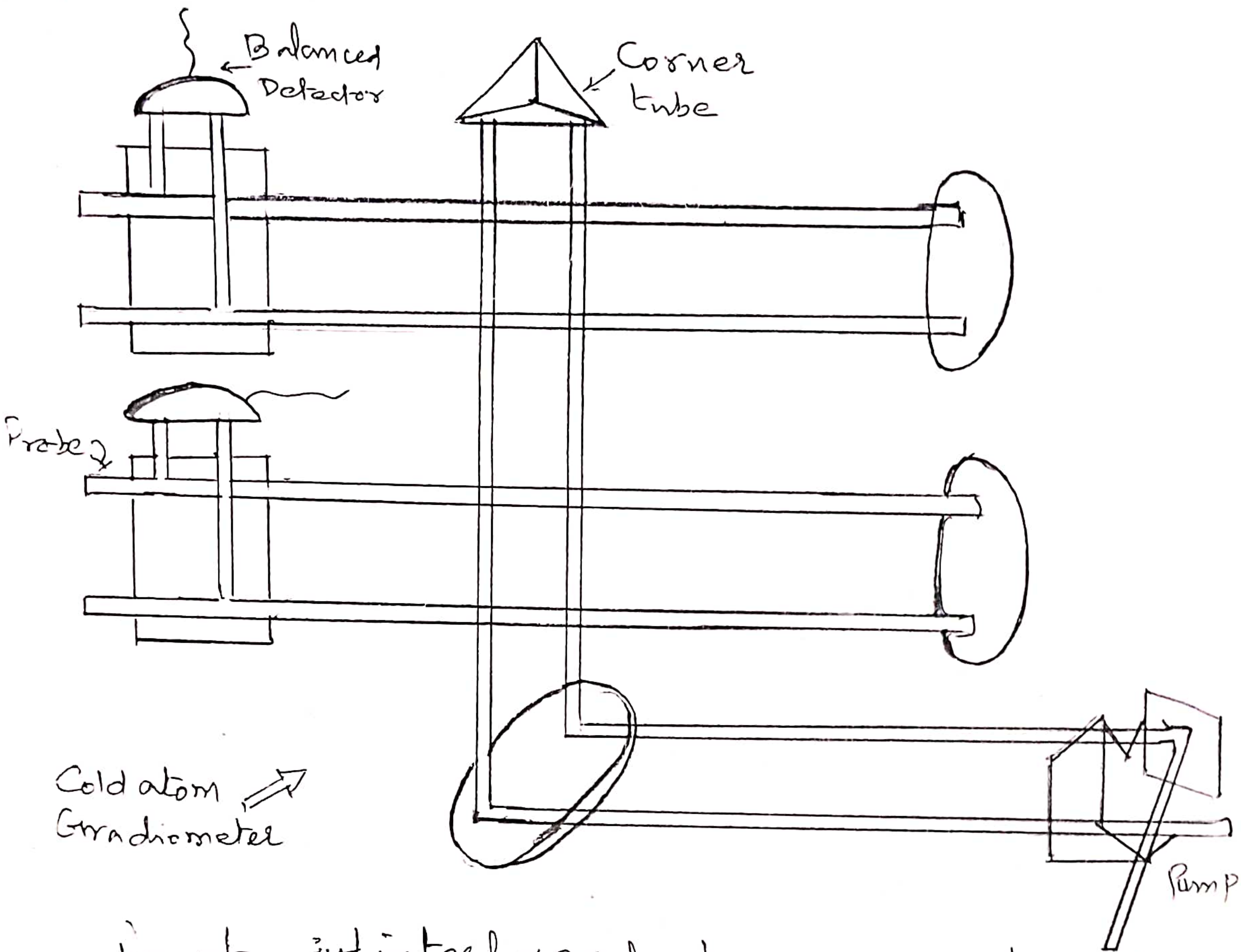
Dis-advantages:-

1) These require the necessity of having scattering entertained in the fluid. Impossible to measure flow rate of cleaned fluid.

2) Cost is high.

3) It is possible to seed the flow with scattering particles. But the constraint is that particles seeded into the flow must be very small so as to follow the flow faithfully

LASER FOR MEASUREMENT OF ACCELERATION.



In atom ~~int~~ interferometer based on an atomic fountain of laser cooled caesium atoms using laser light has been used to make a very accurate measurement of 'g'.

Principle:-

In this interferometer, the frequency of the light is changed in a phase continuous way so that it remains resonant with the transitions as the atom accelerate under the influence of gravity 'g'. As a consequences, the phase difference between the two ~~points~~ paths in the interferometer is proportional to the gravitational attraction.

Cold atom Gradiometer :- (Ref. Fig.)

An atom interferometry technique has been used to create a gravity gradiometer using two laser cooled and trapped sources of caesium atoms and a pair of vertically propagating laser beams.

The device is arranged so that two independent measurements of acceleration can be made using the two vertically separated ensembles of caesium atoms in free fall under the influence of gravity.

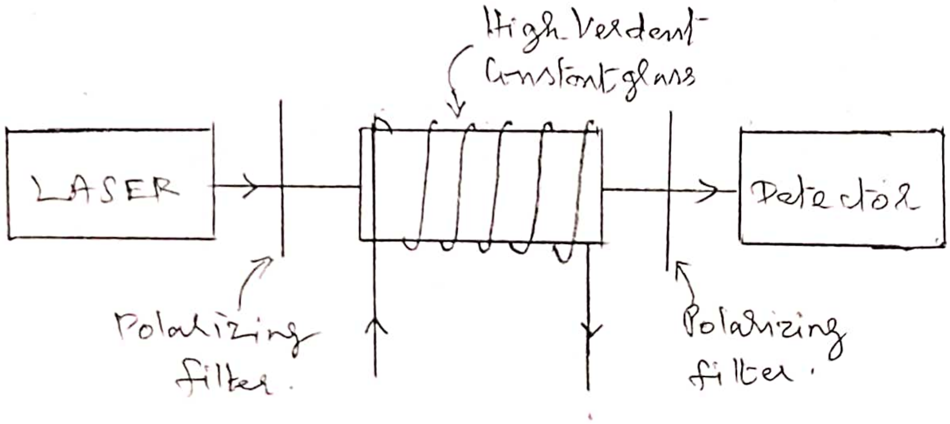
Working :-

① The caesium atoms are launched into a vertically trajectory form the magneto-optical trap and conditioned to be in a particular internal state using optical and microwave techniques. These atoms are then suitable for interacting with the gravity vector and then changes in the atomic states due to gravitational acceleration which can be detected in the interferometer.

② The simultaneous measurements of the effects of gravity on the pair of vertically separated sensors are made with respect to the same set of Raman laser fields. This is achieved by a simultaneous measurements of the fraction of atoms excited by the laser ~~plate~~ pulse sequence at the two positions where the gravity vector is measured.

(3) The differential acceleration is given by the differential phase shift between the upper and lower atomic ensembles and this difference in phase shift is proportional to the difference in the mean value of 'g' measured at the two part of the sensor.

LASER FOR MEASUREMENT OF CURRENT AND VOLTAGE



Principle:-

If polarized light is passed along a magnetic field of strength 'H', the plan of polarization is rotated by an amount given by, $\phi = VNI$.

Working:-

A System for Current/Voltage measurement using the Faraday effect.

Light from the laser Source is passed through a polarizing filter and then through a high verdet-Constant glass rod in the magnetic field of current and Voltage to be measured. With no current flowing, a steady signal will be received at the detector. In the presence of current, the plane of polarization will be rotated clockwise or anticlockwise depending on the direction of the current while the angle of rotation will be a function of the current & Voltage magnitude.

LASER FOR MEASUREMENT OF ATMOSPHERIC EFFECT

The atmosphere is the ability to study its components including cloud, aerosols, ozone and water vapour.

Laser based System called LIDARS (Light Detection and Ranging) is used to Study the atmosphere with high precision.

A LIDAR can penetrate thin or broken clouds in the lower atmosphere. The Space based LIDAR can provide global measurement of the vertical structure of clouds, and atmospheric gases. Both ozone and water vapour are involved in many important atmospheric processes that can affect life on earth, climate changes, weather, global pollution levels etc.,

TYPES OF LIDAR:

Remote sensing, surveying and monitoring have, in the fast few years, reached new heights with the power of the LIDAR technology. The proliferation of LIDAR, which stands for light detection and ranging, is now seen in multiple industries including forestry, disaster management, weather prediction, construction, archaeology and many more:

Terrestrial LIDAR:

As the name suggests, Terrestrial LIDAR is a system that works on the ground. It can be either mounted on a moving vehicle or implated ~~at~~ a static location.

Either way, terrestrial LIDAR data is benefinal for applications that require a detailed survey of the ground or "a closer look" at objects.

Mobile LIDAR :-

A mobile LIDAR setup typically comprises a sensor, a global positioning system (GPS), an Inertial Navigation System (INS) and a few cameras. It is mobile because the unit is placed on top of a moving vehicle, such as a car or a train.

From this moving vehicle, the LIDAR units continues to send out laser pulses in all directions and read the reflections. These valuable point clouds (data points) and then processed to understand the conditions of roads and railway tracks, identify unwanted obstacles on the road and so on.

In self-driven cars, an advanced rotating LIDAR sensor is mounted on top of the car that detects the presence of pedestrians / other vehicles on the road.

Static LIDAR:

In some applications, it is advantageous to have the LIDAR unit fixed at one point rather than have it move around. Such applications use static LIDAR.

In this setup, the LIDAR unit is mounted on a static object, which is usually a tripod. If needed, the entire unit can be moved to another location along with the tripod. In essence, even though this unit is not mobile, it is fully portable.

A static LIDAR unit continues to send laser pulses to the surrounding area from a fixed point. The data is then used to understand the characteristics of the surroundings. This functionality is highly useful in applications such as building construction, mining engineering etc.

Airborne LIDAR:-

When the LIDAR Unit is Airborne, it means that the system is placed either in an aircraft or a helicopter that continues to hover above the surface of the earth, sending laser pulses downward as it moves.

Airborne LIDAR can scan vast areas in a shorter time as compared to terrestrial LIDAR. This makes airborne LIDAR systems suitable for those applications that require a bird's eye view of an area spanning multiple acres. It can be further classified based on what kind of area the LIDAR unit scans,

(i) Topographic and (ii) Bathymetric LIDAR

(i) Topographic LIDAR:

It is used to scan any kind of land, wherein the laser pulses sent down to the surface of the earth, provide an estimate of the various characteristics of the area. The rise and fall of the surface are mapped out based on the altitude of the structures that reflect the laser beams.

In short, It is used to chalk out the topographic map of a particular piece of land. Applications of topographic LIDAR include forestry, infrastructure mapping, geomorphology and so on.

(ii) Bathymetric:

A Bathymetric LIDAR sensor consists of all the components of a topographic LIDAR plus and extra characteristic that allow the unit to send green laser pulses. These pulses can penetrate the water surface and return to the airborne vehicle.

Data collected in this manner gives an estimation of the depth of the water bodies. When used in conjunction with the topographical sensors, these units can identify shorelines and elevations more distinctly. Coastal engineering and marine sciences typically ~~bef~~ benefit from such LIDAR systems.

Satellite LIDAR :-

LIDAR units can also be set up in satellites that revolve around the earth. With satellite LIDAR systems, it is possible to scan greater portions of not just the earth but also the atmosphere above the earth.

Multiple such space-borne LIDAR systems have been used by NASA to understand cloud positioning above the earth, vegetation, the state of the ~~ey~~ ice on the two poles, and so on.

More advanced satellite LIDAR units are being developed that can read particles in the atmosphere as well

LIDAR APPLICATIONS.

(i) Atmospheric Science
(ii) Pollution detection and characterization.
(iii) Dynamic measurements: temperature, waves and winds.
(iv) Topographic mapping.
(v) Erosion monitoring.
(vi) Bathymetry
(vii) Harbor profiling for marine safety.
viii) Allows cavern monitoring for safety workers

MATERIAL PROCESSING:

1. Laser instrumentation for material processing:

The output from the laser beam is incident on the plane mirror. After reflection, it passes through a shutter to control its intensity. A focusing lens assembly is used ~~for~~ to get a fine beam.

2. Powder Feeder:-

Used to spray metal powder on the substrate for alloying or cladding.

3. Laser Heating:-

When the laser beam is incident on the surface of the specimen, there is simultaneous absorption and reflection. Particularly, metals are good reflectors of light. Thus most of the incident energy is wasted in the form of reflected energy. To reduce reflection, anti reflection coating are made on the surface so as to increase the absorption energy. Absorptivity increases with increase of laser beam densities and temperature.

Absorptivity is directly proportional to the square root of resistivity of the specimen and it decreases with increase in wavelength. The absorped energy creates lattice vibration and heating of materials.

4. Laser Welding:-

(i) Continuous / Seam welding

- done by continuous wave beams or overlapping pulses.

(ii) Pulse / Spot welding:

- done by microwelding.

Working:-

High power laser radiation incident on metal gives rise to the following process, Electron and ion emission due to heating effects.

Melting, Vaporization and ejection of droplets of melt from the interactive region. Thermal radiation and X-radiation upto 2 KeV.

Ultrasonic Vibrations in metal due to the periodicity of heating and thermal expansion in the interaction of pulses whose substructure consists of spikes.

Part of the energy of incident radiation is reflected from the target surface itself without contributing to the work process.

Advantages:-

1. High input to the welding spot and low heat release
2. High weld rates.
3. Possibility of welding dissimilar metals.

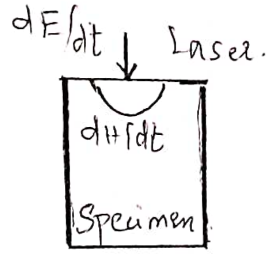
5. Laser Melting:

Due to rise in temperature, there is local melting. In case of Surface modification, the Surface is locally melted and cooled with or without additions of alloying / harde-ning materials. For welding, the surfaces are to be welded are locally melted and bonded together.

In case of cutting and drilling, there is vapourisation after local melting and hole is formed.

There are two methods of melting:

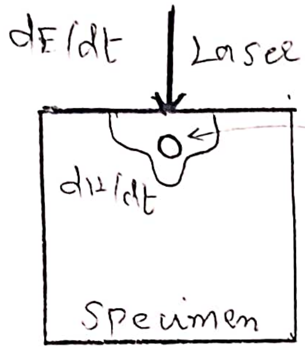
(i) Condustion limited melting / Melting by lower laser



Here the metal obsorps the incident beam on the Surface and heat is conducted through the metal to the sub-surface region. In this melting, the shape of the melted region in the form of hemispherical.

Low power lasers are used in this method. So depth of penetration is limited. The main application for this type of melting is for Surface treatments and welding and cutting of thin specimens. The weld shape is hemispherical due to uniform thermal conduction in all direction.

(iii) Key hole Melting.



In this mode of melting, high power lasers are used. The incident laser beam melts the small cylindrical volume of metal through the thickness of material. A column of vapour is trapped inside this volume surrounded by molten metal.

As the beam is moved, the vapour column moves along with that, melting the metal infront of the column through the depth. The molten metal flows along the base of the column and solidifies on the trailing end. The molten metal present in the walls of the cylindrical column of vapour is held firmly by the equillibrium between high vapour pressure of vapour and the surface tension of the molten metal

The appearance of hole is in the form of key hole. Surrounded by molten metal then solidified metal. This provides greater path penetration due to high absorption of vapour column

LASER TRIMMING OF MATERIAL:

Laser trimming is a manufacturing process that uses a laser to modify the operating parameters of an electronic component or a circuit by reducing the quantity of the component's material incrementally.

A typical application of laser trimming is in adjusting the resistance of an unnecessary thin-film or thick-film resistor by cutting away by smaller proportion of the resisting material.

This trim or cut increases the resistance of a component by narrowing or expanding the resistive material's current paths. Measuring the active resistance value of the material resistor while the trimming process continues is an accurate way of establishing the final results.

Besides, specific capacitors can be accurately laser trimmed to achieve an accurate capacitive. This is usually achieved by removing the upper layer on a multilayer capacitor to decrease its capacitance by reducing the top electrode area.

Process of Laser Trimming:

① Laser trimming technology has many applications such as cutting metal plates. It also makes it possible to cut tiny holes and intricate shapes.

② The laser trim process on stainless steel, mild steel, and aluminium plate is accurate, yields accurate cut quality, and produces a small heat affect zone and a small kerf width.

③ The laser beam comprises a column of highly intense light of a mono colour or wavelength. For instance, of the CO_2 Laser, the wavelength is part of the infrared light spectrum, thus making it invisible to the naked human eye.

④ The beam is about 3/4 inch in its diameter as it passes from the resonator, emitting it through the beam path. The beam can be bounced in various directions using several mirrors and beam benders before focusing on a plate.

⑤ The focussed laser beam passes through a nozzle before it hits the plate. Also, it flows through the nozzle right before it comes into contact with the plate. Besides, compressed gas also flows through the nozzle, for instance, Nitrogen or Oxygen.

A unique lens is used to focus the beam or even a curved mirror, which happens in the laser cutting gear head.

⑥ The beam is accurately concentrated such that the shape of the focus spot and the energy density around the spot is precisely round, centered from the nozzle, and consistent.

⑦ When a giant laser beam is focus down a single pinpoint, the heat density generated is exceptionally high. Take for example, using a magnifying glass to concentrate the sun's rays on a single tip of a reef to start a fire.

⑧ Now consider focusing over 6kW of energy onto a single spot and how the spot becomes. The extreme power density causes rapid heating, melting, welding and complete or partial vaporization of the heated material.

⑨ When trimming mild steel, the laser beam heat is enough to create a standard oxy-fuel heating process since the laser cutting gas is pure oxygen, just like any other oxy-fuel torch.

Passive and Active Trim:-

* Laser trim can be done in two ways: Active and Passive. Passive Trimming involves adjusting a single component such as capacitor or a resistor to a specific value.

* If the trimming changes the entire circuit output, such as its frequency, voltage or attenuation, this is described as an active trim. During the trimming process, the circuit output performance is actively monitored.

* Once the desired output is achieved, the trimming process is automatically shut-off. The process variability arises from the laser power based on the component level, laser spot, size, wavelength, or pulse duration of the laser emitter.

* Electrical contact is required to the component circuit to ensure feedback measurement in both active and passive trim. This is usually done through a dedicated probe card that uses either pressure pins or spring blades.

Advantages of trimming:-

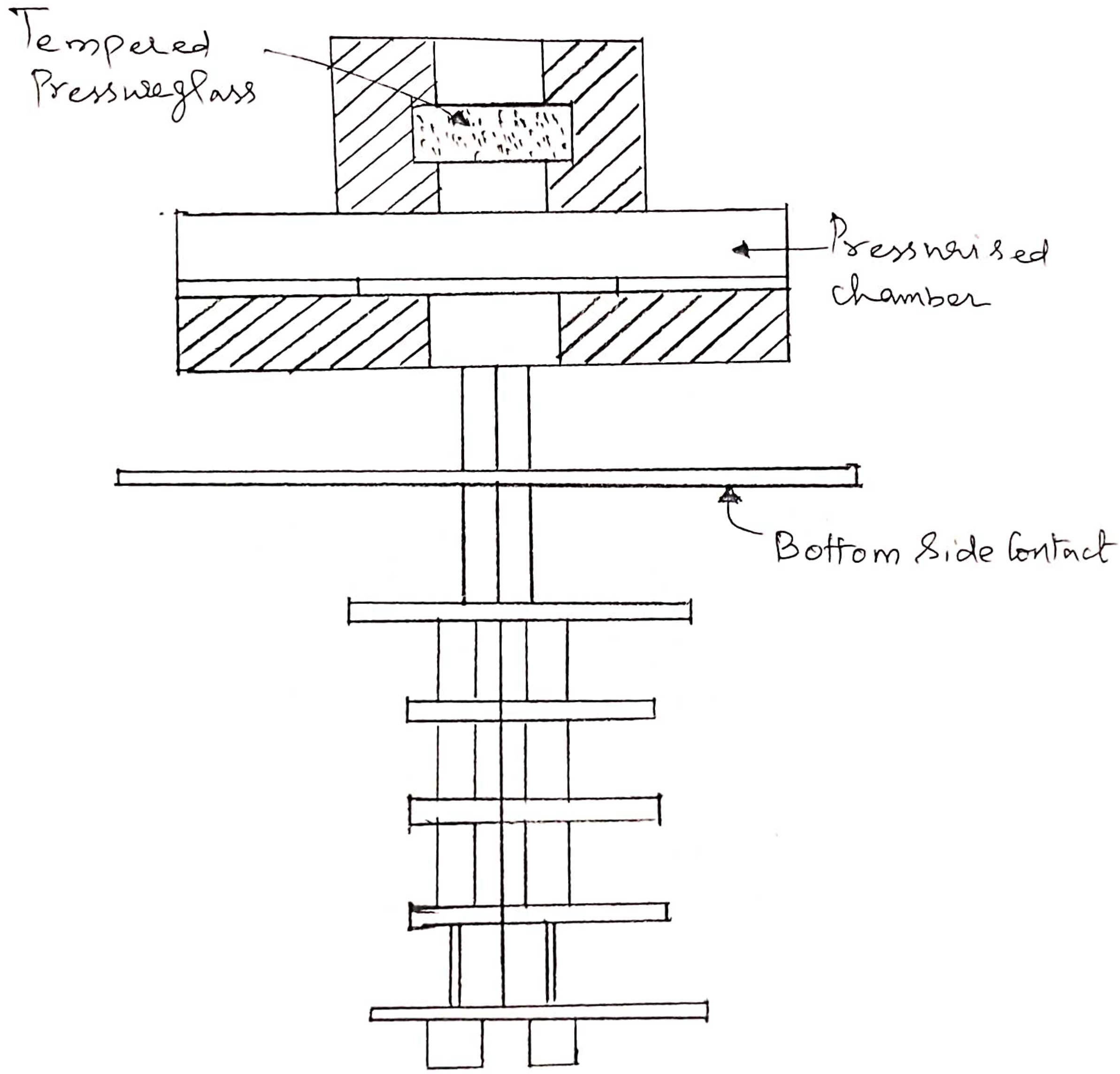
1. we can trim an unlimited number of resistors without hindering regular test probes.
2. No contamination of the adaptor, board, or the trimming System.
3. It has a laser beam density of up to 280 points/cm².
4. Besides, trimming is a useful approach for the Semi-conductor industry.
5. laser alignment involves target modification of electronic circuit properties through link blasting or laser cuts.
6. Better cleanliness when compared to conventional method of abrasive trimming.

MATERIAL REMOVAL AND VAPOURISATION:-

Material processing refers to a variety of industrial operation in which the laser operation in which the laser operates, on a work piece to modify it. Some of the possible applications include welding, hole drilling, cutting, trimming of electronic components, heating and alloying.

properties of laser light that enables material processing applications are its collimation, radiance and focus ability. Because of these properties, laser light can be concentrated by a lens to achieve extremely high irradiance at the surface of work space.

Process of Material Removal:-



① when laser radiation strikes a target surface, part of it is absorbed and part is reflected. The energy that is absorbed begins to heat the surface then penetrates into the target by thermal conduction. When the surface reaches the melting temperature, a liquid interface propagates into the material. With continued irradiation, the material begins to vapourise. If the irradiation is high enough, absorption in the blow off material leads to a hot opaque plasma.

② The plasma can grow back towards the laser as an Laser Supported Absorption (LSA) wave.

x ——————— x

UNIT - V HOLOGRAM AND MEDICAL APPLICATIONS

HOLOGRAPHY:

* The technique of producing a three-dimensional image of an object is called holography. The photograph showing the three-dimensional image of an object is called holograms.

* holos → is the Greek word means "whole"

This technique becomes familiar after the invention of a highly coherent light beam of the laser

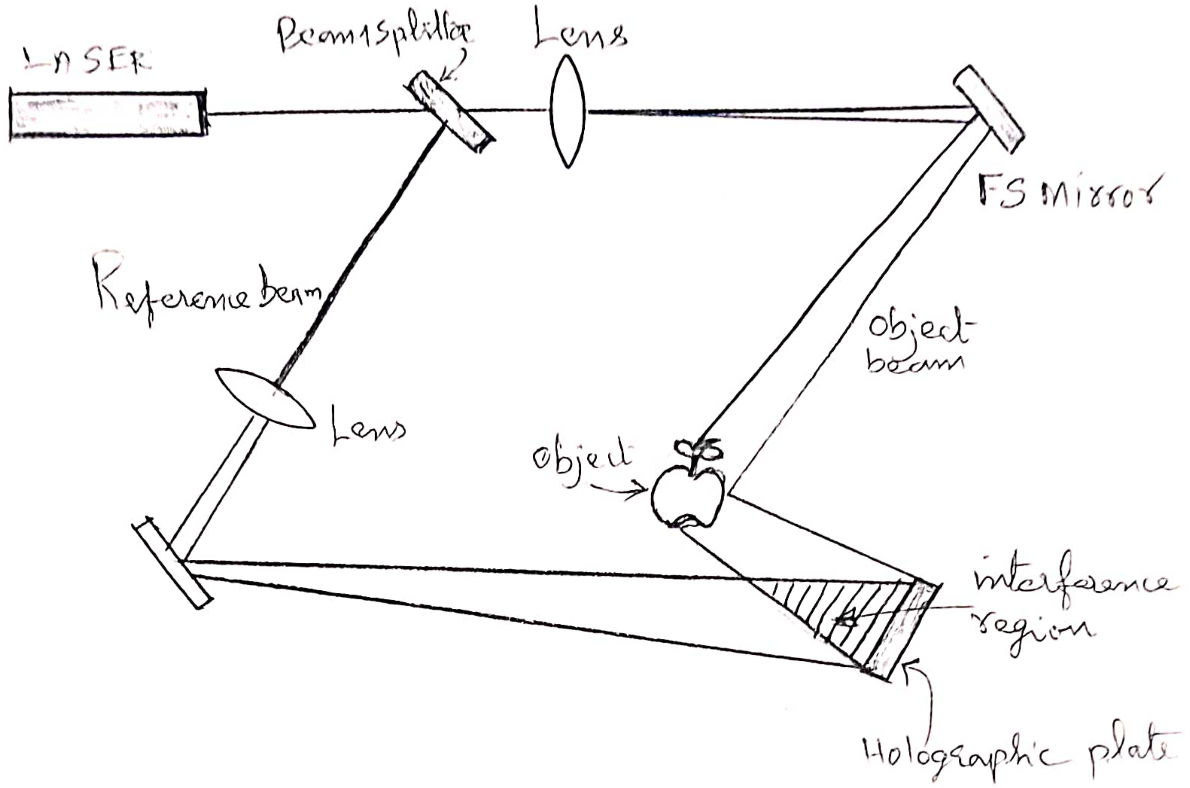
* Holography could also revolutionise medicine, as a tool for visualising patient data while training students and surgeons. ex: MRI Scan, Ultrasound Scans

* The Hungarian-British physicist Dennis Gabor was awarded the Nobel prize in Physics in 1971 "for his invention and development of the holographic method."

* The word holography comes from the Greek words. Ry-alne

* The technique as originally invented is still used in electron microscopy, where it is known as electron holography

How are Hologram pictures formed?



(1) Holograms are made by using a single beam of LASER light.

(2) This beam is then split into two beams by a special lens. That way, you get two laser beams that are exactly the same. one of those beam is the "reference beam" and is shone directly onto the film

(3) The film is basically the same stuff as regular photo film

(4) The second beam is reflected off of the object that you want to make a hologram of.

(5) when two laser beams intersect, they create what's called an interference pattern. This is the pattern that the

two sets of waves make when they overlap

Example:-

To picture this, you can imagine if you dropped two pebbles into a puddle. The pebbles make waves that go outwards, and when the two sets of waves run into each other, they form a pattern. That pattern is what's recorded on to the film. Then when the film is developed, you can see the whole image.

HOLOGRAPHY Vs PHOTOGRAPHY:

S. No	HOLOGRAPHY	PHOTOGRAPHY
1.	It represents a recording of information regarding the light that came from the original scene as scattered in a range of directions.	This allows the scene to be viewed from a range of different angles, as if it were still present.
2.	A holographic recording requires a second light beam (the reference beam) to be directed onto the recording medium.	A photograph can be recorded using normal light sources (sunlight, electric lighting) whereas a laser is required to record a hologram.

	HOLOGRAPHY	PHOTOGRAPHY
3.	The light from the object is Scattered directly on to the recording medium	A lens is required in Photography to record the image.
4.	The holograms can only be viewed with very specific forms of illumination.	The photographs can be viewed in a wide range of lighting conditions.
5.	When a hologram is cut in half, the whole scene can still be seen in each piece. This is because, each point on a holographic recording includes information about light scattered from every point in the scene.	When a photograph is cut in half, each piece shows half of the scene. This is because, each point in a photograph only represents light scattered from a single point in the scene.
6	A hologram is a three dimensional representation. The reproduced viewing range adds many more depth perception ~~cues~~ cues that were present in the original scene. These cues are recognized by the human	A photograph is a two dimensional representation. That can only reproduce a rudimentary 3dimensional effect.

S. no	HOLOGRAPHY	PHOTOGRAPHY
	brain and translated into the same perception of a 3 dimensional image as when the original scene might have been viewed.	
7	The developed hologram's surface consists of a very fine, seemingly random pattern, which appears to bear no relationship to the scene it recorded.	A photograph clearly maps out the light field of the original scene

PRINCIPLE OF HOLOGRAM RECORDING:

Figure: Pls. ref. Section: How are hologram pictures formed?

Holography is a technique that enables a light field, which is generally the product of a light source scattered off objects, to be recorded and later reconstructed when the original light field is no longer present, due to the absence of the original objects.

Holography can be thought of as somewhat similar to sound recording, where by a sound field created by vibrating matter like, musical instruments or vocal cords, is encoded in such a way that it can be reproduced later without the presence of the original vibrating matter.

Apparatus:-

Figure:- Ref. Page no:

A hologram can be made by shining part of the light beam directly on to the recording medium, and the other part on to the object. in such a way that some of the scattered light falls on to the recording medium.

A more flexible arrangement for recording a hologram requires the laser beam to be aimed through a series of elements that change it in different ways. The first element is a beam splitter that divides the beam into two identical beams each aimed in different directions.

Several materials can used as the recording medium. One of the most common is a film very similar to photographic film. A layer of this recording medium (ex: silver halide) is attached to a transparent substrate, which is common glass, but may also be plastic.

CONDITION FOR RECORDING A HOLOGRAM:-

(1) A suitable object or set of objects a suitable laser beam part of the laser beam to be directed so that it illuminates the object and another part so that it illuminates the recording medium directly (the reference beam), enabling the reference beam and light which is scattered from the object on to the recording medium to form an interference pattern a recording medium which converts this interference pattern into an optical element which modifies either the amplitude or phase of an incident light beam according to the intensity of the interference pattern

(2) An environment which provides sufficient mechanical and thermal stability that the interference pattern is recorded.

(3) The object should be fully exposed to radiation

The photographic plate should have,

(i) High resolution.
(ii) High sensitivity
(iii) Wide spectral range.

RECONSTRUCTING AND VIEWING THE HOLOGRAPHIC IMAGE:

* When the hologram plate is illuminated by a laser beam identical to the reference beam which was used to record the hologram, an exact reconstruction of the original object wavefront is obtained.
* An imaging system (an eye or camera) located in the reconstructed beam 'sees' exactly the same scene as it would have done when viewing the original.
* When the lens is moved, the image changes in the same way as it would have done when the object was in place. If several objects were present when the hologram was recorded, the reconstructed objects move relative to one another, i.e. exhibit parallax, in the same way as the original objects would have done.
* It was very common in early days of holography to use a chess board as the object and then take photographs at several different angles using the reconstructed light to show how the relative positions of the chess pieces appeared to change.
* A holographic image can also be obtained using a different laser beam configuration to original recording

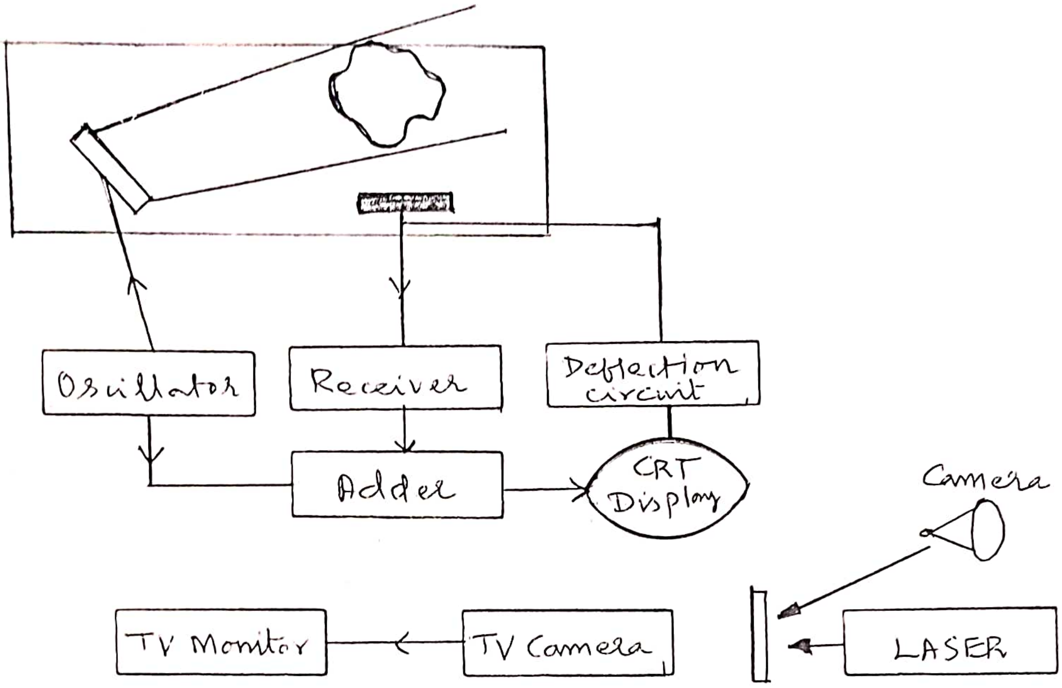
object beam, but the reconstructed image will not match the original exactly. When a laser is used to reconstruct the hologram, the image is speckled just as the original image will have been. This can be a major drawback in viewing a hologram.

* White light consists of light of a wide range of wavelengths. Normally, if a hologram is illuminated by a white light source, each wavelength can be considered to generate its own holographic reconstruction, and these will vary in size, angle and distance. These will be superimposed and the summed image will wipe out any information about the original scene, as if superimposing a set of photographs of the different sizes and orientations.

* However, a holographic image can be obtained using white light in specific circumstances, ex: with volume holograms and rainbow holograms.

* The white light source used to view these holograms should always approximate to a point source, i.e. a spot light or the sun. An extended source (ex: a fluorescent lamp) will not reconstruct a hologram since its light is incident at each point at a wide range of angles, giving multiple reconstructions which will "wipe" one another out.

HOLOGRAPHIC NON-DESTRUCTIVE TESTING:



① A single large ultrasonic transducer which sends out ultrasonic waves towards the object under study and it scans the object.

② The scattered waves from the object from the object waves. A received transducer collects the scattered object wave and converts them into electrical signals. The reference electrical waves are given by the RF oscillator and these objects to reference waves are made to interference by the electronic adder. The interference pattern is formed on the fluorescent screen of the cathode photographic film is developed.

(3) The developed photographic film serves as a hologram. The hologram is illuminated by a low power laser like He-Ne laser which acts as the optical reference source.

(4) The TV Camera takes the videograph of the 3D image of the object and it displays on the T.V. monitor.

Applications of Holographic Interferometry

S. No	Field	Applications
1.	Aerospace.	(i) Defects in honeycomb plates. (ii) Testing of construction materials and welding methods (iii) Inspection of rocket bodies (iv) Flow visualization in Wind Tunnels. (v) Vibration modes of turbine blades.
2.	Automobiles.	(i) Testing of oil pressure sections (ii) Testing of welding methods. (iii) Research in construction of automobiles bodies (iv) Construction of engines.
3	Machine tools and precision instruments.	(i) Measurement of deformations of machine parts, jigs and tools. (ii) Measurement of inside cylinders, (iii) Measurement of stiffness (heat, static & dynamic) and construction of tools.

S. No	Field	Applications
4.	Electrical and Electronic Industries	(i) Vibration modes of turbine blades, motors, transformers and loud speakers. (ii) Testing of welding and adhesion (iii) Testing of circuit parts and Analysis of audio equipments (iv) Leak test of batteries
5	Civil Engineering	(i) Analysis of Constructions (ii) Design of pipes. (iii) Research in Concrete.
6.	Chemical Industry	(i) Measurement of mixed fluids and (ii) Tyre, rubber and NDT of tyres, plastics (iii) Testing of molded products. (iv) Measurement of adhesion defects.
7	Medicine	(i) Measurement of living bodies, chest deformation due to inhalation. (ii) Measurement on teeth and bones. (iii) Testing materials for dental surgery (iv) Testing of urinary track (v) Measurement on eyes, ears, etc.
8.	Musical Instruments	Measurement of vibration modes.
9	Cultural articles and paintings	NDT and restoration

MEDICAL APPLICATIONS OF LASER:

① The highly collimated beam of a laser can be further focused to a microscopic dot of extremely high energy density. This makes it useful as a cutting and cauterizing instrument.

② Lasers are used for photo-coagulation of the retina to halt retinal hemorrhaging and for the tacking of retinal tears.

Higher power lasers are used after cataract surgery if the supportive membrane surrounding the implanted lens becomes milky.

Photo disruption of the membrane often can cause it to draw-back like a shade, almost instantly restoring vision.

③ A focused laser can act as an extremely sharp scalpel for delicate surgery, cauterizing as it cuts. ("cauterizing" refers to long-standing medical practices of using a hot instrument or a high frequency electrical probe to singe the tissue around an incision, sealing off tiny blood vessels to stop bleeding)

④ The cauterizing action is particularly important for surgical procedures in blood-rich tissue such as the liver.

Lasers have been used to make incisions half a micron wide, compared to about 80 microns for the diameter of a human hair.

(5) Medicine has two prime objectives: First to detect disease at an early stage before it becomes difficult to manage and second, to treat it with high selectivity and precision without any adverse effect on uninvolved tissues. Lasers are playing a very important role, in the pursuit of both these objectives

(6) Due to their remarkable properties, Lasers have made possible ultraprecise, minimally invasive surgery with reduced patient trauma and hospitalization time.

(7) Ophthamology, gynaecology, ENT, Cardiovascular diseases, urology, oncology, etc. The use of lasers for biomedical imaging and diagnostics and for phototherapy using photo activated drugs is receiving considerable current attention and is expected to have profound influence on the quality of health care.

(8) Laser spectroscopic techniques have the promise to provide sensitive near real time diagnosis with biochemical information on the disease

(9) Instead of a means of solving an already known clinical problem, the diagnosis may in future screen people for problems that may potentially exist. Further, any potential risk factor so detected can be corrected with high selectivity by the use)

drugs that are activated by light. Because these drugs are inert, until photoexcited by radiation with the right wavelength, the clinician can target the tissue selectively by exercising the control on light exposure (only the tissue exposed to both drug and light will be affected).

(10) A good example is the fast developing photodynamic therapy of cancer. There are indications that selective photo-excitation of native chromophores in the tissue may also lead to therapeutic effects.

LASER-TISSUE INTERACTIONS

(1) Light-Tissue interactions:-

* Radiative and Non-radiative relaxation. Imagine an excited molecule that is alone, without any other nearby molecules to interact with. In this case two things could happen. First, the energy gained by absorbing the photon, and initially stored in one mode, will begin to shared out between all the modes in an non-radiative process of intra molecular redistribution until the molecule is in equilibrium (according to equipartition theorem). However the molecule could also jump abruptly to a lower energy state by emitting a photon

* If the radioactive life time of the molecule is shorter than the redistribution time, then it is likely that a photon will be emitted before the process of intramolecular redistri- -bution has completed

* As some redistribution will always take place before a photon is emitted, the energy of there radiated photons will always be lower than the absorbed photon. There are two possible radiative processes: (i) Fluorescence and (ii) Phosphorescence.

(i) During Fluorescence there is a transition from a state to a similar stage, ex: Singlet - Singlet, and typically fast.

(ii) Phospherescence occurs after an intramolecular inter-system crossing has taken place, so the transition accompanying the radiation typically involves a change from a triplet to a single state which is much less likely to occur (according to quantum mechanics), and so the radiation is of lower energy and occurs over a much longer time scale (ms, seconds or even longer)

All mechanisms that are not radiative are by default non-radiative.

2. Photo chemical Reactions

* When the light absorption gives rise to an electronic transition, the more energetic electron will, on average, orbit the nuclei at a greater distance. As the attractive nuclear force falls rapidly with distance, the electron will be less tightly bound, and will be able to form a chemical bond with another molecule more ~~rapidly~~ readily. This is the basis of Photo-chemistry.

3. Thermalisation, Collisional relaxation.

* While an excited molecule is undergoing intra molecular redistribution, it might collide with another molecule. Some of the vibrational energy in the excited molecule will transferred to the colliding molecule as translational kinetic energy.

* Molecular translational kinetic energy is what appears at a macroscopic level as a temperature rise so leads to photo thermal effects. This process of collisional relaxation will thereby thermalise the absorbed photon energy in a matter of picoseconds, although the resulting macroscopic thermal effects occur over very much longer time scale (ms. to s.)

4. Types of Interactions:-

There are many different mechanisms, by which laser light can interact with tissue, and these have been categorized in a number of different ways.

The most common interaction mechanisms for therapeutic and surgical applications will be divided into:

(i) Photo chemical reactions: when a molecule absorbs a photon of sufficient energy, the energy can be transferred to one of the molecule's electrons. An electron with higher energy can more easily escape the nuclear forces keeping it near to the nucleus, and so excited molecules, are more likely to undergo chemical reactions with other molecules.

(ii) In Photo thermal interactions, the energy of the photon absorbed by chromopores (a term used to refer to any light-absorbing molecules) is converted into heat energy via molecular vibrations and collisions, which can cause a range of thermal effects from tissue coagulation to vaporization. Applications include tissue cutting and welding in laser surgery, and photo acoustic imaging.

(iii) In Photoablation, high energy, UV photons are absorbed by electrons, raising them from a lower energy 'bonding' orbital to a higher energy 'non-bonding' orbital, thereby causing virtually immediate disassociation of the molecules. This naturally leads to a rapid expansion of the irradiated volume and ejection of the tissue from the surface. This is used in eye (corneal) surgery, among other applications.

(iv) In Plasma-induced photo ablation a free electron is accelarated by the intense electric field which is found in the vicinity of a tightly focused laser beam. When this very energetic electron collides with a molecule, it gives up some of its energy to the molecule. When sufficient energy is transferred to a free bound electron, a chain reaction of similar collisions is initiated, resulting in a plasma: a soup of ions and free electrons. One application of this is in lens capsulotomy to treat secondary cataracts.

(v) The final set of related mechanisms, grouped under the term Photo disruption, are the mechanical effects that can accompany plasma generation, such as bubble formation, cavitation, jetting and shock waves. These can be used in lithotripsy (breaking up kidney or gall stones), for example.

5. Selecting an Interaction Mechanism

(1) The type of molecules the tissue is made of and contains. These determine the energy levels - the energies of photons that can be absorbed - and the available de-excitation pathways, ie routes through which the energy leaves the state into which it was absorbed, to end up as heat or perhaps another photon,

(2) The frequency (or wavelength) of the light, ie the energy associated with each individual photon,

(3) The power per unit area delivered by the laser,

(4) The duration of the illumination, and repitition rate of the pulses for a pulsed laser. Because different interaction mechanisms dominate under different conditions (photoablation requires UV light, photo disruption requires very short duration pulses, etc.) by carefully choosing the laser characteristics the interaction can be restricted to a specific mechanism, and therefore a specific effect on the tissue. Lasers are therefore useful for medical applications because;

(a) The energy of the photons can be chosen, as each type of laser will emit photons of only one energy.

(b.) the power can be carefully controlled over a wide range of influence rates.

(c) The beam shape can be well controlled (focused and collimated, etc.) and the duration of the laser pulses can range from as-long-as-you-like to less than 100 femtoseconds.

NOTE:- 100 femtoseconds is really quite a short time. It is about the time it takes light to travel the thickness of a human hair.

LASER INSTRUMENTS FOR SURGERY

Laser light is different from regular light. The light from the sun or from a light bulb has many wavelengths and spreads out in all directions. Laser light, on the other hand, has a single wavelength and can be focused in a very narrow beam. This makes it both powerful and precise. Lasers can be used instead of blades (scalpels) for very careful surgical work, such as repairing a damaged retina in the eye or cutting through body tissue.

1. Laser types and its medical Use:

Lasers are named for the liquid, gas, solid, or electronic substance that's used to create the light. Many types of Lasers are used to treat medical problems, and new ones are being tested all the time.

Nowadays, 3 kinds of lasers are commonly used in Cancer treatment:

(i) Carbon dioxide (CO_2) Lasers.
(ii) Argon Lasers.
(iii) Nd: YAG (Neodymium : Yttrium-Aluminium-Garnet) Lasers.

(i) Carbon dioxide Lasers (CO_2 Lasers):-

The CO_2 Laser is mainly a surgical tool. It can cut or vaporize (dissolve) tissue with fairly little bleeding as the light energy changes to heat. This type of laser is used to remove thin layer from the surface of the skin without going into the deeper layers.

(ii) Argon Lasers:-

The Argon laser only goes a short distance into tissue. It's useful in treating skin problems and in eye surgery. It's sometimes used during colonoscopies (tests to look for colon cancer) to remove growths called polyps before they become cancer. It can be used with light-sensitive drugs to kill cancer cells in a treatment known as Photodynamic Therapy (PDT)

(iii) Nd: YAG (Neodymium: Yttrium-Aluminium-Garnet) Lasers:

Light from this laser can go deeper into tissue than light from other types of lasers, and it can make blood clot quickly. Nd: YAG lasers can be used through thin flexible tubes called endoscopes to get to hard-to-reach parts inside the body, such as the swallowing tube (esophagus) or large intestine (colon). This light can ~~be~~ also travel through optical fibers, which can be bent and put into a tumor to heat it up and destroy it.

(iv) Other lasers used in Medicine:-

Some newer types of lasers – the erbium: Yttrium aluminium ~~garnet~~ garnet (HO: YAG), copper vapor and diode lasers are also being used in medical and dental treatments.

Pros of Laser Surgery.

(1) Lasers are more precise and exact than blades (scalpels). For instance, the tissue near the laser cut (incision) is not affected since there is little contact with skin or other tissue.

(2) The heat produced by lasers helps clean (sterilize) the edges of the body tissue that it's cutting, reducing the risk of infection

(3) Since laser heat seals blood vessels, there is less bleeding, swelling, pain, or scarring. Operating time may be shorter.

(4) Laser surgery may mean less cutting and damage to healthy tissues (it can be less invasive). For example, with fiber optics, laser light can be directed to parts of the body through very small cuts without having to make a large incision.

(5) More procedures may be done in outpatient settings. Healing time is often shorter

Cons of Laser Surgery:-

(1) Fewer doctors and nurses are trained to use lasers.

(2) Cost of laser equipment is high and bulky in size

(3) But advances in technology are slowly helping

reduce their cost and size.

(4) Strict safety precautions must be followed in the operating room when lasers are used.
For example; the entire surgical team and the patient must wear eye protection.

(5) The effects of some laser treatments may not last long, so they might need to be repeated And some times the laser cannot remove all of the tumor in one treatment, so treatments may need to be repeated.

REMOVAL OF TUMORS OF VOCAL CARDS:

* Vocal cord surgery is performed when the vocal cords have growths such as polyps, tumours or other masses that need to be removed for biopsy to improve function. It is also perform to normalise vocal cord functioning when vocal cords are scarred from various causes or otherwise abnormal. These conditions may interfere with the complete opening and closing of the vocal cord, which is necessary of normal speech and breathing.

Performing of Vocal Cord Surgery :-

Surgery on the vocal cords can be performed either directly in an open surgical approach by making an incision in the neck or indirectly through an endoscopic approach through a tube inserted into the mouth and throat. Either procedure is performed under general anesthesia i.e. the person is fully asleep.

BRAIN SURGERY :-

A brain tumor diagnosis is overwhelming under any condition, but it can be worse if surgery is not an option. When tumors are in hard-to-reach brain areas or are close to areas that control vital functions, traditional surgery may be too risky.

Now, however, Cleveland clinic neuro surgeons have a potentially life-extending surgical option for patients with brain tumors once considered inoperable.

~~Song~~ If you have been told that you have an inoperable primary or metastic brain tumour.

1. Destroying Cancer Cells with Laser-Directed Heat:

Laser interstitial thermal therapy (LITT) transmits heat to coagulate, or "cook", brain tumors from the inside out. This technology is not new in cancer treatment, but early approaches posed challenges with limiting the laser energy only to tumors.

Neuro Blate system, the surgeon can "steer" and monitor the effects of the laser beam, thus sparing surrounding healthy tissue. Unlike conventional open surgery, this therapy is minimally invasive. It takes place with the patient in an MRI machine because the laser system is guided, positioned and monitored with MRI.

2. Surgical Techniques:-

The patients will be placed under general anesthesia with great precision, a thin, high intensity laser probe will be inserted through a small hole in your skull, deep into your brain. The tip of the probe emits laser energy sideways, heating and destroying brain tumor tissue in one direction while cooling to remove heat and protect normal tissue in neighboring areas.

* Each burst of laser energy lasts from 30 sec to a few minutes. The laser generates heat up to 160 degrees Farenheit, which is sufficient to coagulate and kill the tumor cells.

* On a computer screen, the surgeon will monitor the tumore destruction as it occurs. A MRI thermometry measures temperature in and around the tumor, providing valuable feedback to the surgeon throughout the procedure. Quick recovery is possible with very few days of hospitalization

Advantages:-

* Is less invasive than even the most minimally invasive open operations enhances patient safety and is less costly than traditional surgery.
* Promotes quicker recovery.
* Has the potential to help some patients whose tumors had been considered too risky to treat, whose tumors did not respond to alternate treatments or who had otherwise been deemed poor candidates for surgery.
* offers a therapeutic option when radio surgery fails may allow for multiple treatments.

PLASTIC SURGERY

1. Goal:

(i) Correction of disfigurement.
(ii) Restoration of impaired function.
(iii) Improvement of physical appearance.

2. Procedure in Plastic Surgery:

* Tissue may be moved to fill a depression, to cover a wound, or to improve appearance.
* Tissue may be completely removed to alter the contours of a feature.

ONCOLOGY:

(1) It is a branch of medicine that studies cancer tumors and seeks to understand their development, diagnosis, treatment and prevention. Lasers can be used in 2 ways to treat cancer.

(2) To shrink or destroy a tumor with heat. To activate a chemical - known as a photosensitizing agent that kills only the cancer cells. This is called Photo Dynamic Therapy or PDT.

Though lasers can be used alone, they are most often used with other cancer treatments, such as chemotherapy or radiation.

3) Lasers are also being studied for treating or preventing side effects of common cancer treatments. For instance, some studies are looking at how low-level laser therapy (LLLT) might be used to prevent or treat severe mouth sores caused by chemotherapy, and how they may be used to treat the swelling (lymphedema) that can result from breast surgery.

Shrinking or destroying tumors directly.

(4) The CO_2 and Nd : YAG lasers are used to shrink or destroy tumors. They can be used with thin flexible tubes called endoscopes that let doctors see inside certain parts of the body, such as the bladder or stomach. The light from some lasers can be sent through an endoscope fitted with fiber optics. This lets doctors see and work in parts of the body that could not be reached otherwise except by major surgery. Using an endoscope also allows very precise aim of the laser beam.

(5) Lasers can be used with low-power microscopes, too. This gives the doctor a large view of the area being treated. When used with an instrument that allows very fine movement (called a micromanipulator), laser systems can produce a cutting area as small as 200 microns in diameter that's less than the width of a very fine thread.

(6) Lasers are used to treat many kinds of cancer. In the intestines or large bowel, lasers can be used to remove polyps, small growths that might become cancer. The CO_2 laser can be used to treat pre-cancerous tissue and very early cancers of the cervix, vagina, and vulva.

(7) Lasers are also used to remove tumors blocking the swallowing tube (esophagus) and large intestine (colon). This does not cure the cancer, but it relieves some symptoms, such as trouble swallowing.

(8) The Nd: YAG laser has also been used to remove cancer that has spread to the lungs from other areas. This helps avoid surgery that would require removing large sections of lung. This type of lasers cannot cure cancers but it can improve breathing and other symptoms in many patients.

(9) Cancers of the head, neck, airways, and lungs can be treated (but usually not cured) with lasers. Small tumors on the vocal cords may be treated with lasers instead of radiation in some patients. Tumors blocking the upper airway can be partly removed to make breathing easier. Blockages deeper in the airway, such as in the branches of the breathing tubes (bronchi), can be treated with a flexible lighted tube called a bronchoscope and an Nd:YAG laser.

(10) Laser induced interstitial thermotherapy (LITT) uses heat to help shrink tumors by damaging cells or depriving them of the things they need to live (like oxygen and food). In LITT, the laser light is passed through a fiber optic wire and right into a tumor, where it heats up, damaging or killing cancer cells. LITT is sometimes used to treat tumors in the liver.

PHOTO DYNAMIC THERAPY :- (PDT)

* In PDT, a special drug called a photosensitizing agent is put into the bloodstream. Over time it is absorbed by body tissues. The drug stays in cancer cells for a longer time than in normal tissue. Shining a certain kind of light on the cancer cells that have the drug in them "turns on" the drug, which then kills the cancer cells.

* Photosensitizing agents are turned on or activated by a certain wave length of light. For example, an Argon laser can be used in PDT. When cancer cells that contain the photosensitizing agent are exposed to red light from this laser, it causes the chemical reaction that kills the cancer cells. Light exposure must be carefully timed so that it's used when most of the agent has left healthy cells, but is still in the cancer cells.

Advantages of PDT over other treatments:-

(1) Cancer cells can be singled out and destroyed but most normal cells are spared. The damaging effect of the photo-sensitizing agent happens only when the drug is exposed to light. The side effects are fairly mild. Still, PDT as it's currently used is not without its problems. Argon laser light cannot pass through more than about 1 cm of tissue (a little more than one-third of an inch.), which means its not useful against deeper tumors. And the photosensitizing agents used today can leave people very sensitive to light, causing sunburn-like reactions after only very brief sun exposure. This can greatly limit the patient's activities until the body gets rid of the drug, which often takes weeks.

(2) PDT is sometimes used to treat cancers and pre-cancers of the swallowing tube (esophagus), and certain kinds of lung cancer that can be reached with endoscopes. PDT is being studied for use in other cancers, such as those of the brain and prostate.

PHOTO DYNAMIC THERAPY — OPERATION:-

Depending on the part of the body being treated, the photo-sensitizing agent is either put into the blood stream through a vein or put on the ~~screen~~ skin. Over a certain amount of time the drug is absorbed by the cancer cells. Then light is applied to the area to be treated. The light causes the drug to react with oxygen, which forms a chemical that kills the cells. PDT might also help by destroying the blood vessels that feed the cancer cells and by altering the immune system to attack the cancer.

The period of time between when the drug is given and when the light is applied is called the drug-to-light interval. It can be anywhere from a couple of hours to a couple of days, depending on the drugs used.

GYNAECOLOGY:-

* The recent advancement in laser technology, has led to the development of new, minimally invasive treatment options for common gynaecological problems such as vaginal relaxation syndrome, urinary incontinence, pelvic organ prolapse and vaginal atrophy. Two noval treatment options called IntimaLase TM and IncontiLase TM are available. Both treatment involve the use of Erbium laser (Er: YAG) at a specific wavelength which is applied to the vaginal tissue for 10-12 minutes.

Working principle:-

* The laser stimulates collagen remodelling and growth of new collagen fibres (neocollagenesis) in the vagina and also along the urethra.

* The end result is that the treated tissue becomes more enriched with new collagen which is tighter and more elastic.

How long does the treatment take?

1. The laser treatment is done in the gynaecological practice rooms and the procedure takes approximately 10-12 minutes.
2. There is no 'cut', no 'pain' and no hospitalization.