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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION

UNIT – I - Fiber Optics and Laser Instrumentation – SIC1605

UNIT I

FIBER OPTICS AND LASER INSTRUMENTATION

OPTICAL FIBERS AND THEIR PROPAGATION

1.1 INTRODUCTION

An optical fiber is a glass or plastic fiber that carries light along its length. Fiber optics 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 longer distances and at higher bandwidths (data rates) because light has high frequency than any other form of radio signal than other 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 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.

1.2 THE GENERAL SYSTEM

An optical fiber communication system is similar in basic concept to any type of communication system. A block schematic of a general communication system is shown in the figure 1. The function is to convey the signal from the information source over the transmission medium to the destination. The communication system therefore consists of a transmitter or modulator linked to the information source, the transmission medium, an a receiver or demodulator at the destination point. In electrical communication the information source provides an electrical signal, usually derived from a message signal which is not electrical ,e.g;(sound) to a transmitter comprising electrical and electronic components which converts the signal to a suitable form for propagation over transmission medium. This is often achieved by a modulating a carrier, may be an electromagnetic wave. Figure 2 shows the block diagram communication system using optic fiber. The transmission medium can 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 where it is transformed in to original electrical information signal (demodulated) before being passed to the destination .However it must be noted that in any transmission medium the signal is attenuated orsuffers loss ,and is subjected to degradations due to contamination by random signals and noise,as well as possible distortions imposed by mechanisms within the medium itself.Therefore in communication system there is a maximum permitted distance between the transmitter and the receiver beyond which the system effectively ceases to give intelligible communication for long haul applications this factors necessitate the installation of repeaters or line amplifiers at intervals ,both to remove signal distortion and to increase signal level before transmission is continued down the link.

1.2.1 Communication System:

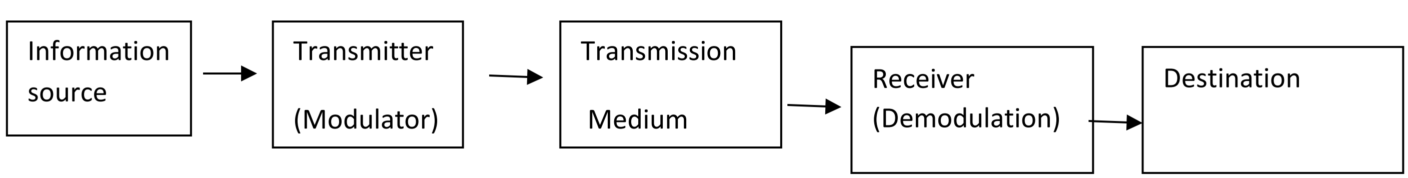

Figure 1.1: General Block Diagram of Communication System

1.2.2 Optical Fiber communication system

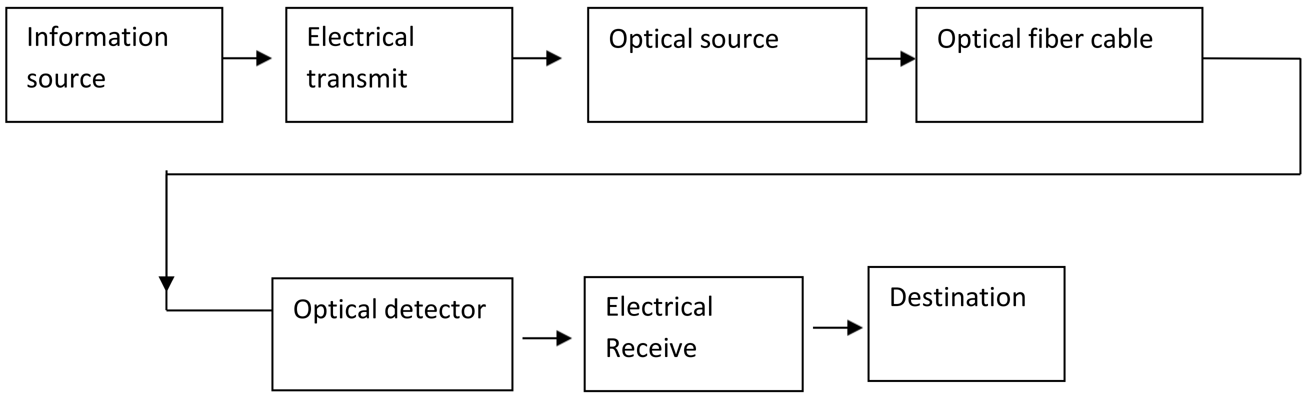

Figure 1.2: General Block Diagram of Optic Fiber Communication System

1.2.3 OPTICAL FIBER CABLE

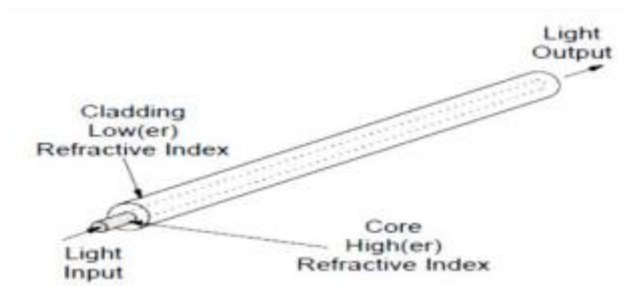

Figure 1.3: Construction of Fiber

An optical fiber is a very thin strand of silica glass in geometry quite like a human hair. In reality it is a very narrow, very long glass cylinder with special characteristics. When light enters one end of the fiber it travels until it leaves the fiber at the other end. An optical fiber consists of two parts: the core and the cladding . The core is a narrow cylindrical strand of glass and the cladding is a tubular jacket surrounding it. The core has a (slightly) higher refractive index than the cladding. Light travelling along the core is confined by the mirror to stay within it even when the fiber bends around a corner.A fiber optic cable has an additional coating around the cladding called the jacket. The jacket usually consists of one or more layers of polymer. Its role is to protect the core and cladding from shocks that might affect their optical or physical properties. It acts as a shock 14 absorber. The jacket also provides protection from abrasions, solvents and other contaminants. The jacket does not have any optical properties that might affect the propagation of light within the fiber optic cable

1.3 GUIDING MECHANISM IN OPTICAL FIBER :

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 always equal to the angle of reflection the reflected light will again be reflected. The light ray will then continue this bouncing path down the length of the fiber optic cable. 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. Light can be guided down the fiber optic cable if it enters at less than the critical angle. This angle is fixed by the indices of refraction of the core and cladding and is given by the formula,

The critical angle is measured from the cylindrical axis of the core. By way of example, if n1 = 1.446 and n2 = 1.430 then a quick computation will show that the critical angle is 8.53 degrees, a fairly small angle.

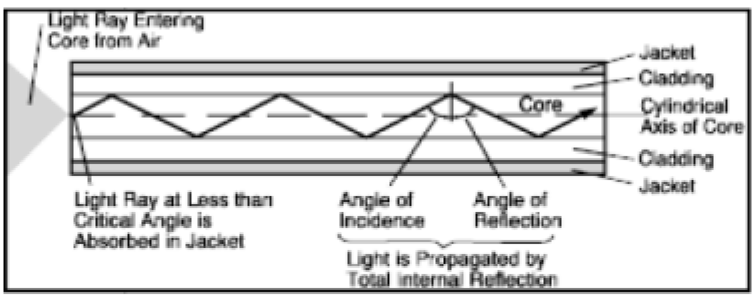

Figure 1.4: Mechanism of Light wave guide in Fiber

Of course, it be noted that a light ray enters the core from the air outside, to the left of Figure. 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. 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.

Basic component of optical fiber communication

1 Transmitters - Fiber optic transmitters are devices that include an LED or laser source, and signal conditioning electronics, to inject a signal into fiber. The modulated light may be turned on or off, or may be linearly varied in intensity between two predetermined levels.

2 Fiber –It is the medium to guide the light from the transmitter to receiver.
3 Receivers – Fiber optic receivers are instruments that convert light into electrical signals. They contain a photodiode semiconductor, signal conditioning circuitry, and an amplifier at the receiver end.

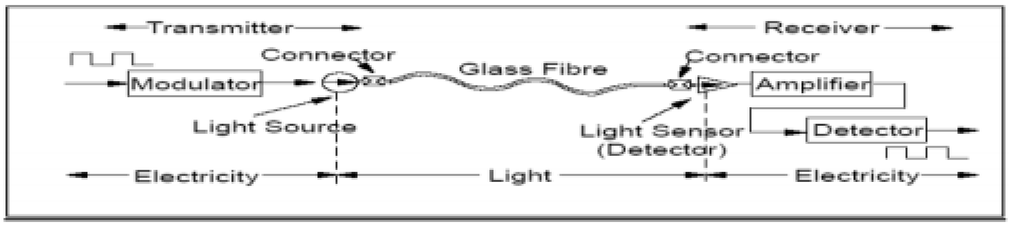

Figure 1.5: The basic components of an optical fiber communication

Process of Optical Fiber Communication

A serial bit stream in electrical form is presented to a modulator, which encodes the data appropriately for fiber transmission.
A light source (laser or Light Emitting Diode -LED) is driven by the modulator and the light focused into the fiber. The light travels down the fiber (during which time it may experience dispersion and loss of strength).At the receiver end the light is fed to a detector and converted to electrical form. The signal is then amplified and fed to another detector, which isolates the individual state changes and their timing. It then decodes the sequence of state changes and reconstructs the original bit stream. The timed bit stream so received may then be fed to a using device

Principle of light propagation through a fibre
Total internal reflection
Acceptance angle (θa)
Numerical aperture.
Skew mode.
Total internal reflection
i) Index of refraction
This is the measuring speed of light in respective medium. It is calculated by dividing speed of light in vacuum to the speed of light in material. The RI for vacuum is 1, for the cladding material of optical fiber it is 1.46, the core value of RI is 1.48(core RI must be more than cladding material RI for transmission. 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: In order to understand ray propagation in a fiber. This is called Snell's Law.n1sin .01= n2sin .02Where n denotes the refractive index of material. 01/02is angles in respective medium. Higher refractive index means denser medium.

$$\theta_c = \arcsin(n_2/n_1)$$

Total Internal Reflection (TIR)

When light traveling in a dense medium hits a boundary at a steep angle (larger than the "critical angle "for the boundary), the light will be completely reflected. This phenomenon is called total internal reflection. This effect is used in optical fibers to confine light in the core. Light travels along the fiber bouncing back and forth off of the boundary; because the light must strike the boundary with an angle greater than the critical angle, possible in air to glass. If we now consider above Figures we can see the effect of the critical only light that enters the fiber certain range of angles can travel down the fiber without leaking out. Total internal reflection occurs when light enters from higher refractive index to lower refractive index material, i.e. from glass to air total internal reflection is possible but it is not possible in air to glass.

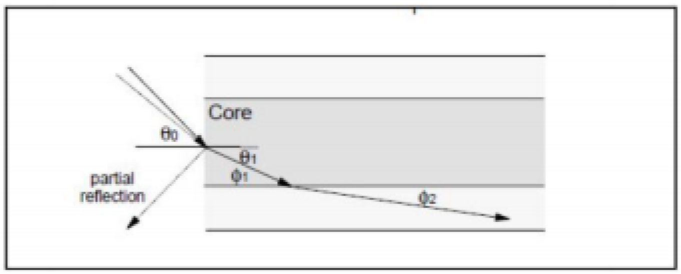

Figure 1.6: (Optical rays leaks out from core i.e., is loss)

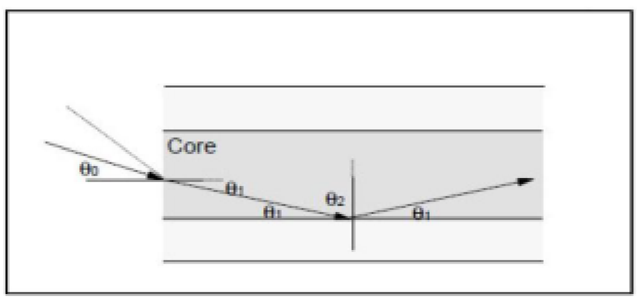

Figure 1.7: (Optical rays reflected back due to TIR)

We see that for rays where angle 01 less than a critical value then the ray will propagate along the fiber and will be bound within the fiber. In fig. 1 we see that where the angle 01 is greater than critical value the ray is refracted into the cladding and will ultimately be lost outside the fiber. This is loss.

1.3.1 Acceptance Angle :

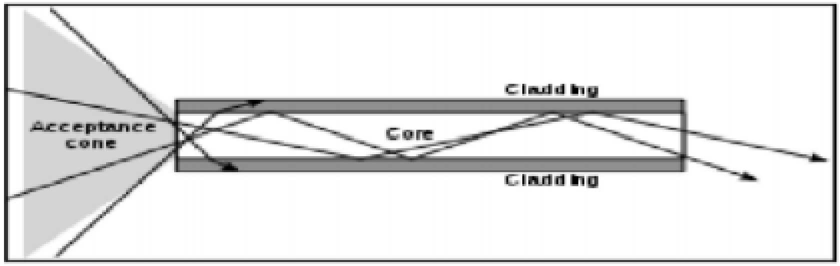

Figure 1.8: Acceptance cone

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. 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 cause any arriving ray to be refracted. This means that there is a maximum 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. 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 the angle within the fiber). Thus there is "cone of acceptance" at the endface of a fiber. Rays arriving within the cone will propagate and ones arriving outside of it will not. The acceptance cone is function of difference of RI of core and cladding.

1.3.2 Numerical Aperture(NA):

One of the most often quoted characteristics of an optical fiber is its "Numerical Aperture". The NA 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 will later encounter the core-cladding interface at an angle such that it will be reflected. This is because the angle 02 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. It is clear that there is a "cone" of acceptance If ray enters the fiber at an angle within the cone then it will be captured and propagates as a bound mode. If a ray enters the fiber at an angle outside the cone then it will leave the core and eventually leave the fiber itself. The Numerical Aperture is the sign of the largest angle contained within the cone of acceptance.

1.3.3 An expression for an Acceptance angle and Numerical aperture

Let us consider an optical fiber, where
n_0 =Refractive Index of Air;
n_1= Refractive Index of Core;

n_2= Refractive Index of Cladding.

The ray AO enter from air into core at an incident angle 'i'Refract thro OB at an angle ''Finally, it is incident from core to cladding surface 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 (ϕ_C= 90 –) at the interface of core and cladding will be more than the critical angle. Hence the ray is totally internally 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.

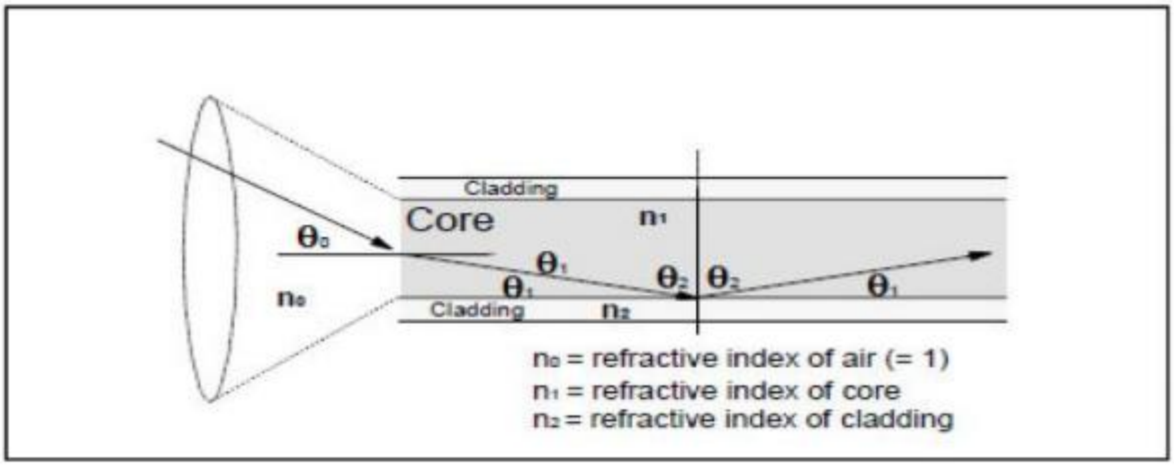

Figure 1.9: Numerical Aperature

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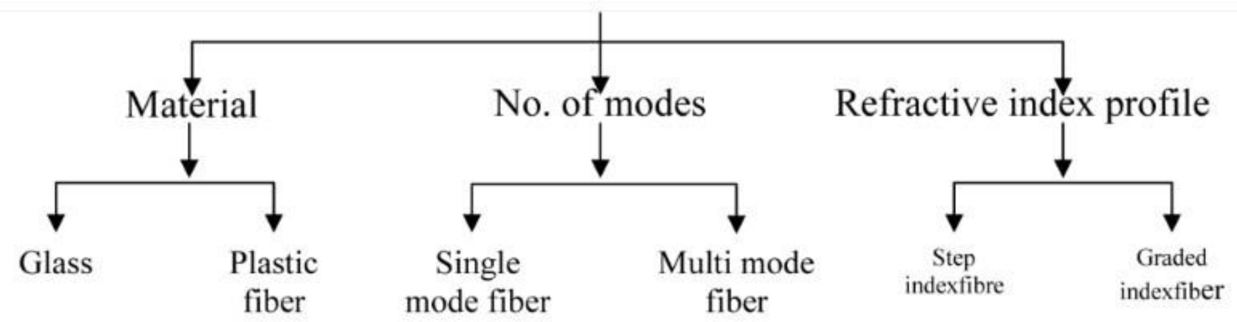
1.3.4 SKEW MODE

The rays follows a helical path through the fiber is called skew ray. The light traveling down the fiber is a group of electromagnetic (EM) 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 ormously helpful to do this, providing an easy concept, some framework to hang our ideas on. We do this all the time and it serves us well providing we are clear that it is only an analogy. Magnetic fields are not reallylines 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 the magnetic field form patterns across the fiber. These patterns are called modes of transmission. Modes means methods — hence methods of transmission. An optic fiber that carries more than one mode is called a multimode fiber (MM). The number of modes is always a whole number. In a given piece of fiber, there are only a set number of possible modes. This is because each mode is a pattern of electric and magnetic fields having a physical size. The dimensions of the core determine how many modes or patterns can exist in the core —the larger the core, the more modes. The number of modes is always an integer, we cannot have incomplete field patterns. This is similar to transmission of motor vehicles along a road. As the road is made wider, it stays as a single lane road until it is large enough to accommodate an extra line of vehicles whereupon it suddenly jumps to a two lane road. We never come across a 1.15 lane road!

Different types of fibers and their properties



1.4 GLASS AND PLASTIC FIBERS

Based on materials in which the fibers are made it is classified into two types as follows:

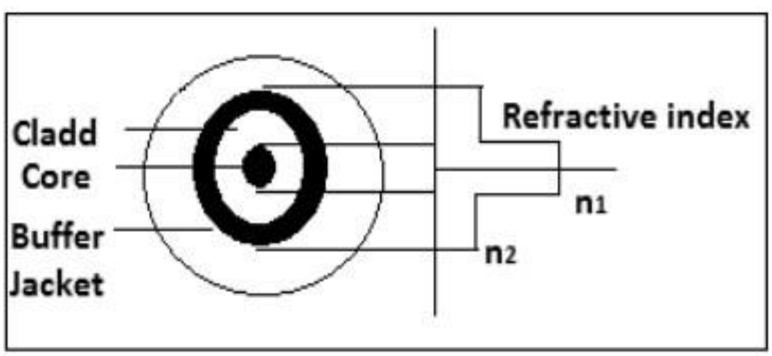
Glass fibers

If the fibers are made up of mixture of metal oxides and silica glasses are called glass

fibers.
Examples:-
(i) Core: SiO_2 ; cladding: P_2O_3–SiO_2
(ii) Core: GeO_2–SiO_2; cladding: SiO_2
Plastic fibers
If the fibers are made up plastics which can be handled without any care due to its toughness and durability it is called plastic fiber.
Examples:-
The plastic fibers are made by any one of the following combinations of core and Cladding.
(i) Core:Polymethylmethacrylate; cladding: co-polymer
(ii) Core: Polystyrene; cladding: Methyl methacrylate

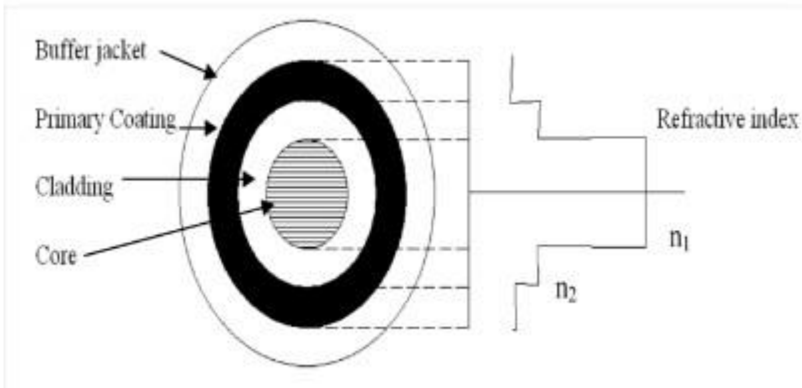
1.4.1 Single and multimode fibers

Mode is described by the nature of propagation of electromagnetic waves in a wave guide. Based on the modes
of propagation the fibers are classified into two types viz.
(i) Single mode fibers(ii) Multi mode fibers
(i) Single mode fibers
1. It has very small core diameter so that it can allow only one mode of propagation and hence called single mode fibers.
2. The cladding diameter must be very large compared to the core diameter.
3. Thus in the case of a single mode fiber, the optical loss is very much reduced.
Structure
Core diameter: 5 –10 μm
Cladding diameter : Around 125 μm
Protective layer: 250 to 1000 μm
Numerical aperture: 0.08 to 0.10
Band width: More than 50 MHz km
(ii) Multi-mode fibers:
1.Here the optical dispersion may occur.
2.They are made by multi-component glass materials.
3.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.



Structure:
Core diameter:50

–
350 μm
Cladding diameter: 125
–
500 μm
Protective layer: 250 to 1100 μm
Numerical aperture: 0.12 to 0.5
Band
width:Less than 50 MHz km



Step index and graded index fibers:
-
Based on the variation in the refractive index of the core and the cladding, the fibers are classified into two types, viz.
(i) Step index fiber (ii) Graded index fiber

1.4.2 STEP INDEX FIBER

Here the refractive indices of air, cladding and core vary step by step and hence it is called as step index fiber.Thereare two types of step index fibers. They are,
1. Step index single mode fiber –there is dispersion will occur.
2. Step index multi modefiber --there is intermodal dispersion will occur

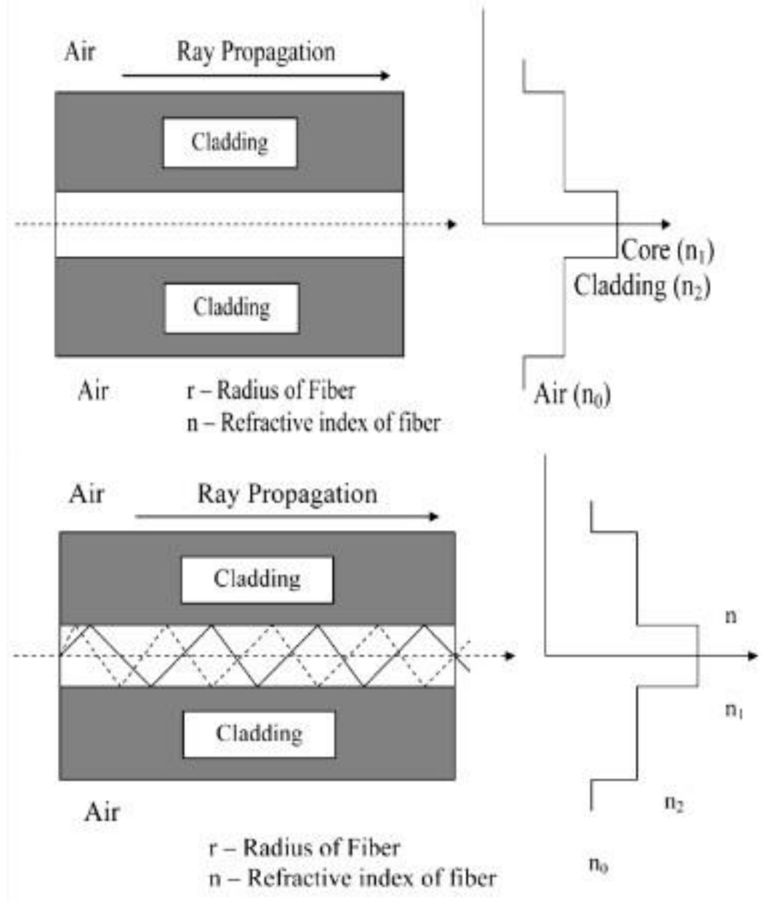


Figure 1.10: Ray propagation in cladding

1.5 GRADED INDEX FIBER

Here the refractive index of the core varies radically from the axis of the fiber. The refractive index of the core is large along the fiber axis and it's gradually decreases thus it is called as graded index fiber. Here the refractive index becomes small at the core –cladding interface. In general the graded index fibers will be of multimode system. The multimode graded index fiber has very less intermodal dispersion compared to multimode step index fiber.

Fiber characteristics

Mechanical characteristics

1. Strength
2. Static fatigue
3. Dynamic fatigue

1. Strength

The cohesive bond strength of the constituent atoms of a glass fiber governs its theoretical intrinsic strength. Maximum tensile strength of 14 GPais observed in short length glass fibers. This is closed to the 20 GPa tensile strength of steel wire. The difference between glass and metal is that, under an applied stress. The difference between glass and metal is that, under an applied stess, glass will extend elastically up to its breaking strength whereas metal can be stretched plastically well beyond their elastic range Eg: 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 than 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. The primary cause of this erosion is the presence of water in the environment which reduces the strength of SiO_2 bonds in glass. The speed of the growth reaction is increased when the fiber is put under test. Fused silica offers the most resistance of glasses in water. In general, coating are applied to the fiber immediately during the manufacturing process which affords a good degree of protection against environmental corriosion.

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. Varying stress also arises in aerial cables that are set into transverse vibration by the wind. Theoretical 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 statics stress that increases at a constant rate.

1.6 TRANSMISSION CHARACTERISTICS

1. Attenuation

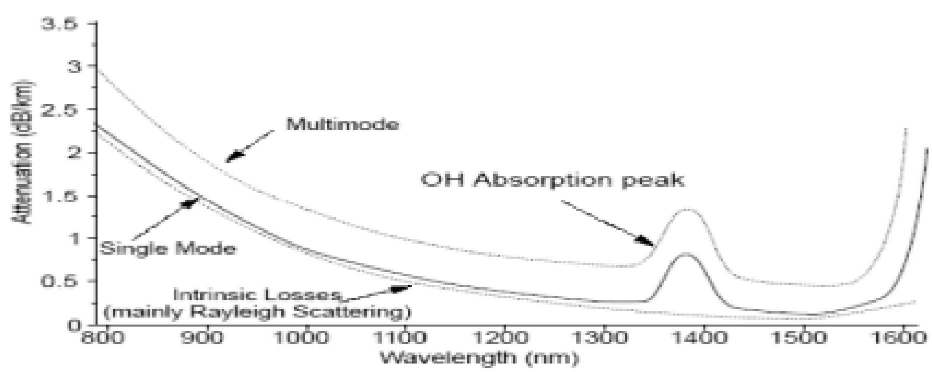


Figure 1.11: Fiber infrared Absorption Spectrum

The lower curve shows the characteristics of a single -mode fiber made from a glass containing about 4% of germanium dioxide (GeO2) dopant in the core. The upper curve is for modern graded index multimode fiber. Attenuation in multimode fiber is higher than in singlemode because higher levels of dopant are used. The peak at around 1400 nm is due to the effects of traces of water in the glass.Attenuationin 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. Attenuation coefficients in fiber optics usually use units of dB/km through the medium

due to the relatively high quality of transparency of modern optical transmission media. Attenuation in an optical fiber is caused by absorption, scattering, and bending losses.
Attenuation is the loss of optical power as light travels along the fiber. Signal attenuation is defined as the ratio of optical input power (Pi) to the optical output power (Po).

Optical input power is the power injected into the fiber from an optical source. Optical output power is the power received at the fiber end or optical detector. Each mechanism of loss is influenced by fiber-material properties and fiber structure. However, loss is also present at fiber connections i.e. connector, splice, and coupler losses.

2.Absorption losses

Absorption in optical fibers is explained by three factors:
Imperfections in the atomic structure of the fiber material The intrinsic or basic fiber-material properties.The extrinsic (presence of impurities) fiber -material properties Imperfections in the atomic structure induce absorption by the presence of missing molecules or oxygen defects. Absorption is also induced by the diffusion of hydrogen molecules into the glass fiber.

Intrinsic Absorption.-

Intrinsic absorption is caused by basic fiber material properties. If an optical fiber were absolutely pure, with no imperfections or impurities, then all absorption would be intrinsic. Intrinsic absorption sets the minimal level of absorption

Extrinsic Absorption.-

Extrinsic absorption is caused by impurities introduced into the fiber material.Trace metal impurities, such as iron, nickel, and chromium, OH ions are introduced into the fiber during fabrication. Extrinsic absorption is caused by the electronic transition of these metal ions from one energy level to another

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. During manufacturing, regions of higher and lower molecular density areas, relative to the average density of the fiber, are created. Light traveling through the fiber interacts with the density areas as shown in Light is then partially scattered in all direction.

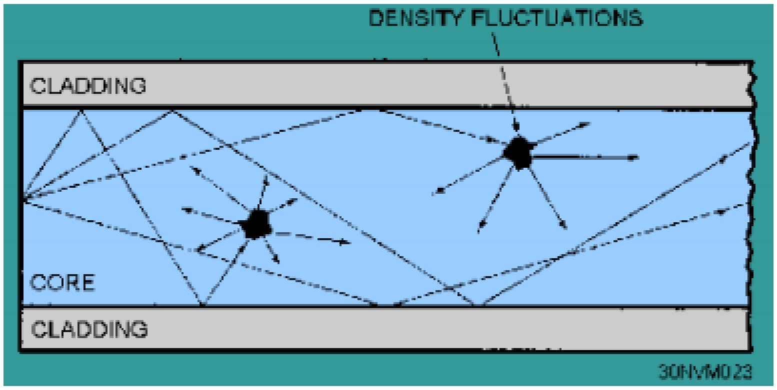


Figure 1.12: Scattering Process

In commercial fibers operating between 700-nm and 1600-nm wavelength, the main source of loss is called Rayleigh scattering. As the wavelength increases, the loss caused by Rayleigh scattering decreases. If the size of the defect is greater than one-tenth of the wavelength of light, the scattering mechanism is called Mie scattering.In commercial fibers operating between 700-nm and 1600-nm wavelength, the main source of loss is called Rayleigh scattering . As the wavelength increases, the loss caused by Rayleigh scattering decreases. If the size of the defect is greater than one-tenth of the wavelength of light, the scattering mechanism is called Mie scattering

Linear scattering losses

1.7 Rayleigh scattering

It occurs because the molecules of silicon dioxide have some freedom when adjacent to one another. Thus, setup 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 light as variations in the refractive index, thus causing the light to reflect –that is, to scatter –in different directions

Rayleigh scattering is a scattering of light by particles much smaller than the wavelength of the light, which may be individual atoms or molecules. Rayleigh scattering is a process in which light is scattered by a small spherical volume of variant refractive index, such as a particle, bubble, droplet, or even a density fluctuation.As light travels in the core, it interacts with the silica molecules in the core. Rayleigh scattering is the result of these elastic collisions between the light wave and the silica molecules in the fiber. Rayleigh scattering accounts for about 96 percent of attenuation in optical fiber Causes of Rayleigh Scattering:It results from non -ideal physical properties of the manufactured fiber. It results from inhomogeneities in the core and cladding.

Because of these inhomogeneities problems occur like

a)Fluctuation in refractive index

b)density and compositional variations.

Minimizing of Rayleigh Scattering:

Rayleigh scattering is caused due to compositional variations which can be reduced by improved fabrication.

Equation of Rayleigh Scattering:

Light scattering can be divided into three domains based on a dimensionless size parameter, α which is defined as

$A = \pi Dp/ \lambda$

where π

Dp is the circumference(The boundary line of a circle) of a particle and λ is the wavelength of incident radiation. Based on the value of α, these domains are:

$\alpha \ll 1$: Rayleigh scattering (small particle compared to wavelength of light)

$\alpha \approx 1$: Mie scattering (particle about the same size as wavelength of light)

1.8 Mie scattering

Non perfect cylindrical structure of the fiber and imperfections like irregularities in the core - cladding interface, diameter fluctuations, strains 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.

Causes of Mie Scattering:

Occurred due to inhomogeneities in the composition of silica. (i.e. inhomogeneities in the density of SiO_2) Irregularities in the core-cladding interface, Difference in core cladding refractive index,Diameter fluctuations\ Due to presence of strains and bubbles.The scattering caused by such inhomogeneities is mainly in the forward direction depending upon the fiber material, design and manufacture. Minimizing of Mie scattering Mie scattering is mainly caused by inhomogeneities which can be minimized by Removing imperfection due to glass manufacturing process.Carefully controlled extrusion(To push or thrust out) and coating of the fiber Both Mie and Rayleigh scattering are considered elastic scattering (elastic scattering is also called Linear scattering) processes, in which the energy (and thus wavelength and frequency) of the light is not substantially changed.

Nonlinear scattering losses Specially at high optical power levels scattering causes disproportionate attenuation, due to non linear behavior . Because of this non linear scattering the optical power from one mode is transferred in either the forward or backward direction to the same, or other modes, at different frequencies. The two dominant types of non linear scattering are :

a) Stimulated Brillouin Scattering and

b) Stimulated Raman Scattering.

a) Stimulated Brillouin Scattering:

This is defined as the modulation of light through thermal molecular vibration within the fiber. The scattered light contains upper and lower side bands along with incident light frequency. An incident photon produces a scattered photon as well as a photon of acoustic frequency. The frequency shift is maximum in the backward direction and it is reduced to zero in the forward direction. 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 about three orders of magnitude higher than the Brillouin threshold for the given fiber, The threshold optical power for Raman scattering is proportional to $d^2\lambda^2\alpha_R$

1.9 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. (In most communications systems bits of information are sent as pulses of light. 1 = light, 0 = dark. But even in analogue transmission systems where in formation is sent as a continuous series of changes in the signal, dispersion causes distortion.)

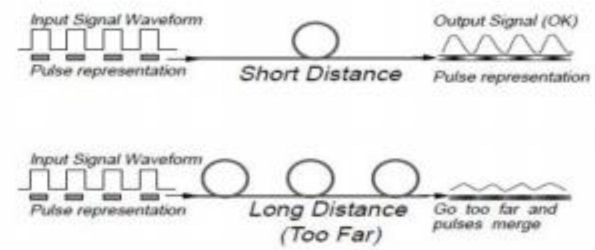


Figure 1.13: Effect of Dispersion

1.9.1 Types of dispersion

There are many kinds of dispersion, each of which works in a different way, but the most important three are discussed below:

1.Material dispersion (chromatic dispersion):-

Both lasers and LEDs produce a range of optical wavelengths (a band Oflight) rather than a single narrow wavelength. The fiber has different refractive index characteristics at different wavelengths and therefore each wavelength will travel at a different speed in the fiber. Thus, some wavelengths arrive before others and a signal pulse disperses (or smears out).

2. Intermodal dispersion (Mode Dispersion):-

When using multimode fiber, the light is able to take many different paths or "modes" as it travels within the fiber. The distance traveled by light in each mode is different from the distance travelled in other modes. When a pulse is sent, parts of that pulse (rays or quanta) take many different modes (usually all available modes). 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.

3. 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. Dispersion in different fibers:Mode dispersion > .material dispersion > waveguide dispersion

PART A

Q.No.	Question
1	What is refractive index? Give its relationship.
2	State Snell's Law?
3	Define angle of incidence?
4	What is total internal reflection?
5	What is critical angle of incidence?
6	What is optical fiber?
7	Show the schematic structure of optical fiber.
8	Why refractive index of cladding is less than the refractive index of core?
9	What are the types of fiber? Explain.
10	What is the purpose of cladding and buffer coating?
11	What are the advantages and disadvantages of multimode fiber?
12	What are skew rays?
13	Give the formula for numerical aperture.
14	What are advantages and disadvantages for selecting glass as fiber material?
15	What is attenuation?
16	How absorption is caused?
17	How scattering loss is caused?
18	What is core cladding loss?
19	What is intramodal dispersion or distortion?

PART-B

Q.No.	Question
1	Explain in detail about optical fiber and its modes?
2	Explain about the ray optic representation.
3	Explain about step index fiber structure and graded index fiber structure.
4	Explain in detail about attenuation and its causes.
5	Explain about Signal degradation or distortion.

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION

UNIT – II - Fiber Optics and Laser Instrumentation – SIC1605

UNIT -II

FIBER OPTICS AND LASER INSTRUMENTATION

2.1 Optical sources

2.1.2 Light Emitting Diode (LED)

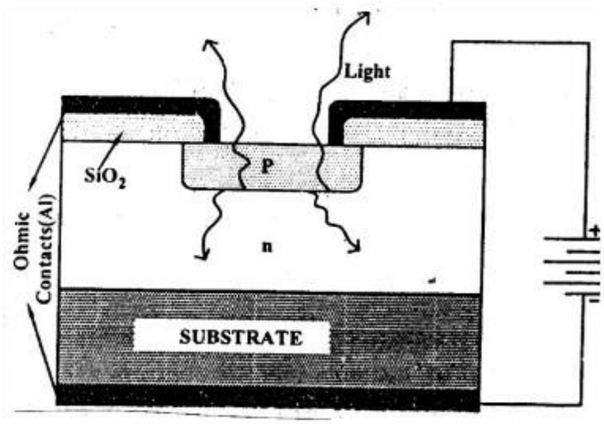
Principle:It's a device used to convert the electrical energy into light energy. When it is forward biased, the majority charge carriers of electrons from n-type and holes from p-type are diffuse into each other.At the junction the electron hole recombination process takes place and energy is emitting in the form of visible light and IR region.

Construction:

The light emitting diode is made by Gallium Arsenide semiconductors. First the PN Junction is formed by epitaxial growth technique.

Si+Ga=n-type; Si+As=p-type.

The thickness of the n-layer is always larger than the p-layer, because of increasing the radiative recombination. Proper electric connection (forward bias) given to the semiconductor through Aluminium contact. P-jn is slightly open for outcoming light rays.



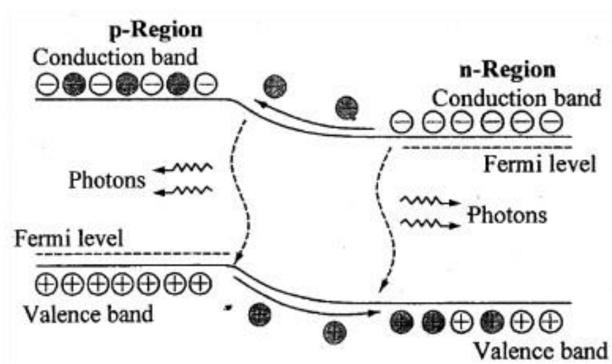


Figure 2.1: schematic diagram of LED

Working:

When the p-n junction diode is forward biased, the barrier width is reduced, raising the potential energy on the n-side and lowering that on the p-side. The free electrons and holes have sufficient energy to move into the junction region. If a free electron meets a hole, it recombines and releases a photon.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 of LED

1.Very small in size

2.Less cost and long life time.

3.It needs less voltage for operate

Disadvantages of LED

1. It requires high power.
2. Its preparation cost is high.

2.2 Photo detectors

PINDiode

Principle: This is a device used to convert the light energy into electrical energy. Under the reverse bias condition, if the light ray 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:

It consists of three layerssuch as p, n and intrinsic region with proper biasing.The P and N region are heavily doped. The intrinsic layer is slightly larger than both the p-type and n-type for receive the light photons.

Working:

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. The mobile charges are accelerated by the applied voltage, which gives rise to photo current in the external circuit.It is a linear device because the photo-current is directly proportional to the incident optical power on the PIN photo- photodiode.

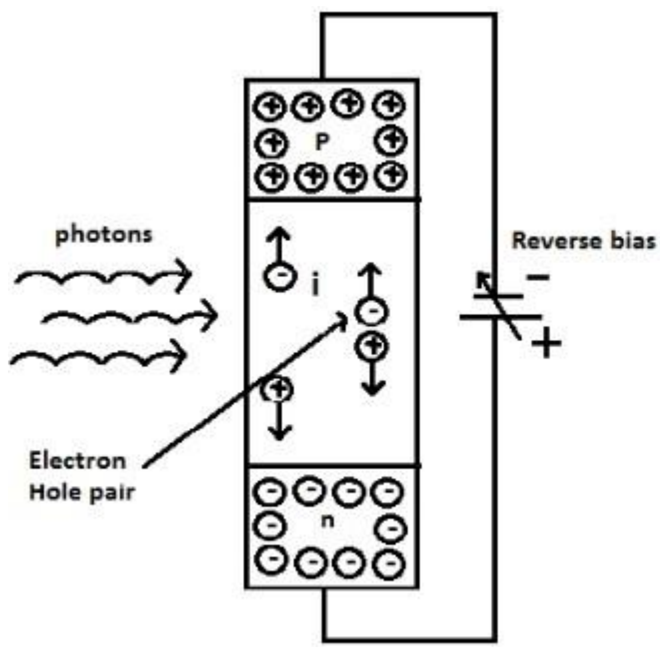


Figure 2.2 : PIN Diode

Introduction

Fiber optics for the commercial and industrial industries provide communication, data links, imaging, data collection, and application specific connectivity solutions in a wide range of capacities. The large majority of commercial & industrial applications in which fiber optic technology is used require each product to have specific construction and/or performance attributes to ensure adequate functionality.

While industry standard fiber optic products can be successfully implemented in some commercial & industrial applications, most standard products do not have the necessary durability and adverse condition performance capabilities necessary to support these applications.

2.3 Fiber optic sensor:

A **fiber optic sensor** is a sensor that uses optical fiber either as the sensing element or as a means of relaying signals from a remote sensor to the electronics that process the signals. Fibers have many uses in remote sensing. Depending on the application, fiber may be used because of its small size, or because no electrical power is needed at the remote location, or because many sensors can be multiplexed along the length of a fiber by using light wavelength shift for each sensor, or by sensing the time delay as light passes along the fiber through each sensor. Time delay can be determined using a device such as an optical time-domain reflectometer and wavelength shift can be calculated using an instrument implementing optical frequency domain reflectometry.

Fiber optic sensors are also immune to electromagnetic interference, and do not conduct electricity so they can be used in places where there is high voltage electricity or flammable material such as jet fuel. Fiber optic sensors can be designed to withstand high temperatures as well Fiber optic sensors are excellent candidates for monitoring environmental changes and they offer many advantages over conventional electronic sensors as listed below:

• Easy integration into a wide variety of structures, including composite materials, with little interference due to their small size and cylindrical geometry.

• Inability to conduct electric current.

• Immune to electromagnetic interference and radio frequency interference.

• Lightweight.

• Robust, more resistant to harsh environments.

• High sensitivity.

• Multiplexing capability to form sensing networks.

• Remote sensing capability.

• Multifunctional sensing capabilities such as strain, pressure, corrosion, temperature and acoustic signals.

2.4 Fiber optic sensor principles

The general structure of an optical fiber sensor system. 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 (oscilloscope, optical spectrum analyzer etc).

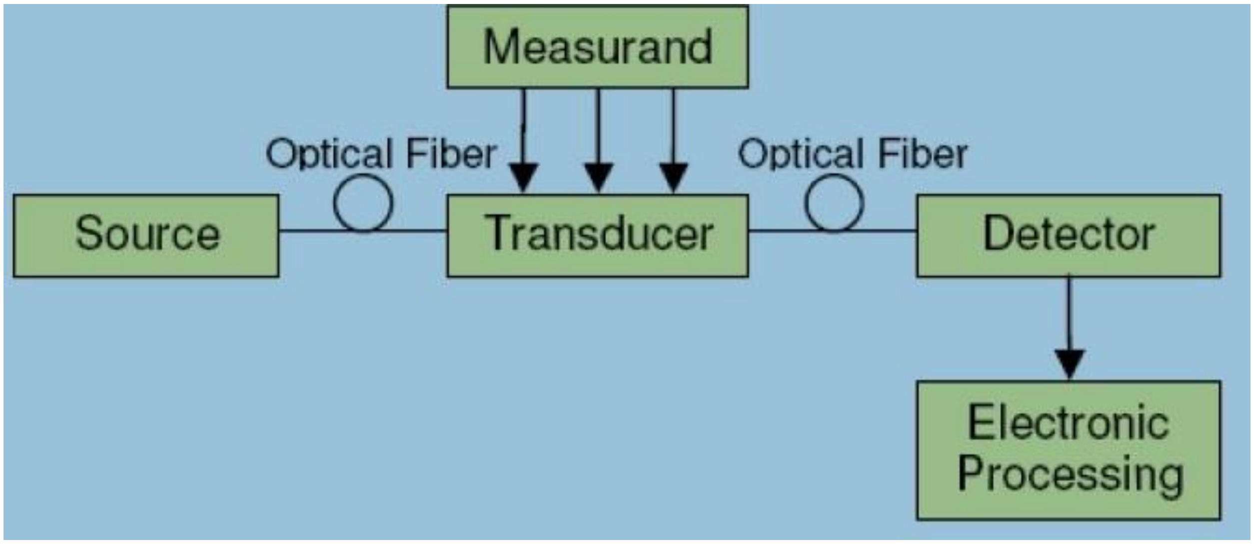


Figure 2.3: Principle of Fiber optic sensor

Fiber optic sensors can be classified under three categories: The sensing location, the operating principle, and the application. Based on the sensing location, a fiber optic sensor 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.

2.4.1 Types of fiber optics
sensor1 Intrinsic sensor
2.Extrinsic sensor

Optical fibers can be used as sensors to measure

1. Strain,
2. Temperature
3. Pressure

2.5 Intrinsicsensor -Temperature/ Pressure
sensorPrinciple:

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.

Working:

A monochromatic source of light is emitted from the laser source. It consists of a Laser source to emit light. A beam splitter, made of glass plate is inclined at an angle of 45º used to split the single beam into two beams. The main beam passes through the lens L1 and is focused onto 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 L2. The spitted beam passes through the lens L3 and is focused onto the test fiber kept in the environment to be sensed. The splitted beam after passing through the test fiber is made to fall on the lens L2. 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.

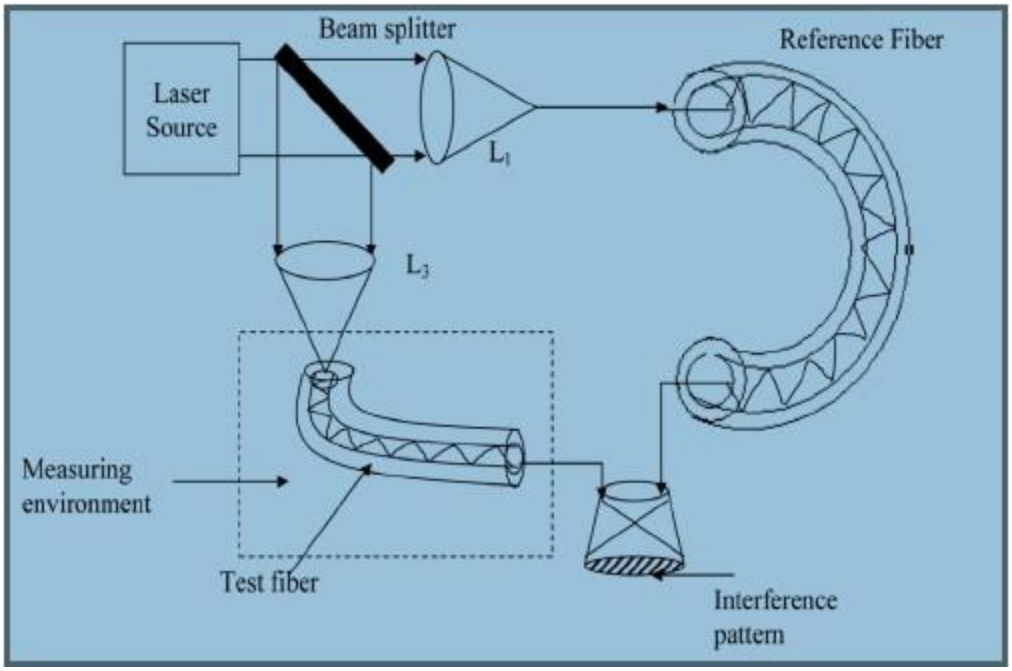


Figure 2.4: Intrinsic senor – temperature/Pressure

Thus the change in pressure (or) temperature can be accurately measured with the help of the interference pattern obtained. 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 in the fiber. Sensors that vary the intensity of light are the simplest, since only a simple source and detector are required. A particularly useful feature of intrinsic fiber optic sensors is that they can, if required, provide distributed sensing over very large distances.

Temperature can be measured by using a fiber that has evanescent loss that varies with temperature, or by analyzing the Raman scattering of the optical fiber. Electrical voltage can be sensed by nonlinear optical effects in specially-doped fiber, which alter the polarization of light as a function of voltage or electric field. Angle measurement sensors can be based on the Sagnac effect. Special fibers like long-period fiber grating (LPG) optical fibers can be used for direction recognition. Optical fibers are used as hydrophones for seismic and sonar applications. Hydrophone systems with more than one hundred sensors per fiber cable have been developed. Hydrophone sensor systems are used by the oil industry as well as a few countries' navies

Both bottom-mounted hydrophone arrays and towed streamer systems are in use. The German company Sennheiser developed a laser microphone for use with optical fibers. A fiber optic microphone and fiber-optic based headphone are useful in areas with strong electrical or magnetic fields, such as communication amongst the team of people working on a patient inside a magnetic resonance imaging (MRI) machine during MRI-guided surgery.

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).

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). They are also used to make hydrogen sensors.

Fiber-optic sensors have been developed to measure co-located temperature and strain simultaneously with very high accuracy using fiber Bragg gratings. This is particularly useful when acquiring information from small complex structures. Brillouin scattering effects can be used to detect strain and temperature over larger distances (20–30 kilometers).

Other examples

A fiber-optic AC/DC voltage sensor in the middle and high voltage range (100–2000 V) can be created by inducing measurable amounts of Kerr nonlinearity in single mode optical fiber by exposing a calculated length of fiber to the external electric field.[12] The measurement technique is based on polar metric detection and high accuracy is achieved in a hostile industrial environment.

High frequency (5 MHz–1 GHz) electromagnetic fields can be detected by induced nonlinear effects in fiber with a suitable structure. The fiber used is designed such that the Faraday and Kerr effects cause considerable phase change in the presence of the external field. With appropriate sensor design, this type of fiber can be used to measure different electrical and magnetic quantities and different internal parameters of fiber material. 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. Experiments have been carried out in support of the technique.

Fiber-optic sensors are used in electrical switchgear to transmit light from an electrical arc flash to a digital protective relay to enable fast tripping of a breaker to reduce the energy in the arc blast

2.6 Extrinsic sensors

Extrinsic fiber optic sensors use an optical fiber cable, normally a multimode one, to transmit modulated light from either a non-fiber optical sensor, or an electronic sensor connected to an optical transmitter. A major benefit of extrinsic sensors is their ability to reach places which are otherwise inaccessible. An example is the measurement of temperature inside aircraftjet engines by using a fiber to transmit radiation into a radiation pyrometer located outside the engine. Extrinsic 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 techniques impossible.

Extrinsic fiber optic sensors provide excellent protection of measurement signals against noise corruption. Unfortunately, many conventional sensors produce electrical output which must be converted into an optical signal for use with fiber. For example, in the case of a platinum resistance thermometer, the temperature changes are translated into resistance changes. The PRT must therefore have an electrical power supply. The modulated voltage level at the output of the PRT can then be injected into the optical fiber via the usual type of transmitter. This complicates the measurement process and means that low-voltage power cables must be routed to the transducer. Extrinsic sensors are used to measure vibration, rotation, displacement, velocity, acceleration, torque, and twisting.

2.7 Phase Modulated FiberOptic Sensors:

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, transverse geometrical dimension of the guide, refractive index and the index profile of the waveguide. If we assume that index profile remains constant with environmental variations, then the depth of phase modulation depends on the other remaining parameters. The total physical length of an 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. The refractive index varies with temperature, pressure and longitudinal strain via photo elastic effect. Waveguide dimensions vary with radial strain in a pressure field, longitudinal strain in a pressure field and by thermal expansion. The phase change occurring in an optical fiber is detected using optical fiber Interferometric techniques that convert phase modulation into intensity modulation’s:".

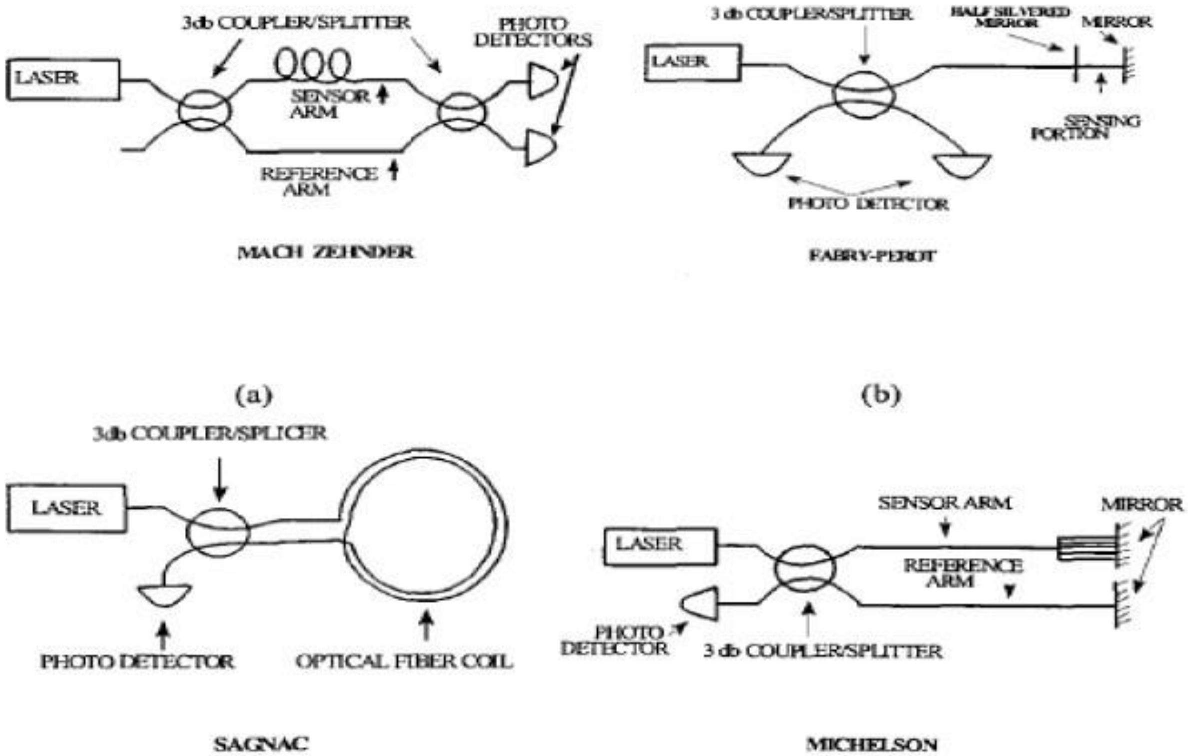


Figure 2.5: Phase modulated Fiber optic sensor

2.8 Displacementsensor (Extrinsic Sensor)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.

Working:

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.

Based on the intensity of light received, the displacement of the target can be measured, (i.e.) 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.

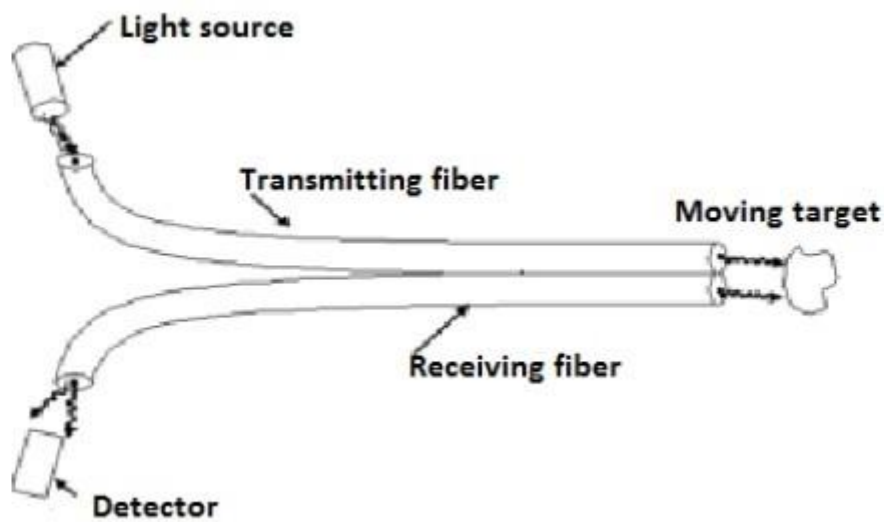


Figure 2.6:Displacement Sensor (Extrinsic Sensor)

2.9 Applications of Fiber Optic Sensors

Fiber optic sensors are used in several areas. Specifically:

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

• Monitoring the physical health of structures in real time.

• Buildings and Bridges: Concrete monitoring during setting, crack (length, propagation speed) monitoring, prestressing monitoring, spatial displacement measurement, neutral axis evolution, long-term deformation (creep and shrinkage) monitoring, concrete-steel interaction, and post-seismic damage evaluation.

• Tunnels: Multipoint optical extensometers, convergence monitoring, shotcrete / prefabricated vaults evaluation, and joints monitoring damage detection.

• Dams: Foundation monitoring, joint expansion monitoring, spatial displacement measurement, leakage monitoring, and distributed temperature monitoring.

• Heritage structures: Displacement monitoring, crack opening analysis, post-seismic damage evaluation, restoration monitoring, and old-new interaction.

2.10 Fiber Optic Instrumentation System1ntroduction

The communication engineers need the fiber characteristics to design the optical fiber link with an efficient waveguide without any loss or dispersion. Similarly, the fiber manufactures 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. Refractive index profile measurement are to know the number of modes propagating the fiber and to determine its numerical aperture.

Measurement of attenuation (by cut back method)

Light from a halogen lamp or white light source is couple into the experimental fiber having length about 1 km. The lens placed in front of the source focuses the light on to the interference filter or monochromatic prism or grating. The light with a given wavelength is incident on the chopper which is used to convert d.c light into square pulses of light (a.c). It also sends the reference signal to the lock in amplifier. Monitor is used to view the intensity of the optical beams. The cladding mode strippers are connected at the input end and output end of fiber. The cladding mode stripper is used to remove the cladding light or cladding modes. Then the jacket fiber is placed in an index matching liquid whose refractive index is slightly higher than that of cladding.

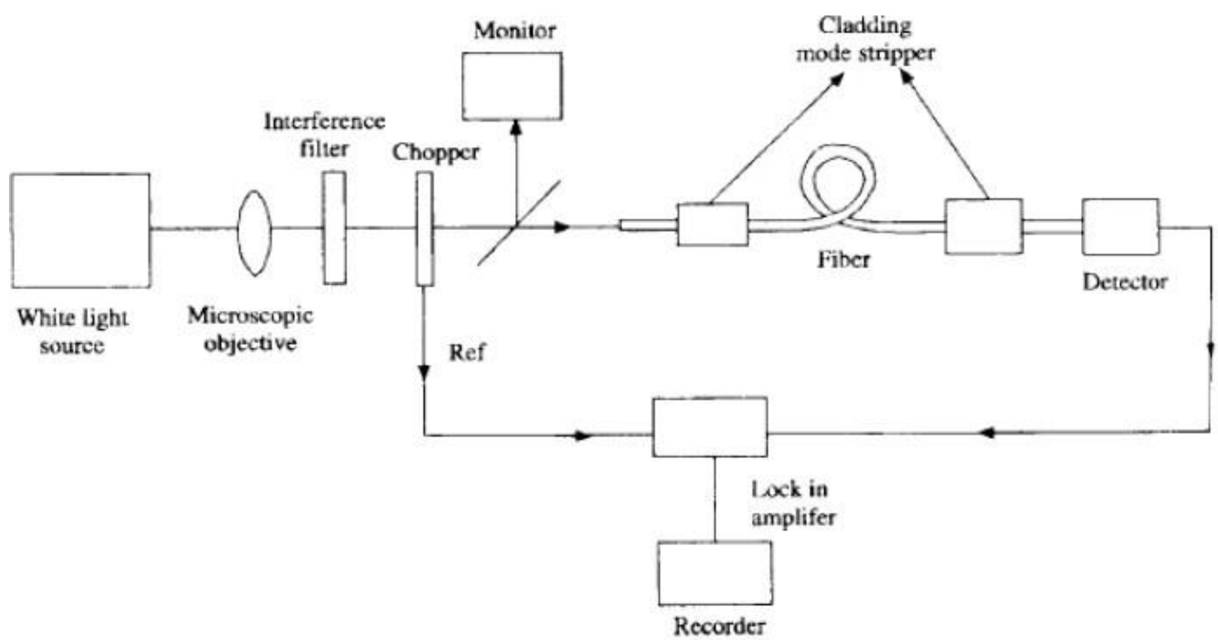


Figure 2.7: Measurement of Attenuation

This arrangement is called cladding mode stripper which will attenuate the light propagating through the cladding. After travelling through the fiber of 1Km length, the given height reaches the index matched photodetector whose output is given to the lock amplifier. 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 is noted Pr (λ) is noted. This procedure is repeated for other wavelength also. Where L is the length of the fiber cut back in Km. In the 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.

Advantage:

This method is very accurate and simple.

Drawback

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

ii) It is a destructive testing method.

2.11 Optical domain reflectometers:

The OTDR is the instrument which is used both in laboratory and field measurements for determining fiber attenuation ,joint losses and detecting fault losses. When the fiber attenuation varies with distance, then the OTDR is the only instrument which can measure the fiber attenuation along the fiber optics link. The OTDR measurement is a non-destructive measurement.

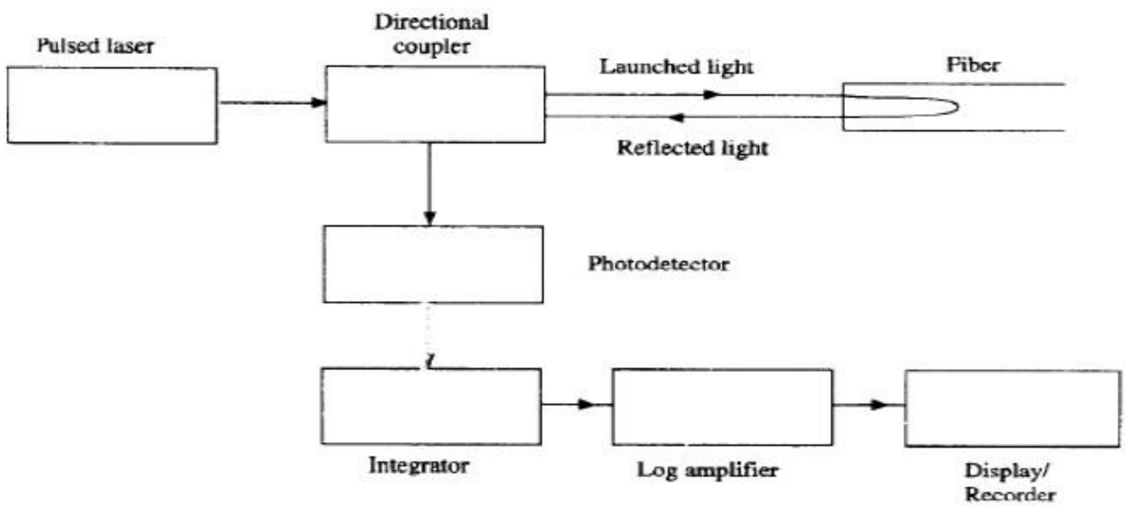


Figure 2.8: Optical domain reflectometers

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 Rayleigh scattering.

Construction and working:

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 photo detector 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 intial peak is caused by the reflection at the fiber end. 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 presence of a fault in the fiber link. There is a 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.

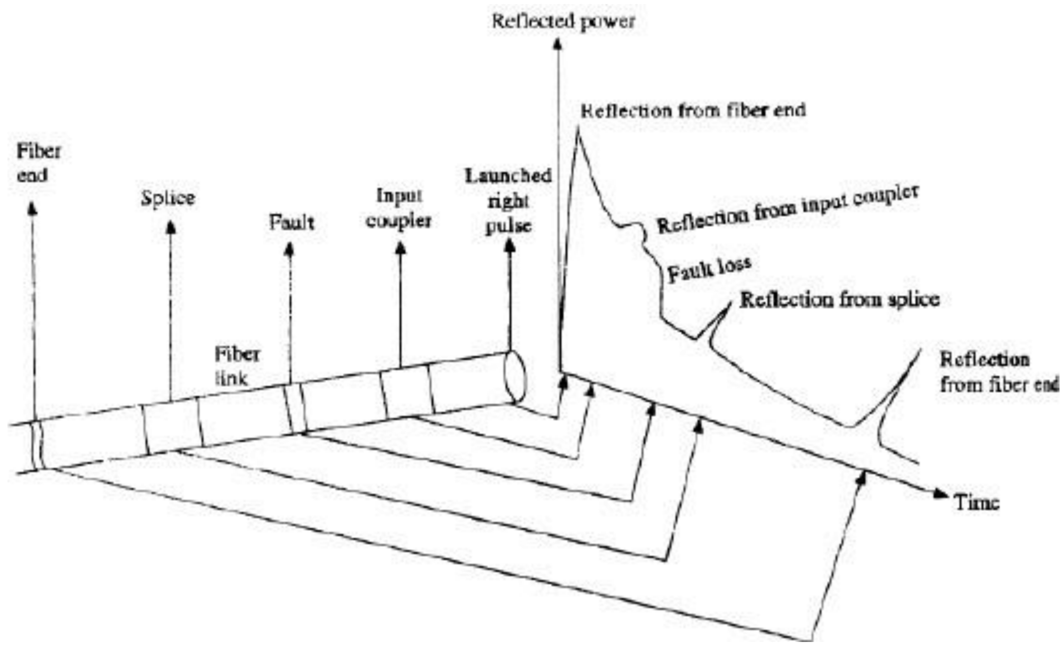


Figure 2.9: Reflected power of Optical domain reflectometers

2.12 Fiber scattering loss Measurement:

Usually a high power laser source like He-Ne laser or Nd-YAG laser is used to provide sufficient input optical power to the fiber. 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. Further the output end of the fiber is in index matched liquid to avoid reflections contributing to the optical signal within the integrating sphere. The light scattered from the fiber core is detected by the series solar cell in the integrating sphere. The integrating sphere also contains the index matching liquid surrounding the fiber. The detected signal by the series of solar cell gives the measurement of the scattered signal. The detected signal is given to lock in amplifier an to then to the recorder or nano voltmeter**.**

2.13 Fiber Absorption Measurement:

Fiber absorption measurement will give the impurity level in the filter. Fiber absorption loss(bB/km)= Fiber attenuation loss (dB/Km)- Fiber scattering loss(dB/km) Thus the fiber absorption lass istrhe difference between fiber attenuation loss and scattering loss.

Principle: Amount of light energy absorbed by the fiber= Heat energy developed in the calorimeter

Construction:

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 separately in silica capillary tubes surrounded by the low refractive index liquid like methanol in the calorimeter for good electrical contact. The light from the laser source is well focused on the fiber under measurement. 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:

When the light enters the fiber under measurement there 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. 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 tubes. The hot junction of the thermocouple and the cold junction of the thermocouple are connected with a nanovoltmeter. 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 in terms of pulse broadening. There are two types of fiber dispersions. One is intermodal dispersion and the other is intra nodal (or) chromatic dispersion. Both dispersion measurements can be performed using the same except the light source. Inter-nodal dispersion measurement is made by the monochromatic laser with narrow spectral width. This intermodal dispersion is dominant in the multimode fibers. The intra- nodal dispersion measurement is made by the injection laser whose frequency or line width increases with respect to time

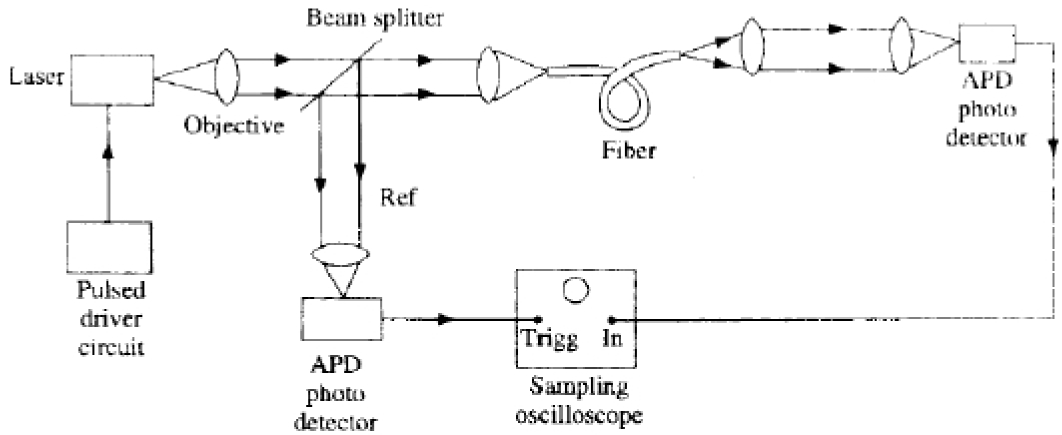


Figure 2.10: Fiber dispersion Measurement

The laser with driver circuit gives short narrow pulses of light. The laser light is focused onto the beam splitter. The beam splitter is used for triggering the oscilloscope and for input pulse with measurement. One of the beams passing through the beam splitter is again focused into the fiber under measurement. Normally its length is 1 km .The focused output laser beam is incident on the avalanche photodiode and it gives the output pulses. The input pulse and output pulse are displayed separately on the screen of sampling oscilloscope and they are in Gaussian shape.

2.14 End reflection method:

The light from the lambertian source is focused onto the entrance end of the fiber having a length 2 metre. 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 the chopper is scanned transversely by a p-i-n detector . The detector output is amplified by a preamplifier. The chopper and the preamplifier are linked with the lock in amplifier. So the phase sensitive detected signal is further amplified and plotted directly on a X-Y recorder. 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

1. There should not be any contamination on the fiber surface
2. The fiber surface should be optically plane.
3. During scanning proper alignment of the fiber is necessary.

Near field scanning techniques:

Theory

When a lambertian source like tungsten filament lamp or LED is used to excite all the guided modes then P® 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.

2.15 Measurement of numerical aperture of the fiber:

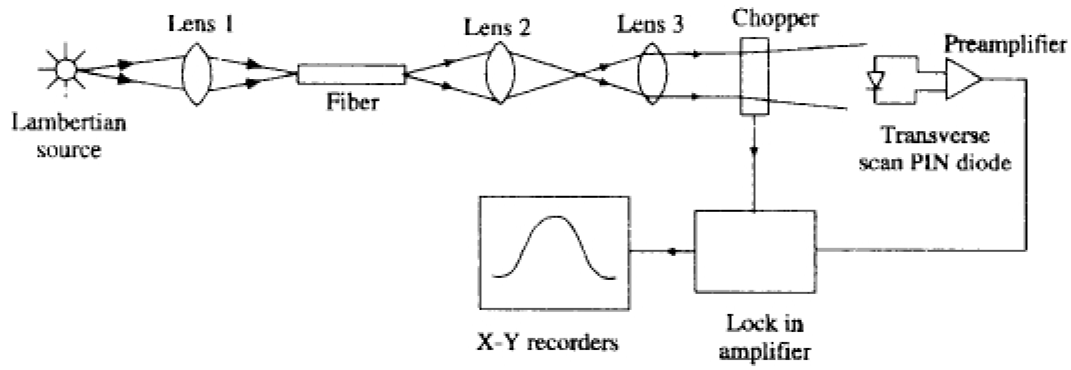


Figure 2.11: Measurement of numerical aperture of the fiber

The lambertian the numerical aperture 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 1m. The far field patteren from the fiber is displaced on the screen which is at a distance 'D' from the output end of the fiber. 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)=sinθa (r) = $(n_1^2(r)-n_2^2)^{1/2}$

2.16Classification of optical modulators

According to the properties of the material that are used to modulate the light beam, modulators are divided into two groups: *absorptive modulators* and *refractive modulators*. In absorptive modulators absorption coefficient of the material is changed, in refractive modulators refractive index of the material is changed.

The absorption coefficient 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. electrooptic 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.

See:

Electro-optic modulator, exploiting the electro-optic effect

Acousto-optic modulator

Magneto-optic modulators

2.17 Electro-optic modulator (EOM) is an optical device in which a signal-controlled elementexhibiting the electro-optic effect is used to modulate a beam of light. The modulation may be

imposed on the phase, frequency, amplitude, or polarization of the beam. Modulation bandwidths extending into the gigahertz range are possible with the use of laser-controlled modulators.
The electro-optic effect is the change in the refractive index of a material resulting from the application of a DC or low-frequency electric field. This is caused by forces that distort the position, orientation, or shape of the molecules constituting the material. Generally, a nonlinear optical material (organic polymers have the fastest response rates, and thus are best for this application) with an incident static or low frequency optical field will see a modulation of its refractive index.
The simplest kind of EOM consists of a crystal, such as lithium niobate, whose refractive index is a function of the strength of the local electric field. That means that if lithium niobate is exposed to an electric field, light will travel more slowly through it. 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. Therefore, the phase of the laser light exiting an EOM can be controlled by changing the electric field in the crystal.
Note that the electric field can be created by placing a parallel plate capacitor across the crystal. Since the field inside a parallel plate capacitor depends linearly on the potential, the index of refraction depends linearly on the field (for crystals where Pockels effect).

MOIRE FRINFGES:

The French term “moiré” originates from a type of textile traditionally of silk textile ,traditionally of silk , with a grained or watered appearance. Now moiré is generally used for a fringe that is created by superposition of two (or more) patterns such as dot arrays and grid lines□The mathematical description of moiré patterns resulting from the and grid lines.The moiré effect is therefore often termed mechanical interference. The mathematical description of moiré patterns resulting from the superposition of sinusoidal gratings is the same as interference patterns formed by electromagnetic waves.

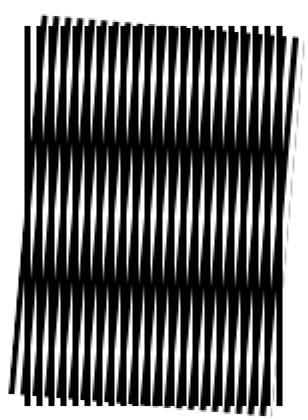
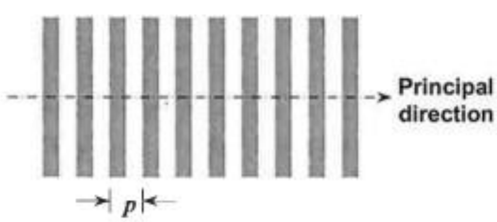


Figure 2.12: Moire Fringes

When two periodic geometric patterns of *nearly* same pitch/period are superimposed, optical interference occurs. This is generally referred to as "moiré phenomenon" and the resulting interference patterns called the 'moiré fringes'. This French word is used to describe wavy patterns seen when sheets of shiny woven silk or wool are superposed. Other examples of moiré 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) of period close 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 moiré patterns seen are generally considered an optical noise and undesirable. However, in other situations, moiré patterns can be used as a gauging signal to perform accurate measurements (such as in-plane and out-of-plane deformations, rotation of an object, surface slopes, etc.,) in solids subjected to mechanical loading.

Here, the discussion will be limited to periodic patterns, often referred to 'gratings', on planar surfaces. The commonly used grating patterns are lines, square mesh (or a dot pattern), concentric circles, radial lines, and spiral patterns. The direction perpendicular to the grating lines is referred to as the **principal direction of the grating**. The line gratings with *rectangular* intensity profile as shown below are often referred to as **Ronchi rulings/Ronchi gratings**.



Using two different gratings, geometric interference representing either linear or rotational mismatch can be created as shown in figures (a) and (b) below. The resulting fringes can be subsequently used for measuring deformations. In the former case (Fig. (a)), using two gratings - a 'master' grating and a 'specimen' grating – of identical grating pitch, shear deformations can be measured. If the specimen grating is affixed (bonded) to the specimen surface, it follows surface deformations as the specimen deforms. That is, the grating lines on the specimen rotate relative to the master grating. This produces moiré fringes and the spacing between the resulting fringes decreases as the angle of rotation increases. Similarly, as the specimen grating deforms in the latter case (Fig. (b)), the grating pitch increases (or decreases) relative to the master grating, causing the fringe spacing to decrease (or increase). These fringe patterns can be used to evaluate the magnitude of displacements.

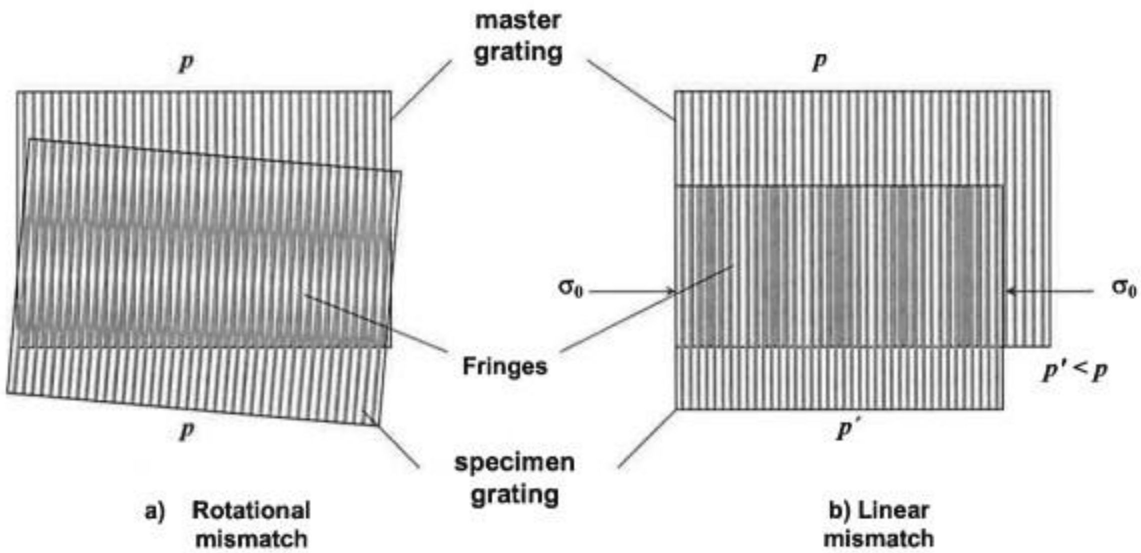


Figure 2.13: Master and Specimen grating

2.18 Measurement using fiber optics sensor:

Measurement of pressure:

All the displacement sensors can be used to measure pressure. Here the pressure is first converted in to displacement and the change in intensity is reflected or transmitted light is measured in terms of displacement. The pressure sensor based on reflective concept. Depending upon the value of pressure, the radius of curvature of the diaphragm is changed. Hence, the intensity of the reflected light is changed. The response curve shows that as the pressure increases, output voltage decreases. 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. 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 continuously and its movement is directionally proportional to temperature. The amount of reflected light is converted in to 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 L fiber length ,n refractive index The arrangement is called mach-zender. The Semiconductor laser acts as a light source. A 3 db splitter acts as the beam splitter which sense the light through the sensing and reference fiber. Another 3 dB 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. If is negligible. By placing a photodetector to measure the intensity of the fringes, 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:

The linearly polarized laser light from the negative laser is launched in to fiber. Cladding mode stripper removes cladding modes. The direction of polarization of the light in the fiber rotated by the longitudinal magnetic field around the current carrying conductor.

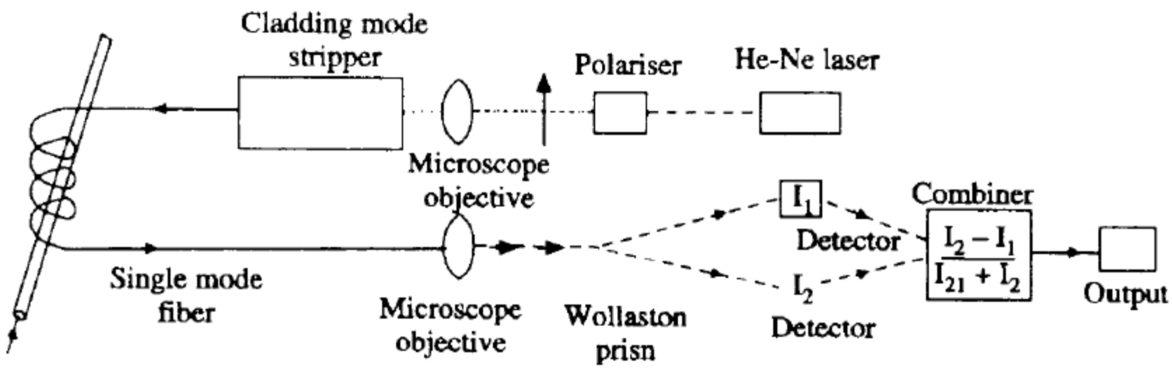


Figure 2.14: measurement of current

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 in to two orthogonal components I1 and I2 . 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

$$= + rE + RE^2$$

Where

no-refractiveindex before the application of electric field.

r – Linear electro optic coefficient

R – Quadratic electrooptic coefficient

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 under goes a phase shift or phase retardation

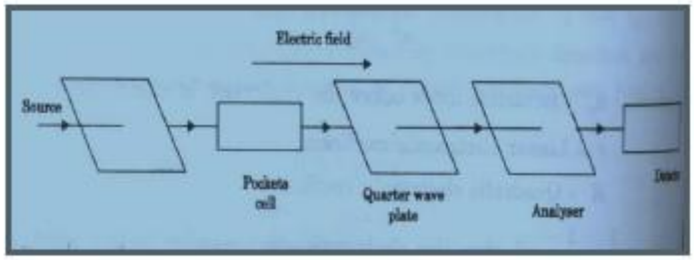


Figure 2.15: Measurement of Voltage

If I0be the incident light intensity , then the intensity of the transmitted light through crystal is I=I0sin2 . Thus , phase produced in the linearly polarized wave is directly proportional to applied electric field/ voltage. The polarizer converts the incident ordinary light in to a linearly polarized light. When there is applied voltage across the pocket cell, phase shift is produced for the transmitted polarized beam. Quarter wave plate produces a phase shift of θ/2. The transmitted light is then analysed through a analyzers.

Measurement of liquid level

Liquid level sensor consists of two fibers which are connected at the base of a glass micro prism. When the tip of the prism is immersed in the liquid, there is no output at the detector. 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.

Disadvantage:

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

2.19 Measurement of Strain :

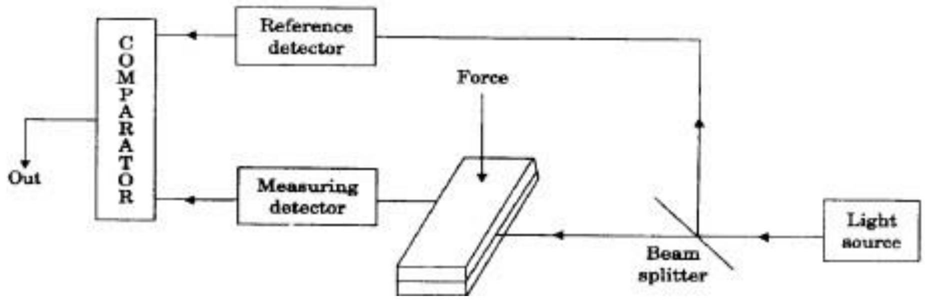


Figure 2.16: Measurement of strain

Micro bending losses are produced in the fiber when the top block presses the fiber by the applied external force. The micro bend 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.

A **fibre optic gyroscope** (**FOG**) senses changes in orientation using the Sagnac effect, thus performing the function of a mechanical gyroscope. However its principle of operation is instead based on the interference of light which has passed through a coil of optical fibre which can be as long as 5 km. The development of diode (semiconductor) lasers and low-loss single-mode optical fibre in the early 1970s for the telecommunications industry enabled Sagnac effect fibre optic gyros to be developed as practical devices.

Two beams from a laser are injected into the same fiber but in opposite directions. Due to the Sagnac effect, the beam travelling against the rotation experiences a slightly shorter path delay than the other beam. The resulting differential phase shift is measured through interferometry, thus translating one component of the angular velocity into a shift of the interference pattern which is measured photometrically.

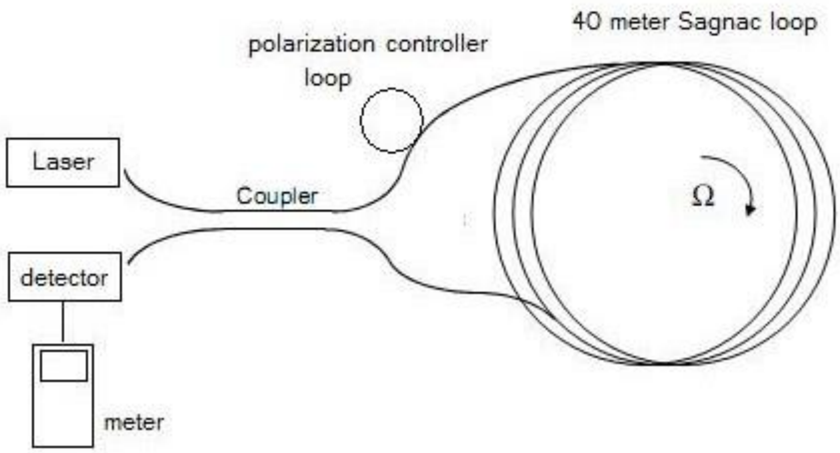


Figure 2.17: Measurement of strain using laser

Beam splitting optics launches light from a laser diode into two waves propagating in the clockwise and anticlockwise directions through a coil consisting of many turns of optical fibre. The strength of the Sagnac effect is dependent on the effective area of the closed optical path: this is not simply the geometric area of the loop but is enhanced by the number of turns in the coil. The FOG was first proposed by Vali and Shorthill in 1976. Development of both the passive interferometer type of FOG, or IFOG, and a newer concept, the passive ring resonator FOG, or RFOG, is proceeding in many companies and establishments worldwide.

Advantages

A FOG provides extremely precise rotational rate information, in part because of its lack of cross-axis sensitivity to vibration, acceleration, and shock. Unlike the classic spinning-mass gyroscope, the FOG has no moving parts and doesn't rely on inertial resistance to movement. Hence, this is perhaps the most reliable alternative to the mechanical gyroscope. Because of their intrinsic reliability, FOGs are used for high performance space applications. The FOG typically shows a higher resolution than a ring laser gyroscope, but suffered from greater drift and worse scale factor performance until the end of the 1990s.FOGs are implemented in both open-loop and closed-loop configurations FOGs are used in the inertial navigation systems of many guided missiles.

1. FOGs can be a navigation aid in remotely operated vehicles and autonomous underwater vehicles.
2. FOGs are used in surveying.

The polarization of light propagating in the fiber gradually changes in an uncontrolled (and wavelength-dependent) way, which also depends on any bending of the fiber and on its temperature. Specialised fibers are required to achieve optical performances, which are affected by the polarization of the light travelling through the fiber. Many systems such as fiber interferometers and sensors, fiber laser and electro-optic modulators, also suffer from Polarization-Dependent Loss (PDL) that can affect system performance. This problem can be fixed by using a specialty fiber so called PM Fiber.

Principle of PM Fiber

Provided that the polarization of light launched into the fiber is aligned with one of the birefringent axes, this polarization state will be preserved even if the fiber is bent. The physical principle behind this can be understood in terms of coherent mode coupling. The propagation constants of the two polarization modes are different due to the strong birefringence, so that the relative phase of such copropagating modes rapidly drifts away. Therefore, any disturbance along the fiber can effectively couple both modes only if it has a significant spatial Fourier component with a wavenumber which matches the difference of the propagation constants of the two polarization modes. If this difference is large enough, the usual disturbances in the fiber are too slowly varying to do effective mode coupling. Therefore, the principle of PM fiber is to make the difference large enough.

In the most common optical fiber telecommunications applications, PM fiber is used to guide light in a linearly polarised state from one place to another. To achieve this result, several conditions must be met. Input light must be highly polarised to avoid launching both slow and fast axis modes, a condition in which the output polarization state is unpredictable.

The electric field of the input light must be accurately aligned with a principal axis (the slow axis by industry convention) of the fiber for the same reason. If the PM fiber path cable consists of segments of fiber joined by fiber optic connectors or splices, rotational alignment of the mating fibers is critical. In addition, connectors must have been installed on the PM fibers in such a way that internal stresses do not cause the electric field to be projected onto the unintended axis of the fiber.

Types of PM Fibers

Circular PM Fibers

It is possible to introduce circular-birefringence in a fiber so that the two orthogonally polarized modes of the fiber—the so called Circular PM fiber—are clockwise and counter-clockwise circularly polarized. The most common way to achieve circular-birefringence in a round (axially symmetrical) fiber is to twist it to produce a difference between the propagation constants of the clockwise and counterclockwise circularly polarized fundamental modes. Thus, these two circular polarization modes are decoupled. Also, it is possible to conceive externally applied stress whose direction varies azimuthally along the fiber length causing circular-birefringence in the fiber. If a fiber is twisted, a torsional stress is introduced and leads to optical-activity in proportion to the twist.

Circular-birefringence can also be obtained by making the core of a fiber follows a helical path inside the cladding. This makes the propagating light, constrained to move along a helical path, experience an optical rotation. The birefringence achieved is only due to geometrical effects. Such fibers can operate as a single mode, and suffer high losses at high order modes.

Circular PM fiber with Helical-core finds applications in sensing electric current through Faraday effect. The fibers have been fabricated from composite rod and tube preforms, where the helix is formed by spinning the preform during the fiber drawing process.

Linear PM Fibers

There are manily two types of linear PM fibers which are single-polarization type and birefringent fiber type. The single-polarization type is characterized by a large transmission loss difference between the two polarizations of the fundamental mode. And the birefringent fiber type is such that the propagation constants between the two polarizations of the fundamental mode are significantly different. Linear polarization may be maintained using various fiber designs which are reviewed next.

Linear PM Fibers With Side Pits and Side Tunnels:

Side-pit fibers incorporate two pits of refractive index less than the cladding index, on each side of the central core. This type of fiber has a W-type index profile along the x-axis and a step-index profile along the y-axis. A side-tunnel fiber is a special case of side-pit structure. In these linear PM fibers, a geometrical anisotropy is introduced in the core to obtain a birefringent fibers.

Linear PM Fibers With Stress Applied Parts:

An effective method of introducing high birefringence in optical fibers is through introducing an asymmetric stress with two-fold geometrical symmetry in the core of the fiber. The stress changes the refractive index of the core due to photoelastic effect, seen by the modes polarized along the principal axes of the fiber, and results in birefringence. The required stress is obtained by introducing two identical and isolated Stress Applied Parts (SAPs), positioned in the cladding region on opposite sides of the core. Therefore, no spurious mode is propagated through the SAPs, as long as the refractive index of the SAPs is less than or equal to that of the cladding.

The most common shapes used for the SAPs are: bow-tie shape and circular shape. These fibers are respectively referred to as **Bow-tie Fiber** and **PANDA Fiber**. The cross sections of these twotypes of fibers are shown in the figure below. The modal birefringence introduced by these fibers represents both geometrical and stress-induced birefringences. In the case of a circular-core fiber, the geometrical birefringence is negligibly small. It has been shown that placing the SAPs closeto the core improves the birefringence of these fibers, but they must be placed sufficiently closeto the core so that the fiber loss is not increased especially that SAPs are doped with materials other than silica. The PANDA fiber has been improved further to achieve high modal birefringence, very low-loss and low cross-talk.

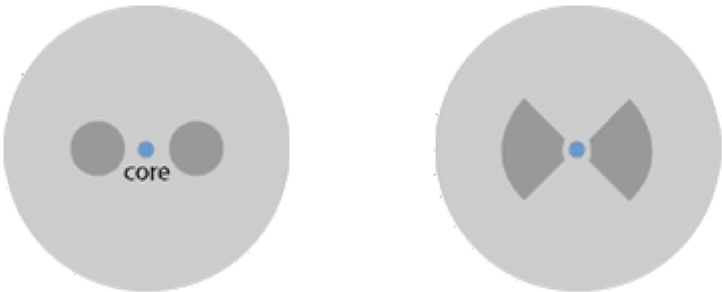


Figure 2.18: PANDA Fiber (left) and Bow-tie Fiber (right). The built-in stress elements made from a differenttype of glass are shown with a darker gray tone.

At present the most popular PM fiber in the industry is the circular PANDA fiber. Oneadvantage of PANDA fiber over most other PM fibers is that the fiber core size and numerical aperture is compatible with regular single mode fiber. This ensures minimum losses in devices using both types of fibers.

PART A

Q.No.	Question
1	What is an optical sensor?
2	What are fiber optic probes?
3	State interferometric concept?
4	What are fiber optic gyroscopes?
5	What is micro bending?
6	What are different types of interferometry?
7	State the concepts behind liquid level sensors.
8	What is reciprocity?
9	What are resonators?
10	What are the two modes of operation in single mode fibers?
11	List the methods used to maintain polarization
12	Draw the response curve of a reflective fiber optic sensor.

PART-B

Q.No.	Question
1	Explain about liquid level sensors.
2	Write about pressure sensors in detail.
3	What are temperature sensor and explain?
4	Explain the concept of polarization in optical fibers and discuss the polarization sensors.
5	Explain about the fiber optic gyroscopes.
6	Write about the acoustic sensors in detail. .

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION

UNIT – III - Fiber Optics and Laser Instrumentation – SIC1605

UNIT -III

FIBER OPTICS AND LASER INSTRUMENTATION

3.1 LASER FUNDAMENTALS

LASER is Light Amplification by Stimulated Emission of Radiation.

3.1.1 Fundamental Characteristics of Lasers

Laser technology is one of the 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. To explain how the laser can be applied in such diverse areas, we need to understand the basic physical principles of the operation of a laser.

In principle, the laser is a device which transforms s energy from other forms into electromagnetic radiation. This is a very general definition, but it helps to understand the basic physics of the laser. The energy put into the laser can be in any form such as: electromagnetic radiation, electrical energy, chemical energy, etc. Energy is always emitted from the laser as electromagnetic radiation (which includes light beams).

3.1.2 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 (in our model further away from the nucleus).The atom is then considered to be in an excited state. The electron can stay only at the specific energy states (levels) which are unique for each specific atom. The electron cannot be in between 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 Energy transfer to and from the atom can be performed in two different ways:

3.1.3 Two-Level Laser

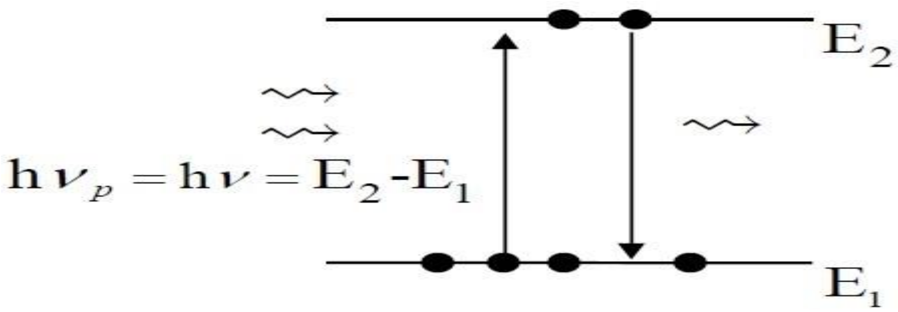

Figure 3.1: Two level laser

Suppose we try to increase N2 with strong light at hν to create a population inversion

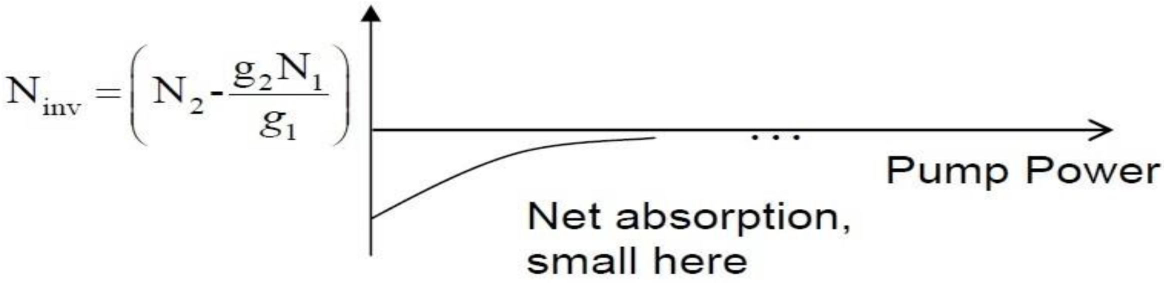

Figure 3.2: Population inversion of Two level laser

3.1.4 Three Level Laser

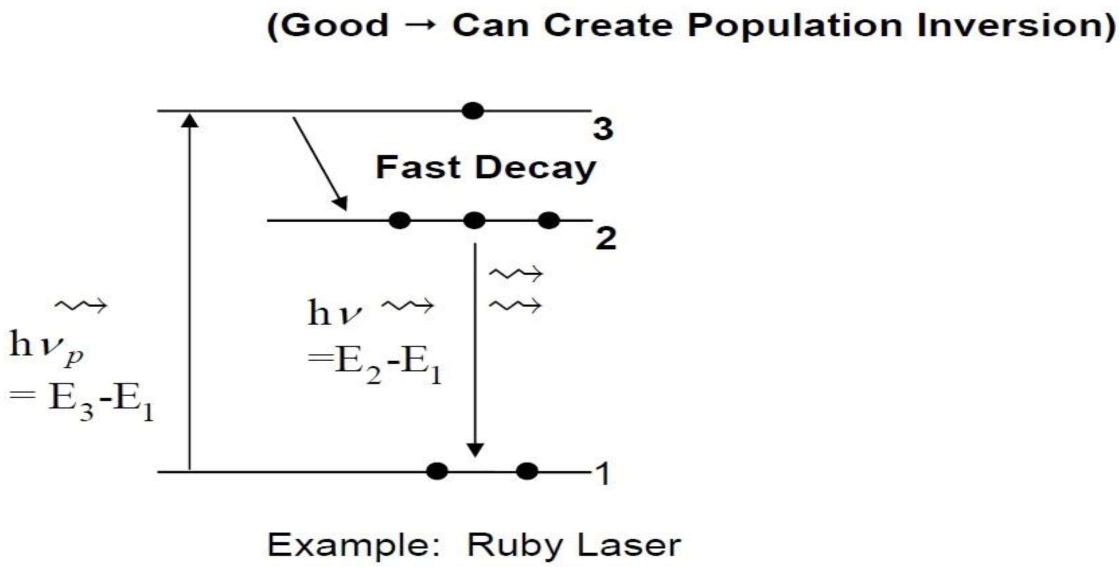

Figure 3.3: Ruby laser

In a three level system, the terminal level for the 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 atoms will drop the electrons to level 2. The difference in energy between levels 3 and 2 appears as heat. Stimulated emission occurs between levels 2 and 1 at frequency,

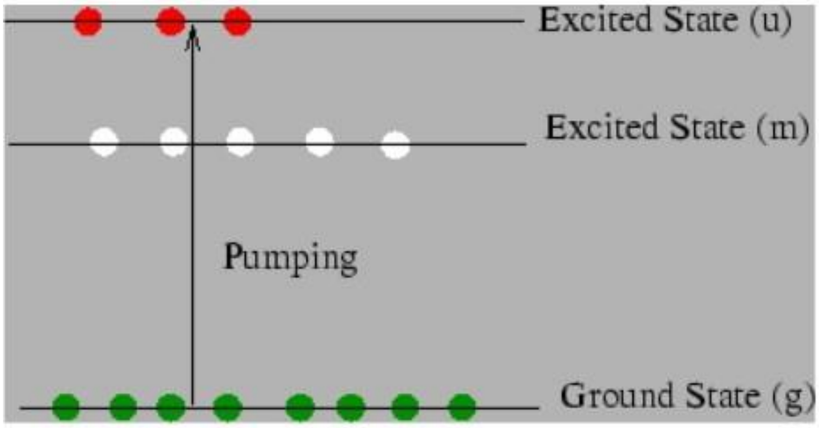

Figure 3.4: Excitation state of Ruby Laser

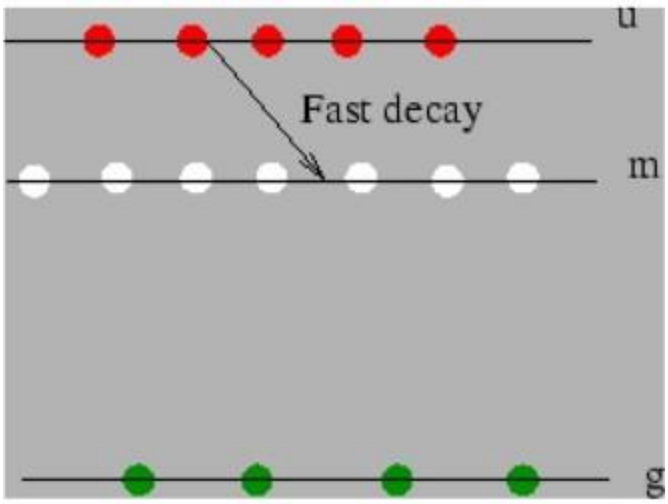

Figure 3.5: Stimulated emission of Ruby Laser

It substantial power at frequency $f_3$is supplied, the transition rate from level 1 to 3 will be large.

3.1.5 Quasi Three Level 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.

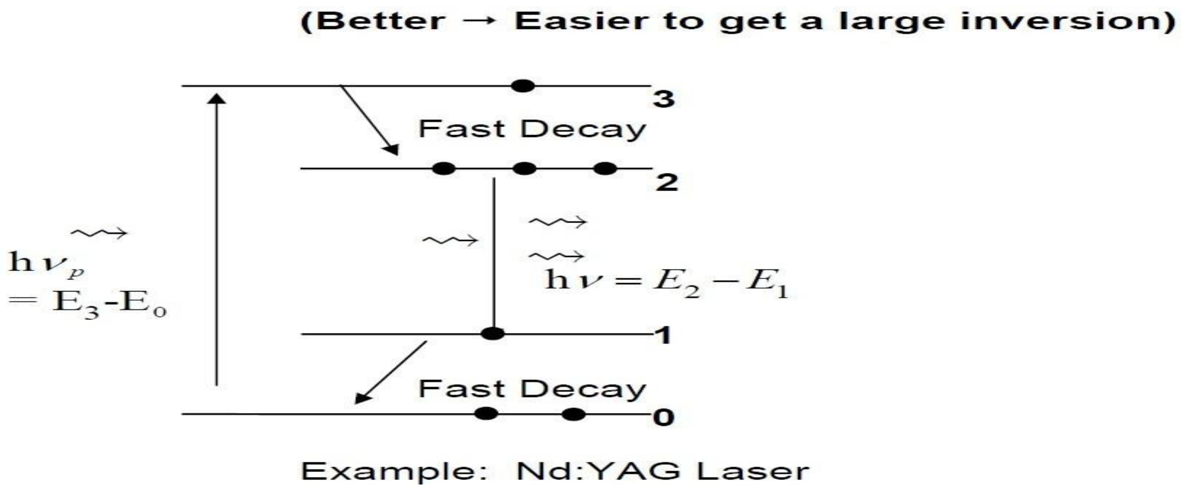

Figure 3.6: Nd- YAG Laser

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.

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

•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 (E2-E1).

•When this energy is absorbed or emitted in a form of electromagnetic radiation, the energy difference between these two energy levels (E2-E1) determines uniquely the frequency (ν) of theelectromagnetic radiation: (ΔE) = E2-E1= hν= h(bar)ω

Eg: The laser is a system that is similar to an electronic oscillator. An Oscillator is a system that produces oscillation s without an external driving mechanism.

3.2 Four level Laser

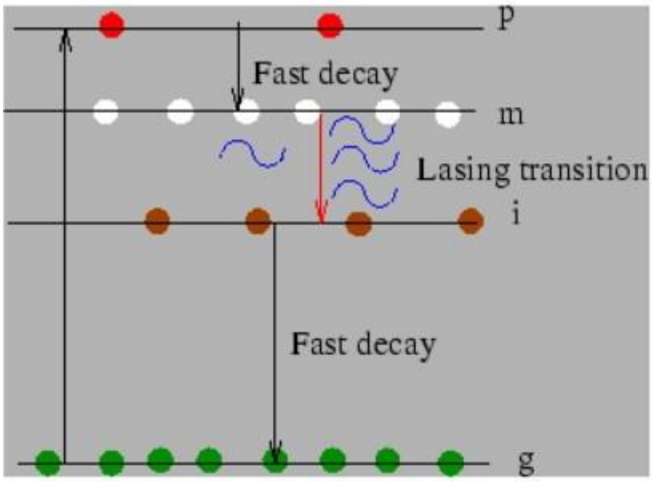

Figure 3.7: Four level Laser

A lower threshold pump power can be achieved with a four-level laser medium, where the lower laser level is well above the ground state and is quickly depopulated e.g. by multiphonon transitions. Ideally, no appreciable population density in the lower laser level can occur even during laser operation. In that way, reabsorption of the laser radiation is avoided (provided that there is no absorption on other transitions). This means that there is no absorption of the gain medium in the unpumped state, and the gain usually rises linearly with the absorbed pump power.

The most popular four-level solid-state gain medium is Nd:YAG. All lasers based on neodymium-doped 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, e.g. with pump light around 880 nm for Nd:YAG. Even though effectively only three levels are involved, the term *three-level system* would not be used here.

3.3 Properties of Laser

Monochromaticity:

This property is due to the following two factors.

First, only an EM wave of frequency n0= (E2-E1)/h can be amplified, n0has a certain range which is called linewidth, this linewidth is decided by homogeneous broadening factors and inhomogeneous broadening factors, the result linewidth is very small compared with normal lights. Second, the laser cavity forms a resonant system, oscillation can occur only at the resonance frequencies of this cavity. This leads to the further narrowing of the laser linewidth, the 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.

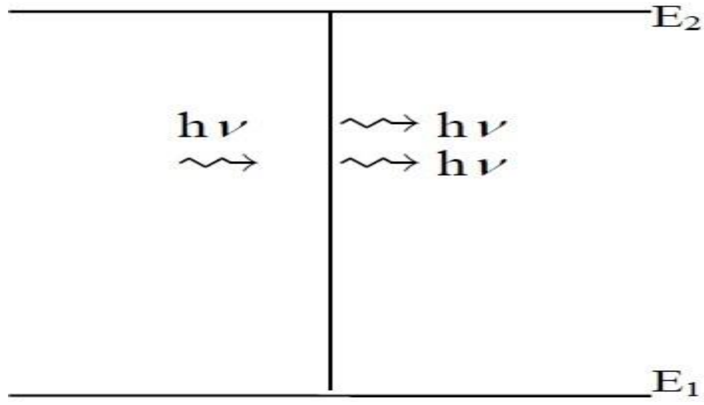

Figure 3.8: Energy level of Nd-YAG Laser

Example: **Nd:YAG Laser** λ=1.064μm, ν=2.8×10^{14} Hz

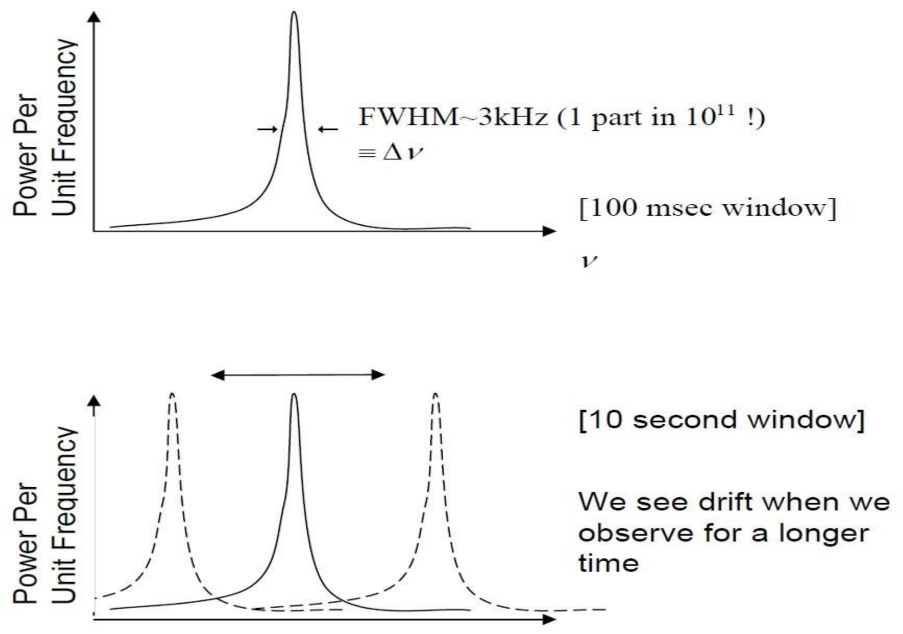

Figure 3.9: Power spectrum of Nd-YAG laser

Coherence:

For any EM wave, there are two kinds of coherence, namely spatial and temporal 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 at time t=0 is k0. If for any time

t>0 the phase difference of EM wave at the two points remains k0, we say the EM wave has perfect coherence between the two points. If this is true for any two points of the wave front, we say the wave has perfect spatial coherence. In practical the spatial coherence occurs only in a limited area, we say it is partial spatial coherence.

Now 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 over a time dt. If dt can be any value, we say the

EM wave has perfect temporal coherence. If this happens only in a range 0<dt<t0, we say it has partial temporal coherence, with a coherence time equal to t0. We emphasize here that spatial and temporal coherence are independent. A partial temporal coherent wave can be perfect spatial coherent. Laser light is highly coherent, and this property has been widely used in measurement, holography, etc.

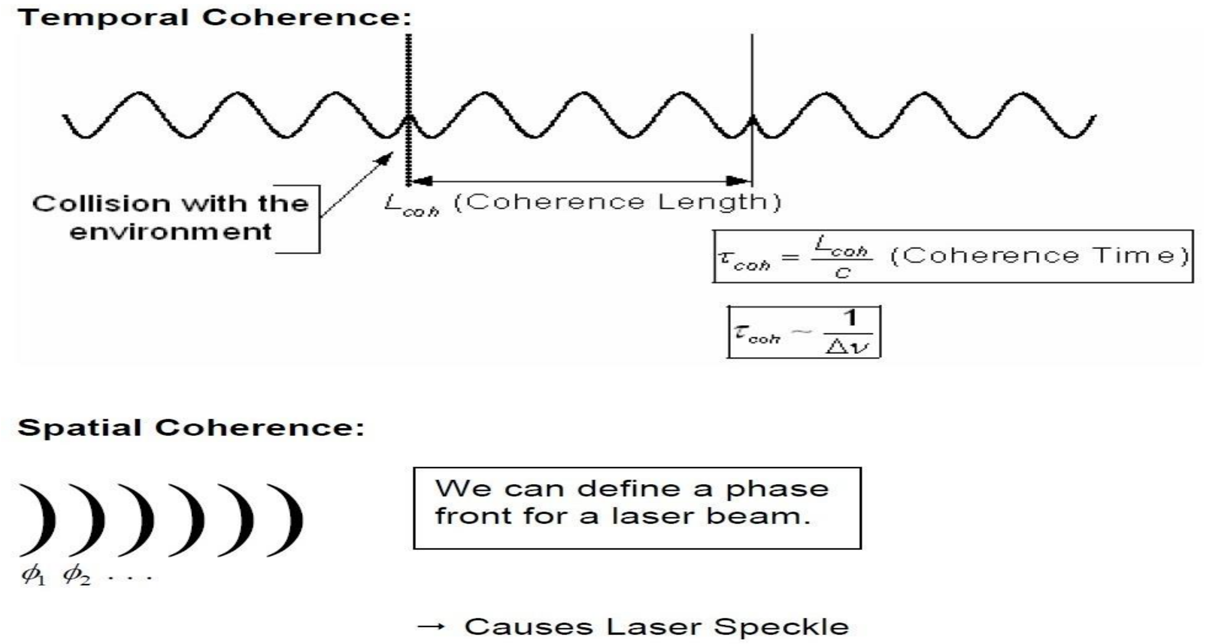

Figure 3.10: Coherence of Laser

Divergence and Directionality:

Laser beam is highly directional, which implies laser light is of very small divergence. This is a direct consequence 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 directionality is described by the light beam divergence angle. Please try the figure below to see the relationship between divergence and optical systems. For perfect spatial coherent light, a beam of aperture diameter D will have unavoidable divergence because of diffraction. From diffraction theory, the divergence angle qd is: qd= b l /D Where l and D are the wavelength and the diameter o

f the beam respectively, b is a coefficient whose value is around unity and depends on the type of light amplitude distribution and the definition of beam diameter. qd is called diffraction limited divergence. If the beam is partial spatial coherent , its divergence is bigger than the diffraction limited divergence. In this case the divergence becomes:

$$q = b \; l \; /(S_c)^{1/2}$$

where S_c is the coherence area.

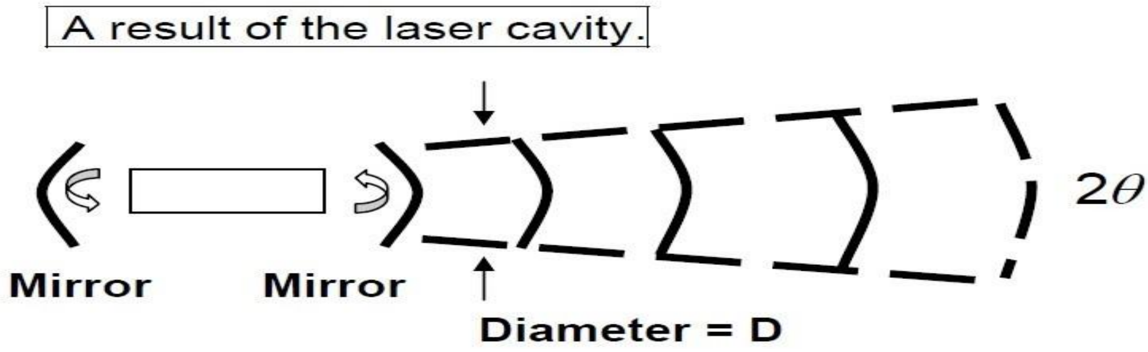

Figure 3.11: Divergence and Directionality of Laser

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 cross section of diameter D and a divergence angle q and the result emission solid angle is p q 2, then the brightness of laser beam is:

$$B=4P/(p\ Dq\ )^2$$

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

$$B_{max}=4P/(p\ l\ b\ )2$$

In case of limited diffraction (q d= l b /D, D=l b /q d, q d=q)

Laser Modes

Surely laser cavity is also very important for a laser in many other aspects, for example, its 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 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. That is:

m = 2L/(c/f) =2L/l , or f = m c/(2L), D f = c/(2L)

Where L is the length of cavity, c is the light speed in laser cavity, f is the frequency of standing wave, l is the wavelength, m is an integer , D f is the frequency difference between two consecutive modes. The number of longitudinal modes may be very large, it can also be as 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 t_o indicate the TEM modes—TEM_{plq}, p is the number of radial zero fields, l is the number of angular zero fields, q is the number of longitudinal fields. We usually use the first two index to specify a TEM mode, like TEM00, TEM10, 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 some times TEM00 mode or Gaussian beam is preferred

3.4 TEM Mode, Beam Diameter, Focal Spot Size and Depth of Focus

Modes are the standing oscillating electromagnetic waves which are defined by the cavity geometry. In the above section, we already computed the Longitudinal Modes frequencies for some simple cases. If the cavity is of closed form, i.e., both the mirrors and side walls are reflective, there will be large amounts of longitudinal modes oscillating inside the cavity, a typical value can be 109 modes for a He-Ne laser.

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. We use the sign TEMpql to specify a TEM mode, where p is the number of radial zero fields, q is the number of angular zero fields, q is the number of longitudinal fields, and we usually use TEMpq to specify a TEM mode, without the third index. A table of TEM patterns is shown below. Clearly, the mode pattern affects the distribution of the output beam energy, which will thus affect the machining process. Then what is the diameter of a laser beam? Usually this diameter is defined as the distance within which 1/e2 of the total power exists.The higher the 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 table below.

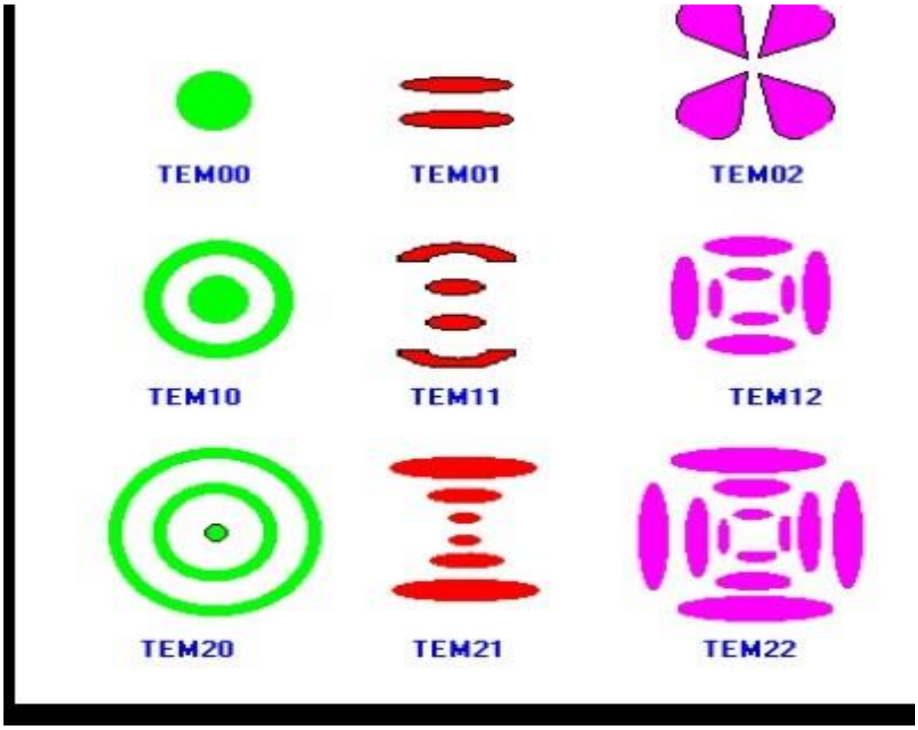

Figure 3.12: TEM mode of Laser

Focal Spot Size:

Focal spot size determines the maximum energy density that can be achieved when thelaser 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 onto a plane, the individual parts of the beam striking the lens can be imagined to be point radiators of new wave front.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.

3.5 Resonator Configuration

The most widely used laser resonators or cavities have either plane or spherical mirrors ofrectangular or circular shape, separated by some distance L. There have appeared Plane Parallel Resonators, Concentric (Spherical) Resonators, Confocal Resonators,Generalized Spherical Resonators and Ring Resonators.

Plane Parallel Resonator consists of two plane mirrors set parallel to each other, as

Shown in the figure below. The one round trip of wave in the cavity should be an integral number times 2ı , the resonant frequencies is ı = 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.

Concentric resonator consists of two spherical mirrors with the same radius R separated by a distance L=2R, so that the centers are coincident. The resonant frequencies use the same equation as above. Confocal resonator consists of two spherical mirrors of the same radius of curvature R separated by a distance of L such that their foci F1 and F2 coincident. In this case, the center 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.

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

Ring Resonator is a particularly important class of laser resonators. The path of the 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 2ı . Then the resonant frequencies are ı = kc/Lp, where k is an integral number, Lp is the loop path length.

Cavities can be identified as stable or unstable according to whether they make the oscillating beam converge 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 intense, the mirror May suffer breakage. Breakage is serious because it causes shut down of the production. So for powers up to 2kW, lasers mainly use stable cavity designslaser output is from the center 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 oscillation between the mirrors.

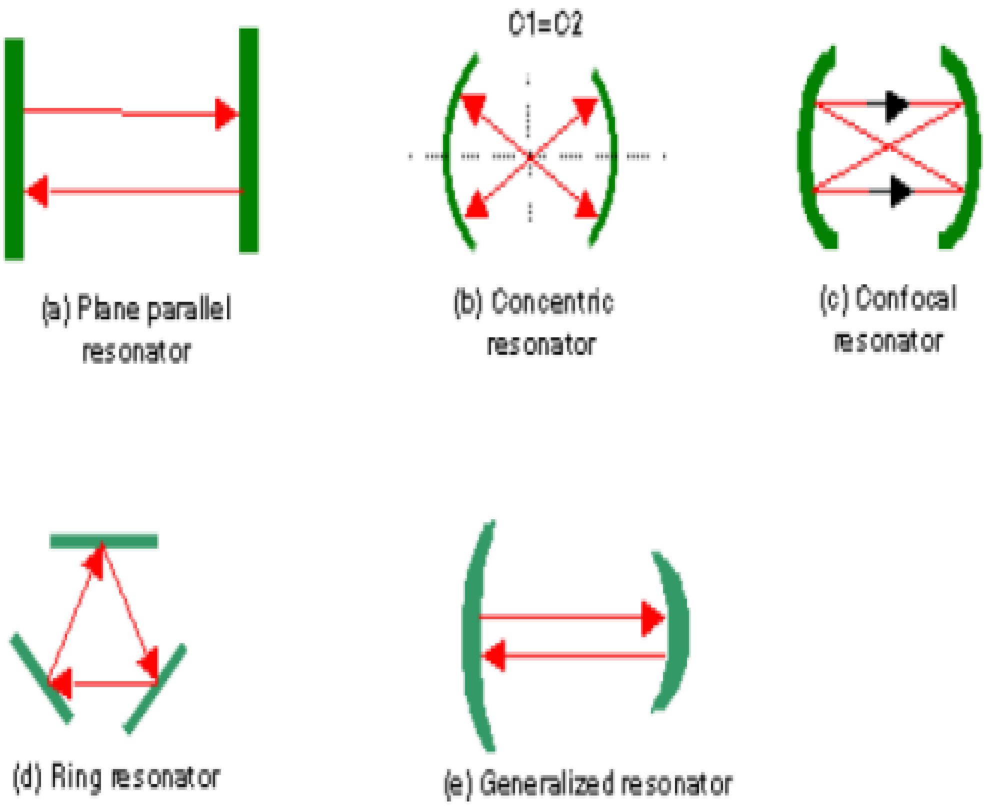

Figure 3.13: Various Resonators

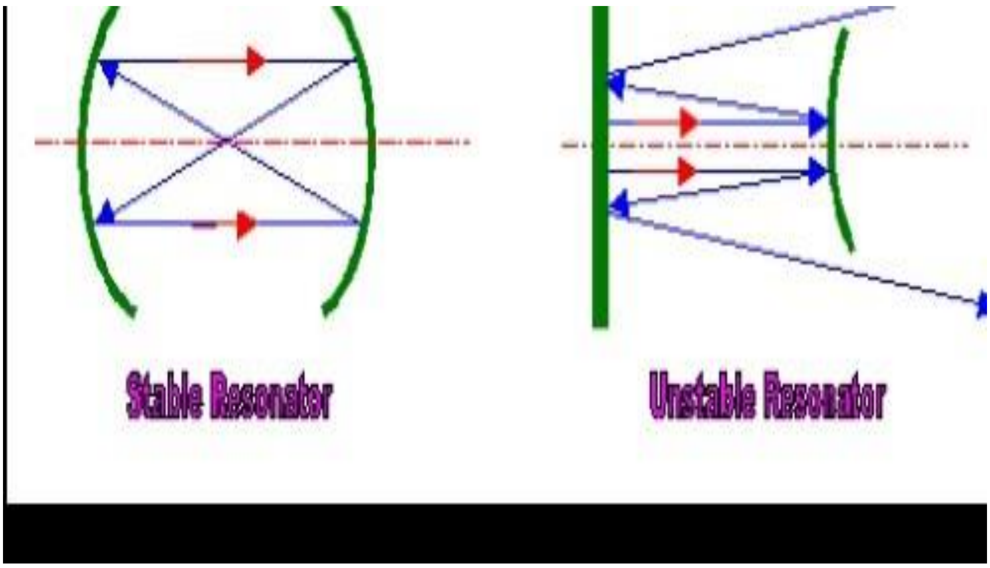

Figure 3.14: Stable and unstable resonator

3.6 Q-Switching and Mode LockingQ-Switching

If the energy stored in the dominant mode is very large, we get high Q. Q – switching means maintaining the population inversion to a very high value above the threshold population inversion and simultaneously bringing down all the atoms to undergo laser transition. Thiswill lead to a gaint pulse with very high power(>10^9 W)

Energy of the pulse(E)= $h\lambda(N_Q$-$N_t)V$

3.7 Q switching technique:

Pockel cell acts as a quarter wave plate producing a phase difference of . 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 M1 to M2. Whem=n the voltage is given to the cell, there is a phase shift of . Therefore, the linearly polarized light ius converted into

circularly polarized light. Reflection at the mirror M2 changes the direction of rotation of circularly polarized light. So, the polarizer does not allow this light to pass through it. 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 oscillation. 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 oscillations. The change o0f voltage from zero to a non zero value should take place within 1 ns.

Mode Locking:

`Modelocking 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 (10-12s) or femto seconds (10-15s).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. 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 Methods for producing mode locking in a laser may be classified as either active or passive. Active methods typically involve using an external signal to induce a modulation of the intra-cavity light. 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

In addition to Q- switching , cavity dumping is a method for producing short pulses with duration is the nano second to microsecond time. Here the laser is excited simultaneously. The resonance cavity has a high Q so that the laser light simply remains in the cavity. An electro optic and device periodically switches pulses out of cavity

Types Of Lasers

Lasers can be divided into gas lasers, solid state lasers and liquid lasers according to the active medium used.

Gas Lasers:

Gas Lasers can be further divided into neutral atom, ion and molecular lasers, whose lasing mediums are neutral atoms, ions or gas molecules respectively.

1. Helium –neon Laser.

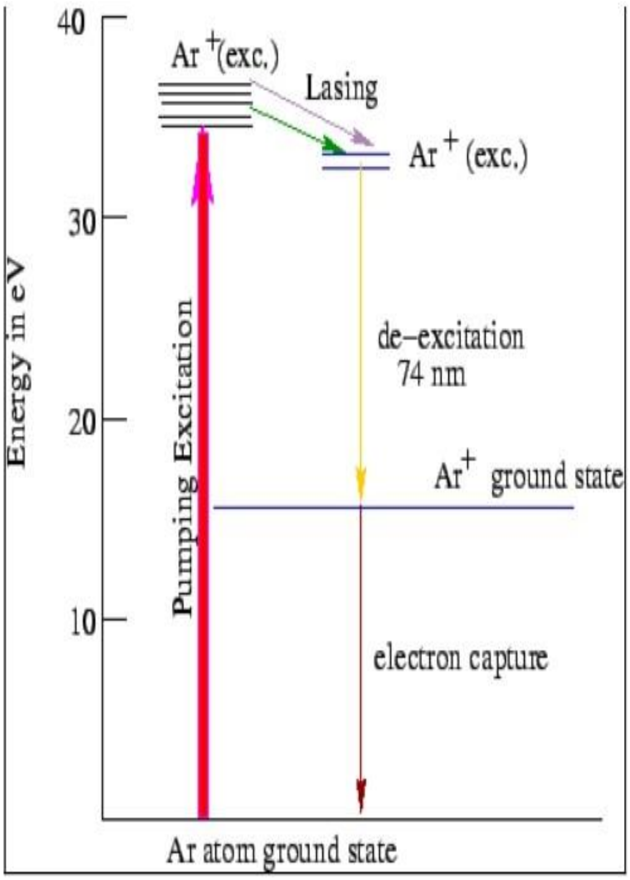

Figure 3.15: He-Ne laser

1. Helium –neon Laser.

Helium-neon (He-Ne) laser is a kind of neutral atom gas laser, the common wavelength

of a He-Ne laser is 632.8 nm, it is tunable from infrared to various visible light frequencies. He and Ne are mixed according to certain percentage, pumping is by DC electrical discharge in the low pressure discharge tube. First He atom is excited. Because Ne atom has an energy level very near to an energy level of He, through kinetic interaction, energy is readily transferred from He to Ne, and Ne atom emit the desired laser light. The typical power of He-Ne laser is below 50 mW, it is widely used in holography, scanning, measurement, optical fiber communication, etc. It is the mostpopular visible light laser.

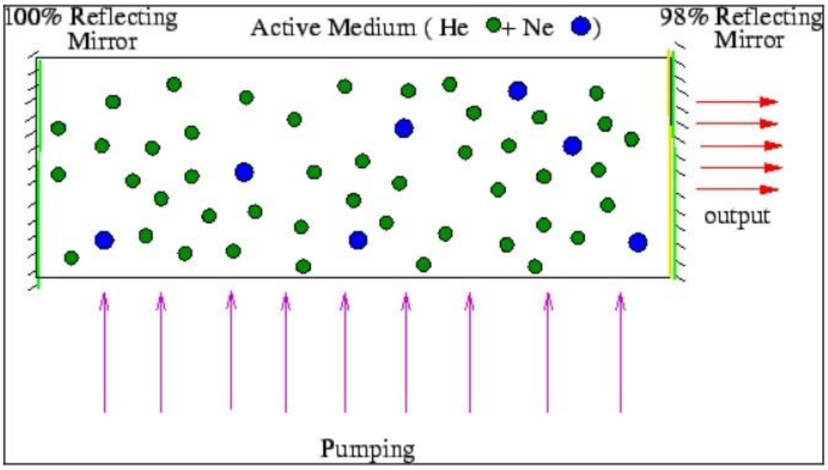

Figure 3.16: Pumping of He-Ne laser

2. Carbon dioxide laser

Carbon dioxide laser is a typical molecular gas laser, it emits laser light at a wavelength of 10.6 m m, its beam power ranges from several watts to 25 kW or even to 100 kW, so CO2 laser is widely used in laser machining, welding and surface treating. For this reason, let's investigate it in detail. The active medium of CO2 laser is a mixture of CO2, helium and nitrogen gases, the approximate constitute is CO2:N2:He::0.8:1:7. Pumping is realized by AC or DC electrical discharge. First most of the electrical discharge energy is absorbed by nitrogen gas, only a small part of the energy is Absorbed by CO2 molecules directly which raise them from ground state (000) to upper state (001). Large amounts of CO2 molecules collide with the nitrogen molecules and gain the excitation energy. Once excitation is achieved, the CO2 molecules at (001) state will give out energy and jump to lower energy state (100) or (020), thus giving out laser light at frequency 10.6m m or 9.6 m m respectively. The remaining decay from state (100) to (010), (020) to (010) or (010) to ground state (000) will dissipate energy in the form heat instead of light.

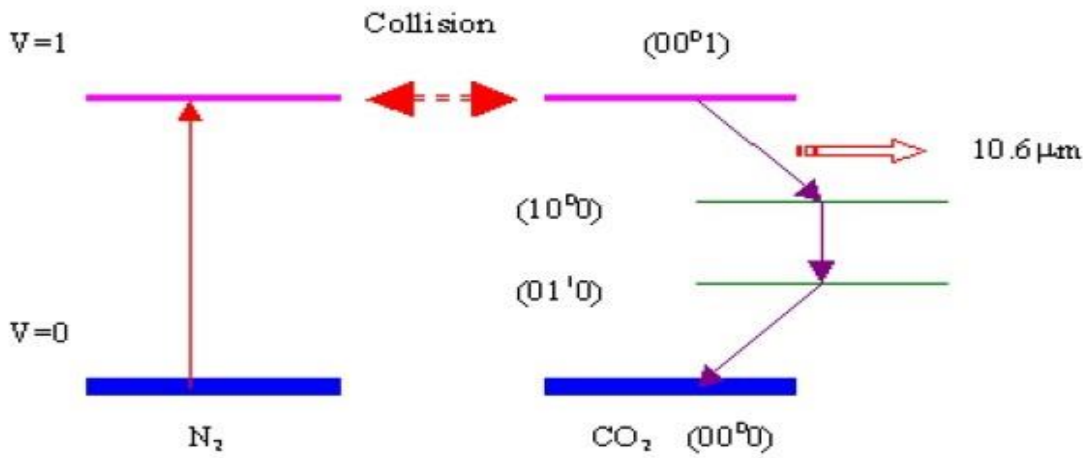

Figure 3.17: Collision diagram of CO_2 Laser

3.8 Solid Lasers

In solid state lasers, ions are suspended in crystalline matrix to generate laser light. The ions emit electrons when excited, the crystalline matrix spread the energy among the ions. The first solid state laser is ruby laser, but it is no longer used because of its low efficiency. Two common solid state lasers are Nd:YAG lasers and Nd:glass lasers, there structures are very similar. Both use krypton or xenon flash lamps for optical pumping.

For Nd:glass lasers, the glass rod has the advantage of growing into larger size than YAG crystals, but the low thermal conductivity of glass limits the pulse repetition rate of Nd:glass laser. So Nd:glass lasers are used in applications which require high pulse energies and low pulse repetition rates. It is suitable for hole piercing and deep keyhole welding operations.

YAG crystal has a higher thermal conductivity than glass, so the thermal dissipation inNd:YAG laser cavity can be improved, operation power can be up to several hundred watts in continuous mode, and high pulse rates (50kHz) can be reached. YAG is a complex crystal of Yttrium-Aluminium-Garnet with chemical composition of Y3Al5O12, it is transparent and colorless. About 1% Nd3+ ions are doped into the YAG crystal, the crystal color then changed to a light blue color. The wavelength of Nd:YAG laser is 1.06m m.Solid state lasers are widely used in laser machining.

YAG Laser

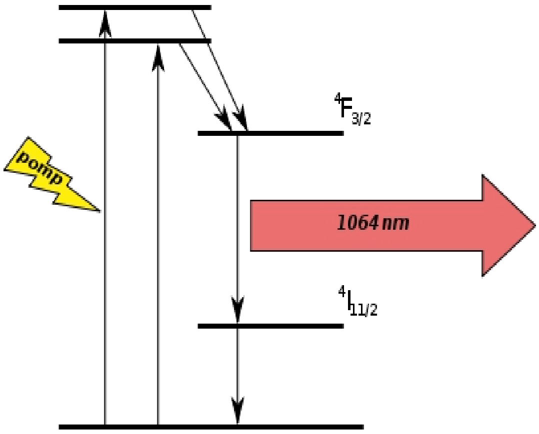

Figure 3.18: YAG Laser

Ruby Lasers

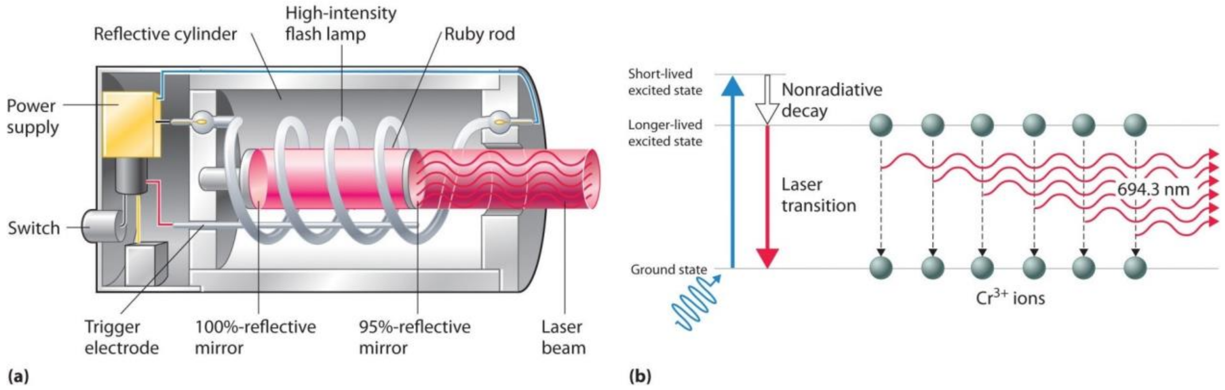

Figure 3.19: Ruby Laser

3. 9 Liquid Lasers

Liquid Lasers use large organic dye molecules as the active lasing medium. These lasers can lase in a wide frequency range, i.e. they are frequency tunable. The spectral range of dyes covers infrared, visible and ultraviolet light. Pumping is by another pulsed/continuous laser, or by pulsed lamp. These lasers are used in spectroscopic investigation and photochemical experiments.

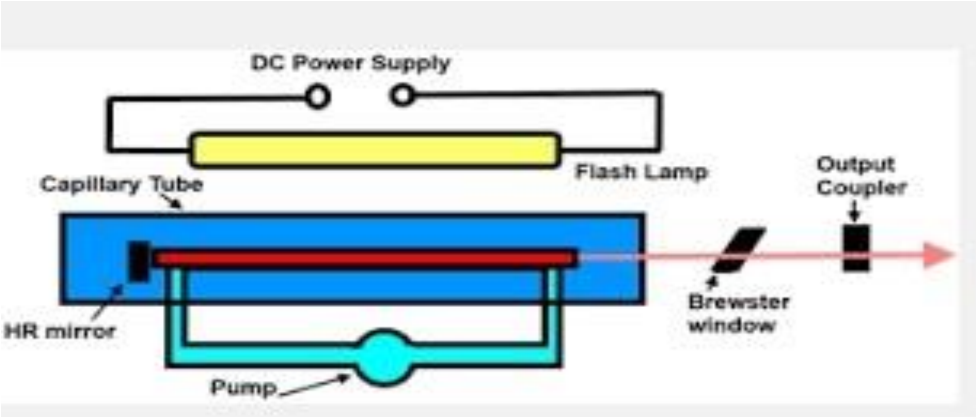

Figure 3.20: Liquid Laser

Semiconductor Lasers.

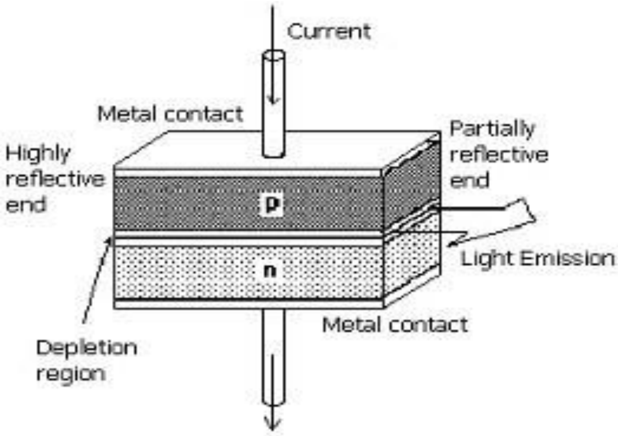

Figure 3.21: Semiconductor Laser

PN-junction Laser: A semiconductor laser is a specially fabricated pn junction device (both the p and n regions are highly doped) which emits coherent light when it is forward biased. It is made from Gallium Arsenide (GaAs) which operated at low temperature and emits light in near IR region. Now the semiconductor lasers are also made to emit light almost in the spectrum from UV to IR using different semiconductor materials. They are of very small size (0.1 mm long), efficient, portable and operate at low power. These are widely used in Optical fibre communications, in CD players, CD-ROM Drives, optical reading, laser printing etc. p and n regions are made from same semiconductor material (GaAs). A p type region is formed on the n type by doping zinc atoms. The diode chip is about 500 micrometer long and 100 micrometer wide and thick. the top and bottom faces has metal contacts to pass the current. the front and rare faces are polished to constitute the resonator

When high doped p and n regions are joined at the atomic level to form pn-junction, the equilibrium is attained only when the equalization of fermi level takes place in this case the fermi level is pushed inside the conduction band in n type and the level pushed inside the valence band in the p type When the junction is forward biased, at low voltage the electron and hole recombine and cause spontaneous emission. But when the forward voltage reaches a threshold value the carrier concentration rises to very high value. As a result the region "d" contains large number of electrons in the conduction band and at the same time large number of holes in the valence band. Thus the upper energy level has large number of electrons and the lower energy level has large number of vacancy, thus population inversion is achieved. The recombination of electron and hole leads to spontaneous emission and it stimulate the others to emit radiation. Ga As produces laser light of 9000 Å in IR region.

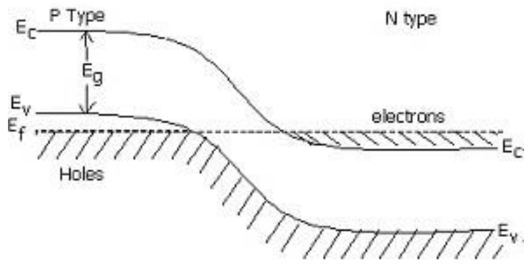

Figure 3.22: Energy Level Diagram of Semiconductor laser

PART A

Q.No.	Question
1	Describe Cavity Dumping
2	Differentiate three level and four level lasers
3	Illustrate Population Inversion
4	Define Q Switching
5	Explain mode locking
6	Compare LED and Laser
7	Discuss Internal quantum efficiency
8	List Properties of Laser
9	Describe Spontaneous Emission.
10	What are Resonators?
11	List the properties of Lasers
12	Sketch the Ruby Laser with a neat diagram.

PART-B

Q.No.	Question
1	Explain Q Switching with a neat diagram.
2	Discuss Mode locking with a neat diagram.
3	Illustrate the cavity dumping with a neat diagram.
4	Sketch the energy band diagram and the constructional details of a Semiconductor laser and explain.
5	Explain Nd:YAG laser with a neat diagram
6	Explain any one of the solid lasers .
7	Illustrate three level and four level lasers and with a neat diagram.

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION

UNIT – IV - Fiber Optics and Laser Instrumentation – SIC1605

UNIT -IV

FIBER OPTICS AND LASER INSTRUMENTATION

4.1 INDUSTRIAL APPLICATIONS OF LASER

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. 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." At Northeast Laser &Electropolish, we utilize pulsed Nd:Yag (Neodymium-Doped Yttrium-Aluminum- Garnet) type lasers for welding. The Nd:Yag rod, when stimulated by a flash lamp, emits light in the ultraviolet range with a wavelength of 1.06 microns. This light is then focused and delivered to the workpiece, where the high energy density beam is used to weld.

Laser For Measurement Of Distance:

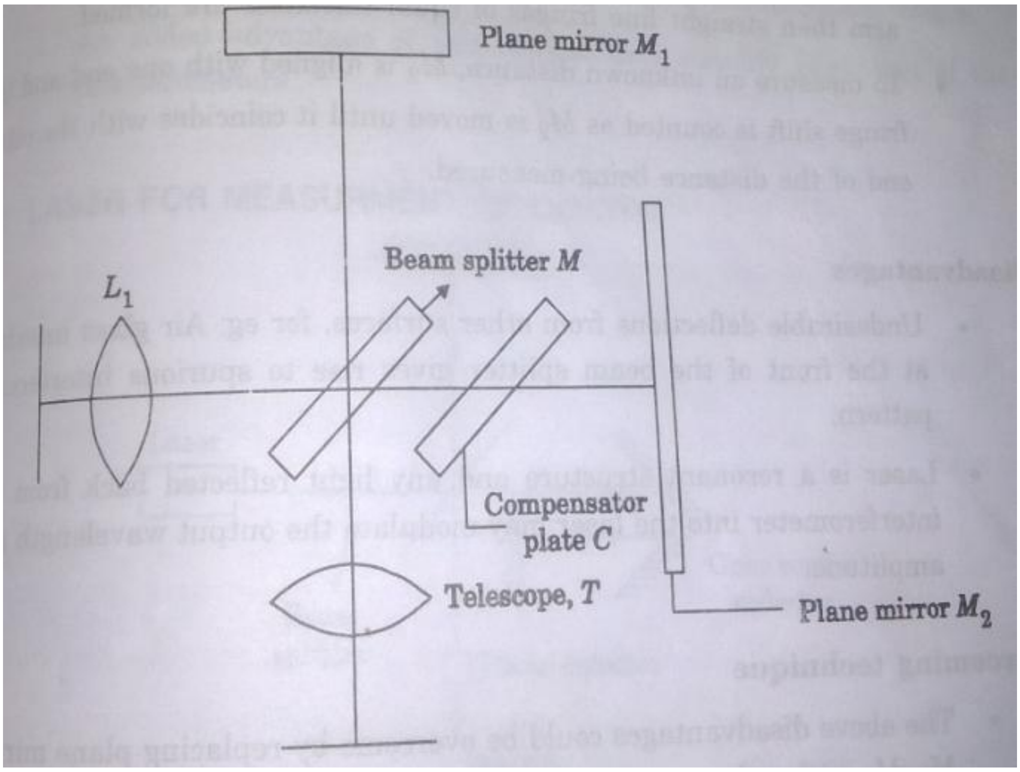

Figure 4.1: Measurement of Distance using Laser

Laser-based distance measurements can be done using interferometric principles.

Measurements of length using optical interferometry have been performed since the 19th century. But the limited intensity and coherence of conventional light sources restricted the measurements, which were difficult and suitable for used only over distances of a few centimeters. The development of lasers removed these restrictions. Lasers have allowed interferometer to develop into a fast, highly accurate and versatile technique for measuring longer distance.

Interferometric measurement of distance can be highly accurate. It offers a higher degree of precision than the pulsed time-of-flight or beam-modulation telemetry methods. However, it is best suited to measurements made in a controlled atmosphere (for example, indoors) over distances no greater than a few tens of meters.

Most laser-based interferometric systems for measurement of distance use a frequency stabilized helium-neon laser. An unstabilized laser, operating in a number of longitudinal

modes, will have a total linewidth around 109 Hz. This spread in the frequency (or wavelength) will cause the interference fringes to become blurred and to lose visibility as the distance increases. An unstabilized laser is suitable for measurement only over distances of a few centimeters. Stabilized lasers, usually in a temperature-controlled environment and operating in a single longitudinal mode, are used for longer distances.

The operation of a system based on the Michelson interferometer is discussed , because it is easy to understand the basic principles of interferometer distance measurement with reference to the Michelson interferometer. Later we will describe variations that provide better stability under conditions of atmospheric turbulence.

The beam from the laser falls on a beam splitter that reflects half the beam in one direction (the reference arm) and transmits the other half (the measurement arm). 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 (retroreflectors) which offer better stability against vibrations than conventional flat mirrors.

Schematic diagram 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 traveled by the two beams before they are recombined.

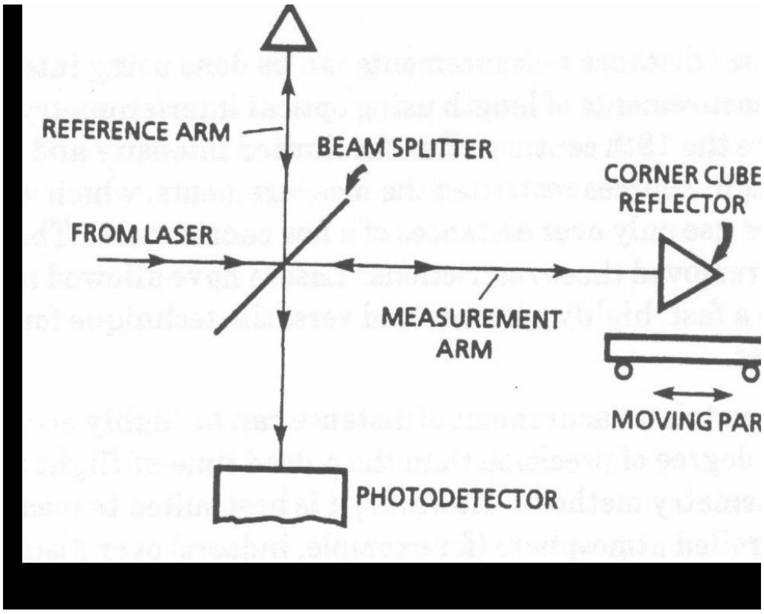

Figure 4.2: working principle of photo-detector

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 moves a distance equal to 1/4 of the wavelength of light, the round-trip distance traversed by the light in the measurement arm will change by 1/2 wavelength, 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 using the equation

d = 4p D *x*/l

where l is the wavelength of the light,

D *x* is the distance that the movable mirror has moved.

It is apparent that this method offers high precision, allowing measurements of D *x* to be made with an accuracy of the order of a fraction of the wavelength of light.

The maximum distance D *x* that can be measured in this way is given by:

D *x max* = *c*/D*v*

Where, c = velocity of light.

D *v* = linewidth (i.e., spread in frequency) of the laser.

4.1.1 Laser For Measurement Of Length

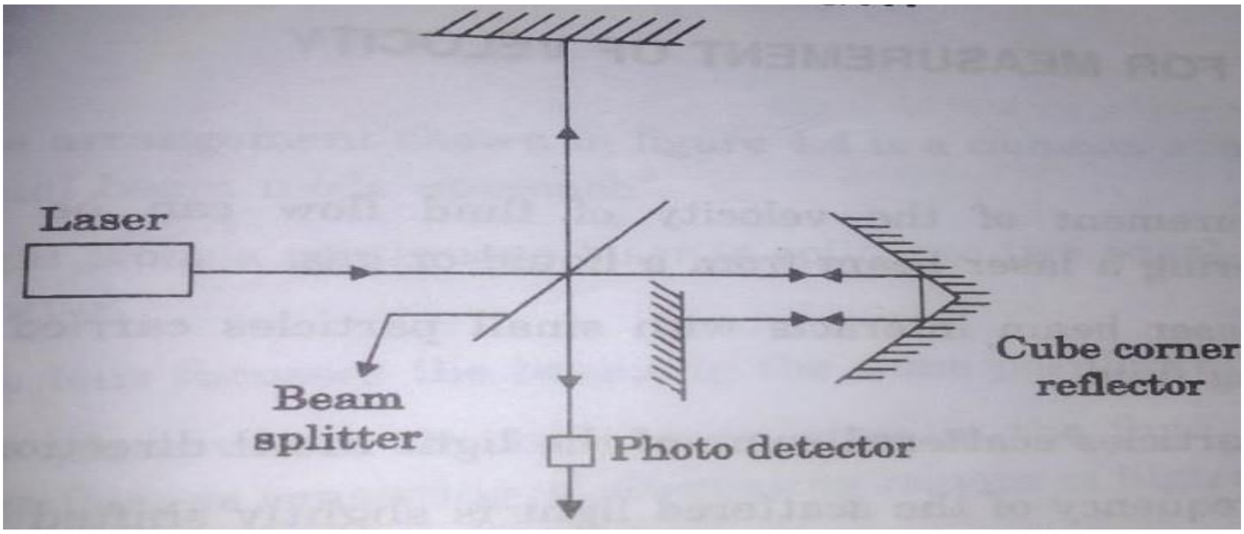

Figure 4.3: Measurement of Length using Laser

The large coherence length and high output intensity coupled with a low divergence enables the laser t find applications in precision length measurements, using interferrometric 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 wave length. 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.

Accuracies upto 0.1µm can be obtained by using such a technique. This technique is used can be obtained by using such a technique. This technique is used for accurate positioning of aircraft components

On a machine tool, for calibration and testing of testing of machine tools, for comparison with standards

4.2 Laser For Measurement Of Velocity

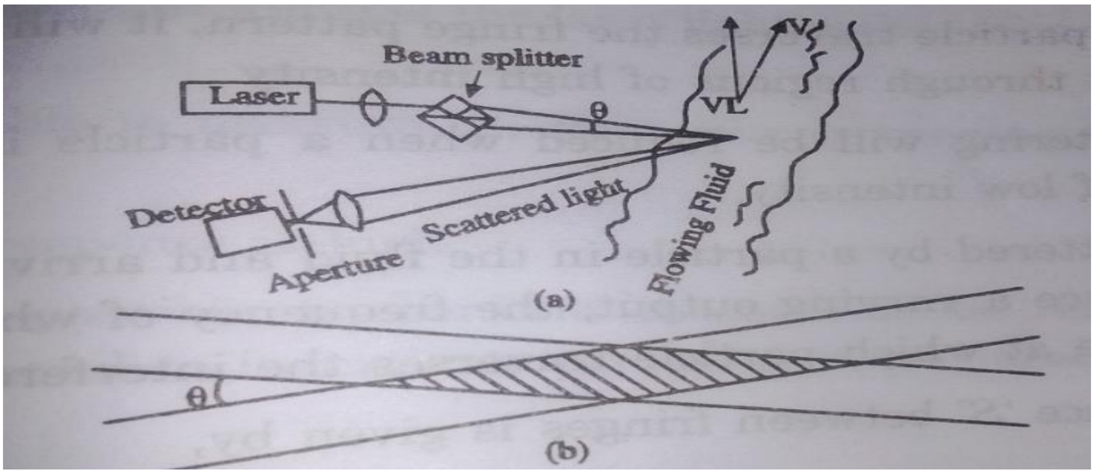

Figure 4.4: Measurement of velocity using laser

Principle

Measurement of the velocity of fluid flow can be performed by scattering a laser beam from a liquid or gas. The laser beam interacts with small particles carried along by the flowing fluid. The particles scattered light is slightly shifted by the Doppler effect. 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:

The measurement techniques basically consist of a focusing laser light at a point within the flowing fluid. Light scattered from the fluid or from particles entrained within the fluid flow is collected and focused on an optical detector. Signal processing of the detector output yields the magnitude of the Doppler frequency shift and hence the velocity of flow.

Working:

The approach towards measurement is called Dual beam approach. Light from a continuous laser is split into two equal parts by a beam splitter. 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 interfere to form fringes consisting of alternating regions of high and low intensity. when the particle transverse the fringe pattern, it will scatter light when it passes through regions of high intensity.

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 transverses the interferences fringes. The distance S between fringes is given by

If a particle passes through the fringes with a component of velocity V_T in the direction perpendicular to the fringes the output signal from the detector will be modulated at a frequency ‘f’
This factor is introduced because the wavelength λ is the wavelength in the fluid which differs from the vacuum wavelength $\lambda 0$, by a factor equal to ‘n’.

Advantages

- No critical contacts with a fluid.
- Flow is not disturbed.
- Hot or corrosive fluids can be measured without problems.
- The nano spectral width of the laser light makes accurate measurement possible.
- It is possible to measure the flow velocity ranging from cm/s to 100s of m/s.
- Speed of response is high.
- Makes it possible to perform measurements related to transient conditions and to investigate turbulent flow characteristics

Disadvantages

- These require the necessity of having scattering entrained in the fluid.
- Impossible to measure flow rate of very cleaned fluid.
- Additional cost is encountered because of the introduction of scattering centers in case very clean fluids.
- It is possible to see 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.

4.3 Laser For Measurement Of Acceleration

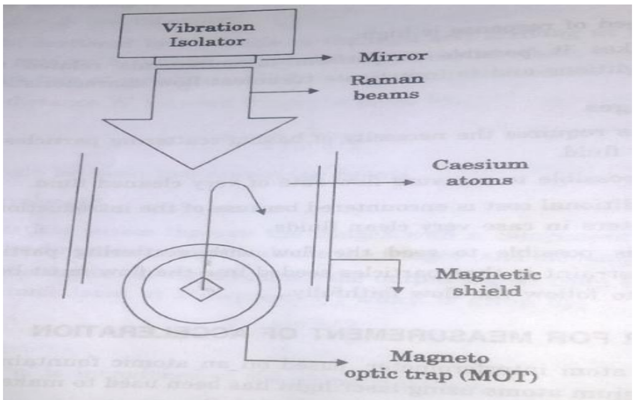

Figure 4.5: Measurement of Acceleration using Laser

An atom interferometer based on an atomic fountain of laser cooled caesium atoms using laser light has been used to make a very accurate measurement og ‘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 atoms accelerate under the influence of gravity. As consequences, the phase difference between the two paths in the interferometer is proportional to the gravitational attraction.

Basic atom Interferometer:

Caesium atoms are extracted from a low pressure back ground vapour and loaded in to a magneto optical trap during a 600 ms period. The magnetic field is turned off and the captured atoms are launched into the atomic fountain of this sensor using a specialized technique known as moving polarization gradient optical molasses.

During this period , further cooling of the 'launched' atoms occur , using resonant techniques. In the final stage of the launch , the laser intensities are reduced to zero in 400μs so that the atoms are cooled. The launched atoms are subjected to a series of pulses that place the atoms in a specific internal state with an effective internal temperature of 10nK.

This low velocity spreads leads to a high fringe contrast over a period of about 150 ms.The interferometer measurements occur in a magnetically shielded region. This type of device is capable of measuring 'g' better than a part per billion accuracy.

Cold atom Gradiometer:

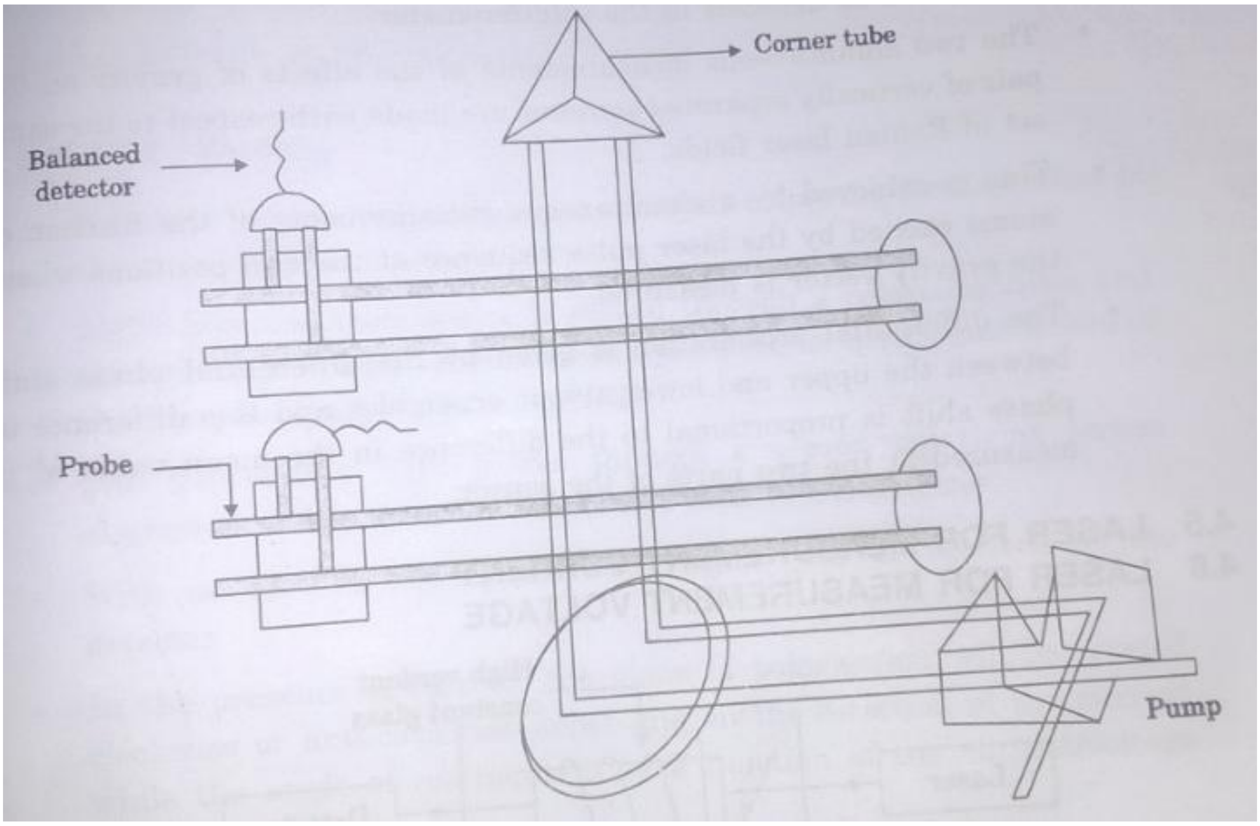

Figure 4.6: Cold atom Gradiometer

An atom interferometer technique has been used to create a gravity gradiometer using two laser cooled and trapped sources of cesium 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 cesium atoms in free fall under the influence of gravity.

Working:

The cesium atoms are launched into a vertical 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.

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 pulse sequence at the two positions where the gravity vector is measured.

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 phase shift is proportional to the difference in the mean value of 'g' measured at the two part of the sensor.

4.4 Laser For Measurement Of Current And Voltage

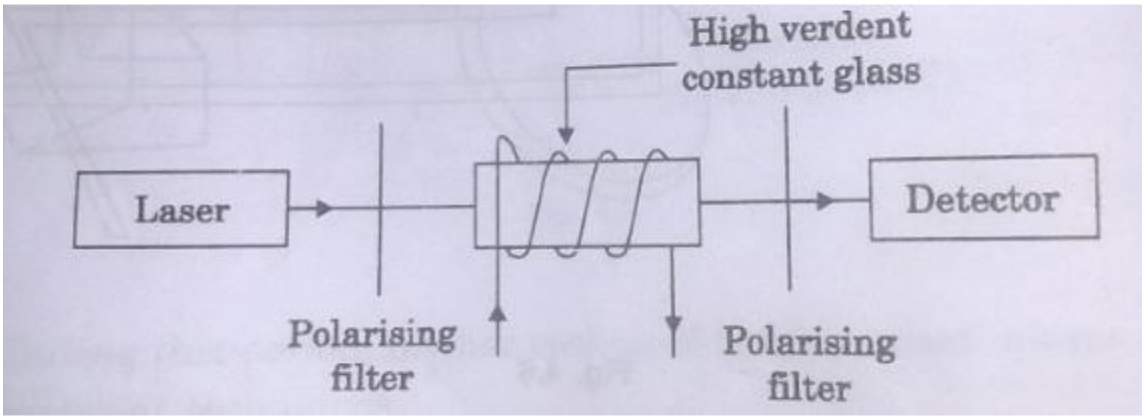

Figure 4.7: Laser For Measurement Of Current And Voltage

Principle:

If polarized light is passed along a magnetic field of strength H, the plane of polarization is rotated by an amount given by,

Φ= 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 verdant 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 rotataed clockwise or anticlockwise depending on the direction of the current while the angle of rotation will be a function of the current & voltage magnitude.

4.5 Laser For Measurement Of Atmospheric Effec

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

i. **Satellite borne LIDARS**

   Provides global coverage but at lower horizontal resolution

ii. **Ground borne LIDARS**

   Reveal the fine detail required for atmospheric process research .

Construction And Working:

A powerful laser transmits a short and intense pulse of light. The pulse is expanded to minimize its divergence and is directed by a mirror into the atmosphere. As the pulse travels upward, it is scattered by atmospheric constitutes and aerosol particulates. Light that is back scattered in the field of view of a co-aligned telescope is collected and channeled towards detector by an optical fiber. Filter \s are used to eliminate light away from the laser's wavelength an d a mechanical shutter can be used to block the intense low attitude returns. The amount of light received is measured as a function of time or distance using sensitive photo detectors and the signals are digitized for storage on a computer's hard disk. Coordination of the experiments is performed by a timing unit. When each laser pulse exists the atmosphere, another pulse is transmitted and the process is repeated.

LIDAR Applications:

- Atmospheric science
- Pollution detection and characterization
- Dynamic measurements: temperature,waves and winds
- Topographic mapping
- Erosion Monitoring
- Bathymetry
- Harbor profiling for marine safety.
- Mineshaft mapping.
- Allows cavern monitoring for safety workers.

Material Processing

Laser instrumentation for material processing.

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

Shielding gas jet:

To remove the molten material and to favour vaporization and also to provide cooling effect. It also protect the focusing optical arrangement against smoke and fumes and to increase the absorption of energy by the sample. During cutting of readily inflammable glass material like ceramics, wood and paper, nitrogen gas is used. This will increase the cutting rate by blowing the molten material out of the hole produced by laser energy further it reduces firing and fire accident. Oxygen gas is mainly used for brittle materials and metals

Powder Feeder:

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

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, antireflection coating are made on the surface so as to increase the absorption energy. Absorptivity increases with increase of laser beam densities and the temperature. Absorptivity is directly proportional to the square root of resistivity of the specimen and it decreases with increase in wavelength.Rate of absorption is more in vapour phase than in liquid and solid phase . The absorbed energy creates lattice vibration and heating of materials.

Laser Welding,

Types of welding

i. continuous/seam welding- done by continuous wave beams or overlapping pulses
ii. Pulse/spot welding- done by Micro-welding.

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 interative 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

- High input to the welding spot by the focused beam of high power density.
- Low heat release in welding elements.
- High weld rates.
- Possibility of welding dissimilar metals difficult to weld by other techniques.

STEPS TO BE FOLLOWED

- Select the proper type of laser.
- Design the weld joint of adequate configuration.
- Estimate the optimal pattern of the beam and the beam parameters depending on the materials of joint elements, their thickness and limitations and heating temperature
- Design the experiment so as to make the most of laser welding practice.
- The choice of the type of the laser depend on the total laser power required, power loss due to reflection from the surface of pieces to be welded, weld efficiency and other factors.

4.6 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/ hardening materials. For welding, the surfaces to be welded are locally melted and bonded together. In case of cutting and drilling, there is vaporization after local melting and a hole is formed.

The two methods of melting are:

i. Conduction limited melting/ Melting by low power laser.
ii. Deep penetration melting or key hole melting.

Conduction Limited Melting:

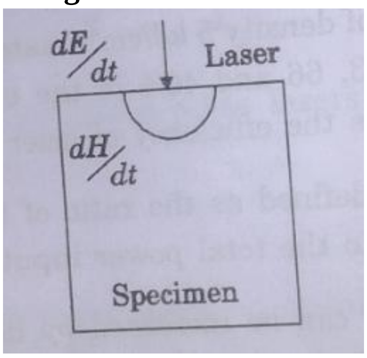

Figure 4.8: Conduction Limited Melting

Here the metal absorbs 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 and_< ___

__: Rate of laser energy incidence

__: Rate of heat conduction.

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.

Key Hole Melting

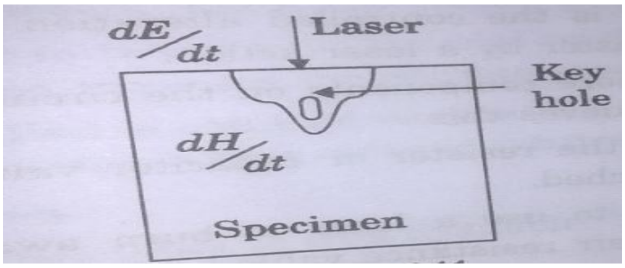

Figure 4.9: Key Hole Melting

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 in front 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 equilibrium 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. Her the shape of the melted region is in the form of key hole.

Trimming Of Material

It is a term used for describing the manufacturing process of using a laser to adjust the operating parameters of an electronic circuit

Process Of Laser Trimming

Laser trimming is the controlled alteration of the attributes of a capacitor or a resistor by a laser action. Selecting one or more components on the circuit and adjusting them with the laser .The trim changes the resistor or capacitor value until the nominal value has been reached. Usually laser is used to burn away small [portions of resistor, raising the resistance value. The burning operation can be conducted while the circuit is being tested by automatic test equipment, leading to extremely accurate final values for trimming of resistors. The resistance value of a film resistor is defined by its geometric dimensions as well as the resistor material. A lateral cut in the resistor material by the laser narrows the current flow path and increases the resistance value. The same effect is obtained whether the laser changes a thick film or a thin film resistor on a ceramic substrate.

Types Of Trim:

Passive trim:

It is the adjustment of a resistor to a given value

Active trim

If the trimming adjusts the whole circuit output is called active trim. During the trim process, the corresponding parameter is measured continuously and compared to the programmed nominal value. The laser stops automatically when the value reaches the nominal value.

Construction And Working:

The resistor to be trimmed is kept inside a [pressurized chamber below the surface of the tempered pressure glass. The laser beam is made to fall on the resistor arrangement and the change of value continuously monitored. After perfect arrival of nominal value, the next resistor arrangement is put into the experimental set up

Advantages:

- Better cleanliness when compared to conventional method of abrasive trimming. Better control of final resistance. Result in a higher yield the larger fraction of the resistor are obtained within the prescribed tolerance

4.7 Material Removal AndVapourisation:

Material processing refers to a variety of industrial operation in which the laseroperation 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 a work space.

4.8 Process Of Material Removal:

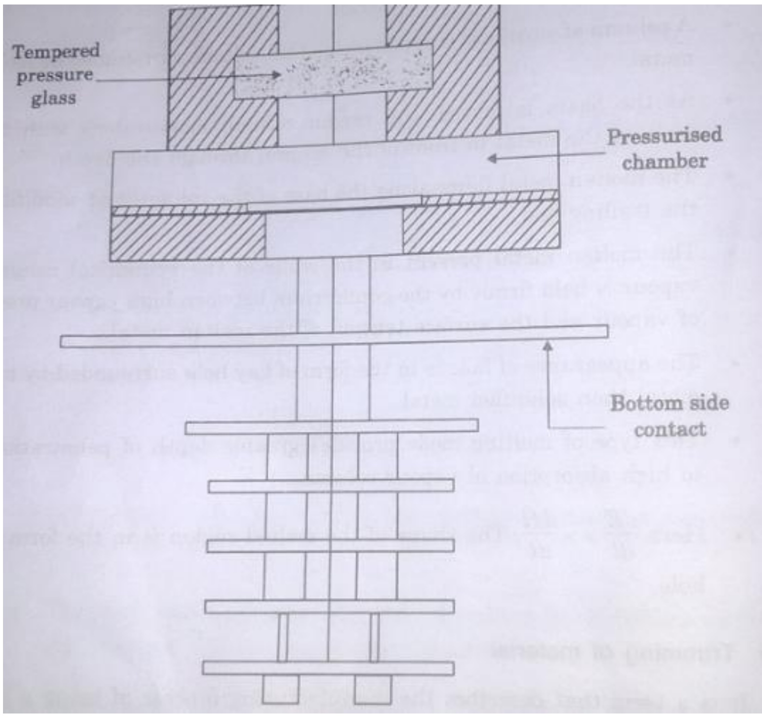

Figure 4.10: Process Of Material Removal

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 vaporize. If the irradiance is high enough , absorption in the blow off material leads to a hot opaque plasma. The plasma can grow back towards the laser as an LSA. (Laser supported Absorption) wave

PART-A

Q.No.	Question	CO
1	Sketch the schematic block diagram of measurement of length using Lasers.	CO6
2	Apply the Dual beam approach in measurement of velocity using Lasers.	CO4
3	State Doppler Effect.	CO4
4	Explain Cold atom Gradiometer.	CO6
5	Find the purpose of polarizing filter in the measurement of voltage.	CO6
6	What is a LIDAR?	CO6
7	List the applications of LIDAR	CO4
8	What are types of laser welding?	CO6
9	Name the methods of laser melting.	CO6
10	Outline the concept of Trimming in Lasers.	CO6

PART-B

Q.No. Question

1 Describe the following with a neat diagram
 a. Measurement of distance using lasers
 b. Measurement of acceleration using lasers

2 Explain the measurement of Velocity of a fluid using basic atom Interferometer with a neat diagram.

3 Illustrate the measurement of atmospheric Effect using lasers with a neat diagram.

4 Select a suitable method to modify any work piece in case of an Electronic component using lasers.

5 Distinguish between conduction limited melting and key hole melting with a neat diagram.

6 Explain the steps involved in the measurement of Laser melting

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION

UNIT – V - Fiber Optics and Laser Instrumentation – SIC1605

UNIT -V

FIBER OPTICS AND LASER INSTRUMENTATION

5.1 Holography

Basic Principle:

Holography is the science of producing holograms; it is an advanced form of photography that allows an image to be recorded in three dimensions

The Hungarian-British physicist Dennis Gabor was awarded the Nobel Prize in Physics in 1971 "for his invention and development of the holographic method". His work, done in the late 1940s, built on pioneering work in the field of X-ray microscopy by other scientists including Mieczysław Wolfke in 1920 and WL Bragg in 1939. The discovery was an unexpected result of research into improving electron microscopes at the British Thomson-Houston (BTH) Company in Rugby, England, and the company filed a patent in December 1947 (patent GB685286). The technique as originally invented is still used in electron microscopy, where it is known as electron holography, but optical holography did not really advance until the development of the laser in 1960. The word *holography* comes from the Greek words *hólos*; "whole" ,*grapy*; "writing" or "drawing").

Holography vs. photography

Holography may be better understood via an examination of its differences from ordinary photography:

- A hologram represents a recording of information regarding the light that came from the original scene as scattered in a range of directions rather than from only one direction, as in a photograph. This allows the scene to be viewed from a range of different angles, as if it were still present.
- A photograph can be recorded using normal light sources (sunlight or electric lighting) whereas a laser is required to record a hologram.
- A lens is required in photography to record the image, whereas in holography, the light from the object is scattered directly onto the recording medium.
- A holographic recording requires a second light beam (the reference beam) to be directed onto the recording medium.
- A photograph can be viewed in a wide range of lighting conditions, whereas holograms can only be viewed with very specific forms of illumination.
- When a photograph is cut in half, each piece shows half of the scene. When a hologram is cut in half, the whole scene can still be seen in each piece. This is because, whereas each point in a photograph only represents light scattered from a single point in the scene, *each point* on a holographic recording includes information about light scattered from *every point* in the scene. It can be thought of as viewing a street outside a house through a 4 ft x 4 ft window, then through a 2 ft x 2 ft window. One can see

all of the same things through the smaller window (by moving the head to change the viewing angle), but the viewer can see more *at once* through the 4 ft window.

- A photograph is a two-dimensional representation that can only reproduce a rudimentary three-dimensional effect, whereas the reproduced viewing range of a hologram adds many more depth perception cues that were present in the original scene. These cues are recognized by the human brain and translated into the same perception of a three-dimensional image as when the original scene might have been viewed.
- A photograph clearly maps out the light field of the original scene. The developed hologram's surface consists of a very fine, seemingly random pattern, which appears to bear no relationship to the scene it recorded.

Principle Of Hologram Recording

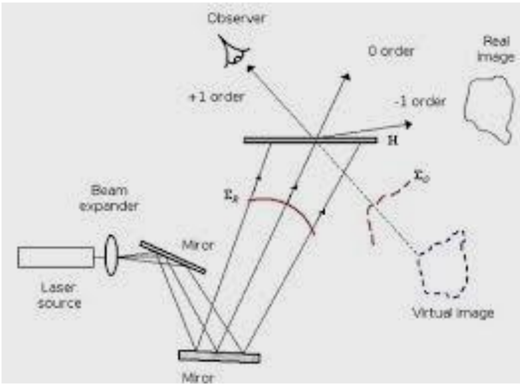

Figure 5.1:Pronciple of Hologram Recording

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.[20] Holography can be thought of as somewhat similar to sound recording, whereby 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.

5.2 Laser

Holograms are recorded using a flash of light that illuminates a scene and then imprints on a recording medium, much in the way a photograph is recorded. In addition, however, part of the light beam must be shone directly onto the recording medium - this second light beam is known as the reference beam. A hologram requires a laser as the sole light source. Lasers can be precisely controlled and have a fixed wavelength, unlike sunlight or light from conventional sources, which contain many different wavelengths. To prevent external light from interfering, holograms are usually taken in darkness, or in low level light of a different color from the laser light used in making the hologram. Holography requires a specific exposure time (just like photography), which can be controlled using a shutter, or by electronically timing the laser.

Apparatus

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

- One beam (known as the illumination or object beam) is spread using lenses and directed onto the scene using mirrors. Some of the light scattered (reflected) from the scene then falls onto the recording medium.
- The second beam (known as the reference beam) is also spread through the use of lenses, but is directed so that it doesn't come in contact with the scene, and instead travels directly onto the recording medium.

Several different materials can be used as the recording medium. One of the most common is a film very similar to photographic film (halide photographic), but with a much higher concentration of light-reactive grains, making it capable of the much higher resolution that holograms require. A layer of this recording medium (e.g. silver halide) is attached to a transparent substrate, which is commonly glass, but may also be plastic.

Process

When the two laser beams reach the recording medium, their light waves, intersect and interfere with each other. It is this interference pattern that is imprinted on the recording medium. The pattern itself is seemingly random, as it represents the way in which the scene's light interfered with the original light source but not the original light source itself. The interference pattern can be considered an encoded version of the scene, requiring a particular key — the original light source in order to view its contents.

This missing key is provided later by shining a laser, identical to the one used to record the hologram, onto the developed film. When this beam illuminates the hologram, it is diffracted by the hologram's surface pattern. This produces a light field identical to the one originally produced by the scene and scattered onto the hologram. The image this effect produces in a person's retina is known as a virtual image

Condition for Recording a Hologram

-
- 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 (the object beam) and another part so that it illuminates the recording medium directly (the reference beam), enabling the reference beam and the light which is scattered from the object onto 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 the phase of an incident light beam according to the intensity of the interference pattern.

- An environment which provides sufficient mechanical and thermal stability that the interference pattern is stable during the time in which the interference pattern is recorded.
- 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 wave front is obtained. An imaging system (an eye or a 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 the 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 the 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 same object of different sizes and orientations. However, a holographic image can be obtained using white light in specific circumstances,

e.g. 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 (e.g. 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

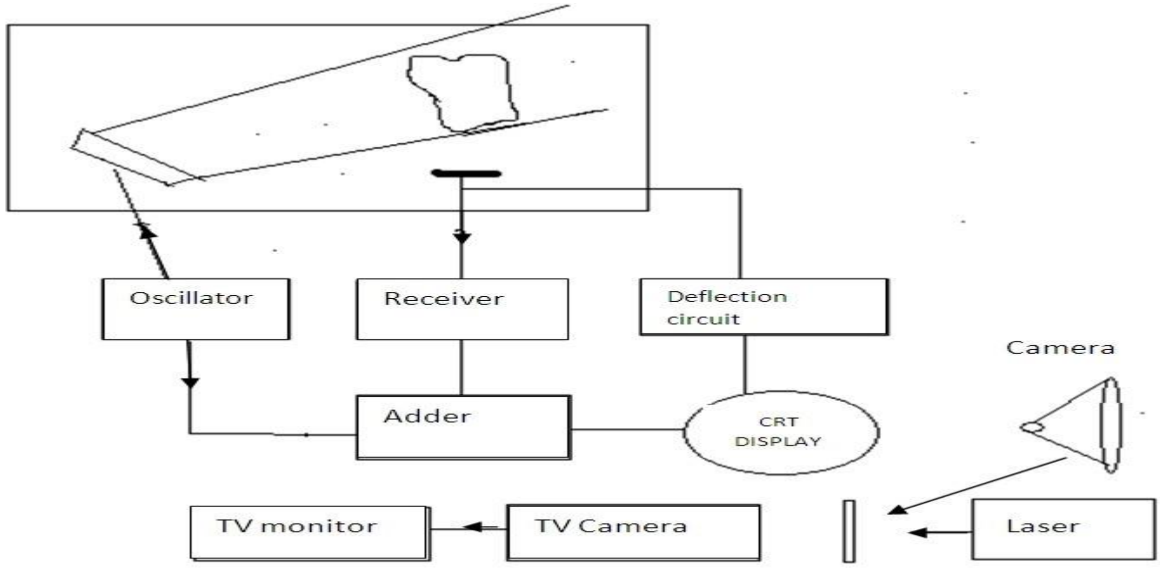

Figure 5.2: Holographic Non-Destructive Testing

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

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. The T.V camera takes the video graph of the 3 D image of the object and it displays on the T.V monitor

5.3 Medical Applications Of Lasers

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. Lasers are used for photocoagulation 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. 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.) 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.

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. Due to their remarkable properties, lasers have made possible ultra precise, minimally invasive surgery with reduced patient trauma and hospitalization time. The use of lasers in surgery is, by now, well established and spans

virtually the entire range of disciplines: ophthalmology, 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.

Laser spectroscopic techniques have the promise to provide sensitive, near real time diagnosis with biochemical information on the disease. These developments have the potential to change the way medical diagnosis is presently perceived. 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 of drugs that are activated by light. Because these drugs are inert, until photo excited 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). 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 And Tissue Interactive

Light-Tissue Interactions

Radioactive 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 be shared out between all the modes in a non-radiative process of intramolecular redistribution until the molecule is in equilibrium (according to the equi -partition 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 redistribution has completed.

As some redistribution will always take place before a photon is emitted, the energy of their radiated photon will always be lower than the absorbed photon. There are two possible radiative processes: fluorescence and phosphorescence. During fluorescence there is a transition from a state to a similar state, eg. singlet-singlet, and is typically fast (ns or shorter).Phosphorescence 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 singlet 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 timescale (ms, seconds or even longer).All mechanisms that are not radiative are by default non-radiative.

5.4 Photochemical 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 readily. This is the basis of photochemistry.

Thermalisation,collisional relaxation.

While an excited molecule is undergoing intramolecular 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 photothermal effects.

This process of collisional relaxation will there by thermal is the absorbed photon energy in a matter of picoseconds, although the resulting macroscopic thermal effects occur over very much longer timescales (ms to s).

Types of Interactions

There are many different mechanisms by which laser light can interact with tissue, and these have been categorised in a number of different ways by different authors. For the purposes of these lectures, the most common interaction mechanisms for therapeutic and surgical applications will be divided into

1. Photochemical 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 close to the nucleus, and so excited molecules (which are molecules with an electron in a higher energy state)are more likely to undergo chemical reactions (exchanging or sharing of electrons) with other molecules. In photodynamic therapy, for instance, a photo sensitising drug (aconcoction of molecules which, when they absorb light, cause reactive oxygen species to form) is used to cause necrosis (cell death) and apoptosis (`programmed' cell death).Photodynamic therapy is increasingly widely used in oncology to destroy cancerou tumours.

2. Inphotothermalinteractions, the energy of the photons absorbed by chromopores (aterm used to refer to any light-absorbing molecules) is converted into heat energy

viamolecular vibrations and collisions, which can cause a range of thermal effects fromtissue coagulation to vaporization. Applications include tissue cutting and welding inlaser surgery, and photoacoustic imaging.

3. Inphotoablation, high-energy, ultraviolet (UV) photons are absorbed by electrons, rais-ing them from a lower energy `bonding' orbital to a higher energy `non-bonding' orbital,thereby causing virtually immediate dissociation of the molecules. This naturally leadsto 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.

4. Inplasma-induced photoablationa free (sometimes called `lucky') electron is accelerated

by the intense electric field which is found in the vicinity of a tightly focussed laser beam. When this very energetic electron collides with a molecule, it gives up some of its energyto the molecule. When sufficient energy is transferred to free a bound electron, a chainreaction of similar collisions is initiated, resulting in a plasma: a soup of ions and freeelectrons. One application of this is in lens capsulotomy to treat secondary cataracts.

5. The final set of related mechanisms, grouped under the termphotodisruption, are

the

mechanical effects that can accompany plasma generation, such as bubble formation,cavitation, jetting and shockwaves. These can be used in lithotripsy (breaking upkidney or gall stones), for example.

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. the 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 repetition rate of the pulses for a pulsed laser. Because different interaction mechanisms dominate under different conditions (photoablation requires UV light, photodisruption 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 onlyone energy (one frequency or wavelength),

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

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

femtoseconds. (100 femtoseconds is really quite a short time. It is about the time ittakes light to travel the thickness of a human hair.)

5.5 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.

Types of lasers

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 timeNowdays, 3 kinds of lasers are commonly used in cancer treatment: carbon dioxide (CO2), argon, and neodymium: yttrium aluminum garnet (Nd:YAG).

i. Carbon dioxide (CO2) lasers

The CO2 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 layers 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). (You can learn more about this in our document titled Photodynamic Therapy.

iii. Nd:YAG (Neodymium: Yttrium-Aluminum-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 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 aluminum garnet (Er:YAG); holium: yttrium aluminum garnet (Ho:YAG), copper vapor, and diode lasers – are also being used in medical and dental treatments.

Lasers have some advantages (pros) and disadvantages (cons) compared with standard surgical tools.

Pros of laser surgery

- Lasers are more precise and exact than blades (scalpels). For instance, the tissue near a laser cut (incision) is not affected since there is little contact with skin or other tissue.
- The heat produced by lasers helps clean (sterilize) the edges of the body tissue that it's cutting, reducing the risk of infection.
- Since laser heat seals blood vessels, there is less bleeding, swelling, pain, or scarring. Operating time may be shorter.
- 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.
- More procedures may be done in outpatient settings.
- Healing time is often shorter.

Cons of laser surgery

- Fewer doctors and nurses are trained to use lasers.
- Laser equipment costs a lot of money and is bulky compared with the usual surgical tools used. But advances in technology are slowly helping reduce their cost and size.
- 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.
- The effects of some laser treatments may not last long, so they might need to be repeated. And sometimes the laser cannot remove all of the tumor in one treatment, so treatments may need to be repeated.

5.6 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 normalize 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.

5.6.1 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 notan option. When tumors are in hard-to-reach brain areas or are close to areas that control vitalfunctions, traditional surgery may be too risky.Now, however, Cleveland Clinic neurosurgeons have a potentially life-extending surgical option forpatients with brain tumors once considered inoperable. If you have been told that you have aninoperable primary or metastatic brain tumor

Destroying Cancer Cells with Laser-Directed Heat

Laser interstitial thermal therapy (LITT) transmits heat to coagulate, or "cook," brain tumors from theinside out. This technology is not new in cancer treatment, but early approaches posed challenges withlimiting the laser energy only to tumors. NeuroBlate system, the surgeoncan "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 inan MRI machine because the laser system is guided, positioned and monitored with MRI.

Surgical techniques

The patients will be placed under general anesthesia.With great precision, a thin, high-intensity

laser probe will be inserted through a smallhole in your skull, deep into your brain. Thetip of the probe emits laser energy sideways,heating and destroying brain tumor tissue inone direction while cooling to remove heat andprotect normal tissue in neighboring areas.

• Each burst of laser energy lasts from 30 secondsto a few minutes. The laser generates heat up to

160 degrees Fahrenheit, which is sufficient tocoagulate and kill the tumor cells.

• On a computer screen, the surgeon willmonitor the tumor 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.

Advantage

- Is less invasive than even the most minimally invasive open operations
- Enhances patient safety
- 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 radiosurgery fails
- May allow for multiple treatments
- Is less costly than traditional surgery

Plastic surgery

Goal

- Correction of disfigurement
- Restoration of impaired function
- Improvement of physical appearance

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.

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

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

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

The CO2 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.

Lasers can be used with low-power microscopes, too. This gives the doctor a larger 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.

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 CO2 laser can be used to treat pre-cancerous tissue and very early cancers of the cervix, vagina, and vulva.

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.

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 laser cannot cure cancer, but it can improve breathing and other symptoms in many patients.

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.

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.

Photodynamic therapy

In photodynamic therapy (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 wavelength 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.

PDT has some advantages over other treatments:

Cancer cells can be singled out and destroyed but most normal cells are spared. The damaging effect of the photosensitizing 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 centimeter of tissue (a little more than one-third of an inch), which means it's not useful against deeper tumors. And9 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.

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. Researchers also are looking at different kinds of lasers and new photosensitizer drugs that might work even better.

Photodynamic Therapy

Photodynamic therapy or PDT is a treatment that uses special drugs, called photosensitizing agents, along with light to kill cancer cells. The drugs only work after they have been activated or "turned on" by certain kinds of light. PDT may also be called photo-radiation therapy, phototherapy, or photo chemotherapy.

Depending on the part of the body being treated, the photosensitizing agent is either put into the bloodstream through a vein or put on the 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 alerting 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 drug used.

Gynaecology

The recent advancement in laser techonology, 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 novel treatment options called Intima LaseTMand Inconti LaseTM 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.

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

PART-A

Q.No.	Question
1	What are Industrial lasers?
2	Distinguish between holography and photography.
3	List the conditions for recording a hologram.
4	Describe Thermalisation.
5	List the applications of holographic interferometer.
6	What is the type of laser used in the treatment of skin related problems?
7	Cite the advantages of PDT.
8	List the procedures in Plastic surgery.
9	What are the uses of shielding gas during material processing by lasers?
10	What are the advantages of laser cutting?
11	What is a Brain tumor?
12	Explain the propagation of light through tissue.

PART-B

Q.No.	Question
1	Explain the principle of Hologram recording using a neat diagram.
2	Illustrate non-destructive testing using hologram.
3	Apply Holographic principle in construction and reconstruction of an image and explain in detail.
4	Describe Laser interaction with tissue in detail.
5	Explain Laser endoscopy in detail.
6	Critique on the laser treatments in medical applications in the field of a. Oncology b. Gynecology
7	Explain the laser treatment in Vocal Chords and in Tumors.

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