LASER

The word Laser stands for Light Amplification by Stimulated Emission of Radiation. It is a device which amplifies light. It has properties like Coherence, Unidirectional, Monochromatic, Focus ability, etc.

Interaction of an electromagnetic wave with matter requires certain conditions. The interaction leads to transition of an atom or a molecule from one energy state to another. If the transition is from lower state to higher state it absorbs the incident energy. If the transition is from higher state to lower state it emits a part of its energy.

If $\Delta E$ is the difference between the two energy levels,

Then \[ \Delta E = (E_2 - E_1) \text{ Joule} \]

According to Max Planck, $\Delta E = h \nu = (E_2 - E_1)$

\[ \nu = (E_2 - E_1)/h \text{ Hz.} \]

Three types of interactions, which are possible:

1) Induced absorption/ Stimulated absorption/absorption
2) Spontaneous emission
3) Stimulated emission.

Emission or Absorption takes through quantum of energy called photons. $h\nu$ is called quantum energy or photon energy.

$h = 6.626 \times 10^{-34}$ Joules is Planck’s constant and ‘$\nu$’ is the frequency.

1) Induced absorption/ Stimulated absorption/absorption:

Induced absorption is the absorption of an incident photon by system as a result of which the system is elevated from a lower energy state to a higher state, wherein the difference in energy of the two states is the energy of the photon.

Consider the system having two energy states $E_1$ and $E_2$, $E_2 > E_1$. When a photon of energy $h\nu$ is incident on an atom at level $E_1$, the atom goes to a higher energy level by absorbing the energy.
When an atom is at ground level \( (E_1) \), if an electromagnetic wave of suitable frequency \( \nu \) is applied to the atom, there is possibility of getting excited to higher level \( (E_2) \). The incident photon is absorbed. It is represented as

\[
\text{Atom} + \text{Photon} \rightarrow \text{Atom}^* 
\]

The frequency of the absorbed photon is

\[ \nu = (E_2 - E_1)/h. \]

The rate of absorption is proportional to \( N_1U_\nu \).

Where ‘\( N_1 \)’ is the number density of the lower energy state, ‘\( U_\nu \)’ is the energy density of incident radiation.

Rate of absorption = \( B_{12}N_1U_\nu \)

Where ‘\( B_{12} \)’ is the proportionality constant called Einstein Coefficient of induced absorption.

1. **Spontaneous Emission:**

The emission of a photon by the transition of a system from a higher energy state to a lower energy state without the aid of an external energy is called spontaneous emission. Let \( E_1 \) and \( E_2 \) be two energy levels in a material, such that \( E_2 > E_1 \). \( E_1 \) is ground level and \( E_2 \) is the higher level. \( h\nu=E_2-E_1 \) is the difference in the energy. The atom at higher level \( (E_2) \) is more unstable as compared to that at lower level \( (E_1) \).

The time taken by the atom to remain in the excited state is normally very short (order of \( 10^{-8} \text{ s} \)) and it is called life time of the atom. In spontaneous emission atom emits the photon without the aid of any external energy. It is called spontaneous emission. The process is represented as

\[
\text{Atom}^* \rightarrow \text{Atom} + \text{Photon} 
\]

The photons emitted in spontaneous emission may not have same direction and phase similarities. It is incoherent.

Ex: Glowing electric bulbs, Candle flame etc.
Spontaneous emission depends on $N_2$ which is the number of atoms present in the higher level.

The rate of spontaneous emission $= A_{21}N_2$

Where ‘$A_{21}$’ is the proportionality constant called Einstein coefficient of spontaneous emission.

2. **Stimulated Emission:**

Stimulated emission is the emission of a photon by a system under the influence of a passing photon of just the right energy due to which the system transits from a higher energy state to a lower energy state.

Initially the atom is at higher level $E_2$. The incident photon of energy $h\nu$ forces the atom to get de-excited from higher level $E_2$ to lower level $E_1$, i.e. $h\nu=E_2-E_1$ is the change in energy.

The incident photon stimulates the excited atom to emit a photon of exactly the same energy as that of the incident photons. The emitted two photons have same phase, frequency, direction and polarization with the incident photon. This kind of action is responsible for lasing action.

Atom + Photon $\rightarrow$ Atom + (Photon + Photon)

The rate of stimulated emission is directly proportional to $N_2U_\nu$, where ‘$N_2$’ is the number of atoms present in the higher energy level and ‘$U_\nu$,’ is the energy density.

The rate of stimulated emission $= B_{21}N_2U_\nu$, where ‘$B_{21}$’ is the proportionality constant called Einstein’s Coefficient of stimulated emission.

**Einstein’s A & B Coefficients:-**

(Note: - First explain the phenomena of spontaneous emission, stimulated emission and spontaneous absorption and continue as explained below)

At thermal equilibrium,

Rate of absorption $= (Rate$ of spontaneous emission $+$ Rate of stimulated emission)$

$B_{12}N_1U_\nu = A_{21}N_2 + B_{21}N_2U_\nu$
\[
U_v (B_{12}N_1 - B_{21}N_2) = A_{21}N_2
\]
\[
U_v = \frac{A_{21}N_2}{(B_{12}N_1 - B_{21}N_2)}
\]

i.e.
\[
U_v = \frac{A_{21}}{B_{21}} \left[ \frac{N_2}{(\frac{B_{12}N_1 - B_{21}N_2}{B_{21}})} \right]
\]

\[
= \frac{A_{21}}{B_{21}} \left[ \frac{1}{\left(\frac{B_{12}N_1}{B_{21}N_2}\right) - 1} \right]
\] \quad \rightarrow (1)

By Boltzmann’s law,
\[
N_2 = N_1 e^{-\left(\frac{E_2 - E_1}{kT}\right)} = N_1 e^{h\nu/kT}
\]
i.e., \( \frac{N_1}{N_2} = e^{h\nu/kT} \)

Eqn. (1) becomes
\[
U_v = \frac{A_{21}}{B_{21}} \left[ \frac{1}{\left(\frac{B_{12}N_1}{B_{21}N_2}\right) - 1} \right]
\] \quad \rightarrow (2)

By Planck’s law,
\[
U_v = \frac{8\pi h \nu^3}{c^3} \left[ \frac{1}{e^{\left(\frac{h\nu}{kT}\right)} - 1} \right]
\] \quad \rightarrow (3)

Comparing equation (2) & (3)
\[
\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3} \quad \& \quad \frac{B_{12}}{B_{21}} = 1 \quad \text{i.e.} \quad B_{12} = B_{21}
\]

The probability of induced adsorption is equal to the stimulated emission.

**Conclusions of Einstein co-efficient:**

**Dependence of nature of emission on frequency:**

Consider \( \frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3} \) \quad \rightarrow (1)

If \( A_{21} \) has high value, the probability of spontaneous emission is high. If \( B_{21} \) has high value, the probability of stimulated emission is high.
Further \( \frac{A_{21}}{B_{21}} \propto v^3 \)

Since \( v = \Delta E/h \), in normal condition, the energy difference between the two levels \( E_1 \) and \( E_2 \) is large

\[
\frac{A_{21}}{B_{21}} \gg 1 \quad \text{or} \quad A_{21} \gg B_{21}
\]

Thus the probability of spontaneous emission is more than the stimulated emission.

**System in thermal equilibrium:**

According to Planck’s law

\[
U_v = \frac{8\pi h v^3}{c^3} \left( \frac{1}{e^{\frac{hv}{kT}} - 1} \right) \rightarrow (2)
\]

Using eqs (1) & (2) and rearranging, we have

\[
\frac{A_{21}}{B_{21} U_v} = e^{\frac{hv}{kT}} - 1 \rightarrow (3)
\]

**Case-1:** \( hv \gg kT \)

When the frequency of radiation is high \( hv \gg kT \), i.e. \( e^{\frac{hv}{kT}} \gg 1 \)

Hence in eqn (3) \( \frac{A_{21}}{B_{21}} \gg 1 \), i.e. \( A_{21} \gg B_{21} \)

That is spontaneous emission is more than the stimulated emission.

**Case-2:** \( hv \approx kT \)

For \( hv \approx kT \), \( e^{\frac{hv}{kT}} \) will be low and comparable to 1

Therefore \( A_{21} \) and \( B_{21} \) become comparable, i.e. stimulated emission became significant.

**Case-3:** \( hv \ll kT \)

For \( hv \ll kT \), \( (e^{\frac{hv}{kT}} - 1) \ll 1 \) and \( \frac{A_{21}}{B_{21}} \ll 1 \) or \( B_{21} \gg A_{21} \)

That is stimulated emission is more for lower frequency.

For microwaves frequency is very less, so achieving \( B_{21} \gg A_{21} \) is easy with microwaves. Therefore first MASER (Microwave Amplification by Stimulated Emission of Radiation) came to exist.
**Non-equilibrium conditions leading to amplification:**

We have

\[
\frac{\text{Rate of emission}}{\text{Rate of absorption}} = \frac{A_{21}N_2 + B_{21}N_2U_Y}{B_{12}N_1U_Y} = \frac{N_2}{N_1} \left( \frac{A_{21}}{B_{21}U_Y} \right)
\]

According to Einstein’s theory we have \(B_{12} = B_{21}\)

\[
\frac{\text{Rate of emission}}{\text{Rate of absorption}} = \frac{N_2}{N_1} \left( \frac{A_{21}}{B_{21}U_Y} + 1 \right)
\] \rightarrow (4)

From eqn (3) if \(\Delta E << KT\) i.e. \(h\nu << KT\)

Then \(A_{21}/(B_{21}U_Y) << 1\)

Hence eqn (4) can be written as

\[
\frac{\text{Rate of emission}}{\text{Rate of absorption}} = \frac{N_2}{N_1}
\]

Under normal conditions \(N_2\) is always less than \(N_1\)

1. **Meta Stable State:** It is the state where the atoms get excited and remains in the excited state for longer time than the normal state.

2. **Population Inversion:** It is the state of the system at which the population of a higher energy level is greater than that of the lower energy level.

   Let \(E_1, E_2, E_3\) be the energy levels of the system \(E_3 > E_2 > E_1\). \(E_2\) is the metastable state of the system. Atoms get excited from the state \(E_1\) to \(E_3\) by means of external source and stay there for short time. These atoms undergo spontaneous transitions to \(E_2\) and \(E_1\). The atoms at the state \(E_2\) stay for longer time. A stage is reached in which the number of atoms at state \(E_2\) is more than the number of atoms at \(E_1\) which is known as population inversion.

3. **Pumping:** The process of producing population inversion is called pumping. It is the process of exciting atoms from lower energy level to higher energy level. It can be achieved by different methods.
   
   a. **Optical Pumping:** Using high intensity light or by operating flash tube. Ex: Ruby Laser.
   
   b. **Electric Discharge:** By applying very high potential between the plates of discharge tube gas gets discharge leads to pumping. Ex: Argon Laser.
c. **Atom-Atom Collision:** Excited atoms collide with other types of atom and transfer its energy to bring other atoms to excited state. Ex: He-Ne Laser.

d. **Chemical Method:** Exothermic chemical reactions liberate energy. This liberated energy is used in pumping the atoms. Ex: Dye Laser.

e. **Using Current:** In semiconductor diode laser the tuning of current input brings the charge carriers to achieve population inversion.

4. **Requisites of a Laser System:**
   1) The excitation source for pumping action.
   2) Active medium for population inversion.
   3) Laser cavity, an active medium bounded by two mirrors. (Resonator/ Fabry-Perot resonator)

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**Co₂ LASER: Construction and Working** *(Ref: [http://www.daenotes.com](http://www.daenotes.com))*

**CO₂ Laser (The molecular gas laser)**

The CO₂ stands for carbon dioxide. In CO₂ laser the laser light takes place within the molecules of carbon dioxide rather than within the atoms of a pure gas. Therefore CO₂ gas laser is considered the type of molecular gas laser. Importantly note that CO₂ lasers use carbon dioxide as well as Helium & Nitrogen as its active medium. In a molecular gas laser, laser action is achieved by transitions between vibrational and rotational levels of molecules. Its construction is simple and the output of this laser is continuous. In CO₂ molecular gas laser, transition takes place between the vibrational states of Carbon dioxide molecules.

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**CO₂ Molecular gas laser**

It was the first molecular gas laser developed by Indian born American scientist Prof. C.K.N. Pillai. It is a four level laser and it operates at 10.6 μm in the far IR region. It is a very efficient laser.

**Energy states of CO₂ molecules**

A carbon dioxide molecule has a carbon atom at the center with two oxygen atoms attached, one at both sides. Such a molecule exhibits three independent modes of vibrations. They are

a) Symmetric stretching mode.

b) Bending mode

c) Asymmetric stretching mode.

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**a. Symmetric stretching mode**

In this mode of vibration, carbon atoms are at rest and both oxygen atoms vibrate simultaneously along the axis of the molecule departing or approaching the fixed carbon atoms.
b. **Bending mode:**

In this mode of vibration, oxygen atoms and carbon atoms vibrate perpendicular to molecular axis.

![Diagram of Bending mode]


c. **Asymmetric stretching mode:**

In this mode of vibration, oxygen atoms and carbon atoms vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atoms in the other direction.

![Diagram of Asymmetric stretching mode]

**Principle:**
The active medium is a gas mixture of CO₂, N₂ and He. The laser transition takes place between the vibrational states of CO₂ molecules.

**Construction:**
It consists of a quartz tube 5 m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO₂ (active medium), helium and nitrogen with suitable partial pressures.

The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized.

Two concave mirrors one fully reflecting and the other partially form an optical resonator.
**Working:**

Figure shows energy levels of nitrogen and carbon dioxide molecules. When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation

\[ N_2 + e^* = N_2^* + e \]

\[ N_2 = \text{Nitrogen molecule in ground state} \]
\[ e^* = \text{electron with kinetic energy} \]
\[ N_2^* = \text{nitrogen molecule in excited state} \]
\[ e = \text{same electron with lesser energy} \]

Now \( N_2 \) molecules in the excited state collide with \( CO_2 \) atoms in ground state and excite to higher electronic, vibrational and rotational levels. This process is represented by the equation \( N_2^* + CO_2 = CO_2^* + N_2 \)

\[ N_2^* = \text{Nitrogen molecule in excited state} \]
\[ CO_2 = \text{Carbon dioxide atoms in ground state} \]
\[ CO_2^* = \text{Carbon dioxide atoms in excited state} \]
\[ N_2 = \text{Nitrogen molecule in ground state} \]

Since the excited level of nitrogen is very close to the \( E_5 \) level of \( CO_2 \) atom, population in \( E_5 \) level increases.

As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible.

1. **Transition \( E_5 \) to \( E_4 \):**
   This will produce a laser beam of wavelength 10.6μm

2. **Transition \( E_5 \) to \( E_3 \):**
   This transition will produce a laser beam of wavelength 9.6μm. Normally 10.6μm transition is more intense than 9.6μm transition. The power output from this laser is 10kW.

**Characteristics:**

1. Type: It is a molecular gas laser.
2. Active medium: A mixture of \( CO_2 \), \( N_2 \) and helium or water vapour is used as active medium
3. Pumping method: Electrical discharge method is used for Pumping action
4. Optical resonator: Two concave mirrors form a resonant cavity
5. Power output: The power output from this laser is about 10kW.
6. Nature of output: The nature of output may be continuous wave or pulsed wave.
7. Wavelength of output: The wavelength of output is 0.6 μm and 10.6 μm.

**Advantages:**
1. The construction of CO₂ laser is simple
2. The output of this laser is continuous.
3. It has high efficiency
4. It has very high output power.
5. The output power can be increased by extending the length of the gas tube.

**Disadvantages:**
1. The contamination of oxygen by carbon monoxide will have some effect on laser action
2. The operating temperature plays an important role in determining the output power of laser.
3. The corrosion may occur at the reflecting plates.
4. Accidental exposure may damage our eyes, since it is invisible (infra red region) to our eyes.

**Applications:**
1. High power CO₂ laser finds applications in material processing, welding, drilling, cutting soldering etc.
2. The low atmospheric attenuation (10.6μm makes CO₂ laser suitable for open air communication.
3. It is used for remote sensing
4. It is used for treatment of liver and lung diseases.
5. It is mostly used in neuro surgery and general surgery.
6. It is used to perform microsurgery and bloodless operations.

**Gallium-Arsenide Laser: Semiconductor laser:**

A Semiconductor diode laser is a specially fabricated p-n junction device that emits coherent light when it is forward biased. In the case of germanium and silicon based diodes, this energy is released in the form of heat because of recombination of carriers take place through interaction with the atoms of the crystal. But in the case of GaAs, the energy is released in the form of photons as the atoms of the crystal are not involved in the release of energy. The wavelength of the emitted photon depends upon the activation energy of the crystal.

**Construction:** A schematic diagram of semiconductor laser is as shown in the figure. The diode is very small size with sides of the order of 1mm. The junction lies in a horizontal plane. The top and bottom surfaces are metalized and Ohmic contacts are provided for external connection. The front and rear faces are polished. The polished faces constitute the Fabry-perot resonator. The other two faces are roughened to prevent lasing action in that direction. The active region consists of about 1μm thickness.

The emitted photon stimulates the recombination of the other carriers.
Cross sectional view of p-n junction diode laser.

**Working:** The energy band diagram of heavily doped pn-junction is as shown unbiased condition. At thermal equilibrium, the Fermi level is uniform across the junction. Because of very high doping on n-side, Fermi level is pushed into the conduction band and electrons occupy the portion of the conduction band lying below the Fermi level. On P-side, the Fermi level lies within the valence band and holes occupy the portion of the valence band that lies above the Fermi level. When the junction is forward biased electrons and holes are injected into the junction region in high concentrations. At low forward current, the electron-holes recombination results in spontaneous emission of photons and the junction acts as a LED. As the forward current is increased gradually and when it reaches a threshold value the carrier concentration in the junction region there will be large concentrations of electrons within the band. As a result condition of population inversion is attained in the narrow region. This narrow zone in which population inversion occurs is called as an active region, at that stage a photon emitted spontaneously triggers stimulated emission. This stimulated electron-hole recombination produces coherent radiation.

Energy level diagram of p-n junction diode laser

(a) Before biasing  (b) After biasing.

The stimulated electron-hole recombination causes emission of coherent radiation of very narrow bandwidth. At room temperature, GaAs laser emits light of wavelength 9000Å and GaAsP laser radiates at 6500Å.
Advantages of semiconductor laser:
1. They are compact
2. They are efficient
3. They are highly stable

Properties of laser:

1. Coherence: The emitted radiation after getting triggered is in phase with the incident radiation.
   Coherence is of two types
   a. Temporal or time coherence: In a source like sodium lamp, two waves of slightly different wavelengths are given out. These waves have slightly different coherence time ($\Delta t$). A definite phase relationship exists between the two types of waves. This is known as coherence of the beam.
      The coherence length $L$ is determined by the relation $L = c \Delta t$
   b. Spatial Coherence: A laser beam is said to possess spatial coherence if the phase difference of the waves crossing the two points on a plane perpendicular to the direction of propagation of the beam is time independent. Spatial Coherence is also termed as transverse or lateral coherence.

2. Monochromaticity: The laser beam is highly monochromatic than any other radiations.
3. Unidirectionality: Laser beam travels in only one direction. It can travel long distance without spreading.
4. Focusability: A laser beam can be focused to an extremely fine spot.
5. Intensity: The power output of the laser may vary from few milliwatts to few kilowatts. But this energy is concentrated in a beam of very small cross section. The intensity of laser beam is approximately given by
   $$ I = \left( \frac{10}{\lambda} \right)^2 P \text{ Wm}^{-2} $$
   Where $p$ is the power radiated by laser.
   In case of He-Ne laser, $\lambda = 6328 \times 10^{-10} \text{m}$ and $P = 10x 10^{-3} \text{W}$,
   the corresponding intensity is
   $$ I = \left( \frac{1}{6328 \times 10^{-10}} \right)^2 100 \times 10^{-3} = 2.5 \times 10^{11} \text{ Wm}^{-2} $$
   To obtain the above intensity from tungsten bulb, the temperature would have to be raised to $4.6 \times 10^6 \text{K}$. The normal operating temperature of the bulb is approximately 2000K.

Application of laser:

1. Laser welding: Laser beam is allowed to fall on the surface to be welded. The beam is absorbed and the surface starts melting due to the heat generated. The reflectivity and thermal diffusivity of the material are the important factors of welding. The reflectivity is more, the energy released is less. To increase the energy, the surface is coated with either cupric oxide or graphite. During the melting, the impurities accumulate on the surface of the material and it becomes a homogeneous solid structure and forms a stronger joint on cooling.
   The laser welding is very narrow and accurate. In laser welding, laser does not have any physical contact with the material to be welded. Hence no contamination
occurs. The properties of the material do not change due to welding. Laser welding can be carried out in normal workshop environment.

2. **Laser cutting:** When the laser is allowed to focus onto a tiny spot, the metal gets vaporized. There will be no physical distortion. CO₂ laser is used for the laser cutting. The laser cutting depends upon the input power for the laser beam and inversely proportional to the thickness of the material. It also depends on the nature of the gas used with the laser beam. Oxygen is commonly used gas. The gas is flown coaxially with the beam. The combustion of the gas helps the metal to get vaporized and it reduces the laser power which is required for cutting. Laser cuts the material accurately.

3. **Drilling:** Laser beam can drill the hardest material or a brittle material with a hole of diameter 10µm. Laser is used to make holes in gemstones, ceramics, without any damage. Very small dimensional holes can be made by using lasers. No contamination occurs as there is no physical contact.

4. **Measurement of pollutants in the atmosphere:** There are various types of pollutants in the atmosphere which include nitrogen, oxides of carbon monoxide, sulphur dioxide and a number of particulate matters. In conventional technique, samples of the atmosphere are collected at desired heights and the chemical analysis is carried out to find out the composition of the pollutants. Whatever the data obtained in this method is not a real time data. Whereas in the laser technique, the laser senses the atmospheric density variation by scanning the required local region and electronic data processes yield the data, which is a real time data.

In the application of laser for measurement of pollutant, laser is made use of the way as RADAR (Radio Detection and Ranging) system is used. Hence it is often referred as a LIDAR (Light Detection and Ranging) technique. In the LIDAR system, the transmitting part consists of pulsed laser and the receiving part consists of a concave mirror, photo detector and a data processor.
When measurements are carried out, the laser beam undergoes scattering at places in the atmosphere where there is congestion due to higher concentration of particulate matter. The back scattered light is received by the concave mirror. The distance of congestion from the measuring station is calculated on the basis of time delay between the pulse emission and reception of the back scattered light. By scanning the space around the station, the concentration of pollutants can be mapped for different vertical section of the atmosphere. This method cannot provide any information regarding the nature of the scattering particles. As this technique don’t provide the information regarding the nature of the scattering particles following two more techniques are followed:

1. Absorption Technique:

   The laser beam is passed through the sample collected from the atmosphere. The transmitted beam is recorded with a detector. While the beam passes through the sample, it undergoes absorption of various degrees depending upon the presence of exact type of chemical substance that the particulate comprise of. Depending upon the characteristic absorption pattern observed in the recording, the composition of the atmospheric pollutants could be determined.

2. Raman Back Scattering: Since laser is highly monochromatic, we expect to see only one line in the spectrum. But due to Raman scattering in the spectrum, several lines of low intensity will be seen symmetrically on either side of the incident line. There wavelength values will be close to that of the incident light. These additional spectral lines are called as side bands. Different gasses produce different side bands. The shifts in frequencies are termed as Raman shifts. Thus by observing the Raman spectrum of the back scattered light in the gas sample one can assess the composition of the pollutants.
Holography

Holography is the technique of producing 3-dimensional image of an object on 2-dimensional recording aid, by the phenomenon of interference. Holography is a Greek word, Holos means complete and graphos means writing. A and B are two identical or coherent beams incident on photosensitive surface at different angles. Due to interference effect, interference fringes are recorded on developing the photographic plate.

Principle of Hologram construction:

Light wave reflected from an object are characterized by their intensity (square of amplitude) and phase. When both intensity and phase attributes of the wave coming from three dimensional object is recorded on a photographic plate, it is called construction of hologram. When recorded photographic plate (hologram) is illuminated by a coherent light source, the three dimensional image of the original object is formed. This formation of image is known as reconstruction process.

Recording phase variation in a Hologram:

In recording hologram of an object a photographic plate is placed in front of an object at a suitable distance. Consider a coherent light incident on the object. The light reflected from two nearby points on the object travel slightly different distances in reaching the photographic plate due to variation in depth on the object. Thus the two wave fronts arrive at the photographic plate in a slightly different phase. Hence the light reflected from different points on the object will have different phases and interfere with the reference beam. The fringes recorded in the hologram carry information regarding the phase difference.

In holography there are two phases:

1) Recording
2) Reconstruction of the image.
Recording has two methods

1) Wavefront division technique.
2) Amplitude division technique.

1) Recording of the image of an object by wave front division technique

Expanded coherent laser beam from the laser source is obtained. A portion of it is made to incident on the mirror and other portion is made to incident on the object as shown in the fig.

Photographic plate is placed at a suitable position so that it receives the light reflected from both the mirror and the object. The light reflected from the mirror form a plane wavefront. It is called reference beam. The light reflected from each point on the object form a spherical wavefront. It is called object beam. Thus the interference effects of the two beams are recorded on the photographic plate.

As the spherical wave intersect the plane wave in circular zones, the interference pattern consists of concentric circular rings having constructive and destructive interference. It is called Gabor Zone plate.

Hologram consists of number of such zone plates. The centre of each is displaced from the other. In the recorded pattern the neighboring zones overlap each other and become apparent, once the film is developed. It is called a hologram.

2) Recording the image of an object by amplitude division technique

Expanded coherent laser beam from the laser source is obtained. It is made to incident on the beam splitter. The beam splitter reflects the portion of the light which is incident on the mirror. The transmitted light from the beam splitter is incident on the object. The reflected plane wavefront from the mirror and reflected spherical wavefronts from different points on the object undergoes interference on the photographic plate kept at a suitable place. The interference fringes are recorded on the photographic plate. The developed photographic plate becomes the hologram of the object.
**Reconstruction of the image from the hologram:**

Original Laser beam is made to incident on the hologram in the same direction as the reference beam was incident on it at the time of recording. The beam undergoes refraction in the hologram. Secondary wavelets originating from each constituting zone plate interfere constructively and generate real image on the transmission side and virtual image on the incident side.

**Applications of holography:**

1) **Holography Microscopy:** Large field of view with better resolution can be obtained using holography. In this technique, a grating divider is used to produce the object beam and the reference beam. First, the object beam is allowed to illuminate and the diffracted light is allowed to pass through a normal microscope. The reflected reference beam interferes with the object beam and the hologram is obtained. It is difficult to get the resolution by the microscope. The resolution of the holographic emulsion and coherence of the reference beam gives the depth of the field.

2) **Size of the Particle:** The fog like particle does not remain for a long time. It is very difficult to focus them. Holography can be used for particle analysis. The hologram of the particles in the volume is made and the reconstruction of hologram gives the idea of the size and geometry of the particle.

3) **Holographic diffraction grating:** The holography is based on the principle of interference. Interference pattern gives alternate dark and bright band. This method produces the rulings more accurate than the normal method.
4) **Holographic Interferometry:** This technique is used to measure vibration amplitudes and minute distortions of objects. The hologram of the stressed object is allowed to illuminate with a monochromatic light. During the reconstruction of hologram, the light reflected from the object interferes with the light reflected from the stressed object. It produces dark and bright interference pattern. By using this technique, we can measure the accurate changes in the body.

5) **ROM (Read Only Memory) Devices:** Since large amount of data can be stored, holograms are used in ROM devices.
Total Internal Reflection:

When a ray of light travels from denser to rarer medium it bends away from the normal. As the angle of incidence increases in the denser medium, the angle of refraction also increases. For a particular angle of incidence called the “critical angle”, the refracted ray grazes the surface separating the media or the angle of refraction is equal to 90°. If the angle of incidence is greater than the critical angle, the light ray is reflected back to the same medium. This is called “Total Internal Reflection”.

In total internal reflection, there is no loss of energy. The entire incident ray is reflected back.

XX\textsuperscript{1} is the surface separating medium of refractive index \( n_1 \) and medium of refractive index \( n_2 \), \( n_1 > n_2 \).

AO and OA\textsuperscript{1} are incident and refracted rays. \( \theta_1 \) and \( \theta_2 \) are angle of incidence and angle of refraction, \( \theta_2 > \theta_1 \). For the ray BO, \( \theta_c \) is the critical angle. OB\textsuperscript{1} is the refracted ray which grazes the interface. The ray CO incident with an angle greater than \( \theta_c \) is totally reflected back along OC\textsuperscript{1}.

From Snell’s law,
Department of Physics
\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

For total internal reflection,
\[ \theta_1 = \theta_c \text{ and } \theta_2 = 90^\circ \]
\[ n_1 \sin \theta_c = n_2 \text{ (because } \sin 90^\circ = 1) \]
\[ \theta_c = \sin^{-1} \left( \frac{n_2}{n_1} \right) \]

In total internal reflection there is no loss or absorption of light energy.
The entire energy is returned along the reflected light. Thus is called Total internal reflection.

**Optical Fibers:**

They are used in optical communication. It works on the principle of Total internal reflection (TIR).

Optical fiber is made from transparent dielectrics. It is cylindrical in shape. The inner cylindrical part is called as core of refractive index \( n_1 \). The outer part is called as cladding of refractive index \( n_2 \), \( n_1 > n_2 \). There is continuity between core and cladding. Cladding is enclosed inside a polyurethane jacket. Number of such fibers is grouped to form a cable.

![Optical Fiber Diagram]

The light entering through one end of core strikes the interface of the core and cladding with angle greater than the critical angle and undergoes total internal reflection. After series of such total internal reflection, it emerges out of the core. Thus the optical fiber works as a waveguide. Care must be taken to avoid very sharp bends in the fiber because at sharp bends, the light ray fails to undergo total internal reflection.
Angle of Acceptance and Numerical Aperture:

Consider a light ray AO incident at an angle ‘θ₀’ enters into the fiber. Let ‘θ₁’ be the angle of refraction for the ray OB. The refracted ray OB incident at a critical angle (90° - θ₁) at B grazes the interface between core and cladding along BC. If the angle of incidence is greater than critical angle, it undergoes total internal reflection. Thus θ₀ is called the waveguide acceptance angle and sinθ₀ is called the numerical aperture.

Let n₀, n₁ and n₂ be the refractive indices of the medium, core and cladding respectively.

From Snell’s law,
\[ n₀ \sinθ₀ = n₁ \sinθ₁ \quad \rightarrow (1) \]

At B the angle of incidence is (90° - θ₁)

From Snell’s law,
\[ n₁ \sin(90°-θ₁) = n₂ \sin90° \]
\[ n₁ \cosθ₁ = n₂ \]
\[ \cosθ₁ = n₂ / n₁ \quad \rightarrow (2) \]

From eqn (1)
\[
\sin \theta_0 = \frac{n_2}{n_0} \sin \theta_1
\]

\[
= \frac{n_1}{n_0} \sqrt{1 - \cos^2 \theta_1}
\]

→ (3)

Using eqn (2) in (3)

\[
\sin \theta_0 = \frac{n_1}{n_0} \sqrt{1 - \frac{n_2^2}{n_i^2}}
\]

\[
= \frac{\sqrt{n_1^2 - n_2^2}}{n_0}
\]

→ (4)

The surrounding medium is air, \(n_o = 1\)

\[
\sin \theta_0 = \sqrt{n_1^2 - n_2^2}
\]

Where \(\sin \theta_i\) is called numerical aperture.

\[
\text{N.A} = \sqrt{n_1^2 - n_2^2}
\]

Therefore for any angle of incidence equal to \(\theta_i\) equal to or less than \(\theta_0\), the incident ray is able to propagate.

\[
\theta_i < \theta_0
\]

\[
\sin \theta_i < \sin \theta_0
\]

\[
\sin \theta_i < \sqrt{n_1^2 - n_2^2}
\]

\(\sin \theta_i < \text{N.A}\) is the condition for propagation.

**Fractional Index Change:**

“\(\Delta\) is the ratio of the refractive index difference between the core and cladding to the refractive index of the core of an optical fiber”.

\[
\Delta = \frac{n_1 - n_2}{n_i}
\]

**Relation between N.A and \(\Delta\):**

Consider \(\Delta = \frac{n_1 - n_2}{n_1}\)
\[ n_1 - n_2 = \Delta n_1 \]

We have

\[ \text{N.A} = \sqrt{n_1^2 - n_2^2} = \sqrt{(n_1 + n_2)(n_1 - n_2)} \]

Considering \( n_1 \approx n_2 \)

\[ = \sqrt{(n_1 + n_2)\Delta n_1} \]

\[ N.A = \sqrt{2n_1^2\Delta} \]

\[ N.A = n_1\sqrt{2\Delta} \]

Increase in the value of \( \Delta \) increases N.A

It enhances the light gathering capacity of the fiber. \( \Delta \) value cannot be increased very much because it leads to intermodal dispersion intern signal distortion.

**V-number:**

The number of modes supported for propagation in the fiber is determined by a parameter called V-number.

If the surrounding medium is air, then

\[ V = \frac{\pi d}{\lambda} \sqrt{n_1^2 - n_2^2} \]

Where ‘d’ is the core diameter, \( n_1 \) and \( n_2 \) are refractive indices of core and cladding respectively, \( \lambda \) is the wavelength of light propagating in the fiber.

\[ V = \frac{\pi d}{\lambda} (NA) \]

If the fiber is surrounded by a medium of refractive index \( n_0 \), then,

\[ V = \frac{\pi d}{\lambda} \sqrt{n_1^2 - n_2^2} \frac{1}{n_0} \]

For \( V > 1 \), the number of modes supported by the fiber is given by, number of modes \( \approx V^2/2 \).

**Types of optical fibers:**

In an optical fiber the refractive index of cladding is uniform and the refractive index of core may be uniform or may vary in a particular way such that the refractive index decreases from the axis, radically.
Following are the different types of fibers:

1. Single mode fiber
2. Step index multimode fiber
3. Graded index multimode fiber

1. **Single mode fiber**: Refractive index of core and cladding has uniform value; there is an increase in refractive index from cladding to core. They are used in submarine.

2. **Step index multimode fiber**: It is similar to single mode fiber but core has large diameter. It can propagate large number of modes as shown in figure. Laser or LED is used as a source of light. It has an application in data links.
3. **Graded index multimode fiber**: It is also called GRIN. The refractive index of core decreases from the axis towards the core cladding interface. The refractive index profile is shown in figure. The incident rays bends and takes a periodic path along the axis. The rays have different paths with same period. Laser or LED is used as a source of light. It is the expensive of all. It is used in telephone trunk between central offices.

**Signal distortion in optical fibers:**
The propagation of a signal through the optical fiber involves total internal reflection of light rays many times. Further, the rays are reflected at various angles. The rays reflected at higher angles travel greater distances than the rays reflected at lower angles. As a result, all the rays do not arrive at the end of the fiber simultaneously and the light pulse broadens as it travels through the fiber. Since the output pulse does not match with the input pulse, the signal is said to be distorted.

If white light is used instead of monochromatic light, another kind of distortion occurs. Since radiation of different wavelengths has different velocities, they do not arrive at the output simultaneously. This distortion is called chromatic dispersion.

The signal distortion is quite considerable in multimode step index fibers. In graded index fibers, the light travels with different velocities in different parts of the core as the refractive index varies radially along the core. The rays travel faster near the interface. Hence all the rays arrive at the output almost at the same time and the signal distortion is reduced. In a single mode step index fiber the distortion is less than that in multimode step index fibers.

**Signal attenuation in optical fibers:**

Attenuation is the loss of optical power as light travels through a fiber. It is expressed in decibel/kilometer [db/km]. A fiber with lower attenuation will allow more power to reach its receiver than a fiber with higher attenuation. If $P_{in}$ is the input power and $P_{out}$ is the output power after passing through a fiber of length $L$, the mean attenuation constant or coefficient ‘$\alpha$’ of the fiber, in units of db/km is given by

$$\alpha = -10 \log_{10} \left( \frac{P_{out}}{P_{in}} \right) \text{ dB/km}$$

Attenuation can be caused by three mechanisms.

1. **Absorption:** Absorption of photons by impurities like metal ions such as iron, chromium, cobalt and copper in the silica glass of which the fiber is made of. During signal processing photons interact with electrons of impurity atoms. The atoms are excited and de-excite by emitting photons of different characteristics. Hence it is a loss of energy. The other impurity such as hydroxyl ions (OH) causes significant absorption loss. The absorption of photons by fiber material itself is called intrinsic absorption.

2. **Scattering:** When the wavelength of the photon is comparable to the size of the particle then the scattering takes place. Because of the non uniformity in manufacturing, the refractive index changes with length leads to a scattering. This type of scattering is called as Rayleigh scattering. It is inversely proportional to the fourth power of wavelength. Scattering of photons also takes place due to trapped gas bubbles which are not dissolved at the time of manufacturing.

3. **Radiation losses:** Radiation losses occur due to macroscopic bends and microscopic bends.
Macroscopic bending: All optical fibers are having critical radius of curvature provided by the manufacturer. If the fiber is bent below that specification of radius of curvature, the light ray incident on the core cladding interface will not satisfy the condition of TIR. This causes loss of optical power.

Microscopic bending: Optical power loss in optical fibers is due to non-uniformity of the optical fibers when they are laid. Non-uniformity is due to manufacturing defects and also lateral pressure built up on the fiber. The defect due to non-uniformity (microbendings) can be overcome by introducing optical fiber inside a good strengthen polyurethane jacket.

**Fiber Optics Communication System:**

Optical fiber communication system consists of transmitter, information channel and receiver. Transmitter converts an electrical signal into optical signal. Information channel carries the signal from transmitter to receiver. The receiver converts optical signal to electrical form. The block diagram of optical fiber communication system is shown in fig.

**Message origin:** It converts a non electrical message into an electrical signal.

**Modulator:** It converts the electrical message into proper format and it helps to improve the signal onto the wave which is generated by the carrier source.

There are two types of format. They are Analog and digital. Analog signal is continuous and it doesn't make any change in the original format. But digital signal will be either in ON or OFF state.

**Carrier source:** It generates the waves on which the data is transmitted. These carrier waves are produced by the electrical oscillator. Light emitting diodes (LED) and laser diodes (LD) are the different sources.
**Channel Coupler: [Input]** The function of the channel coupler is to provide the information to information channel. It can be an antenna which transfers all the data.

**Information channel:** It is path between transmitter and receiver. There are two types of information channel. They are guided and unguided. Atmosphere is the good example for unguided information channel. Co-axial cable, two-wire line and rectangular wave guide are example for guided channel.

**Channel Coupler: [Output]** The output coupler guides the emerged light from the fiber on to the light detector.

**Detector:** The detector separates the information from the carrier wave. Here a photo-detector converts optical signal to electronic signal.

**Signal processor:** Signal processor amplifies the signals and filters the undesired frequencies.

**Message output:** The output message will be in two forms. Either person can see the information or hear the information. The electrical signal can be converted into sound wave or visual image by using CRO.

**Advantages of optical communication system:**

1) It carries very large amount of information in either digital or analog form due to its large bandwidth.
2) The materials used for making optical fiber are dielectric nature. So, it doesn’t produces or receives any electromagnetic and R-F interferences.
3) Fibers are much easier to transport because of their compactness and lightweight.
4) It is easily compatible with electronic system.
5) It can be operated in high temperature range.
6) It does not pick up any conducted noise.
7) Not affected by corrosion and moisture.
8) It does not get affected by nuclear radiations.
9) No sparks are generated because the signal is optical signal.

- Note: - Optical fibers are used in sensors like pressure sensor, voltage sensor and current sensors.
  Optical fibers are used in local networks like data link purpose.

**Objective Type Questions**

1) Emission of a photon by an excited atom due to interaction with a passing photon nearby is called ----- stimulated emission
2) Emission of a photon by an excited atom without being aided by any external agency is called ----- spontaneous emission.
3) \( n_1 \) be the number density of the lower energy state \( E_1 \) and \( n_2 \) be the number density of the higher energy state \( E_2 \), then the condition \( n_1 < n_2 \) is called ----- inverted population
4) supply of energy to the atom for excitation is called ----- pumping
5) important characteristic of laser beam is --- coherence
6) The life time of an atom in the metastable state is of the order of few milliseconds
7) Pumping process used in diode laser is forward bias
8) The characteristic of laser are a) directionality b) monochromaticity c) coherence d) focus ability e) high intensity.
9) Metastable states are the excited energy states in which the atom stays for very long interval of time (10^{-3} to 10^{-2}s). Few milliseconds. In normal excited states the life time of an atom is of the order of few nanoseconds.
10) In a semiconductor laser mirrors are not used because a pair of parallel planes cleaved and polished at a particular angle in a crystal reflect the light efficiently.
11) The wavelength of the GaAs laser is \( \lambda = \frac{hc}{E_g} \) (\( E \equiv h\nu = \frac{hc}{\lambda} \))
   \[
   \lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.4 \times 1.6 \times 10^{-19}} = 8400 \times 10^{-10} \text{m}
   \]
12) LIDAR is used to measure the atmospheric pollutants in air using the principle of scattering and reflection
13) He – Ne laser is a gas laser
14) GaAs laser is a semiconductor diode laser
15) If \( n_1 \) and \( n_2 \) are the number densities of the lower and excited states then a) under equilibrium condition \( n_1 = n_2 \) b) under non equilibrium condition \( n_1 < n_2 \) is called inverted population.
16) The rate of absorption is \(-B_{12}N_1 U_v\)
17) The rate of stimulated emission is \(B_{21}N_2 U_v\)
18) The rate of spontaneous emission is \(A_{12}N_1\)
19) The relation between energy density and Einstein coefficient is
   \[
   U_v = \frac{A_{21}N_1}{B_{12}N_1 - B_{21}N_2} = \frac{A_{21}}{B_{21}} \left[ \frac{1}{B_{21}N_1 - B_{21}N_2} \right]
   \]
20) Boltzmann’s law is
   \[
   N_2 = N_1 e^{-\frac{E_2 - E_1}{kT}} = N_1 e^{-\frac{-h\nu}{kT}} \quad \therefore \quad \frac{N_1}{N_2} = e^{\frac{h\nu}{kT}}
   \]
21) The relation between energy density and Einstein coefficient and Boltzmann’s law is
   \[
   U_v = \frac{A_{21}}{B_{21}} \left[ \frac{1}{B_{21}^2 e^{\frac{h\nu}{kT}} - 1} \right]
   \]
22) Planck’s law is
   \[
   U_v = \frac{8\pi h\nu^3}{c^3} \left( \frac{1}{e^{\frac{h\nu}{kT}} - 1} \right)
   \]
23) The relation between Einstein coefficient \( A_{21} \), \( B_{21} \) and frequency of radiation is
   \[
   \frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}
   \]
24) At thermal equilibrium the equation for energy density is
25) At non equilibrium condition
\[ \frac{\text{rate of emission}}{\text{rate of absorption}} = \frac{N_2}{N_1} \]

26) IN He –Ne laser the ratio of He to Ne gas is of the order of 10 : 1

27) The neon atoms which are there in the metastable state come down to the lower energy state by collision.

28) The depopulation of the 1s state in neon atom in He –Ne laser is made efficient by decreasing the diameter of the tube.

29) Quartz plates are fixed at the ends of the discharge tube in a He –Ne laser so that the emerging light is polarized.

30) In a laser the mirrors are there in either side of the device so that some photons continue to stimulate further batches of stimulated transitions.

31) Laser welding gives a strong joint because the impurities are expelled to the exterior zone.

32) The requisites of laser system are
   A) An excitation source for pumping action
   B) An active medium which supports population inversion
   c) A laser cavity/Fabry Perot Resonator.

33) Brewster window is designed on the principle of Brewster angle and refractive index of the material of the surface given by \( \tan \alpha = \mu \).

34) Supply of energy to atoms for excitation is called pumping.

35) Pumping process used in diode laser is forward bias.

36) The purpose of the optical resonator in a laser is to send laser in specified direction.

37) The number of modes of standing waves in the resonant cavity of length 1m. If He-Ne laser operating at a wavelength of 6328x10^-10m is \(-3.16x10^6\).

38) 3D image of an object constructed by a hologram is the process of both phase and intensity information recording.

39) In a semiconductor laser the material used is direct band gap semiconductor.

40) In recording the image on the photographic plate, the reference beam and the object beam undergo Interference at the photographic plate.

41) Wavelength of laser beam can be used as a standard of length.

42) Image is stored on a hologram in the form of interference pattern.

43) Which event is likely to takes place when a photon of difference in energy between two levels is incident in a system- absorption and emission.

**Numericals:**

1. Find the ratio of population of two energy levels in a Laser if the transition between them produces light of wavelength 694.3 nm. Assume the ambient temperature to be 27°C. ( July 2008)

2. A He-Ne laser is emitting a beam with an average power of 4.5mW. Find the number of photons emitted per second by the laser. The wavelength of the emitted radiation is 6328Å. ( Jan 2008)
3. Find the number of modes of the standing waves and their frequency separation in the resonant cavity of length 1m of He-Ne laser operating at wavelength 632.8nm. (July 2007, July 2011)
4. The average output power of laser source emitting a laser beam of wavelength 633nm is 5mW. Find the number of photons emitted per second by the laser source? (Jan 2011)
5. The ratio of population of two energy states in a laser is 1.059x10^{-30}. If the temperature of the system is 57°C, what is the wavelength of the laser (Dec 2010)
6. A ruby laser emits pulse of 20ns duration with average power per pulse being 100kW. If the number of photons in each pulse is 6.981x10^{15}, calculate the wavelength of photons. (Jan 2010)

**Descriptive Type questions:**
2. Explain the sketches the basic principle of operation of lasers? (Jan 2007)
3. Explain the construction and working of CO₂ laser with the help of energy level diagram (July 2008, Jan 2008, Jan 2011)
5. Describe the recording and reconstruction processes in Holography with the help of suitable diagrams (Jan 2008)
6. Describe briefly the application of lasers in welding, cutting, drilling and in air pollutant measurement. Mention the nature and property of the lasers used in these. (July 2007)
7. Write a note on holographic technique. Mention the applications of holography (July 2007, Jan 2011)
8. Explain the requisites and conditions of a laser system. (July 2011)
9. Describe the principle and working of LIDAR used to measure pollutant in atmosphere (July 2011)
10. Describe the recording and reconstruction process in holography, with the help of suitable diagram (Jan 2010)

**OPTICAL FIBERS**

1) Optical fibers work on the principle of total internal reflection
2) If n₁ is the refractive index of the core and n₂ is the refractive index of the cladding then for total internal reflection at the core and cladding Interface n₁ > n₂
3) n₁ and n₂ are the refractive indices of the core and cladding respectively and if θₖ is the critical angle then

\[ \theta_c = \sin^{-1} \frac{n_2}{n_1} \]
4) if \( n_1, n_2, n_0 \) are the refractive indices of the core cladding and the surrounding medium respectively then the waveguide angle \( \theta_0 \) is
\[
\sin \theta_0 = \sqrt{\frac{(n_1^2 - n_2^2)}{n_0^2}}
\]

5) If \( \theta_i \) is the angle of incidence in an optical fiber and N.A is the numerical aperture then the condition for the propagation is------ \( \sin \theta_i < \text{N.A} \)

6) Numerical aperture for the optical fiber depends upon the -----acceptance angle.

7) If \( n_1 \) and \( n_2 \) the are refractive indices of core and cladding then the fractional index change is given by--------- \( \Delta = \frac{(n_1-n_2)}{n_1} \)

8) Fractional index change for an optical fiber with core and cladding refractive indices 1.563 and 1.498 respectively is ------ 0.04159

9) Number of mode supported by optical fiber cable is -----\( \sqrt{\frac{\pi d \sqrt{(n_1^2-n_2^2)}}{\lambda n_0}} \)

10) For \( \nu \gg 1 \) the number of modes supported by the fiber cable is ------ \( \approx \frac{V^2}{2} \)

11) Loss of power by an optical signal through the optical fiber is mainly due to Rayleigh scattering.

12) In an optical fiber Rayleigh scattering occurs when a photon ----- encounters sharp change in the refractive index over distance smaller than its wavelength

13) Attenuation means ----- loss of signal strength

14) Delay distortion occurs due to ------- spreading of pulse

15) Having cladding around the core is preferred to coating the core with a reflecting material (silvering) because ----- reflection at the core and cladding interface is superior to the one by any coated material

16) Loss of power during transmission through optical fiber is called ------ attenuation.

17) In a single mode fiber the diameter of the core is 8-10\( \mu \)m.

18) The numerical apertures of an optical fiber is 0.2 when surrounded by air. The acceptance angle when the fiber is in water of refractive index 1.33 is 8.65\(^\circ\).

19) Attenuation in optical fiber causes due to absorption, scattering and dispersion.

20) The numerical aperture of an optical fiber in air is 0.32. The numerical aperture in water \( (n=4/3) \) is --------0.24.

21) Graded index fiber can be multimode fiber only.

22) The optical fiber kept in the medium of refractive index \( \mu>1 \) instead of air, the acceptance angle is decreases.

23) In graded index fiber, the RI of cladding is constant and RI of core varies linearly from axis of fiber to the core cladding interface.

**Numericals**

1. An optical glass fiber of refractive index 1.50 is to be clad with another glass to ensure internal reflection that will contain light travelling within 5\(^{\circ}\)of the fiber axis. What maximum index of refraction is allowed for the cladding?( Jan 2010)

2. The angle of acceptance of an optical fiber is 30\(^{\circ}\) when kept in air. Find the angle of acceptance when it is in a medium of RI 1.33 ( July 2011)

3. An optical signal has lost 85\% its power after travelling 400 m of fiber. What is the fiber loss? ( July 2007)
4. The angle of acceptance of an optical fiber is $30^\circ$ when kept in air. Find the angle of acceptance when it is in a medium of refractive index 1.33 (Jan 2000).

5. Calculate the numerical aperture, fractional index change and V-number for a fiber of core diameter 40 $\mu$m and with refractive indices of 1.55 and 1.50 respectively for core and cladding. The wavelength of the propagating wave is 1400 nm. Assume that the fiber is in air? (Jan 2008)

**Descriptive type questions:**

1. What is meant by acceptance angle for an optical fiber? Show how it is related to numerical aperture. (July 2007)

2. Obtain an expression for numerical aperture and arrive the condition for propagation (Jan 2009)

3. Discuss types of optical fibers and modes of propagation using suitable diagram. (July 2007, July 2011)

4. Describe the point to point communication system, with the help of a block diagram? (Jan 2010)