Lasers:

Lasers are optical phenomena which are used in many fields of science and technology like radio astronomy, satellite - communication, holography or three dimensional photography, data processing, testing and welding of materials, medicine etc.

LASER is acronym for Light Amplification by Stimulated Emission of Radiation. Similarly Maser is acronym for Microwave Amplification by Stimulated Emission of Radiation. In the laser, the maser principle has been extended to optical or frequencies of 1014 to 1015 Hz and is therefore termed as optical maser. Now-a-days laser principle is extended upto X-rays and Gamma rays. Gamma ray lasers are called Grasers.

Conditions for Laser action:

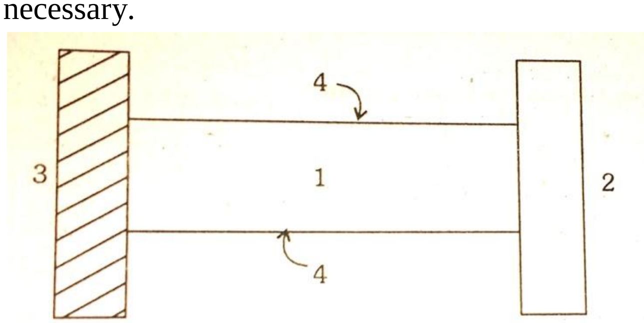
1. Laser beam contains high intense radiation in unique direction without spreading of its energy in other directions. Further it has high monochromacity and high directionality. For this, coherent radiation is necessary. Stimulated Emission can produce this coherent radiation.

2. For continuous stimulated chain reaction or for continuous output reaction or for continuous output from laser, population inversion or population reversal should be maintained. This can be done by optical pumping or by electrical pumping.

Laser principle:

Population of atoms in higher energy level as compared to lowest energy level is increased by pumping the matter by photons of appropriate energy. Thus atoms are excited to higher energy states. During the period in which the atom is excited, it can be stimulated to emit a photon if it is struck by an outside photon having precisely the energy of the photon that would have otherwise been emitted in spontaneous emission. That is for stimulated emission, the energy of the stimulating photon should be equal to the energy difference b/w the transition levels, otherwise the emitted light may be due to spantaneous emission.

The stimulated photon (emitted wave) falls precisely in phase with the stimulating photon (incident wave). These two photons stimulate other two atoms and produce another two photons. This chain reaction goes on and there is an intense beam of radiation. Thus the electromagnetic radiation is amplified. For stimulated emission to predominate over absorption; it is essential that excited atoms should be in excess in the active medium. For continuous output, population inversion is necessary.



1. Active material (Resonant cavity)
2. Partially transparent reflector
3. Perfect reflector
4. Transparent side

Active material:

Active material is shaped into a cylinder with parallel transparent sides and reflectors at both ends. Active-material is energized by the pulses of light from flash tube. Then emission begins;

photons that can not travel parallel to the axis of the cylinder will leave the cylinder through the transparent sides either immediately or after I one or two off angle reflections. Thus such photons will not collide with other excited atoms of the active material.

Photons moving parallel to the axis of the tube will suffer several reflections between the two end reflectors During the reflections in their way they interact with other excited atoms of the active material and thus producing more .photons. Due to the chain reaction of stimulated emission, intensity of photon beam parallel to the axis of the tube increases gradually. If one of the reflectors is partially transparent (say 10%) then some of the coherent light (stimulated photon beam which is parallel to the axis of the tube) would emerge through this reflector and serves as output laser beam.

Differences between Laser source and conventional source:

The most important features of laser are:

i) its high directionality

ii) Its high intensity

iii) Its extraordinary monochromacity and

iv) It high degree, of coherence

Einstein's quantum theory of radiation:

We are very familiar with the Planck's quantum theory on black body radiation. Einstein's theory of absorption and emission of light by an atom is based on Planck's theory of radiation.

We consider two energy levels of an atomic system E_1 and E_2 respectively such that $E_2 > E_1$. Let N_1 and N_2 be the number of atoms per unit volume present in the energy levels E_1 & E_2 respectively. If radiation at a frequency corresponding to the energy [difference (E_2-E_1) falls on the atomic system, it can interact in three distinct ways.

a) Absorption

b) Stimulated Emission

c) Spontaneous Emission

Threshold pumping power:

$p_{th} = Nh\, v_p / 2\, \tau_{sp}$

where N is the density of atoms in the ground level and v_p is the frequency of the radiation from pumping source.

Different kinds of lasers:

1. Solid state lasers
2. Gas lasers
3. Liquid lasers
4. Dye lasers
5. Semiconductor lasers

Solid state lasers are very high power lasers. There are three level and four level lasers in them. Ruby laser is a three level solid state laser. Among the solid state lasers, four level types are widely used because it is easy to establish population inversion and wastage of power input is low in these four level lasers. CO_2, Nitrogen and He-Ne are the Important gas lasers. CO_2 lasers are used for cutting and welding of materials due to their high power. Similarly He-Ne lasers are used in the laboratory experiments. Dye lasers have high gain and high efficiency and these are wide band quantum amplifiers. From these we can get laser beam at any desired frequency. Semiconductor lasers are used in communication. Gallium Arsenide Semiconductor laser is an important one. It gives- laser pulses at the wavelength of 8400A.

Ruby Laser:

Ruby Laser is a solid state three level laser and was constructed by Maiman.

Helium - Neon Laser:

For the continuous laser beam, gas lasers are used. Higher stability, high directional, high monochromacity and most pure spectrum can be obtained from them. But the output power is generally moderate when we compare them with the solid state-lasers.

Carbon di-oxide laser:

In the Ruby laser or in He-Ne laser, the transitions are taking place among the various excited electronic states of an atom or an ion. In CO_2 laser, the laser transitions are occurring between different vibrational states of the carbon di-oxide molecule. An Indian Engineer, Patel the first person who designed CO_2 laser.

Gallium Arsenide (Ga As) diode laser Principle:

Among the semiconductors there are direct band gap semiconductors and indirect band gap semiconductors. In the case of direct band gap semiconductors, there is a large possibility for direct recombination of hole and electron emitting a photon. But in indirect band gap semiconductors, like Germanium and silicon, direct recombination of hole and electron is not possible and hence there is no photon emission. GaAs is a direct bandgap semiconductor and hence it is used to make light emitting diodes and lasers. The wavelength of the, emitted light depends on the band gap of the material.

Modern laser diodes:

Today laser diodes are mostly used in optical communication. The source of light used in optical communication should be stable with long life. Further it should have high monochromacity, high coherence and high directionality. To achieve these in semiconductor lasers,, the laser diodes are made from a double heterostructure.

Uses of Lasers:

1. Communication
2. Computers
3. Metrology
4. Chemistry
5. Photography
6. Detection & ranging
7. Industries
8. Medicine

Photometry:

Photometry is a branch of optics which deals with the measurement of the brightness of sources of light by comparing with a standard source of light. The instruments used for this purpose are called photometers.

Inverse square law (Lambert's law):

The intensity of illumination of a surface due to a light source, is directly proportional to the illuminating power of the source and inversely proportional to the; square of the distance between the source and the surface. Further it is directly proportional to the cosine of the angle of incidence.

Thus $I \propto L$

$I \propto \frac{1}{d^2}$ (inverse square law)

$I \propto \cos\theta$

$\therefore I = k\frac{1}{d^2}\cos\theta = \frac{1}{4\pi}\frac{L}{d^2}\cos\theta$

Where I is the intensity of illumination of a surface, θ the illuminating power of the source, the angle of incidence, d the distance b/w the

source and surface and k the constant of proportionality equal to.
For normal incidence, $\theta = 0$

$$\therefore I = \frac{1}{4\pi}\frac{L}{d^2} Lux$$

Principle of photometry:
The principle of photometry is based on the adjustment of the distances of the two sources so that they produce equal intensity of illumination at a point.

i.e. $\frac{L_1}{4\pi d_1^2} = \frac{L_2}{4\pi d_2^2}$ for normal incidence

or $\frac{L_1}{L_2} = \frac{d_1^2}{d_2^2}$

Optical fibers and their applications:
a) Optical fibers in communication:
The optical fibers are used as electric wavegides for electromagnetic energy at optical frequencies. Optical fibers are greatly utilized for communication, sensing and imaging purposes. Now we are in the age of optical fibre communication. The optical fibre cables have the potential to transmit simultaneously a relatively much larger number of telephone conversations in the form of light waves than the metallic cables that carry telephone conversations in the form of electric current. Through one copper wire pair, only 48 independent speech signals can be sent simultaneously. But in optical fibers, the transmission of 15000 or more simultaneous telephone conversations is possible utilising light as the carrier (since the information carrying capacity of an electromagnetic carrier is roughly proportional to the frequency of the carrier). The light is guided through transparent glass fibers by total internal reflection. A typical glass fibre consists of a central core glass (= 50 pm) surrounded by a cladding made of a glass of slightly lower refractive index and of an overall diameter of about 125 to 200 micrometer. Thus the fibre optic cable has small size and light weight unlike metallic cables. The maximum angle ϕ_{max} with which a ray can enter, the end of the fiber and still be totally internally reflected is given by $\sin\phi_{max} = \sqrt{n_1^2 - n_2^2}$ = N.A where N.A is defined as the numerical aperture of the fiber which is the measure of the amount of light rays that can be accepted by the fiber and n_1 and n_2 are the refractive index of core and cladding respectively.

Different types of fibers:
Based on the refractive index profile, .we have two types of fibers:
i) Step index fiber
ii) Graded index fiber
In the step index fiber, the refractive index of the core is uniform throughout and undergoes an abrupt change (or step) at the cladding boundary. The diameter of the core is about 50-200 pm. The light rays propagating through it are in The form of meridional rays which will cross the fiber axis during every reflection at the cbre1-cladding boundary.
In the graded index fiber, the refractive index of the core, is made to vary in the parabolic manner such that the maximum refractive index is present at the centre of the core. The diameter of the cure is about 50μm only. The light rays propagating through it are in the form of skew rays or helical rays which will not cross the fiber axis at any time.
Based on the number of modes propagating through the fiber, we have multi mode fiber and single mode fiber.

In fact since the fiber is acting as an electromagnetic waveguide. Only certain angles or modes satisfy the boundary conditions. Kevlar is used as strength member in fiber optic cable to improve the mechanical strength of the fibers. Multimode fiber allows a large number of paths or modest for the light rays travelling through them. The total number of modes possible for such a guide is given approximately by

$N = 4.9\left(\frac{d.N.A}{\lambda}\right)^2$

where λ is the optical wavelength and d is the cqre diameter.

When d$\leq\frac{0.76\lambda}{\text{N.A}}$ only a single mode will propagate and it is called single mode fiber. Thus single mode fiber will have smaller core diameter .than multimode fiber and the difference between the retractive indices of the core and the cladding is very small. In practice them is no dispersion (i.e. no degradation of signal) in single mode fibers. Since information transmission capacity in optical fiber is inversely proportional to dispersion the single mode fibers are more suitable for communication than multimode fibers. But launching of light into singlet fibers and jointing of fibers are very difficult multinode fibers.

Advantages of Fiber optic communication:

Since Fiber optics are made from material media with extremely low loss, they have very large repeater spacing as compared to metallic transmission media. Since these fibers are composed of dielectric materials they are immune to extraneous interfering electromagnetic signals.

There is virtually no signal leakage from them and hence cross talks between neighbouring fibers are absent. Since signals do not leak away from the fibers, they are resistant to intrusion and are highly suited for secure communications as in defence communication networks. These are hundred percent safe for use in the neighbourhood of explosives or in warfield since there is no spark of short circuit problems.

Optical fibre materials:

The basic raw material used in the fabrication of low loss fibers is silica. Fibers for optical communication applications must guide light efficiently with very low optical scattering, low dispersion and low absorption or attenuation Materials satisfying these requirements are- glasses and plastics. Fiber optic cables used in electronic-systems are categorised by the optical properties of the fiber and the number of fibers in the cable. For wide bandwidth and long distance communication. Systems high quality, low loss, graded index glass fiber cables single or in multiples are used. For applications requiring lesser bandwidth and smaller distances, less expensive step index glass fiber cables are used. For short distances glass and plastic fibers with large cores are used. Single fiber sizes ranging from 100 to 125 μm are used, for telecommunication. 250 to 300 pm size cables are used for computer and process, control applications.

Optical losses in the fibers are greatly reduced by careful' choice of material composition and improvement in fiber design. The radial variation in refractive index of the fiber is achieved by appropriately doping the core of the silica preform with higher index germanium and the cladding with fluorosilicates during the preform fabrication. The fibre drawn from the preform maintains this profile but with greatly reduced lateral dimensions Absorption loss has been effectively eliminated in silica fibre materials at communication wavelengths of 1.3 and 1.55 mm by reducing absorbing impurity levels to below one part per billion. Rayleigh scattering loss is the dominant loss at shorter wavelengths like ultraviolet region, whereas cut longer wavelengths multiphoton absorption the dominant loss.

Fiber optic delay lines:

The recent advent of loss optical fibers has provided the possibility of a new type of extremely wide band delay line using such fibers as the delay medium. Above 1 GHZ low loss optical fibers, are far superior to any] practical alternative currently available since the propagation attenuation for fibers at 10 GHZ IS 0.4 dB/ps but at the same time for acoustic waves it is about 100 dB/ps. Thus glass fibers, with attenuation coefficients as low as 0.4 dB/μs for electromagnetic energy in the 1 μm wavelength region can do various microwave signals processing functions such as delay lines with time bandwidth products as high as 10^5 and matched filters.

Fiber optic sensors:

The high sensitivity of fibers to external influences, like phase sensitivity, micro bending losses and modal noise is utilised to develop sensors.

Physical parameter to Modulation effects be measured in optical fibers

1. Mechanical force Stress birefringence
2 Pressure Piezo optic effect
3, Electric field Electro optic effect
4. Electric current Electro luminescence
5. Magnetic: field Magneto optic effect
6. Temperature Thermoluminescence
7. Nuclear radiations Radiation induced luminescence
8. Density Triboluminescence

For magnetic field sensors, polarisation maintaining fibers are used. A longitudinal magnetic field applied on the length of an optical fibre produces a change in the state of polarisation in the optical beam - Faraday rotation. Even though this effect can be increased by doping silica fibers with rare earth ions, the detection of such a small change even with an interferometer is extremely difficult because of the very low S/N ratio. Now-a-days mimetic field sensors are based on the attachment of fiber to a magnetostrictive material. The change in length of magnetostrictive material along its length in the presence of magnetic field induces a change in the optical path in an optical fibre by means of longitudinal strain in the fiber. This path length difference can be detected and measured using an interferometer. Current is also measured using the same principle.

Fiber endoscopes:

Using low quality, lare diameter and short length silica fibers one can design fiberoscopes of endoscopes. These are greatly used in hospitals and industries for nondestructive testing. The Broncho fiberoscopes, Gastrointestinal fiberoscopes and Laparoscopes are the important endoscopes used in hospitals for examination, treatment of diseases and surgery. These are flexible and rigid. Usually in endoscope, there are two fibers. One is used to illuminate the inner structure of object. Other is used to collect the reflected light from that area and from that we can view the inner structure of object. In industries, to check the status of inner structure of any machine, endoscopes are greatly used. By means of these, we can reduce the testing time of each machine, infrared transmitting fibers such as chacogenide glasses are under active investigation for the delivery of C02 laser power in surgical and robotic applications and for remote sensing of thermal images.

1. Light from a mercury arc after passing- through a green filter is incident on two narrow slits 0.0006m apart. The interference pattern is formed on a screen 2.5m away. The distance between the adjacent green lines is found to be 2.27mm. Determine the wavelength of light.

   Solution:

   Bandwidth $\beta = \frac{D}{d}\lambda$

   $\therefore 0.00227 = \frac{2.5\lambda}{0.0006}$

   or $\lambda = \frac{0.00227 \times 0.0006}{2.5}$

   $= 5449 \times 10^{-10}$

2. Fringes are produced by monochromatic light of wavelength 5.45×10^{-5} cm. A thin plate of glass of refractive index 1.5 is placed in the path and the central bright band of the fringe system is found to move into the position previously occupied by the third bright band from the centre. Calculate the thickness of the glass plate.

   Solution:

   $\lambda = 5.45 \times 10^{-5}$ cm $\mu = 1.5$

   $X_o = 3\beta$

   Now $X_o = \frac{\beta}{\lambda}(\mu - 1)t$

   $3\beta = \frac{\beta}{\lambda}(\mu - 1)t$

   $\therefore t = \frac{3\lambda}{\mu - 1} = \frac{3 \times 5.45 \times 10^{-5}}{0.5}$

   $= 3.27 \times 10^{-4}$ cm

3. A silica optical fiber has a core refractive index of 1.50 and a cladding refractive Index of 1.47. Determine (a) the critical angle at the core cladding interface (b) The N.A. for the fiber and (C) the acceptance angle in air for the fiber.

   Solution:

   The critical angle, $\phi_c = \sin^{-1}\frac{n_2}{n_1}$

   $= \sin^{-1}\frac{1.47}{1.50} = 78.5°$

   The numerical aperture, N.A.

   $= (n_1^2 - n_2^2)^{1/2}$

   $= (1.50^2 - 1.47^2)^{1/2}$

   $= 0.30$

   The acceptance angle in air, $\phi_{max} = \sin^{-1}$ NA=17.4°

4. Calculate the fotal number of guided modes propagating in the multimode step index fiber having diameter of 50 pm and numerical aperture of 0.2 and operating at a wavelength of 1pm.

   Solution:

   $N = \left[\frac{d \times N.A}{\lambda}\right]^2 4.9$

   $= 4.9\left[\frac{50 \times 10^{-6} \times 0.2}{1 \times 10^{-6}}\right]^2 = 490$

   Hence the fiber can support approximately 490 guided modes. In the case of graded index fiber, the number of modes propagated inside the fiber-$N_{step/2}$ = 245 only