Q.1 Write the characteristics of laser in detail.

—4 The characteristics of laser are:

i) Coherence.

"A fixed relationship between the phase of waves in a beam of radiation of a single frequency." Two beams of light are coherent when the phase difference between their waves is constant.

Since all the constituent (ingredient) photons of laser beam possess the same energy, momentum and propogate in same direction, so the laser beam is highly coherent.

ii) High Intensity.

Due to coherency, the laser has the ability to focus on small area of 10^{-6} m^2 i.e. extremely high concentration of it's energy over a small area.

iii) High Directionality.

An ordinary light source emits light in all possible directions. But, since laser travels as a parallel beam it can travel over a long distance without spreading.

The Angular Speed of laser is 1 mm/meter.

iv) High Monochromaticity.

The light from a normal monochromatic source spreads over a range of wavelength of the

order 100nm. But, the spread is of the order of 1nm for laser. Hence, laser is highly monochromatic (shows single colour) i.e. it can emit light of a single wavelength.

Q.2. Mention various application of laser.

—4 Lasers are used in various applications. The most significant applications ~~are~~ include:

i) Laser in Medicine
- Used for bloodless surgery
- Used to destroy kidney stones
- Used in cancer diagnosis and therapy.
- Used to create plasma.
- Used for eye lens curvature corrections.

ii) Laser in Industries.
- Used to cut glass and quartz.
- Used for Trimming the components of ICs.
- Used to collect the information about the prefixed prices of various products in shops from the bar-code printed on the product.
- Used for heat treatment in automotive industry.
- Ultraviolet lasers are used for photolithography (manufacturing of PCB & microprocessor) in semiconductor industry.

iii) Laser in Communication.
- Used in underwater communication network.
- Used in space communication, radars and satellites.

› Used in optical fiber communications to send information over large distances with low loss.

iii) Laser in Military.

› Used in LIDAR's to accurately measure the distance to an object.

› The laser beam can serve as a war weapon i.e. A powerful laser beam can be used to destroy an object like plane, missiles, etc in seconds, by pointing at them. For this reason, it's also called "Death Ray".

› Used as a secretive illuminators for reconnaissance during night with high precision.

iv) Laser in Science and Technology.

› Used for detecting earthquakes and underwater nuclear blasts.

› Used in Computer printers.

› Helps in determing the rate of rotation of the earth, accurately.

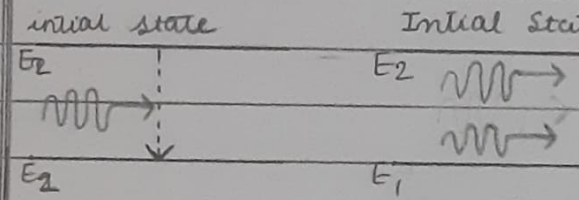
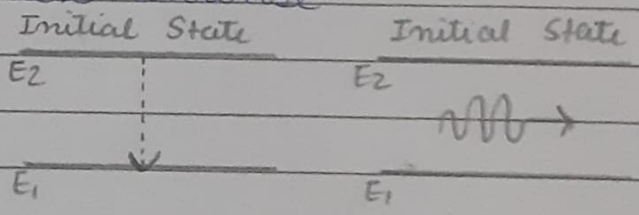
› Helps in studying the Brownian motion of particles

› Helps to count the number of atoms in a substance.

› Used to store large amount of information in CD-ROM.

Q.3 Give any four differences between stimulated emission and spontaneous emission.

—4

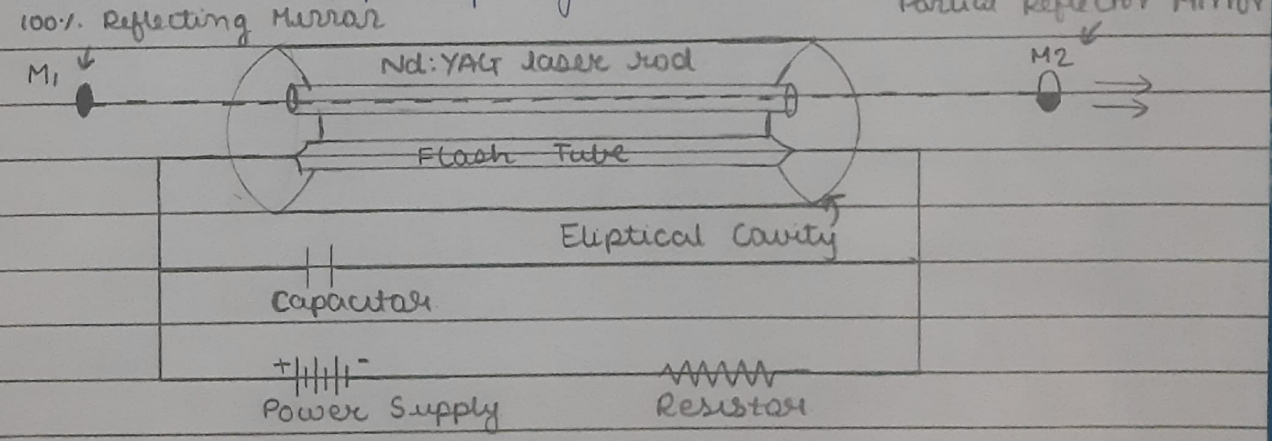
Stimulated Emission	Spontaneous Emission
Emission of a light photon takes place through an inducement i.e. by an external photon	Emission of a light photon takes place immediately without any inducement.
It is a systematic process.	It is a random process.
Monochromatic Radiation	Polychromatic Radiation
More intense	less intense.
	

Q.4 Write a short note on Nd : YAG laser.

—4

Neodymium - doped Yttrium Aluminium Garnet (Nd:YAG) laser is a solid state ~~laser~~ and a four - level laser. It generates laser light commonly in the near infrared region of the spectrum at 1064 nm. (also at 1440 nm, 1320 nm, 1120 nm, and 940 nm).

- Active Medium
Yttrium Aluminium Garnet ($Y_3Al_5O_{12}$), doped with neodymium ions Nd^{+3} is the active medium. The active medium is taken in the form of a crystal and is drawn into a rod. The neodymium ions Nd^{3+} are the active centres.
- Optical Cavity.
The end faces of the Nd YAG rod are ground ~~plo~~ polished and silvered to act as the optical resonator mirrors.
- Optical Pumping.
A Xenon flash tube or Krypton flash tube is used as a pumping source.

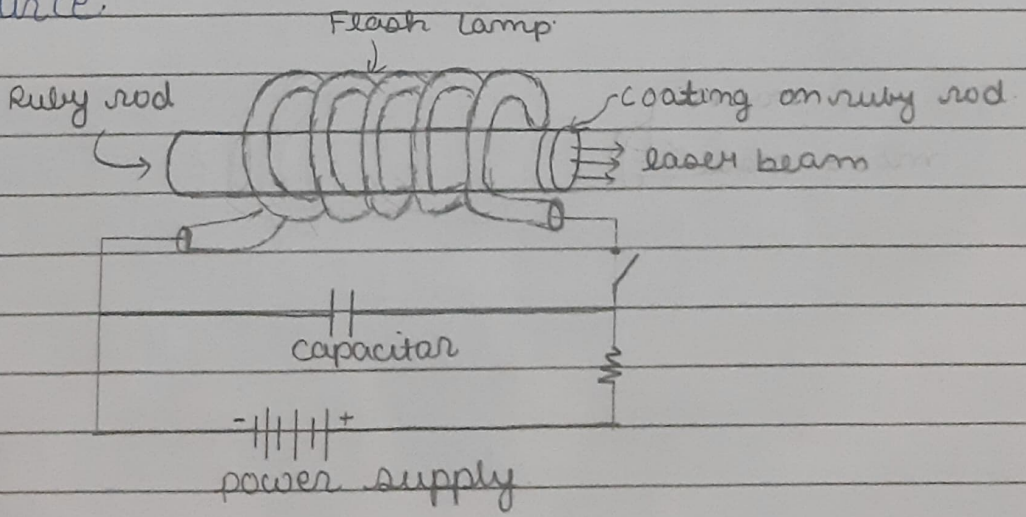


- Applications :-
- Used in long haul communication
- Used in the study of inertial confinement fusion.
- These lasers are widely used for cutting, drilling, welding and surface hardening of the industrial products.

Q.5 Write a short note on Ruby Laser.

—4 A Ruby laser is a solid state laser that uses the synthetic ruby crystal as its laser medium. Ruby laser is the first successful laser developed by Maiman in 1960. Ruby laser is one of the few solid-state laser that produces visible light. It emits red light of wavelength 694.3 nm

In a ruby laser, a single rod of crystal of ruby ($Al_2O_3 : Cr^{3+}$) in the form of cylinder which acts as laser medium. The laser medium in the ruby laser is made of the host of sapphire (Al_2O_3) which is doped with small amounts of chromium ions (Cr^{2+}). In a ruby laser, we use flashtube as the energy source or pumping source.



One end of the cylindrical rod is fully silvered whereas, at another end the mirror is partially silvered. This acts as optical cavity for ruby laser.

Q.6 Justify the sentence: For laser action the necessary condition is $N_2 > N_1$.

—4 In order to achieve more stimulated emission, the population N_2 of the excited state should be made larger than the population N_1 of the lower state. This condition is called population Inversion. It can be achieved by a process called pumping.

$$\frac{\text{Stimulated transition}}{\text{Absorption transition}} = \frac{N_2 B_{21} S(\nu)}{N_1 B_{12} S(\nu)} = \frac{N_2}{N_1}$$

we use here the fact that $B_{21} = B_{12}$.

Q.7. How laser classified based on active medium and pumping method.

—4 Active Medium: A collection of atoms or molecules, which can be excited into a population inversion situation and can have electromagnetic radiation extracted out of it by stimulated emission.

i) Solid-state laser: laser that uses solid as an active medium, eg: ruby, Nd-YAG etc

ii) Gas laser: laser in which electric current is discharged through a gas inside the active medium to produce laser light. eg: CO_2 laser, He-Ne laser.

iii) Liquid laser: laser that uses a liquid as active medium. eg: dye laser.

iv) Semiconductor laser: laser uses a semiconductor as active medium, in which most are electrically pumped

Pumping Method: The process of raising the particles from a lower energy state to a higher energy state.
i) Optically pumped laser
ii) Electrically pumped laser
iii) Chemically pumped laser
iv) Thermally pumped laser.

Q.8 What is full form LASER? Explain absorption with figure in laser.

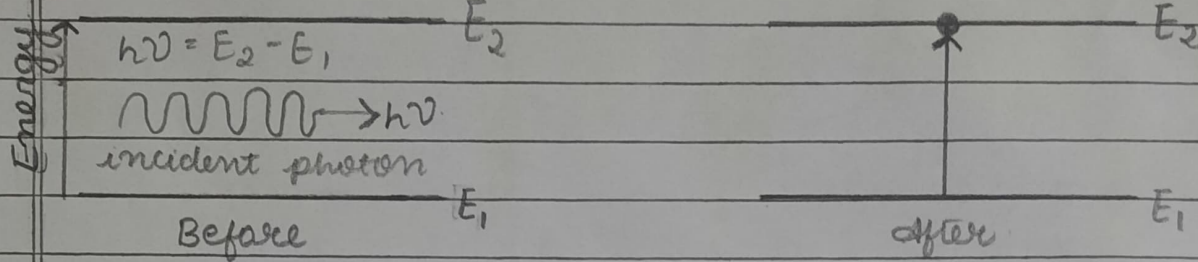
—4 LASER is an acronym of "Light Amplification by Stimulated Emission of Radiation".

Absorption: When a photon (or light) is incident on atoms then that atoms absorbs the energy from the photon and jump from a lower energy state to a higher energy state. This transition is called absorption.

For example, suppose an atom is in the lower energy E_1, if a photon of energy (E_2-E_1) is incident on the atom, it imparts its energy to the atom and disappears. Then we say that the atom absorbed the incident photon. As a result of absorption of adequate energy, the atom jumps to excited state E_2.
We may express the process as,

$$A + h\nu = A^*$$

where A is an atom in lower state and A^* is an excited atom.



The probability that absorption transition occurs is proportional to the photon density $S(\nu)$.

$$P_{12} \propto S(\nu)$$

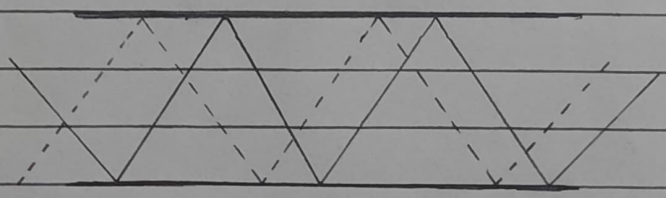
$$P_{12} = B_{12} S(\nu)$$

where B_{12} is the constant of proportionality.

Q.9 Explain ~~sig~~ single mode optical fiber and multimode optical fibre.

→ Single Mode Optical Fiber

An Optical fiber that is used to transmit over longer distances. It is a single glass fiber strand used to transmit a single mode or ray of light.

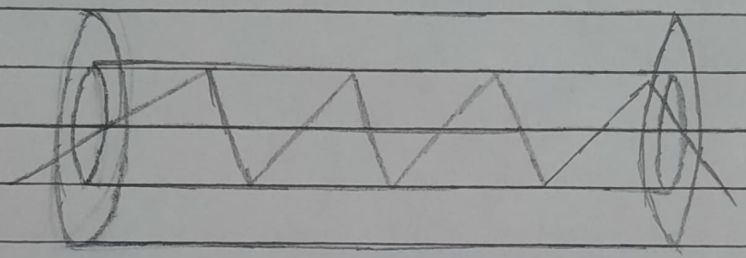


SMF has very small diameter and can support only one mode of propogation. It can carry only one wavelength of light across its length. This wavelength is usually between 1310 nm to 1550 nm. But it has higher bandwidth (1000 MHz) and used for high speed communication as there is no loss of intensity of light signals.

They show no dispersion effect. They are highly efficient and having V number (The normalized frequency parameter of a fiber) is less than 2.405.

Multimode Optical Fiber

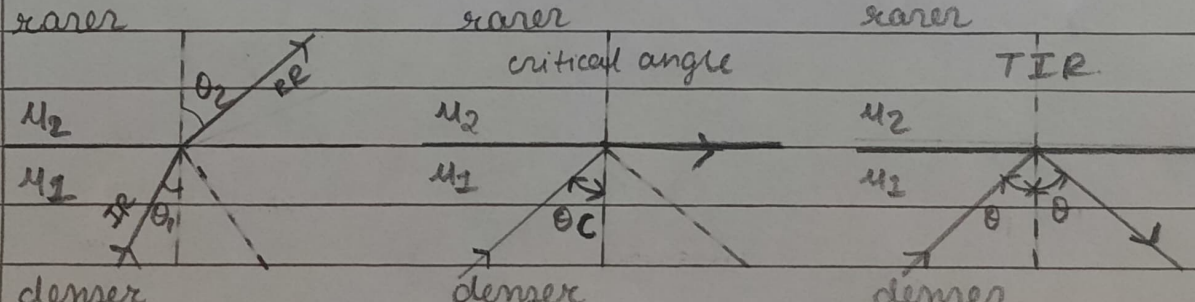
Optical fiber designed to carry multiple light rays or modes simultaneously, each at a marginally different reflection angle inside the optical fiber core.



MMF has larger core diameter and can support large no. of mode of propogration. The wavelength of light waves in MMF are in visible spectrum range of 850 nm to 1300 nm.

Q.10 What is the principale of ~~laser~~ optical fiber? Also, what is relation between numerical aperature and acceptance angle?

—4 "Total Internal Reflection" is the principle on which optical fiber is based on.



The phenomenon which occurs when the light rays travel from a ~~denser~~ optically denser medium to optically rarer medium, so that the light ray bends away from the normal is called total internal reflection. $\left(\frac{n_1}{n_2} = \frac{\sin r}{\sin i}\right)$

According to Snell's Law,

$$\sin\theta_2 = \left(\frac{\mu_2}{\mu_1}\right)\sin\theta_1$$

if $\theta_1 < \theta_c$, the ray reflects into rarer medium
if $\theta_1 = \theta_2$, the ray just grazes the interface of rarer to denser medium.
if $\theta_1 > \theta_c$, the ray is reflected back into the denser medium.

when $\theta_1 = \theta_c$, $\theta_2 = 90^\circ$

$$\mu_1 \sin\theta_c = \mu_2 \sin 90^\circ = \mu_2$$

$$\therefore \sin\theta_c = \frac{1}{\mu}$$

Relation between numerical ~~operator~~ aperature and acceptance angle.

The numerical aperature is defined as the sin of the acceptance angle.

Numerical aperature = $\sin\theta_a$

$$[NA = \sin\theta_a]$$

Q.11 Calculate the refractive indices of the core and cladding material of a fiber. (Given, NA = 0.22 and relative refractive index difference is 0.012).

—Y Numerical aperature is mathematically defined as $\sqrt{\mu_1^2 - \mu_2^2}$; where μ_1 = Refractive index of the core, μ_2 = Refractive index of the cladding.

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$$\text{So, } \quad 0.22 = \sqrt{\mu_1^2 - \mu_2^2}$$

$$\therefore (0.22)^2 = \mu_1^2 - \mu_2^2$$

$$\therefore 0.484 = (\mu_1 - \mu_2)(\mu_1 + \mu_2) \quad \text{— ①}$$

Now, fractional refractive index change $= \frac{\mu_1 - \mu_2}{\mu_1}$

$$\therefore 0.012\,\mu_1 = \mu_1 - \mu_2$$

$$\therefore \mu_2 = 0.988\,\mu_1 \quad \text{— ②}$$

Substituting the value of μ_2 from eq ② to eq ①.

$$\therefore 0.484 = (\mu_1 - 0.988\,\mu_1)(\mu_1 + 0.988\,\mu_1)$$

$$\therefore 0.484 = 1.988\,\mu_1 \text{ 3X } 0.012\,\mu_1$$

$$\therefore \mu_1^2 = 2.029$$

$$\therefore \boxed{\mu_1 = 1.424}$$

Now, $\mu_2 = 0.988\,\mu_1$

$$\therefore \mu_2 = 0.988\,(1.424)$$

$$\therefore \boxed{\mu_2 = 1.407}$$

Q.12 An Optical fiber has a numerical aperature of 0.20 and a cladding refractive index of 1.55. Determine the acceptance angle for the fiber in water has a refractive index 1.33.

—ↄ $NA = 0.20 \quad \mu_0 = 1.33$

$$\therefore NA = \mu_0 \sin\alpha.$$

$$\therefore 0.20 = 1.33 \sin\alpha$$

$$\therefore 0.150 = \sin\alpha$$

$$\therefore \alpha = \sin^{-1}(0.150)$$

$$\therefore \boxed{\alpha = 8.626^\circ}$$

Q.13 Explain step index fibre and graded index optical fibre. An optical fibre core and cladding have refractive indexes of 1.545 and 1.495.

—4. Step Index Fibre

A step index fibre has a very thin fine core of 8 μm to 12 μm. It is usually made of germanium doped silicon. The core is surrounded by a thick cladding of lower refractive index. The fibre is surrounded by a opaque protective sheet. The refractive index of the fiber changes abruptly at the core - cladding boundary.

Graded Index Fibre.

It is a multimode fiber with a core consisting of concentric layers of different refractive indexes. Therefore, refractive index of the core varies with distance from the fiber axis

$\therefore \sin\theta_c = \frac{\mu_2}{\mu_1} = \frac{1.495}{1.545} = 0.96 \Rightarrow \boxed{\theta_c = 75^\circ}$

$\therefore \sin\theta_i = \sqrt{\mu_1^2 - \mu_2^2} = \sqrt{(1.545)^2 - (1.495)^2} = 0.38.$

$\therefore \theta_i = \sin^{-1}(0.38)$

$\therefore \boxed{\theta_i = 22.33^\circ}$

$NA = \sin\theta_i = \sqrt{\mu_1^2 - \mu_2^2}$

$\therefore \boxed{NA = 0.38}.$

Q.14 The refractive index of the core and cladding materials of an ~~opp~~ optical fiber are 1.54 and 1.5 respectively. Calculate the numerical aperture of the optical fibre.

—4 Numerical Aperature (NA) of a fiber is defined as the sine of the largest angle an incident ray can have for total internal reflectance in the core. For an optical fibre with index of core n_1 and indere of cladding n_2, its numerical aperture is, $NA = \sqrt{n_1^2 - n_2^2}$.

Now, $n_1 = 1.54$ $n_2 = 1.5$

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

$$\therefore NA = \sqrt{(1.54)^2 - (1.5)^2}$$

$$\therefore NA = \sqrt{2.3716 - 2.25}$$

$$\therefore NA = \sqrt{0.1216}$$

$$\therefore \boxed{NA = 0.348.}$$