Introduction about LASER

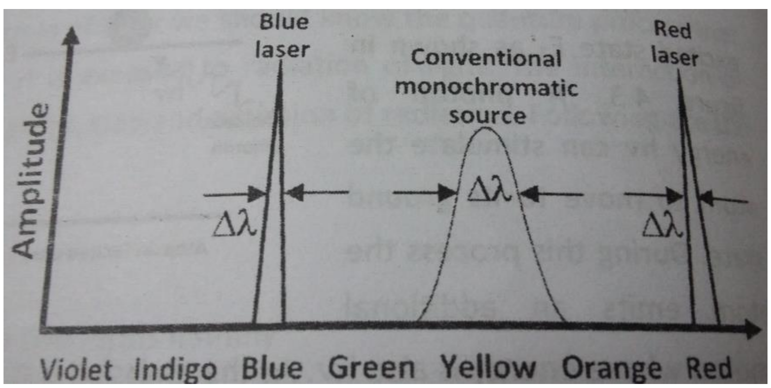
The word LASER is an acronym for "Light Amplification by Stimulated Emission of Radiation". It is a powerful monochromatic light source of collimated beam in which the light waves are highly coherent. The laser light has many superior features compared to conventional light source. Einstein introduced this concept in 1917. Dr. T.H. Maiman demonstrated the first laser namely theruby laser in the year 1960.

Laser characteristics:

Laser differs from the ordinary light with respect to some properties. They are

- Monochromaticity
- Directionality
- Coherence
- Intensity

Monochromaticity

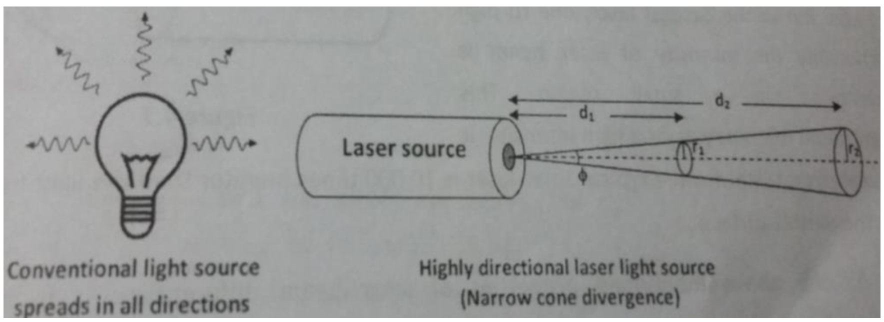


Laser beam is highly monochromatic. It emits single wavelength (one colour). i.e, it possesses good spectral purity since range of laser beam wavelength ($\Delta\lambda$) is very narrow. But ordinary light emits combination of wide range of wavelength (colours).

Directionality

The ordinary source emits light in all directions and its angular spread is 1 metre/metre. But the laser is highly directional and its angular spread is 1mm/metre. The angular spread (ϕ) or divergence is given by,

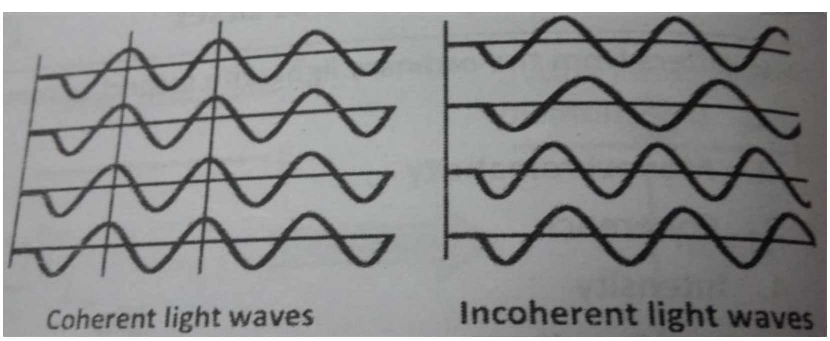
$$\phi = \frac{r_2 - r_1}{d_2 - d_1} \text{ degree}$$



where d_1, d_2 are any two distances from the laser source emitted and r_1, r_2 are the radii of the beam spots at a distance d_1 and d_2, respectively.

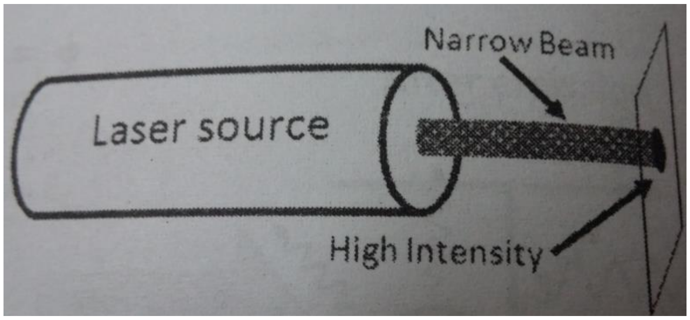
Coherence

The light from a source consists of wave pattern. These wave patterns when identical in phase and direction are called coherent. Laser has a high degree of coherence than the ordinary sources. The coherence of laser emission results in an extremely high power of 5×10^6 watt/m^2. A laser beam can be focused to a very small area of about 0.7 μm diameter.



Intensity

The ordinary light spreads in all directions, so the intensity reaching the target is very less. But in the case of laser, due to high directionality the intensity of laser beam is concentrated in a small region. This concentration of energy gives a high intensity. It is estimated that light from a typical 1mW laser is 10,000 times brighter than the light from the sun at the earth's surface.



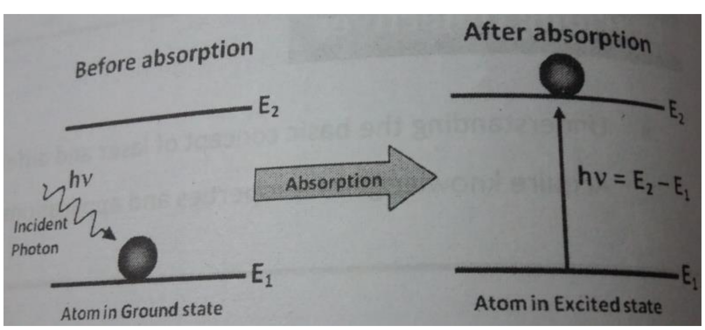
Ground state and Excited states:

Laser emission is shaped by the rules of quantum mechanics, which limit atoms and molecules to having discrete amounts of stored energy that depend on the nature of the atom or molecule. The lowest energy level for an individual atom occurs when its electrons are all in the nearest possible orbits to its nucleus (*see* electronic configuration). This condition is called the **ground state**. When one or more of an atom's electrons have absorbed energy, they can move to outer orbits, and the atom is then referred to as being "**excited.**" Excited states are generally not stable; as electrons drop from higher-energy to lower-energy levels, they emit the extra energy as light.

Principles of laser

Absorption of radiation

An atom is in the ground state with energy E_1 absorbs a photon of energy hν and goes to the excited state with energy E_2 as shown in Fig. This transition is known as stimulated absorption or induced absorption or simply absorption. Here the energy difference is given as $(E_2 - E_1) = h\nu$.



If there are many number of atoms in the ground state then each atom will absorb the energy from the incident photon and goes to the excited state then,

The rate of absorption (R_{12}) is proportional to the following factors

(i.e) $R_{12} \propto$ Energy density of incident radiation (ρ_v)

$\propto$ No. of atoms in the ground state (N_1)

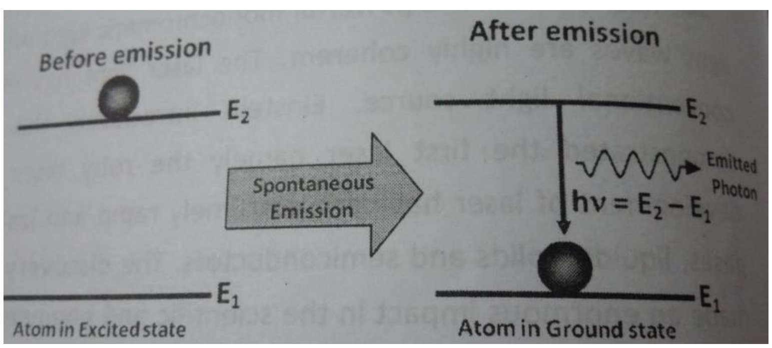
$$\boxed{R_{12} = B_{12}\ \rho_v\ N_1}$$

$$R_{12} \propto \rho_v\ N_1$$

where B_{12} is a constant which gives the probability of absorption transition per unit time

Spontaneous emission

The natural tendency of an atom is to seek out the lowest energy configuration. The excited atoms do not stay in the excited state for longer time but tend to return to the lower state by giving up the excesses energy hν as shown in fig. The atom in the excited state E_2 returns to the ground state E_1 by emitting a photon of energy hν without any external energy. Such emission of radiation not initiated by any external influence is called spontaneous emission. This emission is uncontrollable.



The rate of spontaneous emission R_{21} (Sp)

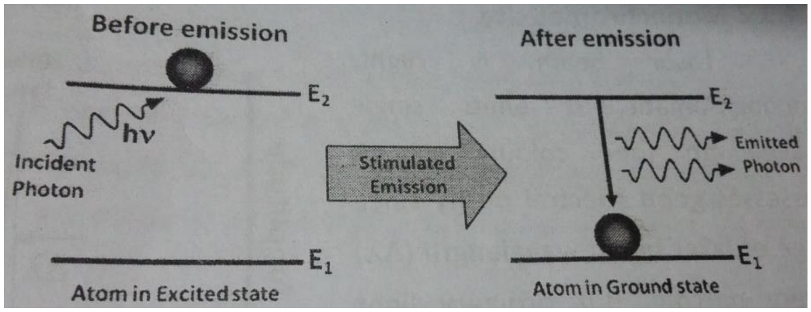
(i.e) R_{21} (Sp) $\propto$ N_2

$$\boxed{R_{21}\ (Sp) = A_{21}N_2}$$

where A_{21} is a constant which gives the probability of spontaneous emission transitions per unit time

Stimulated emission

The atom in the excited state E_2 as shown in fig.--. A photon of energy hν can stimulate the atom to move to its ground state. During this process the atom emits an additional photon whose energy is also hν. As the emission is stimulated by external photon, this process is known as stimulated emission.



The rate of stimulated emission R_{21} (St) is given by

(i.e) $R_{21} (St) \propto \rho_\nu N_2$

$$\boxed{R_{21} (St) = B_{21} \rho_\nu N_2}$$

where B_{21} is a constant which gives the probability of stimulated emission transitions per unit time

Einstein's theory of stimulated emission

Einstein's theory of absorption and emission of light by an atom is based on Planck's theory of radiation. Also under thermal equilibrium, the population of energy levels obeys the Bolzmann's distribution law.

At thermal equilibrium,

The rate of absorption = The rate of emission

$$B_{12} \rho_\nu N_1 = A_{21}N_2 + B_{21} \rho_\nu N_2 \quad \text{--------------------------} \quad (1)$$

$$\rho_\nu [B_{12} N_1 - B_{21} N_2] = A_{21}N_2$$

$$\rho_\nu = \frac{A_{21}N_2}{B_{12}N_1 - B_{21}N_2}$$

$$\rho_\nu = \frac{A_{21}}{B_{12}(N_1/N_2) - B_{21}} \quad \text{----------------------} \quad (2)$$

We know from Bolzmann distribution law

$N_1 = N_0\, e^{-E1/K_B T}$

$N_2 = N_0\, e^{-E2/K_B T}$

Where, K_B is the Bolzmann constant,

T is the absolute temperature and

N_0 is the number of atoms at absolute zero

At equilibrium, we can write the ratio of population as follows,

$$\frac{N_1}{N_2} = e^{(E2 - E1)/K_B T}$$

since $E_2 - E_1 = h\nu$, we have

$$\frac{N_1}{N_2} = e^{h\nu/K_B T} \text{ -- } (3)$$

Sub (3) in (2) we have,

$$\rho_\nu = \frac{A_{21}}{B_{12}(e^{h\nu/K_B T}) - B_{21}}$$

$$\rho_\nu = \frac{A_{21}}{B_{21}} \frac{1}{(B_{12}/B_{21}\, e^{h\nu/K_B T}) - 1} \text{ ------------------------------ } (4)$$

This equation has a very good agreement with Planck's energy distribution radiation law,

$$\rho_\nu = \frac{8\pi h \nu^3}{c^3} \frac{1}{e^{h\nu/K_B T} - 1} \text{ --------------------------------- } (5)$$

Therefore comparing equations (4) and (5),

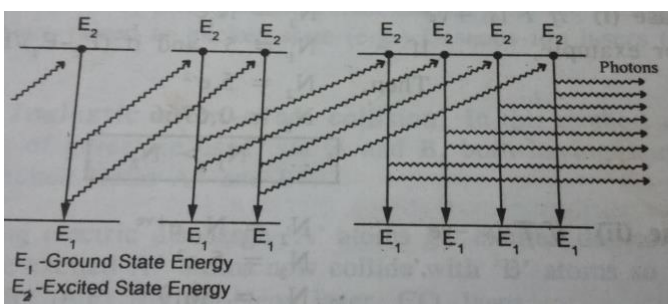
$$B_{12} = B_{21} = B \quad \text{and} \quad \frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3}$$

Taking $A_{21} = A$, *The constants A and B are called as Einstein coefficients.*

S. No	Stimulated emission	Spontaneous emission
1.	An atom in the excited state is induced to return to ground state, thereby resulting in two photons of same frequency and energy is called stimulated emission.	The atom in the excited state returns to ground state thereby emitting a photon, without any external inducement is called spontaneous emission.
2.	The emitted photons move in same direction and are highly directional.	The emitted photons move in all directions and are random.
3.	The radiation is high intense, monochromatic and coherent.	The radiation is less intense and is incoherent.
4.	The photons are in phase.	The photons are not in phase.
5.	The rate of transition is given by R_{21} (St) = $B_{21}\,\rho_\nu\,N_2$	The rate of transition is given by R_{21} (Sp) = $A_{21}N_2$

Light amplification

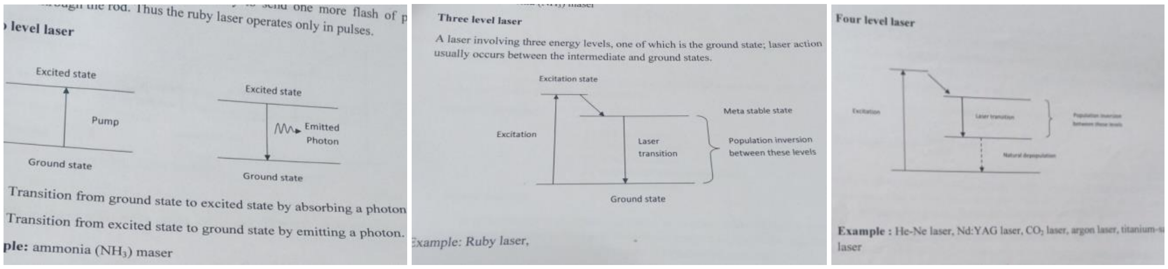
Let us consider many numbers of atoms in the excited state. We know the photons emitted during stimulated emission have same frequency, energy and are in phase as the incident photon. Thus results in 2 photons of similar properties. These two photons induce stimulated emission of 2 atoms in excited state thereby resulting in 4 photons. These 4 photons induce 4 more atoms and give rise to 8 photons etc., as shown in Fig.



Principle: Due to stimulated emission the photons multiply in each step giving rise to an intense beam of photons that are coherent and moving in the same direction. Hence the Light is Amplified by Stimulated Emission of Radiation, termed as LASER.

Energy levels:

A population inversion can be produced in a laser through two basic mechanisms, either by creating an excess of atoms or molecules in a higher energy state, or by reducing the population of a lower energy state. This topic explores meta-stable states for both three-level and four-level laser systems.



Population inversion:

When a system is in thermal equilibrium, the distribution of energy states at a given temperature follows the Boltzmann's law as

$$N = N_0 e^{\left(\frac{-E}{KT}\right)}$$

where,

N_0 is the population in the ground state

N is the population in the given energy state

K is the Boltzmann's constant

T is the absolute temperature

From the above equation, it is clear that the population is maximum in ground state and decreases exponentially as one goes to higher energy state as shown in fig. 4(a). ie., $N_1 > N_2$.

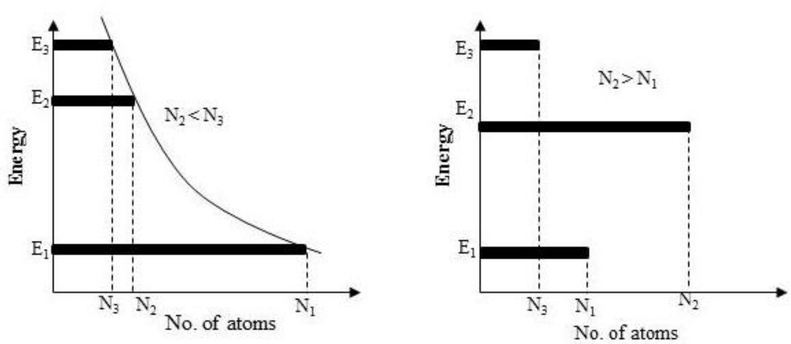


Fig. 4 (a) population at different energy states of atoms (b) population inversion through pumping process

If the situation is just reverse, ie there are more atoms in an excited state than the ground state as shown in fig 4 (b), a net emission of photons can result. **This condition is called population inversion. In this case $N_2 > N_1$.**

Meta stable state

It is an excited state of an atom with a longer life time than the other excited states. However it has a shorter life time than the stable ground state. Atoms in the metastable state remain excited for a considerable time in the order of 10^{-6} to 10^{-3} s.

Active Medium

The active laser medium consists of a collection of atoms, molecules or ions. The excited state of the active laser medium has a meta stable state having longer lifetime ($\approx 10^{-8}$ sec) compared to excited states which usually have short life times.

Conditions required for Laser action:

(a) Population inversion should be achieved.

(b) Stimulated emission should be predominant over spontaneous emission.

Pumping methods

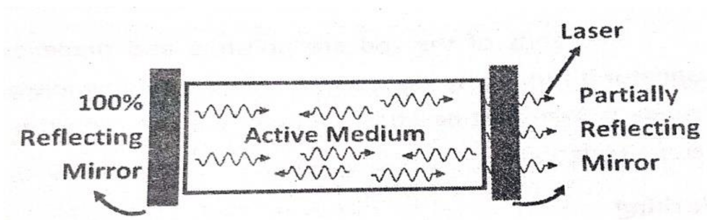
The process of achieving population inversion is called pumping. Pumping can be classified into the following types based on the type of source of pumping.

1. **Optical pumping**: Here the atoms are excited with the help of photons emitted by an optical source. The atoms absorb energy from the photons and raises to excited state. (e.g.) Ruby Laser, Nd-YAG Laser
2. **Electrical pumping**: The electrons are accelerated to very high velocities by strong electric field and they collide with gas atoms and these atoms are raised to excited state. (e.g.) Argon Laser, CO_2 Laser
3. **Direct Conversion**: Due to electrical energy applied in direct band gap semiconductor like GaAs etc., the combination of electrons and holes takes place and electrical energy is converted into light energy directly. (e.g) Semiconductor Laser.
4. **Inelastic collision between atoms**: During electric discharge "A" atoms get excited due to collision with electrons. The excited A* atoms now collide with "B" atoms so that B goes to excited state B* (e.g.) He – Ne Laser.

5. **Chemical pumping**: Due to some chemical reactions, the atoms may be raised to excited state. (e.g.) Dye Laser.

Optical resonator

The optical resonator contains a pair of reflecting surfaces of which one is fully reflecting and the other partially reflecting. The active material is kept in between the two reflecting surfaces. Photons(light) emitted due to transitions between the energy states of the active material are bounced back and forth between the two reflecting surfaces, so the intensity of the light is increased enormously. Finally the intense amplified beam called laser is coming out through the partial mirror as shown in the diagram.



Types of LASERS

1. Solid state laser : It is classified into two types (a) 3 level laser (e.g) Ruby laer, (b) 4 level laser (e.g) Nd-YAG laser
2. Gas laser: Egs. : CO2 laser, He-Ne laser
3. Semiconductor laser : Egs. GasAs
4. Liquid laser : Eg; Europium benzoyl acetone dissolved in alcohol.
5. Dye laser and chemical lasers.

Nd:YAG LASER (The Neodymium: yttrium- aluminium- garnet (Nd:YAG) laser)

Nd:YAG laser is a solid state laser in which lasing medium is obtained by embedding Nd^{3+} ions in YAG ($Y_3Al_5O_{12}$) crystal. The crystalline host, in general, is doped with around 1 % of neodymium by atomic percent. Krypton flash lamp is used for optical pumping. Instrumentation arrangement is shown in fig (1). Laser operation of Nd:YAG was first demonstrated by Geusic et.al. at Bell laboratories.

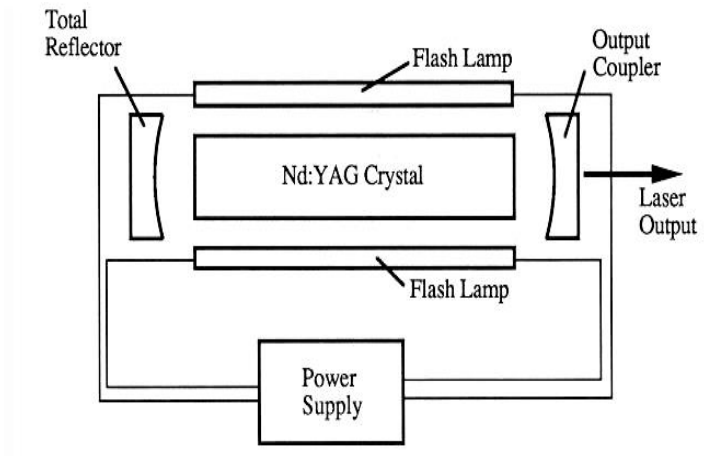


Fig. (1) schematic diagram of Nd:YAG laser

The energy level structure and laser transition in Nd:YAG laser are shown in fig (2). Nd:YAG laser is optically pumped using a flash lamp or laser diodes. Flash lamp pumping is possible due to the broadband pump absorption mainly in the 0.8 μm region and the four level characteristics. The krypton flash lamp emits most of its output light in the infrared region and of the absorption bands of Nd:YAG and, therefore, it is the best spectral match.

Nd^{3+} ions in the ground state absorb photons and are raised in energy to one of the pump bands. The state of lifetimes of the order of 10^{-8}sec, and the atoms quickly drop to the upper lasing level by radiation less transition. The upper lasing level, has a fluorescent lifetime of about 0.3ms. The population inversion develops and lasing occurs, with the atoms dropping to the lower lasing level. This level is very close to the ground state, and excited atoms rapidly return to the ground state by another radiationless transition. So, laser action is usually obtained between the levels E_3 and E_2 at a wavelength of about 1.06 μm in the infrared region.

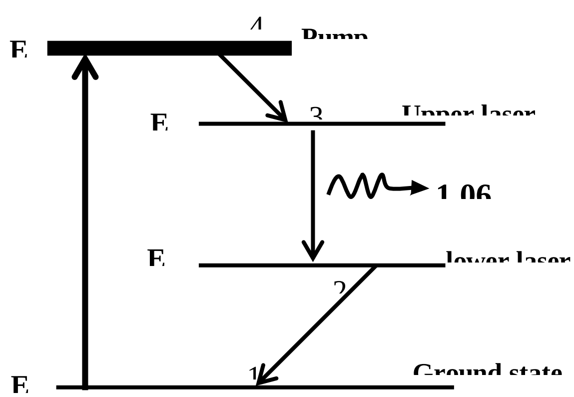


Fig.(2) energy level diagram of Nd:YAG laser

- **Advantages:**
- Output energy is very high
- Repetition rate is very high
- Population inversion is easily achieved
- Excitation can be easily achieved by lower threshold energy.
- **Disadvantage:**
- The electron energy level structure of Nd3+ in YAG is complicated
- **Applications:**
- Nd:YAG laser have wide range of applications.
- In industry they are used for material processing: drilling, spot welding and laser marking
- Medical applications include many types of surgery, such as memberane cutting, gall – bladder surgery
- It is used to study laser induced fusion reactions

SEMICONDUCTOR LASER

A semiconductor is a typically fabricated p-n junction diode which emits coherent light when it is forward biased. The active medium in a semiconductor laser is formed by heavily doping p and n type material hence the semiconductor laser is also called diode laser or injection laser. There are two types of semiconductor lasers,

1.Homojunction Laser : P and N regions are made upof the same semiconductor.
Example: Gallium Arsenide(Ga As)

2.Heterojunction Laser : One side of the junction differs from the other side of the junction.
Example: Ga Al As is grown on Ga As

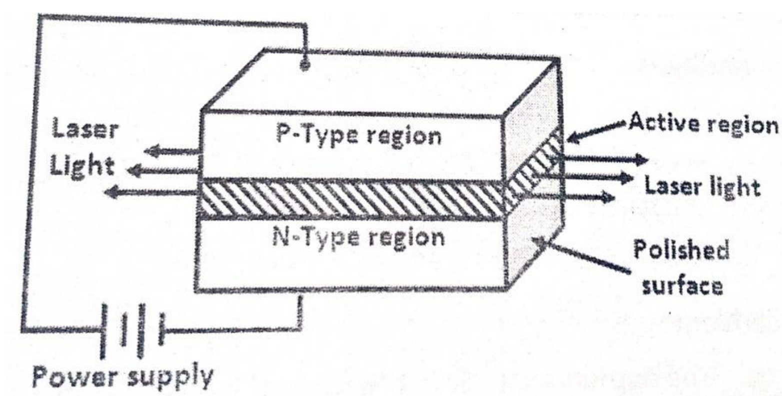
Homo junction Semiconductor Laser

A semiconductor diode is a specifically fabricated pn-junction device that emits laser light when it is a forward biased.In a certain semiconductor like Ga As,when the junction is forward biased electron from n-region and holes from p- region recombines with each other at the junction.

During recombination process, light energy is released form this radiation of energy is called recombination radiation and the corresponding energy is called activation energy. The wavelength of the light emitted depends on the activation energy. The photon emitted during recombination stimulates other charges and as a result, stimulated emission takes place.

Construction

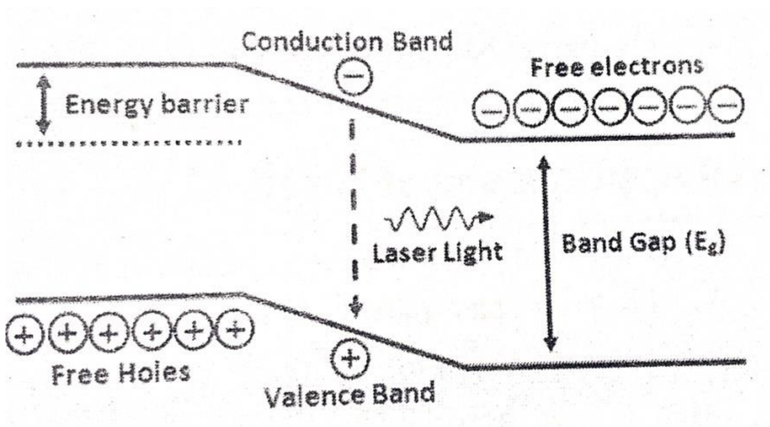
The basic construction of the semiconductor laser is shown in figure. The active medium is a pn-junction diode made from a single crystal of gallium arsenide (Ga As). It is cut in the form of a plate having narrow thickness (0.5mm) so that the emitted laser radiation has larger divergence. The end faces of the junction diode are well polished and parallel to each other. Since the refractive index of Ga As is high it acts as optical resonator through which the emitted light will come out. The upper and lower electrodes fixed in the "p" and 'n' region helps to supply current to the diode.



Working

The energy level diagram of the semiconductor laser is shown in the diagram. The p-n junction is forward biased with large applied voltage. The electrons and holes are injected into junction region. The region around the junction contains large amount of electrons within the conduction band and large amount of holes in the valence band. If the population density is high, the population inversion is achieved. The electron and holes recombine each other and produce radiation in the form of light.

When forward biased voltage is increased, more and more light protons are emitted and light instantly becomes stronger. These photons can trigger a chain of stimulated recombination resulting in the release of photons in phase. The photon moving at the plane of junction travels back and forth by reflection between the two polished sides. After gaining enough strength, it comes out as th user beam. The output wavelength is given by



$$\chi = \frac{hc}{E_g}$$

Where, for Ga As, Eg=1.44 ev and the output wavelength emitted by a diode made up of

$$\chi = \frac{6.626\times 10{-}34\times 3\times 10^{8}}{1.44\times 1.6\times 10^{19}} = 8626Å$$

The wavelength is near IR region.

Advantages

1. It is very small in size.
2. It exhibits high efficiency.
3. It consumes low power.
4. It requires very little auxiliary equipment.

Disadvantages

1. The output is usually in the form of a wide beam
2. It is mostly monochromatically is poorer than the other types of laser.

Applications

1. It is mostly used in fibre optic communications.
2. It is used to heal the wounds by means of infrared radiation.
3. It is used in computer printers and CD drives.

LASER Cutting

Laser is used as a tool to cut thin metal sheets by properly focusing the laser onto any particular area to be cut, for a longer time. Thus due to thermal effect the sheet is cut.

LASER Welding

In ordinary welding process the heat will be made to fall on the area to be welded, so that the material in that area will go to molten state. This on cooling will join the material. In this process the heat will spread all over the surroundings and will affect the other area of the material and hence the material gets damaged. This damage can be avoided by using laser welding. In laser welding the beam is focused onto the area to be welded and other areas remain unaffected. Without affecting the material the area to be welded alone melted and joined.

LASERS in Industry

Using high power lasers we can weld or melt any material. We can produce very small holes that cannot be done by mechanical drilling. Lasers can be used for cutting and for testing the quality of the materials. During laser welding and drilling there is no damage the structure of the materials. Lasers can be used for surface hardening techniques.

MEDICAL APPLICATIONS OF LASERS

Laser cosmetics surgery is used for removing tattoos, scars, stretch marks, sunspots, wrinkles and hairs.

1. Laser types used in dermatology:

It include Ruby (694nm), pulsed diode arrays (810nm), Nd: YAG (1064nm) and Er : YAG (2940nm)

2. Laser eye surgery:

   Laser eye surgery is a medical procedure that uses a laser to reshape a surface of the eyes. This is done to correct short sightedness, long sightedness and astigmatism (uneven curvature of the eye surface).

3. Soft- Tissue surgery:
   a. In soft tissue laser surgery, a highly focused laser beam vapourises the soft tissue with the high water content
   b. Soft tissue laser surgery is used in a variety of applications which include general surgery, neuro surgery, ENT, dentistry and oral surgery.
   c. Soft tissue laser surgery is also used in veterinary surgical fields.

4. Laser light therapy

   Laser light therapy involves exposure to laser light of specific variant. The light is administered for a prescribed amount of light. This is commonly used for skin diseases and disorders.

5. Laser is widely used for no-touch removal of tumors, especially of the brain and spinal cord
6. In dentistry, laser is used for tooth whitening and carries removal.

LASER SURGERY

A type of surgery that uses the cutting power of a laser beam to make bloodless cuts in tissue or remove a surface lens such as a skin tumor. There are a number of different types of lasers that differ in emitted light wavelengths and power ranges and in their ability to clot, cut or vapourise tissue. Among the commonly used lasers are pulsed dye laser, the YAG laser, the CO_2 laser and the argon laser.

Model Questions

1. What are coherent sources?
2. Distinguish between spontaneous and stimulated emission?
3. List out the characteristics of LASER.
4. What is meant by Spontaneous emission?
5. What is meant by stimulated emission?

6. What is meant by population inversion?
7. What is meant by pumping?
8. What are different methods of pumping?
9. What are the conditions required for laser action?
10. What are Einstein‘s coeffecients?
11. Define active medium.
12. Explain inelastic atom-atom collision.
13. What is meant by Optical resonator or Resonance cavity?
14. Give some applications of laser in medical field.
15. Give the applications of laser in industry.
16. Describe the construction and working of Nd: YAG.
17. What are the medical applications of lasers?
18. Explain the modes of vibrations of CO_2 molecule. Describe the construction and working of CO_2 laser with necessary diagrams.
19. Derive Einstein’s relation for stimulated emission and hence explain the existence of stimulated emission.
20. Discuss with theory the construction and working of homojunction semiconductor laser.
21. Discuss the applications of laser in various fields.

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FIBRE OPTICS

Introduction

Fiber optics deals with the light propagation through thin glass fibers. Fiber optics plays an important role in the field of communication to transmit voice, television and digital data signals from one place to another. The transmission of light along the thincylindrical glass fiber by total internal reflection was first demonstrated by John Tyndallin 1870 and the application of this phenomenon in the field of communication is tried only from 1927. Today the applications of fiber optics are also extended to medical field in the form of endoscopes and to instrumentation engineering in the form of opticalsensors.

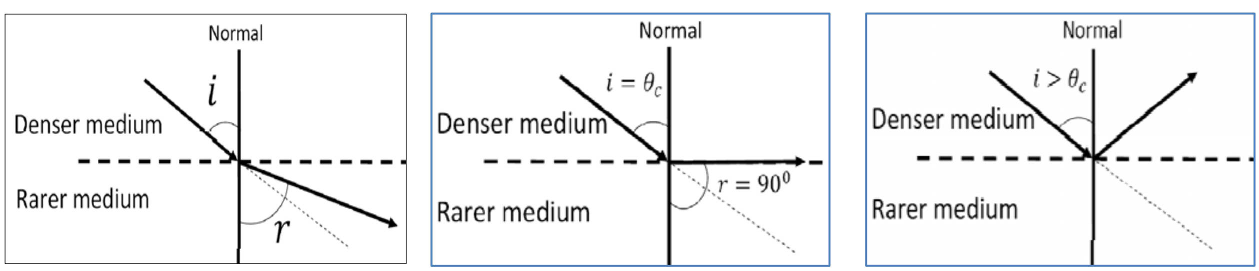
1. Principle of working of optical fiber/ Total Internal Reflection:

Principle:
The basic principle of optical fiber in the transmission of optical signal is total internal reflection.

Total internal reflection:-

When the light ray travels from denser medium to rarer medium the refracted ray bends away from the normal. The angle of incidence at which the refracted ray makes angle of refraction 90 with the normal then the angle of incidence is called as critical angle. When the angle of incidence is greater than the critical angle, the refracted ray reflects (refraction angle greater than 90 then it becomes reflection) into the same medium. This phenomenon is called ***total internal reflection.***

The refracted ray bends towards the normal as the ray travels from rarer mediumto denser medium. The refracted ray bends away from the normal as it travels from denser medium to rarer medium.



Let, a light ray traveling from denser medium (refractive index n_1) to rarer medium (refractive index n_2) with an angle of incidence $\boldsymbol{i}$, then the angle of refraction $\boldsymbol{r}$ can be obtained by Snell's law.

$$n_1 \, Sin\, i = n_2 \, Sin\, r$$

When the angle of incidence is increased angle of refraction also increases and for a particular angle of incidence ($\boldsymbol{i}$=$\boldsymbol{\theta_c}$) the refracted ray travels along the interface of two mediums(ie; angle of refraction is 90). This angle of incidence is known as ***Critical Angle ($\boldsymbol{\theta_c}$).***

$$n_1 \, Sin\, \theta_C = n_2 \, Sin\, 90$$

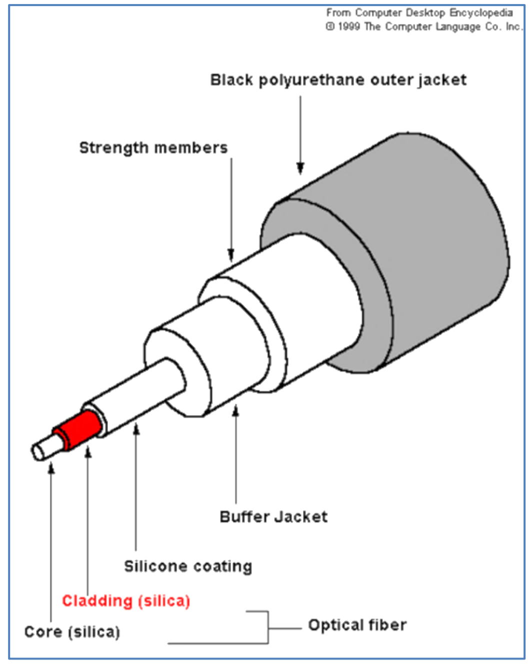
$$n_1 \, Sin\, \theta_C = n_2 \;\; \Rightarrow Sin\, \theta_C = {n_2}/{n_1}$$

$$\theta_C = Sin^{-1}\left(\frac{n_2}{n_1}\right)$$

When the angle of incidence is greater than the critical angle ($\boldsymbol{i}$=$\boldsymbol{\theta_c}$), the incident ray reflects back into the same medium. This phenomenon is called Total Internal Reflection (TIR).

2. Construction of optical fiber:-

The optical fiber mainly consists the following six parts as shown in figure



Core:

The core is a transparent inner most part of highest optical density material that carries light. Its diameter is of the order of 9 µm to 100 µm. The core is made by glass and plastic materials.

Cladding:

The core of the fiber is surrounded by a transparent material is called as cladding. Its refractive index is lower than the refractive index of the core material. The diameter of cladding is from 125 µm to 200 µm. For cladding glass and plastics are used.

Silicon Coating:

Silicon coating is provided between buffer jacket and cladding. It improves the quality of transmission of light.

Buffer Jacket:

Silicon coating is surrounded by buffer jacket. Buffer jacket is made of plastic andprotects the fiber cable from moisture.

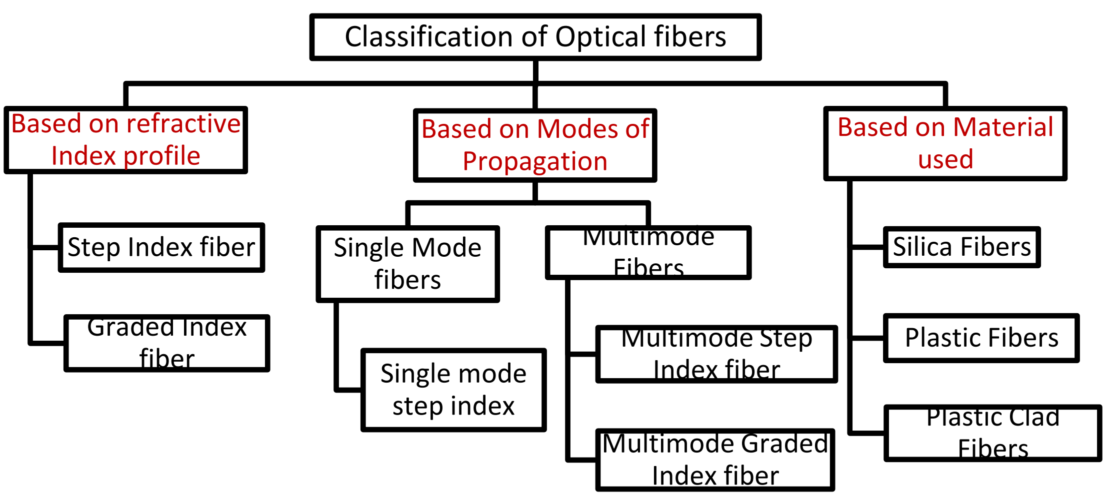
Strength Member:

Buffer jacket is surrounded by strength member. It provides strength to the fibercable.

Outer Jacket:

Finally the fiber cable is covered by polyurethane outer jacket. Because of this arrangement fiber cable will not be damaged during pulling, bending, stretching and rolling though the fiber cable are made up of glasses.

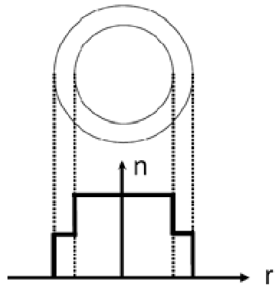
3. Classification of fibers:-

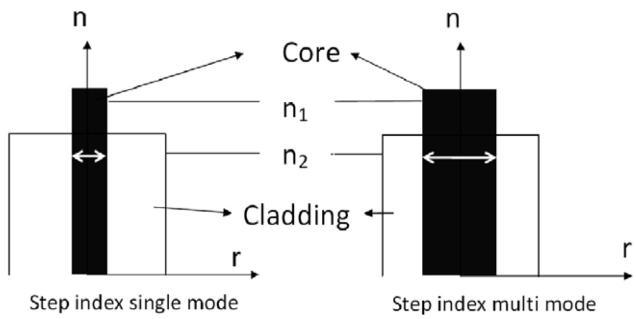


Step Index Fiber:

In step index fibers the refractive index of the core medium is uniform and undergoes an abrupt change at the interface of core and cladding as shown in figure.

The diameter of core is about 10 micrometers in case of single mode fiber and 50 to 200 micrometers in multi-mode fiber.





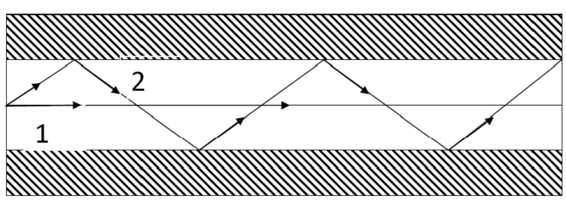
Attenuation is more for step index multi-mode fibers but less in single mode step index fibers.

Numerical aperture is more for step index multi-mode fibers but it is less in step index single mode fibers.

Transmission of signal in step index fiber:

The transmitted optical signal will cross the fiber axis during every reflection at the core cladding boundary. The shape of propagation of the optical signal is in zigzag manner.

Generally the signal through the fiber is in digital form i.e. in the form of pulses representing 0s and 1s.

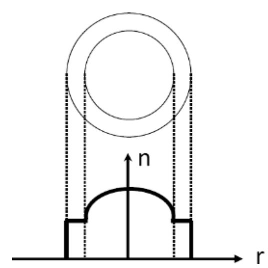


From figure the ray 1 follows shortest path (i.e. travels along the axis of fiber) and the ray 2 follows longer path than ray 1. Hence the two rays reach the received end at different times. Therefore, the pulsed signal received at other end gets broadened. This is called intermodal dispersion. This difficulty is over come in graded index fibers.

<u>Graded index fiber</u>:-

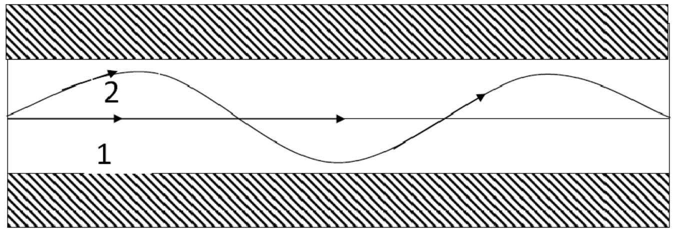
In graded index fibers, the refractive index of the core medium is varying in the parabolic manner such that the maximum refractive index is present at the center of the core.

The diameter of the core is about 50 micro meters.
Attenuation is very less in graded index fibers.
Numerical aperture is less in graded index fibers.



Transmission of signal in graded index fiber:-

The shape of propagation of the optical signal appears in the helical or spiral manner.

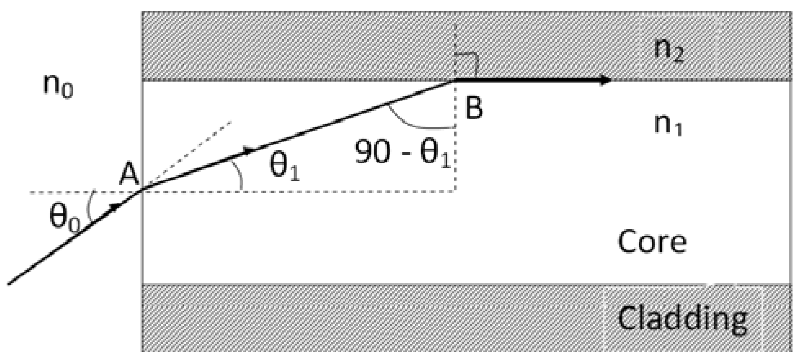


As shown in figure, the ray 1 is traveling along the axis of the core and the other ray 2 traveling away from the axis undergoes refraction and bent. Since, ray 2 is traveling in the lesser refractive index medium with higher speed, the two rays reach the other end simultaneously. Thus the problem of intermodal dispersion can be overcome by using graded index fiber.

4. Acceptance angle (θ_0):-

Definition:-

Acceptance angle is defined as the maximum angle of incidence at the interfaceof air-core boundary for which the light ray enters into the core and travels along the interface of core and cladding.



Let n_0, n_1 and n_2 be the refractive indices of the air, core and cladding media. Let a light ray OA is incident on the interface of air core interface with an angle of incidence $\boldsymbol{\theta}_0$ then the refracted ray AB(angle of refraction=$\boldsymbol{\theta}_1$)is then incident on the core cladding interface making angle $\boldsymbol{\theta}_2$= 90- $\boldsymbol{\theta}_1$. If $\boldsymbol{\theta}_2$ is equal to the critical angle for the core cladding media the ray shall travel along the interface making angle of refraction to 90.

If the external angle of incidence at the air core boundary is less than the $\boldsymbol{\theta}_0$ then the angle of refraction inside the core will be less than $\boldsymbol{\theta}_1$ which in turn makes greater angle than the critical angle at the core cladding boundary. Consequently the ray will do total internal reflection.

According to Snell's law at point A,

$$n_0 \sin \theta_0 = n_1 \sin \theta_1$$

$$\sin \theta_0 = (n_1/ n_0) \sin \theta_1 \qquad \ldots(1)$$

According to Snell's law at point B,

$$n_1 \sin(90 - \theta_1) = n_2 \sin 90$$

$$n_1 \cos \theta_1 = n_2$$

$$\therefore \cos \theta_1 = n_2/ n_1 \qquad \ldots(2)$$

$\text{Sin } \theta_1 = \sqrt{1 - cos^2\theta_1}$ ...(3)

Putting (3) in (1)

$$\text{Sin } \theta_0 = (n_1/ n_0)\sqrt{1 - cos^2\theta_1}$$

Using (2) above equation can be written as ,

$$\text{Sin } \theta_0 = (n_1/ n_0)\sqrt{1 - {n_2^2}/{n_1^2}}$$

Taking n_0=1 ie refractive index of air, above equation written as

$$\text{Sin } \theta_0 = n_1\sqrt{{n_1^2 - n_2^2}/{n_1^2}}$$

$$\boxed{\therefore \textbf{Sin } \boldsymbol{\theta_0} = \sqrt{\boldsymbol{n_1^2 - n_2^2}} \textbf{ = Numerical Aperture (NA)}}$$

Also,

$$\boxed{\boldsymbol{\theta_0} = \mathbf{sin^{-1}}\sqrt{\boldsymbol{n_1^2 - n_2^2}} \quad \text{Acceptance angle for the fibre.}}$$

Numerical Aperture (NA):-

Definition: -

Numerical aperture is defined as the light gathering capacity of an optical fiberand it is directly proportional to the acceptance angle.

Numerically it is equal to the sin of the acceptance angle.

NA = Sin(acceptance angle)

NA=Sin $\boldsymbol{\theta_0}$

$$\textbf{NA= Sin } \boldsymbol{\theta_0} = \sqrt{\boldsymbol{n_1^2 - n_2^2}}$$

$$\text{NA=} \sqrt{(n_1 - n_2)(n_1 + n_2)}$$

As n1 and n2 having very close values, 2n1=$n_1 + n_2$

Therefore we may write,

$$\text{NA=} \sqrt{2n_1(n_1 - n_2)}$$

$$\textbf{NA= } \boldsymbol{n_1}\sqrt{\mathbf{2}\Delta}$$

Where, $\Delta = {\boldsymbol{n_1 - n_2}}/{\boldsymbol{n_1}}$

This is known and fractional change in relative refractive index.

The above equation gives a relationship between numerical aperture and fractional change in relative refractive index.

5. V Number/ Normalized Frequency (V) and Number of allowed modes(Nm):

An optical fibre is characterized by another important parameter called as the V umber or normalized frequency. It is given by,

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} = \frac{2\pi a}{\lambda}\ NA$$

Where **a** is the radius of the core, **λ** is wavelength of light and **NA** is the Numerical aperture.

The maximum number of modes or maximum possible order supported by the fibre is given by

$$N_m = \frac{V^2}{2} \quad \text{, for Step index fibres}$$

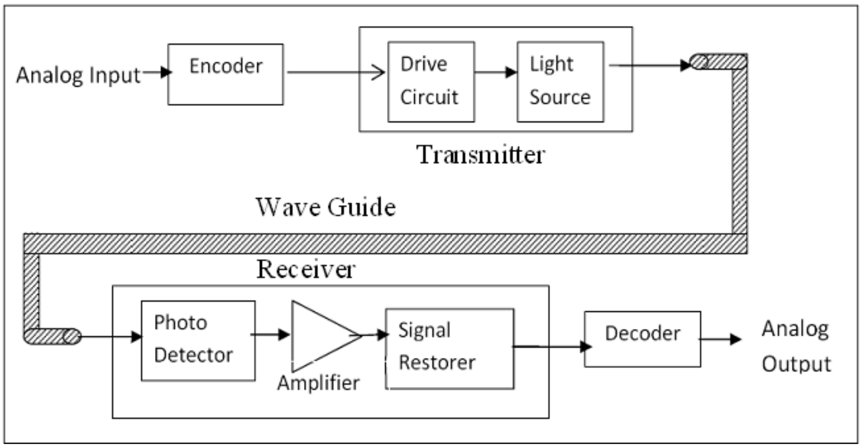
$$N_m = \frac{V^2}{4} \quad \text{, for Graded index fibres}$$

For single mode operation it is found that one must have V<2.405

6. <u>Optical fiber communication system</u>:-

An optical fiber communication system mainly consists of the following parts as shown in figure.

1. Encoder
2. Transmitter
3. Wave guide.
4. Receiver
5. Decoder



1. Encoder

Encoder is an electronic system that converts the analog information like voice, figures, objects etc., into binary data.

2.Transmitter

It contain two parts, they are drive circuit and light source. Drive circuit suppliesthe electric signals to the light source from the encoder in the required form. The light source converts the electrical signals into optical form.

With the help of specially made connector optical signals will be injected into wave guide from the transmitter.

3.**Wave guide**.

It is an optical fiber which carriers information in the form of optical signals over distances with the help of repeaters. With the help of specially made connector optical signals will be received by the receiver from the wave guide.

4.Receiver.

It consists of three parts; they are photo detector, amplifier and signal restorer. The photo detector converts the optical signal into the equivalent electric signals and supplyto hem to amplifier. The amplifier amplifies the electric signals as they become weak during the long journey through the wave guide over longer distance. The signal restorer deeps the electric signals in a sequential form and supplies to the decoder in the suitable way.

5.Decoder

It converts electric signals into the analog information.

7) Differences between step index fibers and graded index fibers:-

Step index fiber	Graded index fiber
1. In step index fibers the refractive index of the core medium is uniform through and undergoes an abrupt change at the interface of core and cladding.	1. In graded index fibers, the refractive index of the core medium is varying in the parabolic manner such that the maximum refractive index is present at the center of the core.
2. The diameter of core is about 10micrometers in case of single mode fiber and 50 to 200 micrometers in multi- mode fiber.	2. The diameter of the core is about 50 micro meters.
3. The transmitted optical signal will cross the fiber axis during every reflection at the core cladding boundary.	3. The transmitted optical signal will nevercross the fiber axis at any time.
4. The shape of propagation of the optical signal is in zigzag manner.	4. The shape of propagation of the optical signal appears in the helical or spiral manner
5. Attenuation is more for multi mode step index fibers but Attenuation is less in single mode step index fibers	5. Attenuation is very less in graded index fibers
6. Numerical aperture is more for multi mode step index fibers but it is less in single mode step index fibers	6. Numerical aperture is less in graded index fibers

8) Differences between single mode and multi mode fibers:-

Single mode fiber	Multi-mode fiber
1. 1. In single mode optical fibers only one mode of propagation is possible	1. In multi-mode optical fibers many mummer of modes of propagation are possible.
2. In case of single mode fiber the diameter of core is about10 micrometers	2. In case of in multi-mode fiber the diameter of core is 50 to 200 micrometers.
3. The difference between the refractive indices of core and cladding is very small.	3. The difference between the refractive indices of core and cladding is also large compared to the single mode fibers.
4. In single mode fibers there is no dispersion, so these are moresuitable for communication.	4. Due to multi-mode transmission, the dispersion is large, so these fibers are not used for communication purposes.
5. The process of launching of lightinto single mode fibers is very difficult	5. The process of launching of light into single mode fibers is very easy.
9) The condition for single modeoperation is when V<2.405 then fibre supports **only one mode**	6. The condition for multi-mode propagation is When V>2.405 then fibre supports **multi-mode**
7. Fabrication is very difficult and the fiber is costly.	7. Fabrication is very easy and the fiber is cheaper.

9) Advantages of fiber optic communication:-

The optical fiber communication has more advantages than conventional communication.

i. Enormous bandwidth
ii. low transmission loss
iii. electric isolation
iv. signal security
v. small size and less weight
vi. low cost
vii. immunity cross talk

1. **Enormous bandwidth**

The information carrying capacity of a transmission system is directly proportionalto the frequency of the transmitted signals. In the coaxial cable (or convectional communication system) transmission the bandwidth range is up to around500MHZ. only. Where as in optical fiber communication, the bandwidth range is large as 10^5 GHZ.

2. **Low transmission loss:-**

The transmission loss is very low in optical fibers (ie 0.2 dB/km) less compare with the convectional communication system. Hence for long distance communicationfibers are preferred.

3. **Electric isolation**

Since fiber optic materials are insulators, they do not exhibit earth and interface problems. Hence communicate through fiber even in electrically danger environment.

4. **Signal security**

The transmitted signal through the fiber does not radiate, unlike the copper cables, a transmitted signal cannot be drawn from fiber without tampering it. Thus the optical fiber communication provides 100% signal security.

5. **Small size and less weight**

The size of the fiber ranges from 10μm to 50 μm, which is very small. The space occupied by the fiber cable is negligibly small compared to conventional electrical cables. Optical fibers are light in weight.

6. **Low cost**

Since optical fibers made up of silica which is available in abundance, optical fibers are less expensive.

7. **Immunity cross talk**

Since the optical fibers are dielectric wave guides, they are free from any electromagnetic interference and radio frequency interference. Since optical interference among different fibers is not possible, cross talk is negligible even many fibers are cabled together.

10) Applications of optical fibers

i. Optical fibers are extensively used in communication system.
ii. Optical fibers are in exchange of information between different computers
iii. Optical fibers are used for exchange of information in cable televisions, space vehicles, submarines etc.
iv. Optical fibers are used in industry in security alarm systems, process control and industrial auto machine.
v. Optical fibers are used in pressure sensors in biomedical and engine control.
vi. Optical fibers are used in medicine, in the fabrication in endoscopy for the visualization of internal parts of the human body.
vii. Sensing applications of optical fibers are Displacement sensor, Fluid level detector Liquid level sensor, Temperature and pressure sensor, Chemical sensors
viii. Medical applications of optical fibers are Gastroscope, Orthoscope Couldoscope, Peritonescope, Fiberscope

Question Bank

Principle of an optical fiber (total internal reflection)

1. Explain briefly 'basic principle of an optical fiber'. OR
Explain the principle of total internal reflection.

Acceptance angle and Numerical aperture

2. Explain the terms numerical aperture and acceptance angle. OR
3. Derive expressions for the numerical aperture and fraction change in refractive index change of an optical fiber.

Optical fiber communication system

4. Explain the advantages of an optical fiber communication system.
5. Draw the block diagram of fiber optic communication system and explain thefunction of each block

Applications of optical fibers

6. Write a note on the applications of an optical fiber.

Fibers classification

7. Explain how the optical fibers are classified.
8. Describe different types of fibers by giving the refractive index profiles andpropagation details
9. Distinguish between
Step index fiber graded index fiber Single mode and multimode optical fiber.

Construction of an optical fiber

10. With the help of suitable diagram explain the principle, construction and working of an optical fiber as a waveguide.

Problems

11. An optical fiber has a core material of refractive index of 1.55 and cladding material of refractive index of 1.50. The light is launched it in air. Calculate the its numerical aperture.
12. Calculate the angle of acceptance of a given optical fiber, if the refractive indices os the core and cladding are 1.563 and 1.498 respectively.
13. The numerical aperture of an optical fiber is 0.39. If the difference in the refractive indices of the material of its core and cladding is 0.05. Calculate refractive index of the core material.
14. Calculate fractional change in refractive for a given optical fiber if the refractive indices of the core and the cladding are 1.563 and 1.498 respectively.