

LASER

Light amplification by stimulated emission of radiation. The stimulated emission is used for amplifying light wave.

Characteristics of Laser light:-

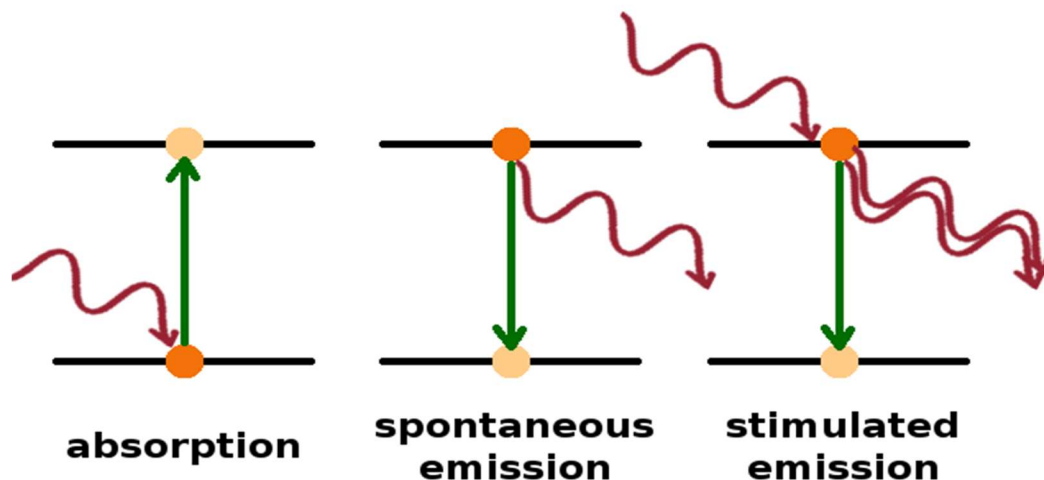
- Laser light is coherent source.
- Laser light is highly mono chromatic.
- A laser beam is highly directional.
- Laser can produced a light in a very narrow wavelength beam.
- The laser light has brightness compare to an ordinary light. Due to its high intensity it can also be used for welding, cutting and drilling.

Spontaneous emission:-

An atom cannot stay in the excite state for a longer time. In a time of about 10^{-8} second the atom returns to the lower energy state by releasing a photon of energy $E_2 - E_1 = hf$. The emission of a photon by an atom without any external impetus is called spontaneous emission.

Stimulated emission:-

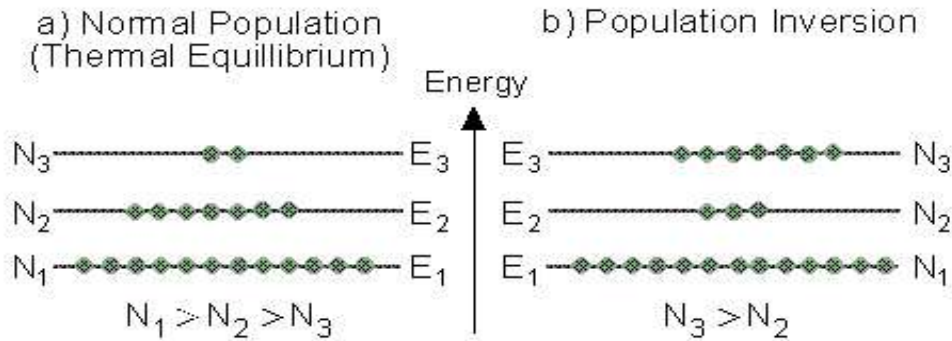
The atom in the excited state can be returned to original state before spontaneous emission by the incident of an external photon with the emission of both incident and stimulated photon. This type of emission of radiation is called the stimulated emission or induced emission.



Optical pumping and population inversion:-

To achieve a high percentage of stimulated emission, a majority of atoms should be at the higher energy level than lower level. The establishment of situation in which the number of atoms in the higher energy level is greater than that of lower energy level is called population inversion.

The process carried out to achieve population inversion by supplying energy to laser medium is called pumping. When the pumping is done by light energy it is called optical pumping.



Meta-stable state:-

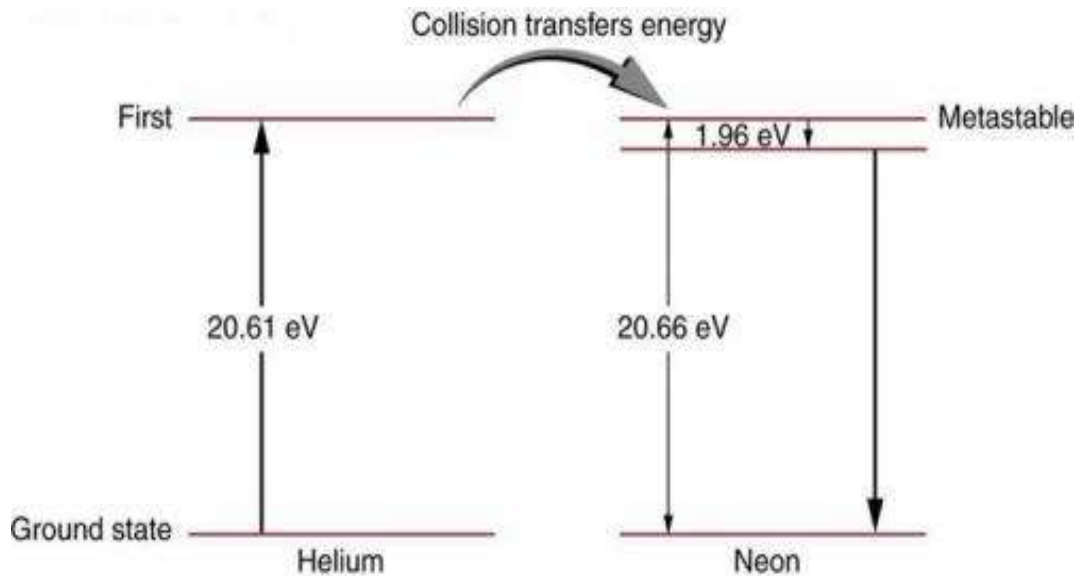
Normally the life time of an atom in excited state is very short (10^{-8} sec). However the atoms of special elements can stay for longer time in the higher energy state where the life time is greater than 10^{-4} sec. Such higher state is called meta-stable state.

Active medium:-

Atoms are generally characterized by a large no of energy levels. However all types of are not suitable for laser operation. Even in a medium consisting of different species of atoms, only a small fraction of atoms of a particular type have energy level suitable for achieving population inversion such atoms can produce more stimulated emission than spontaneous emission and causes amplification of light. These atoms are called active centers. The rest of the medium acts as host and supports active center. The medium hosting the active center is called active medium.

He-Ne Laser:-

The He-Ne laser consists of a long and narrow discharge tube. The lasing material is the mixture of gases with a concentration of about 15% He and 85% Neon. The electrodes in the discharge tube are connected to a high voltage source of few KV DC. So an electric discharge takes place within the gas. With this high voltage some of the helium atoms are rise to a meta-stable state $E_1 = 20.61\text{eV}$ above the ground state as shown in figure. It so happens that Ne atoms has a meta-stable state at nearly the same energy $E_3 = 20.66\text{eV}$. The helium atoms do not quickly return to the ground state by spontaneous emission rather it transfer the energy to neon atom during collision.



With such collision the energy of excited helium atoms will be transfer and it drops to ground state, however getting excess energy neon atoms is excited to the state E_3 . The kinetic energy of the helium atom provides the additional 0.05 eV required for excitation of neon atoms. In this way the higher state E_3 of neon becomes the meta-stable state. Hence, the lasing action takes place by stimulated emission between E_3 and E_2 states of neon. The laser light emitted is 632.8nm.

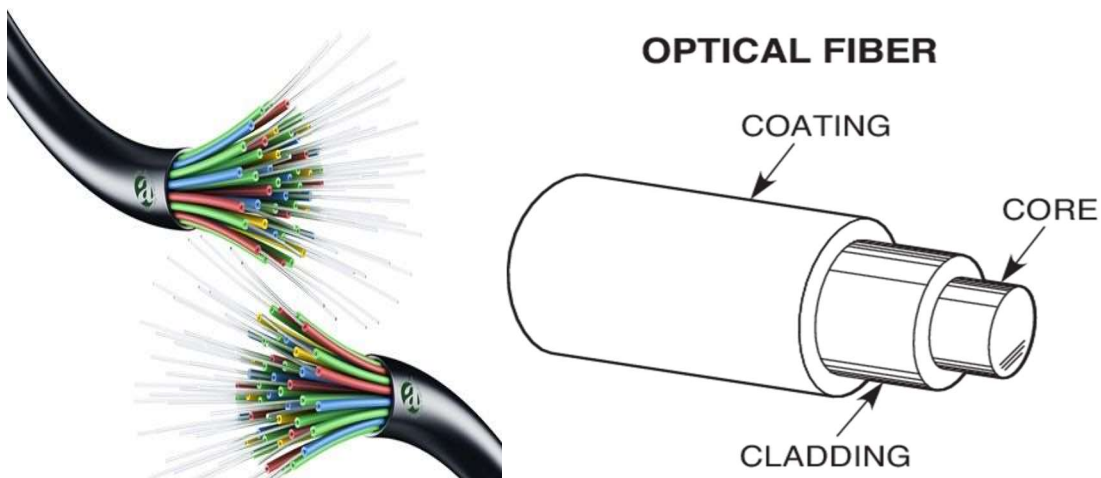
Uses of Laser:-

- Laser light is used to investigate the basic laws of interaction of atoms and molecule with electromagnetic wave. (Scientific uses)
- It is used for distance measurement.
- It can be used in different communication system.
- It can be used in wars to target missiles.
- It is highly intense. Therefore it can be used in drilling, welding, and cutting of material.
- Laser light is used in eye surgery, treatment of dental decay, destruction of tumor and for treatment of skin diseases. (Medical uses)
- It can be used in scientific research. Such as in the study of chemical and crystalline structure of various molecule, in Raman spectroscopy, in astronomy.
- Laser light is used for automatic control for rockets and satellite. It can also be used for detection and destroy of aero planes, missiles and tanks.
- It can be used in laser induced fusion process, isotopes separation and to measure the optical depth.

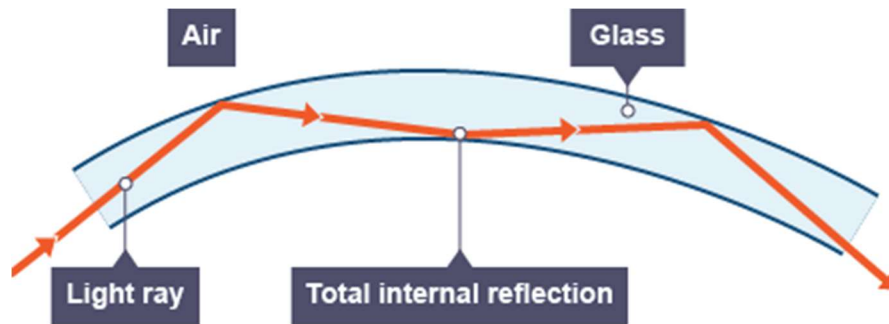
Exercise:-

1. Differentiate between spontaneous and stimulated emission of radiation. Explain the construction and working of He-Ne laser with a suitable energy diagram.
2. What is population inversion? Explain why laser action cannot occur without population inversion between atomic levels?
3. What are active medium, population inversion and optical pumping? Give the importance in the study of laser. Write a method for getting He-Ne laser.
4. Explain the term stimulated emission, population inversion, optical pumping and meta-stable state. Explain working principles of He-Ne laser.
5. Differentiate between LASER and ordinary light.

Optical Fiber

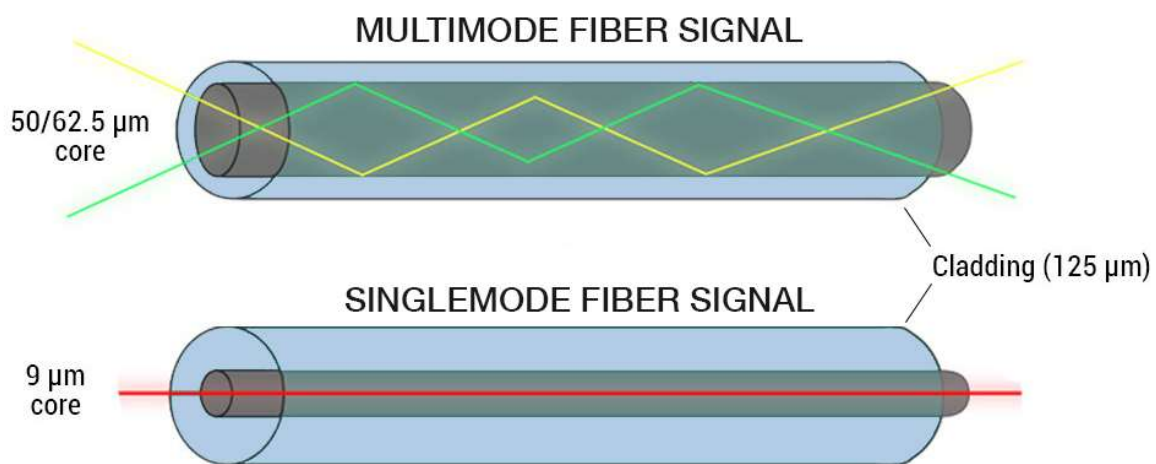


An optical fiber is a transparent cylindrical system, as thin as human hair, made up of glass or clear plastic, designed to guide light wave along its length. An optical fiber works on the principle of total internal reflection. The central part of the system is known as core and the seal outside the core is known as cladding. The refractive index of the core material is always greater than that of the cladding. The coating outside the cladding is known as buffer coating. In fact both core and cladding both are made from glass material. The optical fibers are strong wires and can be easily bent in rolls.



Types of optical fiber:-

On the basis of modes of propagation there are two types of optical fibers.



1. Single mode Optical fiber:-

In single mode optical fiber there is only one mode of propagation. It is smaller core diameter. It is step index fiber.

2. Multimode Optical fiber:-

In multimode optical fiber there are two or more than two modes of propagation, so it has larger core diameter.

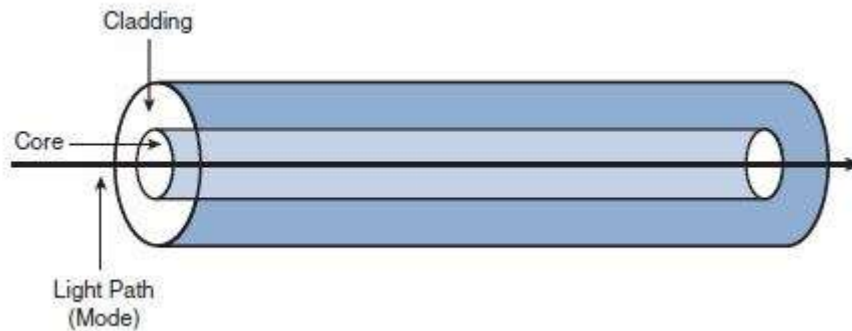
On the basis of index profile, optical fibers are further classified into two groups. a) Step index fiber and b) graded index fiber.

The single mode fiber is usually of step index type but the multimode optical fiber is of both step index and graded index type.

1. Single mode step index Fiber:-

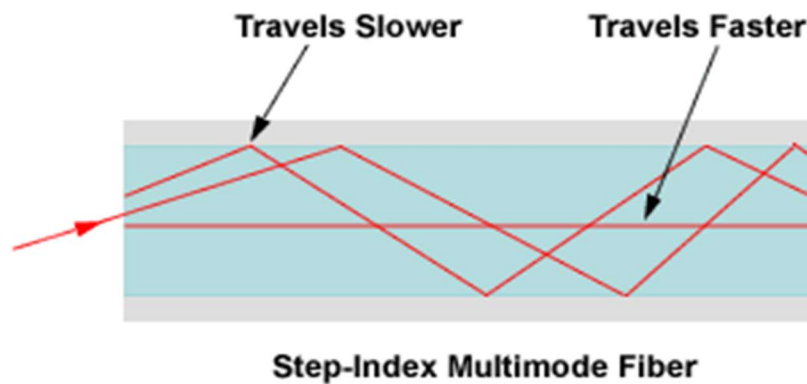
In single mode fiber, there is only one mode of propagation. In this type of fiber, core has higher constant refractive index ($\mu_1 = 1.52$) and cladding has lower constant refractive index ($\mu_2 =$

1.48). So refractive index changes abruptly at the core cladding interface. Therefore it is called step index fiber. It has high transmission loss due to abrupt change in refractive index. It is difficult to manufacture and handle and therefore it is costly.



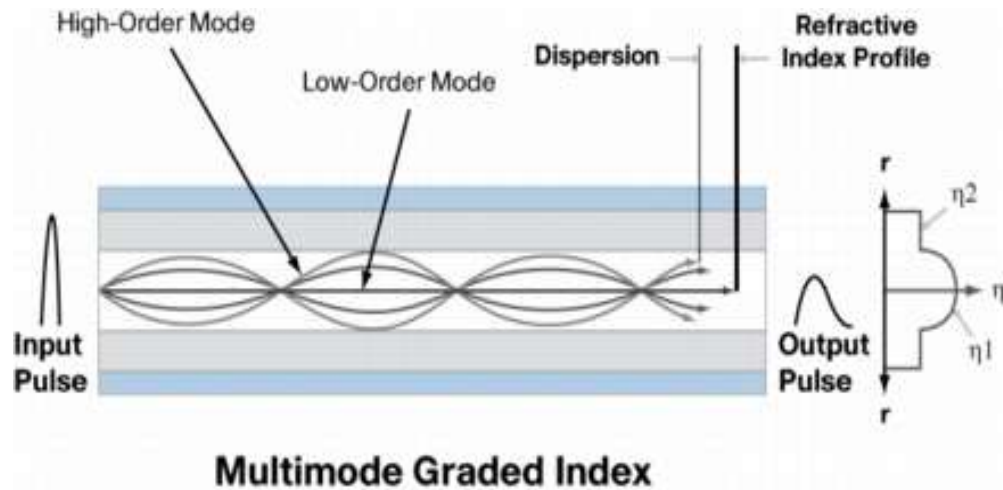
2. Multimode step index Fiber:-

In multimode fiber, there are multiple modes of propagation. In this type of fiber, core has higher constant refractive index ($\mu_1 = 1.52$) and cladding has lower constant refractive index ($\mu_2 = 1.42$). So refractive index changes abruptly at the core cladding interface. Therefore it is called step index fiber. It has high transmission loss due to abrupt change in refractive index. It is easy to manufacture and is less costly.

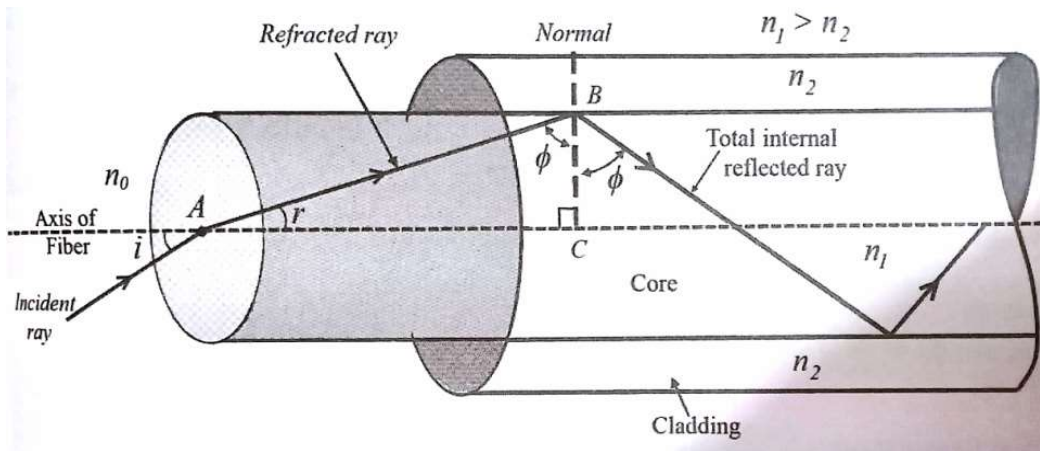


3. Multimode Graded index Fiber:-

In multimode fiber, there are multiple modes of propagation. The number of modes in graded index fiber is about half of that in multimode step index fiber. So it has lower dispersion than in multimode step index fiber. It has low transmission loss because the continuous decrease in the refractive index causes bending of light towards the centre of the core. Its manufacture is more complex than step index multimode fiber.



Propagation of light wave in Optical Fiber:-



Consider a ray incident on an optical fiber, making an angle 'i' with axis from outside as shown in figure. The refractive index of outside is μ_0 , that of core is μ_1 and cladding is μ_2 respectively. From Snell's law, for ray from air to core is;

$$\frac{\mu_1}{\mu_0} = \frac{\sin i}{\sin r}$$

$$\text{or, } \mu_0 \sin i = \mu_1 \sin r \dots \dots \dots (1)$$

$$\text{or, } \frac{\mu_0}{\mu_1} \sin i = \sin r$$

$$\text{or, } \frac{\mu_0}{\mu_1} \sin i = \sin(90 - \phi)$$

$$\text{or, } \frac{\mu_0}{\mu_1} \sin i = \cos \phi$$

$$\therefore \cos \phi = \frac{\mu_0}{\mu_1} \sin i \dots \dots (2)$$

Now, the angle of incidence 'i' is critical angle 'c', when angle of refraction is a right angle.

$$\mu_1 \sin c = \mu_2 \sin 90 \dots \dots (3)$$

From equation (2) and (3), squaring and adding we get;

$$\sin^2 c + \cos^2 c = 1 \quad (\text{when } \phi = c)$$

$$\text{or, } \frac{\mu_2^2}{\mu_1^2} + \frac{\mu_0^2}{\mu_1^2} \sin^2 i = 1$$

$$\text{or, } \sin^2 i = \frac{\mu_1^2 - \mu_2^2}{\mu_0^2}$$

$$\therefore \sin i = \sqrt{\frac{\mu_1^2 - \mu_2^2}{\mu_0^2}}$$

For air medium, $\mu_0 = 1$, in such case $\sin i$ can have a maximum value;

$$\text{i.e. } \sin i_{\max} = \sqrt{\mu_1^2 - \mu_2^2}$$

The quantity $\sqrt{\mu_1^2 - \mu_2^2}$ is known as **numerical aperture (NA)** of the optical fiber and it measure the light gathering power of fiber.

$$\text{i.e. } NA = \sqrt{\mu_1^2 - \mu_2^2}$$

$$= [(\mu_1 - \mu_2)(\mu_1 + \mu_2)]^{\frac{1}{2}}$$

$$= \left[\frac{\mu_1 - \mu_2}{\mu_1} \cdot \frac{\mu_1 + \mu_2}{2} \cdot 2\mu_1 \right]^{\frac{1}{2}}$$

$$\text{when, } \mu_1 \cong \mu_2, \text{ then } \frac{\mu_1 + \mu_2}{2} = \mu_1$$

$$= \left[\frac{\mu_1 - \mu_2}{\mu_1} \cdot \mu_1 \cdot 2\mu_1 \right]^{\frac{1}{2}}$$

$$= [\Delta \cdot 2\mu_1^2]^{\frac{1}{2}}$$

$$\therefore NA = \mu_1 \sqrt{2\Delta} \quad \text{where, } \Delta = \frac{\mu_1 - \mu_2}{\mu_1}$$

It is seen that NA only depends on the refractive indices of core and cladding.

Normalized frequency (V-number):-

The V-number determines the number of modes that can propagate through a fiber. It is an important parameter that characterized an optical fiber.

Mathematically it is given by;

$$V = \frac{2\pi a}{\lambda} \sqrt{\mu_1^2 - \mu_2^2}$$

Where a is the radius of wire λ is the wavelength, μ_1 and μ_2 are refractive indices of core and cladding.

- For $V < 2.405$, fiber can support only one mode and is called single mode fiber.
- For $V > 2.405$, fiber can support number of modes simultaneously and is called multimode fiber.

Acceptance angle:-

It is a maximum value of angle of incidence ' θ ' for which light ray can propagate through fiber. It is the angle made by incidence ray with fiber axis.

Application of optical fiber:-

- Fiber optics essentially deals with the communication including voice signal, video signal or digital data. This is done by transmission of light through optical fiber.
- The fiber optics are used in the fabrication of fiber scope in endoscopy in medical science. Such fiber scopes are used in visualization of internal organ of human body.
- The fiber optics is also useful in industry. It can be used to examine welds nozzle and combustion chamber inside aircraft engine.

Advantages:-

Optical fiber has many advantages that are not found in conducting wire.

- Cheaper:- Optical fiber are made from silica(SiO_2), which is one of the most easily available material on the earth.
- Optical fibers are light in weight and flexible.
- Optical fiber transmit light wave not electrical so they are not hazardous.
- Band width of light wave is greater than that of electrical wave so greater amount of information carried over in optical fiber.
- There is less interference of waves so the cross talk is negligible in fiber communication.
- Optical fibers have longer life time.
- Low loss per unit length.

Numerical Examples:-

1. An optical fiber has fractional index difference of 0.2 and cladding refractive index 1.59. Determine the acceptance angle for the fiber for water in which, have refractive index of 1.33.

Solution:-

Fractional index difference (Δ) = 0.2

Cladding refractive index (μ_2) = 1.59

Refractive index of water (μ_0) = 1.33

Acceptance angle (i) = ?

We know that;

$$\Delta = \frac{\mu_1 - \mu_2}{\mu_1}$$

$$\text{or, } 0.2 = \frac{\mu_1 - 1.59}{\mu_1}$$

$$\text{or, } 0.2\mu_1 - \mu_1 = -1.59$$

$$\text{or, } -0.8\mu_1 = -1.59$$

$$\therefore \mu_1 = 1.9875$$

Also for acceptance angle, we have;

$$\sin i = \sqrt{\frac{\mu_1^2 - \mu_2^2}{\mu_0^2}} = \sqrt{\frac{(1.987)^2 - (1.59)^2}{(1.33)^2}}$$

$$\text{or, } \sin i = 0.88$$

$$\therefore \text{Acceptance angle (i)} = 62^\circ$$

2. A glass clad fiber is made with core glass of refractive index 1.5 and cladding is doped to give a fractional index difference of 5×10^{-4} . Determine (i) cladding index (ii) critical angle (iii) acceptance angle, and (iv) Numerical aperture.

Solution:-

Core refractive index (μ_1) = 1.5

Fractional index difference (Δ) = 5×10^{-4}

Cladding index (μ_2) = ?

Critical angle (C) = ?

Acceptance angle (i_{\max}) = ?

Numerical aperture (NA) = ?

(i) We have $\Delta = \frac{\mu_1 - \mu_2}{\mu_1}$

$$\text{or, } 5 \times 10^{-4} = \frac{1.5 - \mu_2}{1.5}$$

$$\therefore \text{cladding index } (\mu_2) = 1.49925$$

(ii) Critical angle; $\sin C = \frac{\mu_2}{\mu_1} = \frac{1.49925}{1.5}$

$$\therefore C = 88^\circ$$

(iii) $\sin i_{\max} = \sqrt{\mu_1^2 - \mu_2^2} = \sqrt{(1.5)^2 - (1.49925)^2}$

$$\therefore i_{\max} = 2.79^\circ$$

(iv) $NA = \mu_1 \sqrt{2\Delta} = 1.5 \times \sqrt{2 \times 0.005} = 0.0474$

- 3. The refractive index for core and cladding for a step index fiber are 1.52 & 1.41 respectively. Calculate (i) critical angle (ii) Numerical aperture, and (iii) The maximum incidence angle.**

Solution:-

Refractive index of core (μ_1) = 1.52

Refractive index of cladding (μ_2) = 1.41

(i) Critical angle; $\sin C = \frac{\mu_2}{\mu_1} = \frac{1.41}{1.52}$

$$\therefore C = 68.068$$

(ii) We have; $\Delta = \frac{\mu_1 - \mu_2}{\mu_1} = \frac{1.52 - 1.41}{1.52} = 0.072$

$$\therefore NA = \mu_1 \sqrt{2\Delta} = 1.52 \times \sqrt{2 \times 0.072} = 0.576$$

$$(iii) \sin i_{\max} = \sqrt{\mu_1^2 - \mu_2^2} = \sqrt{(1.52)^2 - (1.41)^2}$$

$$\therefore i_{\max} = 34.591^\circ$$

Exercise:-

6. Trace the ray diagram that shows the propagation of light through the step and graded index optical fiber. Write the importance of self-focusing in an optical fiber.
7. What is optical fiber? Explain numerical aperture and acceptance angle. Also compare the attenuation property efficiency and cost of single mode and multimode optical fibers.
8. Discuss the physical significance of numerical aperture (NA). How does it depend on refractive index of core and cladding?
9. What is an optical fiber? Show that Numerical aperture of an optical fiber is given by the expression, $NA = \mu_1 \sqrt{2\Delta}$, where the symbols carry their usual meanings.
10. An optical fiber has a numerical aperture of 0.22 and core refractive index 1.62. Determine the acceptance angle for the fiber in liquid which has a refractive index of 1.25. Also, determine the refractive index change.
11. Calculate the refractive index of the core and materials of a fiber from following data. Numerical Aperture (NA) = 0.22 and fractional refractive index change $\Delta = 0.012$.