FIBER OPTICS

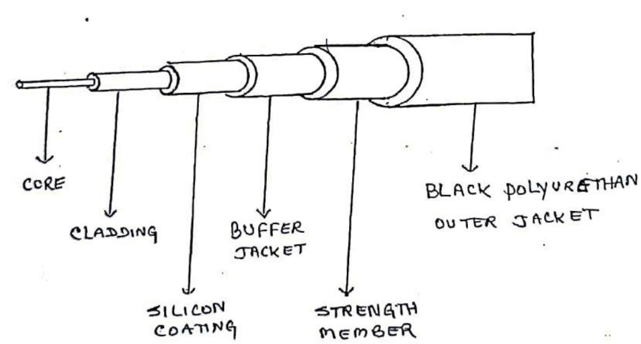
Introduction to fiber optics - Total Internal Reflection - Critical angle of propagation - Acceptance angle, Acceptance cone - Numerical Aperture - V number (qualitative) - Classification of fibers based on Refractive index profile, modes - Applications of optical fiber - Fiber optic Sensors (temperature, displacement).

Introduction:

Fiber optics technology is increasingly replacing wire transmission lines in communication systems. Optical fibers offer several important advantages over wire lines. Optical fibers are the light, very high bandwidth and hence very high information carrying capacity. The development in the fields of communication and information technology demand very easy and rapid transmission of data over long distances.

"For proper guiding of information carrying light waves we need a proper guiding medium or material, known as Optical Fiber."

Fiber Structure and Construction:



To guide the light waves, optical fiber shows a transparent and to minimise the transmission losses through the fiber, it is made thin,. Thus, an optical fiber is a very thin, transparent and flexible materials which guides the information carrying light waves.

(or)

It is a very thin, transparent and flexible thread made of glass or plastic in which light is transmitted through multiple total internal reflection.

It contains i) core ii) cladding and iii) protective jacket(sheath)

The core is the innermost section . It acts like a continuous layer of two parallel mirrors. The core is surrounded by its own cladding having optical properties different from those of the core. Silicon coating is provided between buffer jacket and cladding in order to **improve the quality of transmission of light.** The buffer jacket protects the fiber from **moisture and abrasion**. To provide necessary **toughness and tensile strength**, a layer of strength member is arranged surrounding the buffer jacket. Finally, it is covered with black polyurethane outer jacket which provides the protection against **crushing and other environmental dangers**.

The core as well as cladding is made of either glass or plastic. We have two types of optical fibers namely glass fibers and plastic fibers. The most common material used in glass fiber is silica. It has a refractive index of 1.458 at 850 nm wavelength.

Fiber	**Core**	**Cladding**
Glass	SiO_2+GeO_2	SiO_2
Glass	$SiO_2+P_2O_5$	SiO_2
Plastic	Polysterene	Methylmethacryl
Plastic	Methylmethacryl	Co-polymer

Fiber dimensions:

Core	5-600 μm
Cladding	125-750 μm
Optical fibre	0.1 to 0.15 mm

Principle of Optical Fiber:

In 1870, John Tyndall demonstrated that light could be guided within a water jet based circular varun waveguide called optical fiber, on the phenomenon of multiple total internal reflection. The total internal reflection at the fiber wall can occur only if the following two conditions are satisfied.

i) The refractive index of the core material n_1 must be slightly higher than that of refractive index of cladding n_2 ($n_1 > n_2$)

(ii) At the core-cladding interface the θ must be greater than Critical angle.($i>\theta_c$)

Let us consider a denser(core) and rarer(cladding) media of refractive indices n1 and n2 respectively. The R.I of core is slightly greater than the R.I. of cladding. i.e. n1(1.48) > n2 (1.46). Let a ray of light move from core to cladding with 'i' as the angle of incidence and 'r' as the angle of refraction as shown in fig.1 The refracted ray bends away from the normal as it travel from denser to rarer medium With a increase of incident angle to angle of refraction also increases shown in fig.2.

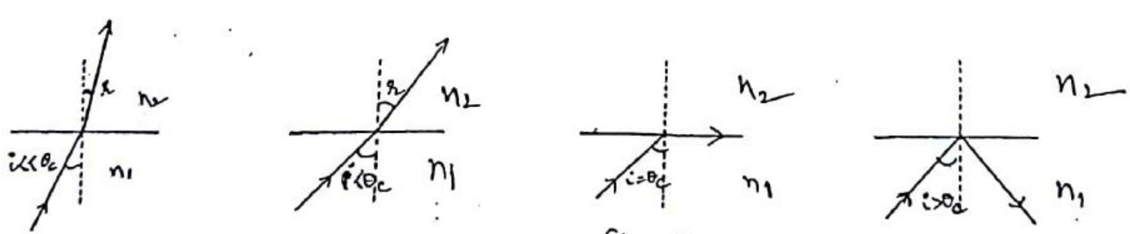


fig-1 fig-2 fig-3 fig-4

For a particular angle of incidence, the refracted ray just grazes the interface between the core and cladding. This angle of incidence is known as **critical angle** (θ_c).(fig-3) When the angle of incidence is further increases, the ray is reflected back into the same denser medium obeying the law of reflection as shown in fig-4. This phenomena is known as **total internal reflection**.
Applying Snell's law,

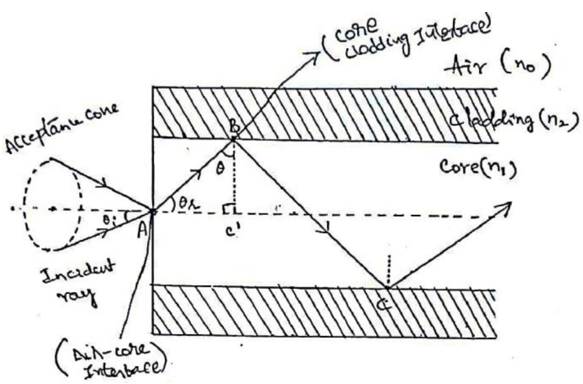
$$n_1 \sin i = n_2 \sin r$$

When i= θ_c, then r =90° , $\frac{n1}{n2} = \frac{1}{\sin\theta_c}$, (sin90 = 1)

If the rarer medium is air, then n_2=1, $n1 = \frac{1}{\sin\theta_c}(or)\theta_c = \sin^{-1}(\frac{1}{n_1})$

Acceptance angle and Acceptance Cone:

The ray which makes the angle of incidence greater than critical angle at the core-cladding interface undergo total internal reflection and propagate through the core. This maximum angle of launch is called 'acceptance angle'. The other rays are refracted to the cladding and are lost.



Let us consider a cross sectional area of an optical fiber having core and cladding of R.I n_1 and n_2 respectively. (n_1>n_2), Let us assume that the fiber is in air medium of R.I. n_0 as shown in figure.
Let a ray of light is incident at A making an angle of incidence θ_i called angle of launching with the axis of the fiber inside the core medium, the ray of light travels along AB and incident at point B on core-cladding interface. Let θ_A is the angle of refraction at A and θ is the angle of incidence at B. Let θ_c is the critical angle of core-cladding media.

When θ> θ_c the ray of light undergoes total internal reflection and takes the path BC as shown in figure.

<u>Acceptance angle:</u> It is the maximum angle of launch upto which all the light rays incident at one end face of the fibre can propagate through it due to multiple total internal reflection
Applying Snell's law, at point A(air-core interface) and B (core-cladding interface), we have

$$n_0 \sin\theta_i = n_1 \sin\theta_r \rightarrow \sin\theta_i = \frac{n_1}{n_0}\sin\theta_r$$

$$n_1 \sin\theta = n_2 \sin 90 \rightarrow \sin\theta = \frac{n_2}{n_1}$$

From figure, in ΔABC' , θ_r = 90- θ

$$\sin\theta_i = \frac{n_1}{n_0}\sin(90\text{-}\theta) = \frac{n_1}{n_0}\cos\theta$$

Let θ_a is the maximum angle of launch at A called Acceptance angle i.e. $\theta_a = \theta_i$

$$Sin\theta_a = \frac{n_1}{n_0}\cos\theta_c.$$

From eq.(1) $\cos\theta_c = \sqrt{1 - Sin^2\theta} = \sqrt{1 - \frac{n_2^2}{n_1^2}} = \frac{\sqrt{n_1^2 - n_2^2}}{n_1}$

$$\therefore\ Sin\theta_a = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

$$\theta_a = \mathrm{Sin}^{-1}\left(\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right)$$

For air medium, $n_0=1$, $\theta_a = \mathrm{Sin}^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$

The maximum angle is called the acceptance angle or acceptance cone half angle. Rotating the acceptance angle about the fiber axis, describes the acceptance cone of the fiber.Larger acceptance angle make launching easier.

Numerical Aperture:

"Light gathering capacity of an fiber and is proportional to the acceptance angle is expressed in terms of 'Numerical aperture'. Sine of the maximum acceptance angle is called the Numerical aperture(NA) of the fiber".

$$\mathrm{NA} = Sin\theta_a$$

$$\mathrm{NA} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \qquad \text{--------------} \quad (1)$$

The fractional change in refractive index of core and cladding is given by

$$\Delta = \frac{n_1 - n_2}{n_1} \quad = n_1 - n_2 = n_1\Delta \qquad \text{--------------} \quad (2)$$

For most of the fibers $n_1 \approx n_2 == (n_1 + n_2) = 2n_1$

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

$$\therefore \mathrm{NA} = n_1\sqrt{2\Delta}$$

The numerical aperture of a fiber i. e., its light collecting capacity is effectively dependent only on the refractive indices of the core and cladding materials.

Note: NAs for the fibers used in short distance communication are in the range of 0.4-0.5, whereas for long distance communications , in the range of 0.1 - 0.3.

V-number:

V-number is a dimensionless parameter which is often used in the context of step-index fibers.

It signifies the number of modes propagated in the fiber.

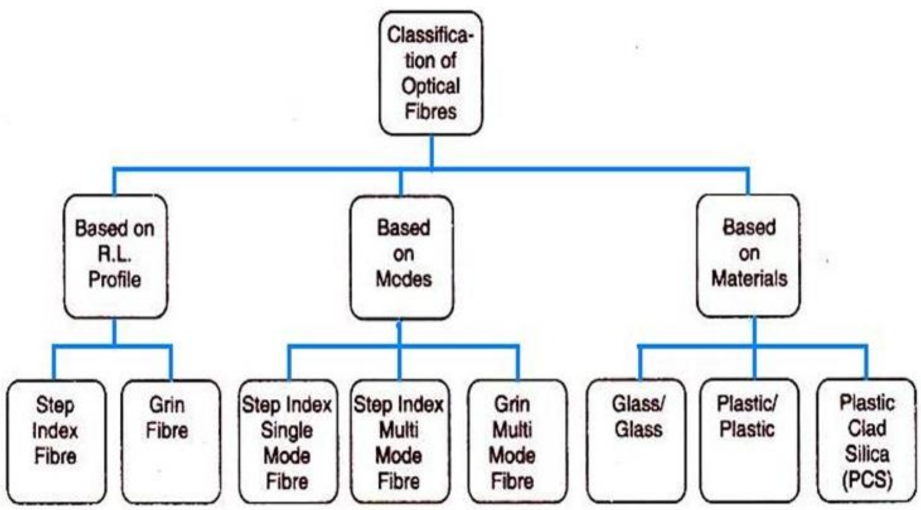
The number of possible modes propagation in the core (V) is $\frac{2\pi a (NA)}{\lambda}$

Where a = radius of core, NA = Numerical aperture, λ = Wavelength of light

Number of modes through step index fiber is $\frac{V^2}{2}$

Number of modes through GRIN fiber is $\frac{V^2}{4}$

Classification of Optical Fibers:



Single mode and Multimode fibers:

The light launched at one end of the fiber within the acceptance cone alone propagates through the fiber by total internal reflection. But all the light within the acceptance cone will not propagates but only specified directions are allowed which are satisfy constructive interference conditions. The rays traveling in these directions are called **Modes (or) Paths**. The number of modes depends on the dimensions of the fiber. If the thickness of the fiber is so small, it supports only one mode then the fiber is called mono mode or single mode fiber. It’s diameter of the order of 2 to 8 μ m. If the fiber supports more than one mode then it is called multimode fiber. It’s diameter is of the order of 50 μ m.

Step Index and Graded Index Fibers:

Step Index Optical Fibers:-

In a step-index optical fiber, the R.I of the core remains constant through out the core material. As we go radially, the RI undergoes an abrupt or a step change at the core-cladding interface. Based on the mode of propagation of light rays, they are classified as

a) Single mode step index optical fiber b) Multi mode step index optical fiber

Single mode step index optical fiber

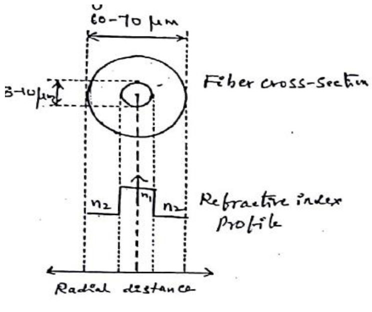


Figure – 1

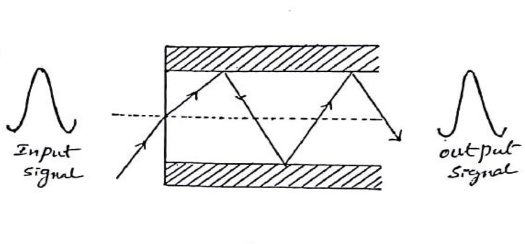
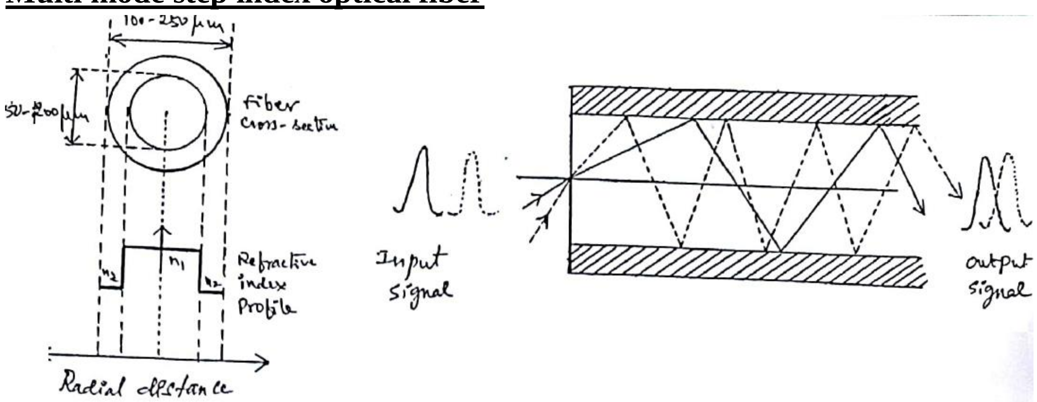


Figure – 2

In this type of fibers, the core diameter is about 8-10 μm and outer diameter of the cladding is about 60-70 μm. Due to the smaller diameter of the core, the numerical aperture is very less.

For Single mode step index fiber, there is only one mode for ray propagation. In general, the signal is transmitted through the fiber is digital for i.e. 0's and 1's.In this fibers both input and output signals match with each other i.e. no distortion is observed in output signal. Nearly 80% of the fibers manufactured today in the world are sing mode fibers. These fibers are mainly used in submarine cable systems

Multi mode step index optical fiber



The construction of multi mode step index optical fiber is similar to single mode step index fiber except that its core and cladding diameter are much longer to have multi paths for light propagation. The core diameter of multi mode step index fiber varies from 50 to 200 μm whereas the outer diameter of the cladding varies from 100-250 μm. Due to large diameter of the core material, the NA be more for multi mode.

The light ray shown by solid lines makes small angle with the fiber axis suffers less number of reflections and within a short time, it traverses the optical fiber. The light ray shown by dotted lines makes larger angle with the axis suffer more reflections through the fiber and takes more time to traverse the fiber. At the output end, we receive solid line first and later we receive dotted ray. Due to the path difference between the light rays, the signals are overlapped at the output end. As a result, the output signal is broadened. So, in multimode, we got signal distortion. This distortion is known as **intermodal dispersion**. Due to the signal distortion, the transmission rate through the multi mode decreases.

The step index fibers are known as reflection type. The number of modes through step index fiber is given by , Number of modes = $V^2/2$

where V= $(2\pi/\lambda)(a)(NA)$, called V number

λ=wavelength of light

a=radius of fiber core, NA=numerical aperture

Graded index Optical Fibers:-

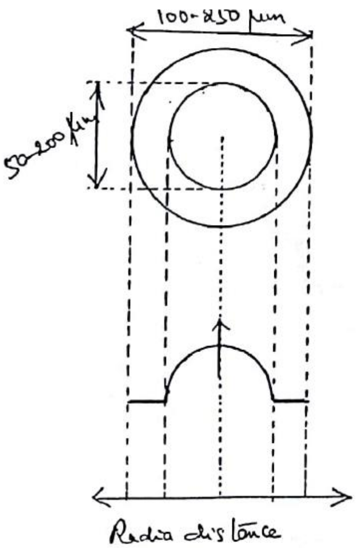
In Graded index multimode fiber, the refractive index of the core decreases gradually from the fiber axis to the core-cladding interface in a parabolic manner, i.e., R.I is maximum at the centre and minimum at the surface of the core. The fibers can be single or multi mode.

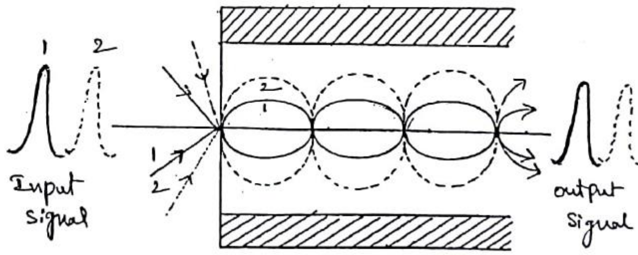
The variation of refractive index of the core(n) with radius(x), measured from the centre of the core is given by $n(x) = n\left[1 - 2\Delta\left(\frac{x}{a}\right)^p\right]^2$

where n is the RI at the center of the core, Δ is the relative RI of the core-cladding media, a is the radius of the core and p is the grading profile index number.

As the RI changes continuously radially outward is core, the light ray suffers continous refraction inside the core materials. So the propagation of the ight rays is not due to total internal reflection but by continuous refraction Hence, this fiber is of refractive type. In this fiber, the light ray takes sinusoidal path as shown in figure.

In graded index, light rays travel at different speeds at different parts of the core material. Near the interface, the light rays travel faster than the rays at the centre, because of this, all the light rays arrive at the output end approximately at the same time. When the light rays 1 and 2 making different angles with the axis enter into the fiber, they adjust their velocities due to variation of RI and come to focus at the same point. This phenomenon is known as **Focussing effect**. As a result, all the rays will be received at the output end at the same time. The output signals match with input signals. Thus, there is no intermodal dispersion in graded index fiber. The number of modes through graded index is equal to $V^2/4$.



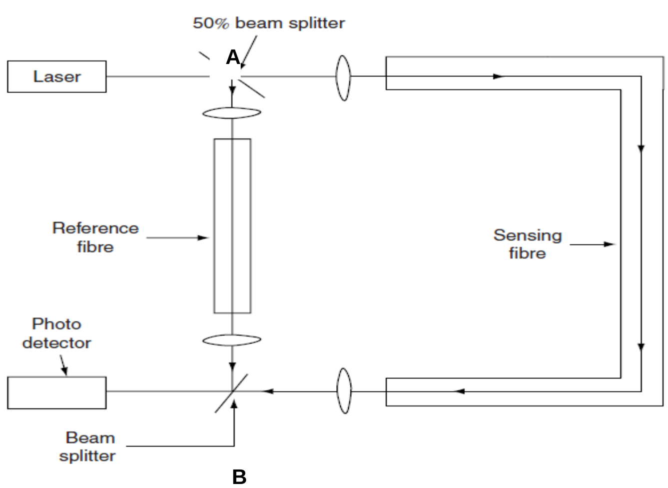


Applications of Optical Fibers:

<u>Fiber optic Sensors</u>:

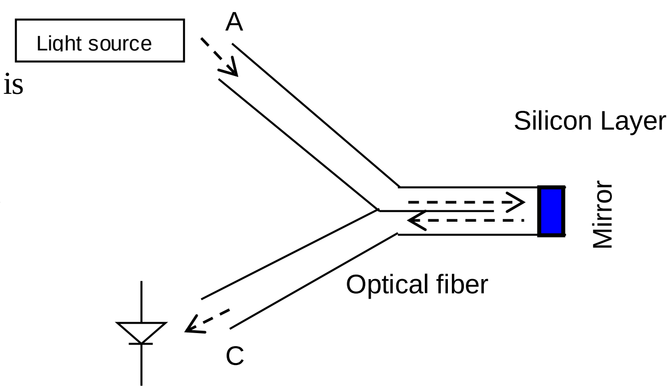
Sensors are devices used to measure/monitor quantities such as displacement, pressure, temperature, flow rate, liquid level, etc. Sensors developed using fibers are more sensitive and reliable.

i. Temperature sensor / Pressure sensor :



The light coming from the laser is divided into two rays with beam splitter (A). One beam (50%) passing through the sensing fiber, other beam (50%) through the reference fiber, the two beams were superimposed using another beam splitter (B) and causes interference pattern. The intensity of the fringes depends on the phase relation between the two waves. If the sensing fiber is subjected to temperature / pressure, as results the in refractive index changes / length changes, this causes change in phase of light at the end of the fiber. The phase change is directly proportional to magnitude of the change in pressure / temperature. If the waves are in phase, then the intensity is maximum; this happens when the sensing fiber is not disturbed. The intensity is minimum if the waves are out of phase due to $\lambda/2$ change in length of sensing fiber. The intensity of interference fringes can be measured with a photo detector and temperature or pressure changes can be measured.

(Or)



The typical temperature sensor with multimode fiber is shown in fig. One end (B) of the fiber is coated with thin silicon layer and it is coated with reflecting layer. Here silicon layer acts as the sensing element. Whenever light is launched in to the fiber at end 'A', the light passing through the fiber cable and then through silicon layer at B, then it is reflecting from mirror coating. Now once again light back through the silicon layer and finally the reflected light emerges out from end 'C' and is collected by a photo detector. The amount of reflected light is converted into voltage by the photo detector. The absorption of light by the silicon layer varies with temperature and the variation modulates the intensity of light received at the detector. Here the change in intensity of the reflected light is proportional to the change in temperature. This sensor sensitivity is about $\pm 0.001^0$C.

ii. Displacement Sensor:

The displacement sensor consists of a light source 'S', transmitting fiber 'T', receiving fiber 'R', an object 'O' and the detector 'D'. The fibers 'T & R' coupled properly to the source and detector. The light from laser source is passing through fiber cable 'T' and is incident on the moving object. The light is reflected from the moving object 'O' is received by the receiving fiber (R) and transmit it to a detector. The intensity of the light collected depends on the how far the reflecting target is from the fiber optic probe.

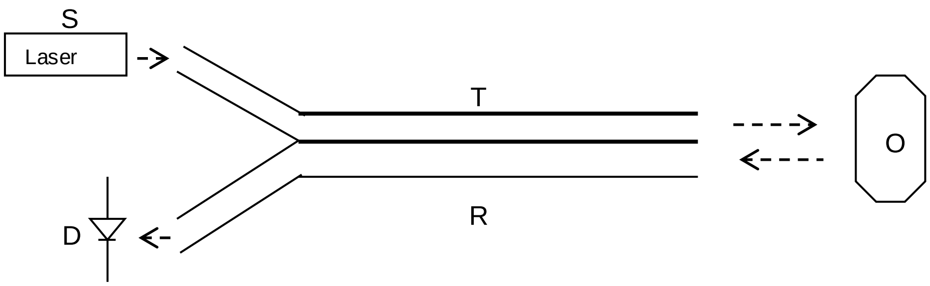


Fig. shows the detected light intensity versus distance from the target. The accuracy depends on the probe configuration. If there is increasing in the intensity of light (is noticed by the detector), the object is moving towards the sensor. If there is decreasing in the intensity, the object moving away from the sensor.

Note: If a bimetallic strip is attached to the reflecting surface in displacement sensor it serves as temperature sensor.

Applications of optical fibers:

1. Optical fibers are used in communication systems.
2. It is used to transmit the large number of TV signals in digital form
3. Optical fibers are used in endoscope, blood less surgeries.
4. These are used for removing the small blood blocking in heart, kidneys….
5. In the treatment of cancer also optical technology is used.
   (IR energy is transmitted through the fiber cables destroys the cancerous cells.)
6. Optical fibers are used in space vehicles, submarines, etc…
7. These are used in super computers, radars.
8. These are used as sensors (for measuring physical parameters like pressure, temperature, strain,
   magnetic field, acoustic field, liquid flow, moisture, etc….)
9. Glass fiber with stand up to 800° C, hence they are used in industry security / fire alarm systems.
10. Optical fibers are used in military application.
    (Aircraft, ships need tons of copper wire for communication equipment. For example, ship board radar
    system requires about 250 m cables with Wight about 7 Tones, if theses cable are replaced with optical
    fiber weighing 20 kg.)

Solved Problems

1. *The refractive indices of core and cladding materials of a step index fibre are 1.48 and 1.45, respectively. Calculate: (i) numerical aperture, (ii) acceptance angle, and (iii) the critical angle at the core-cladding interface and (iv) fractional refractive indices change.*

(Set-1–May 2006)

Sol: Let the refractive index of core, $n_1 = 1.48$

and the refractive index of cladding , $n_2 = 1.45$

(i) Numerical aperture $(\text{NA}) = \sqrt{n_1^2 - n_2^2}$

$$= \sqrt{(1.48)^2 - (1.45)^2} = \sqrt{2.1904 - 2.1025} = \sqrt{0.0879} = 0.2965$$

(ii) Let θ_0 be the acceptance angle

Then, $\sin\theta_0 = \text{NA} = \sqrt{n_1^2 - n_2^2}$

$\theta_0 = \sin^{-1}\sqrt{n_1^2 - n_2^2} = \sin^{-1}(0.2965) = 17°15'$

(iii) $n_2 \sin 90 = n_1 \sin\theta_c$ $\quad$ [θ_c = critical angle]

$\sin\theta_c = \dfrac{n_2}{n_1}$

$\theta_c = \sin^{-1}\dfrac{n_2}{n_1} = \sin^{-1}\left(\dfrac{1.45}{1.48}\right) = 78°26'$

(iv) The fractional refractive indices change, $\Delta = \dfrac{n_1 - n_2}{n_1} = \dfrac{1.48 - 1.45}{1.48} = 0.02$

2. *Calculate the angle of acceptance of a given optical fibre, if the refractive indices of the core and cladding are 1.563 and 1.498, respectively.*

(Set-3–Sept. 2008), (Set-1–May 2004)

Sol: Refractive index of core, $n_1 = 1.563$

Refractive index of cladding, $n_2 = 1.498$

Numerical aperture, $\text{NA} = \sqrt{n_1^2 - n_2^2} = \sqrt{1.563^2 - 1.498^2} = 0.446$

Acceptance angle, $\theta_0 = \sin^{-1}(\text{NA}) = \sin^{-1}(0.446) = 26°30'$.

3. *Calculate the fractional index change for a given optical fibre if the refractive indices of the core and cladding are 1.563 and 1.498, respectively.*

(Set-1–Sept. 2007), (Set-4–May 2004)

Sol: Refractive index of the core, $n_1 = 1.563$

Refractive index of cladding, $n_2 = 1.498$

The fractional refractive indices change, $\Delta = \dfrac{n_1 - n_2}{n_1} = \dfrac{1.563 - 1.498}{1.563} = 0.0416.$

4. *An optical fibre has a core material of refractive index 1.55 and cladding material of refractive index 1.50. The light is launched into it in air. Calculate its numerical aperture.*

(Set-4–May 2006), (Set-2–May 2004)

Sol: Refractive index of core, $n_1 = 1.55$

Refractive index of cladding, $n_2 = 1.50$

Numerical aperture, $\text{NA} = \sqrt{n_1^2 - n_2^2}$

$$= \sqrt{1.55^2 - 1.50^2} = 0.3905$$

5. *The numerical aparture of an optical fibre is 0.39. If the difference in the refractive indices of the material of its core and the cladding is 0.05, calculate the refractive index of material of the core.*

(Set-1–May 2008), (Set-3–May 2004)

Sol: Numerical aperture, NA = 0.39

The difference in refractive indices $= n_1 - n_2 = 0.05$ ____________ (1)

Refractive index of the core, $n_1 = ?$

From Equation (1)

$n_1 = n_2 + 0.05$ ____________ (2)

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

$0.39 = \sqrt{0.05 \times (n_1 + n_2)}$

$\dfrac{0.39^2}{0.05} = n_1 + n_2 = 3.042$ ____________ (3)

Substituting Equation (2) in (3), we get:

$3.042 = \text{n}_2 + 0.05 + n_2 = 2n_2 + 0.05$

$n_2 = 1.496$

$\therefore\ n_1 = n_2 + 0.05 = 1.493 + 0.05 = 1.546.$

6. *An optical fibre has a core material of refractive index 1.55 and cladding material of refractive index 1.50. The light is launched into it in air. Calculate its numerical aperture.*

(Set-4–May 2006), (Set-1–June 2005)

Sol: Refractive index of core, $n_1 = 1.55$

Refractive index of cladding, $n_2 = 1.50$

Numerical aperture, $\text{NA} = \sqrt{n_1^2 - n_2^2} = \sqrt{1.55^2 - 1.50^2} = 0.3905$

7. *Calculate the numerical aperature and acceptance angle for an optical fibre with core and cladding refractive indices being 1.48 and 1.45, respectively.*

(Set-4–May 2007), (Set-4–June 2005)

Sol: Refractive index of core, $n_1 = 1.48$

Refractive index of cladding, $n_2 = 1.45$

Numerical aperture, NA = ?

acceptance angle, $\theta_0 = ?$

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{1.48^2 - 1.45^2} = 0.2965$$

$$\theta_0 = \sin^{-1}\sqrt{n_1^2 - n_2^2} = \sin^{-1}0.2965 = 17°15'.$$

8. *Calculate the refractive indices of core and cladding of an optical fibre with a numerical aperture of 0.33 and their fractional difference of refractive indices being 0.02.*

(Set-2–May 2006)

Sol: Refractive index of core, $n_1 = ?$

Refractive index of cladding, $n_2 = ?$

Numerical aperture, NA = 0.33

Fractional difference of refractive index, $\Delta = 0.02$

$$\Delta = \frac{n_1 - n_2}{n_1} \quad \text{or} \quad 0.02n_1 = n_1 - n_2$$

$$n_2 = (1 - .02)$$

$$n_1 = 0.98n_1$$

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

$$0.33 = \sqrt{n_1^2 - (0.98n_1)^2}$$

$$0.33 = n_1 \times 0.198997$$

$$n_1 = 1.6583$$

$$n_2 = 0.98 \times 1.6583 = 1.625$$

9. *An optical fibre has a numerical aperture of 0.20 and a cladding refractive index of 1.59. Find the acceptance angle for the fibre in water which has a refractive index of 1.33.*

(Set-3–May 2006), (Set-1, Set-2, Set-4–Sept. 2006), (Set-2–May 2007), (Set-2–Sept. 2007)

Sol: Numerical aperture of the fibre, NA = 0.20

Refractive index of cladding , $n_2 = 1.59$

Refractive index of water, $n_0 = 1.33$

Acceptance angle of fibre in water, $\theta_0 = ?$

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

$$NA^2 = n_1^2 - n_2^2$$

$$0.04 = n_1^2 - (1.59)^2$$

$$n_1^2 = 0.04 + (1.59)^2$$
$$= 2.5681$$
$$n_1 = 1.60253$$

$$\sin\theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

$$= \frac{\sqrt{(1.60253)^2 - (1.59)^2}}{1.33}$$

$$= \frac{\sqrt{2.5681 - 2.5281}}{1.33} = \frac{0.2}{1.33}$$

$$= 0.15037$$
$$\theta_0 = \sin^{-1}[0.15037]$$
$$= 8°38'56''$$

10. *A fibre has the core and cladding refractive indices 1.45 and 1.44 respectively. Find the relative refractive index difference.*

(Set-4–Sept. 2007)

Sol: Refractive index of core (n_1) = 1.45

Refractive index of cladding (n_2) = 1.44

Relative refractive index difference (Δ)

$$= \frac{n_1 - n_2}{n_1} = \frac{1.45 - 1.44}{1.45} = 6.896 \times 10^{-3}$$

11. *The refractive index of core of step index fibre is 1.50 and the fractional change in refractive index is 4%. Estimate: (i) refractive index of cladding, (ii) numerical aperture, (iii) acceptance angle in air and (iv) the critical angle at the core-cladding interface.*

Sol: (i) The refractive index of the core, $n_1 = 1.50$

The fractional change in refractive index, $\Delta = \frac{n_1 - n_2}{n_1} = \frac{4}{100}$

where n_2 = refractive index of cladding

$$\therefore \frac{n_1 - n_2}{n_1} = 0.04$$

$$n_1 - n_2 = 0.04 \times 1.5 = 0.06$$
$$1.5 - n_2 = 0.06$$
$$\therefore n_2 = 1.44$$

(ii) Numerical aperture, $\text{NA} = \sqrt{n_1^2 - n_2^2}$

$$= \sqrt{(1.5)^2 - (1.44)^2} = \sqrt{2.25 - 2.0736} = \sqrt{0.1764} = 0.42$$

(iii) Acceptance angle, $\theta_0 = \sin^{-1}$ (NA)

$$= \sin^{-1}(0.42) = 24°50'$$

(iv) Critical angle, $\theta_c = \sin^{-1}\dfrac{n_2}{n_1}$

$$\sin^{-1}\frac{1.44}{1.50} = \sin^{-1} 0.96 = 73°44'$$

12. *The refractive indices of core and cladding of a step index optical fibre are 1.563 and 1.498, respectively. Calculate: (i) numerical aperture and (ii) angle of acceptance in air.*

Sol: Refractive index of core (n_1) = 1.563

Refractive index of cladding (n_2) = 1.498

(i) Numerical aperture (NA) = ?

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

$$= \sqrt{1.563^2 - 1.498^2} = 0.446$$

(ii) Acceptance angle (θ_0) = ?

$$\theta_0 = \sin^{-1}(\text{NA})$$

$$= \sin^{-1}(0.446)$$

$$= 26°30'$$

Multiple-choice Questions

1. The light sources used in fibre optic communication are. ( )

   (a) LEDs (b) semiconductor lasers
   (c) phototransistors (d) both a and b

2. Acceptance angle is defined as the __________ angle of incidence at the endface of an optical fibre, for which the ray can be propagated in the optical fibre is. ( )

   (a) maximum (b) minimum
   (c) Either a or b (d) none of the above

3. The core diameter of single mode step index fibre is about: ( )

   (a) 60 to 70 μm (b) 8 to 10 μm
   (c) 100 to 250 μm (d) 50 to 200 μm

4. In multimode graded index fibre, light rays travel __________ in different parts of the fibre. ( )

   (a) at different speeds (b) with same speed
   (c) both a and b (d) none of the above