(Optical Fiber - Basic Terms)

- As a light ray passes from one transparent medium to another, it changes direction; this phenomenon is called refraction of light. How much that light ray changes its direction depends on the refractive index of the mediums.

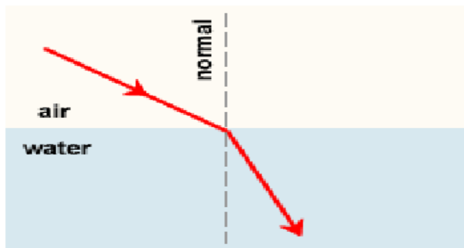

Fig.(1):Incident and transmitted rays at a boundary between two medium.

Refractive Index:

Refractive index is the speed of light in a vacuum (abbreviated **c**, **c**=299,792.458km/second) divided by the speed of light in a material (abbreviated **v**). Refractive index measures how much a material refracts light. Refractive index of a material, abbreviated as **n**, is defined as

$$n=c/v$$

Snell's Law:

In 1621, a Dutch physicist named Willebrord Snell derived the relationship between the different angles of light as it passes from one transparent medium to another. When light passes from one transparent material to another, it bends according to Snell's law which is defined as:

$$n_1\sin(\theta_1) = n_2\sin(\theta_2)$$

where:
n_1 is the refractive index of the medium the light is leaving
θ_1 is the incident angle between the light beam and the normal (normal is 90° to the interface between two materials)
n_2 is the refractive index of the material the light is entering
θ_2 is the refractive angle between the light ray and the normal

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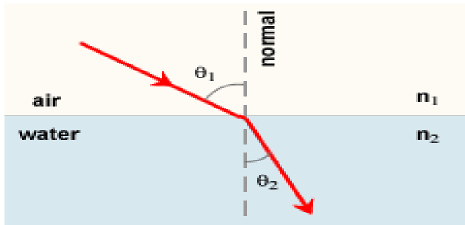

Fig.(2):Incident and transmitted rays at a boundary between two medium with angles.

Note:

For the case of $\theta_1 = 0°$ (i.e., a ray perpendicular to the interface) the solution is $\theta_2 = 0°$ regardless of the values of n_1 and n_2. That means a ray entering a medium perpendicular to the surface is never bent.

The above is also valid for light going from a dense (higher n) to a less dense (lower n) material; the symmetry of Snell's law shows that the same ray paths are applicable in opposite direction.

Total Internal Reflection:

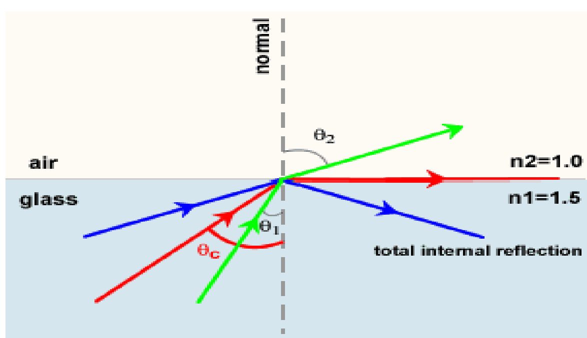

Fig.(3):Incident, reflected and transmitted rays at a boundary between two medium.

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When a light ray crosses an interface into a medium with a higher refractive index, it bends towards the normal. Conversely, light traveling cross an interface from a higher refractive index medium to a lower refractive index medium will bend away from the normal.

This has an interesting implication: at some angle, known as the **critical angle θ_c**, light traveling from a higher refractive index medium to a lower refractive index medium will be refracted at 90°; in other words, refracted along the interface.

If the light hits the interface at any angle larger than this critical angle, it will not pass through to the second medium at all. Instead, all of it will be reflected back into the first medium, a process known as **total internal reflection**.

The critical angle can be calculated from Snell's law, putting in an angle of 90° for the angle of the refracted ray θ_2. This gives θ_1:

$$\theta_1=\sin^{-1}[(n_2/n_1) * \sin(\theta_2)]$$

Since

$$\theta_2 = 90°$$

So

$$\sin(\theta_2) = 1$$

Then

$$\theta_c = \theta_1 = \sin^{-1}(n_2/n_1)$$

For example, with light trying to emerge from glass with n_1=1.5 into air (n_2 =1), the critical angle θ_c is $\sin^{-1}(1/1.5)$, or 41.8°.

For any angle of incidence larger than the critical angle, Snell's law will not be able to be solved for the angle of refraction, because it will show that the refracted angle has a sine larger than 1, which is not possible. In that case all the light is totally reflected off the interface, obeying the law of reflection.

The Structure of an Optical Fiber

Optical fiber is a long, thin strand of very pure glass about the diameter of a human hair. Optical fibers are arranged in bundles called **optical cables** and used to transmit light signals over long distances. Typical optical fibers are composed of core, cladding and buffer coating.

The core is the inner part of the fiber, which guides light. The cladding surrounds the core completely. The refractive index of the core is higher than that of the cladding, so light in the core that strikes the boundary with the cladding at an angle larger than critical angle will be reflected back into the core by total internal reflection. Optical fibers are based entirely on the principle of total internal reflection. This is explained in the following picture.

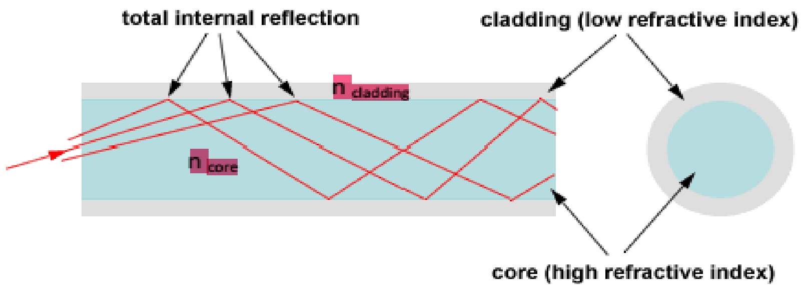

Fig.(4): Total Internal Reflection (TIR) in optical fibers.

For the most common optical glass fiber types, which includes 1550nm single mode fibers and 850nm or 1300nm multimode fibers, the core diameter ranges from 8 ~ 62.5 µm. The most common cladding diameter is 125 µm. The material of buffer coating usually is soft or hard plastic such as acrylic, nylon and with diameter ranges from 250 µm to 900 µm. Buffer coating provides mechanical protection and bending flexibility for the fiber.

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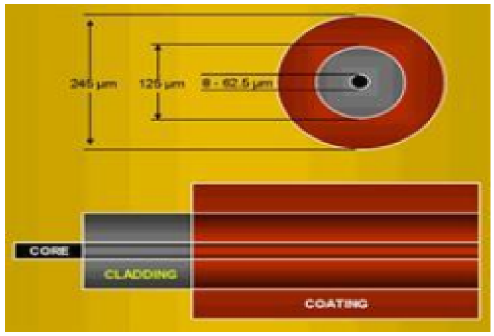

Fig.(5): Optical Fiber Design.

Types of Optical Fibers:

According to the refractive index profile optical fibers can be divided into two categories namely **Step index fibers** and **Graded index fibers** which are described below.

1- Step index fibers :

If the refractive index profile of a fiber makes a step change at the core cladding interface then it is known as step index fiber. A multimode step index fiber is shown in figure 6(a), the core diameter of which is around 50µm. Some physical parameters like relative refractive index, index difference, core radius etc determines the maximum number of guided modes possible in a multimode fiber. A single mode fiber has a core diameter of the order of 2 to 10µm and the propagation of light wave is shown in fig.6(b) It has the distinct advantage of low intermodal dispersion over multimode step index fiber. On the other hand multimode step index fibers allow the use of spatially incoherent optical sources and low tolerance requirements on fiber connectors.

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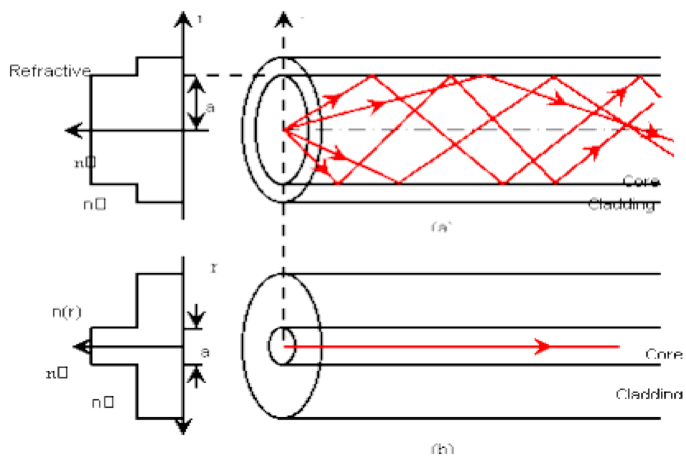
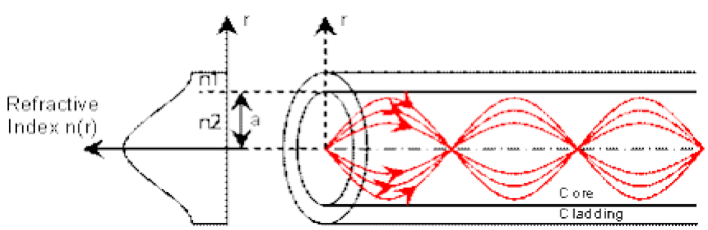


Fig.(6): (a) multimode step index fiber. (b) Single mode fiber

2- Graded index fibers :

The graded index fibers have decreasing core index $n_{(r)}$ with radial distance from a maximum value of n_1 at the axis to a constant value n_2 beyond the core radius a in the cladding as shown in figure 7. The graded index fiber gives best results for multimode optical propagation for parabolic refractive index profile. Due to this special kind of refractive index profile multimode graded index fibers exhibit less intermodal dispersion than its counterpart i.e. multimode step index fibers.



Figure(7): Multimode Graded Index Fiber.

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