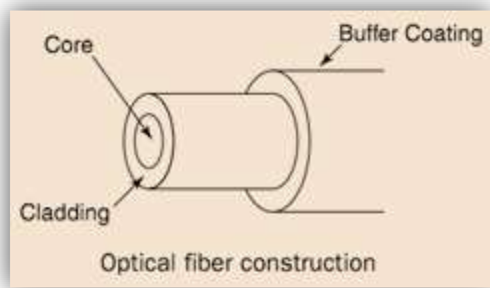
<u>Optical Fiber Construction and Light Guiding</u>



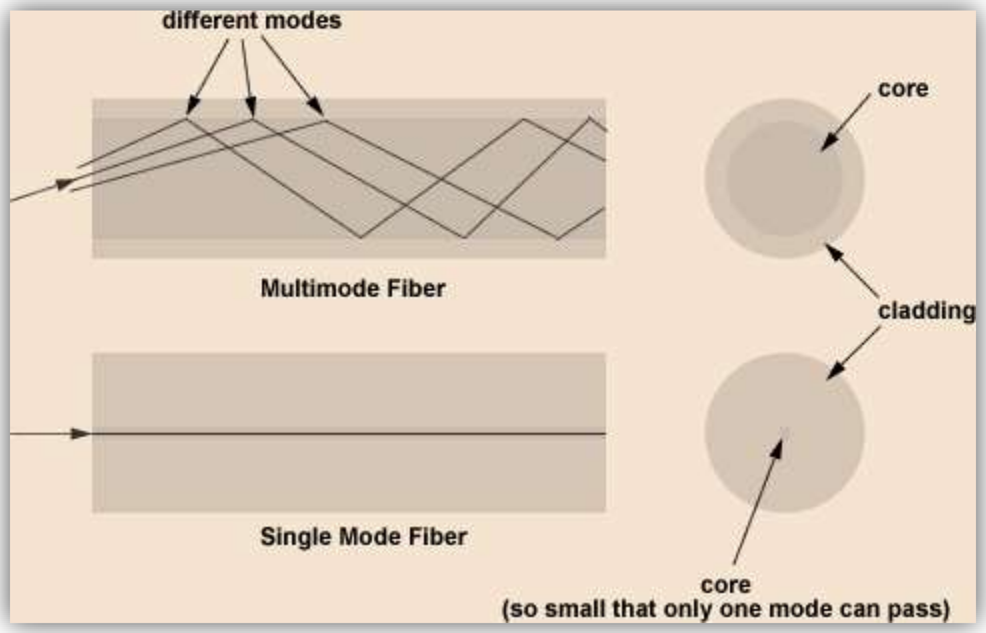
Optical fiber (shown here) is comprised of a light-carrying core (higher refractive index) surrounded by a cladding (lower refractive index). This construction traps the light in the core by the principle of Total Internal Reflection.

Since the fiber core has a higher refractive index, the light in the core is totally reflected at the boundary of the cladding for all light that strikes at greater than the critical angle.

The core and cladding are usually fused silica glass covered by a plastic coating, called the buffer. The buffer protects the glass fiber from physical damage and moisture.

Optical Fiber Mode

What is Fiber Mode?



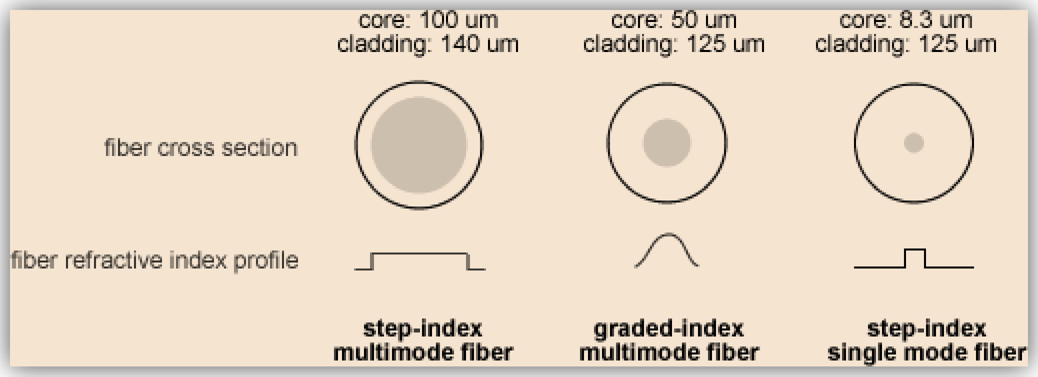
An optical fiber guides light waves in distinct patterns called *modes*. Mode describes the distribution of light energy across the fiber. The precise patterns depend on the wavelength of light transmitted and on the variation in refractive index that shapes the core. In essence, the variations in refractive index create boundary conditions that shape how light waves travel through the fiber, like the walls of a tunnel affect how sounds echo inside.

We can take a look at large-core step-index fibers. Light rays enter the fiber at a range of angles, and rays at different angles can all stably travel down the length of the fiber as long as they hit the core-cladding interface at an angle larger than critical angle. These rays are different modes.

Fibers that carry more than one mode at a specific light wavelength are called multimode fibers. Some fibers have very small diameter core that they can carry only one mode which travels as a straight line at the center of the core. These fibers are single mode fibers. This is illustrated in the picture shown above.

Optical Fiber Index Profile

Index profile is the refractive index distribution across the core and the cladding of a fiber. Some optical fiber has a step index profile, in which the core has one uniformly distributed index and the cladding has a lower uniformly distributed index. Other optical fiber has a graded index profile, in which refractive index varies gradually as a function of radial distance from the fiber center. Graded-index profiles include power-law index profiles and parabolic index profiles. The following figure shows some common types of index profiles for single mode and multimode fibers.

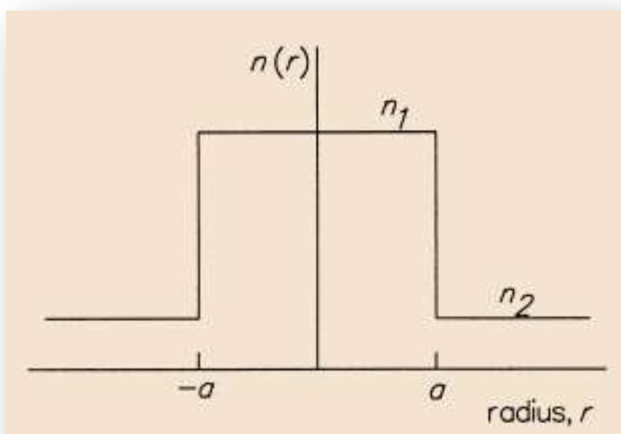


Refractive Index Profile of a Step-Index Fiber

The corresponding refractive index distribution (in the transverse direction) is given by

$$\mathbf{n(r) = n_1, 0 < r < a \ \ (core)}$$

$$\mathbf{= n_2, r > a \ \ (cladding)}$$



Refractive index profile of a step-index fiber.

where r is the cylindrical radial coordinate and a is the radius of the core. Typically, for a step index (multimode) silica fiber,

$$\mathbf{n_1 \approx 1.48, \ \ n_2 \approx 1.46, \ \ a \approx 25um}$$

This following table summarizes some of the typical parameters associated with standard fibers. (the values are representative only). Δ is the fractional change in the index of refraction, given by

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \approx \frac{n_1 - n_2}{n_1}$$

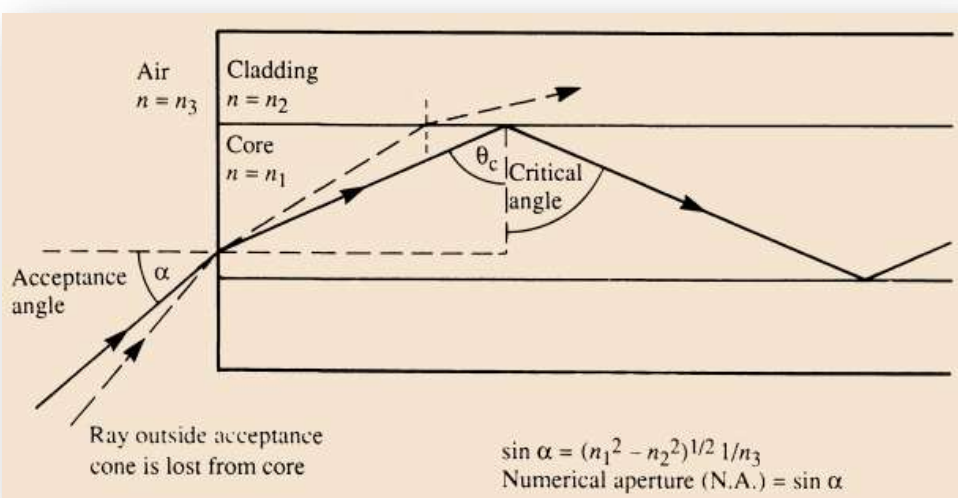
Type	core diam. (um)	cladding diam. (um)	△	Application
8/125 Single Mode	8	125	0.1% to 0.2%	long distance, high data rate
50/125 Multimode	50	125	1% to 2%	short distance, moderate data rate
62.5/125 Multimode	62.5	125	1% to 2%	local area network
100/140 Multimode	100	140	1% to 2%	local area network, short distance

Optical Fiber's Acceptance Angle and Numerical Aperture

Another way to look at light guiding in a fiber is to measure the fiber's acceptance angle – the angle over which light rays entering the fiber will be guided along its core. Let's look at the illustration below.

It can be seen that a ray that meets the first core-cladding interface at the critical angle. This ray meets the fiber core at an incident angle of α, this incident angle α is defined as the acceptance angle of the fiber.

Any light rays incident at the fiber core with an angle greater than α will not be refracted sufficiently to undergo Total Internal Reflection at the core-cladding interface, and therefore, although they will enter the core, they will not be accepted into the fiber for onward transmission.



Acceptance angle is measured in air (refractive index ≈ 1) outside the fiber. The acceptance angle normally is measured as **Numerical Aperture (NA)**, which for light entering a fiber from air is approximately

$$NA = n_{air} * sin\alpha = 1 * sin\alpha = \sqrt{n_1^2 - n_2^2}$$

So for a typical fiber n_1 = 1.48, n_2 = 1.46, NA = 0.242. This implies the acceptance angle is about 14°.

The amount of light accepted into a fiber is directly proportional to its core cross-sectional area and the square of its numerical aperture. The NA of a fiber is a very important property and essentially determines the efficiency of coupling from a light source to the fiber as well as losses across a misaligned joint in a splice.

To maximize the amount of light accepted it is normal to choose fibers with large core diameter and high NA but, as we will see later in the discussion of modes in optical fiber, these fibers tend to lose most light and have relatively low bandwidths.

References