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Lecture 5 : *Optical fiber waveguide*

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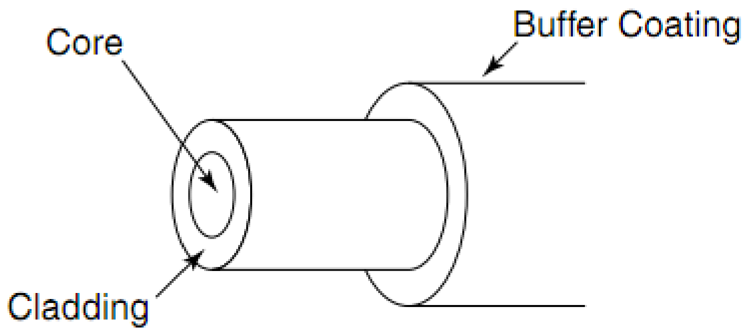
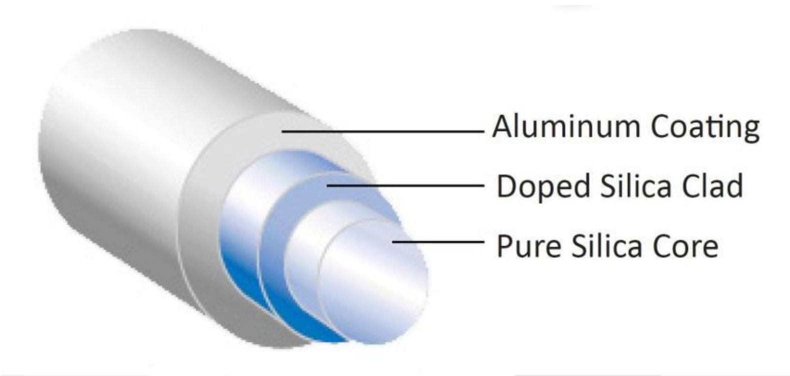
1. Optical Fiber : A long cylindrical dielectric waveguide, usually of circular cross-section, transparent to light over the operating wavelength.

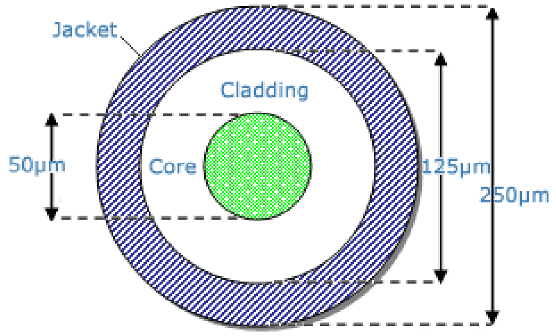


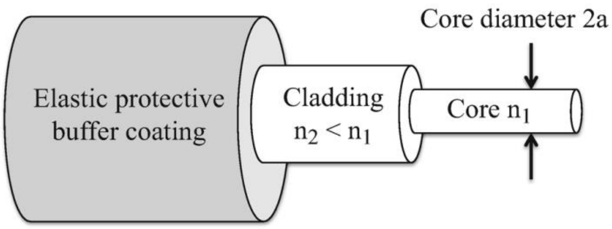
Optical fiber construction

2. Fiber Structure

A solid dielectric of two concentric layers. ¬ Inner layer - Core of radius ‘a’ and refractive index ‘$\mathbf{n_1}$ ’ ¬ Outer layer - Cladding has refractive index ‘$\mathbf{n_2}$ ’. $\mathbf{n_2 < n_1}$ → Condition necessary for TIR.



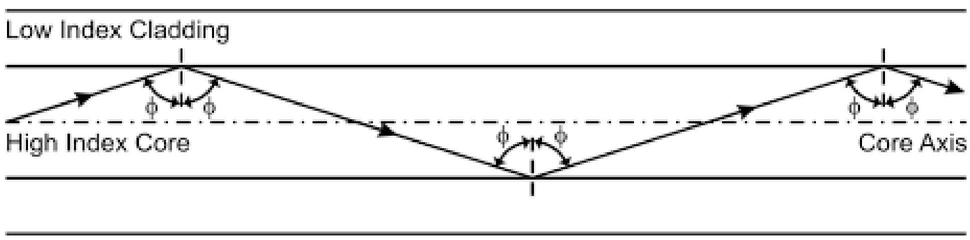


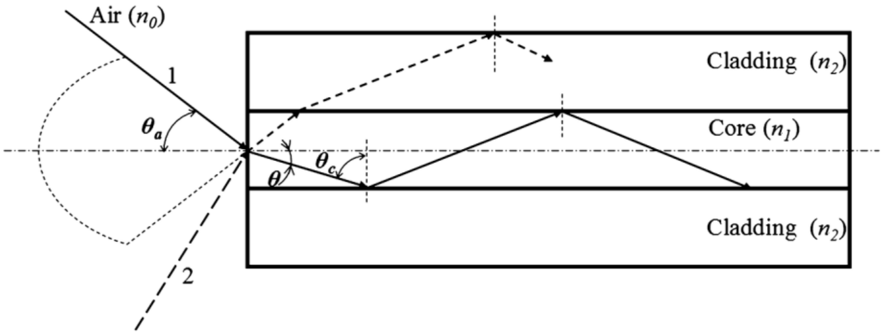


1. The optical fiber is a waveguide used for transmission of light. It consists of a dielectric fiber core, usually (pure silica), surrounded by a layer of (doped silica) characterized by <u>the refraction index lower than that of the core</u>, then coated by aluminum layer.
2. The light transmitted through the optical fiber is trapped inside the core due to the total internal reflection phenomenon. The total internal reflection occurs at the core-cladding interface when the light inside the core of the fiber is incident at an angle greater than the critical angle **θc** and allows for light propagation along the fiber.

3. The amount of light reflected at the interface changes **depending on** the incidence angle and the refraction indexes of the core and the cladding.
4. Fibers are waveguides that guide in two dimensions and can effectively be used as flexible pipes for light.
5. An optical ray is guided by total internal reflections within the fiber core if its angle of incidence on the core-cladding boundary is greater than the critical angle

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$





Light rays subtending an angle greater than critical angle will get guided by the fiber :

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

Typical values of NA = 0.2 to 0.6

Acceptance angles = 11.5º to 37º

The acceptance angle is the maximum angle at which light-ray enters or hits the fiber core and getting propagate though it in zig-zag path. The acceptable angle

θa is determined by the refractive index contrast between core and cladding of the fiber with assumption that the incident beam comes from air or vacuum.

Note : **Any rays which are incident into the fiber core at an angle > θa have an incident angle less than θc at the core-cladding interface. These rays will NOT be totally internal reflected.**

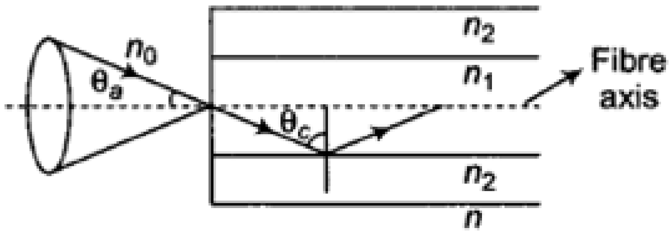
The fiber acceptance angle is related to the numerical aperture as:

$$NA = n_1 \sin \theta a = \sin \theta a = \sqrt{(n_1^2 - n_2^2)}$$

3. Example 1

What is the fiber acceptance angle θ_a when $n_1 = 1.46$ and $n_2 = 1.44$?

{ Light rays will be confined inside the fiber core if it is input-coupled at the fiber core end-face within the acceptance angle θa}



Acceptance angle of fibre

$\theta c = \sin^{-1} (n_2/n_1) = \sin^{-1}\left(\frac{1.44}{1.46}\right) = \sin^{-1} 0.986 = 80.5o$ =>

$\alpha_c = 90^o - \theta_c = 9.5o$ (α_c هي الزاوية المقابلة ل θc في المثلث القائم الزاوية اعلاه)

applying Snell's law :

n_1 sine $\theta_1 = n_2 \sin \theta_2$ =>

$n_1 \sin \theta a = n_2 \sin \alpha_c$

$1 \times \sin \theta a = 1.44 \times \sin 9.5$ =>

$\sin \theta a = 1.44 \times 0.165 = 0.2376$

Thus, $\theta a = \sin^{-1}(0.2376) = 13.7^0 \approx 14^0$

4. **Example 2**

What is the fiber numerical aperture when $n_1 = 1.46$ and $n_2 = 1.44$?

$$NA = \sin \theta a = \sqrt{(n_1^2 - n_2^2)} = (1.46^2 - 1.44^2)^{1/2} = 0.24$$

It is a common practice to define a relative refractive index Δ as:

$$\Delta = (n_1 - n_2) / n_1 \Rightarrow NA = n_1 (2\Delta)^{1/2}$$

i.e. Fiber NA only depends on n1 and Δ

5. Medical instrument designers of in-body detection solutions depend on the flexibility and robust construction of Flexible Fiber Optic Light Guides. Ideal for thrombosis, endoscopy and other small area imaging applications. These guides can be sent through complex pathways, and can be used in corrosive, hazardous and high-voltage environments without damage. These guides are also ideal for reduced weight applications to provide small-fiber lighting, including vehicle, space and aviation instrumentation. Fiber Optic Lighting solutions can withstand temperatures to 250°C.
6. The use of fiber optics provides **doctors the ability to deliver UV and IR laser power for the destruction and removal of diseased tissues**, the devices used are called arthroscopes or endoscopes.
7. **Bandwidth–distance product (or bandwidth–length product)**

   It is usually defined as **the product of the length of a fiber-optic link and its maximum signal bandwidth**.

   The bandwidth-distance product is usually stated in megahertz-kilometer (MHz-km) or gigahertz-kilometer (GHz-km).

Note: The bandwidth · distance factor implies that bandwidth and distance are reciprocally related. عرض نطاق الليف الزجاجي يتناسب عكسيا مع طوله