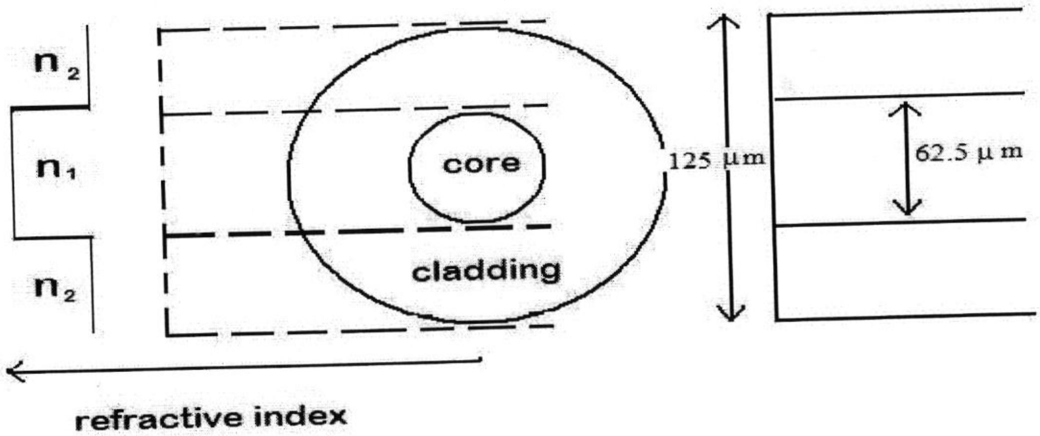
Lecture 2

2.0 Optical Fibers

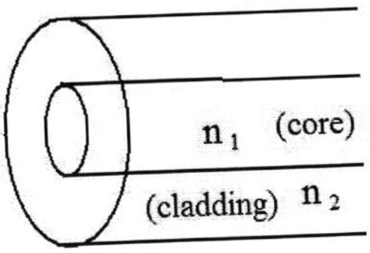
Step-index fiber .The basic structure



- An optical fiber is a thin, transparent, flexible strand and consists of a core surrounded by cladding.
- The core and cladding are made of the same material; a type of glass known as silica. The only differ in their refractive indexes.
- In step indexes, the structure looks like a step in terms of their refractive index.
- The differences in the refractive indexes can be achieved by doping the silica with different dopants, resulting into a strict optical boundary between the core and cladding.

- The third layer is a coating applied over the cladding to protect the entire structure (can be made of different materials, e.g. polymers)
- The most important concept is the total internal reflection at the core-cladding interface/boundary. The core's refractive index n_1 be greater than cladding's index n_2:

$$n_1 > n_2$$



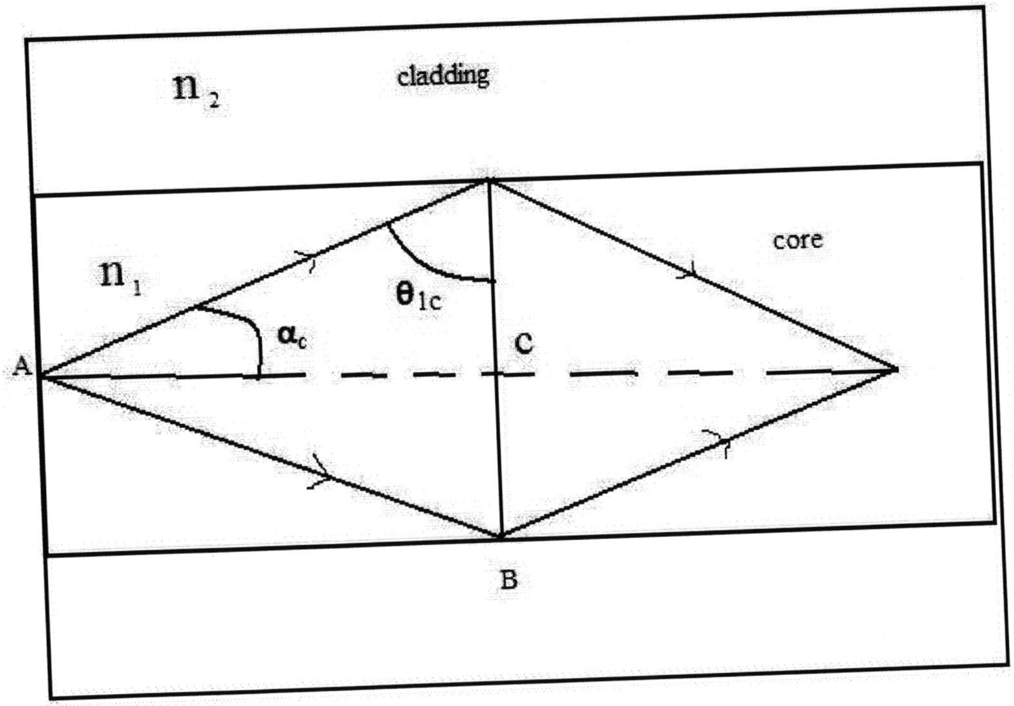
Total internal reflection, critical angle and critical propagation angle.

- Critical incident angle, θ_{1c}
- Critical propagation angle, α_c

} Two Important parameters

- The critical incident angle, θ_{1c} is the angle the beam makes with the line perpendicular to the optical boundary between the core and cladding.
- The critical propagation angle, α_c is the angle the beam makes the centerline of the optical fiber (critical angle).

Figure 2.2



From the figure, the right angle triangle A-B-C:

$$\alpha_c = 90^\circ - \theta_{1c}$$

<u>E.g.</u> $n_1=1.48$, $n_2= 1.46$ to have total internal reflection (light trapped)

$n_1 \sin\theta_1 = n_2 \sin\theta_2$, critical angle , $\theta_2 = 90^\circ$

$$\sin\theta_{1c} = n_2 / n_1$$

Therefore $\theta_{1c} = \sin^{-1}\left(\frac{n2}{n1}\right) = \sin^{-1}(0.9865) = 80.57^\circ$

This implies that θ must be more than 80.57° for the light to be trapped in the core through total internal reflection.

Why is α_c important?

Let us say a beam has an angle $\alpha = 10^\circ > \alpha_c$ $(\alpha > \alpha_c)$

then $\theta_1 < \theta_{1c}$ →The condition for total internal reflection has been violated ; it is important to maintain the angle α less than α_c $(\alpha < \alpha_c)$

Note : The critical propagation angle α_c represents the requirement to achieve total internal reflection , a necessary condition to propagate light into fiber.

E.g. core, n_1=1.48 and cladding, n_2=1.46. Find the critical propagation angle.

a) From $\sin\theta_{1c} = n_2/n_1$, since $\alpha_c = 90^\circ - \theta_{1c}$,

$$\therefore \quad \sin\theta_{1c} = \cos\alpha_c$$

Hence, $\cos\alpha_c = n_2/n_1$

Or $\sin\alpha_c = \sqrt{1 - \cos^2 \alpha_c}$

$$\text{Hence } \alpha_c = \sin^{-1}\sqrt{1 - \left[\frac{n_2}{n_1}\right]^2}$$

$$= \sin^{-1}\sqrt{1 - \left[\frac{1.46}{1.48}\right]^2}$$

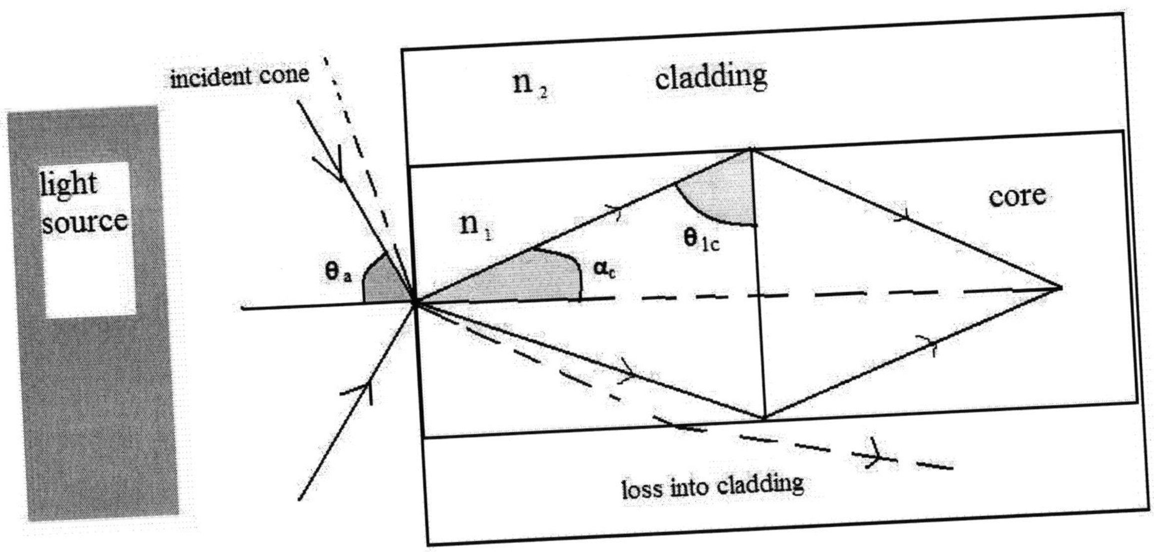
$$= 9.43^\circ$$

b) For plastic fiber, n_1=1.495 ((core), n_2=1.402 (cladding)

$$\alpha_c = \sin^{-1}\sqrt{1-\left[\frac{n_2}{n_1}\right]^2} \quad \text{..... (2.2)}$$

Acceptance Angle

- How to launch the light so that satisfies the angle α_c
- LED / LD



- At the gap fiber interface, the beam at an angle θ_a is the incident beam that will be refracted into the core α_c..

From Snell's Law, $n_a \sin\theta_a = n_1 \sin\alpha_c$ ...... (2.3)

N_a : air (gap is assumed to be air)

$\sin\theta_a = n_1 \sin\alpha_c$ ..... (2.3a)

- To have light inside the fiber, we have to direct it from the

outside of the fiber at an angle of θ_a or less.

- Should be confined to within the core 2 θ_a

Where 2 θ_a = acceptance angle

E.g. a) Find the acceptance angle for the fiber when

n_1=1.48 and n_2 = 1.46

From Snell's Law, $n_a \sin \theta_a = n_1 \sin \alpha_c$

For air , n_a = 1.00

$\therefore \alpha_c = 9.43^\circ$

Hence $\sin \theta_a$ =1.48 , $\sin 9.43^\circ$ = o.2425

Numerical Aperture (NA)

- The acceptance angle is normally measured as NA.All the sbove can be written in terms of NA.
- The numerical aperature ,NA is given as :

$$NA = \sin \theta_a \quad ....(2.4)$$

But $\sin \theta_a = n_1 \sin\alpha_c$ and $\sin \alpha_c = \sqrt{1 - \left[\frac{n_2}{n_1}\right]^2}$

$$\therefore NA = n_1 \sin \alpha_c = n_1 \sqrt{1 - \left[\frac{n_2}{n_1}\right]^2}$$

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

n_1 : refractive index of the core

n_2 : refractive index of the cladding

E.g. a) NA of fiber with n_1=1.48,n_2 =1.46

$$NA = \sqrt{n_1^2 - n_2^2}$$
$$= \sqrt{1.48^2 - 1.46^2}$$
$$= 0.2425$$

b)For plastic fiber,NA = $\sqrt{1.495^2 - 1.402^2}$

= 0.5192

Note: We depend on only two parameters, n_1 and n_2.

Flow diagram

$\Theta_{1c} \rightarrow \alpha_c \rightarrow \theta_a \rightarrow NA$

Fiber optic communication technology makes of the numerical aperture, NA , which is described as the ability of an optical fiber to gather light from a source and then the ability to preserved.

Note: NA can also be related with the differences of the refractive indexes, Δn, where $\Delta n = n_1 - n_2$ (core-cladding).

$$\therefore \quad \Delta n = n_1 - n_2 \quad \text{..... (2.6)}$$

Δn is always positive

$$\Delta = \frac{n_1 - n_2}{n} \quad \text{...... (2.7)}$$

Δ is the reflective index

n is the average refractive index = $\frac{n_1+n_2}{2}$

Note : In reality n_1 is very close to n_2

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

To change NA we need to vary n and Δn to make NA from 0.1 to 0.3

- How to measure NA?