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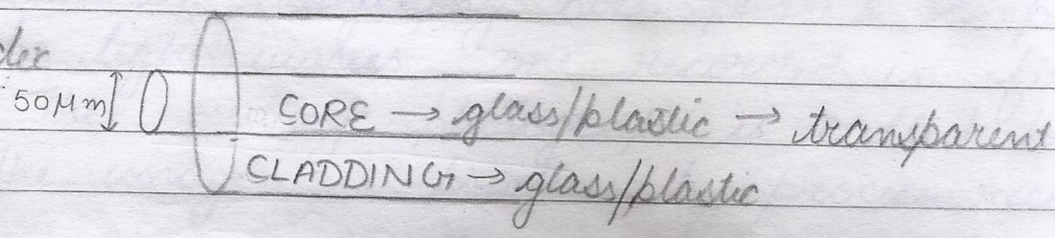
FIBRE OPTICS

- Optical fibre - It is a very thin glass or p[...] conduit designed to guide light waves [...] the length of fibre

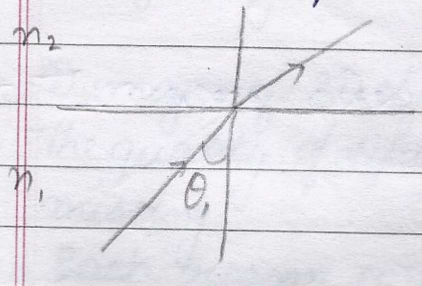
As long as refractive index of this fi[...] is greater than that of its surrounding[...] light shall suffer a large no. of total inte[...] reflections & hence much of light launched [...] one end will emerge from other end due [...] small losses.

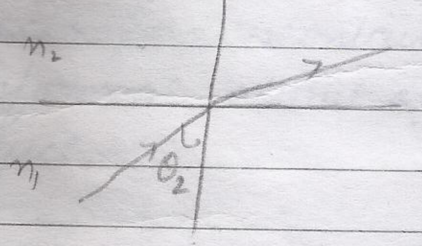
refractive index
CORE = n_1
Cladding = n_2



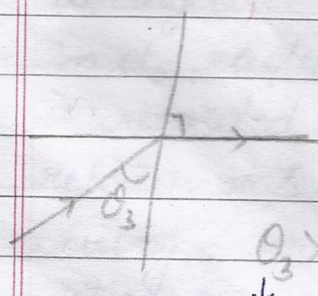
- The basic principle of optical fibre is TIR

$n_1 >$ [...]

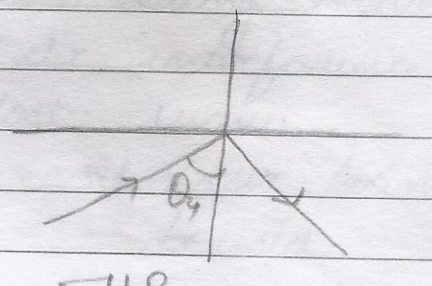




$\theta_2 > \theta$[...]



$\theta_3 > \theta_2 > \theta_1$
↓
θ_c → critical angle



$\theta_4 > \theta_3 > \theta_1$ [...]

TIR

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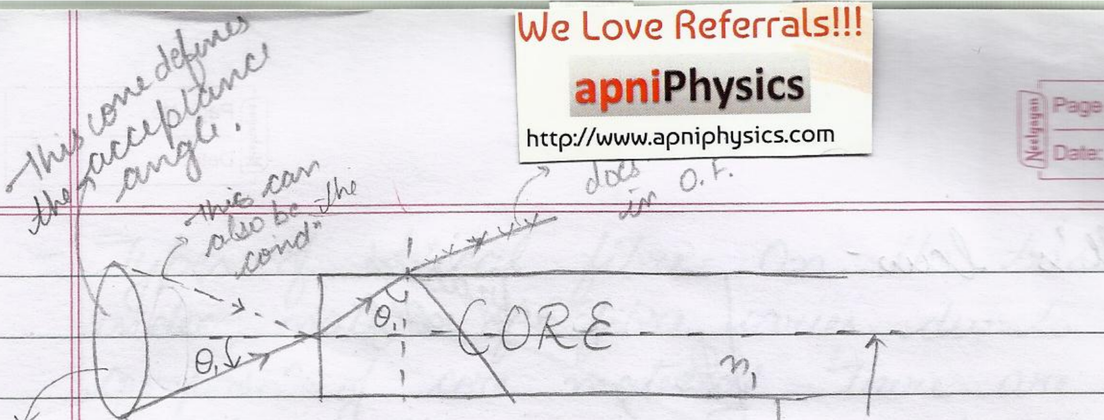
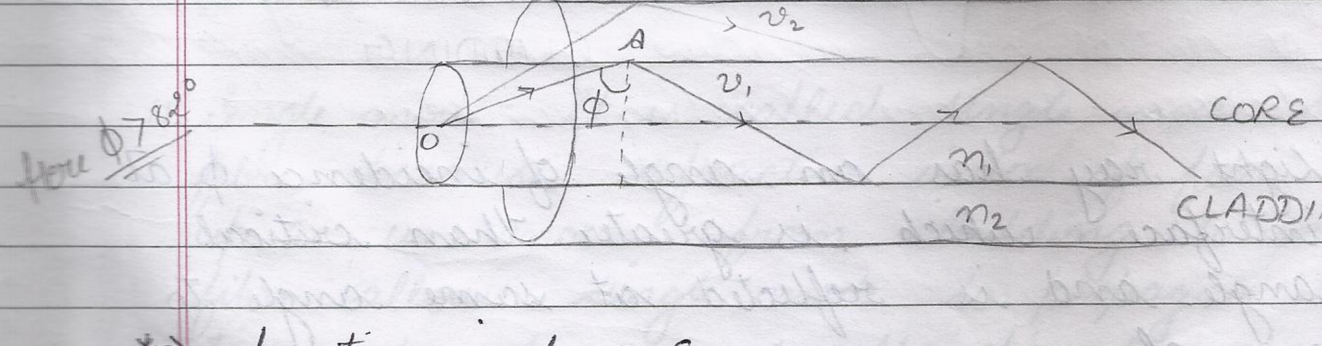


The light which will entre through this cone, TIR of that light will definitely take place.

- The transmission & reflection of any light ray depends on n_1 & n_2.
- If signal entre in cladding, then signal is lost.
- Optical fibres ~~are~~ use~~d~~ light to carry digit-al signals
- The basis of this technology is TIR.
- The digital signal that is carried by ligh-t is reflected inside optical cable & hence transfers informa^n
- Main concepts of physics involved in Optical fibre are refraction, refractive indeces, critical angle, and TIR.
- In case of optical fibre, critical angle is 82°.



$\star \rightarrow$ refractive index $= \frac{c}{v}$

- There is no role of cladding except to protec^n of core.

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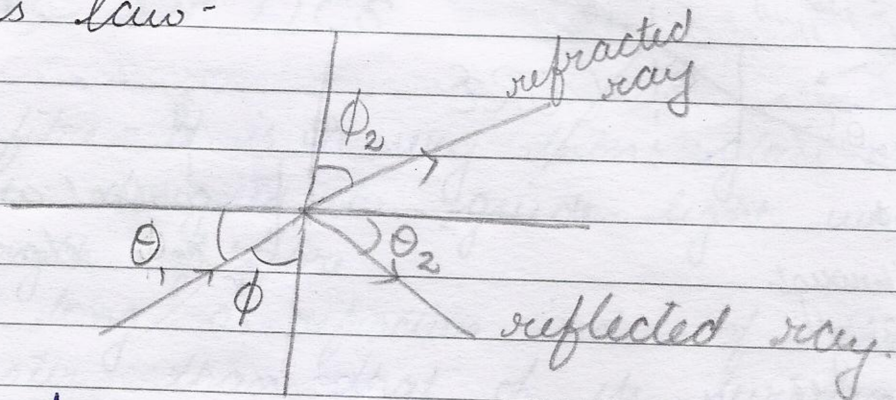
- Snell's law -



$n_1 \sin \phi_1 = n_2 \sin \phi_2$

$\phi_1 = \phi_c$ when $\phi_2 = 90°$

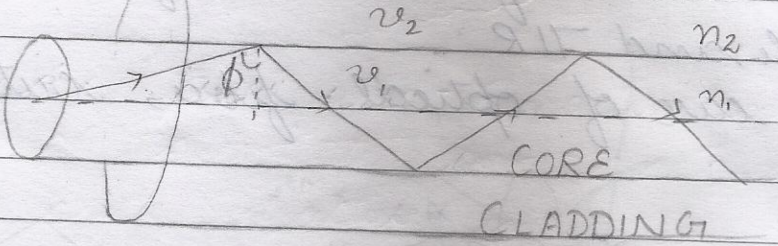
$\Rightarrow n_1 \sin \phi_c = n_2 \sin 90° = n_2$

$\Rightarrow \sin \phi_c = \dfrac{n_2}{n_1}$

or $\boxed{\phi_c = \sin^{-1} \dfrac{n_2}{n_1}}$

also $\boxed{n_1 \cos \theta_1 = n_2 \cos \theta_2}$

- Transmission of light ray in optical fibre



Light ray has an angle of incidence ϕ at interface which is greater than critical angle and is reflected at same angle to normal.

- Mode of a wave guide - propaga^n of a light along waveguide can be described as set of guided electromagnetic wave

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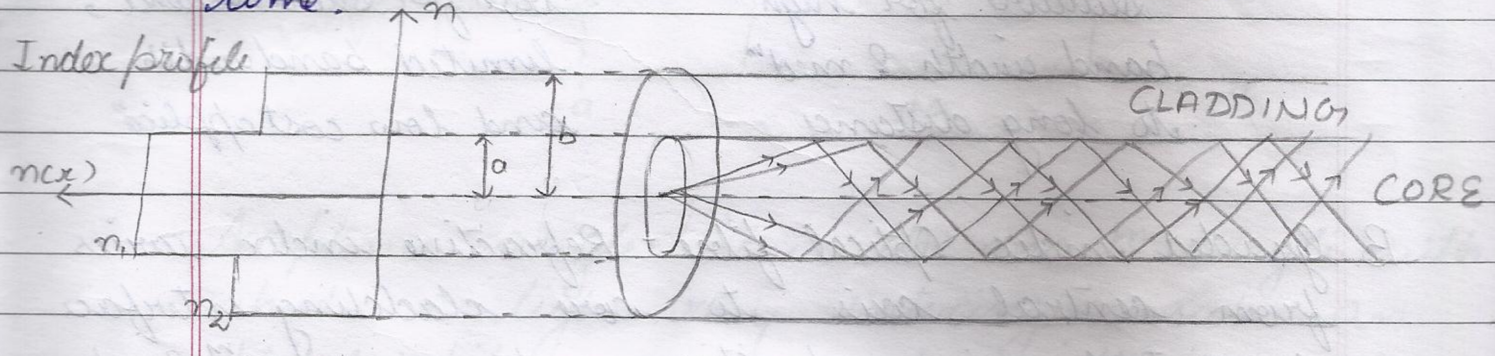
– Types of optical fibre – On the basis of refractive index, nature of fibre varies due to variaⁿ in composiⁿ of core material. There are two types of optical fibre on the basis of refractive index:

i) Step index optical fibre
ii) Graded index optical fibre

A. Step index optical fibre – In it, refractive index is constant throughout the core along the length & diameter & abrupt change occurs in step of core cladding interface.

Types of step index optical fibre –

1. Multimode – These allow more than one mode to propagate. Over 100 modes can propagate at a time.



II. Single mode – It is called single mode step index fibre because refractive index of fibre steps up as we move from cladding to core & this fibre allows single mode to propagate at a time due to very small diameter of its core.

P. T. O. –

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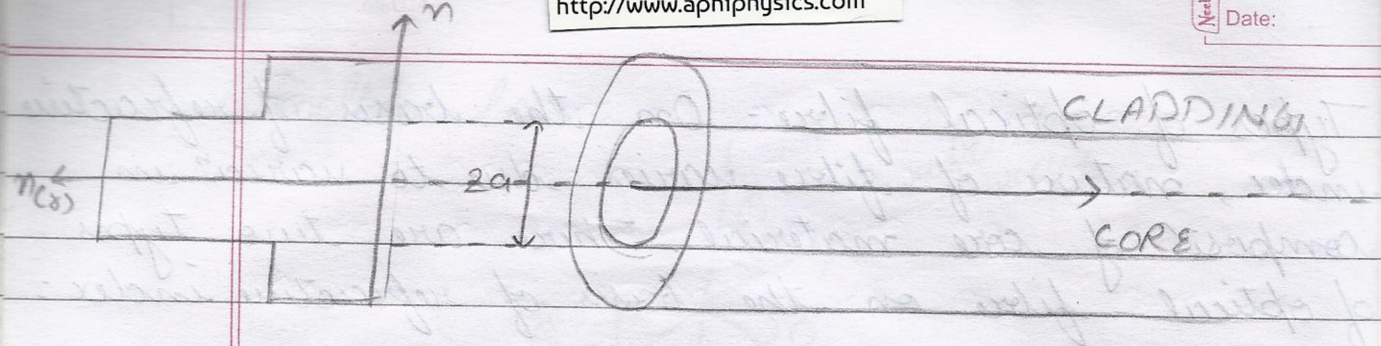
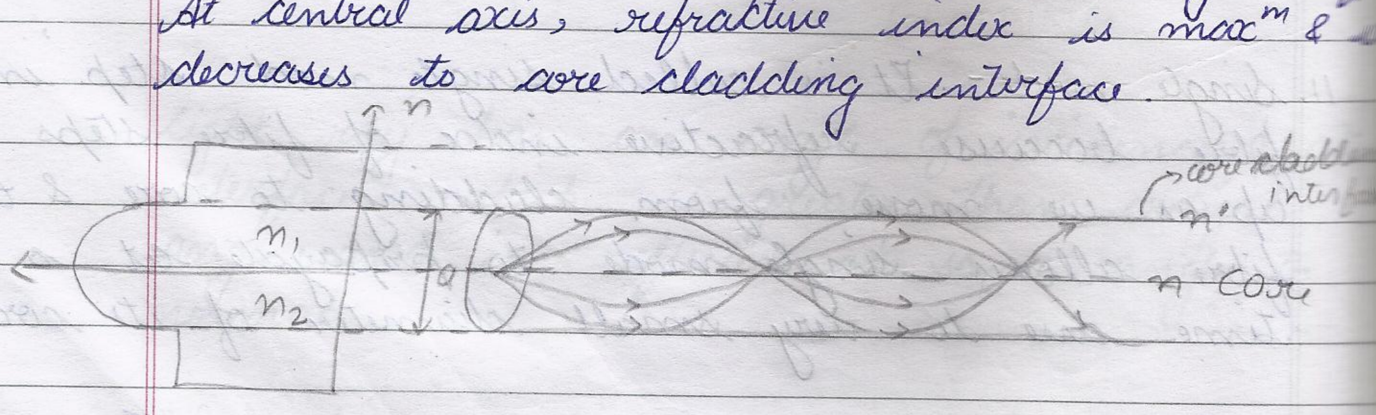


	Single mode S.I. O.F.	Multimode S.I. O.F.
Core diameter	5-8 μm (0-10)	50-80 μm
Cladding diameter	120 μm	125 μm
Numerical aperture	0.08 - 1.5	0.16 - 0.5
Band width	>500 MHz km	6-50 MHz km
	Suitable for high band width & med^m to long distance	best for short distance limited bandwidth and low cost applic^n

B. Graded index Optical fibre - Refractive index varies from central axis to core cladding interface. At central axis, refractive index is max^m & decreases to core cladding interface.



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In above fig, we see that all signals reache-d on same time. This is due to the formula:

$$n = c/v \quad -(1)$$

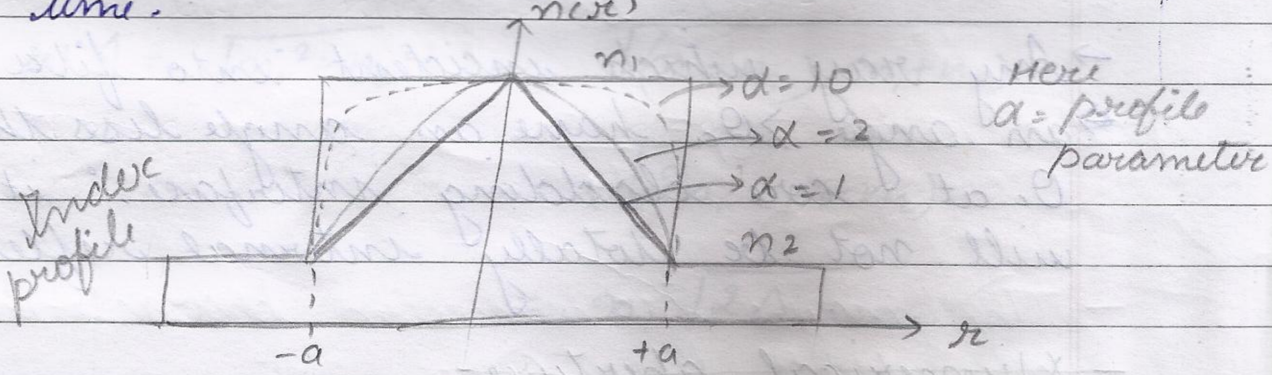
as $n > n'$

$\therefore$ from (1)

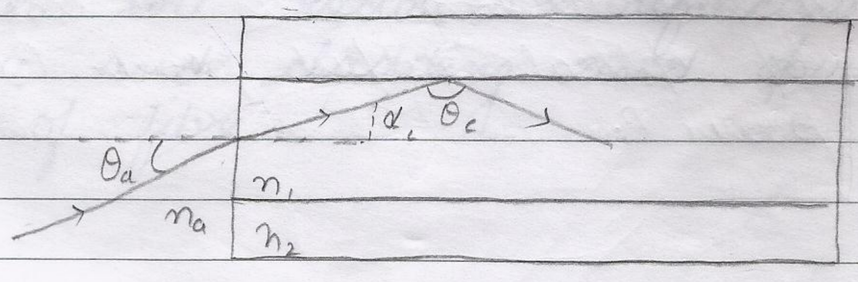
$$n' \propto \frac{1}{v}$$

n = refractive index at central axis
n' = refrative index at core cladding inter face

$\therefore$ at the end, signal reaches on same time.



- Acceptence angle- It is the max^m angle with which a light ray entering inside an optical fibre can make with its axis, so that it enters the fibre and undergoes TIR inside it



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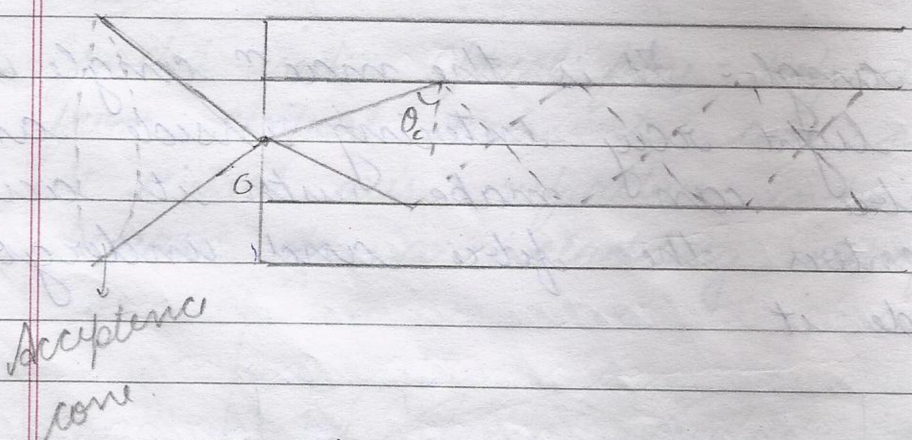
Ray A incident at criticle angle θ_c at core cladding interface enters the fibre at an angle θ_a to fibre axis and is refracted at air core surface

At θ_a : $n_a \sin\theta_a = n_1 \sin\alpha_c$
launching the light from air $n_a = 1$

$$\sin\theta_a = n_1 \sin\alpha_c$$
$$= n_1 \cos\theta_c \qquad [\alpha_c = 90 - \theta_c]$$
$$= n_1 (1 - \sin^2\theta_c)^{1/2}$$
$$= n_1 (1 - n_2^2/n_1^2)^{1/2}$$
$$= (n_1^2 - n_2^2)^{1/2}$$

→ Any ray which incident into fibre at an angle $> \theta_a$ have an angle less than θ_c at core cladding interface ∴ it will not be totally internal reflected

~~Numerical aperture~~



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- Numerical aperture -

$$NA = \sin\theta_a = \frac{1}{n_a}\sqrt{n_1^2 - n_2^2}$$

relative numerical aperture -

$$\Delta = \frac{n_1 - n_2}{n_1}$$

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

Fibre NA depends on n_1 & Δ

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

$$= \sqrt{2n_1(n_1 - n_2)}$$

$$= n_1\sqrt{2\Delta}$$

- V-Number and normalised frequency.

- V-Number is intimately related with the no. of modes N supported by a fibre.
- It is a dimensionless quatity that combines several designs parameters of a fibre like: core radius a, refractive indicis of core and cladding and operating wavelength of fibre.

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$V < 2.405$ - single mode -
$V > 2.405$ - multi mode

$$V_n = \frac{\pi d}{\lambda} \sqrt{n_1^2 - n_2^2}$$

$$= \frac{\pi d}{\lambda} \cdot NA$$

$$\text{no. of modes} = \frac{1}{2} (V_n)^2$$

$$\left[\begin{array}{l} \text{single index } V_s = \frac{V^2}{2} \\ \text{graded index } V_G = \frac{V^2}{4} \end{array} \right] \rightarrow \text{no. of modes}$$

- The major transmission characteristics of an optical fibre are-

I) attenuation
II) dispersion

1. Attenuation - When light travels along the fibre, there is loss of optical power, which is called attenuation. It is measure of decrease of optical output power P_o w.r.t. input power P_i

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Optical input power is power transmi-tted into fibre from an optical source.

Optical output power is power receive-d from fibre at receiver end.

Attenuation losses-

$$\alpha = \frac{10}{L} \log_{10} \frac{P_{in}}{P_{out}}$$

Here α = signal attenuation / absorp^n coff.

units of α = dB/km

overall attenuation (dB) = $10 \log_{10} \frac{P_{in}}{P_{out}}$

$$\frac{P_{in}}{P_{out}} = (10)^{dB/10}$$

11. Dispersion-

Pulse dispersion - In an optical fibre, the different modes of propagation with in the given pulses may take different times to propagat along same length of fibre leadin-g to time broadening of these pulse-s. It is called pulse dispersion

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It is of Two types-

1. Intra model - occurs in single mode fibre. It is of two types - wave guide & material dispersion.

Material dispersion occurs due to variation of core refractive index due to wavelength. This causes a wavelength dependence of mode velocity and causes dispersion even when different wavelengths follow same path.

$$v = \frac{c}{n_1} \; , \; n_1 \propto \frac{1}{\lambda^2}$$

Waveguide dispersion occurs because of waveguide structure of optical fibre. Due to its small core diameter, a single mode fibre does not confine all light in core. Some of light gets propagated along cladding also. Dispersion occurs due to fact that light travelling through cladding travels faster than that of through core.

11. Intermodal - It occurs in multimode fibres & more in step index than in graded index

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- Advantage of Graded index over step index is - Decrease in modal dispersion.

Waveguide dispersion occurs because of wavegui-de structure of opticle fibre

Due to small core diameter, a single mode fibre does not confine all light in core. Some of light gets propagated along claddin-g also. Dispersion occurs due to fact that light travelling through cladding travels faster than that of through core.