Section - B
Optical Fibers

OPTICAL FIBERS STRUCTURES
&
THEIR TYPES

MODES-Planar Guide

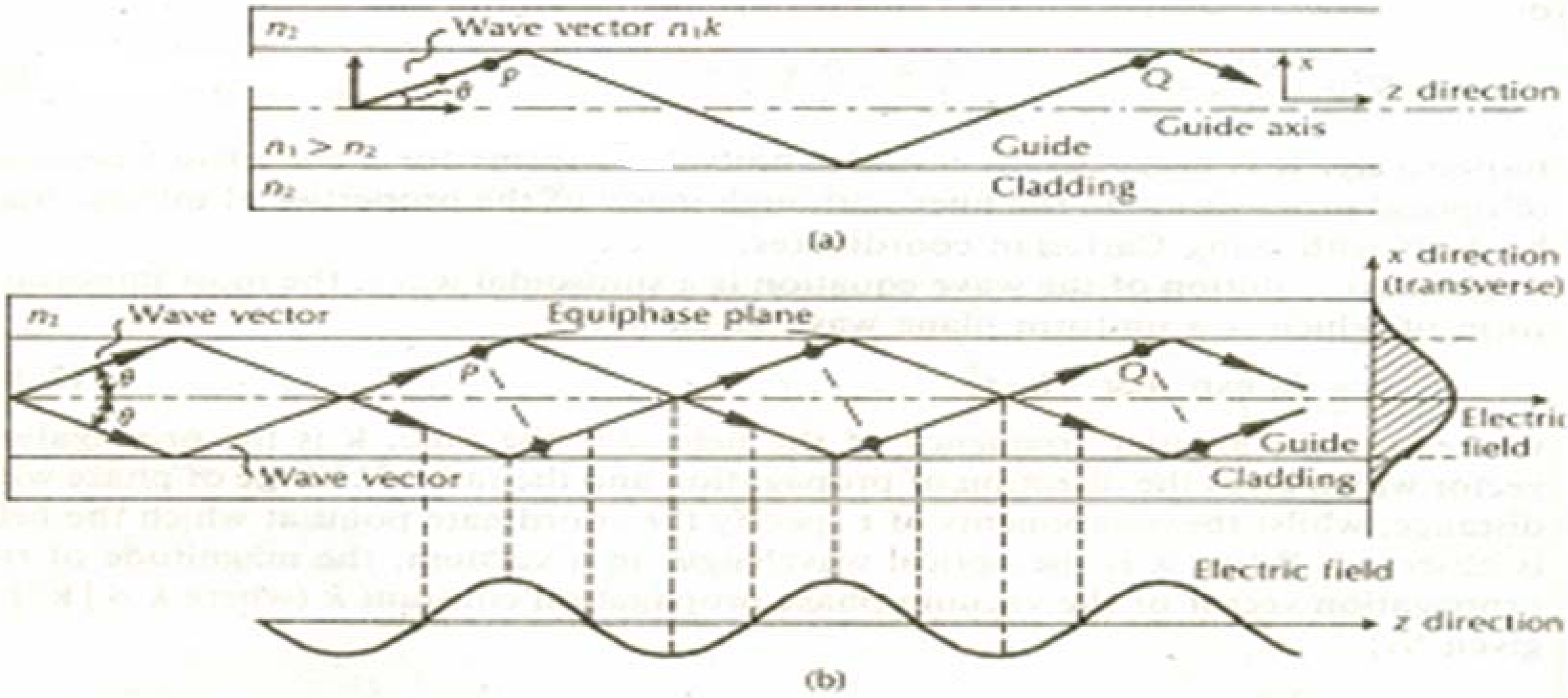


Figure The formation of a mode in a planar dielectric guide: (a) a plane wave propagating in the guide shown by its wave vector or equivalent ray – the wave vector is resolved into components in the z and x directions; (b) the interference of plane waves in the guide forming the lowest order mode ($m = 0$).

MODES (contd)

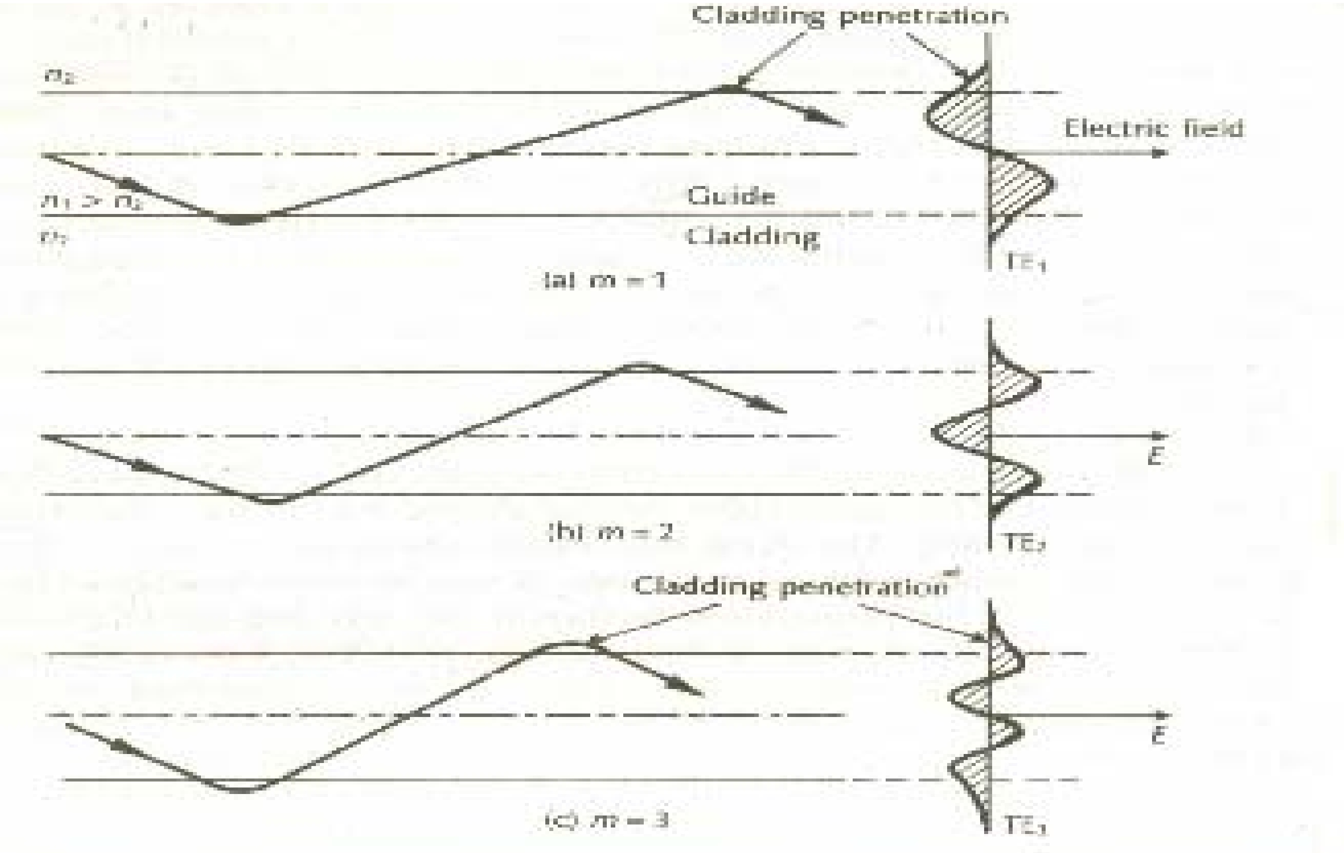


Figure Physical model showing the ray propagation and the corresponding transverse electric (TE) field patterns of three lower order models ($m = 1, 2, 3$) in the planar dielectric guide.

MODES (contd)

Mode: The stable field distribution in the X direction with only a periodic Z dependence is called a mode

- Each distinct value of θ corresponds to a mode
- **β= propagation constant= 2π / λ**
- **$e^{j(\omega t-\beta z)}$** ; factor describes a mode propagating in Z direction
- The integer m denotes the number of zeroes in the transverse field pattern
- m = mode number= order of the mode

MODES (contd)

TE Mode:

Electric field is perpendicular to the direction of propagation, Ez= 0(Hz is not 0)

TM Mode:

Magnetic field is perpendicular to the direction of propagation

So Hz=0(Ez is not 0)

- The field varies harmonically in guiding region (n1) and decays exponentially outside this region.
- Lower order Modes: Field concentrated near centre(axis)
- Higher order modes: Field distributed more towards edges of the guide and penetrates farther into cladding.

V number= Value of fiber

- $V = \frac{2\pi a}{\lambda} (n1^2 - n2^2)^{1/2} = \frac{2\pi a}{\lambda} (NA) = \frac{2\pi a\, n1}{\lambda} (2\Delta)^{1/2}$
- V is a dimensionless parameter
- The number of guided modes depends on the value of V (a, Δ, λ)

$$M = \frac{V^2}{2}$$

- There is a cut off value of normalized frequency Vc for guided modes below which they cannot exist.

Note: most of the optical power is carried in the core region and not in the cladding.

MODES & MODE COUPLING

MODES: IN CYLINDERICAL WAVE GUIDES VARIOUS MODES OF PROPAGATION ARE REFERED TO TE $_{lm}$ or TM $_{lm}$ where l & m are integers.

. **MODE COUPLING**: wave guides are not perfect

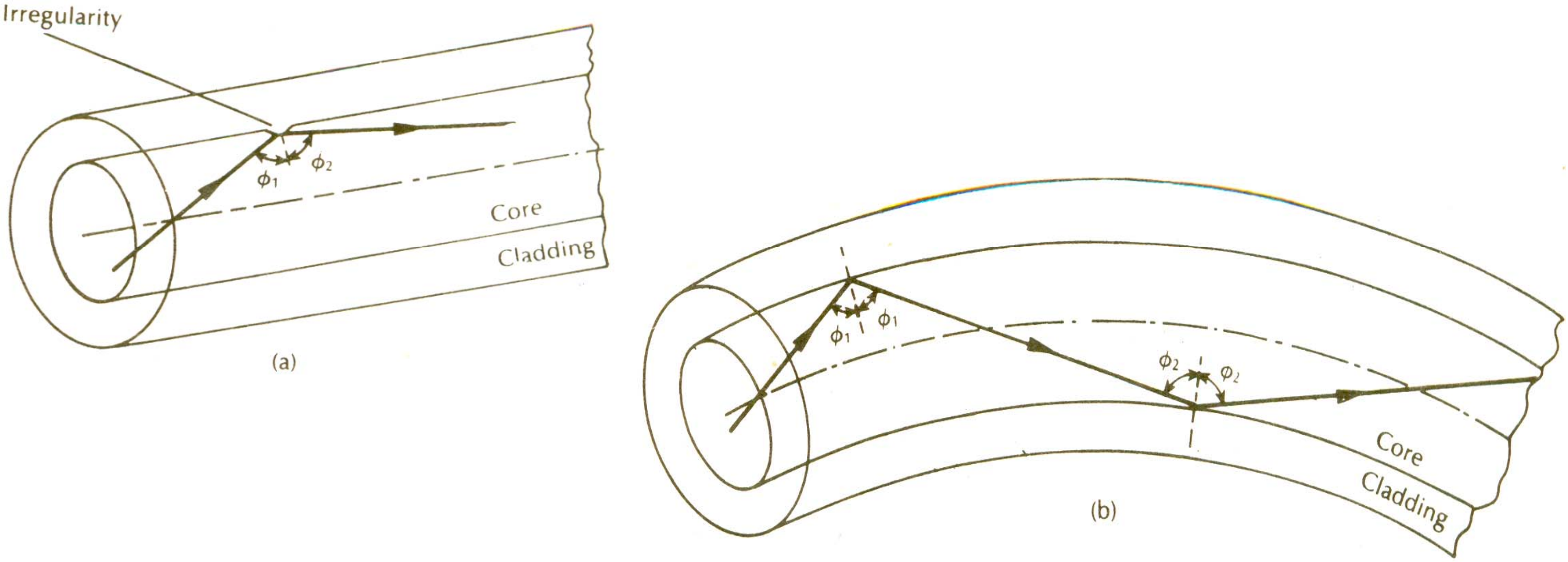
WAVE GUIDE IMPERFECTIONS: (a) fiber axis deviations from straightness.

(b) Variations in core dia

(c irregularities at the core cladding interface.

(d) Refractive index variation

Due to any /some of these disturbances, the energy travelling in one mode gets coupled to another mode.



Ray theory illustrations showing two of the possible fiber perturbations which give mode coupling: (a) irregularity at the core—cladding interface; (b) fiber bend.

- Change of angle corresponds to a change in the propagating mode for the light (mode coupling) `

MODE- COUPLING(contd)

- **Thus individual modes do not propagate throughout the length of the fiber without large energy transfers to adjacent modes, even when the fiber is exceptionally good quality and is not strained or bent by its surroundings.**

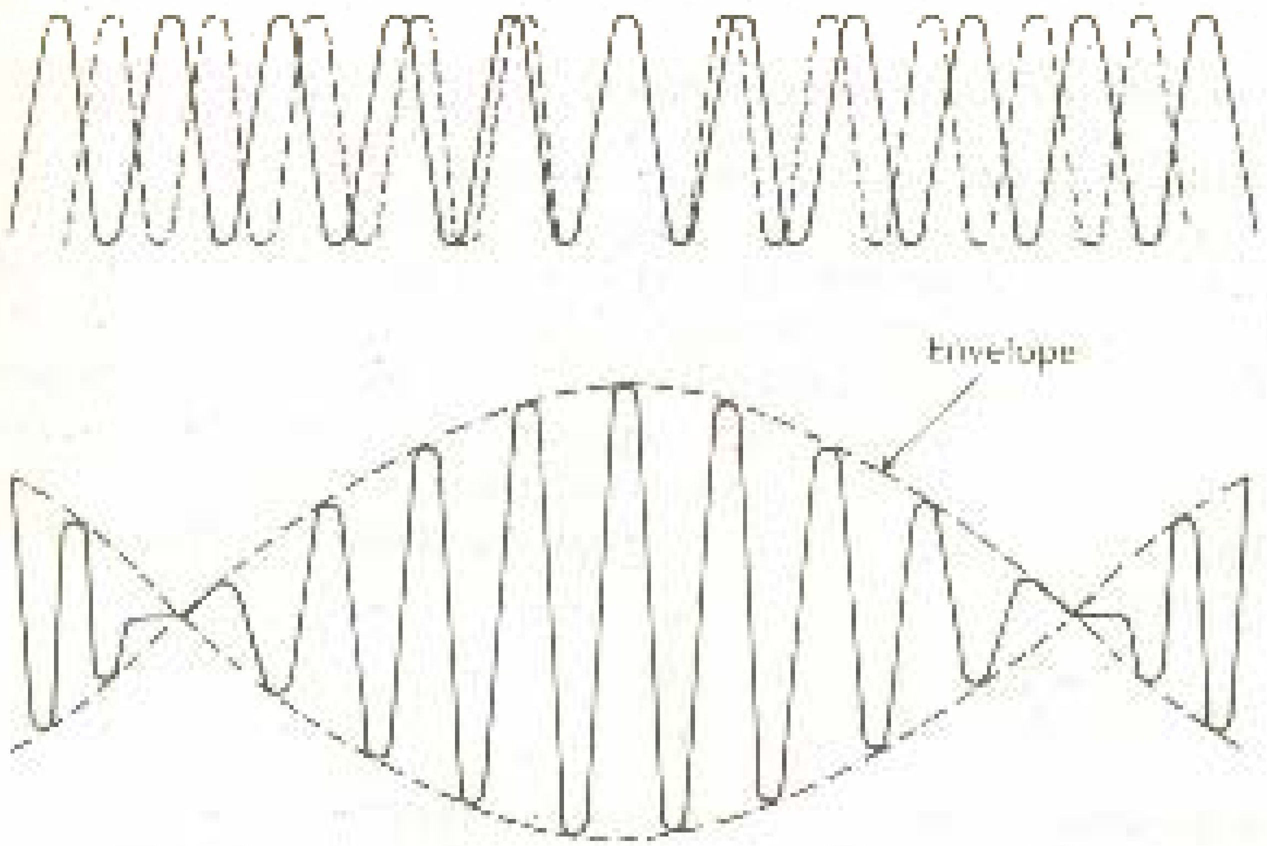
PHASE VELOCITY & GROUP VELOCITY

- WITHIN ALL EM WAVES, (PLANE OR OTHERWISE) THERE ARE POINTS OF CONSTANT PHASE.
- WAVE FRONT REFERS TO THE SURFACE FORMED BY CONSTANT PHASE POINTS.
- WAVE FRONT TRAVELS WITH A PHASE VELOCITY Vp

  $V_p = \omega / \beta$ ω - ANGULAR FREQ. OF THE WAVE

  β - PROPAGATION CONSTANT
- LIGHT IS GENERALLY COMPOSED OF A SUM OF PLANE WAVE COMPONENTS OF DIFFERENT FREQUENCIES.

Formation of wave packet



The formation of a wave packet from the combination of two waves with nearly equal frequencies. The envelope of the wave package or group of waves travels at a group velocity v_g.

GROUP INDEX(Vg)

$$v_g = \frac{d\omega}{d\beta} = \frac{d\omega / d\lambda}{d\beta / d\lambda} = \frac{d\omega}{d\lambda}\left[\frac{d\beta}{d\lambda}\right]^{-1}$$

$$= \frac{d\omega}{d\lambda}\left[\left\{\frac{d}{d\lambda}(n_1 \frac{2\pi}{\lambda})\right\}^{-1}\right] = \frac{d\omega}{d\lambda}\left[\frac{1}{2\Pi}\left\{\frac{d}{d\lambda}\left(\frac{n_1}{\lambda}\right)\right\}^{-1}\right]$$

GROUP INDEX(Vg)

$$= \frac{dw}{d\lambda}\left[\frac{1}{2\pi}\left\{\frac{\lambda.\frac{dn_1}{d\lambda} - n_1}{\lambda^2}\right\}^{-1}\right] = \frac{d\omega}{2\pi\lambda}\left[\frac{dn_1}{d\lambda}\frac{1}{\lambda} - \frac{n_1}{\lambda^2}\right]^{-1}$$

$$= \frac{\omega}{2\pi\lambda}\left[\frac{dn_1}{d\lambda}\frac{1}{\lambda} - \frac{n_1}{\lambda^2}\right]^{-1} = \frac{\frac{\omega}{2\pi\lambda}}{\frac{dn_1}{d\lambda}\frac{1}{\lambda} - \frac{n_1}{\lambda^2}}$$

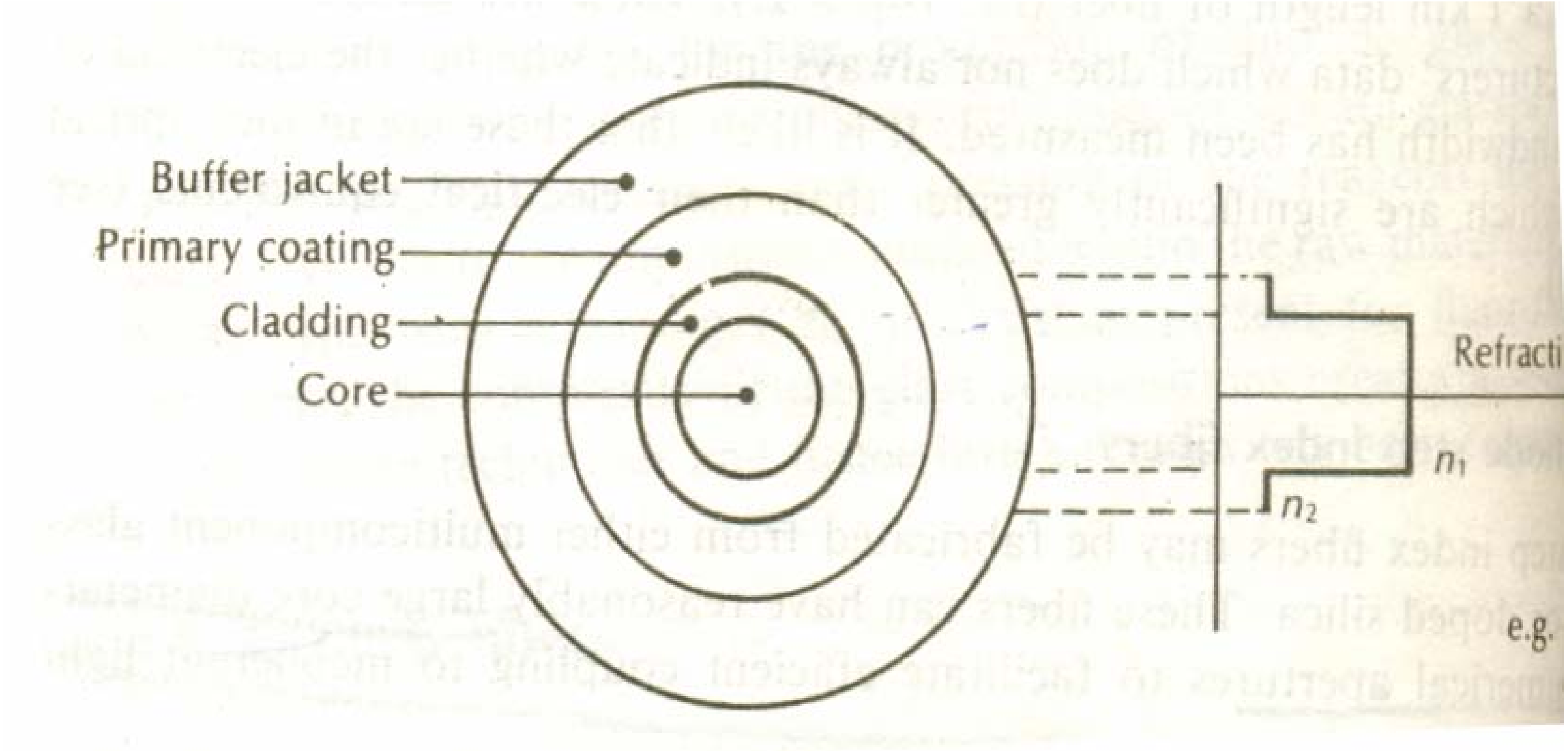
GROUP INDEX(Ng)

- Multiply numerator & denominator by λ^2
- N_g - Group Index of the guide

$$\frac{\dfrac{\omega\lambda}{2\pi}}{\lambda \dfrac{dn_1}{d\lambda} - n_1} = \frac{-\dfrac{2\pi f\lambda}{2\pi}}{n_1 - \lambda \dfrac{dn_1}{d\lambda}}$$

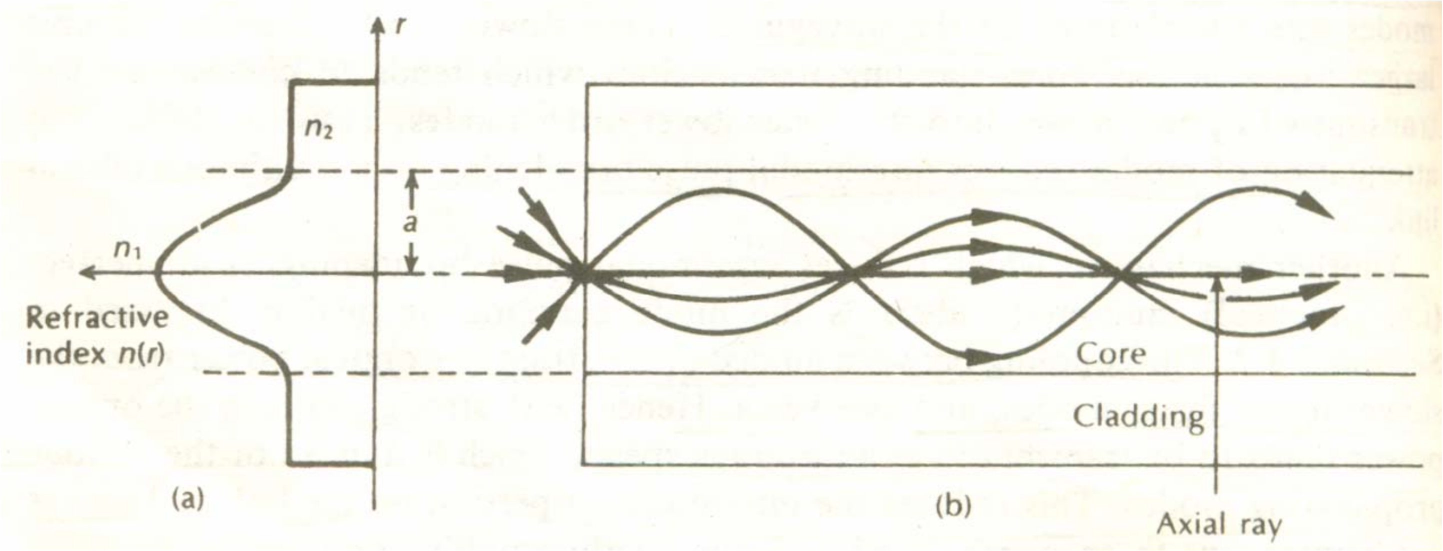
$$= \frac{c}{n_1 - \lambda \dfrac{dn_1}{d\lambda}} = \frac{c}{N_g}$$

MULTIMODE STEP INDEX FIBERS



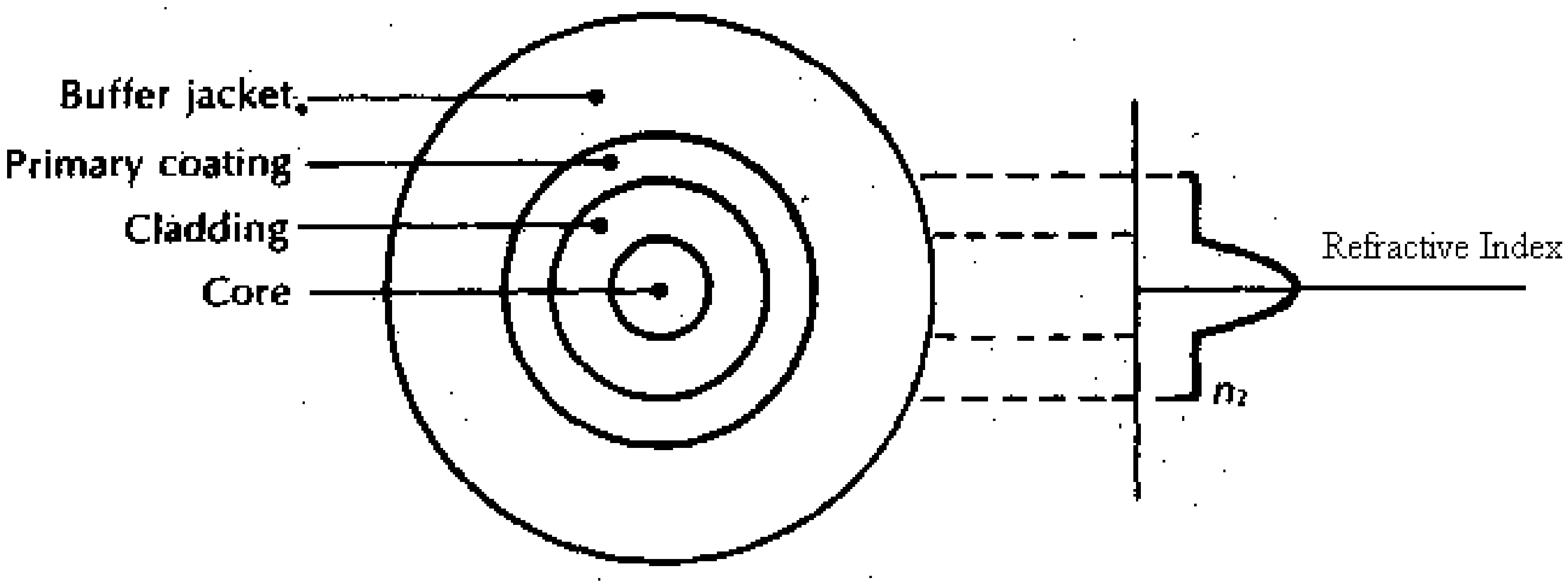
MULTIMODE GI FIBER(contd)

- The gradual decrease in ref index from the centre of the core ,creates many refractions of the rays .(High to low ref. index)



A multimode graded index fiber: (a) parabolic refractive index profile; (b) meridional ray paths within the fiber core.

GRADED INDEX FIBER (contd)



GRADED INDEX FIBERS

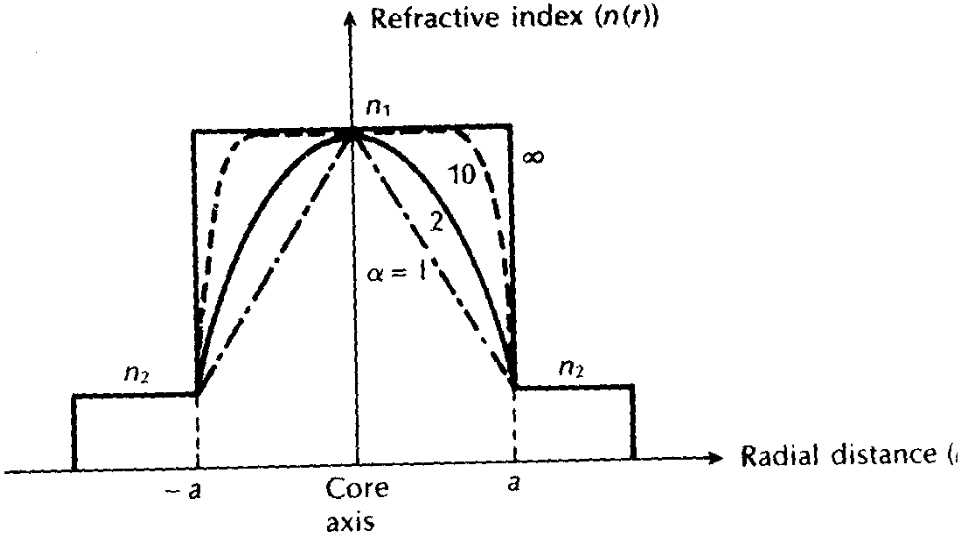
Max value of n_1 at the axis

Constant value of n_2 beyond core radius a.

$n(r) = n_1 (1-2\Delta (r/a)^{\alpha})^{1/2}$ r< a (core)

$n_1 (1-2\Delta)^{1/2} = n_2$ $r \geq a$ (cladding)

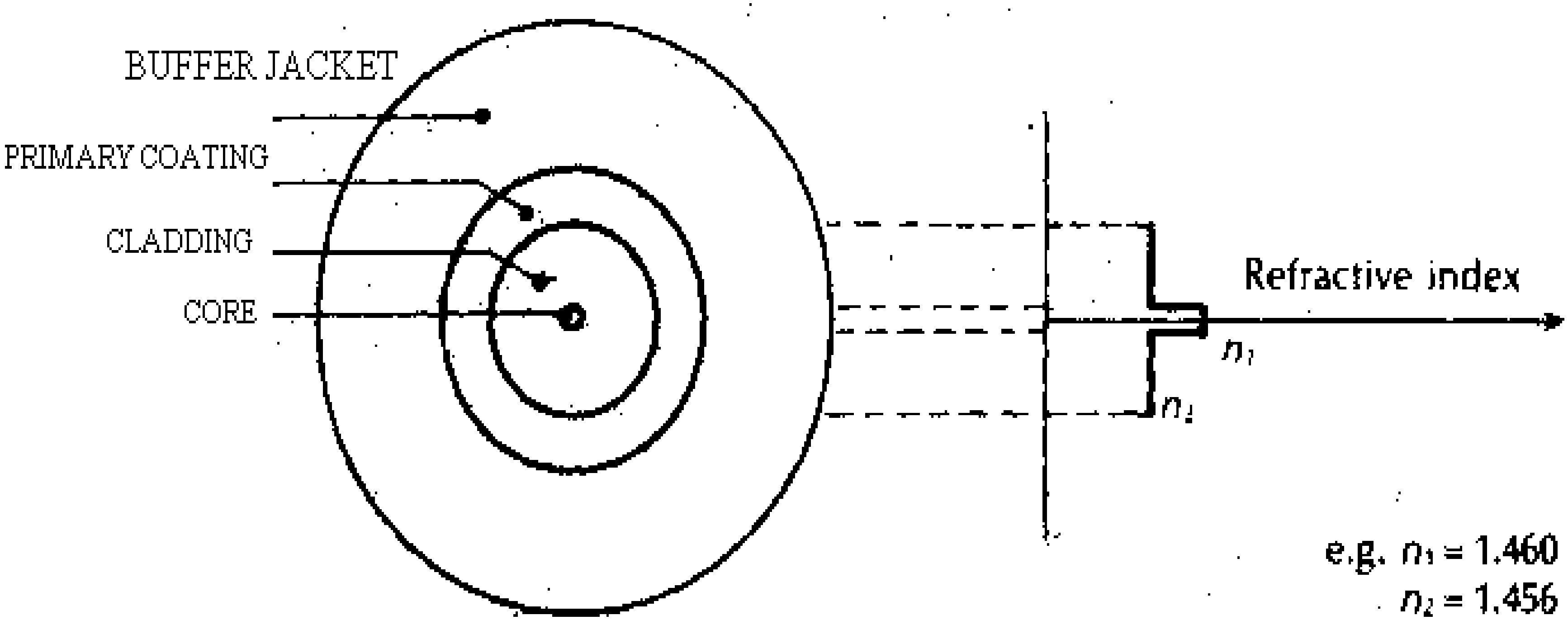
where α = profile parameter



Refractive index profile for diff values of α

Parabolic ref. index profile produces the best results for multi mode opt .propagation (α =2)

SINGLE MODE FIBERS



MULTIMODE STEP INDEX FIBERS

Material of fabrication-doped silica or multi component glass compounds

Doped silica fiber exhibit best performance.

Structure: core DIA: 50 to 400 µm

Cladding DIA: 125 to 500µm

Buffer Jacket DIA: 250 to 1000µm

Numerical aperture: 0.16 to 0.5