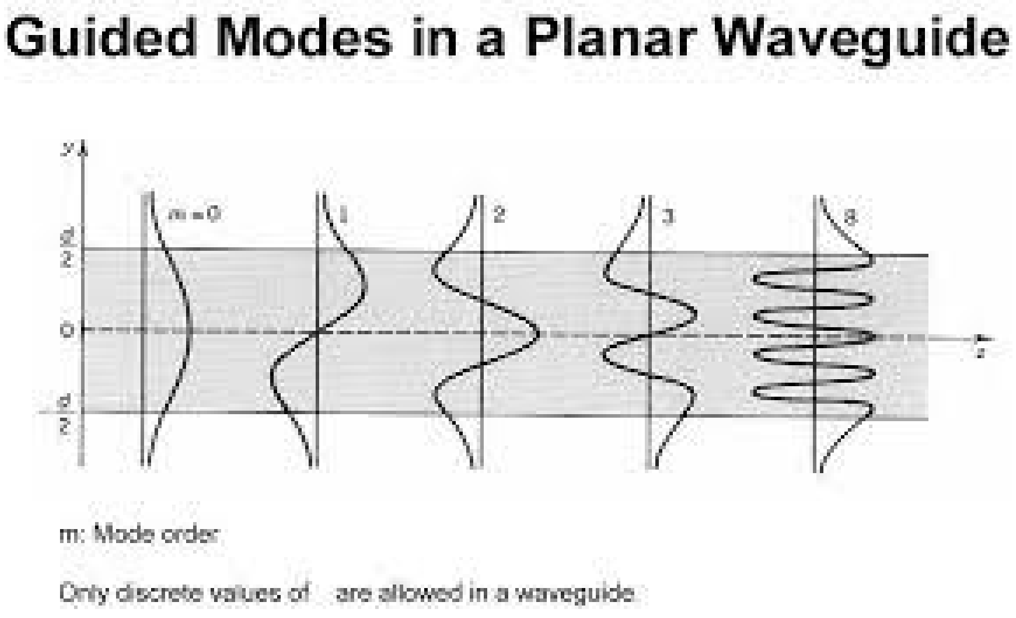
OPTICAL FIBERS **WAVEGUIDE-I**



Optical Fiber Waveguide

- To understand transmission mechanisms of optical fibers with dimensions approximating to those of a human hair;
  - Necessary to consider the optical waveguiding of a cylindrical glass fiber.

- Fiber acts as an open optical waveguide – may be analyzed using simple ray theory – **Geometric Optics**
  - Not sufficient when considering all types of optical fibers

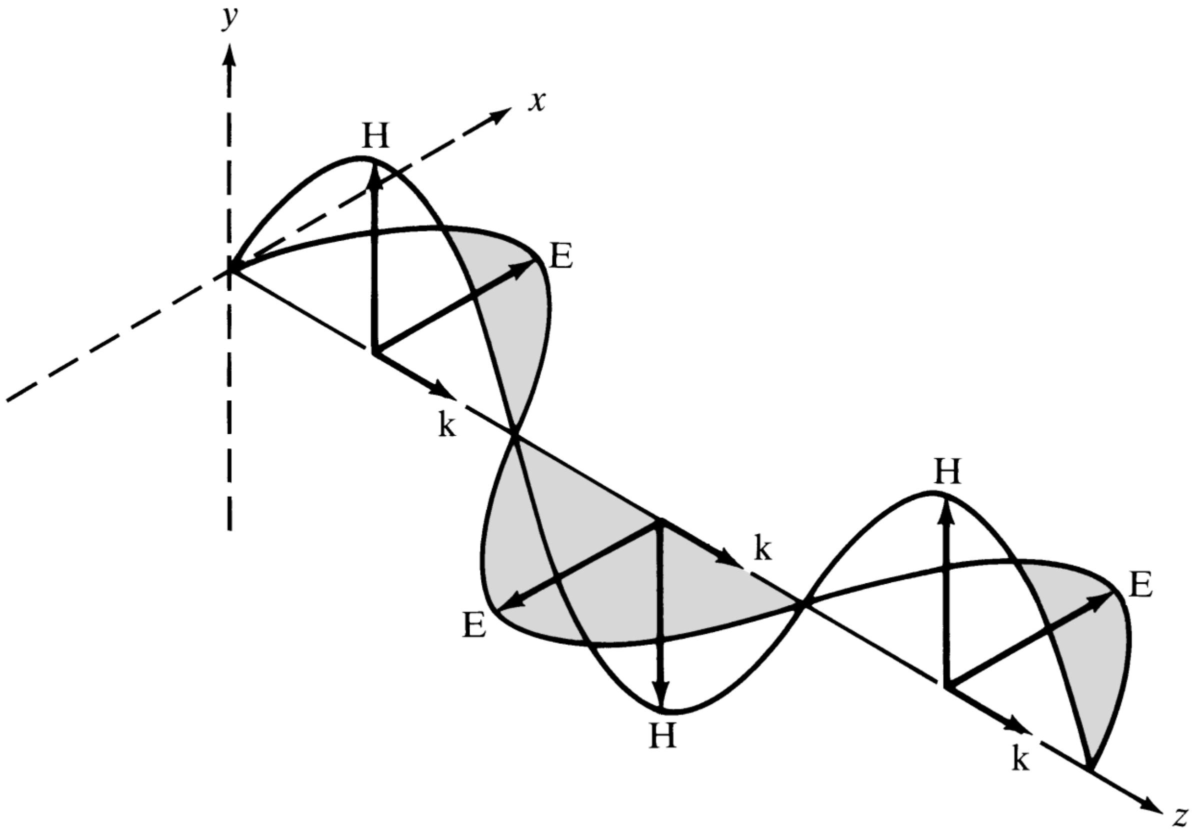
- **Electromagnetic Mode Theory** for Complete Picture

ELECTROMAGNETIC THEORY

- **To obtain an detailed understanding of propagation of light in an optical fiber**
  - Light as a variety of EM vibrations **E** and **H** fields at right angle to each other and perpendicular to direction of propagation.
  - Necessary to solve Maxwell's Equations
    - Very complex analyses - ***Qualitative aspects only***

Field distributions in plane E&H waves

- Light as a variety of EM vibrations **E** and **H** at right angle to each other and perpendicular to direction of propagation.



Maxwell's Equations

- Assuming a linear isotropic dielectric material having no currents and free charges

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t}$$

$$\nabla \cdot \mathbf{D} = 0$$

$$\nabla \cdot \mathbf{B} = 0$$

where $\mathbf{D} = \epsilon \mathbf{E}$ and $\mathbf{B} = \mu \mathbf{H}$.

Maxwell's Equations

Substituting for **D** and **B** and taking curl of first equation

$$\nabla \times (\nabla \times \mathbf{E}) = -\mu \frac{\partial}{\partial t}(\nabla \times \mathbf{H}) = -\epsilon\mu \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

Using vector identity

$$\nabla \times (\nabla \times \mathbf{E}) = \nabla(\nabla \cdot \mathbf{E}) - \nabla^2 \mathbf{E}$$

We get

$$\nabla^2 \mathbf{E} = \epsilon\mu \frac{\partial^2 \mathbf{E}}{\partial t^2}$$

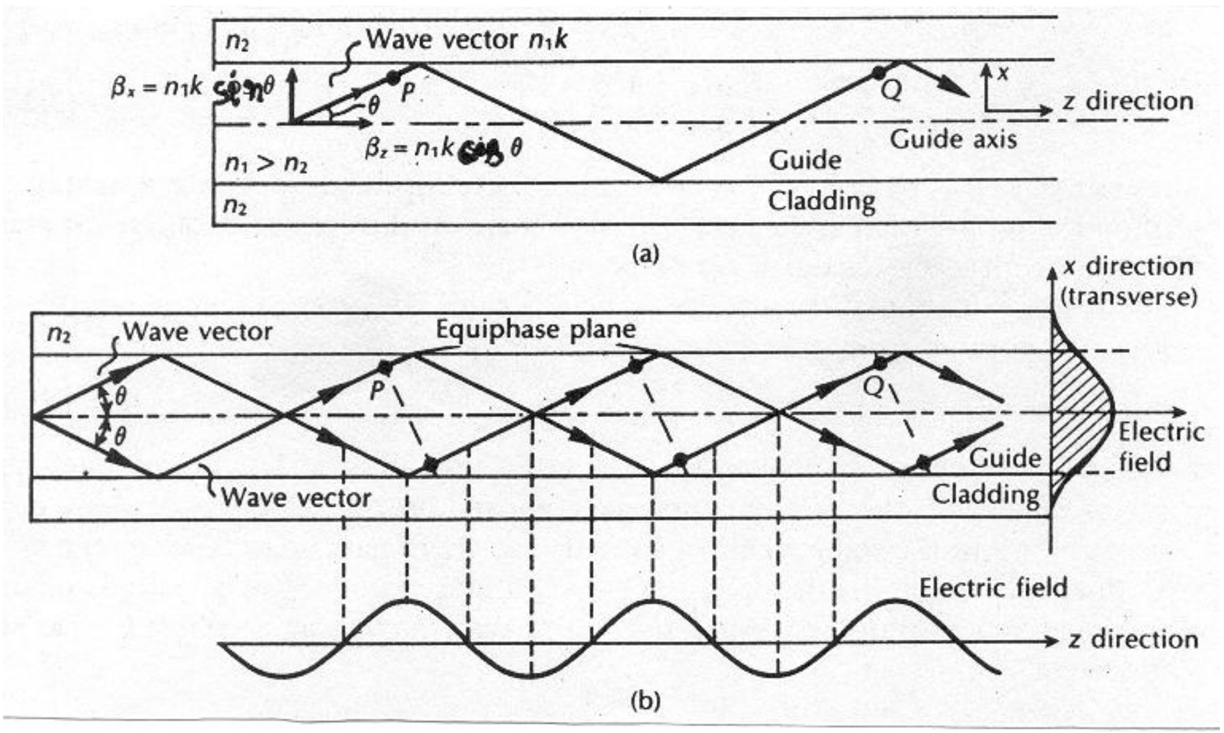
Similarly

$$\nabla^2 \mathbf{H} = \epsilon\mu \frac{\partial^2 \mathbf{H}}{\partial t^2}$$

- Wave equations for each component of the field vectors **E** & **H**.

Concept of Modes

- **A plane monochromatic wave propagating in direction of ray path within the guide of refractive index n_1 sandwiched between two regions of lower refractive index n_2**



(a) A plane wave propagating in the guide (b) Interference of plane wave in the guide (forming lowest order mode m=0)

- Wavelength $= \lambda/n_1$
- Propagation constant
  $\beta = n_1k$
- Components of β in z and x directions

  $\beta_z = n_1k\cos\theta$

  $\beta_x = n_1k\sin\theta$
- Constructive interference occurs and standing wave obtained in x-direction

Concept of Modes

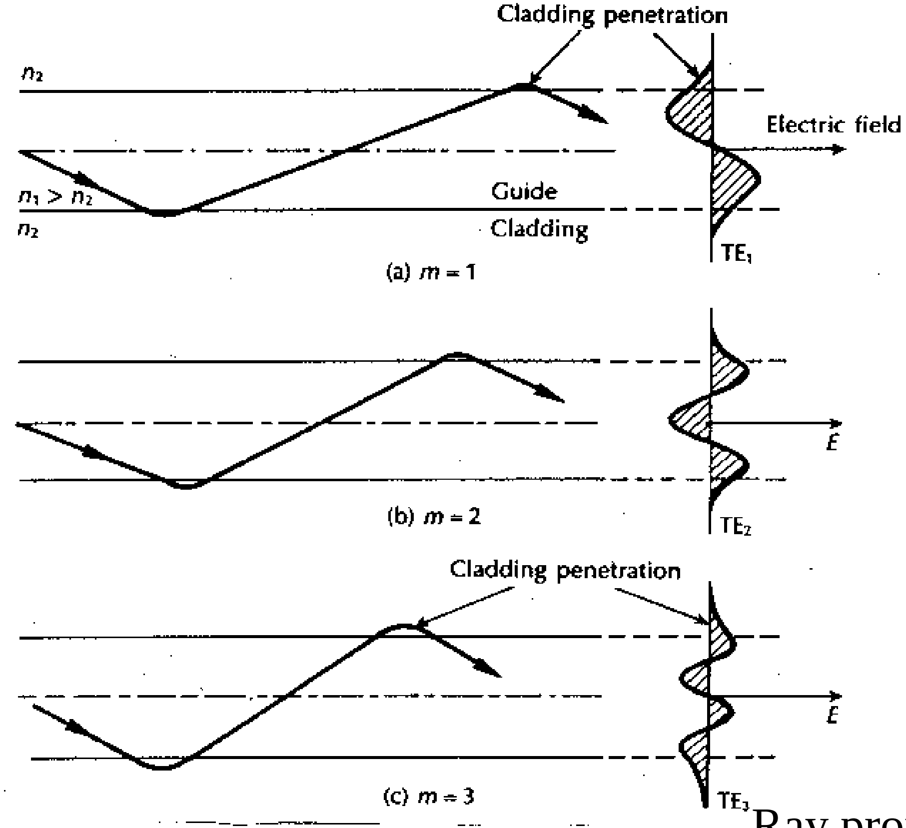
- Components of plane wave in x-direction reflected at core-cladding interface and interfere
  - **Constructive**: when ***total phase change*** after two reflection is equal to $2m\pi$ radians; m an integer - **Standing wave in x-direction**
  - The optical wave is confined within the guide and the electric field distribution in the x-direction does not change as the wave propagate in the z-direction – **Sinusoidally varying in z-direction**

- **The stable field distribution in the x-direction with only a periodic z-dependence is known as a MODE.**
  - Specific mode is obtained only when the angle between the propagation vectors or rays and interface have a particular value – **Discrete modes** typified by a distinct value of θ
  - Have periodic z-dependence of $\exp(-j\beta_z z)$ or commonly $\exp(-j\beta z)$
  - Have time dependence with angular frequency ω, i.e. $\exp(j \omega t)$

Higher Order Modes

❖ For monochromatic light fields of angular frequency ω, a mode traveling in positive z-direction has a time and z-dependence given by

exp j(ωt- βz)



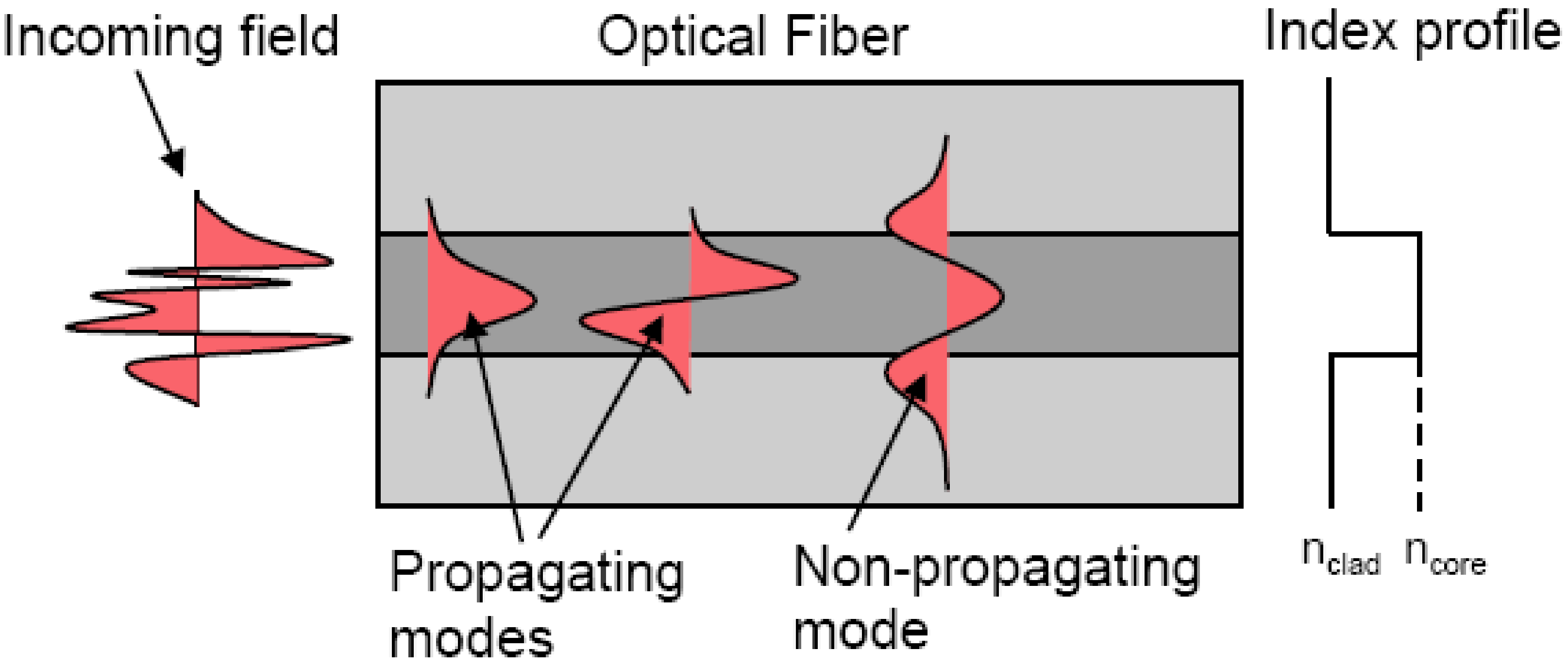
Dominant modes propagating in z-direction with electric field distribution in x-direction formed by rays with m=1,2,3

m denotes number of zeros in this transverse pattern.

It also signifies the order of the mode and is known as **mode number**.

Ray propagation and corresponding TE field patterns of three lower order modes in planar guide.

Wave picture of waveguides



- The step-index profile provide focusing just like lenses and GRIN materials
- The guides modes of the fiber are those that propagate without changing their profile
- The guided modes are those intensity profiles, for which the focusing, due to the index profile, exactly matches the diffraction
- In the core is small, only one such mode exists (single mode fiber)

TE and TM modes

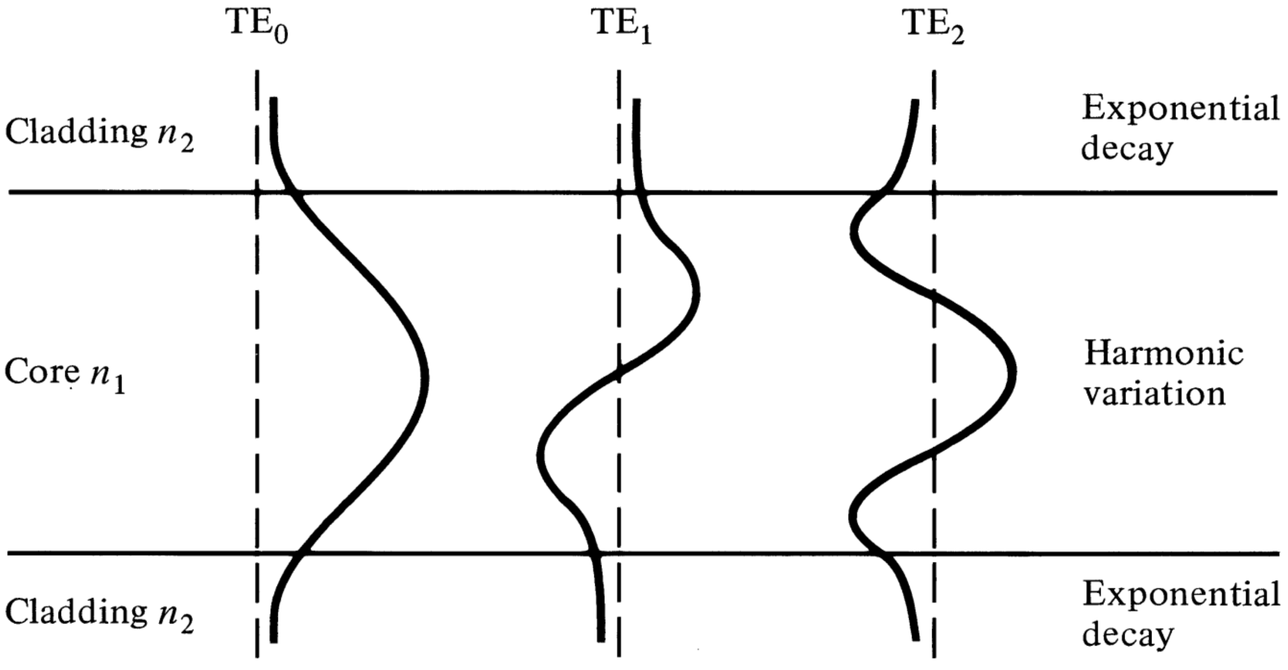
- **Transverse Electric mode (TE)**: When electric field is perpendicular to the direction of propagation, i.e. $E_z=0$, but a

  corresponding component of the magnetic field **H** is in the direction of propagation.

- **Transverse Magnetic (TM) mode**: When a component of **E** field is in the direction of propagation, but $H_z=0$.

- **Transverse ElectroMagnetic (TEM)** : When total field lies in the transverse plane in that case both E_z and H_z are zero.

Low-order TE or TM mode fields



THANK YOU