properties

* Light as electromagnetic waves

     − Satisfy Maxwell's equ.

for a plane EM wave

     − represented by wave equ.

propagating in +z direction

$$\vec{E} = \left( \hat{a}_x E_x + \hat{a}_y E_y e^{j\phi} \right) e^{-jkz}$$

$$\nabla^2 \vec{E} + k^2 \vec{E} = 0 \qquad \nabla^2 \vec{H} + k^2 \vec{H} = 0$$

If $\phi = 0 \Rightarrow$ linear polarization

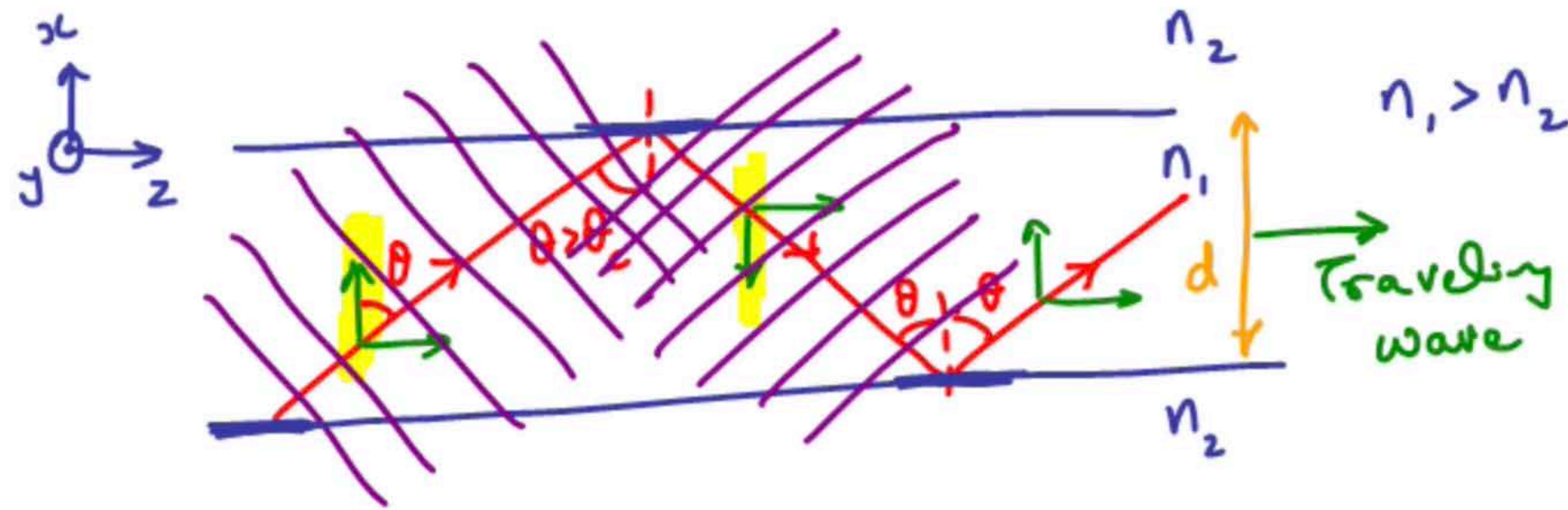If $\phi = \pm \pi/2 \Rightarrow$ circular polarization

$E_x = E_y$

Any other $\Rightarrow$ Elliptical polarization

* For a given structure,

only specific field configurations are allowed
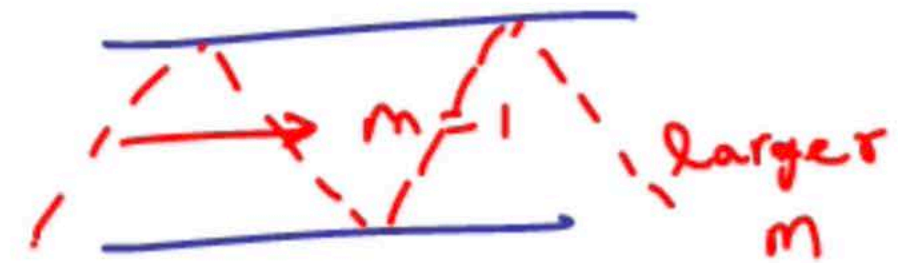
$\Rightarrow$ Eigenmodes or Modes of the structure

$$\nabla \cdot \vec{D} = \rho_v$$

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

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

$$\nabla \times \vec{H} = \vec{J}_c + \frac{\partial \vec{D}}{\partial t}$$

$$\vec{D} = \epsilon \vec{E}$$

$$\vec{B} = \mu \vec{H}$$

# Example:



$n_2$

$n_1 > n_2$

$n_1$

Traveling wave

$d$

$n_2$

Does any angle $\theta > \theta_c$ survive in the waveguide?

neglecting

$\boxed{\phi_{boundaries}} + k_x \cdot 2d = 2\pi m$

$k \cos\theta \cdot 2d = 2\pi m$

$\frac{2\pi}{\lambda} n_1 \, 2d \cos\theta = 2\pi m$

$$\boxed{\cos\theta_m = \frac{m\lambda}{2n_1 d}}$$

\# of modes supported, $\frac{n}{d}$



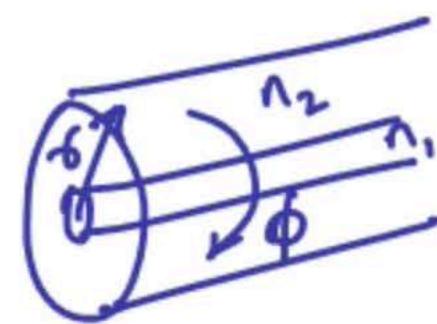$m=1$  larger $m$

$\theta_c < \theta_m < \frac{\pi}{2}$

For $m=1$, $\theta_m$ is highest $\left(\frac{\pi}{2}\right)$

$d \to \lambda \Rightarrow$ fundamental mode

If $d \gg \lambda \Rightarrow$ large \# of modes (multimode)

$n_2$

$n_1$

$\phi$

$n_{eff}$

$n_1$

$n_2$

Prop. const. $b = \dfrac{n_{eff} - n_2}{n_1 - n_2}$

$V < 2.405$

Single mode
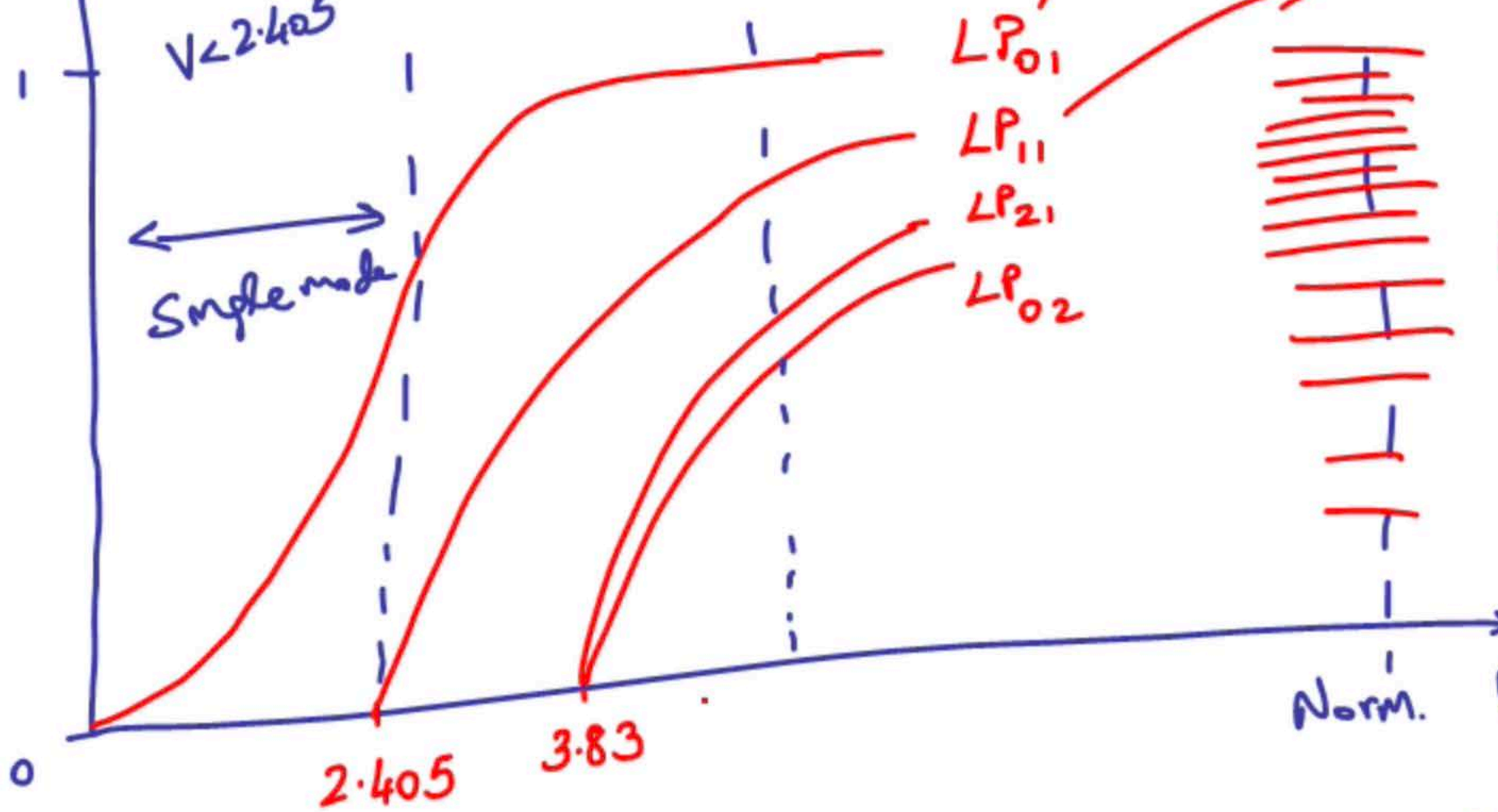
$LP_{01}$

$LP_{11}$

$LP_{21}$

$LP_{02}$

Multimode fiber

$LP_{02}$

Norm. Frequency

2.405    3.83

$n_2$
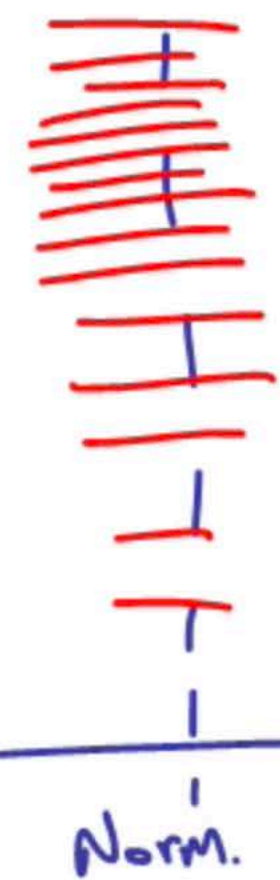
$V = \dfrac{2\pi a}{\lambda} \boxed{\sqrt{n_1^2 - n_2^2}}$  NA
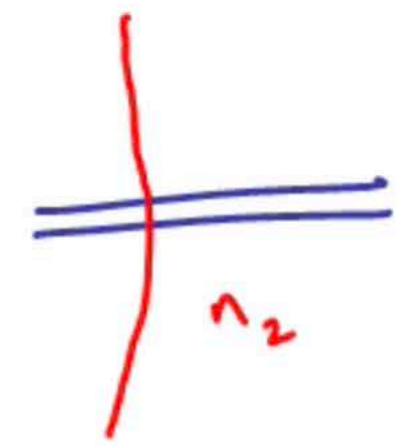
$LP_{mn}$

\# of maxima in $\phi$-dir    \# of maxima in $\gamma$-dir
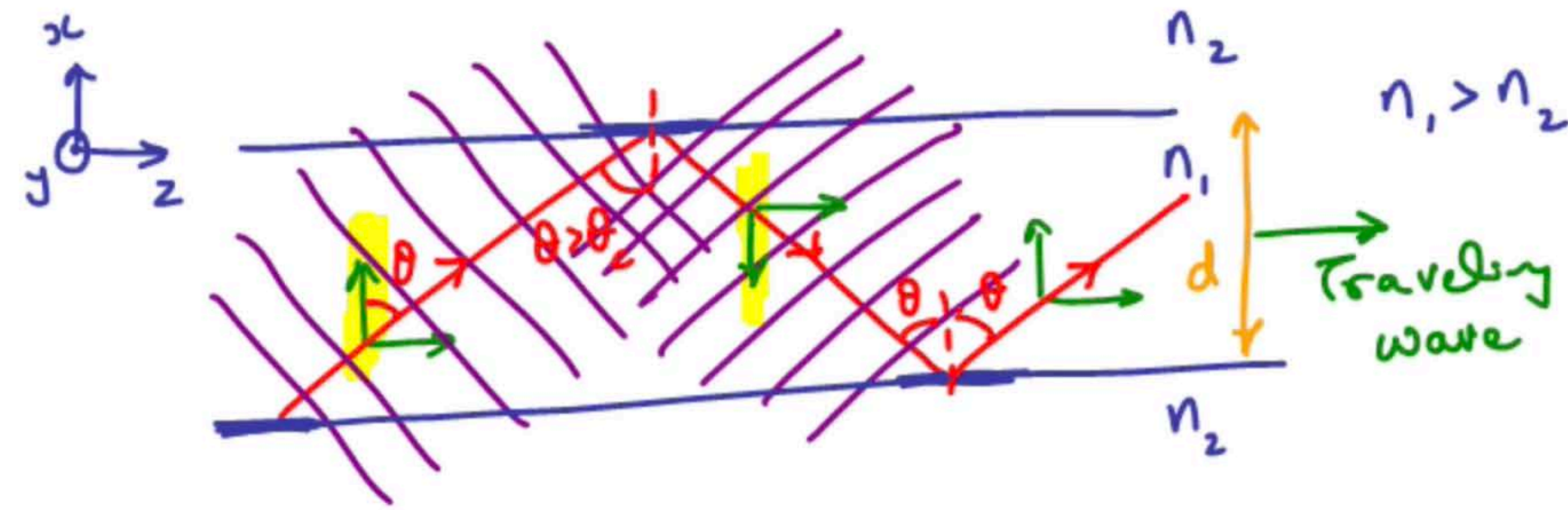
**Example:**



$n_2$

$n_1$     $n_1 > n_2$

$x$ ↑   $y$ ⊙ → $z$

$\theta$   $\theta = \theta_c$   $\theta, \theta$   $d$   Traveling wave

$n_2$

Does any angle $\theta > \theta_c$ survive in the waveguide?

neglecting

$\boxed{\phi_{boundaries}} + k_x \cdot 2d = 2\pi m$
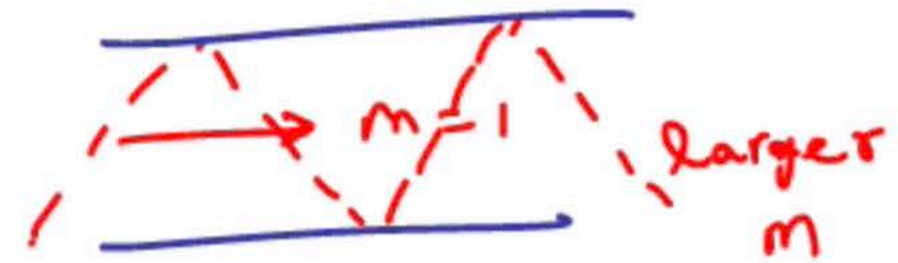
$k \cos\theta \cdot 2d = 2\pi m$

$\dfrac{2\pi}{\lambda} n_1 \, 2d \cos\theta = 2\pi m$

$$\boxed{\cos\theta_m = \dfrac{m\lambda}{2n_1 d}}$$

# of modes supported, $\boxed{\dfrac{1}{d}}$ depends on



m=1   larger m

$\theta_c < \theta_m < \frac{\pi}{2}$

For $m=1$, $\theta_m$ is highest $\left(\frac{\pi}{2}\right)$

$d \to \lambda \Rightarrow$ fundamental mode

If $d \gg \lambda \Rightarrow$ larger # of modes (multimode)