



COMSOL® Design Tool: Simulations of Optical Components Week 5: Waveguides – Mode Solver

Manuel Kohli, Raphael Schwanninger

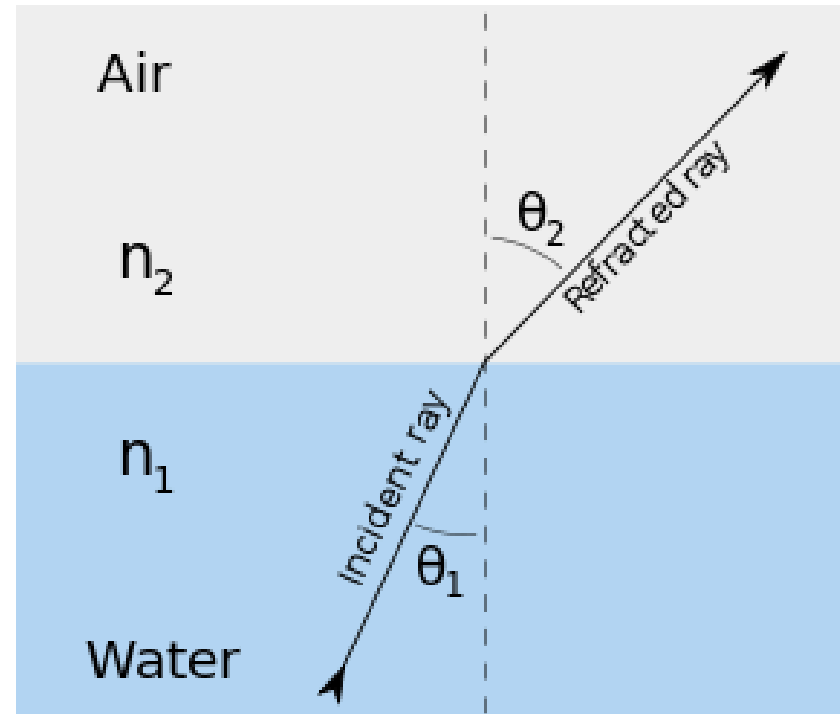
Content

- Revision on waveguiding theory
 - Confinement
 - TE and TM modes
 - Multi-Mode Waveguides
- COMSOL
 - Silicon ridge waveguide
 - Glass fiber

Snell's Law

Snell's law

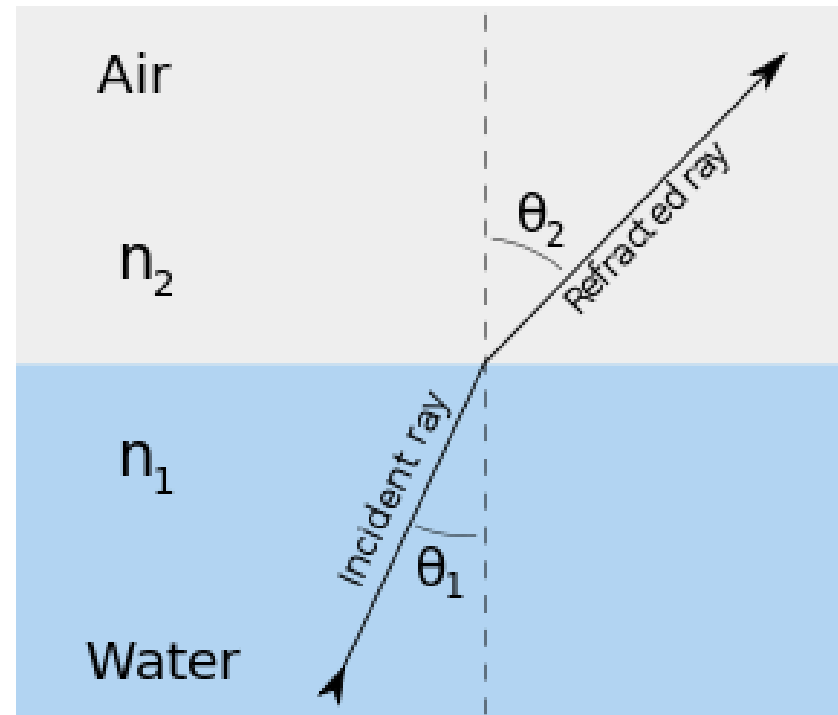
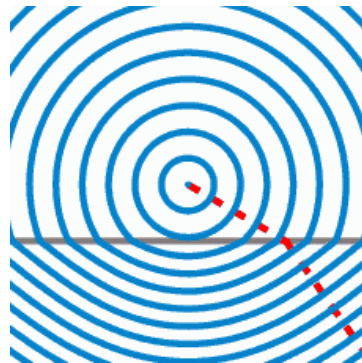
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$



Snell's Law

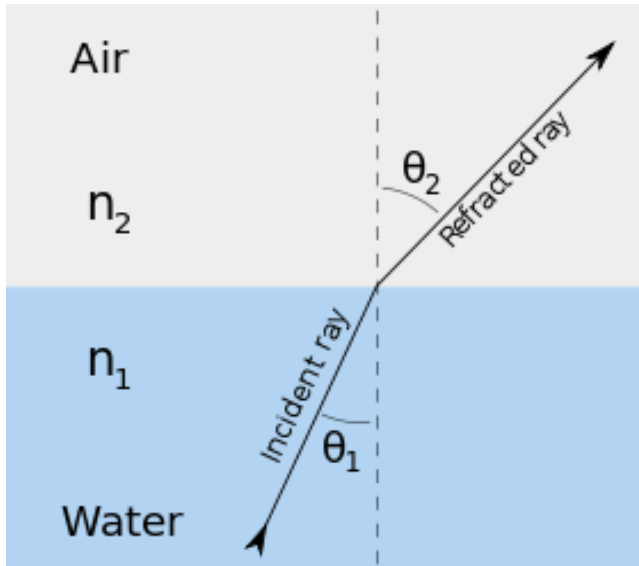
Snell's law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$



Snell's Law

- What happens at the boundary between two materials?



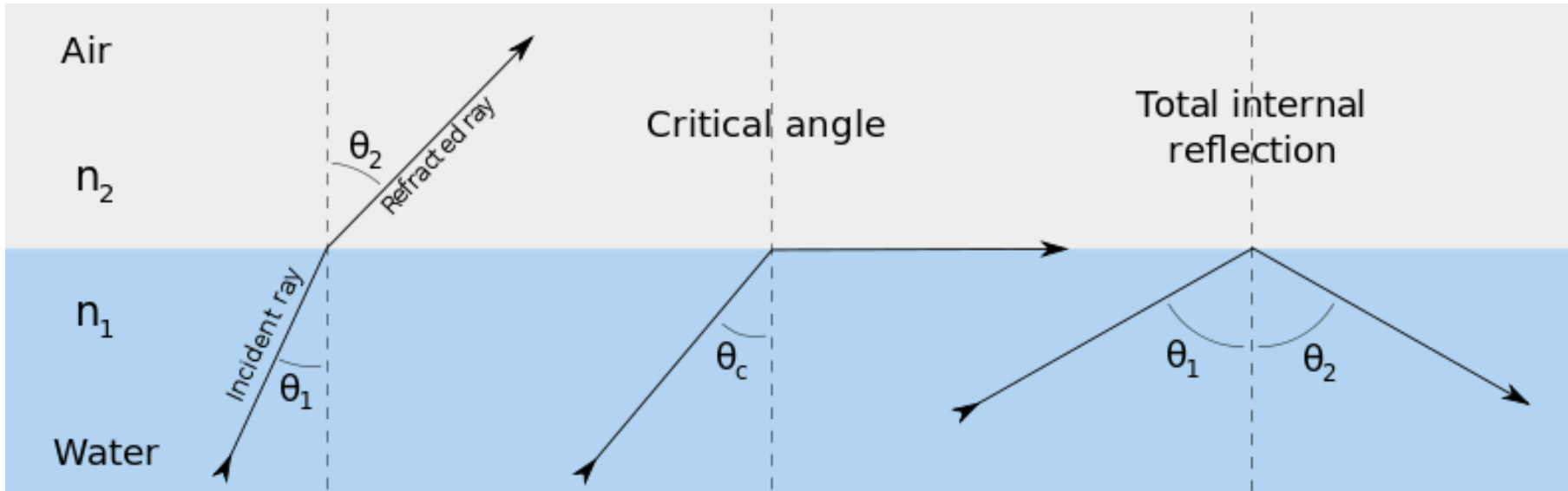
Snell's law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

- What if happens if this condition cannot be fulfilled? $\left(\frac{n_1}{n_2} \cdot \sin(\theta_1) > 1\right)$

Snell's Law

- What happens at the boundary between two materials?

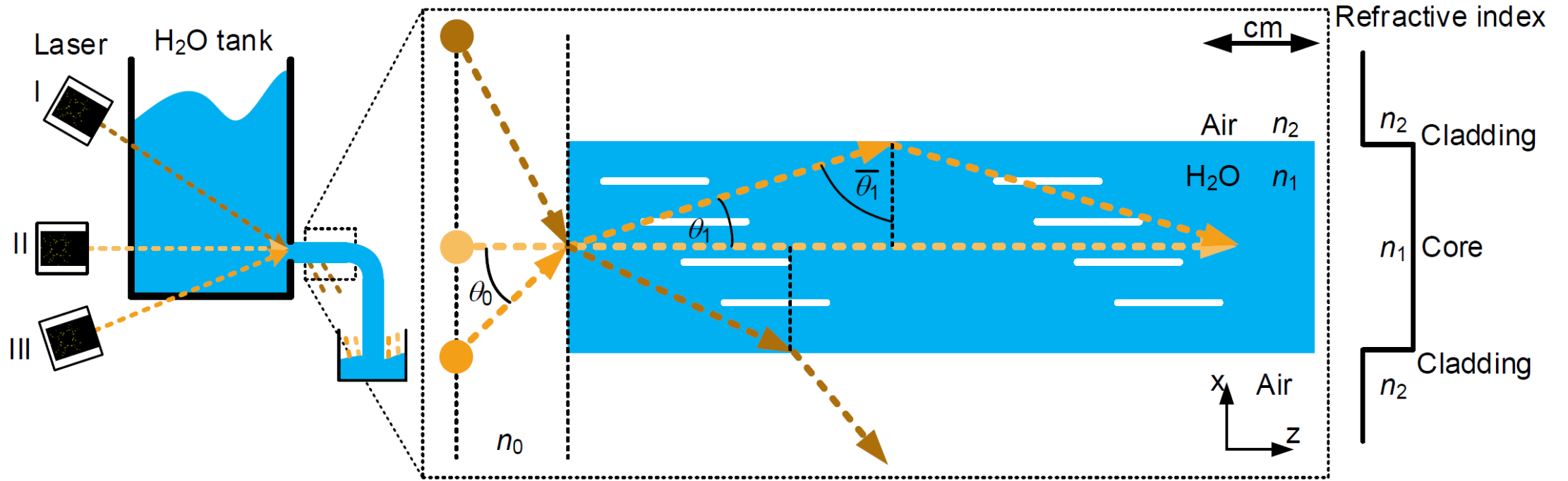


Snell's law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

- What if happens if this condition cannot be fulfilled? $\left(\frac{n_1}{n_2} \cdot \sin(\theta_1) > 1\right)$
 - There is critical angle $\theta_c = \arcsin\left(\frac{n_2}{n_1}\right)$
 - $n_1 > n_2$: Light prefers to stay in higher index material!
 - Everything is reflected \rightarrow **total internal reflection!**

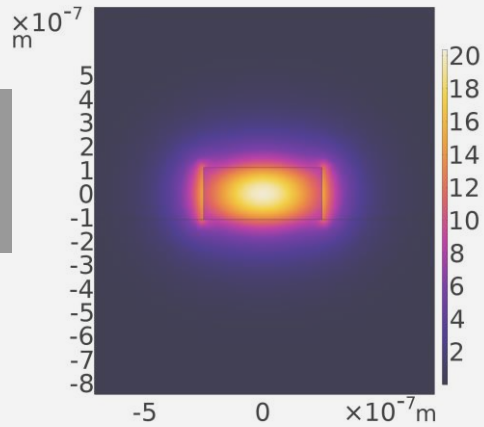
Snell's Law



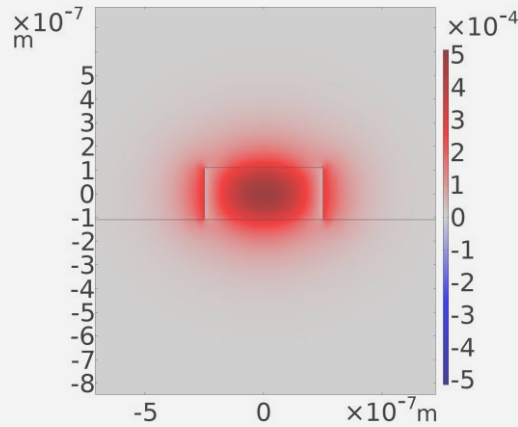
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Mode in a Waveguide

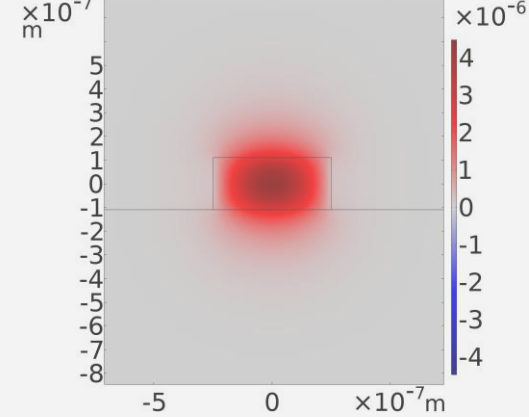
E-Field Normalized



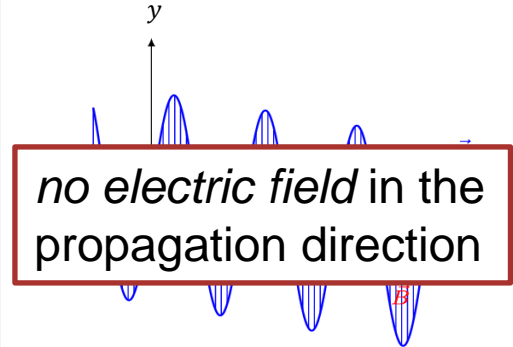
E_x



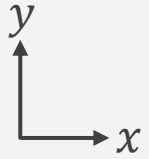
H_y



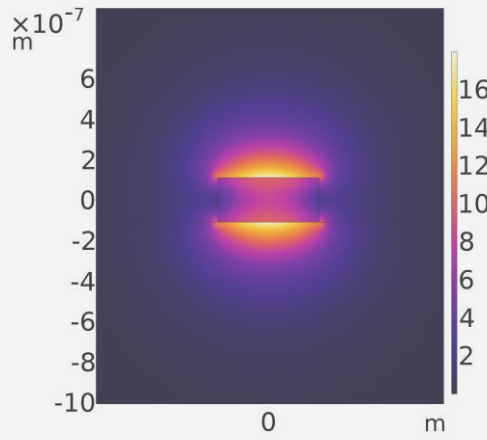
H_z



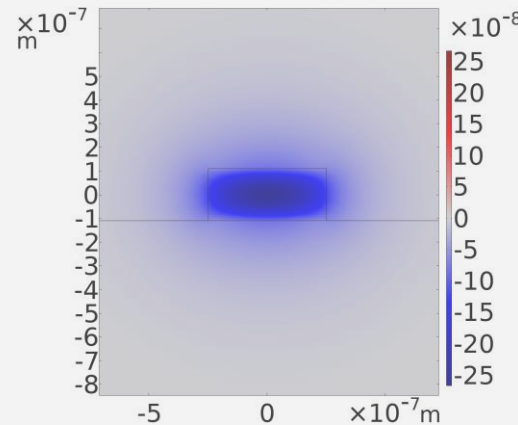
TE Mode



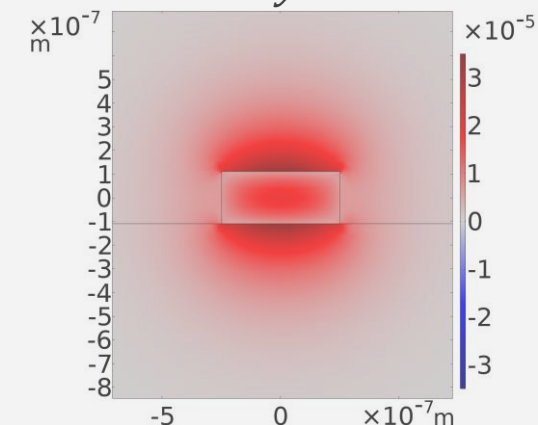
E-Field Normalized



H_x



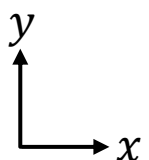
E_y



E_z

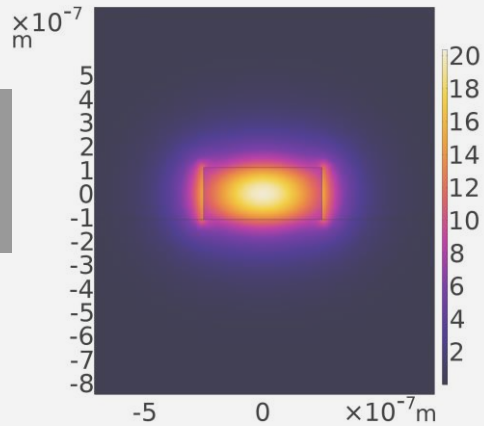
TM Mode

no magnetic field in the propagation direction



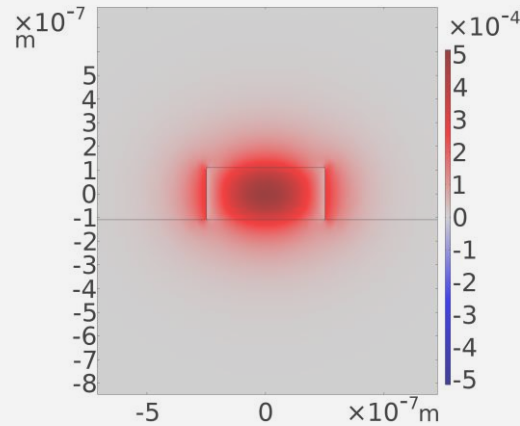
Mode in a Waveguide

E -Field Normalized

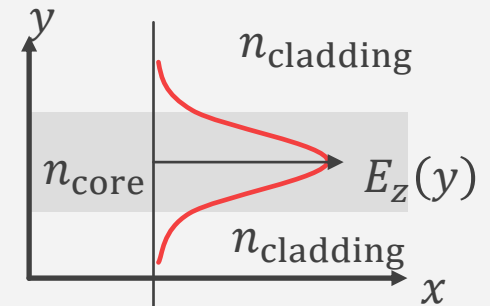
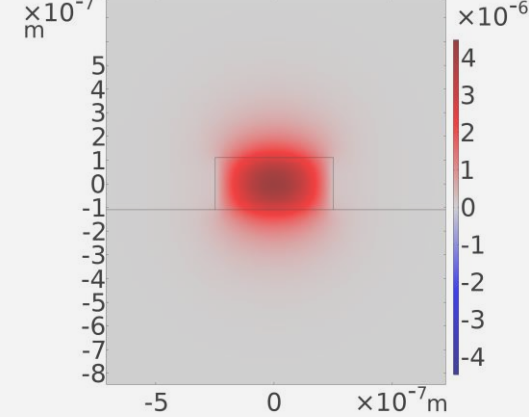


TE Mode

E_x

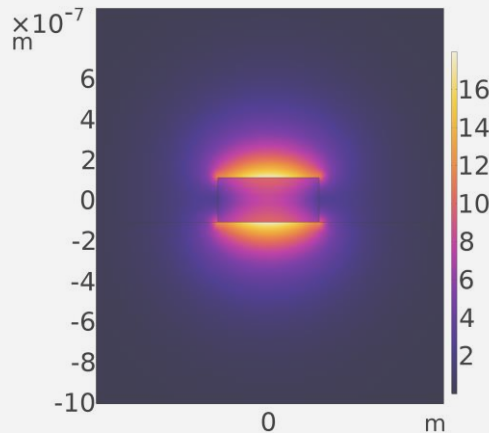


H_y

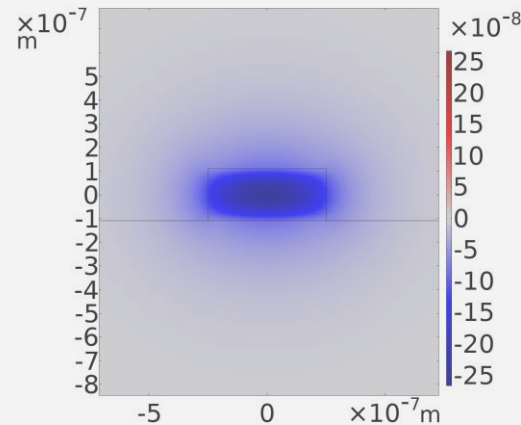


Strongly confined
Wave mostly in the
core

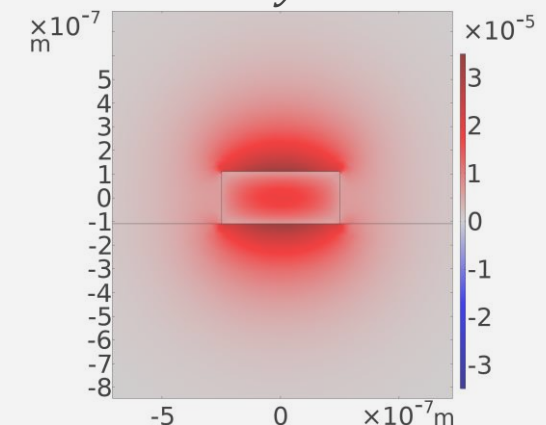
E -Field Normalized



H_x



E_y

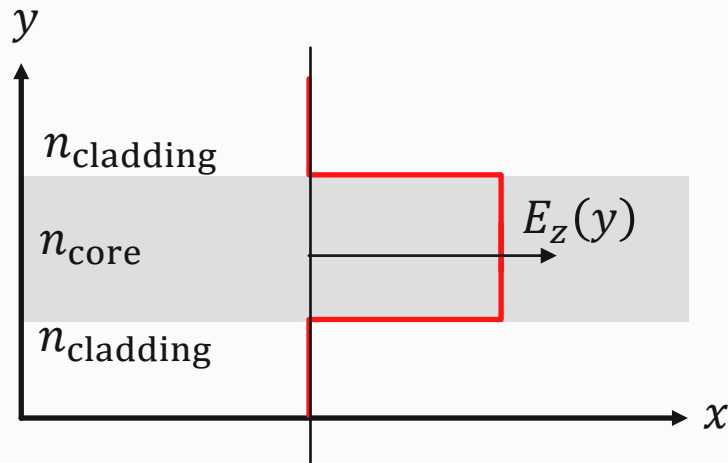


TM Mode

Weakly confined
Wave leaks into
cladding

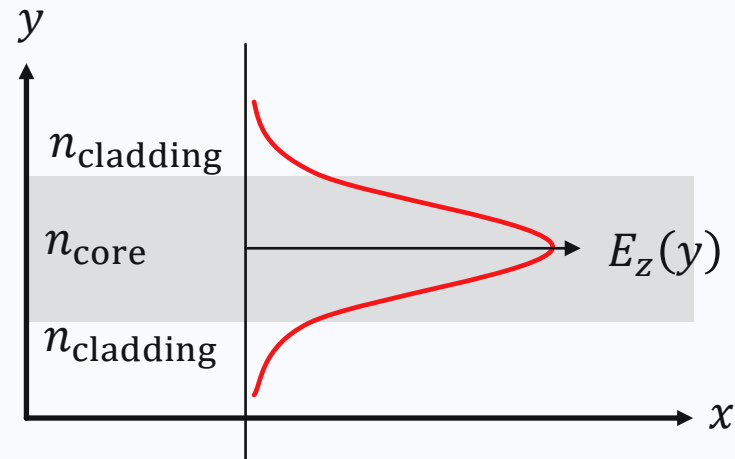
Waveguiding: Theory

Completely confined



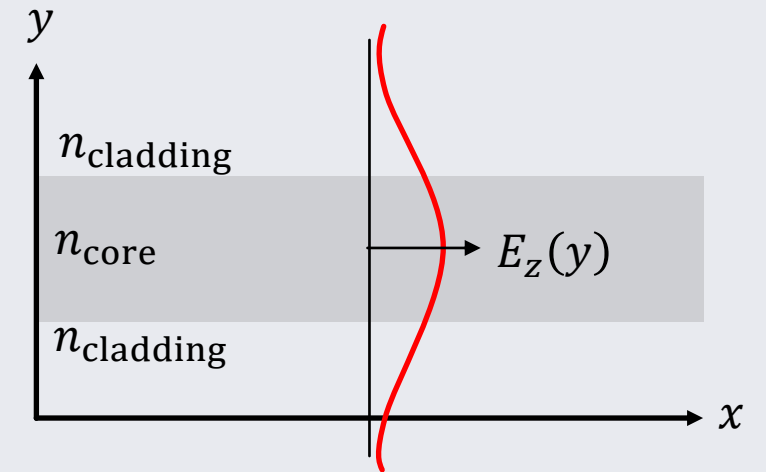
Wave only in the core
 $n_{\text{eff}} = n_{\text{core}}$

Strongly confined



Wave mostly in the core
 n_{eff} close to n_{core}

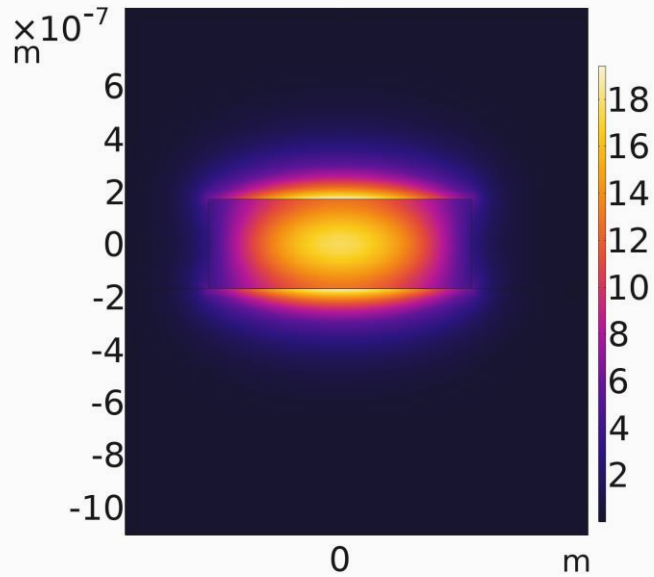
Weakly confined



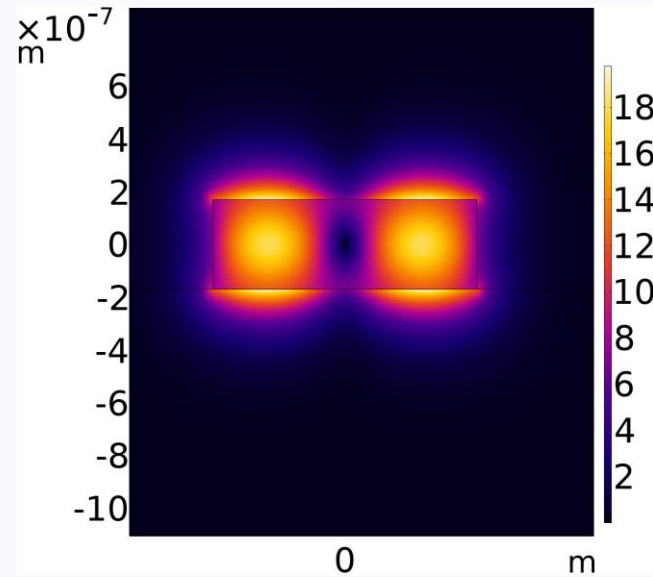
Wave leaks into cladding
 n_{eff} close to n_{cladding}

Multimoded Waveguide

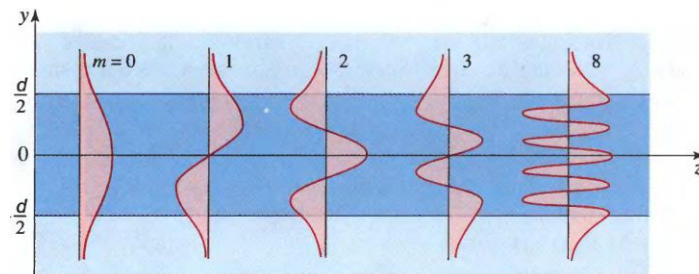
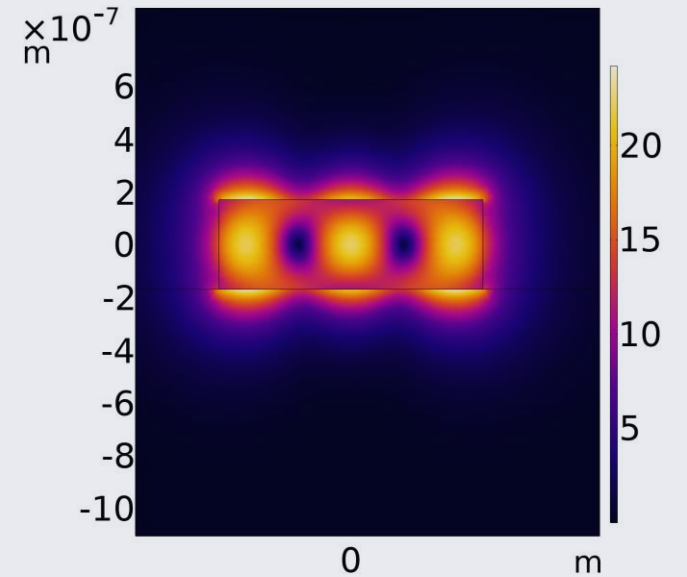
TM Fundamental



TM 1st Order Mode



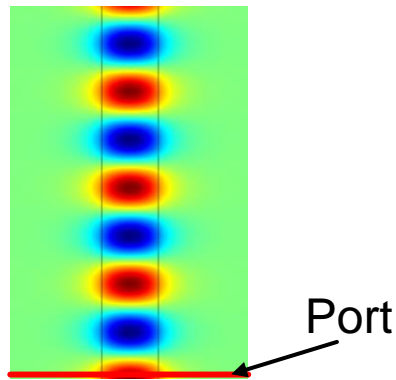
TM 2nd Order Mode



Waveguiding in COMSOL

- Propagation
 - *In-plane*: Ports need to be defined (eigenvalue solution to the defined port)

Last week



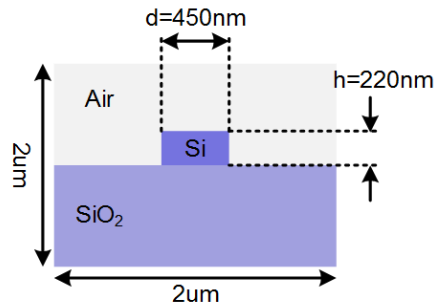
In-plane

Excitation
from boundary

Electromagnetics
node: TE or TM

- *Out-of-plane*: Ports are not defined (eigenvalue solution to the whole geometry)

Today



Out-of-plane

Excitation
from surface
plane

Electromagnetics
node: NO PORT

