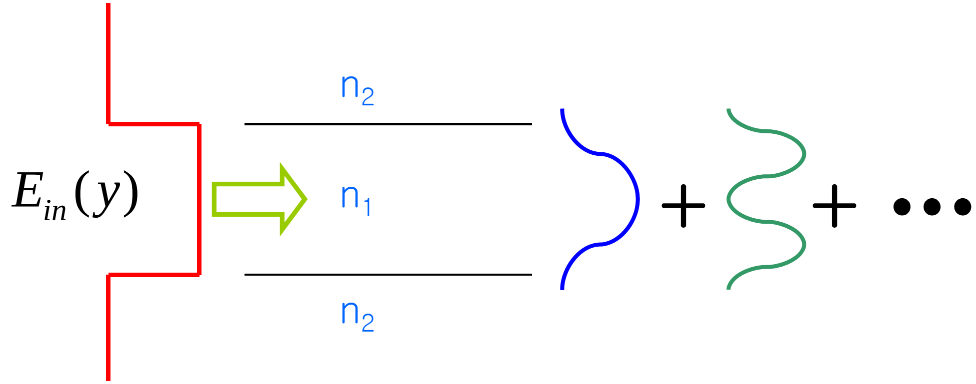
# Lect. 5 Waveguides (2)

Partitioning of input field into different guided modes.




$$E_{in}(y) \sim \sum_m a_m E_m(y)$$

For $a_m$, use the fact that $E_m(y)$'s are orthogonal: $\int E_m(y) E_n(y) dy = 0$ if $m \neq n$

(Sturm-Liouville theory)

$$\int E_{in}(y) E_m(y) dy \sim \int \left[ \sum_n a_n E_n(y) \right] E_m(y) dy = \sum_n \int a_n E_n(y) E_m(y) dy = \int a_m E_m{}^2(y) dy$$

$$\therefore a_m = \frac{\int E_{in}(y) E_m(y) dy}{\int E_m{}^2(y) dy}$$

Dot product between $E_{in}(y)$ and $E_m(y)$
Or projection of $E_{in}(y)$ into basis $E_m(y)$

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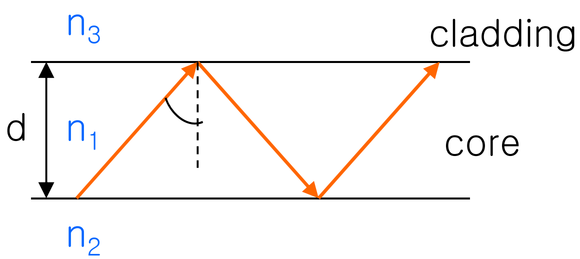
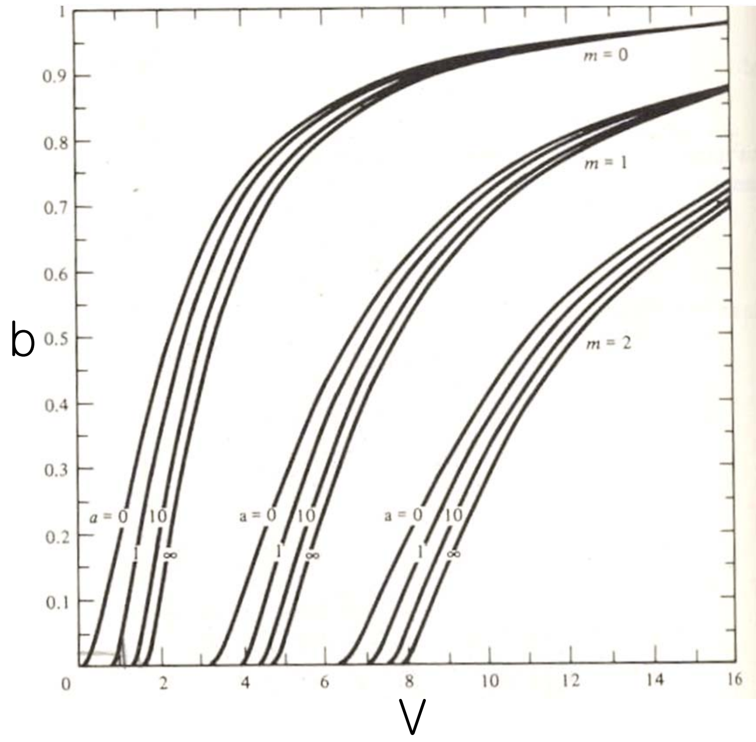



Asymmetric waveguide?

– Graphical solution

b–V diagram for TE mode




$$V = k_0 d (n_1^2 - n_2^2)^{1/2}$$

(Normalized $k$)

$$a = \frac{n_2^2 - n_3^2}{n_1^2 - n_2^2}$$

(Asymmetry factor)

$$b = \frac{\left(\beta / k_0\right)^2 - n_2^2}{n_1^2 - n_2^2}$$

(Normalized $\beta$)

For a given waveguide: V,a ➔ b from the diagram

Then, determine β

# Lect. 5 Waveguides (2)

Issues for practical waveguides

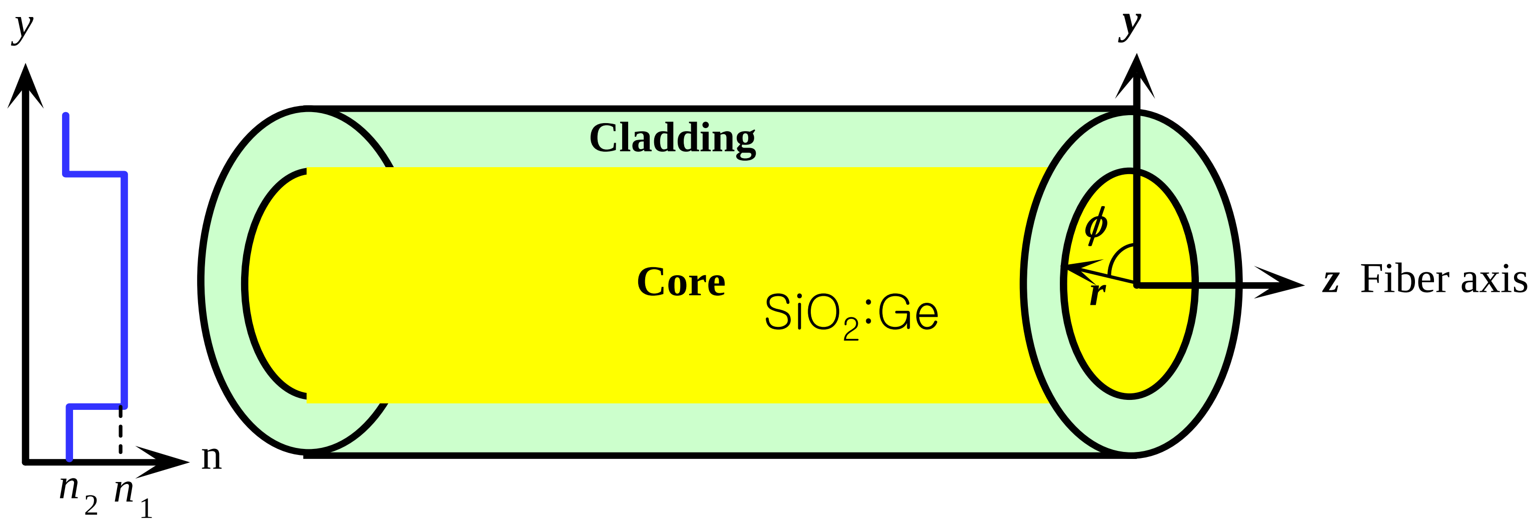
- Precise control of dimension and refractive index
- Low loss at desired $\lambda$
- Mass production possible
- Integration desirable
- Electrical control of refractive index and/or absorption

Materials used for waveguides

- Silica ($SiO_2$ with Ge doping) ➔ Optical fiber
- Dielectric materials: $LiNbO_3$ with Ti doping
- Semiconductors: GaAlAs, InGaAsP, $Si/SiO_2$

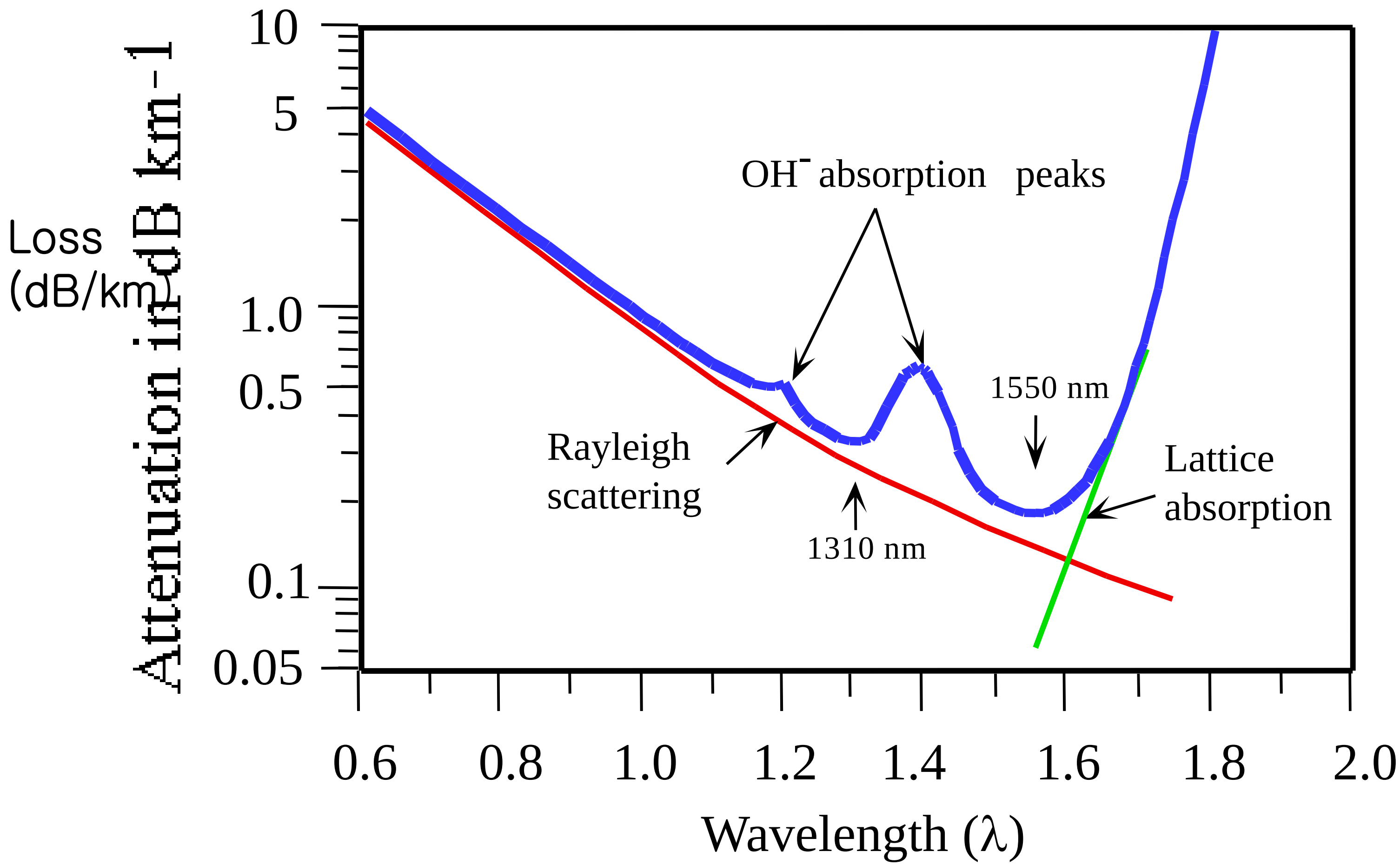
# Lect. 5 Waveguides (2)

Optical Fiber: Circular dielectric waveguide made of silica ($SiO_2$)

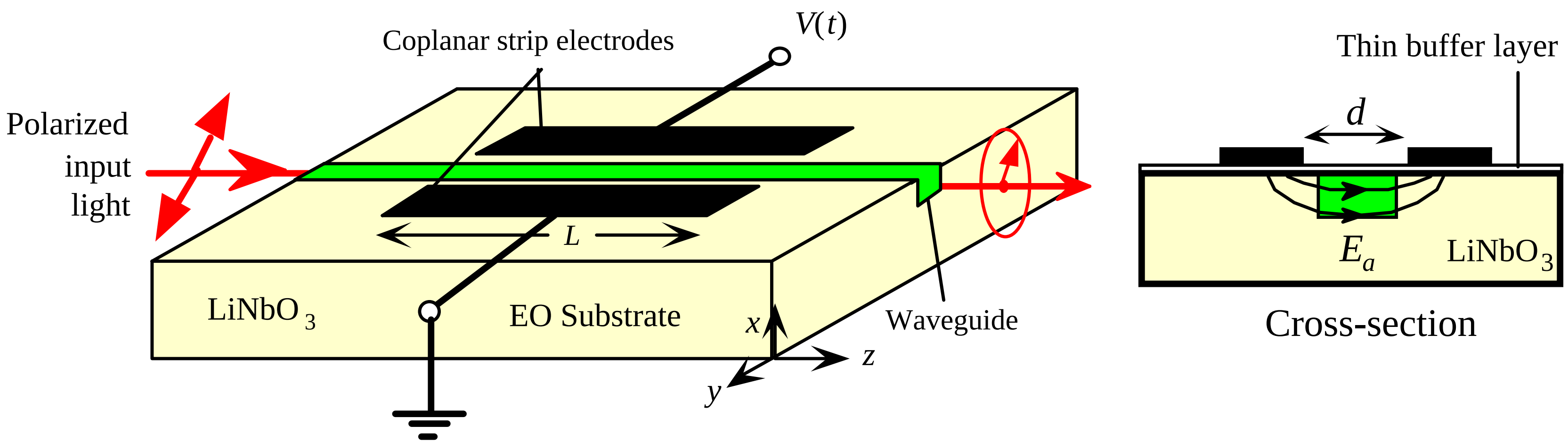



What is special about fiber?
- Extremely low loss: 0.2dB/km
- Can be very long: 100's of km

## Loss in fiber



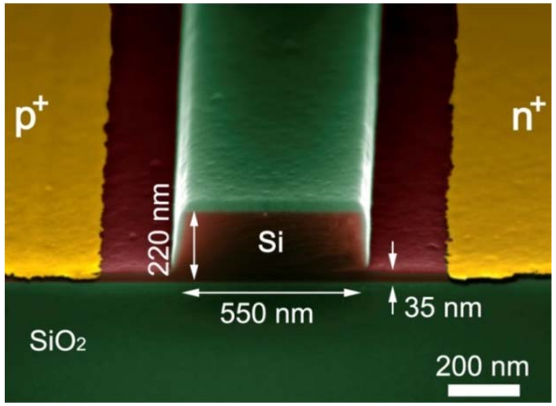
## $LiNbO_3$ waveguide (Phase Modulator)

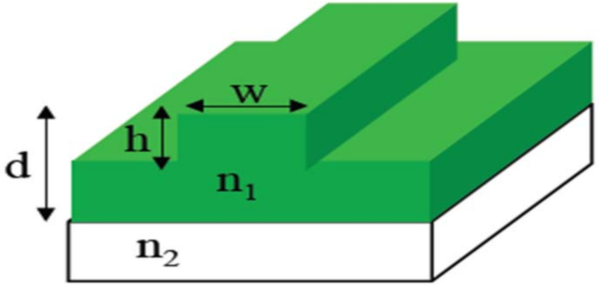



- Used for high-speed optical modulator

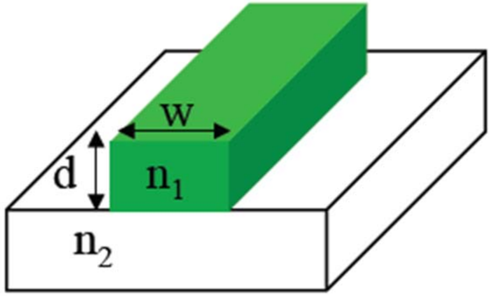
# Lect. 5 Waveguides (2)

Si/$SiO_2$ waveguide on SOI wafer fabricated with Si technology




(Rib/Ridge Waveguide)




(Strip/Channel Waveguide)

What affects the characteristics of Si/SiO2 waveguides?

# Lect. 5 Waveguides (2)

How to simulate practical waveguides?

- Numerical solutions of the wave equation:

  MODE Solutions, FDTD (Finite-Difference Time-Domain) Solutions by Lumerical will be used in this class