Opto-Electronics and Photonics

Lecture 17 : Optical Fiber

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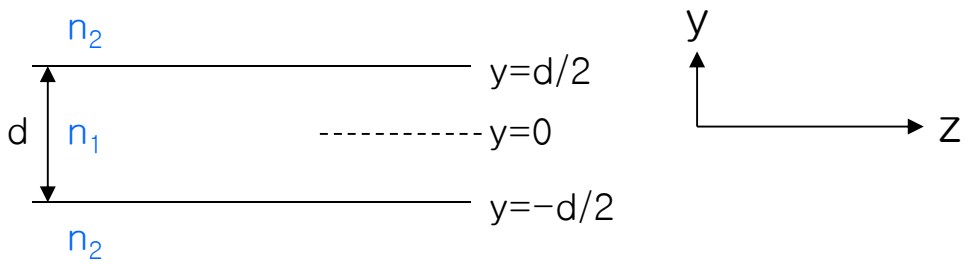
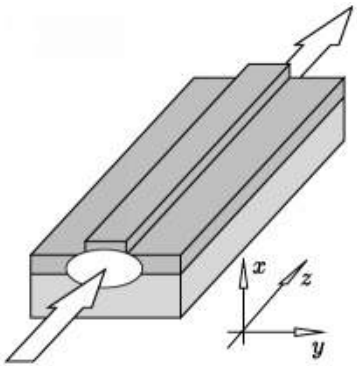
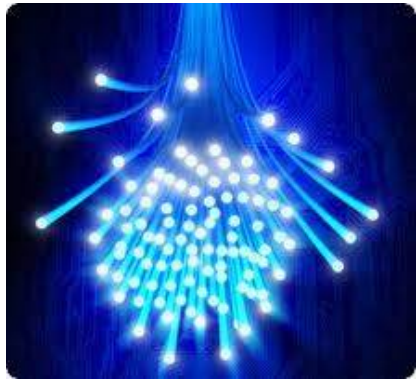
Lecture 17: Optical Fiber

3-layer dielectric waveguide



Practical dielectric waveguides





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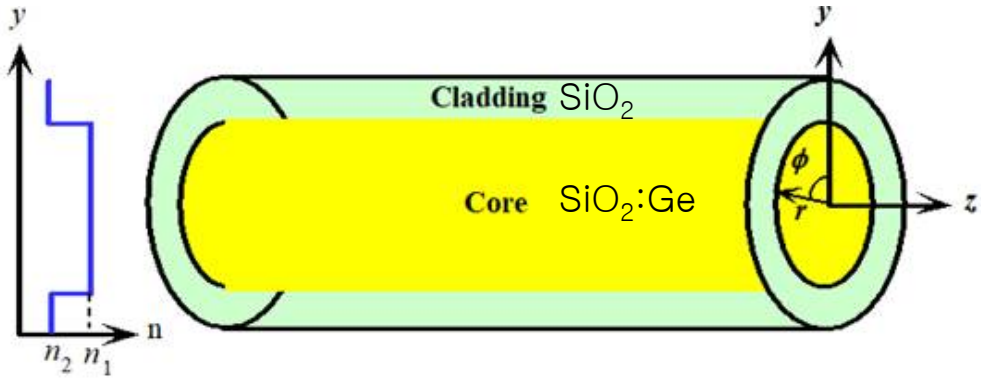
Optical Fiber: Circular dielectric waveguide made up of silica (SiO_2)



Cladding diameter: ~150 μm

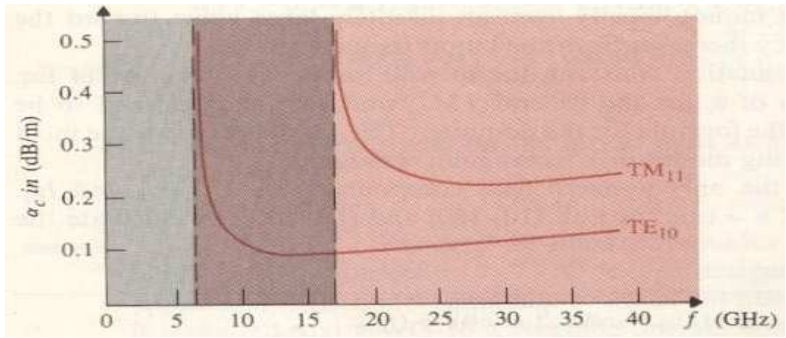
Core diameter: ~10 μm for single-mode fiber

10's of μm for multi-mode fiber

What is special about silica fiber?

- Extremely low loss: 0.2dB/km
- Can be very long: 100's of km

Loss in rectangular metal waveguide



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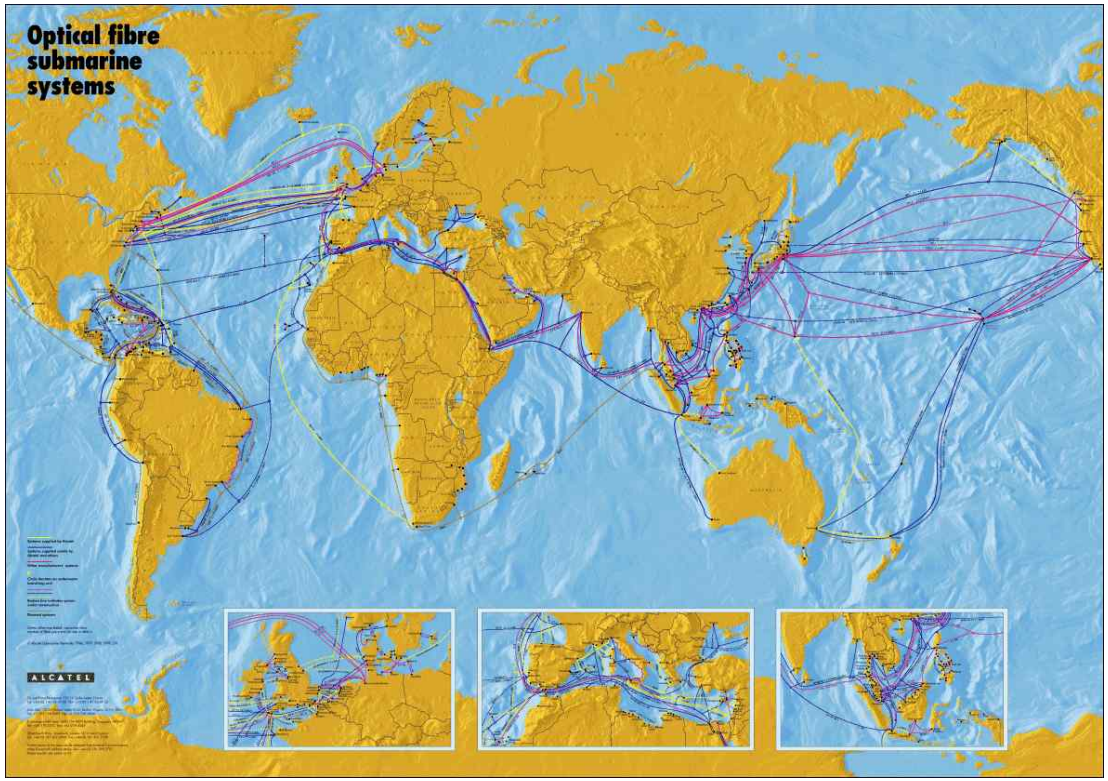
Basis for Global Optical Communication Networks



Total undersea fiber length: ~0.5 billion km (>700 round trips between earth and moon)

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Charles K. Kao (1993~2018)

2009 Nobel Prize in Physics

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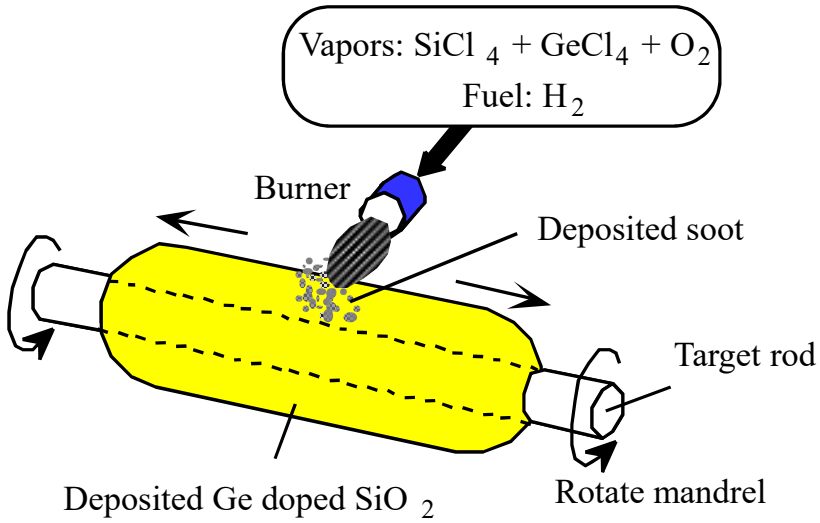
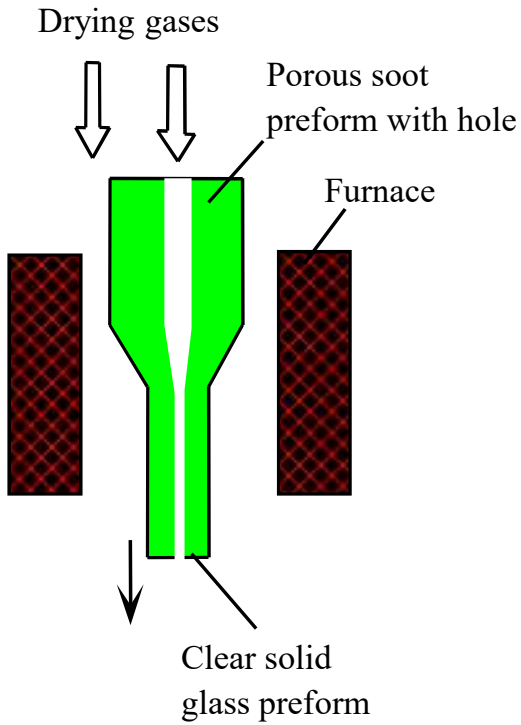
How to make silica optical fiber





$SiCl_4 + O_2 \rightarrow SiO_2 + 2Cl_2$

$GeCl_4 + O_2 \rightarrow GeO_2 + 2Cl_2$

Sintering at 1400–1600 deg C

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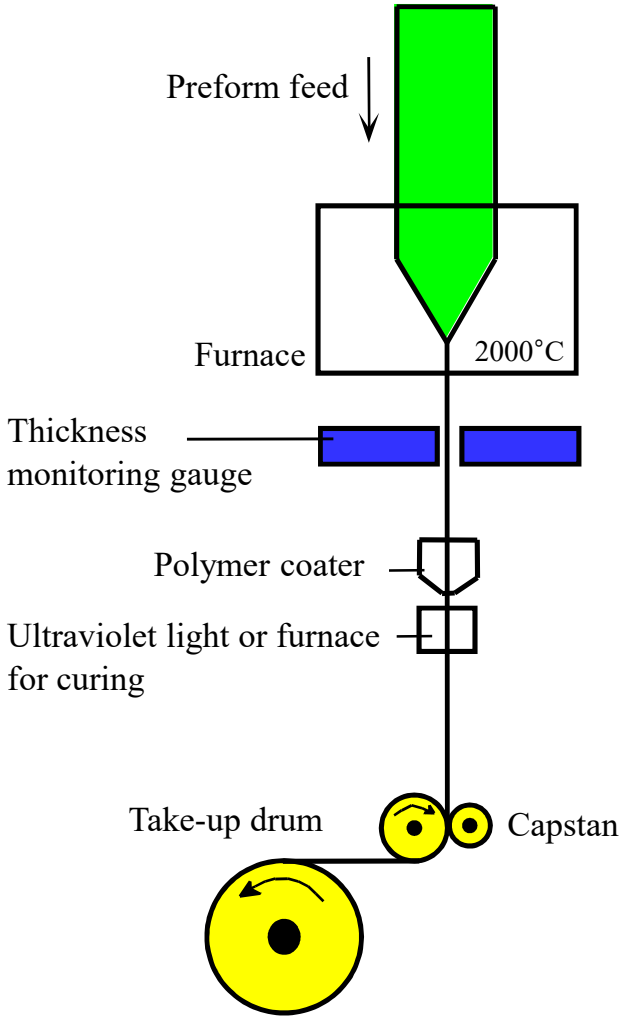

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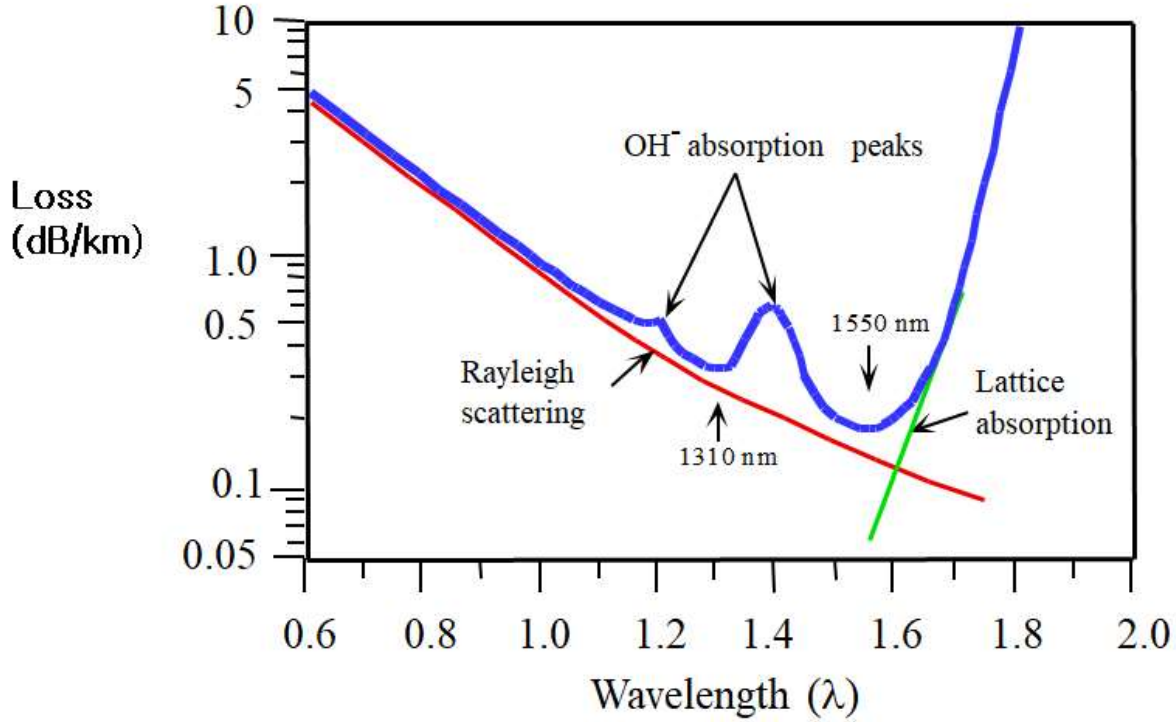
Loss in fiber



Minimum loss at 1.55μm

1.55μm for long-distance optical communication

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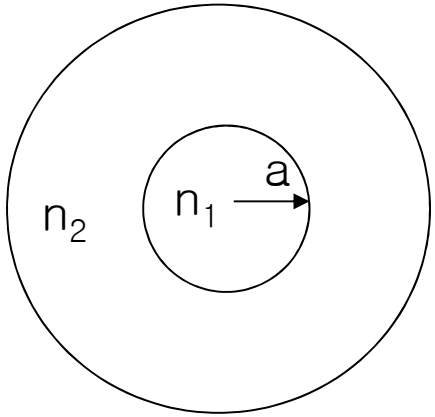
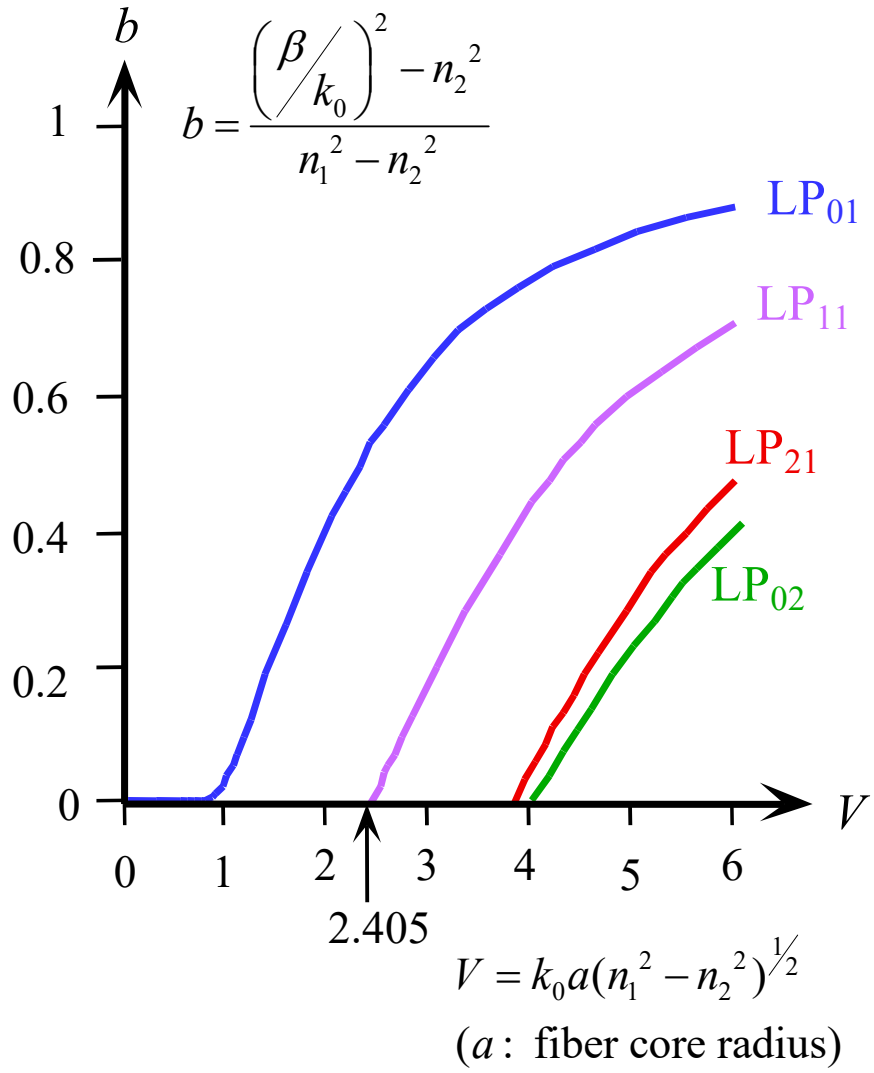


Solve for guided modes in (r, ϕ, z) coordinate

With an approximation, LP (linearly polarized) mode solutions are obtained

$$E_{LP} = E_{lm}(r,\phi)\,\mathrm{e}^{-j\beta_{lm}z}$$

LP_{lm} mode



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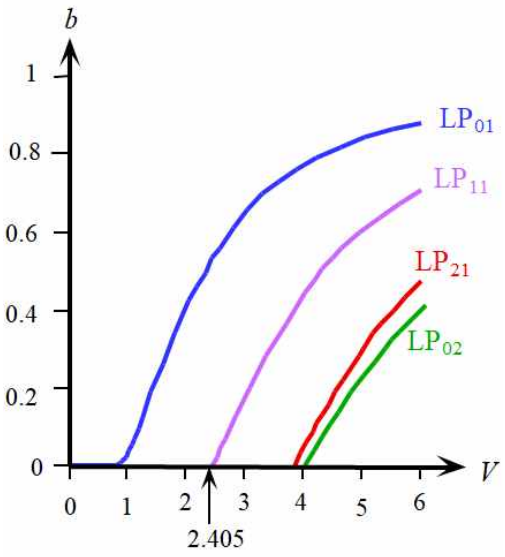
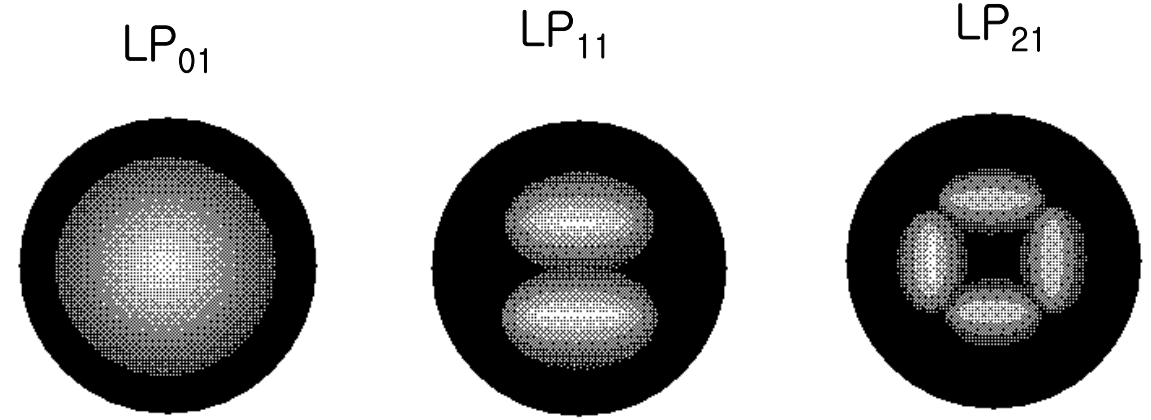
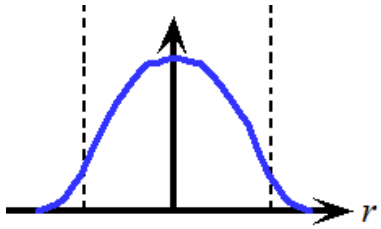


LP_{lm}





m: the number of peaks along r

2l: the number of peaks along ϕ

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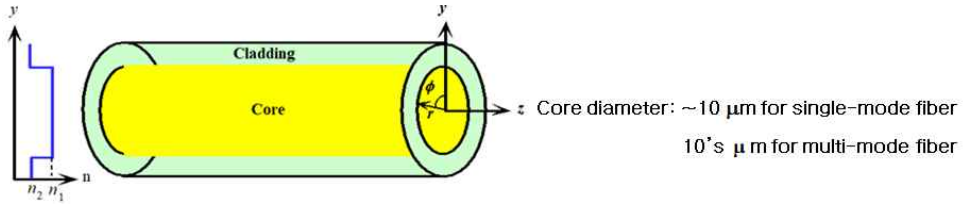
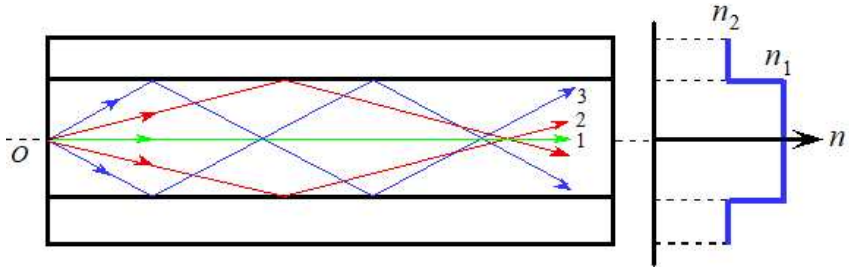
Single-mode fiber vs Multi-mode fiber

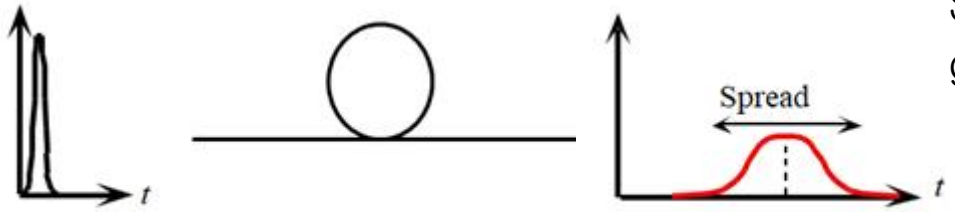




Each mode has its own group velocity

$$(v_g = \frac{\partial \omega}{\partial \beta})$$

Multi-mode fiber suffers from modal dispersion



Spread determined by
group velocity differences and distance

➔ Transmission data rate limited

➔ Single-mode fiber for high-speed, long-distance optical communication

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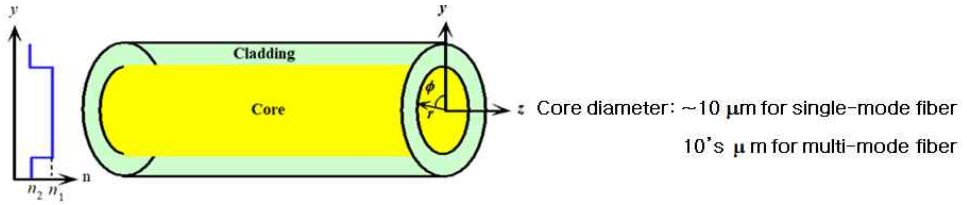
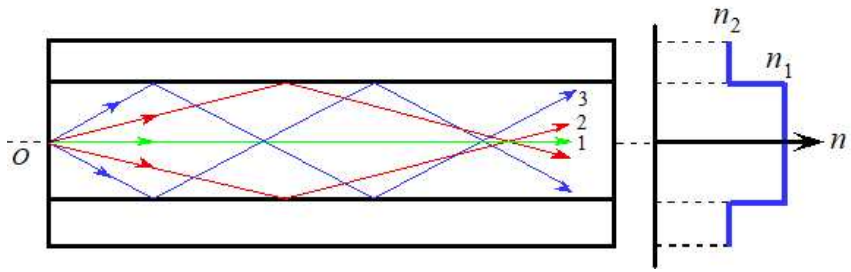
Single-mode fiber vs Multi-mode fiber





➔ Single-mode fiber for high-speed, long-distance optical communication

Single-mode fiber has higher packaging cost

➔ Multi-mode fiber for short-distance optical communication

λ=1.55μm not required

λ=0.85 μm often used for cost effectiveness

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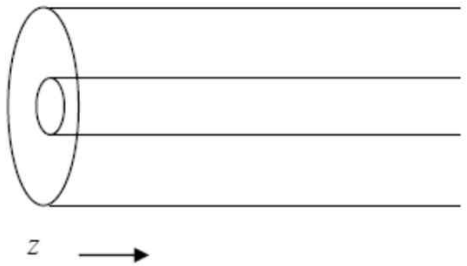
Homework: (Due on 11/16)

A fiber has its core refractive index given as $n_1(z) = n_0 + \Delta n \sin[(2\pi/d)\, z)$ as shown below.



$n_2 = 1.497$

$n_1 = 1.5 + \Delta n \cdot \sin(\frac{2\pi}{d} Z)$, core radius: $5\mu m$

(a) Using the fiber b–V diagram given in the lecture notes, determine the approximate value of the effective index for the fundamental guided mode. For this problems, assume $\Delta n = 0$, the cladding layer is infinitely thick and $\lambda = 1.5\mu m$.

(b) With a very small amount of Δn so that the effective index of the guided mode does not change from the value obtained in (a), the fiber can reflect light having a specific wavelength of $1.5\mu m$. Determine the numerical value d (with its unit) so that the reflection efficiency is highest.