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3-dimentioanl dielectric waveguide?





planar waveguide

circular waveguide

➔ optical fiber





Optical Fiber: Circular dielectric waveguide made of silica (SiO₂)





Optical Communication Networks



Total undersea fiber length: 0.4 billion km (628 round trips between earth and moon)











$SiCl_4 + O_2 ->SiO_2 + 2Cl_2$ $GeCl_4 + O_2 ->GeO_2 + 2Cl_2$

Sintering at 1400-1600 deg C



















Lattice Absorption: EM waves cause vibration of ions inside fiber. Peak absorption occurs at around λ = 9 µm in Silica fiber.





Rayleigh scattering A small portion of EM waves get directed away from small dielectric particles that are due local fluctuation of fiber refractive index. More scattering with smaller wavelength (inversely proportional to λ^3).





Dispersion in Fiber

- Multi-Mode Fiber: Modal Dispersion



Each mode has its own group velocity

If a light pulse is decomposed into many modes, the pulse gets dispersed (broadened) after propagation

Prevention: Use single mode fiber!



But single mode fiber also has small but non-zero dispersion

- Waveguide dispersion Waveguide solution depends on wavelength

- Material (or chromatic) dispersion: Refractive index of any material depends on wavelength (frequency)

 \rightarrow v_a for SMF depends on wavelength(frequency)





Dispersion exists because β is not not linear with ω

Mathematically,

$$\beta(\omega_0 + \omega) = \beta(\omega_0) + \frac{\partial \beta}{\partial \omega} \Big|_{\omega_0} \cdot \omega + \frac{1}{2} \frac{\partial^2 \beta}{\partial \omega^2} \Big|_{\omega_0} \cdot \omega^2 + \bullet \bullet \bullet$$
$$\approx \beta(\omega_0) + \beta_1(\omega_0) \cdot \omega + \frac{1}{2} \beta_2(\omega_0) \cdot \omega^2$$
$$= \beta(\omega_0) + \frac{1}{v_g(\omega_0)} \cdot \omega + \frac{1}{2} \frac{\partial}{\partial \omega} \left(\frac{1}{v_g}\right) \Big|_{\omega_0} \cdot \omega^2$$

In Silica fiber, $\beta_2 \sim -20 \text{ ps}^2/\text{km}$ at $\lambda = 1.5 \mu \text{m}$ With $\beta_2 < 0$, v_g increases as ω increases



Often, dispersion parameter D is used.





Homework

The time-domain profile of an E-field for an optical pulse is sketched below. Assume the carrier frequency is f_0 and the envelop has a Gaussian shape.



(a)(10) Sketch the frequency-domain spectrum (f>0 only) of the E-field pulse. Clearly indicate important features of your sketch.

(b)(10) The pulse has propagated in a fiber with a positive dispersion parameter (D>0). Sketch the resulting time-domain profile of the E-field pulse. Clearly indicate important features of your sketch.

