Signal Distortion

- **Dispersion**
  - Material
  - Intramodal
  - Intermodal

  (Multi-mode only)

- **Attenuation**
  - Material
    - Absrption
    - Scattering $\sim \lambda^{-4}$

    Micro-bending

    Radiation

    (Macro-bending)

Lec No-8
5/1/06

Dispersion

Group Velocity $v_g \equiv \frac{\partial \omega}{\partial \beta} = 2\pi c \frac{\partial}{\partial \beta}(1/\lambda)$

Group Delay per unit length $t_g = 1/v_g$

Pulse Broadening $\tau_g = \frac{dt_g}{d\lambda}\sigma_\lambda = -\frac{\sigma_\lambda}{2\pi c}\left\{2\lambda\frac{d\beta}{d\lambda} + \lambda^2\frac{d^2\beta}{d\lambda^2}\right\}$

Dispersion $D = \frac{dt_g}{d\lambda}$ = Pulse broadening per unit distance per unit spectral width (ps/Km/nm)

Phase constant

$$\beta = \frac{2\pi}{\lambda} n(\lambda)$$

$$\rightarrow t_g = \frac{\partial \beta}{\partial \omega}$$

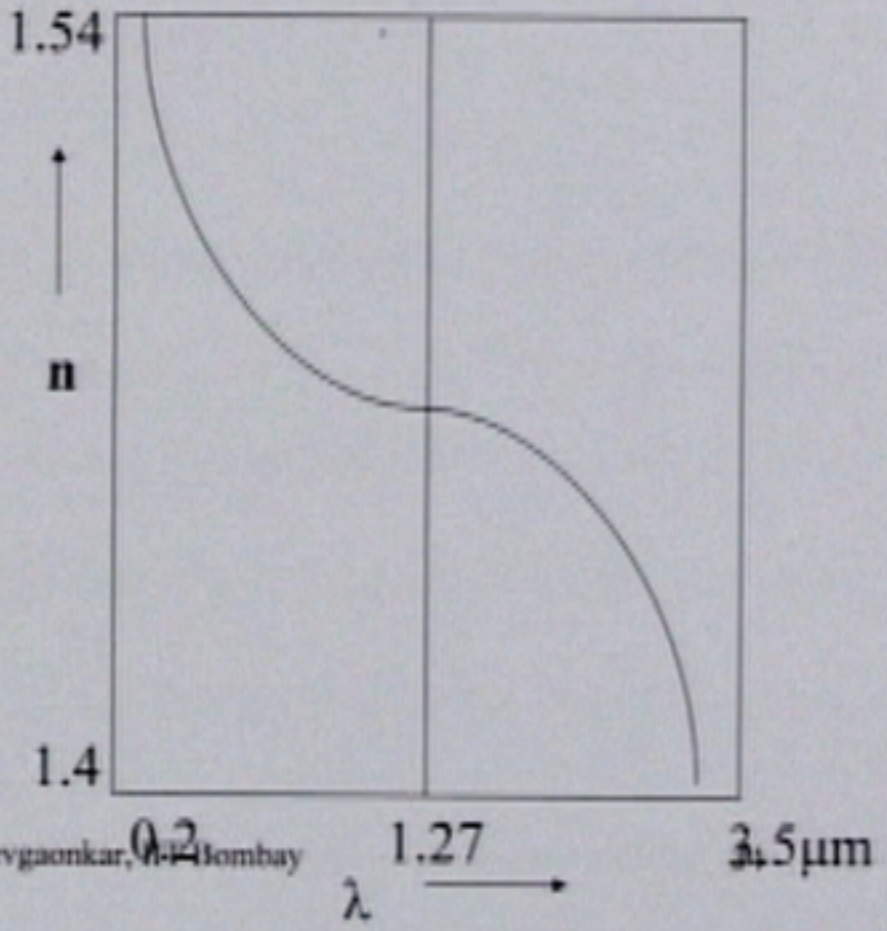
$$D = \frac{d t_g}{d\lambda}$$

$$D_{mat} = -\frac{\lambda}{c} \frac{d^2 n}{d\lambda^2}$$

Material Dispersion

$$D_{mat} = -\frac{\lambda}{c}\frac{d^2 n}{d\lambda^2}$$

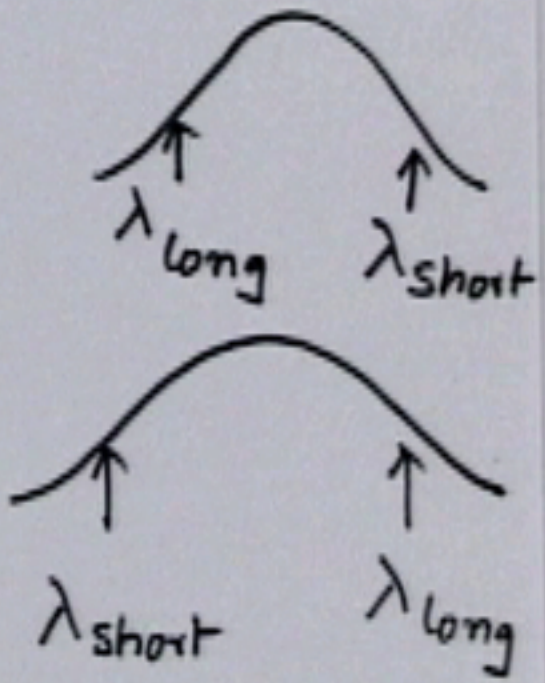
Wavelength λ	D mat ps/Km/nm
850 nm	85
1310 nm	0.1
1550 nm	-20

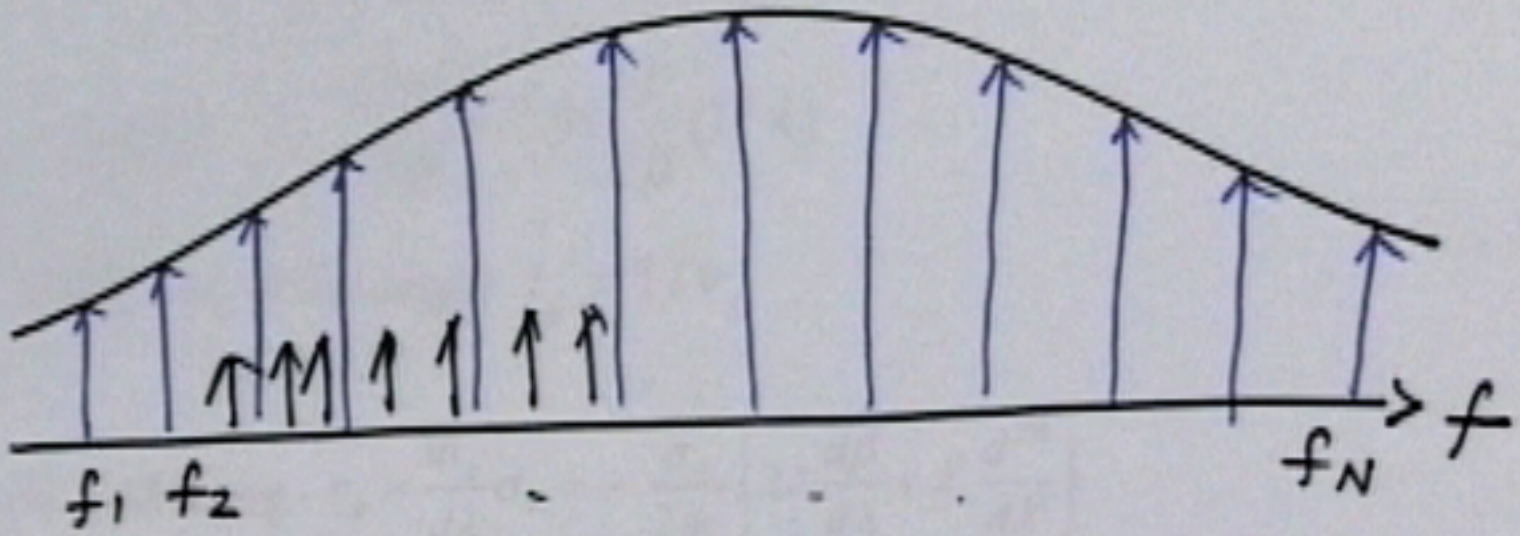


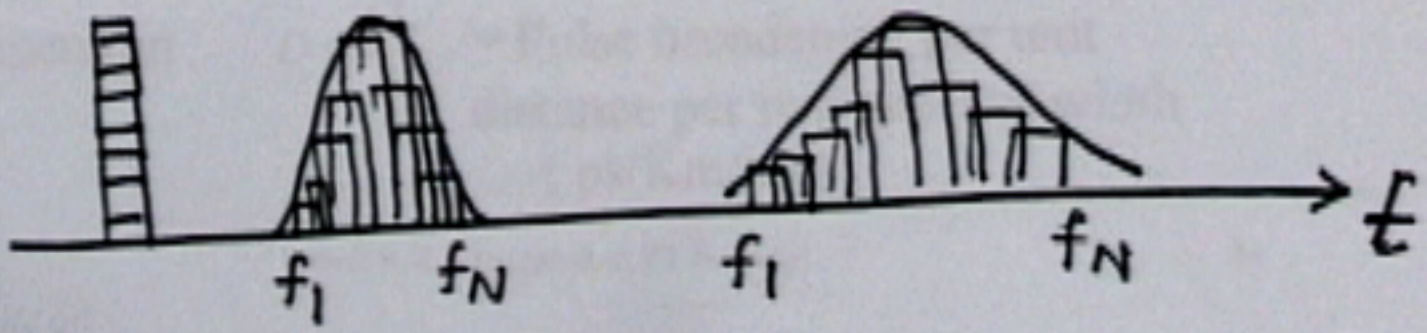
$$D = \frac{d t_g}{d\lambda}$$

+ve $t_g \uparrow$ $\lambda \uparrow$

−ve $t_g \downarrow$ $\lambda \uparrow$




f
f_1 f_2
f_N


f
f_1
f_N
f_1
f_N

$$b = \frac{\beta^2 - \beta_2^2}{\beta_1^2 - \beta_2^2} = \frac{(\beta - \beta_2)(\beta + \beta_2)}{(\beta_1 - \beta_2)(\beta_1 + \beta_2)}$$

$$n_1 \approx n_2 \quad , \quad \Delta = \frac{n_1 - n_2}{n_1}$$

$$\approx \frac{n_1 - n_2}{n_2}$$

$$\beta_2 < \beta < \beta_1$$

$$n_2 \beta_0 < \beta < n_1 \beta_0$$

$$b = \frac{\beta - \beta_2}{\beta_1 - \beta_2}$$

$$\beta = \beta_2 + b(\beta_1 - \beta_2)$$

$$= \beta_2 \left\{ 1 + b \frac{\beta_1 - \beta_2}{\beta_2} \right\}$$

$$= \beta_2 \left\{ 1 + b \frac{n_1 - n_2}{n_2} \right\}$$

$$\beta = \beta_2 \{ 1 + b\Delta \}$$

$$= \frac{\omega}{c} n_2 \{ 1 + b\Delta \}$$

Group Delay $t_g = \frac{\partial \beta}{\partial \omega} = \frac{n_2}{c} \{ 1 + b\Delta \} + \frac{n_2 \omega}{c} \frac{db}{d\omega}$

$$t_g = \frac{n_2}{c}\{1 + b\Delta\} + \frac{n_2\omega}{c} \cdot \frac{db}{dV} \cdot \frac{dV}{d\omega}\Delta$$

$$V = \frac{\omega}{c} a\,(NA)$$

$$\frac{dV}{d\omega} = \frac{a\,(NA)}{c} = \frac{V}{\omega}$$

$$t_g = \frac{n_2}{c}\{1 + b\Delta\} + \Delta\frac{n_2\omega}{c} \cdot \frac{db}{dV} \cdot \frac{V}{\omega}$$

$$= \frac{n_2}{c}\left\{1 + b\Delta + \Delta V \frac{db}{dV}\right\}$$

$$t_g = \frac{n_2}{c}\left\{1 + \Delta \frac{d(bV)}{dV}\right\}$$

Waveguide Dispersion

$$D_{WG} = \frac{d\tau_g}{d\lambda}$$

$$= \frac{n_2 \Delta}{c} \frac{d}{d\lambda} \left\{ \frac{d(bV)}{dV} \right\}$$

$$= \frac{n_2 \Delta}{c} \frac{d^2(bV)}{dV^2} \cdot \frac{dV}{d\lambda}$$

$$V = \frac{\omega}{c} a(NA) = \frac{2\pi}{\lambda} \cdot a \cdot (NA)$$

$$\frac{dV}{d\lambda} = - \frac{2\pi a (NA)}{\lambda^2} = - \frac{V}{\lambda}$$

Wave-guide Dispersion

Dispersion due to non-linear b-V diagram

$$D_{wg} = -\frac{n_2 \Delta}{c\lambda} V \frac{d^2(bV)}{dV^2}$$

At 800 nm Dmat >> Dwg

At 1300nm Dmat << Dwg

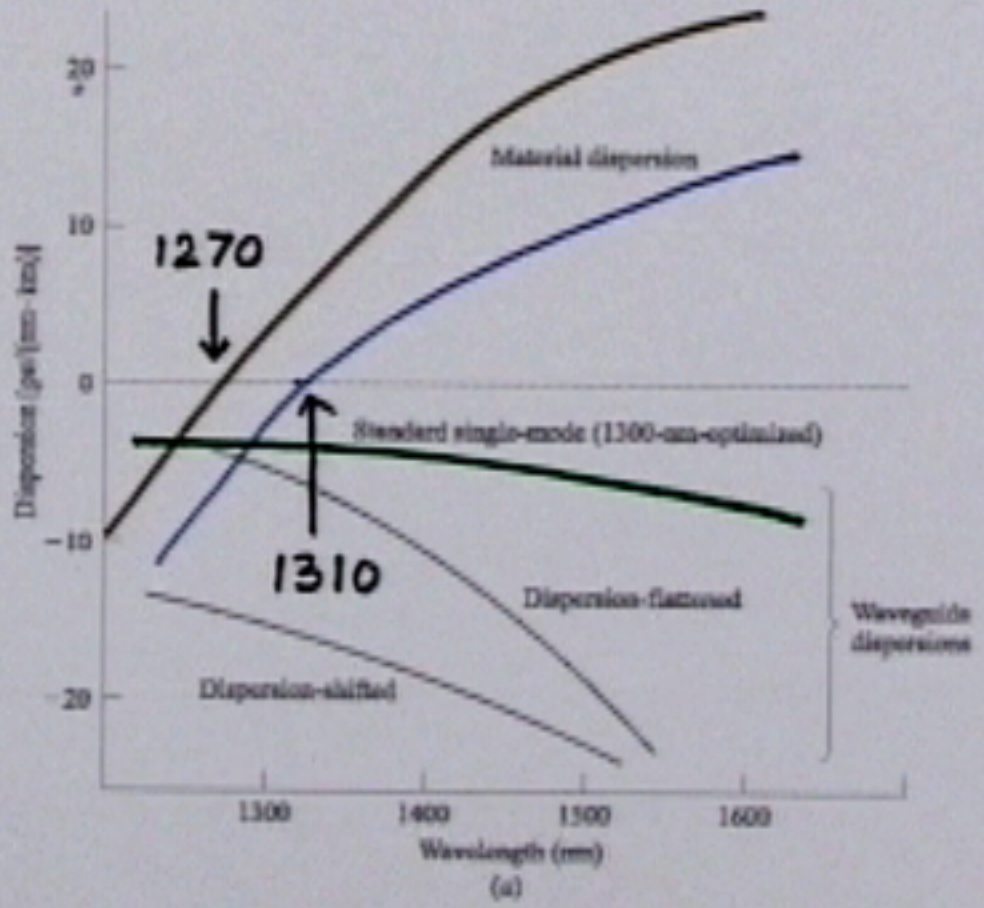
Dwg peaks around V =1.2

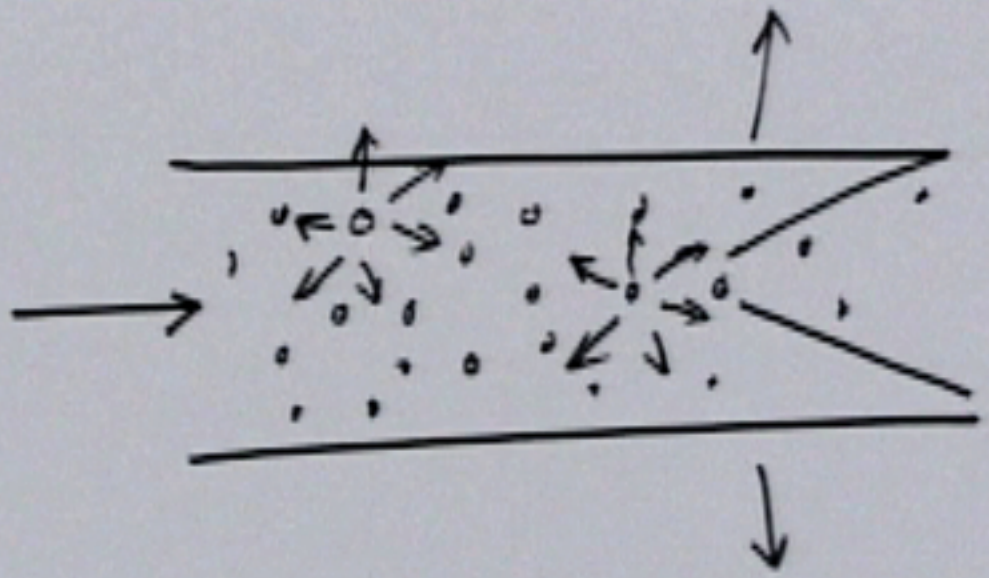
To reduce waveguide dispersion V-number should be close to but not greater than or equal to 2.4

Chromatic Dispersion

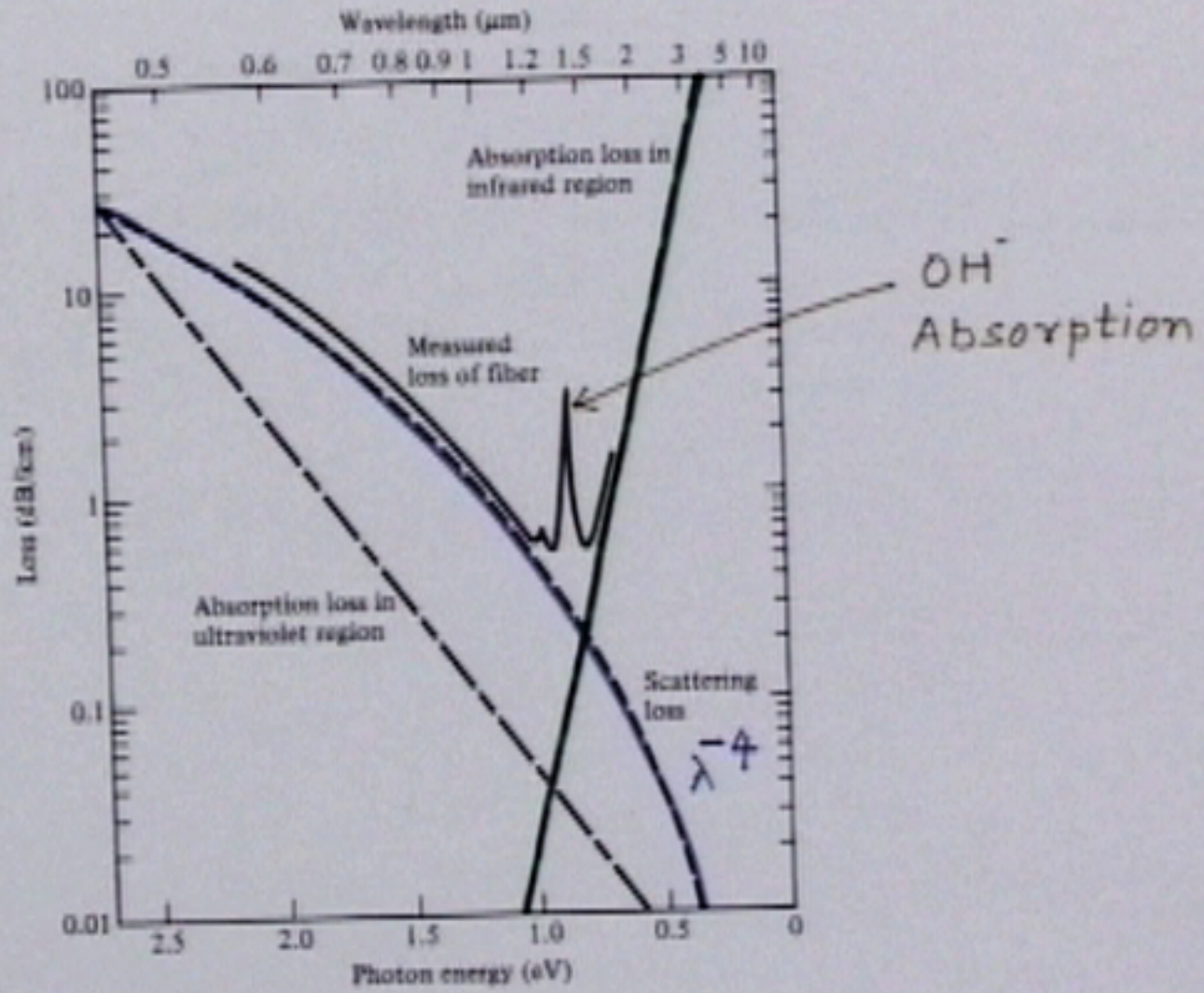
$$\simeq D_{mat} + D_{WG}$$

SM-fiber dispersions

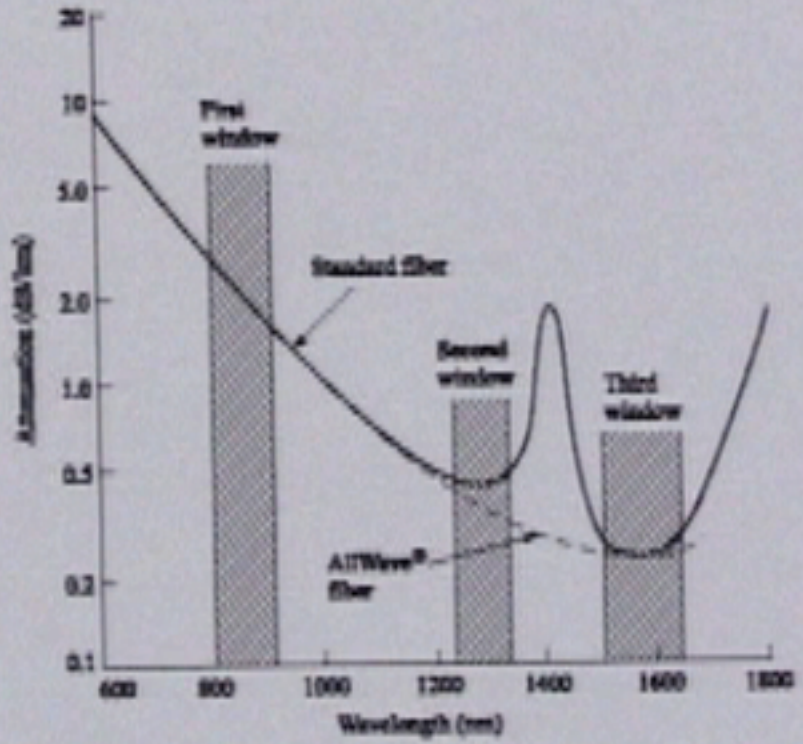




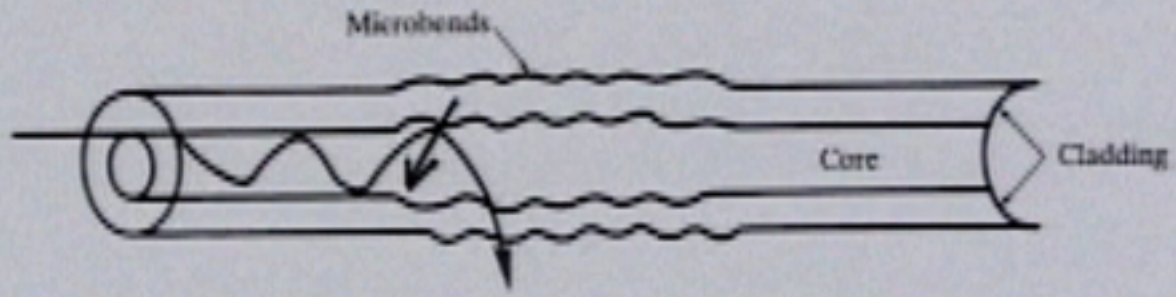
Attenuation characteristics



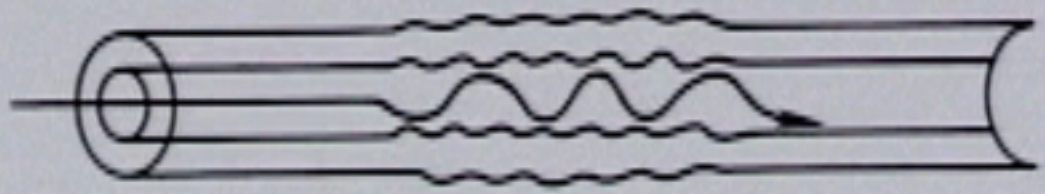
Optical fiber attenuation



Microbending losses



Power loss from higher-order modes



Power coupling to higher-order modes