Attenuation - sources
1) material absorption
2) absorption to impurities
3) Rayleigh scattering
4) surface scattering
5) bending loss

} attenuation

Beer's Law

$$P_{out} = P_{in} e^{-\alpha z} \qquad \alpha = \text{attenuation coef. } cm^{-1} \qquad dB = 10 \log \frac{P_{out}}{P_{in}}$$

material absorption

complex refractive index $n = n' + jn''$

leads to complex propagation constant

$$e^{-jk_0 n z} = e^{-jk_0(n' + jn'')z} = e^{-jk_0 n' z} e^{-k_0 n'' z}$$

$$\frac{\alpha}{2} = k_0 n'' \qquad \text{(see Fig. 8.2 GaAs)}$$

for semiconductor, transparency below bandgap

fused silica, absorption band @ 8.9eV (140 nm)

electric transitions (see Table 8.1)

Raman transition - vibrational / rotational states, IR

impurities

dopants - Na or Ge in silica ?

transition metal impurities - Cr, Ti, Fe

OH^{-1} (water) - loss ~~at~~ near 1550nm, silica, SiON

Rayleigh scattering - not absorbing, scattering from density fluctuations

$\Delta p(t) = \Delta\epsilon E(t)$ instantaneous dipole moment for particle

(see Fig. 8.4) $\Delta\epsilon$ = excess polarizability

dipole re-radiates away from incident $P_{rad} = \dfrac{\omega^4 (\Delta\epsilon)^2 E^2}{12\pi\epsilon_0 c^3}$ $\quad \frac{1}{\lambda^4}$ scaling

multiply by N particles

$$\alpha_R = \frac{8\pi^3}{3\lambda_0^4}\left[(n^2-1)kT\beta + \underbrace{2n\left(\frac{\partial n}{\partial c}\right)^2 \overline{\Delta c^2}\, \delta V}_{\text{dopant}}\right]$$

mean square dopant conc.

melting of wg. mtl

T = transition temp.

β = isothermal compressibility

Surface scattering (see Fig. 8.8)

scattering from etched surfaces, dominant source of loss

$SiO_2 <, 1\ cm^{-1}$

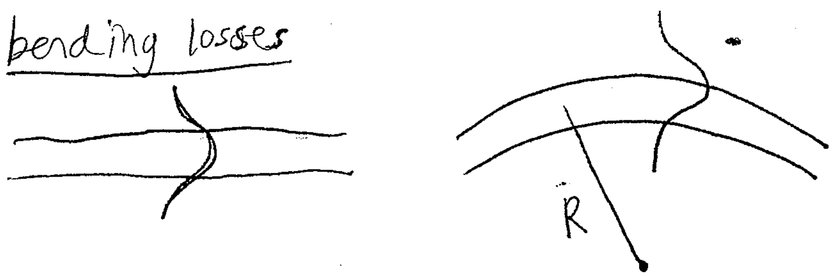
$Si \sim 1\ cm^{-1}$

similar to Rayleigh scattering (dominates Rayleigh)

loss related to index contrast $\Delta G = n_f^2 - n_s^2$

strong overlap can occur with rough surfaces, can control with waveguide design (fig. 8.8)

bending losses



phase front at outside must travel faster than on inside

at some point, will have to travel faster than c/n_{clad} and must radiate

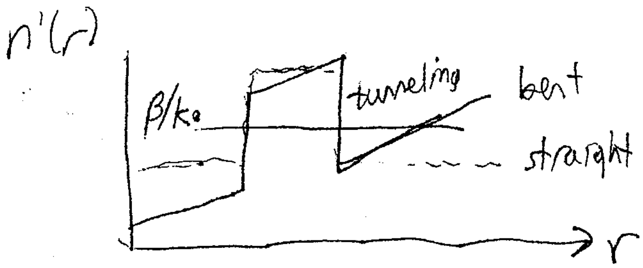
transform refractive index profile in bend

$$n'(r) = n(r)\left(1+\frac{r}{R}\cos\Phi\right)$$

$n(r)$ = actual profile

R = radius of curvature

Φ = azimuthal angle



weakly guided mode, lower β/k_0 (near cutoff) will have > loss

tail will extend into region where $\beta/k_0 < n(r)$ and radiate

modes with larger β/k_0 (n_{eff}) will have less loss.

$$\alpha = \frac{1}{2}\left(\frac{\pi}{aV^3}\right)^{1/2}\left[\frac{Ka}{\gamma a K_1(\gamma a)}\right]^2 R^{-1/2} e^{-UR}$$

$$U = 4\Delta(\gamma a)^3/3aV^2 n_{clad}$$

a = core radius

Δ =

K_1 = Bessel func. of 2nd kind, 1st order

$$\Delta = \frac{n_1-n_2}{n_1}$$ (see Fig. 8.11)