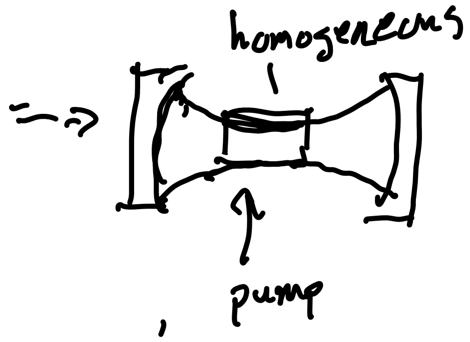
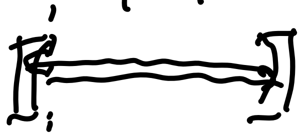
Lecture 6 - Lasers

Practical considerations



Want: - single mode operation
- maximize the power



$(ABCD)_{RT}$

$$\frac{1}{q} = \frac{-(A-D)}{2B} \pm j\,\frac{\sqrt{1-\frac{A+D}{2}}}{B}$$

$$\frac{1}{q} = \frac{1}{R(z)} - j\,\frac{\lambda}{\pi W_0^2}$$

HW problem on this

Spatial higher order modes

Hermite-Gaussian modes

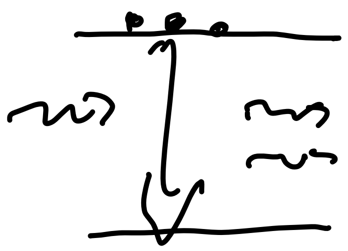
$$H_m = (-1)^m e^{u^2} \frac{d^m e^{-u^2}}{du^m}$$

$$\frac{E(x,y,z)}{E_{m,p}} = H_m\left[\frac{2^{1/2}x}{W(z)}\right] H_p\left[\frac{2^{1/2}y}{W(z)}\right] \times$$

same as Gaussian mode $\times \frac{W_0}{W(z)} \exp\left(\frac{-(x^2+y^2)}{W^2(z)}\right)$

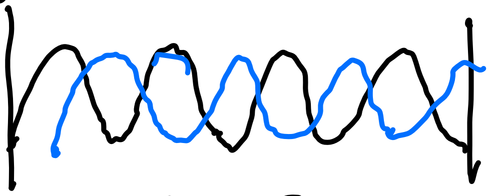
same $\rightarrow \times \exp\left(-j\frac{kr^2}{2R(z)}\right)$

extra phase $\times \exp\left[-j\left[kz-(1+m+p)\tan^{-1}\left(\frac{z}{z_0}\right)\right]\right]$



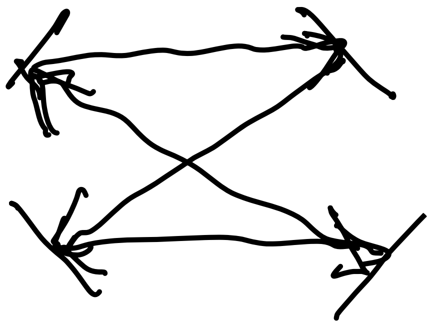
Typically, have one mode clamped at N_{th}

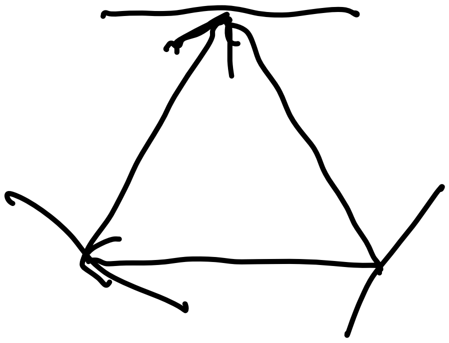
mode ν



Spatial hole burning for Fabry-Perot

Bow tie





No standing wave

↓

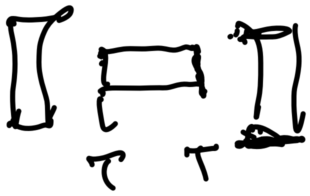
no spatial hole burning

Fabry-Perot (linear) $k \cdot 2L = 2\pi q$ $\quad q = 1, 2, 3$

$k = \frac{2\pi\nu}{c}$ $\quad \nu_q = q\frac{c}{2L}$ $\quad \Delta\nu = \frac{c}{2L}$

Ring $k \cdot L = 2\pi q \Rightarrow \Delta\nu = \frac{c}{L}$

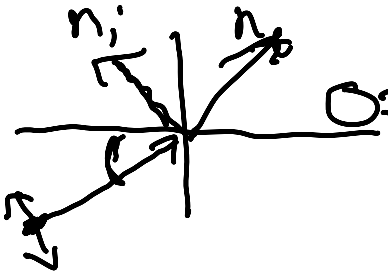
Internal losses



$$N_{th} = \frac{1}{2\sigma l}\ln\left(\frac{1}{R_1 R_2 T^4}\right)$$

fresnel

p-polarized



$$0 = r_p = \frac{n_t\cos\theta_i - n_i\cos\theta_t}{n_t\cos\theta_i + n_i\cos\theta_t}$$

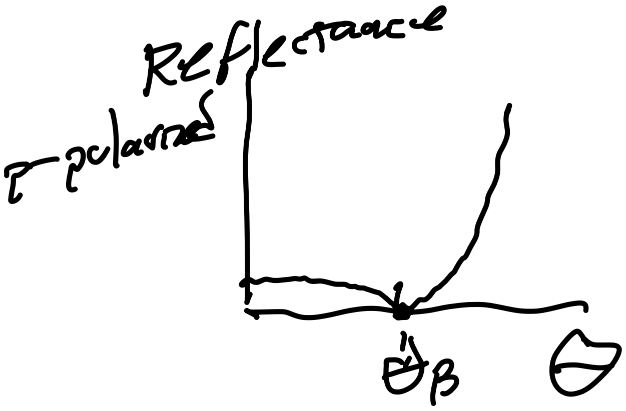
$$n_t\cos\theta_i = n_i\cos\theta_t$$

Snell's Law: $n_i\sin\theta_i = n_t\sin\theta_t$

$$\tan\theta_i = \left(\frac{n_t}{n_i}\right)^2\tan\theta_t$$

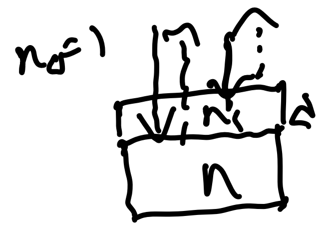
$$\theta_i + \theta_t = 90^\circ$$

$$\tan\theta_i = \frac{n_t}{n_i}$$ — Brewster's angle



Perfect transmission at θ_B

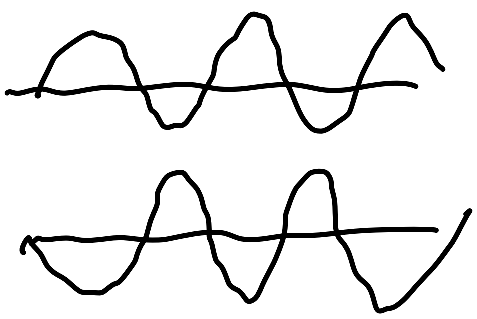
Anti-reflection coating



1) equal magnitude

2) Destructive interference

$$\frac{n_0-n_1}{n_0+n_1} = \frac{n_1-n_2}{n_1+n_2} \Rightarrow n_1 = \sqrt{n_0 n_2}$$



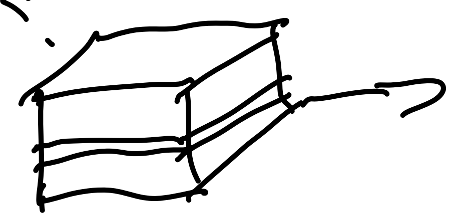
$$2n_1 d = \frac{\lambda}{2} \Rightarrow d = \frac{\lambda}{4n_1}$$

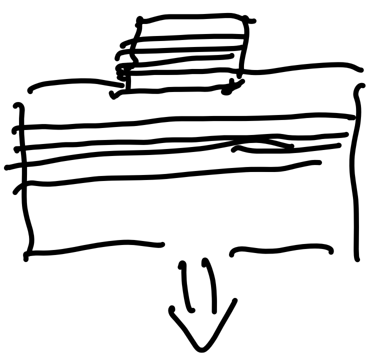
quarter-wave thickness

optimize R_1 & R_2

Tradeoff between intracavity intensity & extraction (HW problem on this)

Don't need large R's here

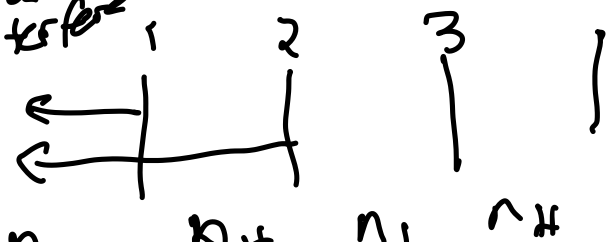




VCSEL

Need high R due to short cavity

constructive interference



$$\Delta = 2n_H d_H = 2n_H \frac{\lambda}{4n_H} = \frac{\lambda}{2} \rightarrow \pi$$

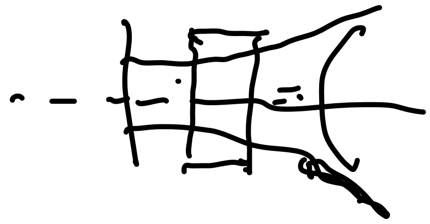
$$\Delta\phi = \pi + \pi - 0 = 2\pi$$

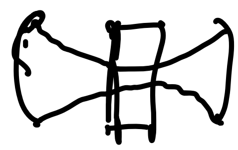
low-high

$$r = \frac{n_H - n_L}{n_H + n_L} \Rightarrow R = \left(\frac{n_0(n_H)^{2N} - n_0(n_L)^{2N}}{n_0(n_H)^{2N} + n_0(n_L)^{2N}}\right)^2$$

$$\frac{\Delta\nu}{\nu_0} = \frac{4}{\pi}\sin^{-1}\left(\frac{n_h - n_l}{n_h + n_l}\right)$$

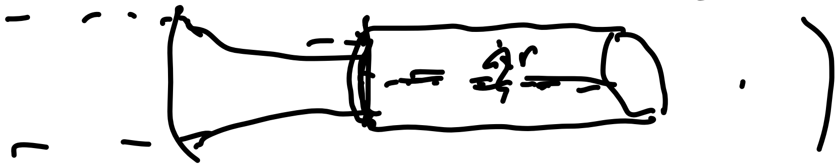
<u>High-power</u> unstable resonators





<u>Temperature effects</u>

non-uniform of gain medium - thermal lensing



$\frac{dn}{dT}$ (see thermal_lensing-2.html)

$$M_{GRIN} = \begin{pmatrix} \cos(\alpha L) & \frac{1}{\alpha}\sin(\alpha L) \\ -\alpha\sin(\alpha L) & \cos(\alpha L) \end{pmatrix}$$

$$\alpha = \sqrt{\frac{-2}{n_0}\frac{d^2 n}{dr^2}} \qquad \alpha L = \frac{\pi}{2} \qquad f = \frac{1}{\alpha}$$

$$\begin{pmatrix} 1 & f \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 0 & f \\ -1/f & 0 \end{pmatrix}\begin{pmatrix} 1 & f \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix}$$

thermal birefringence ~ (see visualization)

n ~ same all directions "polarization_transmission.html"