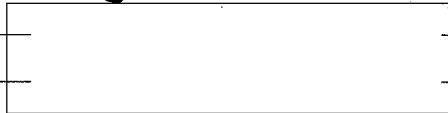


Frequency control of cw lasers [Read Svelto 7.6-7.8]

Single vs multimode oscillation -

Usually many longitudinal cavity modes span the laser gain bandwidth.



150 MHz for $L=1\text{m}$.

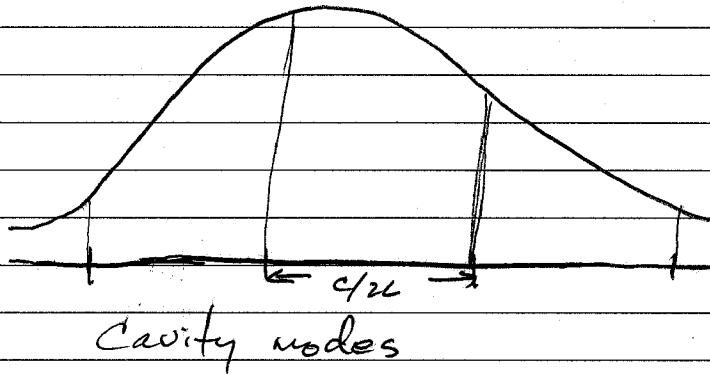
Gain bandwidth - typical:

- Doppler broadened visible atomic transition ~ 1 GHz
- Crystal ior in solid state host: ~ 300 GHz
- organic dye laser ~ 40 THz ($\sim 50\text{ nm}$)
- vibronic solid state lasers [Ti:sapphire] ~ 100 THz ($\sim 200\text{ nm}$)

Often we want to select one single axial mode and lowest order transverse mode for oscillation.

How?? Also nice to tune!

For a peaked gain spectrum, homogeneously broadened, why does more than one mode oscillate?

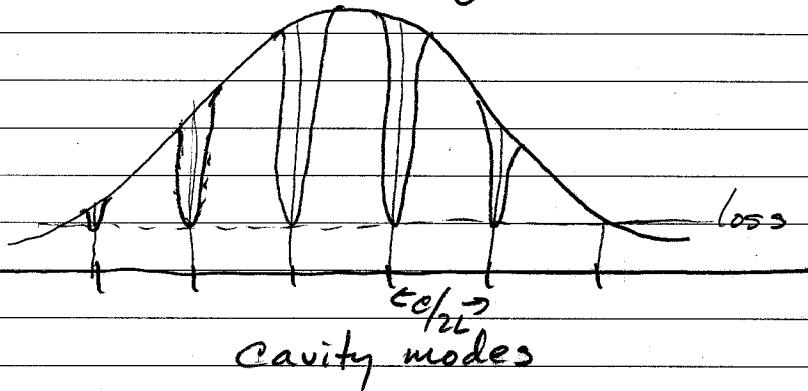


Once inversion reaches critical value for the highest gain mode, the inversion clamps. Gain for other modes is suppressed.

Answer: "spatial hole-burning".

Each standing wave mode creates a periodic pattern of gain saturation - strong at the antinodes. As the pump rate increases, the regions of the nodes of the cavity mode are not saturated, so the gain becomes high. Adjacent cavity modes have different standing wave patterns, so can take advantage of the unsaturated gain and hence oscillate.

For inhomogeneously broadened gain -
"spectral hole burning"

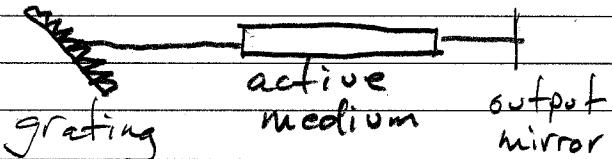


gain only saturates in a narrow spectral region around the oscillating mode. So off modes with gain above threshold can oscillate.

Solution to mode selection - in general -
→ wavelength selective loss using passive components.

Examples:

1. Diffraction grating in "Littrow" configuration



- Frequency selectivity of grating

grating equation $d \cos \theta = \lambda$ first order

grating angular dispersion.

The beam divergence of the laser mode is of order

$$\Delta \theta_d = \frac{\lambda}{\pi d}$$

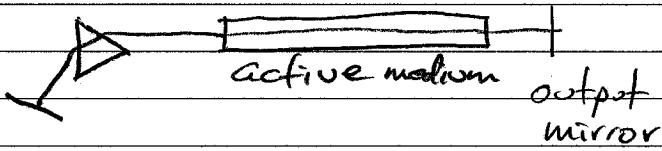
Typical spot size might be $\sim 200\mu\text{m}$, so for 600nm laser

Then the estimate for is $\Delta \lambda = \frac{d}{2} \cdot (9.5 \times 10^{-4})$

for grating spacing of 2cm , $\Delta \lambda = 9.5 \times 10^{-4}\mu\text{m}$
which translates to $\sim 800\text{GHz}$

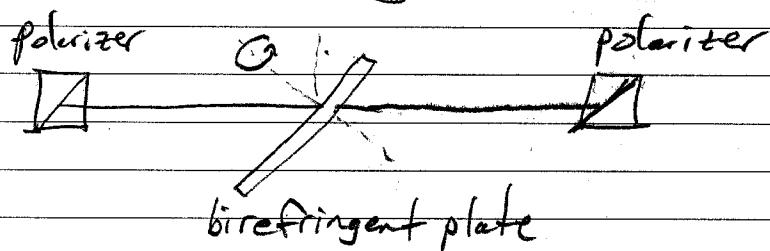
So the grating does not provide high selectivity.
Also lossy for visible light. But often used
in infrared lasers, such as CO_2 .

Similar performance from prism tuning, but losses can
be low, with prism faces designed for Brewster angle.



(101)

Another "coarse" tuning element - birefringent filter



two orthogonal polarizations experience a relative phase shift

n_e, n_o - extraordinary, ordinary index
 l_e - path length in the plate

When $\Delta\phi = l_e 2\pi$ with l integer then the polarization is unchanged after passing through the plate, so the transmission is maximum.

The frequency separation between maxima is the "free spectral range"

Typical values $l_e = 1.5 \text{ mm}$, $\lambda = 600 \text{ nm}$, $n_o = 1.47$, $n_e = 1.51$
 Orient plate at $Q_B = \arctan n = 56.13^\circ$, $l_e = 1.81 \text{ mm}$
 Then $\Delta V_{FSR} = 4 \text{ THz}$, or $\sim 5 \text{ nm}$

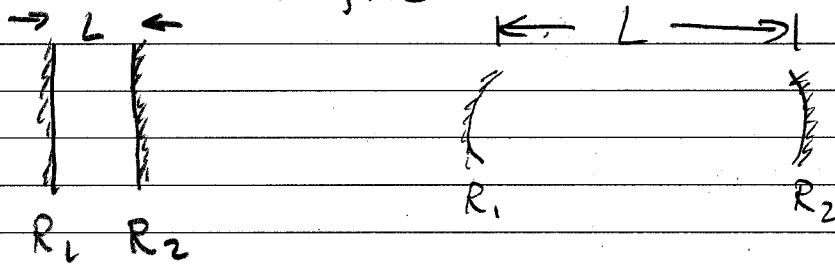
This is not as selective as the grating, but more comparable to a prism. It is more convenient since it is in-line, and can be tuned just by rotating about the normal.

For low-gain laser, the frequency selectivity is much less than ΔV_{FSR}



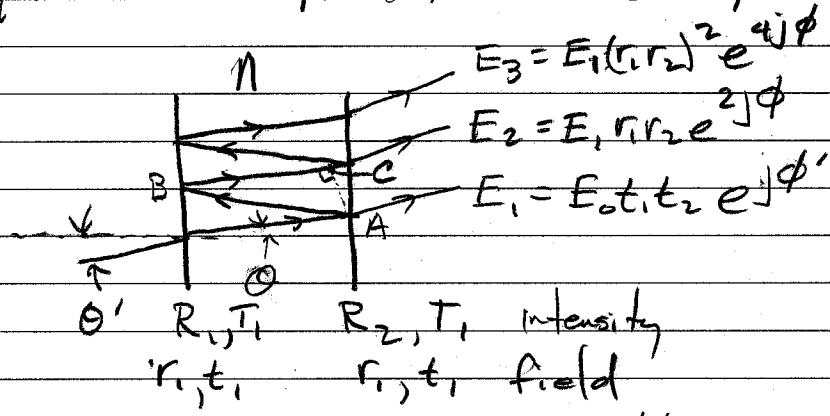
A very useful narrowband filter element is the Fabry-Pérot Etalon [read Svelto 4.5]

2 planar or spherical mirrors separated by distance L , reflectivities R_1, R_2 .



Either air-spaced or solid. Solid etalon is particularly convenient.

Analysis of multiple interference in planar FP.



$$E_t = \sum_{l=1}^{\infty} E_l = [E_0 t_1 t_2 e^{j\phi'}] \sum_{m=0}^{\infty} (r_1 r_2)^m e^{2jm\phi}$$

The phase shift for successive reflections works out to

[this is not completely obvious,
Requires a little geometric analysis]

The series can be summed to give

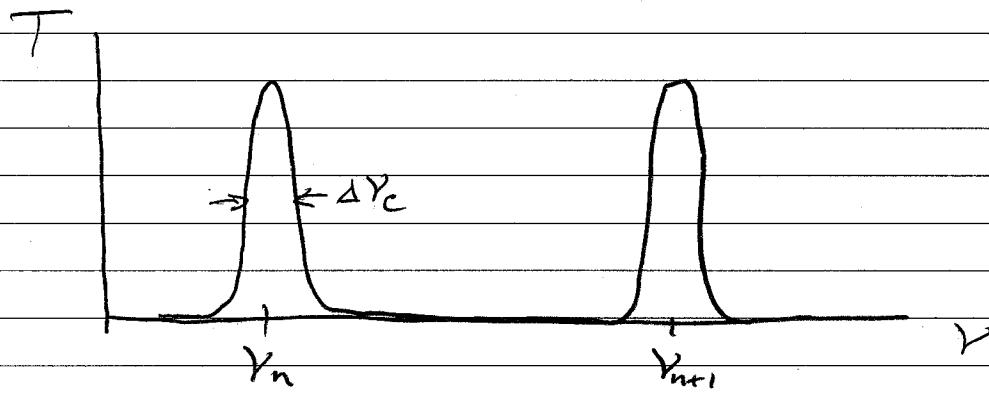
$$E_t = E_0 e^{j\phi'} \frac{t_1 t_2}{1 - (r_1 r_2) e^{j2\phi}}$$

Power transmission

$$T = \frac{E_t^2}{E_0^2} = \frac{t_1^2 t_2^2}{1 - 2r_1 r_2 \cos 2\phi + r_1^2 r_2^2}$$

For lossless mirrors

$$T = \frac{(1-R_1)(1-R_2)}{\left[1-(R_1 R_2)^{1/2}\right]^2 + 4R_1 R_2^{1/2} \sin^2 \phi}$$



maxima occur at

Free spectral range $\nu_{fsr} = \frac{c}{2nL \cos \theta}$

$$= 1 \quad \text{if } R_1 = R_2$$

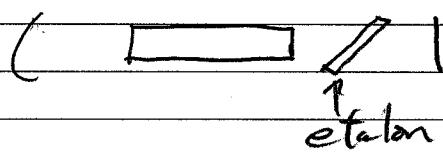
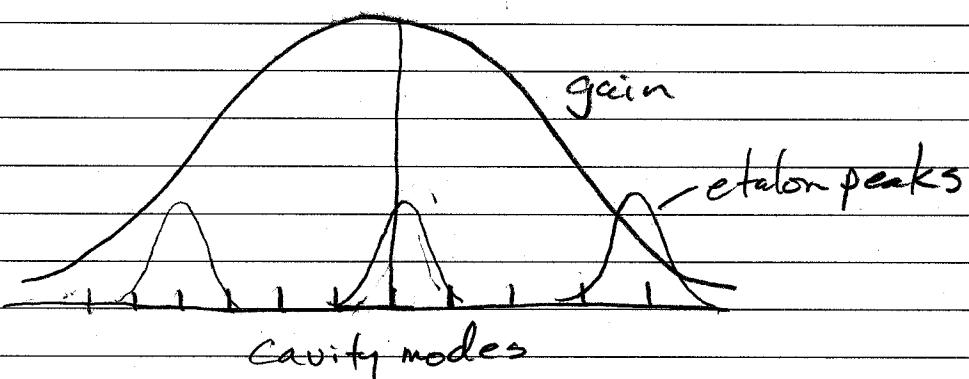
$$\text{Peak width } \Delta\nu_c = \frac{c}{2nL \cos \theta} \frac{1 - (R_1 R_2)^{1/2}}{\pi(R_1 R_2)^{1/4}}$$

Finesse is defined as

$$F = \frac{\Delta\nu_{fsr}}{\Delta\nu_c} = \frac{\pi(R_1 R_2)^{1/4}}{1 - (R_1 R_2)^{1/2}}$$

high reflectivity \rightarrow high finesse

Using an FP etalon for mode selection



Etalons can be used in combination in cases of very broadband lasers, use a thick and a thin etalon. The thick etalon selects one mode, the thin etalon selects on thin etalon peak

