Fabry Perot Interferometer

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Motivation

• Goal: build a Fabry Perot for use in the lithography experiment

• Need a single frequency $\omega_a$ of light to form a standing wave in the cell – two or more frequencies would lead to a travelling wave

• Atoms will concentrate around the nodes; the size of the region determines the precision or lithography

• Possible other frequencies: $\omega_a - 52\text{MHz}$ and $\omega_a + 22\text{MHz}$
Properties of Fabry-Perot

- Two opposing highly reflecting surfaces
- Transmission is a function of wavelength
- Phase build-up for a round trip is:
  \[ \delta = \frac{4 \pi n l \cos(\theta)}{\lambda} \]

- Transmission:
  \[ \frac{I_t}{I_i} = \frac{(1-r)^2}{(1-r)^2 + 4r \sin(\delta/2)} \]

  \[ \frac{I_t}{I_i} = 1 \text{ for } \delta = 2m\pi \text{ or } \nu_m = \frac{mc}{2nl \cos \theta} \]

- Free spectral range:
  \[ \Delta \nu = \nu_{m+1} - \nu_m = \frac{c}{2nl \cos \theta} \]

- Finesse:
  \[ F = \frac{\Delta \nu_{FWHM}}{\Delta \nu} = \frac{\pi \sqrt{r}}{1-r} \]
Geometry and Stability

• Stability condition: \( 0 \leq \left( 1 - \frac{L}{R_1} \right) \left( 1 - \frac{L}{R_2} \right) \leq 1 \)

\[ g_1 = 1 - \frac{L}{R_1} \quad g_2 = 1 - \frac{L}{R_2} \]

• The resonator is stable only inside of the shaded region

• The aim is to minimize diffraction loses, e.g. energy “spill over” the mirror edges

• Flat mirrors not suitable – beam size would increase steadily, also cannot be manufactured to required precision

• The spot size on the mirrors is minimal in the confocal configuration, \( L=R_1=R_2=R \)
Confocal Fabry-Perot

• The radii of curvature of mirrors are chosen to be the same as those of the beam wavefronts.

• Then there is no change in the transverse profile.

• For a symmetrical resonator:

\[ z_0^2 = \frac{(2R - l)l}{4} \]
\[ \omega_0 = \sqrt{\frac{\lambda z_0}{n\pi}} \]
\[ \omega_{\text{spot}} = \left( \frac{\lambda z_0}{n\pi} \right)^{1/2} \left( \frac{2R^2}{l(R - l/2)} \right)^{1/4} \]

• For the confocal geometry, these reduce to:

\[ z_0 = \frac{R}{2} \]
\[ \omega_0 = \left( \frac{\lambda R}{2n\pi} \right)^{1/2} \]
\[ \omega_{\text{spot}} = \left( \frac{\lambda R}{n\pi} \right)^{1/2} \]
Materials

- A rigid tube – \( \Delta L \ll \lambda / 2 \)
  \[
  \frac{\lambda}{2L\Delta T} \approx 7 \cdot 10^{-6} \text{K}^{-1}
  \]
  or \( \alpha < 10 \text{K}^{-1} \) at \( \Delta T = 1 \text{K} \)

- Two mirrors coated appropriately, \( r > 0.99 \), geometric finesse \( F > 300 \)

- Epoxy (cures w/o shrinking)

- PZT translator, at least \( 1 \mu m \) sweep
  \[
  \Delta L \approx d_{31} \cdot L \cdot \frac{U}{d}, \quad d_{13} = -200 \text{pm/V}
  \]
  for \( L = 0.5'' \), \( d = 0.03'' \), \( V \approx 300 \text{V} \)

- High voltage supply (with negative feedback, as PZTs show hysteresis)

<table>
<thead>
<tr>
<th>Material</th>
<th>( \alpha ) [K(^{-1})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>metals</td>
<td>10-20</td>
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<td>Glass</td>
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<tr>
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<tr>
<td>Diamond</td>
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<tr>
<td>Fused quartz</td>
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</tbody>
</table>

- Length \( L = 15 \text{cm} \)
- \( \Delta \nu_{\text{FSR}} \approx 500 \text{MHz} \)
- \( \omega_0 = 0.16 \text{mm} \)
- \( \omega_{\text{spot}} = 0.23 \text{mm} \)
Design

Highly simplified design – increased stability
FSP is fixed - no flexibility
Preliminary Measurements

Length sweep (Gaussian fit):
$R^2=0.96$, $W=0.44$

Angle sweep (Gaussian fit):
$R^2=0.89$, $W=0.34$

Oscilloscope trace (peaks were produced by sweeping the laser frequency)
Literature: