Fabry Perot Interferometer

Marija Kotur
Optics Rotation
Stony Brook University
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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: $\omega_a - 52 MHz$ and $\omega_a + 22 MHz$
Properties of Fabry-Perot

• Two opposing highly reflecting surfaces
• Transmission is a function of wavelength

Phase build-up for a round trip is:

\[ \delta = \frac{4\pi nl \cos(\theta)}{\lambda} \]

Transmission:

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

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

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 losses, 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:

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

- For the confocal geometry, these reduce to:

\[
\begin{align*}
    z_0 &= R/2 \\
    \omega_0 &= \left(\frac{\lambda R}{2n\pi}\right)^{1/2} \quad \omega_{spot} = \left(\frac{\lambda R}{n\pi}\right)^{1/2}
\end{align*}
\]
Materials

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

- Two mirrors coated appropriately, $r > 0.99$, geometric finesse $F > 300$

- Epoxy (cures w/o shrinking)

- PZT translator, at least $1 \mu m$ sweep
  $\Delta L \approx d_{31} \cdot L \cdot \frac{U}{d}$, $d_{13} = -200 pm/V$
  for $L = 0.5”$, $d = 0.03”$, $V \sim 300 V$

- 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>
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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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</table>

- Length $L = 15 cm$
- $\Delta \nu_{FSR} \approx 500 MHz$
- $\omega_0 = 0.16 mm$
- $\omega_{spot} = 0.23 mm$
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: