Spectroscopic Interferometry Using Slow-Light Media

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Introduction to Slow Light

- In a dispersive medium, pulses propagates at the group velocity
  \[ v_g = \frac{d\omega}{dk} = \frac{c}{n_g} \]

- Group index
  \[ n_g = n + \omega \frac{dn}{d\omega} \]

- Slow light medium:
  \[ n_g \gg n \]

  Atomic Vapor \( n_g \approx 1.76 \times 10^7 \)  

  Solid system \( n_g \approx 5.2 \times 10^6 \)  
Introduction to Slow Light

- Promising Applications in Communications Systems
  - Optical Buffers/Delay lines
  - Data Re-synchronization
  - Jitter Correction

- How About Applications in Other Areas?
  - Interferometry
Spectroscopic Interferometry

- Certain types of spectroscopic interferometers are sensitive to frequency change
  - Mach-Zehnder type
  - Michelson type
  - Fabry-Perot type
  - Sagnac type
  - …

1. M. Soljačić et al., JOSA B 19(9) p. 2052, 2002
2. M.S. Shahriar et al., ArXiv, quant-ph/0507139
Mach-Zehnder Interferometer

\[ T(\omega) = \frac{1}{2} (1 + \cos \Delta \phi) = \frac{1}{2} + \frac{1}{2} \cos \frac{L \omega n(\omega)}{c} \]

**Sensitivity:** \[ \frac{d \Delta \phi}{d \omega} = \frac{L}{c} n g \]
Mach-Zehnder Interferometer

- Numerical Ex. $L = 2\text{cm}$
- Spectral Resolution can be enhanced $n_g$ times

$\Delta \lambda \approx 0.01\text{nm}$

$\Delta \lambda \approx 0.001\text{nm}$
Wedge Etalon Interferometer

Frequency change -> fringe movement

Moving rate of fringe patterns

$$\frac{dx_m}{d\omega} = -\frac{cm\pi n_g}{\theta n^2 \omega^2}$$
**Experiment**

- **Material:** $\text{CdS}_{0.75}\text{Se}_{0.25}$
  - Absorption band edge at 2.24eV (theory); 2.15eV (measured)
  - ~0.5mm thick, c-cut, single crystal

- **Laser:** Rhodamine 6G
  - Dye laser
  - Range: 585 - 605 nm

Experimental Result

- Fringe Patterns (CCD image)
  - 587.5 – 587.7 nm w/ 0.01 nm increment

![Fringe Patterns Image](image)

- x direction
- y direction

wavelength = 587.5 nm
Detection of Fringe Movement

- Raw data: single cross-section

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![Image of a graph showing relative intensity in the x direction with a wavelength of 587.5 nm.](image)

- Relative Intensity (a. u.)
  - 0           20        40         60          80        100      120
  - 0       0.2      0.4      0.6     0.8      1.0
Detection of Fringe Movement

- Sinusoidal fitting

![Graph showing sinusoidal fitting with wavelength = 587.5 nm]
Detection of Fringe Movement

- Fringe movement = Phase Change of the fitted sinusoidal function
Spectral Sensitivity Analysis

- Relative phase vs. detuning
  - One cross-section, detuned near 587.5nm

![Graph showing relative phase vs. detuning with sensitivity proportional to slope]
Spectral Sensitivity Analysis

- Relative phase vs. detuning
  - All cross-sections, detuned near 587.5nm
Spectral Sensitivity Analysis

- Relative phase vs. detuning
  - Detuned near different wavelengths
    (587.5 – 605 nm, step 2.5nm)
Spectral Sensitivity Analysis

- Phase change rate (i.e., spectral sensitivity) vs. wavelength

Ref. for $n$ data: Jensen et al., JOSA B, 3(6) p.857, 1986
Summary

- The sensitivity of certain types of spectroscopic interferometers are proportional to the group index $n_g$ of the media in its optical paths.

- The spectral resolution of such interferometers can be greatly enhanced (in the order of $10^6$ or larger is possible) by introducing a slow light medium into it.
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Thank you for your attention!