Enhancing the Spectral Sensitivity and Resolution of Interferometers Using Slow-Light Media

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Introduction to Slow Light

Pulse Propagation in a slow-light medium

Group velocity

\[ v_g = \frac{d\omega}{dk} = \frac{c}{n_g} \]

\[ n_g = 2 \]
Introduction to Slow Light

Group index

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

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


Solid system \( n_g \approx 5.2 \times 10^6 \)

Application in Optical Communications

- All-optical buffer / delay line

Slow-light device
A slow-light medium has other applications

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

\[ \frac{d\Delta \phi}{d\omega} = \frac{L}{c} \left( n + \omega \frac{dn}{d\omega} \right) = \frac{Ln_g}{c} \]
Spectral sensitivity

- Transmission varies as wavelength changes
- Spectral Resolution can be enhanced $n_g$ times

\[ n_g = 1 \]
\[ \Delta \lambda \approx 0.01 \text{ nm} \]

\[ n_g = 10 \]
\[ \Delta \lambda \approx 0.001 \text{ nm} \]

$(\lambda = 500 \text{ nm}, L = 2 \text{ cm})$
Multi-Beam Interferometers

- Transmission

\[ T(y) \approx \frac{T_s^2 T_L}{(1 - R_s T_L)^2} \frac{1}{1 + \mathcal{F} \sin^2 \Delta \phi(y)} \]

\( T_s / R_s \) : Transmissivity / reflectivity at air-medium interface,

\( T_L \) : Transmissivity through the medium,

\( \mathcal{F} \) : Finesse
Spectral Performance

- **Spectral sensitivity**

\[ S = \frac{1}{\Lambda} \frac{dy_m}{d\lambda} = \frac{2L_0 n_g}{\lambda^2} \]

- **Resolving Power**

\[ R = \frac{\lambda}{\Delta \lambda_{\text{min}}} = \frac{\pi L_0 n_g \sqrt{F}}{\lambda} \]
Experiment

- **Slow-light medium:** CdS$_{0.75}$Se$_{0.25}$
  - Absorption band edge: 2.15 eV (577 nm)
  - $L_0 \approx 0.5$ mm thick, c-cut, single crystal

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

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*Jensen et al., JOSA B, 3(6) p.857, 1986*
Observation of Fringes Movement

wavelength = 587.5 nm
Calculation of Spectral Sensitivity

Measure the movement rate of fringes at different wavelengths

wavelength = 587.5 nm

Intensity (a.u.)

Lateral position $y$ (a.u.)
Experimental Results

- Spectral sensitivity

\[ S = \frac{1}{\Lambda} \frac{dy_m}{d\lambda} = \frac{2L_0 n_g}{\lambda^2} \]

Shi et al., Optics Lett. 32, p.915-917 (2007)
Summary

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

- The spectral performance can be greatly enhanced by introducing a slow-light medium into it. In our proof-of-principle experiment, $n_g = 3.5$, but $n_g$ up to $10^7$ is possible.
Acknowledgement

- Dr. Gary W. Wicks and Renee Pedrazzani

- Research Group of Nonlinear Optics at Univ. of Rochester.

- Funding Agencies

Thank you for your attention!