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

Zhimin Shi[1], **Robert W. Boyd**[1], **Daniel J. Gauthier**[2] , **and C. C. Dudley**[3]

[1]*The Institute of Optics, University of Rochester, Rochester, NY 14627 USA*
URL: http://www.optics.rochester.edu/~boyd

[2]*Department of Physics and The Fitzpatrick Institute for Photonics, Duke University, Durham, North Carolina, 27708 USA*

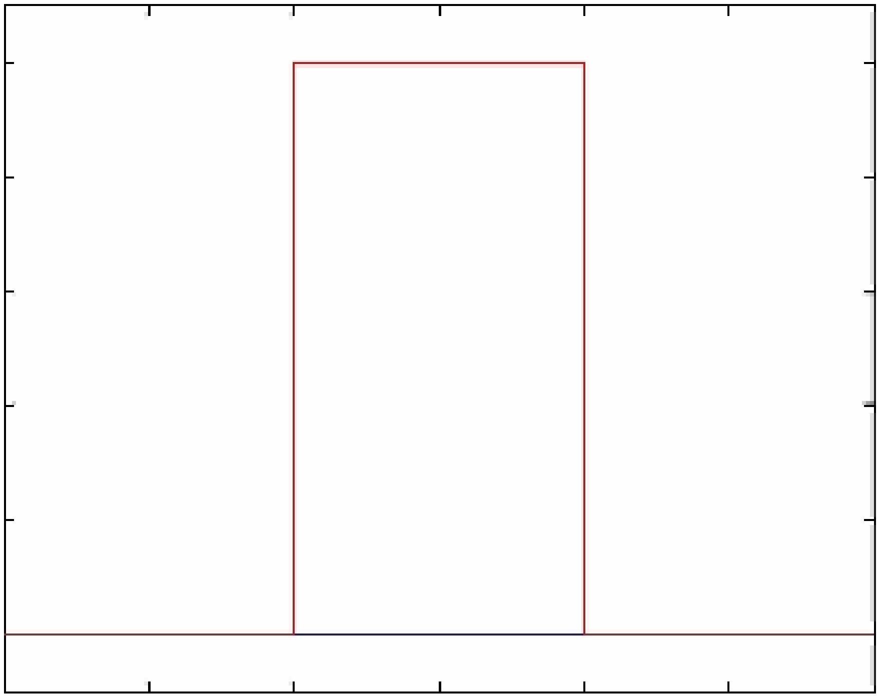
[3]*was at Naval Research Laboratory, Remote Sensing Division, Code 7211, Washington, DC 20375 USA*

Introduction to Slow Light

- Pulse Propagation in a slow-light medium

Group velocity

$$v_g = \frac{d\omega}{dk} = \frac{c}{n_g}$$

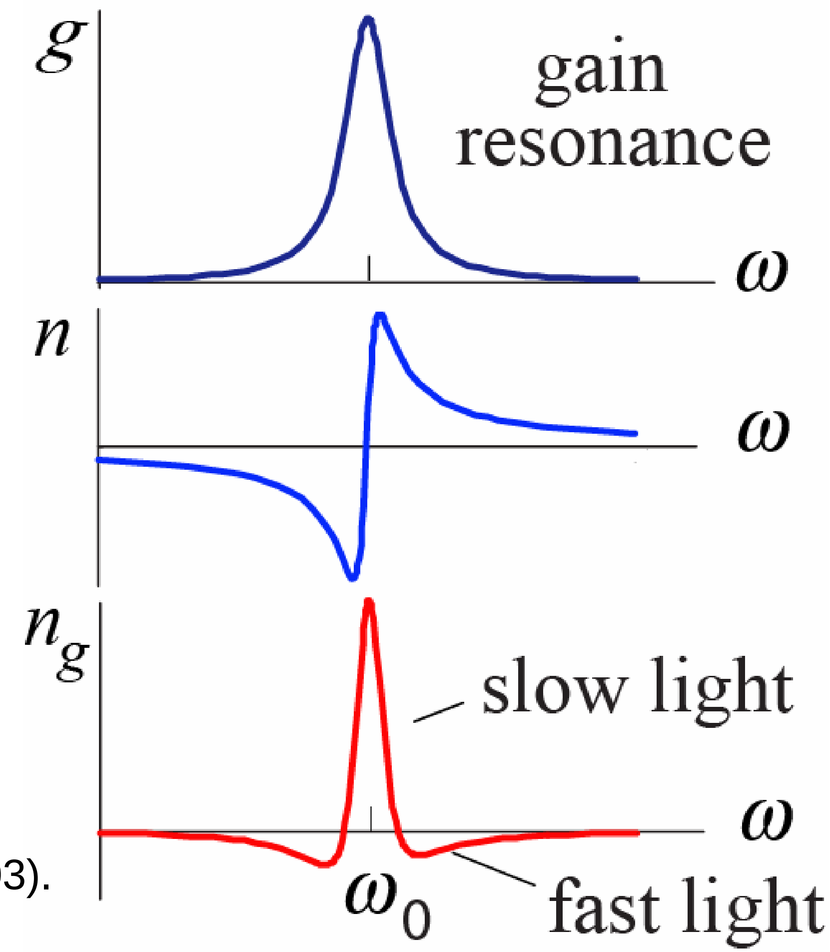


$$n_g = 2$$

Introduction to Slow Light

Group index

$$n_g = n + \omega \frac{dn}{d\omega}$$



Atomic Vapor $n_g \approx 1.76 \times 10^7$

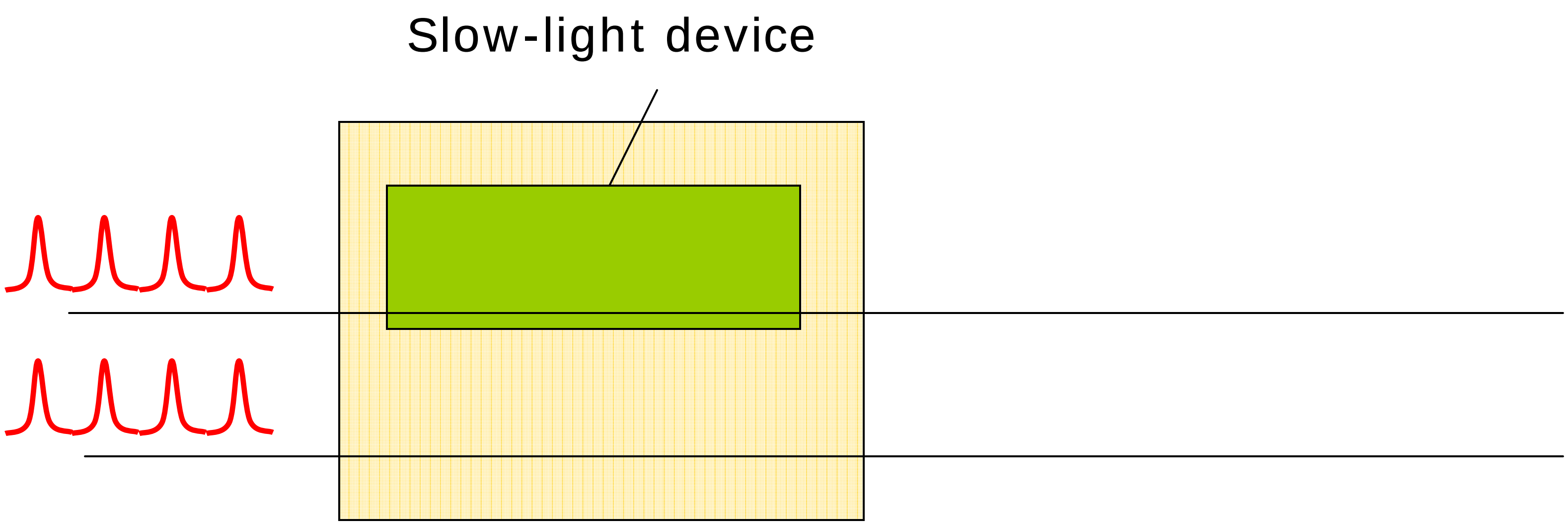
Hau, *et al.*, Nature **397**, p.594 (1999).

Solid system $n_g \approx 5.2 \times 10^6$

Bigelow, *et al.*, Science, **301** , p.200 (2003).

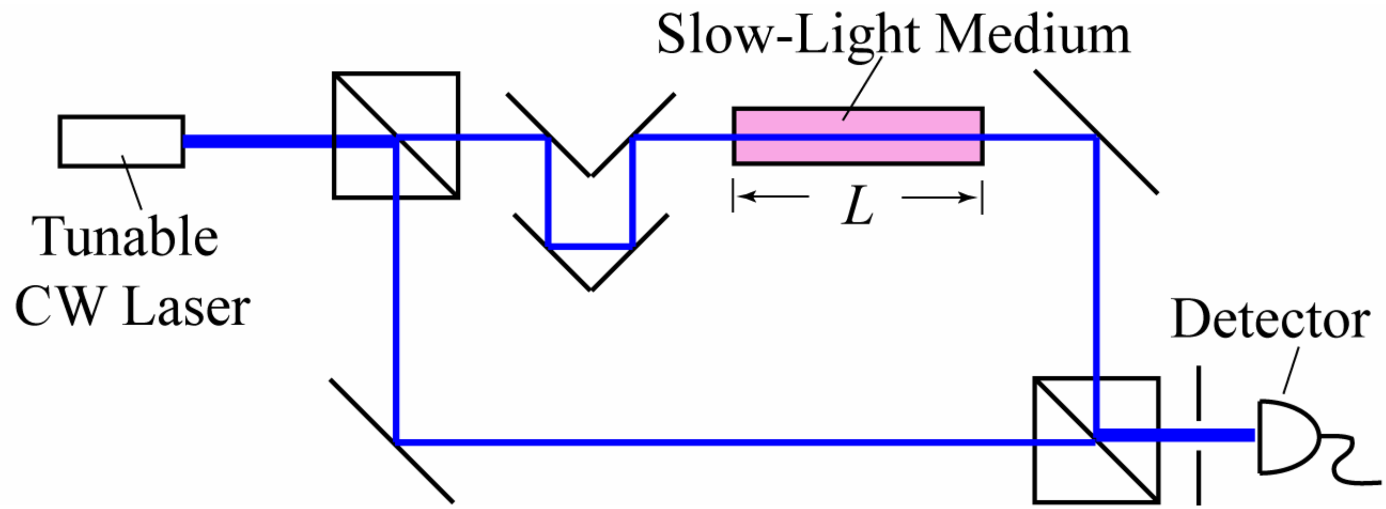
Application in Optical Communications

- All-optical buffer / delay line



Slow-Light Interferometry

- A slow-light medium has other applications

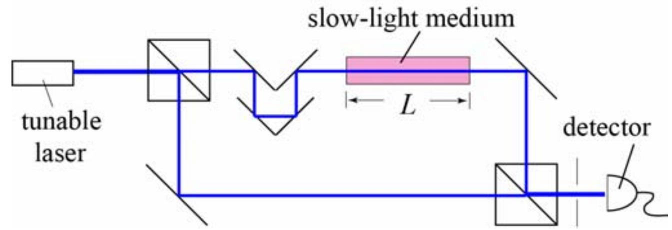


$$T(\omega) = \frac{1}{2}\left(1 + \cos\Delta\phi\right) = \frac{1}{2} + \frac{1}{2}\cos\frac{L\omega n(\omega)}{c}$$

$$\frac{d\Delta\phi}{d\omega} = \frac{L}{c}\left(n + \omega\frac{dn}{d\omega}\right) = \frac{Ln_g}{c}$$

Spectral sensitivity

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



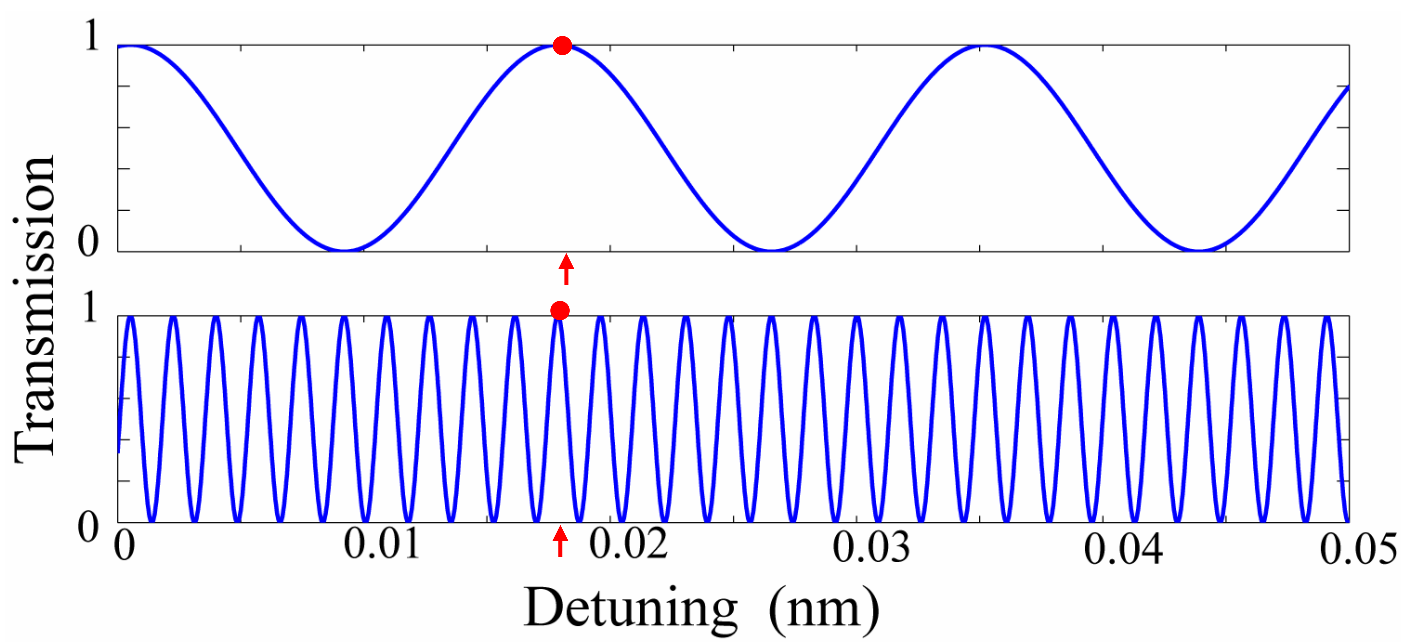
$(\lambda = 500 \text{ nm}, L = 2 \text{ cm})$

$n_g = 1$

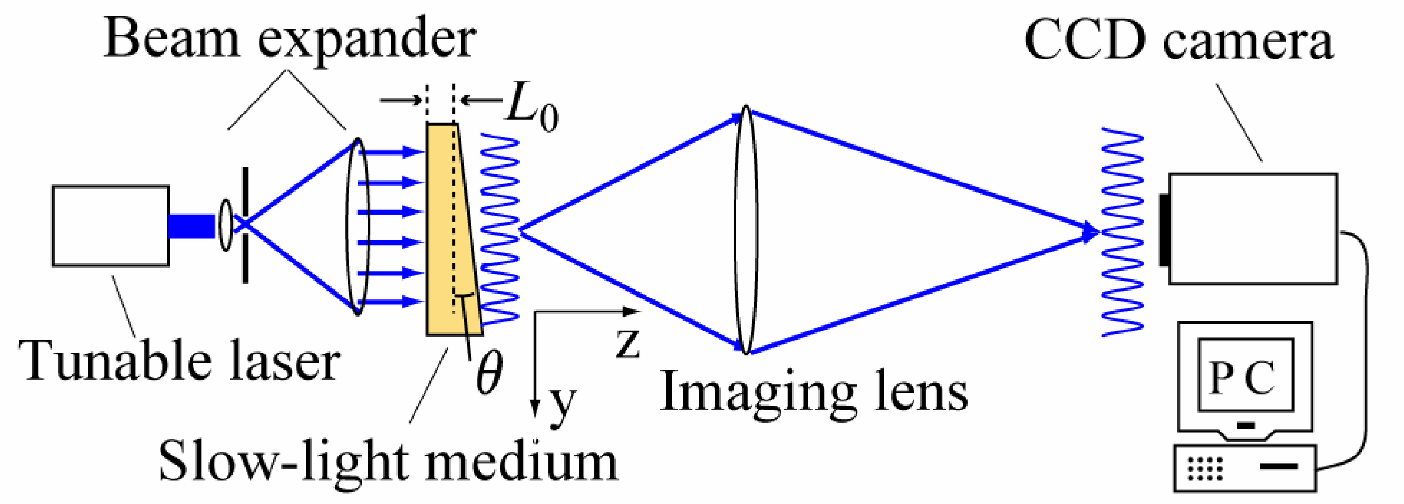
$\Delta\lambda \approx 0.01 \text{ nm}$

$n_g = 10$

$\Delta\lambda \approx 0.001 \text{ nm}$



Multi-Beam Interferometers



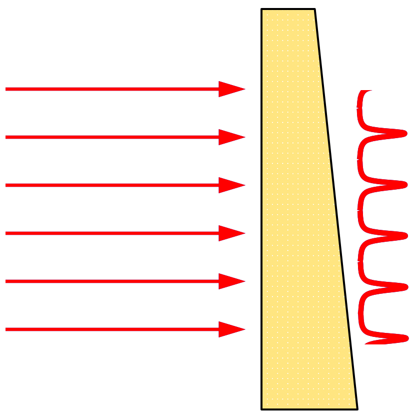
- Transmission

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

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

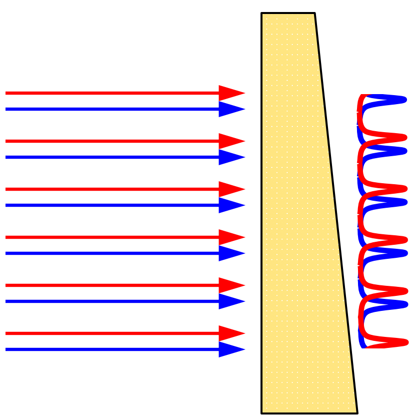
T_L: Transmissivity through the medium, $\mathcal{F}$: Finesse

Spectral Performance



- Spectral sensitivity

$$\mathcal{S} = \frac{1}{\Lambda}\frac{dy_m}{d\lambda} = \frac{2L_0 n_g}{\lambda^2}$$

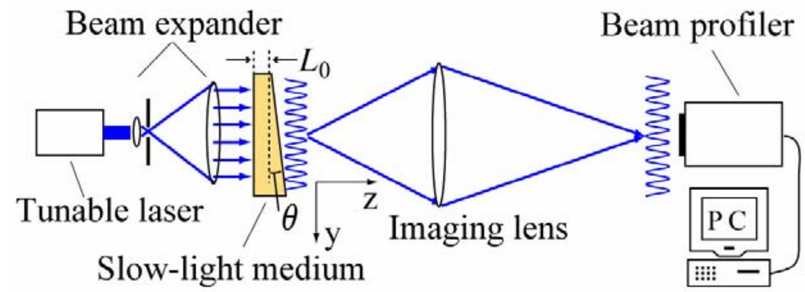


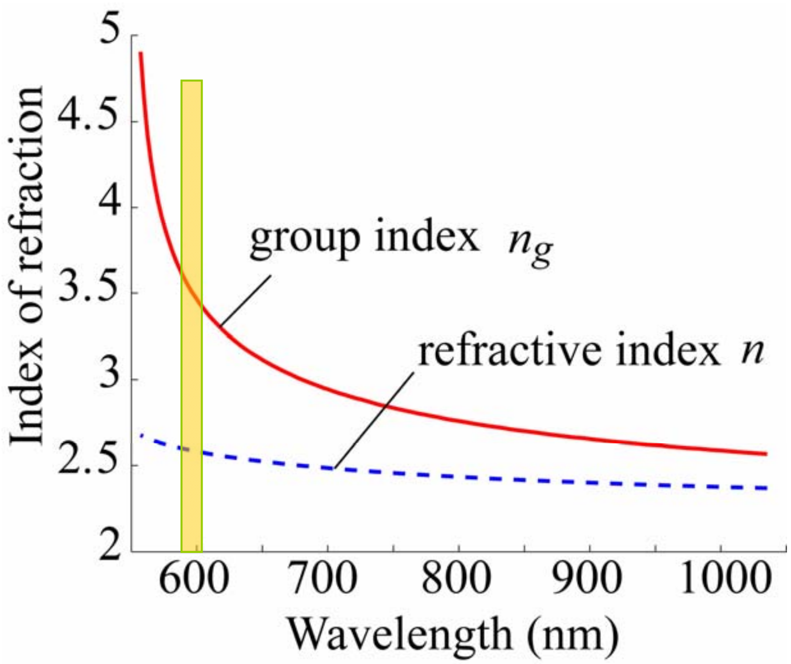
- Resolving Power

$$\mathcal{R} = \frac{\lambda}{\Delta\lambda_{\mathrm{min}}} = \frac{\pi L_0 n_g \sqrt{\mathcal{F}}}{\lambda}$$

Experiment

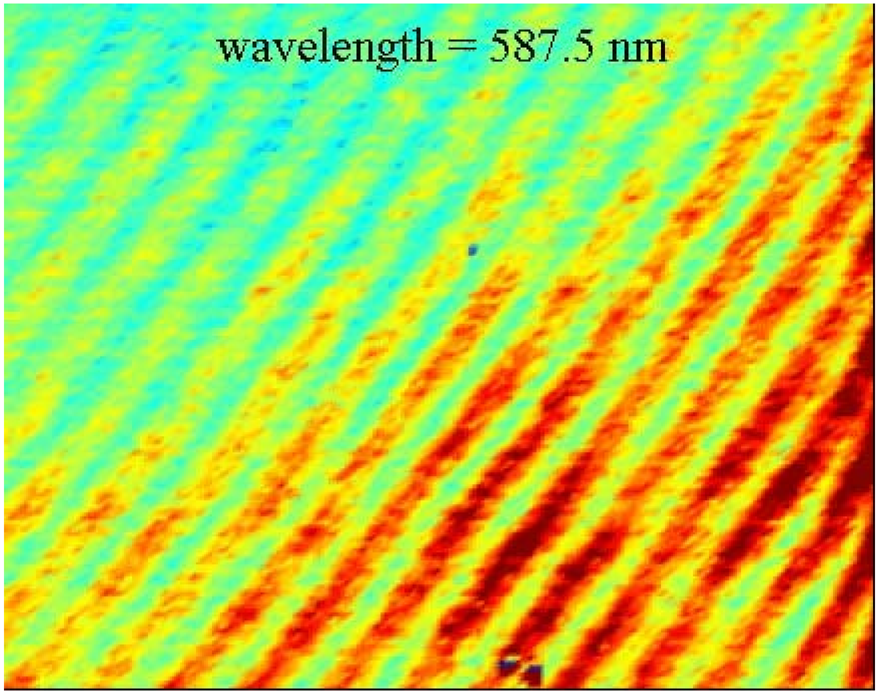
- Slow-light medium: $CdS_{0.75}Se_{0.25}$
  - Absorption band edge: 2.15 eV (577 nm)
  - L_0~0.5 mm thick, c-cut, single crystal
- Laser: Rhodamine 6G Dye laser
  - Range: 585 - 605 nm



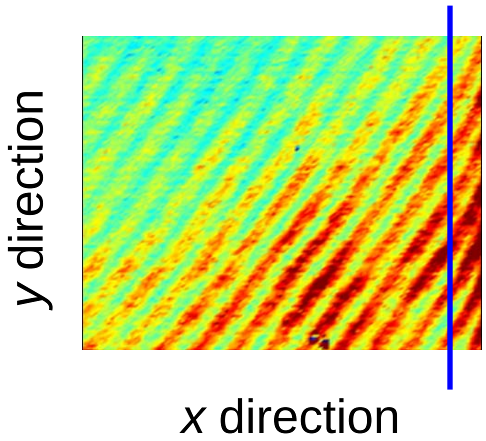


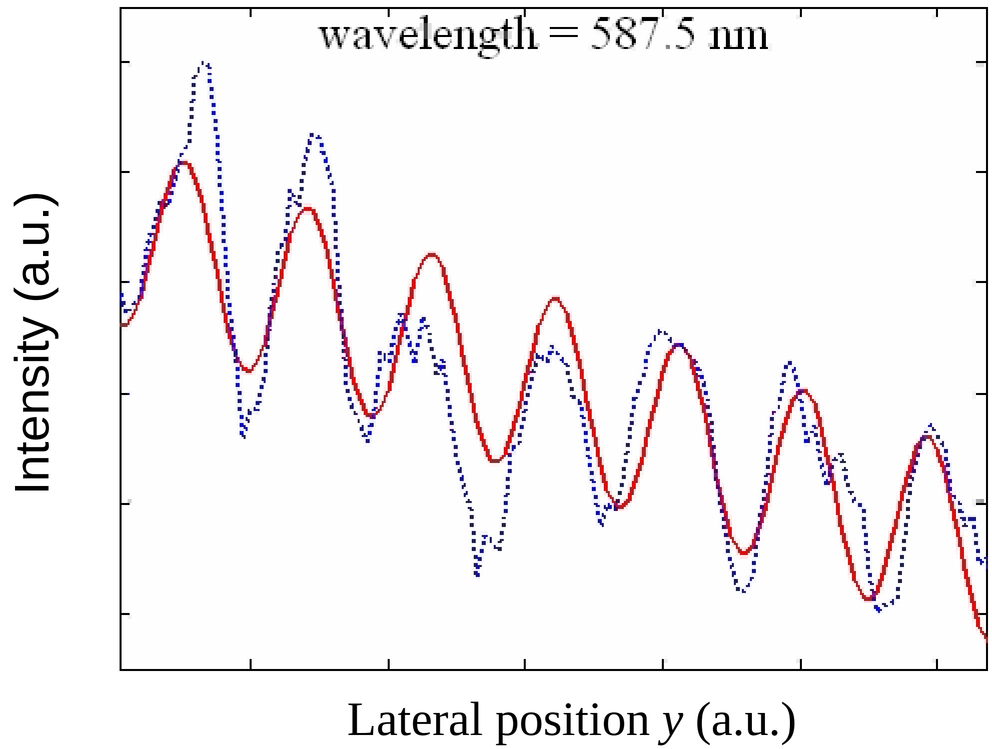
Jensen *et al.*, JOSA B, **3**(6) p.857, 1986

Observation of Fringes Movement



Calculation of Spectral Sensitivity

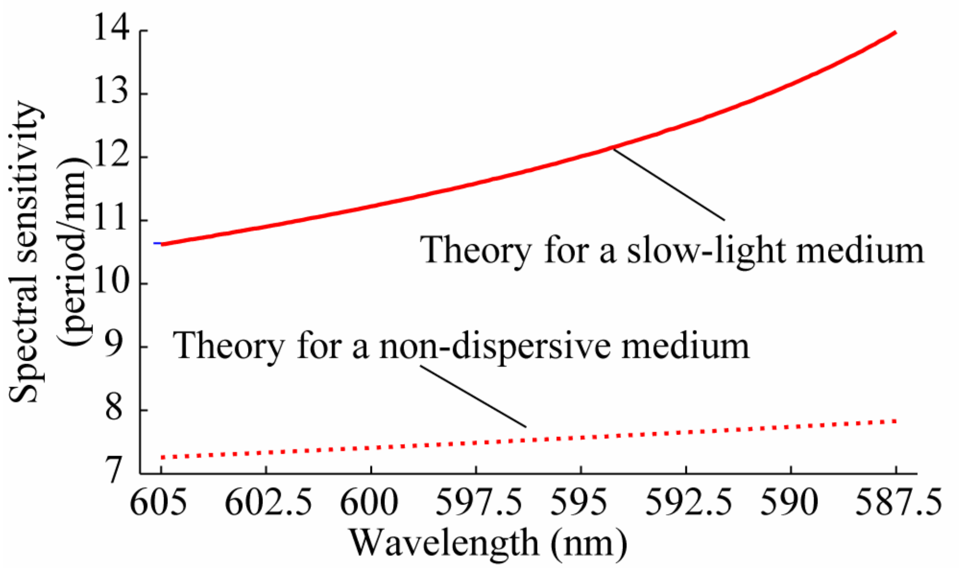




Measure the movement rate of fringes at different wavelengths

Experimental Results

- Spectral sensitivity $\mathcal{S} = \frac{1}{\Lambda}\frac{dy_m}{d\lambda} = \frac{2L_0 n_g}{\lambda^2}$



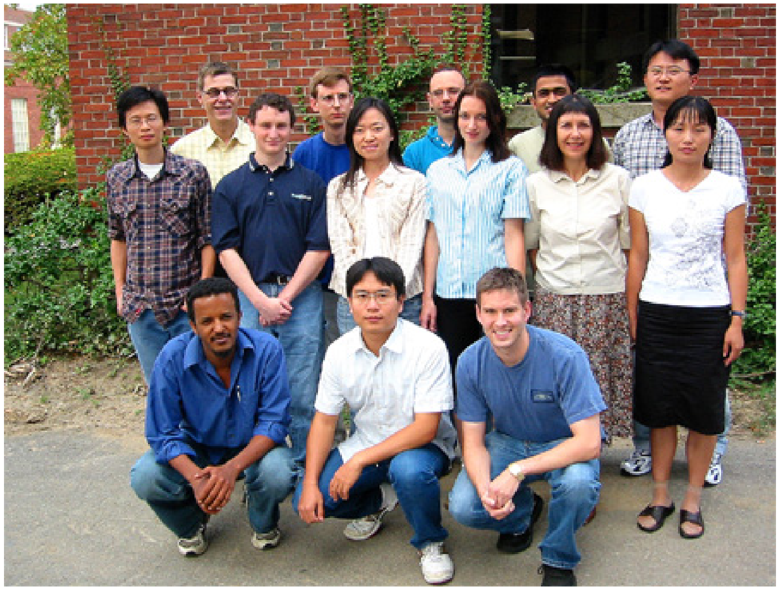
Shi *et al.,* Optics Lett. **32**, p.915-917 (2007)

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!