



IIT ROORKEE



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CERTIFICATION COURSE

Lecture 18: Interference, Diffraction and Optical Fiber Sensors

Fabry Perot Sensors, Diffraction Gratings, XRD, FBG, Multichannel & Distributed Sensing

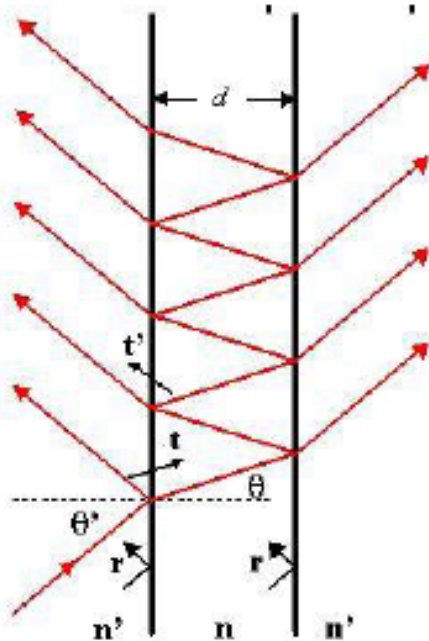
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Department of Physics



Fabry-Perot Interferometer

Fabry-Perot resonator: Lightwave is resonant between two parallel plates.



Path difference between two successive rays:

$$\frac{d}{\cos \theta} + \frac{d}{\cos \theta} \cdot \cos 2\theta = 2d \cos \theta$$

Total output E-field:

$$E_t = E_i t t' + E_i t t' r r' e^{j\delta} + E_i t t' r^2 r'^2 e^{j2\delta} + \dots = \frac{E_i t t'}{1 - r r' e^{j\delta}},$$

where $\delta = 2kd \cos \theta = \frac{4\pi n d \cos \theta}{\lambda_0}$ is the optical phase difference, and d is the thickness.

Fabry-Perot Interferometer (FPI) based Sensing

When the FPI system is subjected to a change in temperature (ΔT), The relative phase shift

$$S(\text{Phase}) = \frac{\Delta\phi}{\phi\Delta T} = \frac{1}{n} \frac{\partial n}{\partial T} + \frac{(\Delta n)_{\text{Strain}}}{n} + \frac{\Delta d}{d}$$

Δd = Change in Cavity Thickness

$(\Delta n)_{\text{Strain}}$ = Strain induced change in refractive index

For Polychromatic Source

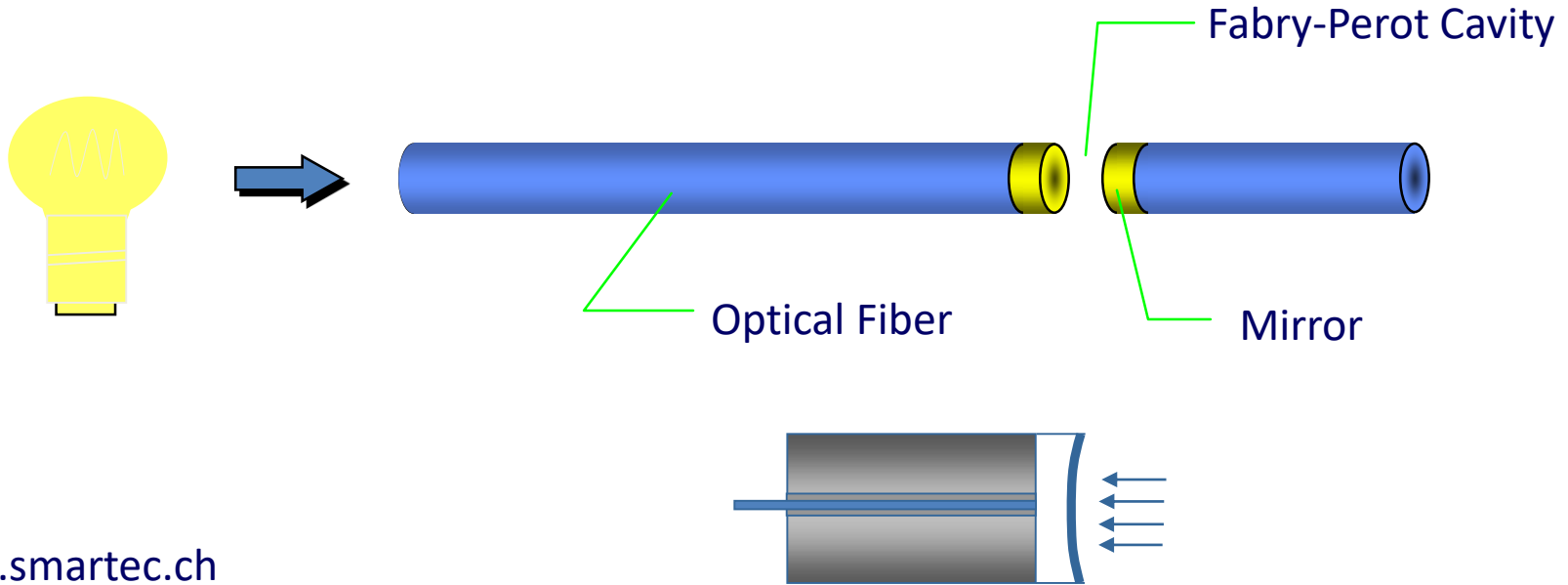
$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta d}{d}$$



n, d

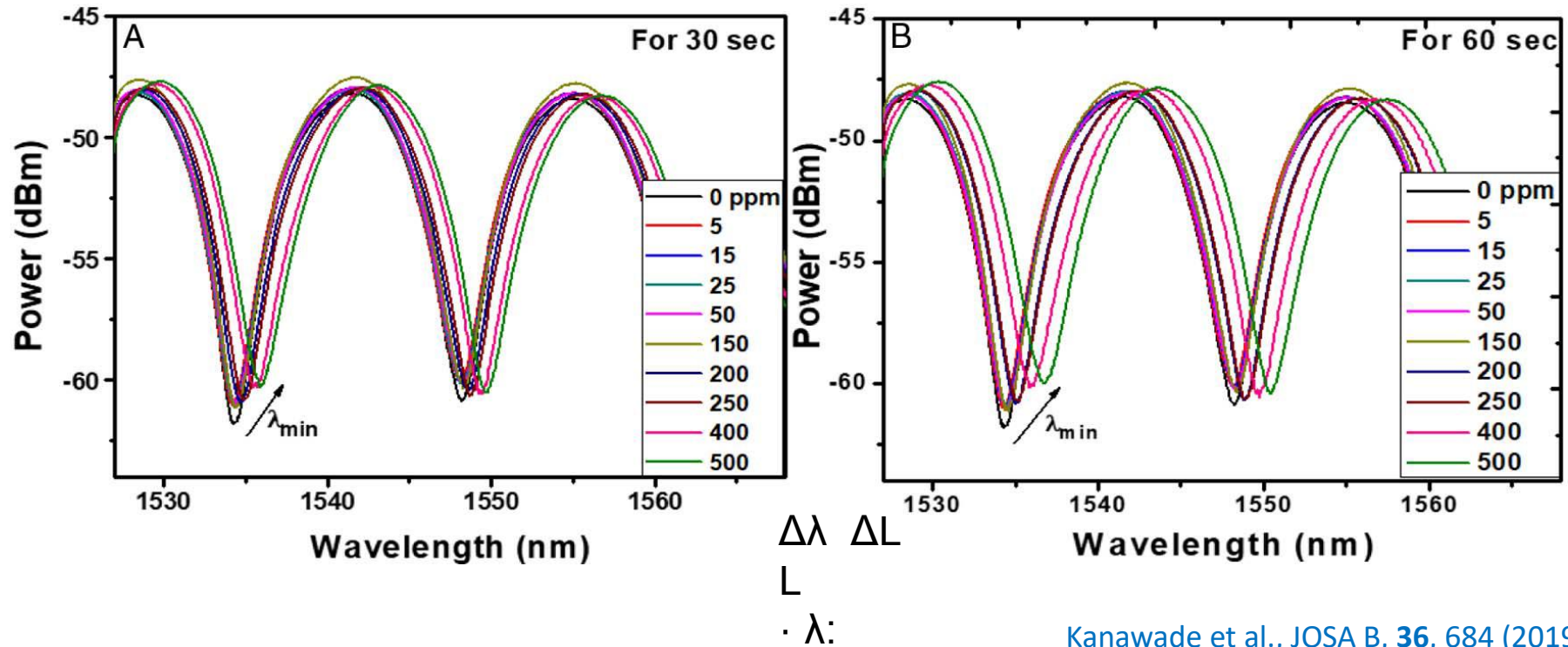
Fiber Optic Fabry – Pérot Sensors

Measurement is achieved by measuring the Fabry-Perot cavity length using white light interferometry



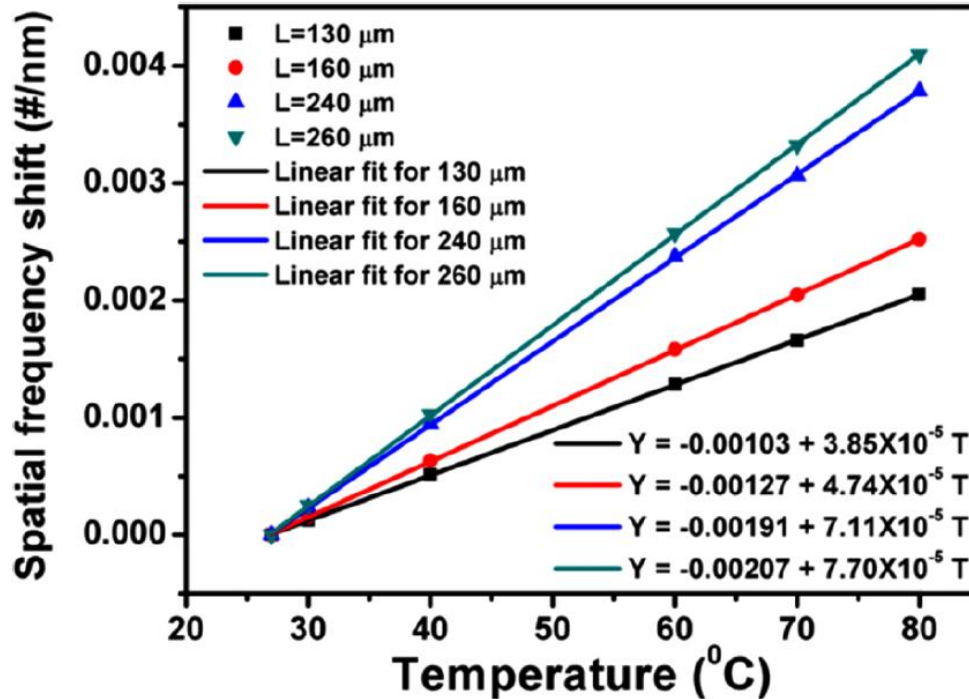
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FPI Sensor for detection of Ammonia



Kanawade et al., JOSA B, **36**, 684 (2019)

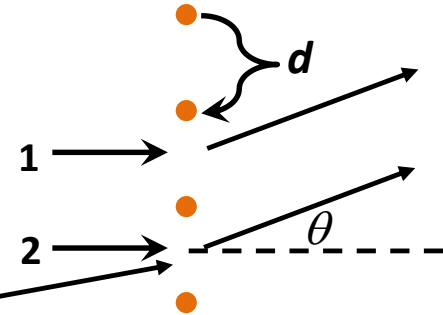
Polydimethylsiloxane (PDMS) FPI based Temperature Sensor



Pawar et al., OSA Cont. 2, 2353 (2019)

Fraunhofer Diffraction

- “Fraunhofer” => incident, outgoing rays parallel
- Start with single plane of atoms (a grating)
- Wave “in phase” – incident crests and troughs aligned
- Extra distance traveled by 2 is $d \sin \theta$
- If this is an integer number of wavelengths, we get constructive interference



Condition for Maxima

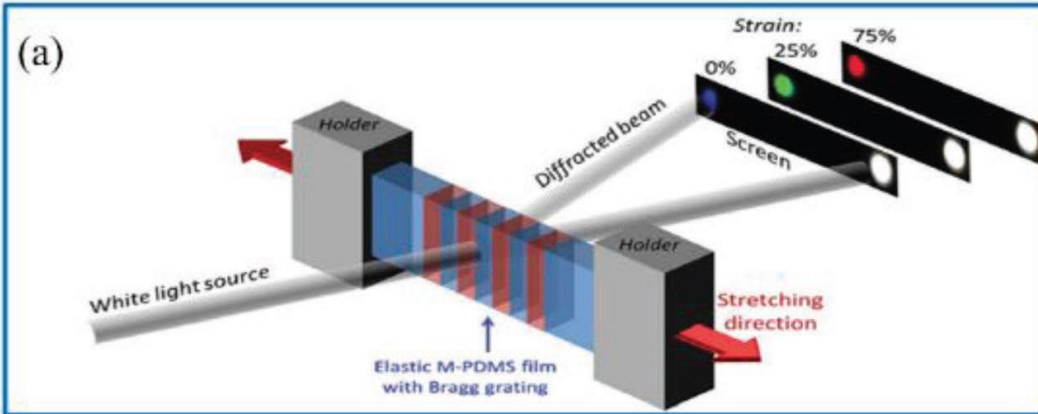
$$d \sin \theta = m\lambda$$

where $m = 0, 1, 2, \dots$

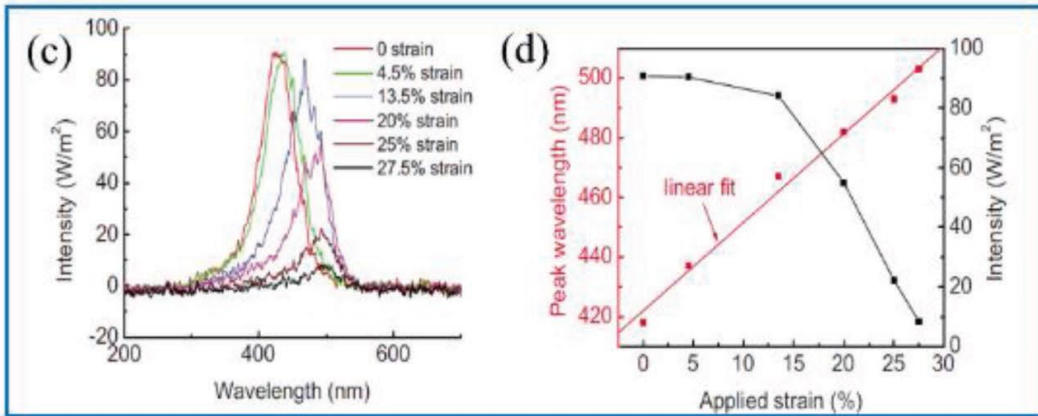
If λ is known, measuring θ tells us d

- Or if d is known we can get λ , etc.

Diffraction based Sensing



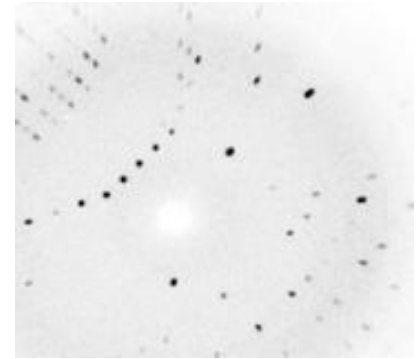
Stretchable diffraction grating based strain sensor



Ryabchun et al., Adv. Opt. Mater., **4**, 169 (2016)

X-Ray Diffraction

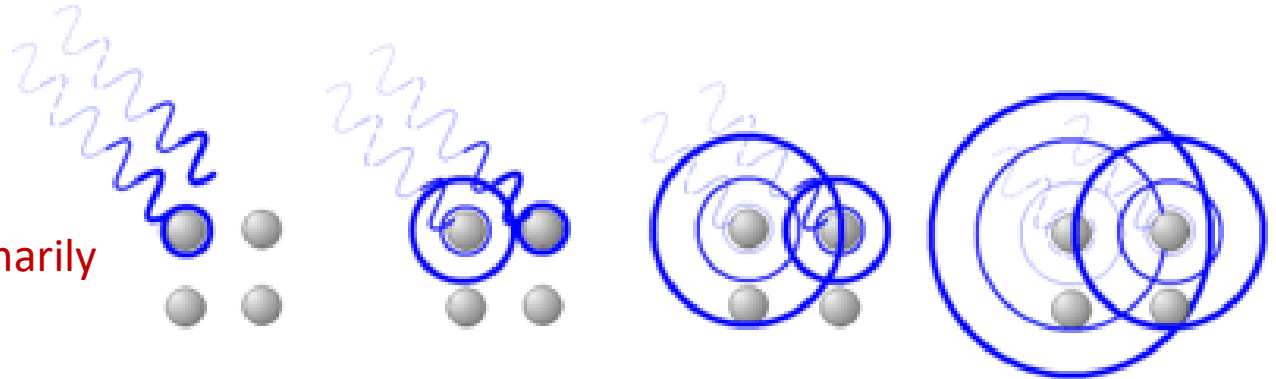
- X-rays have wavelengths comparable to atomic sizes and spacings, about 10^{-10} m
- Crystals and molecules reflect X-rays in specific patterns depending on their structures



Interaction of X-Rays with Atoms

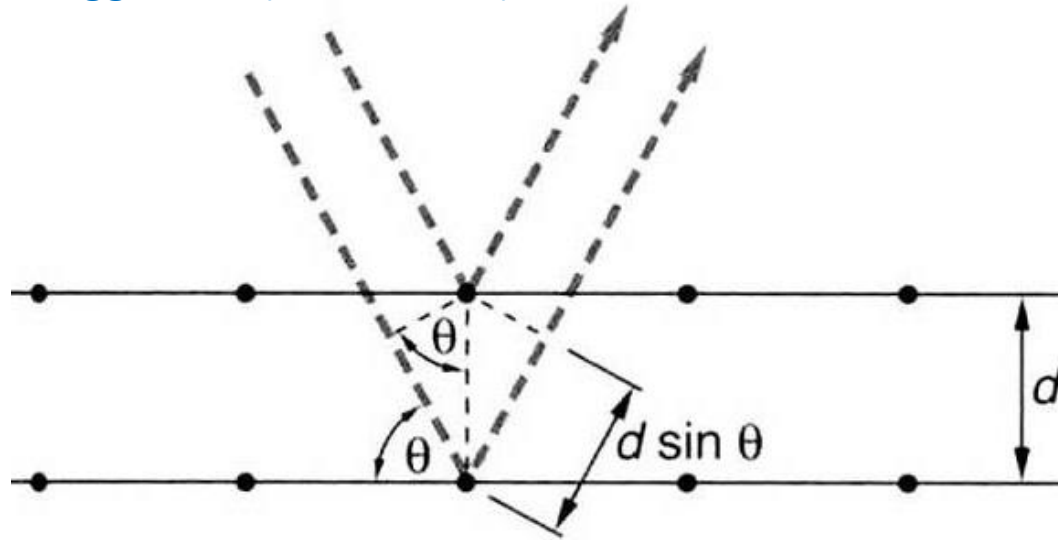
X-ray diffraction pattern of myoglobin

Involves the electrons, primarily



Bragg Diffraction

W. H. Bragg and W. L. Bragg, 1913 (Nobel 1915)



- Condition for constructive interference:

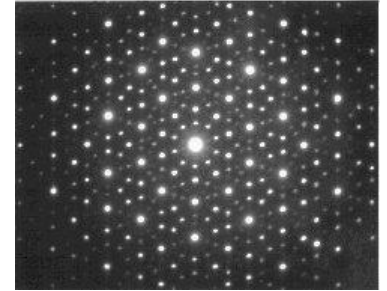
$$2d \sin \theta = n\lambda$$

Bragg's Law

- Diffraction from different sets of planes in the crystal gives a picture of the overall structure

More Information

- *Intensities* of diffraction maxima can vary – more information about detailed structure
- *Symmetry* of the crystal structure is reflected in the diffraction pattern

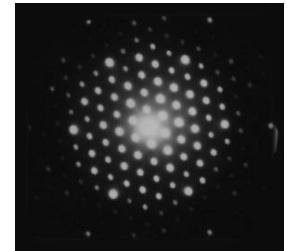


Electron Diffraction

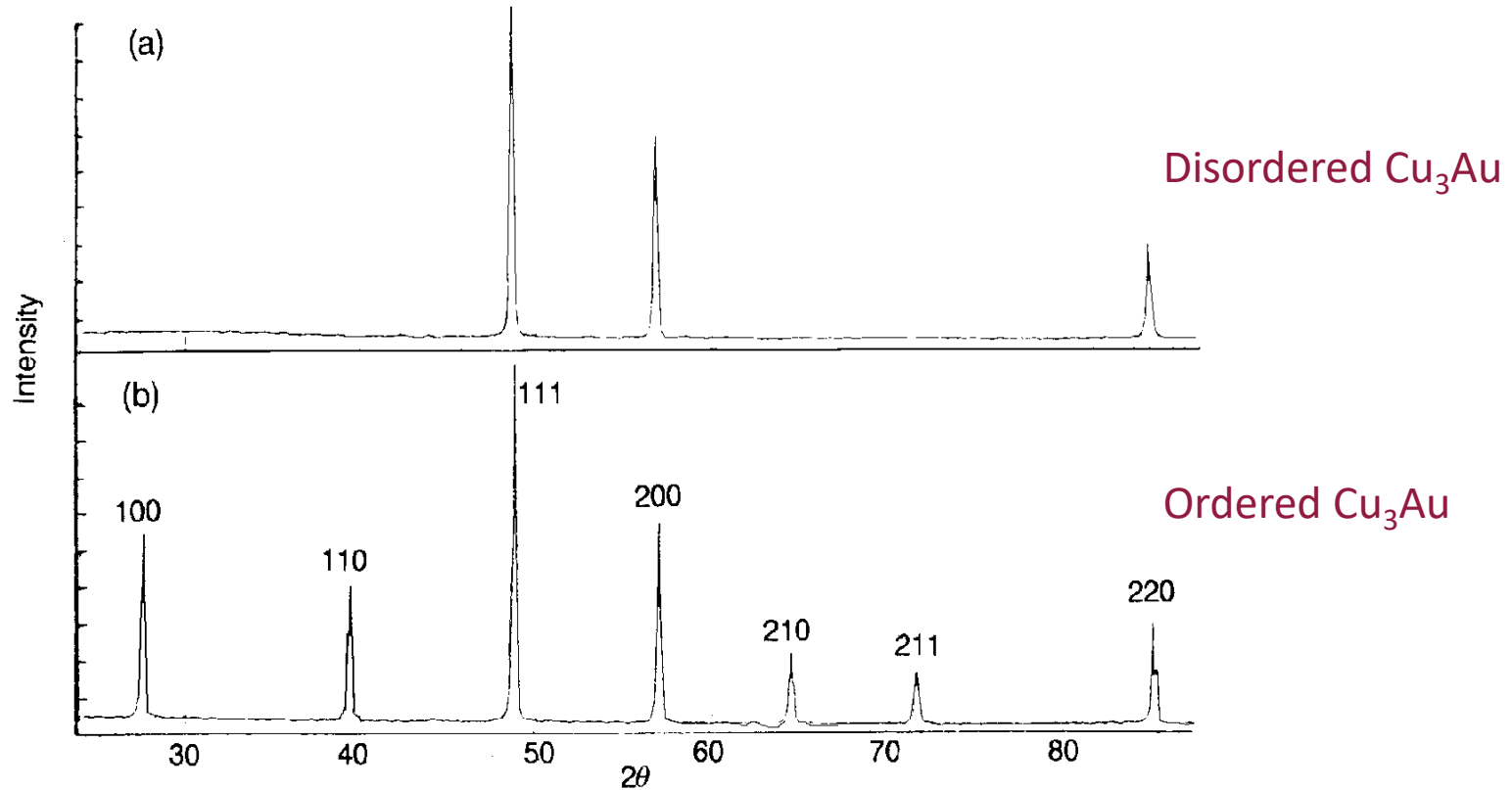
- Can be done with particles too, due to their wave nature!
- Direct test of the De Broglie relation

$$\lambda = h/p$$

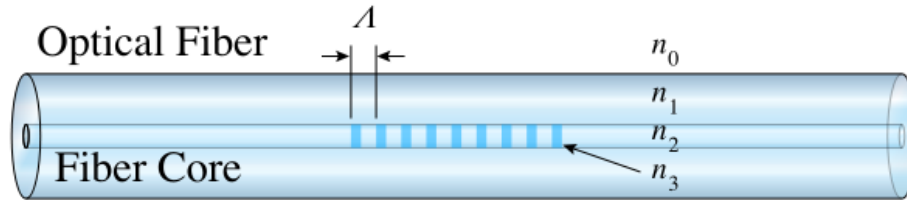
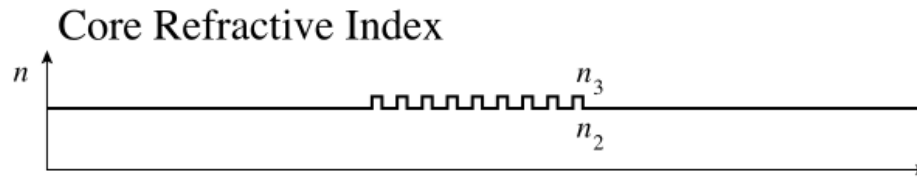
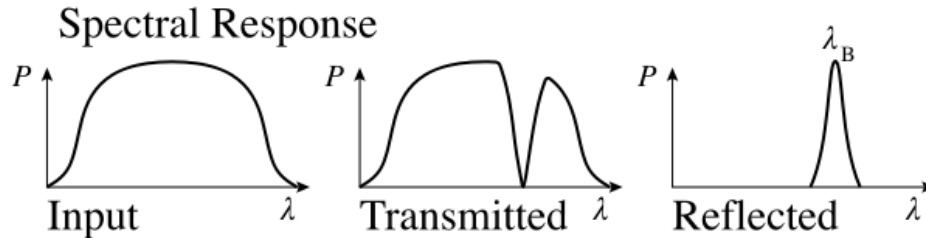
(Davisson and Germer, Thomson)



Sensing based on Order-Disorder Transformation



Fiber Bragg Grating Sensors

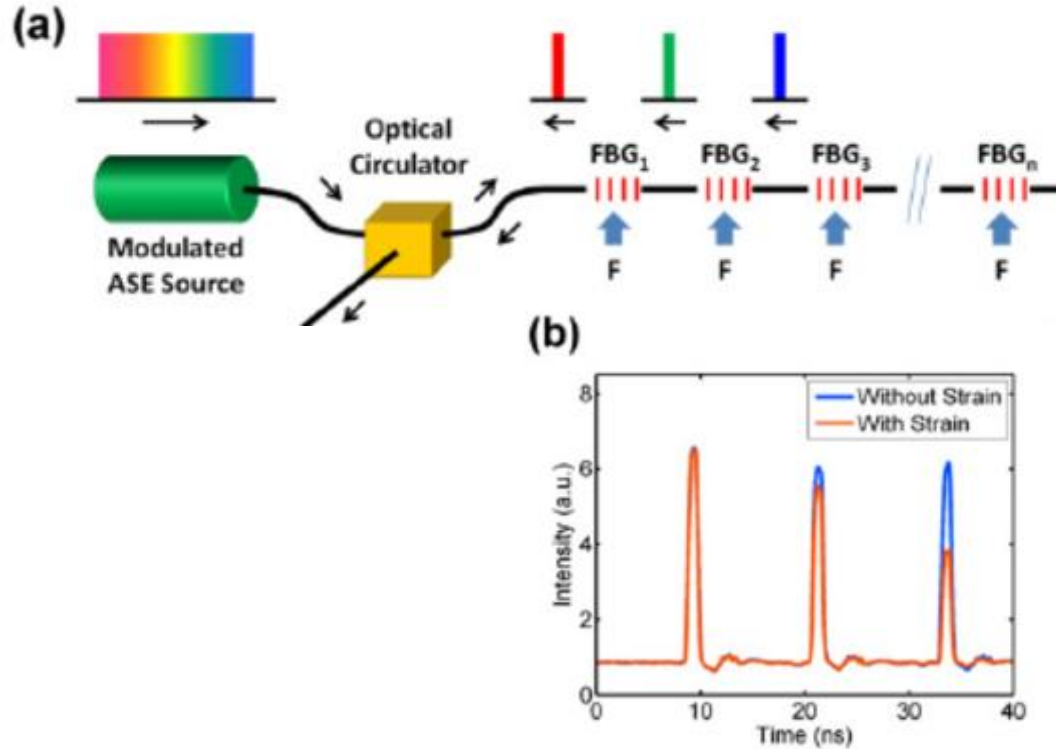


The reflected wavelength (λ_B), called the Bragg wavelength, is defined by

$$\lambda_B = 2n_e \Lambda$$

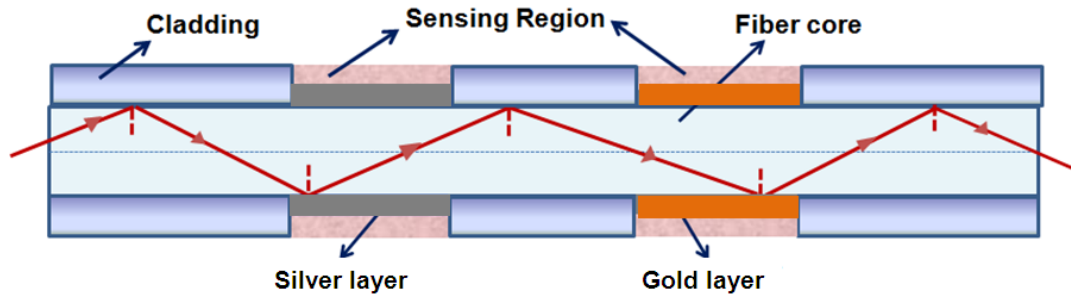
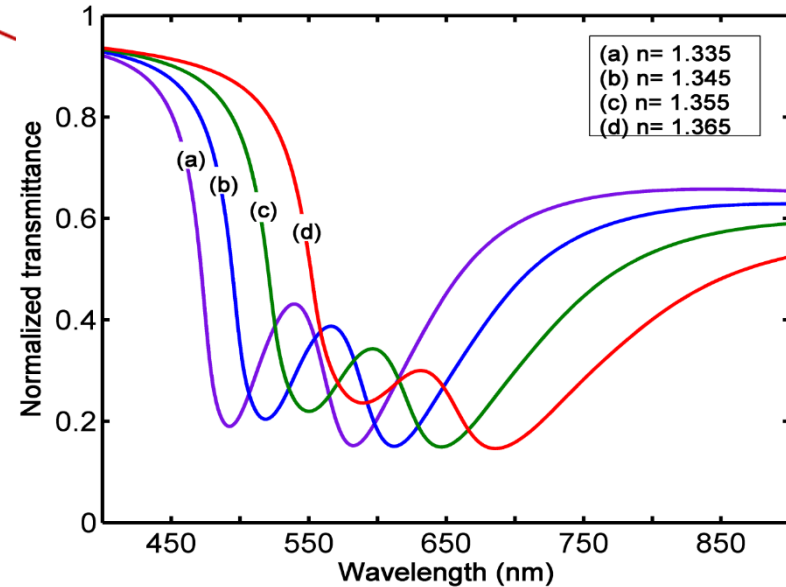
The reflected wavelength depends on the strain and temperature of the fiber

Cascaded Fiber Bragg Gratings



Monitoring of Highways and Bridges

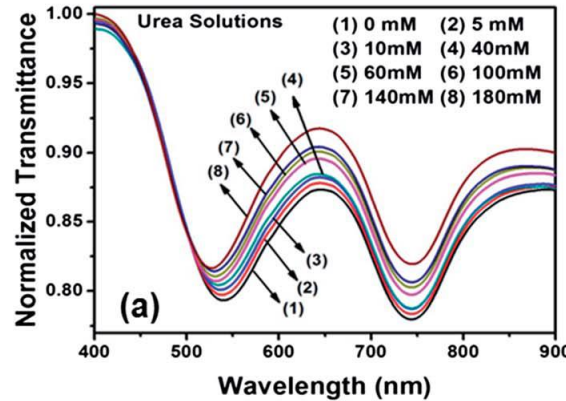
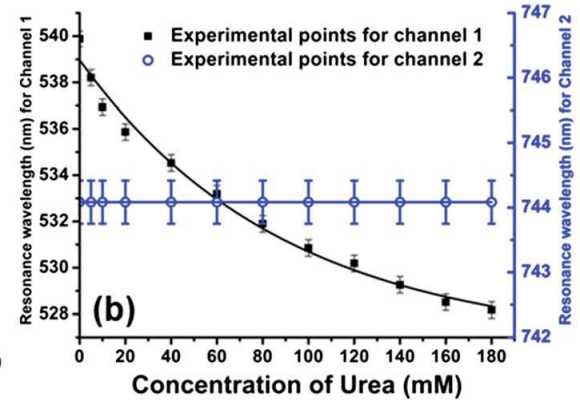
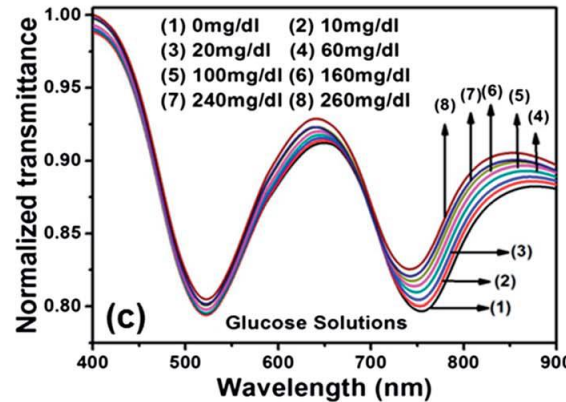
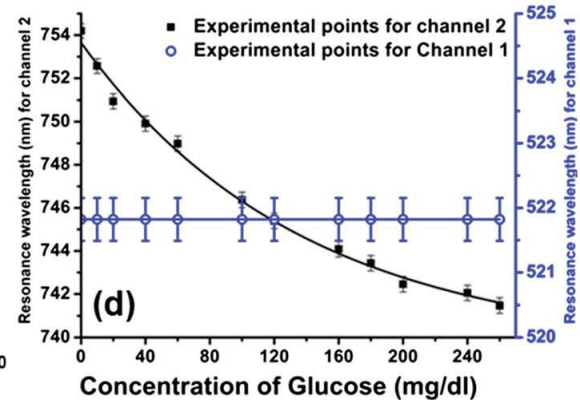
Multichannel, Multianalyte Fiber Optic Sensors



Verma et al., Proc. SPIE, (2012)

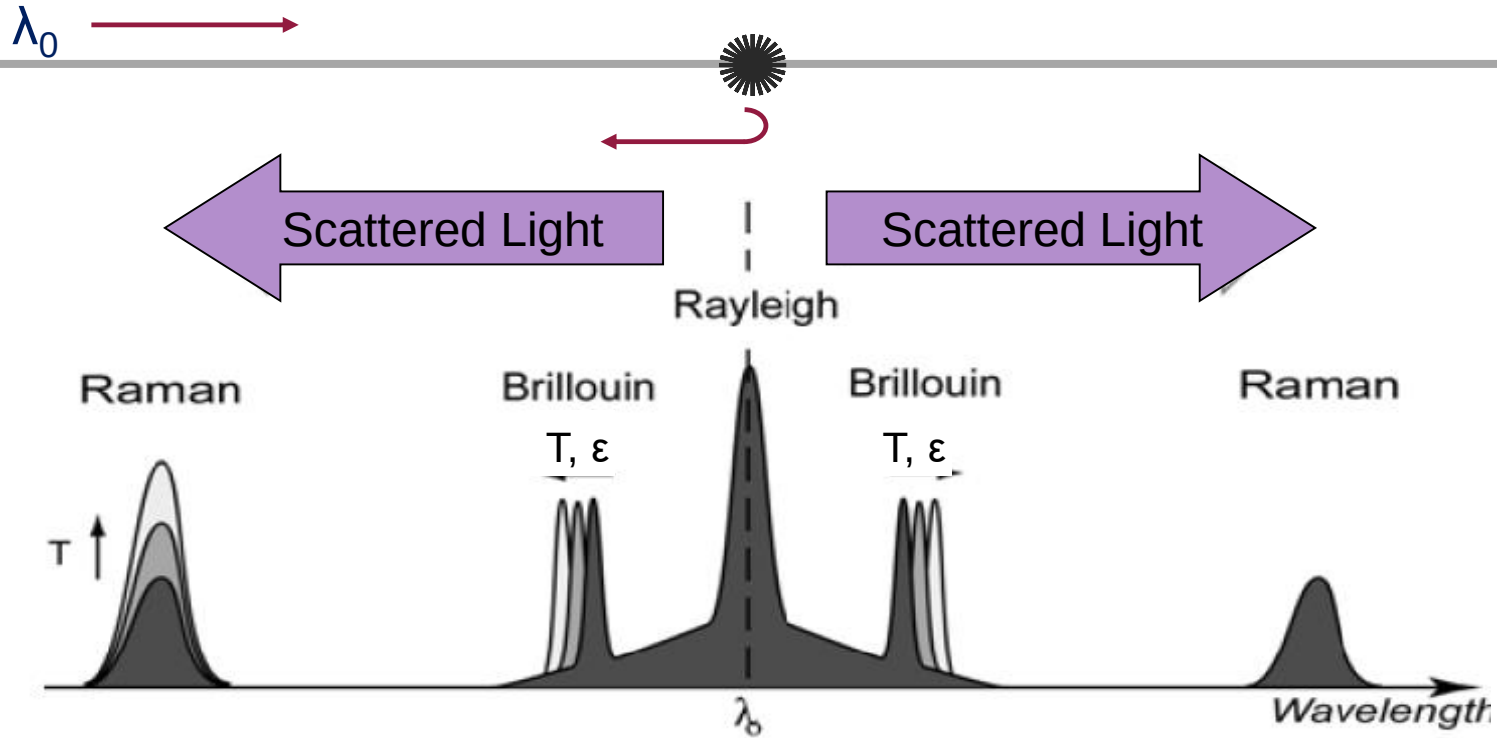
Dual Channel SPR Sensor

Simultaneous sensing of urea and glucose



Verma and Gupta, Analyst, 139, 1449 (2014)

Optical scattering in silica fibers

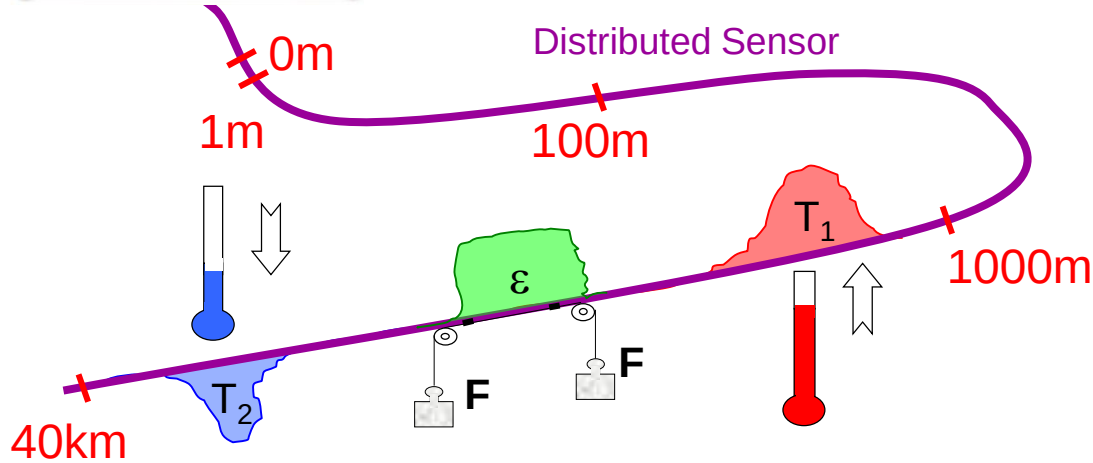
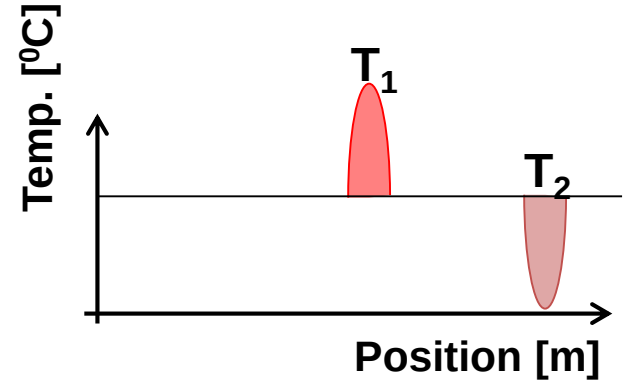
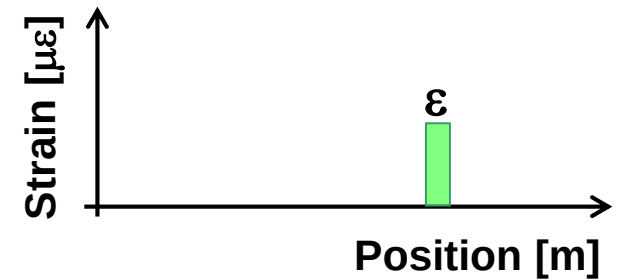


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Distributed Sensing



Reading Unit



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Summary

1. Fabry Perot Interferometry and sensors based on it were discussed
2. Fraunhofer diffraction and sensors based on it were discussed
3. XRD, Bragg diffraction and their sensing applications were discussed.
4. Fiber Bragg Gratings based sensors were discussed
5. Multi-analyte and multichannel fiber sensors were introduced
6. Principles of fiber optic distributed sensing were discussed

Thank You

