Strain and Temperature Measurement with Optical Fiber Bragg Grating Sensor

CROMeP ECOLE DES MINES D'ALBI CARMAUX

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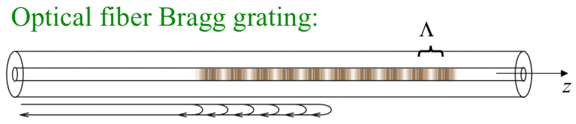
What is a fiber Bragg grating ?

Optical fiber Bragg grating:



• Quasi-sinusoidal refractive index variation:

$$n(z) = n_{dc}(z) + \Delta n_{ac}(z)\cos\left[\frac{2\pi}{\Lambda}z + \theta(z)\right]$$

• Acts as a filter :

$$\lambda_{reflected} \approx 2n\Lambda$$

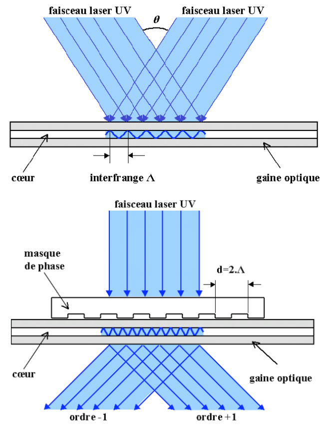
n and Λ depend on temperature, strain, pressure => can be used as a **sensor**

Advantages

- linear measurement, relative signal (no calibration)
- high temperature and strain sensitivity
- multiplexing capabilities
- long term stability
- immune to electromagnetic interference
- flexibility and small diameter => embedding in structure possible
- independent of the intensity of the light (spectral measurement)

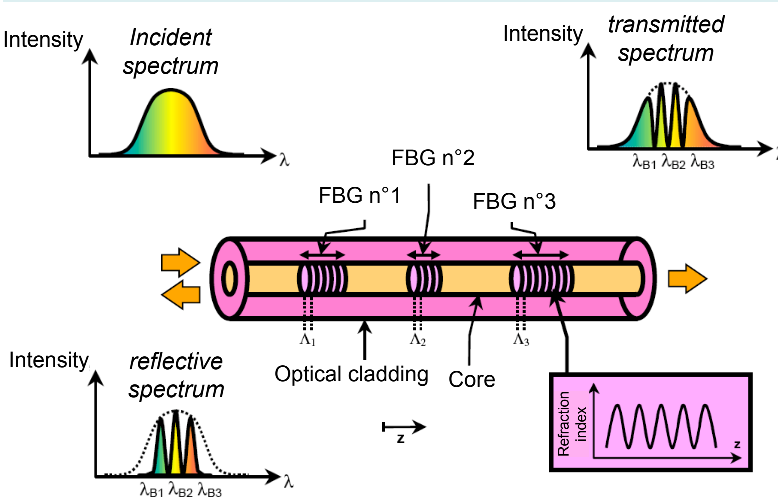
Grating inscription

Photosensitivity of silica: a UV pattern is printed into the fiber core as index variation



- holographic method: the fiber is positioned under classical interferometric fringes
- phase mask method: the fiber is positioned under the interferometric fringes obtained by the one order diffraction produced by the mask

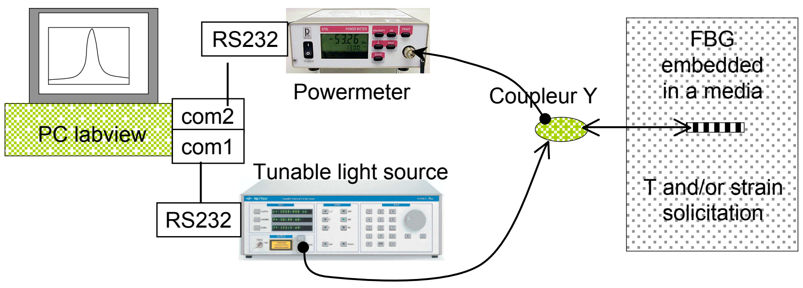
Principle of the sensors



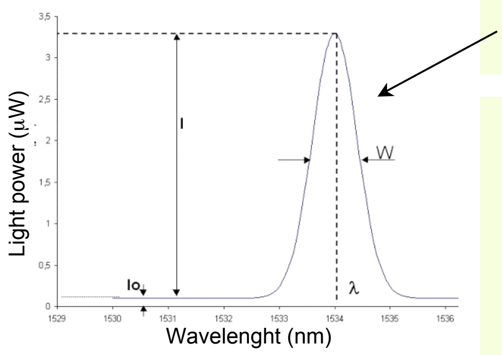
- Periodical structure of pitch Λ formed by refractive index (n) variation of the core
- Characteristic wavelength of the grating: $\lambda_b = 2\,n\,\Lambda$
- Variation of the Bragg wavelength (hypothesis: isotropic optical fiber under uniaxial longitudinal strain ε): $\frac{\Delta\lambda_b}{\lambda_b} = a\Delta T + b\varepsilon + c\Delta P$, a, b and c **constant**
- In detail, thermal variation: $\frac{\Delta\lambda_{bT}}{\lambda_b} = a\Delta T = (\alpha + \xi)\Delta T$
- In detail, longitudinal strain: $\frac{\Delta\lambda_b}{\lambda_b} = \left(1 - \frac{n^2}{2}\left[\rho_{12} - \nu(\rho_{11} + \rho_{12})\right]\right)\varepsilon = (1 - p_e)\varepsilon = b\varepsilon$

Applications: structural health monitoring of civil construction, intelligent sensing for innovative structures, composite (aeronautic) structure, seismology, medical and chemistry, measures and controls during industrial process, …

Experimental measurement device



Maximum resolution : 1pm <=> 0,1°C or 1με



Peak extraction: minimization (Levenberg-marquardt) of $f(\lambda) = I_0 + Ie^{-\frac{(\lambda-\lambda_B)^2}{2W^2}}$

Metrological performances (1550 nm):

- -100 < T < 500 °C
- 0.1 < P < 100 MPa
- 10^{-4} % < ε < 2 %

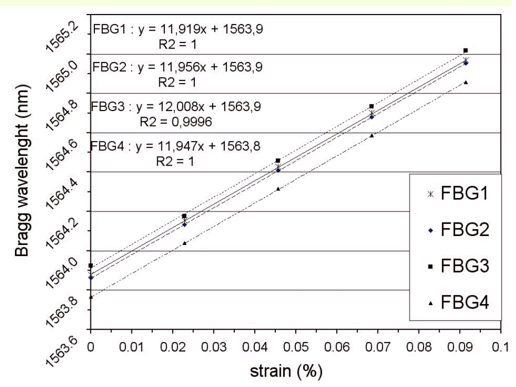
} *range*

- Thermal: 12 pm / °C
- Strain: 1,2 pm / με
- Hydrostatic pres.: -4,5 pm / MPa

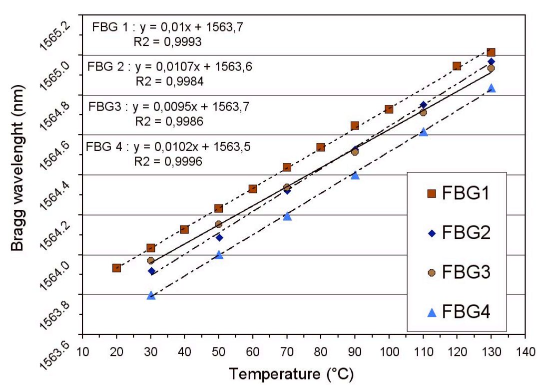
} *sensitivity*

Experimental validation

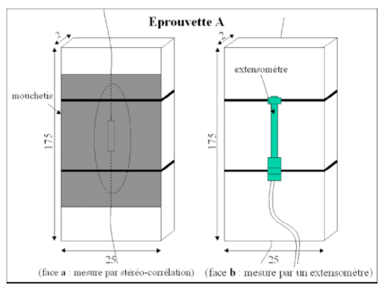
Bare FBG submitted to tension

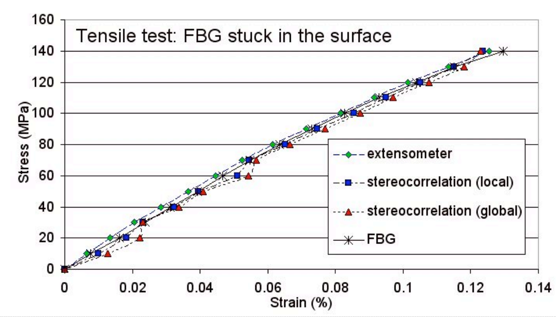


Bare FBG submitted to temperature

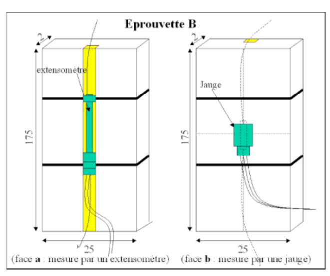


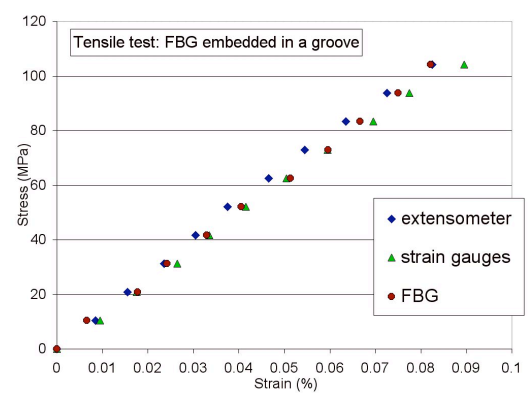
FBG stuck on the surface of a specimen - comparison with strains measured by mechanical extensometer and full field strain measure (stereocorrelation)

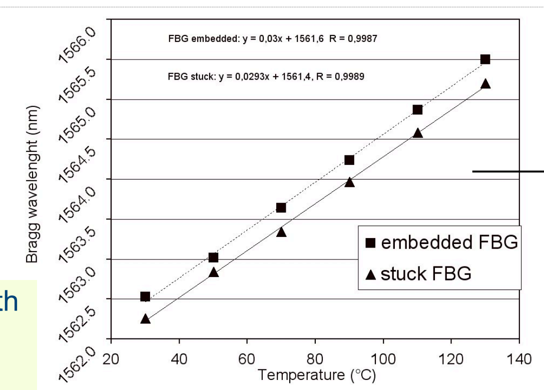




FBG embedded with epoxy resin in a groove - comparison with strains measured by mechanical extensometer and strain gauge







Temperature variation of the Bragg wavelength for stuck and embedded FBGs: sensibility depends on the material

- need temperature and strain discrimination
- birefringence phenomena induced by radial strains
- FBG embedded in complex media needs numerical simulation

References: techniques de l'ingénieur (P. Ferdinand, R6 735, R2 802, M. Lequime R 460), S. Vacher (PhD Thesis, ENSMSE, St-Etienne, 2004)