Fiber Bragg Grating (FBG) Sensors

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(Brief Information on **Optical Strain Sensing** using Fiber Bragg Sensors; May 2011)

1. Introduction

In comparison to traditional electric strain gages, optical strain sensors offer several advantages:

- Immunity Against any **Electric Influences.**
  (high voltages, high currents, short circuits, flashes, …)
- **No Electric Power** at Measurement Site.
  (applicable to harsh & explosive environment)
- Detection of **High Strain.**
  (>10.000µm/m in single tests & >5.000µm/m in repeated cycles)
- **Multiple Sensors in Single Fiber.**
  (up to 13 sensors in a single measurement fiber, avoidance of strong cabling, kilometer long fiber distances & multiplexing capability)

This justifies in many cases the usage of the more expensive optical counterparts instead of electric sensors. Here, a brief outline of this optical strain sensing technology is given.

<u>Abbreviations in Optics:</u>

λ = "lambda" (lower-case letter) for *Wavelength*
Λ = "Lambda" (capital letter) for *Bragg Grating Period*
nm = "nanometer" as *Wavelength Unit*.

2. Fiber Bragg Grating and Optical Interrogator

The **F**iber **B**ragg **G**rating (**FBG**) is a periodic structure written into the core of an optical fiber. It consists of ~10.000 grating periods on a total Bragg grating length *L*~6mm, acting as a flexible "scale" upon strain by increasing resp. reducing the spacing between the grating periods.

Fig. 1 demonstrates the construction principle of a Fiber Bragg Grating. Incoming light is filtered and reflected by the Bragg grating, giving rise to a "Bragg peak" in the reflection spectrum at the *Bragg wavelength* λ_B.

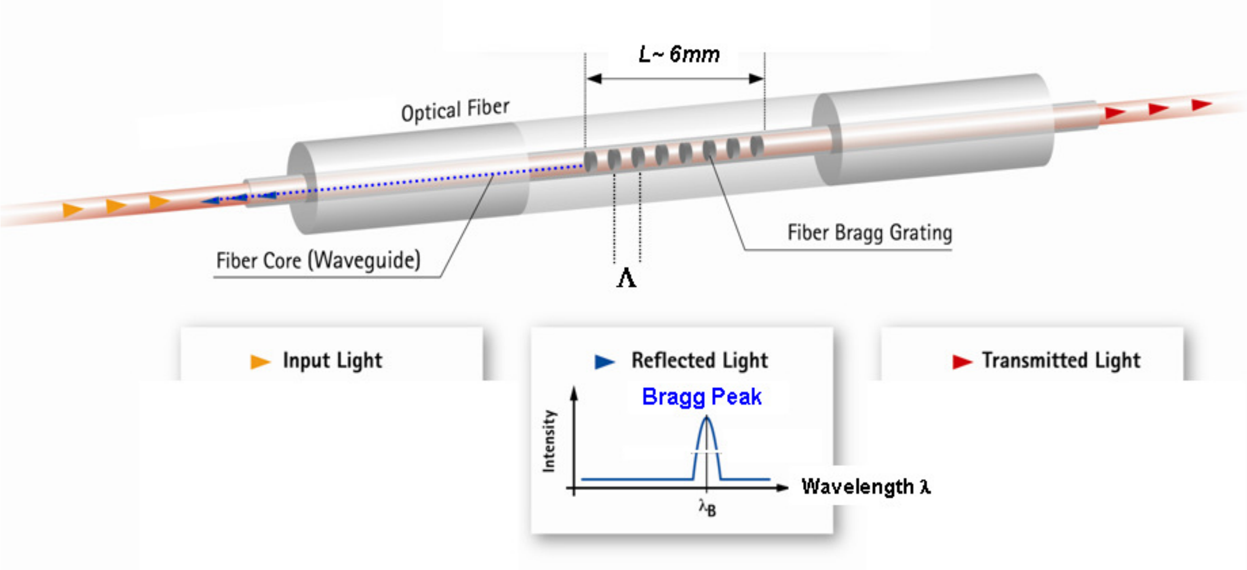

Fig. 1. Construction and measurement principle of a Fiber Bragg Grating (FBG).

The *Bragg wavelength* λ_B directly depends both on the *grating period* Λ and on the *effective refraction index* n_{eff} of the fiber core:

$$\lambda_B = 2\, n_{eff}\, \Lambda \quad (1)$$

This is the basic equation for the Fiber Bragg Grating.

In the presence of *strain* ε along the fiber, the grating periods experience a relative length change, $\varepsilon = \Delta\Lambda/\Lambda$. In the case of homogeneous strain, this also applies to the total grating length *L*, $\varepsilon = \Delta L/L$. Therefore, strain directly translates into a relative change of the Bragg wavelength:

$$\Delta\lambda/\lambda_B = k \cdot \varepsilon \quad (2)$$

This is the basic equation for strain sensing with Fiber Bragg Sensors.
The *k-factor* for Fiber Bragg Sensors is typically k~*0.79* (detailed on each data sheet).

The optical spectrum of the Bragg fiber, especially the Bragg peak, is measured by *optical interrogators*. Our present interrogators basically contain a light source combined with a tunable optical filter, several fiber couplers and fiber splitters, and an array of photodiodes to record the light reflected from each Bragg grating. During the measurement process, input light from the tunable light source is permanently swept in the wavelength range between 1510nm and 1590nm, which includes the spectral range of the HBM FBG sensors. Once the sweeping wavelength passes the Bragg wavelength of a FBG sensor, the Bragg peak reflection signal is recorded by a photodiode and further used for data processing (by interrogator hardware and HBM *Catman* Software).

HBM interrogators:
"SI" series for "static interrogation", 1-10Hz measurement rate.
"DI" series for "dynamic interrogation", 500Hz to 1kHz measurement rate.

The principle setup of a 4-channel optical interrogator together with four Bragg fibers is shown in **Fig. 2**.

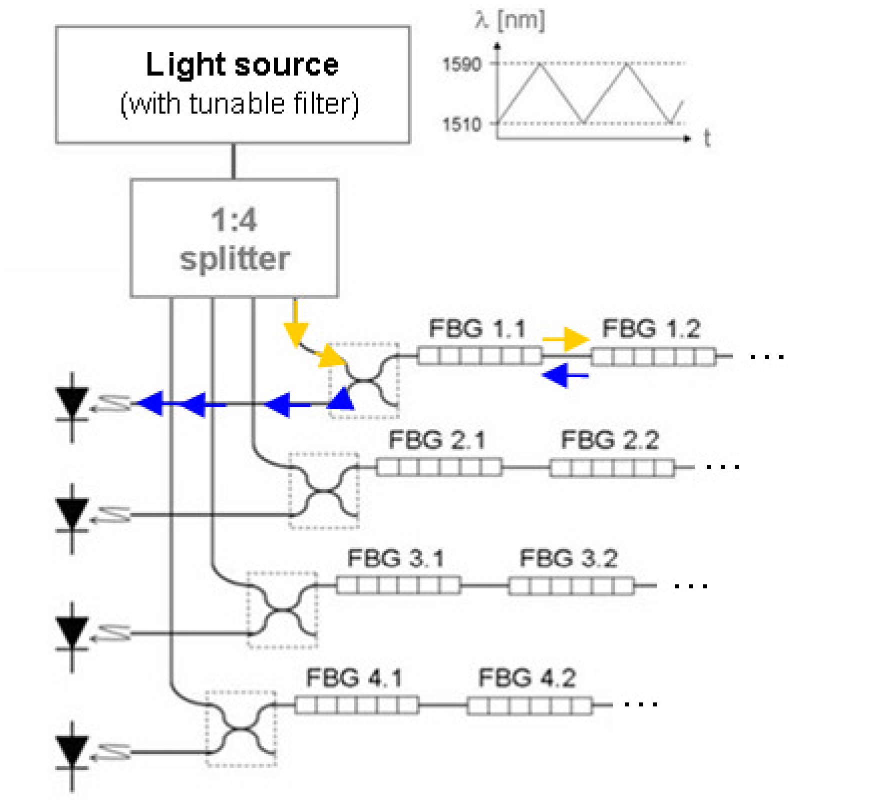

Fig. 2. Optical Interrogator with four optical measurement chains (FBG chains). Incoming (reflected) light indicated by yellow (blue) arrows.

3. HBM Fiber Bragg Sensors

HBM offers an *Optical Linear (OL) Strain Gage* for strain sensing in one dimension as well as an *Optical Rosette (OR) Strain Gage* for planar strain and stress analysis. The OL sensor contains one Bragg grating; the OR sensor contains 3 Bragg gratings in 60° configuration.

Since fiber optical sensors are amenable to temperature influences, compensation of temperature effects is necessary in many cases. Therefore, HBM offers an *Optical Temperature Compensation (OTC) Gage* to be placed nearby the optical strain gage in quest.

The present HBM optical sensor portfolio is shown in **Fig. 3**.

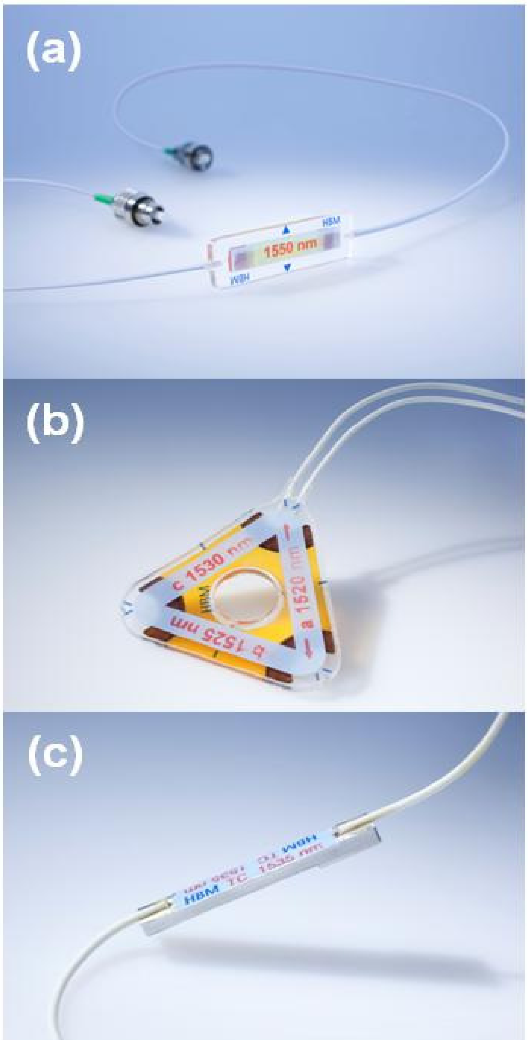

Fig. 3. HBM Fiber Bragg Sensors:

(a) **OL** (Optical Linear Strain Gage),

(b) **OR** (Optical Rosette Strain Gage),

(c) **OTC** (Optical Temperature Compensation Gage)

Fig. 4 shows the spectrum of an optical measurement chain containing 13 FBG sensors (OL, OR, OTC) recorded by an HBM SI-interrogator. The HBM standard spectral distance between the Fiber Bragg gratings is $\Delta\lambda_B$~5nm. Intensities of the Bragg peaks are either displayed in a dB-scale (for static interrogators) or in a %-scale (for dynamic interrogators).

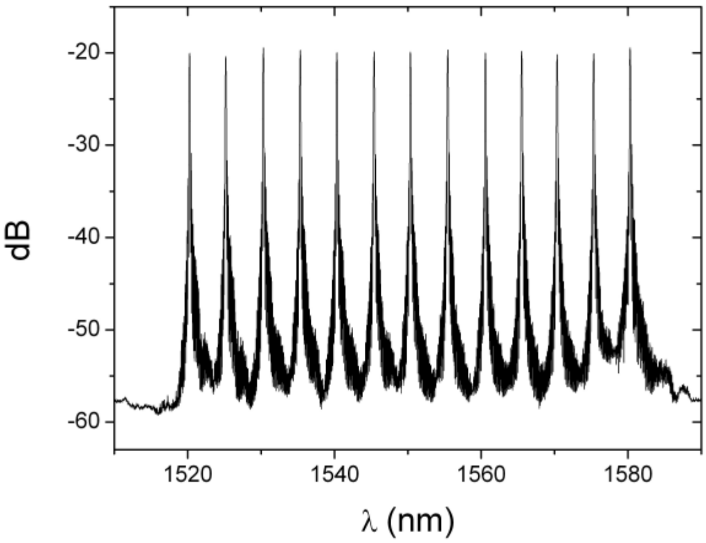

Fig. 4. Spectrum of an optical measurement chain (FBG sensor chain).

An exemplary strain measurement using HBM fiber optical technology is displayed in **Fig. 5**, where two OL sensors were bonded on both sides of an oscillating spring out of GRP (glass fiber reinforced plastic).

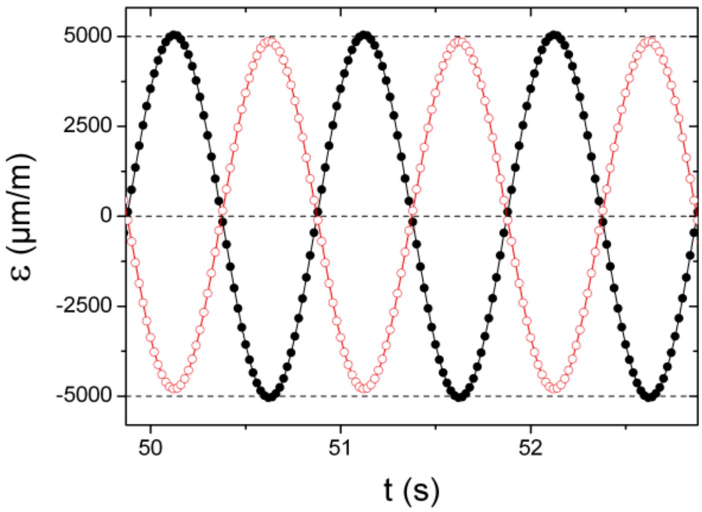

Fig. 5. Exemplary strain measurement with two OL sensors.