Conception and preliminary evaluation of an optical fibre sensor for simultaneous measurement of pressure and temperature

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Conception and preliminary evaluation of an optical fibre sensor for simultaneous measurement of pressure and temperature

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Abstract. This paper presents a novel concept of simultaneously measuring pressure and temperature using a silica optical fibre extrinsic Fabry-Perot interferometric (EFPI) pressure sensor incorporating a fibre Bragg grating (FBG), which is constructed entirely from fused-silica. The novel device is used to simultaneously provide accurate pressure and temperature readings at the point of measurement. Furthermore, the FBG temperature measurement is used to eliminate the temperature cross-sensitivity of the EFPI pressure sensor.

1. Introduction

Optical fibre extrinsic Fabry-Perot interferometric (EFPI) pressure sensors can be constructed entirely from fused-silica (i.e. entirely made of glass), e.g. using a glass capillary [1][2], a hollow core fibre [3] or standard telecommunication fibres [4][5]. Moreover, such all silica sensors have many advantages: present a cost-effective; have a simple fabrication process; are small in size; mechanically robust and are capable of operating at high temperatures [1]. In addition to their pressure sensitivity, all-fused silica optical fibre EFPI pressure sensors are also sensitive to temperature. This cross-sensitivity to temperature is due to the thermal expansion of the glass components and the air within the EFPI sensor cavity. Therefore, in practice the temperature cross-sensitivity of EFPI sensors can be a source of error in pressure measurements.

In this paper a novel concept is presented, which can be used to simultaneous measure pressure and temperature. This hybrid sensor is based on a fibre Bragg grating (FBG) sensor for temperature measurement and an EFPI pressure sensor to measure pressure simultaneously. The all-fused silica optical fibre EFPI pressure and FBG sensor are both on the same fibre and co-located at the measurement point. In the embodiment presented, the FBG is used as a reference sensor to eliminate the temperature cross-sensitivity of the EFPI pressure sensor. The combination of an all-fused silica optical fibre EFPI pressure sensor and a FBG retains the advantages of an all-glass structure, is miniature size, exhibits a relatively high pressure sensitivity and facilitates the discrimination of pressure and temperature readings at the point of measurement. These properties make the novel FBG/EFPI hybrid sensor potentially suitable for many applications in both the biomedical and industrial domains.

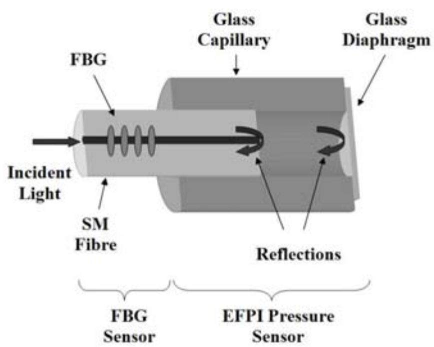

Fig. 1: Concept of FBG/EFPI hybrid sensor

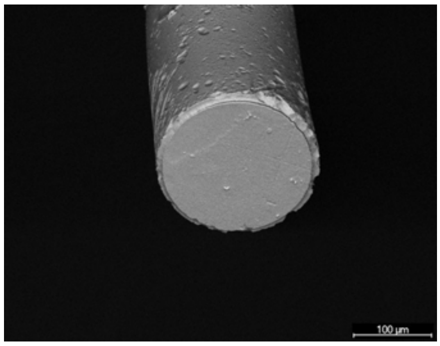

Fig. 2: Fabricated EFPI pressure sensor

2. Sensing head fabrication

The concept of the FBG/EFPI hybrid sensor is shown in Fig. 1. The cavity of the EFPI pressure sensor is formed between the end face of the optical single mode (SM) fibre and the inner and outer surface of the glass diaphragm. Due to the low reflectance of light at all glass/air and air/glass interfaces the EFPI can be treated as a low-finesse interferometer.

Based on the fabrication of an all-fused silica optical fibre EFPI pressure sensor, as described in [1], a standard communication FBG with a Bragg wavelength of $\lambda_B=1550nm$ was inserted into a 133/220µm inner/outer diameter glass capillary. To obtain an air cavity the capillary end face was fusion spliced to a 200µm glass fibre and the FBG was fusion spliced to the glass capillary. After that the 200µm glass fibre was cleaved, polished and wet etched to achieve a glass diaphragm. As shown in Fig. 2, a FBG/EFPI hybrid sensor was realized with a cavity length of $L=60\mu m$ and a diaphragm thickness of approx. $d=3\mu m$. At least the whole sensor was inserted into a second glass capillary to keep the FBG strain free. The latter can be avoided by encapsulating the FBG in the glass capillary of the EFPI pressure sensor.

3. Preliminary evaluation

The interrogation system for the FBG/EFPI hybrid sensor is illustrated in Fig. 3. Light from an ASE broadband source was coupled via a 3dB-coupler into the sensor. The reflected output spectrum of the sensor was monitored and normalised using an optical spectrum analyser (OSA) (HP86140A). The normalised reflected output spectrum is shown in Fig. 4.

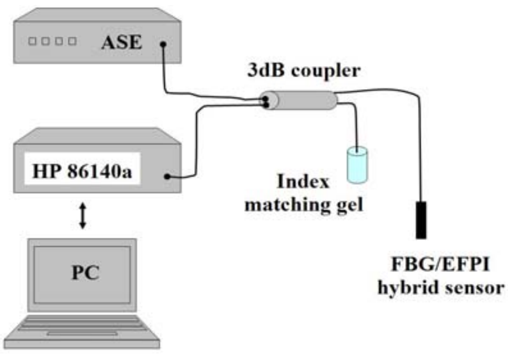

Fig. 3: Interrogation system

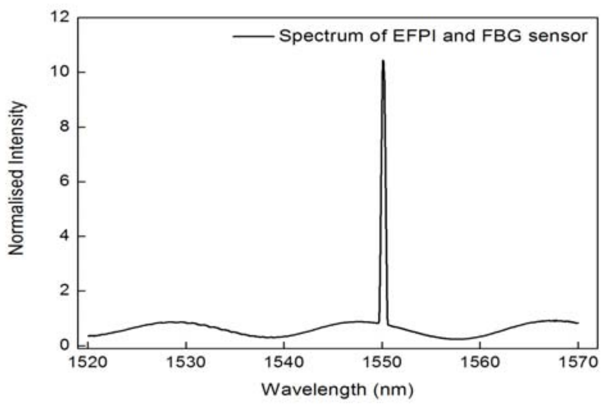

Fig. 4: Spectrum of FBG/EFPI hybrid sensor

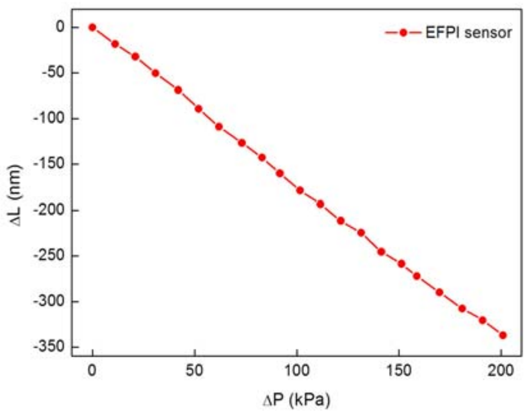

Fig. 5: Pressure response of FBG/EFPI hybrid sensor

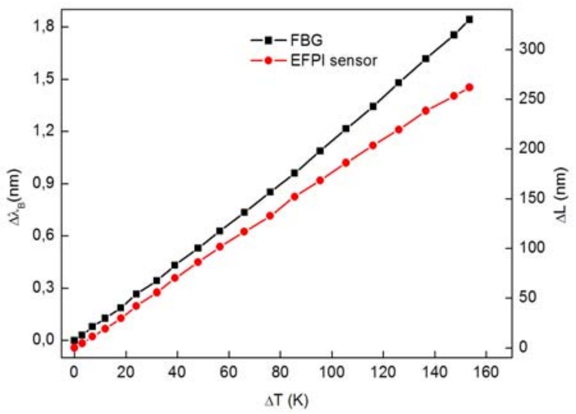

Fig. 6: Temperature response of FBG/EFPI hybrid sensor

The reflected output spectrum of the EFPI pressure sensor is similar to a sinusoidal wave, whereas the output of the FBG sensor has a narrow bandwidth with a high reflectivity. The cavity length L of the EFPI pressure sensor was measured from the sinusoidal wave of the reflected spectrum as:

$$L = \frac{\lambda_1 \lambda_2}{2(\lambda_2 - \lambda_1)} \tag{1}$$

In Equation (1), λ_1 and λ_2 are two wavelengths that are 2π out of phase. The shift of the Bragg wavelength $\Delta\lambda_B$ was measured by correlating the normalized output spectrum with the known spectrum of the FBG.

Fig. 5 and Fig. 6 illustrate the relative pressure and temperature response of the FBG and EFPI pressure sensor. Pressure measurement began near atmospheric pressure (labeled with 0 kPa) and increased incrementally up to 200 kPa. Due to the relative low pressure sensitivity of the FBG sensor [6], only the pressure response of the EFPI pressure sensor is shown in Fig. 5. The temperature measurement was started at room temperature (about 23°C) and increased incrementally up to 180°C. Both measurements were made independently at constant temperature and constant pressure respectively. The pressure and temperature coefficients of the FBG and EFPI pressure sensor were calculated to be *11.16 pm/K* (FBG) and *-1.685 nm/kPa; 1.7 nm/K* (EFPI pressure sensor).

Using the temperature and pressure coefficients from both sensing units a matrix equation can be constructed as [7]:

$$\begin{bmatrix} \Delta\lambda_B \\ \Delta L \end{bmatrix} = \begin{bmatrix} 0 & 11.16\,pm/K \\ -1.685\,nm/kPa & 1.7\,nm/K \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta T \end{bmatrix} \tag{2}$$

The inversion of the matrix can be used to determine the pressure ΔP and temperature ΔT information from the FBG and EFPI pressure sensor.

4. Summary

In this investigation the concept of a novel FBG/EFPI hybrid sensor has been successfully demonstrated. The preliminary evaluation verifies that the FBG/EFPI hybrid sensor is able of measuring pressure and temperature simultaneously. Therefore the temperature cross-sensitivity of the all-fused silica optical fibre EFPI pressure sensor can be eliminated. Moreover, a good correlation was observed between the FBG/EFPI pressure hybrid sensor and the measurands. These results are promising and warrant further investigation of the FBG/EFPI hybrid sensor.

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