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Optical fibre refractive index sensor in a hybrid fibre grating configuration

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Abstract

A temperature compensated Refractive Index (RI) sensor incorporating a Long Period Grating (LPG) and a Fibre Bragg Grating (FBG) in a series configuration has been developed and evaluated. The LPG was used as a RI sensor allowing it to respond to external RI variations while the FBG was used for temperature compensation. The LPG and FBG wavelengths were chosen to be within suitable spectral bandwidths for efficient interpretation of both RI and temperature. The performance of the hybrid sensor was evaluated for use as a chemical sensor by varying sodium chloride (NaCl) concentrations in water from 0.25 – 2 %NaCl and temperature from 10-95 ^{o}C and by recording its corresponding attenuation band shifts. The sensitivity of the hybrid sensor to NaCl concentration and temperature is calculated to be 0.61 nm/%NaCl and 8 pm/^{o}C respectively.

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Keywords: Fibre Bragg grating (FBG), Long period grating (LPG), Refractive index (RI)

1. Introduction

Chemical detection forms one of the most researched areas of study in the sensors field and one technique used for the quantification of chemical concentration in a solution is monitoring its RI variation resulting from changes in concentration. Fibre gratings, which forms the basis of the work presented here, are fabricated by subjecting a portion

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of a photosensitive fibre into ultra violet (UV) light that consequently creates a periodic RI variation. Depending on the period of the RI modulation, fibre gratings may be considered as belonging to two basic categories – Fibre Bragg Gratings (FBGs) and Long Period Gratings (LPGs). FBGs have a very narrow loss band resulting from typical grating periods within the 1-2 μm range, while LPGs show a response which comprises a series of loss bands resulting from relatively longer (as the name suggests) grating periods that typically are in the region of several hundreds of micrometres. In this work both are exploited, in series on an optical fibre, to create an effective hybrid sensor.

Since LPGs are inherently sensitive to the surrounding RI, this has been utilized to form sensors that could be used for the measurement of chemical concentrations and other environmental conditions [1-3]. Previous work by the authors [1-3] has demonstrated that a LPG can be utilized as a RI sensor in reflection mode to increase the resolution of measurement. It is important, however, to control the temperature of the test environment to avoid calibration errors arising from the LPG wavelength shift due to temperature. In this work, an LPG/FBG hybrid sensor has been designed and evaluated for simultaneous measurement of RI and temperature which was then used as a temperature compensated NaCl concentration sensor.

1.1. Fibre gratings

For the case of FBGs, part of the light propagating in the core reflects when experiencing the RI modulation in the core, resulting in a narrow band reflection from the grating, allowing the structure formed in the core of the fibre to behave like a notch filter. The wavelength at which light is reflected is termed the Bragg wavelength and is given by the equation below, where n_{core}^{eff} is the effective RI of the core and Λ_{FBG} is the grating period.

$$\lambda_{Bragg} = 2n_{core}^{eff}\Lambda_{FBG}$$

By contrast, in the case of LPGs, part of the light propagating in the core mode couples to the co-propagating cladding modes at the grating when the mode coupling conditions are satisfied. The resonance wavelength for the loss band is given by the equation below, where n_{core}^{eff} and $n_{clad,m}^{eff}$ are the effective refractive indices of the fundamental core mode and the mth cladding mode, respectively, and Λ_{LPG} is the grating period of the LPG.

$$\lambda_{res}^{m} = \left(n_{core}^{eff} - n_{clad,m}^{eff}\right)\Lambda_{LPG}$$

1.2. Hybrid sensor configuration

It is evident from equations above that while FBGs are sensitive to variations in its period of RI modulation, the LPGs are sensitive to the surrounding RI variations (in addition to being sensitive to the grating period). Previous work by the authors [1-2] have established that the external RI sensitivity of LPGs can successfully be utilized to design RI sensors. However, typically the sensor performance was evaluated while maintaining a constant temperature. The work presented here is aimed at enhancing the previous sensor design to suit it better for practical applications by incorporating a FBG in series (and operating at a closely related wavelength) to allow effective temperature compensation to be achieved in a series configuration. Therefore the hybrid sensor is based on the optimum characteristic of each grating by having a LPG-based RI sensor in line with a FBG for temperature compensation, containing the hybrid sensor within a single series fibre design.

2. Experimental Procedure

2.1. Sensor fabrication

The fibre gratings used in this work were fabricated using phase/amplitude masks illuminated by light from a 248 nm KrF excimer laser with pulse energy of 12 mJ and a pulse frequency of 200 Hz. The FBG and LPG grating periods used were 1053 nm and 168 μm respectively. The FBG resulted in a sharp attenuation trough at 1527.1 nm while the highest attenuation band of the LPG was seen at 1586 nm. The transmission spectrum of the hybrid sensor is shown in Fig.1. In the case of the LPG, a period of 168 μm was chosen so that a greater RI sensitivity can be achieved by using the attenuation band of a higher order mode, i.e. mode 12 in B-Ge fibre, and within the detectable range of the Optical Spectrum Analyzer (OSA) used. Upon fabrication, all gratings were annealed at 185 °C for 4 hours prior to the rest of the procedure in order to achieve good thermal stability.

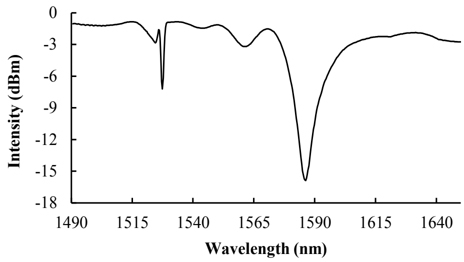

Fig. 1 – The transmission spectra of the FBG/LPG hybrid sensor.

2.2. Sensor performance evaluation

The hybrid sensor was put inside an environmental chamber as can be seen from Fig. 2 which shows one end of the hybrid sensor connected to a broadband light source (Halogen Source – Ocean Optics type LS-1), and the other to an OSA (Yokogawa AQ 6370C). Prior to the RI calibration, both the sensors were subjected to a temperature calibration over the range from 10-95 ºC and the results can be seen from Fig. 3. The temperature coefficients of the FBG and LPG were calculated to be 7.9 pm/ºC and -0.42 nm/ºC respectively. After the temperature analysis, the hybrid sensor was then subjected to changes of surrounding RI using different NaCl concentrations over the range from 0.25-2 %NaCl. During this procedure the temperature was kept constant, above room temperature, at 30 °C. Then the sensor was subjected to variation in temperature from 15-30 ºC at 1 %NaCl.

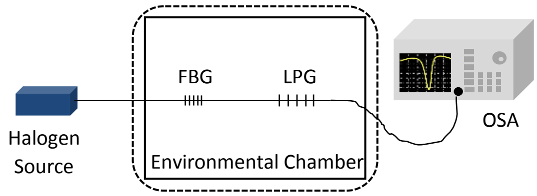

Fig. 2 – Experimental setup for temperature calibration.

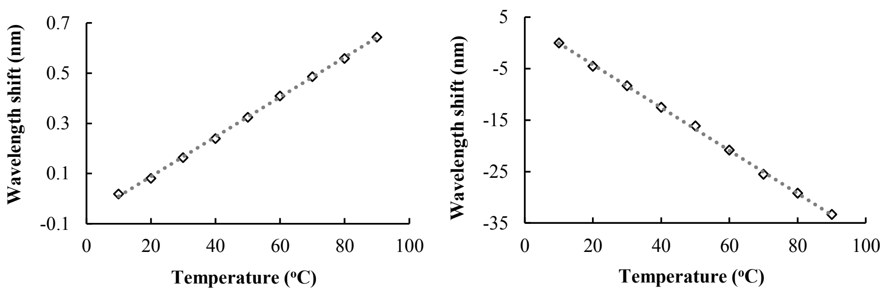

Fig. 3 – Temperature variation on the bare hybrid sensor; FBG (left) and LPG (right) performance.

3. Results and discussion

As can be seen from Fig. 3, the sensitivity of the LPG to temperature (0.42nm/°C) is very high, therefore it is vital to ensure that this temperature effect be removed for the actual calibration for NaCl concentration measurement under varying temperature conditions. The temperature data obtained from the FBG is designed to decouple the temperature induced wavelength shift of the LPG, experiencing closely the same conditions since both the gratings are written together in the same fibre, with the physical distance between the gratings less than 15 mm.

The response of the LPG sensor to varying NaCl concentration and temperature can be seen from Fig. 4. The LPG sensor has a sensitivity of 0.61 nm/%NaCl when the NaCl concentration was varied from 0.25 – 2 %NaCl while having negligible wavelength shift for temperature variation (after compensation).

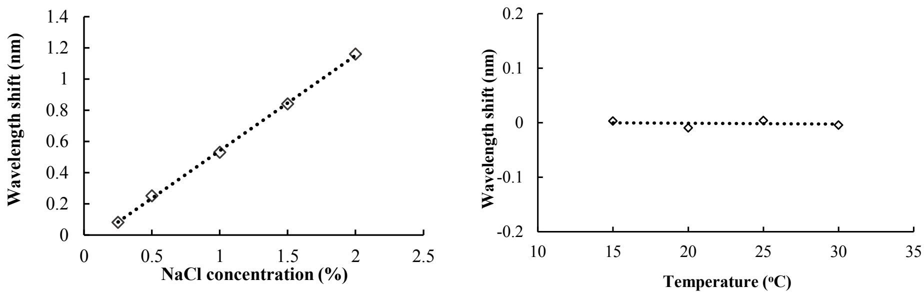

Fig. 4 – Wavelength shift of the LPG due to NaCl concentration variations at 30 °C (left) and temperature compensated LPG wavelength shift due to varying temperature at 1 %NaCl concentration (right).

It can be seen that the hybrid sensor performance is satisfactory in terms of achieving adequate RI sensitivity from the LPG and temperature compensation data from the FBG simultaneously in a short, single fibre length. In summary, the sensitivity of the hybrid device was determined to be 0.61 nm/%NaCl and 8 pm/°C. The strength of the approach that can be seen from the results is building on the different characteristics of the two gratings, utilizing the greater wavelength shift of the LPG for the RI change and the sharp spectral feature of the FBG for accurate temperature measurement, and thus compensation, with low hysteresis being observed in tests carried out.

4. Conclusion

In this work it has been established that the different and complementary sensitivities of both FBGs and LPGs can successfully be utilized to design and realize an effective RI sensor with excellent temperature compensation. A good performance was observed following the sensor being subjected to increasing and then decreasing NaCl concentrations. Work is ongoing to optimize the performance and design using LabView-based software to provide the necessary data for the user on the RI change and the temperature excursion when in use.

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