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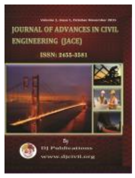

RESEARCH ARTICLE

Hybrid Fibre Grating Structure of an Optical Fibre Refractive Index Sensor

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ABSTRACT

The refractive index which is compensated with temperature by incorporating an LPG and FBG has been established and evaluated in a series configuration. As refractive index is used by Long Period Grating which allows it to be responsive to external refractive index difference ,for temperature compensation the Fibre Bragg Grating was used. For efficient interpretation of both refractive index and temperature the Long Period Grating (LPG) and Fibre Bragg Grating (FBG) wavelengths were chosen to be within suitable spectral bandwidths. For the use as a chemical sensor the hybrid sensor performance was rated by varying sodium chloride (NaCl) concentrations in temperature from 11-96 ^{o}C and water from 0.25 – 2 %NaCl and by recording its related attenuation band shifts. The hybrid sensor to NaCl concentration and temperature sensitivity is found to be 0.62 nm/%NaCl and 9 pm/^{o}C respectively.

Keywords: Temperature compensation, Spectral bandwidths, Optical spectrum analyzer, Hybrid sensor, Chemical sensor.

1. INTRODUCTION

One of the most sought out research areas of study in the sensor field is the chemical detection forms and one technique used as a solution for the chemical concentration quantification is tracking its refractive index difference resulting from transitions in concentration. Fibre grating is the basis work forms presented here, that are manufactured by subjecting a section of a photosensitive fibre into ultra violet (UV) light. As a result it generates a duration of refractive index variation. The fibre gratings may be considered as belonging to two basic categories depending on the period of the refractive index modulation. They are Fibre Bragg Gratings (FBGs) and Long Period Gratings (LPGs). Fibre Bragg Gratings have a narrow loss band, due to regular grating periods within the 1-3μm range, while Long Period Gratings show a reply which comprises of loss bands series resulting from relatively longer grating periods that generally are in the several hundred regions of micrometres. In this proposed work Long Period Grating (LPG) and a Fibre Bragg Grating (FBG) in series on an optical fibre, which is an effective hybrid sensor created. 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. In [4] a dual-parameter optical sensor device is achieved by UV inscription of a hybrid long-period grating–fiber Bragg grating structure in D fiber. The

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hybrid configuration permits the detection of the temperature from the latter's response and measurement of the external refractive index from the former's response. In addition, the host D fiber permits effective modification of the device's sensitivity by cladding etching. The grating sensor has been used to measure the concentrations of aqueous sugar solutions, demonstrating its potential capability to detect concentration changes as small as 0.01%.[5] demonstrated a type of fiber optic bend sensor with a hybrid structure made up of a long period grating (LPG) and a tilted fiber Bragg grating (TFBG). The sensing mechanism is based on the spectrum of power transfers between the core and cladding modes from a TFBG located downstream from an LPG. It showed that the curvature of a beam can be determined by the reflected power difference between the core mode and the recoupled cladding modes. It further provided design rules for the LPG and TFBG to optimize and linearize the sensor response. In addition, the temperature cross-sensitivities of this configuration are also investigated for two different types of fiber.[6] presented the LPG-FBG hybrid configuration which was adopted as the sensor, because both of the refractive index and the temperature should be monitored generally in such a solution. The LPG was fabricated by using a CO_2 laser, and the temperature and refractive index coefficients were measured to be used for the monitoring. The monitoring system was configured such that the monitored data were sent to a computer machine via a web server, and the data were processed by an application in the machine. Thus, the monitoring system worked over the world-wide-web. The monitoring function of the system was examined by sensing the refractive index changes of a liquid with known physical values, when the liquid temperature changed. The results clarified that the refractive index changes were monitored successfully by the system function.[7] used cladding-mode-recoupling-based hybrid long period grating (LPG)/fiber Bragg grating (FBG) sensors for the simultaneous measurement of temperature and strain is proposed. A set of counter-propagation cladding modes can be achieved through a specially fabricated hybrid LPG/FBG structure, and experimental results indicate that the intensity of cladding modes and FBG resonance show different temperature and strain response, which can be used for simultaneous measurement of temperature and strain through power-reference-based ratiometric detection.[8] say that two peaks appear in reflection spectrum of CLBG device, and the higher peak is determined by FBG while the other peak is influenced by FBG and LPG. Temperature and solution concentration are adopted to test the performance of multi-parameter sensing simultaneously. By comparing two schemes, using wavelength shifts of the two peaks may solve the cross-sensitivity problem, but its resolution is still very low. Here, another scheme based on light intensity changes and wavelength shifts of the two peaks in reflection spectrum is designed to improve the resolution further. Experiment result proved that the resolution of the proposed method is higher than that of the improved way, and the CLBG device keeps higher sensitivity with this method. [9]optimized parameters of concatenated structure in the method of simulated and discussed the influence that the lengths, periods and dc induced index changes of FBG and LPG and length of optical fiber between LPG and FBG has to influence reflection spectrum. Secondly, based on the optimized parameters for concatenated structure, such structures are fabricated and used to monitor concentration and temperature simultaneously. Simulation result proves that by increasing the length of FBG and LPG properly and the length of optical fiber between LPG and FBG is fixed as 20 mm, more clearly reflection spectrum can be obtained. Experiment result shows a novel optical fiber sensor based on a concatenated strong fiber Bragg grating with a weak long period grating (CLBG) device and can be used to monitor concentration and temperature simultaneously. The result of research has reference value in multi-parameter simultaneously sensing. [10] reports for the first time a planarised optical fiber composite formed using Flame Hydrolysis Deposition (FHD). As a way of format demonstration a Micro-Opto-Electro-Mechanical (MOEMS) hot wire anemometer is formed using micro-fabrication processing. It is a planarised device and is rigidly secured to a silicon wafer using optical quality doped silica that has been deposited using flame hydrolysis and consolidated at high temperature. The resulting structure can withstand temperatures exceeding 580K and is sensitive enough to resolve free and forced convection interactions at low fluid velocity.

1.1. Gratings of fibre

For the case of Fibre Bragg Gratings, when experiencing the RI modulation in the core, part of the light propagating in the core reflects. Because of this a reflection of narrow band from the grating, allows core of the fibre in which the structure is formed and to behave like a notch filter. The light which is reflected from the wave length is termed the Bragg wavelength and the equation is given below,

where n^{eff}_{core} is the refractive index effective of the core and Λ_{FBG} is the period of grating

$$\lambda_{Bragg} = 2\, n^{eff}_{core}\, \Lambda_{FBG} \qquad (1.1)$$

By contrasting the Long Period Grating case the propagating part of the light in the mode in core pairs to the co-propagating cladding modes at the grating when the conditions of mode coupling are satisfied. The below equation shows that the resonance wavelength for the loss band.

where n^{eff}_{core} is the refractive indices effective of the fundamental core mode and $n^{eff}_{clad,m}$ is the effective refractive indices of the m^{th} cladding mode respectively and Λ_{LPG} is the LPG grating period .

$$\lambda^{m}_{res} = (n^{eff}_{core} - n^{eff}_{clad,m})\, \Lambda_{LPG} \qquad (1.2)$$

1.2. Configuration of hybrid sensor

From the above equation it is clearly stated that Fibre Bragg Gratings are sensitive to the RI modulation period variations, the LPGs are sensitive to variations in its surrounding refraction index and are sensitive to the period of grating. In the previous work, the authors [1-2] have developed that the sensitivity of refraction index of Long Period Grating can be utilized successfully to design sensors of RI. However, generally the performance of sensor was assessed while maintaining a temperature constant. The proposed work is aimed at increasing the design of the previous sensor to suit the incorporating FBG in series in practical application and to permit the effective compensation of temperature to be reached in a series configuration. Hence based on the optimum characteristic in the hybrid sensor of each grating by having a Long Period Grating based RI sensor in line with a Fibre Bragg Grating for compensation of temperature, contains the hybrid sensor within a single series design of fibre.

2. TESTING PROCESS

2.1. Fabrication for sensor

In this proposed work fibre gratings, using the phase or amplitude for fabrication where there masks are illuminated by light from a 348 nm KrF excimer laser with 13 mJ pulse energy and 300 Hz pulse frequency. The grating periods of Fibre Bragg Gratings and Long Period Grating were denoted as 1054 nm and 169µm respectively. The attenuation of sharp Fibre Bragg Gratings trough was seen at 1528.1nm while the Long Period Grating resulted in a highest attenuation band at 1587 nm. The hybrid sensor transmission spectrum is shown in figure 1. In the case of Long Period Grating, a 169 µm period was selected so that a greater sensitivity of refractive index can be achieved by using a higher order mode attenuation band i.e. mode 13 in B-Ge fibre, and used within the range of detectable. Upon fabrication, in order to achieve good thermal stability, all gratings were annealed at 186 °C for 4 hours before the rest of procedure.

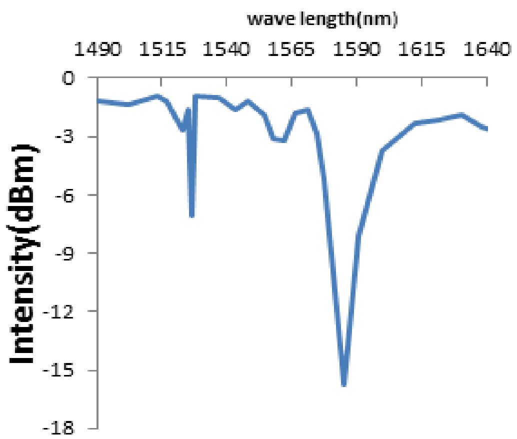

Figure 1.FBG/LPG hybrid sensor transmission spectra

2.2. Evaluation of sensor performance

Inside an environmental chamber, the hybrid sensor was put inside and it can be seen from figure A1. It shows that one end of the hybrid sensor is connected to a broadband light source and the other end of the hybrid sensor is connected to an Optical Spectrum Analyzer. Before the calibration of refractive index, both the sensors were incurred to a calibration of temperature over the range from 11-96 ^{o}C and figure A2 shows the results. The FBG and LPG temperature coefficients were calculated to be 8.9 pm/^{o}C and -0.52 nm/ ^{o}C respectively. After the analysis of temperature, the hybrid sensor was then incurred to surrounding changes refractive index using different concentrations of NaCl over the range from NaCl of 0.35-3 %. During this process the temperature was above room temperature and is kept constant at 30 °C. Then the sensor was incurred to temperature variation from 16-32 ^{o}C at 2 %NaCl.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In the above figure A2, the Long Period Grating sensitivity to temperature is very high and therefore it is main to confirm that this effect of temperature be removed for the actual calibration for concentration of NaCl measurement under varying conditions in temperature. The data of temperature obtained from the Fibre Bragg Gratings is designed to disconnect the induced wavelength of temperature shift of the Long Period Grating by closely experiencing the same conditions since both the FBG and LPG are written together in the same fibre, with the distance in physical arrangements between the gratings less than 16 mm. Figure A3 shows the LPG sensor's response to varying concentration of NaCl and varying temperature. The sensor of LPG has a sensitivity of 0.61 nm/%NaCl when concentration of NaCl was varied from 0.35 – 3%NaCl while having wavelength of negligible shift for variation in temperature (after compensation).

It can be seen that the performance of hybrid sensor is satisfactory in terms of attaining enough RI sensitivity from the Long Period Grating and data of compensation of the temperature from the Fibre Bragg Gratings simultaneously in a short, single length of fibre. In short, the hybrid device sensitivity was determined to be 0.62nm/% NaCl and 9pm/oC. The approach strength that can be seen from the experimental results is building on the different two gratings characteristics, using the greater wavelength shift of the Long Period Grating for the change in refractive index and the feature in sharp spectrum of the Fibre Bragg Gratings for measurement of accurate temperature and thus compensation. Lowest hysteresis is observed in experiments carried out.

4. CONCLUSION

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

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APPENDIX A

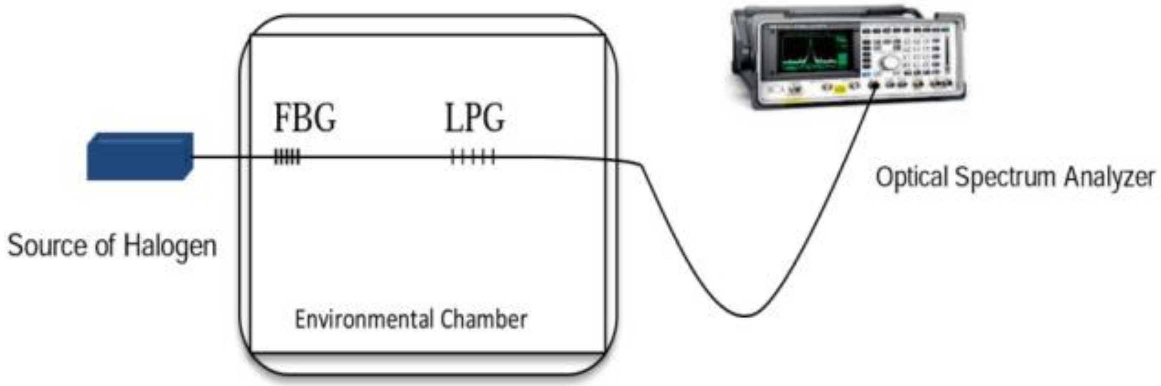

Figure A1.Experimental setup for calibration of temperature

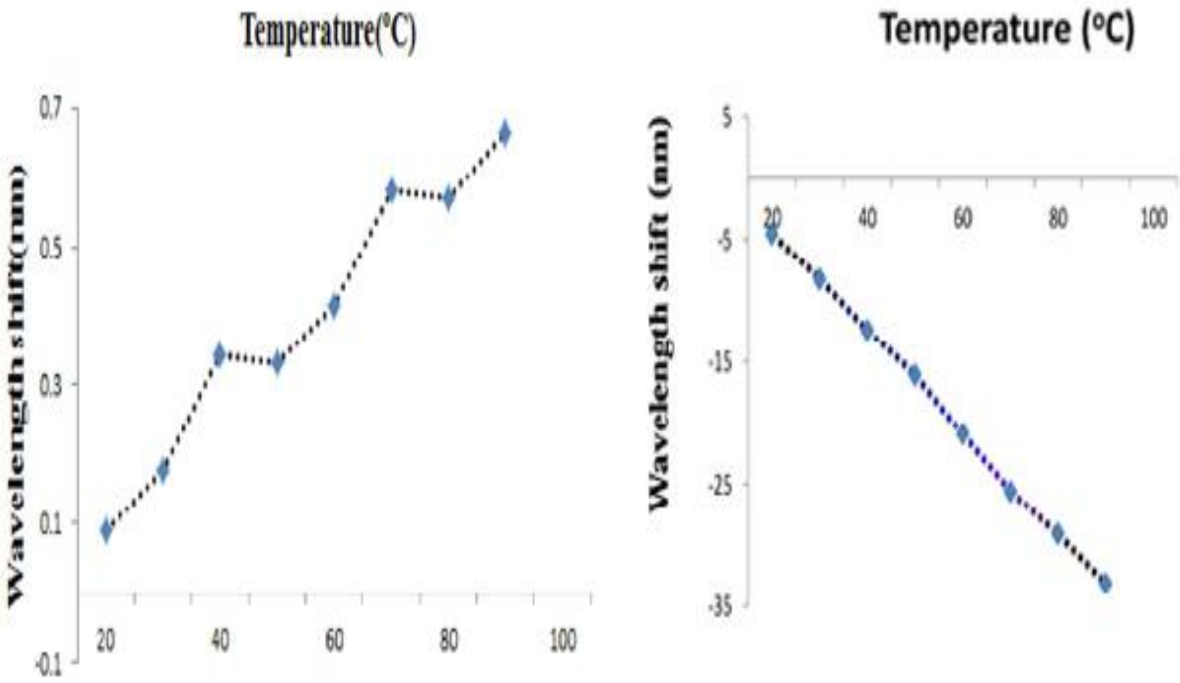

Figure A2.Variation of temperature on the bare hybrid sensor, Performance of FBG (left) and LPG (right)

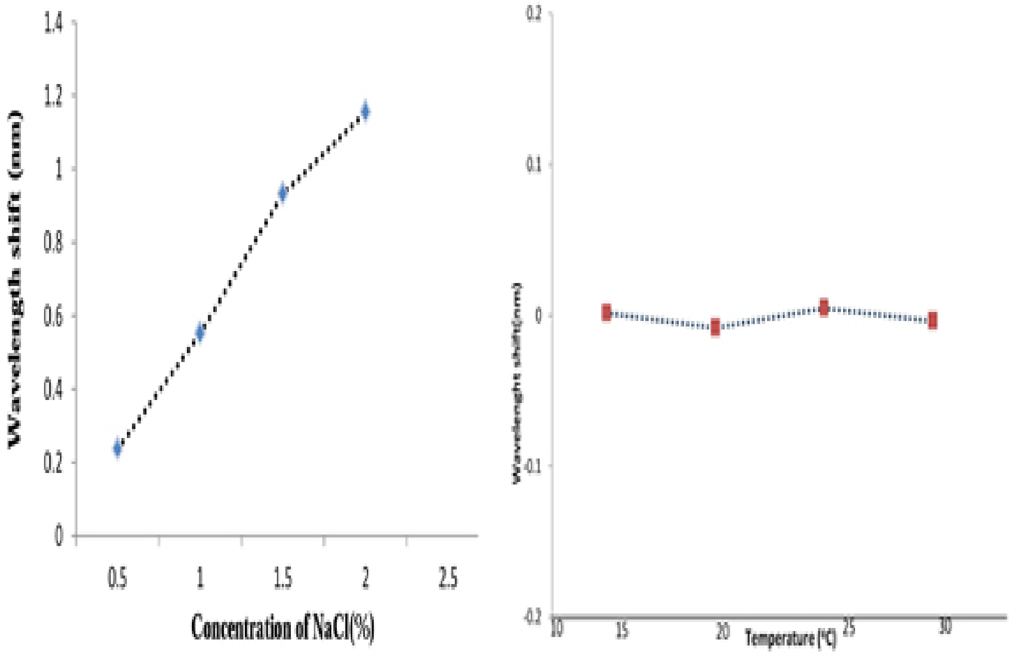

Figure A3.LPG Wavelength shift due to variations in concentration of NaCl at 30 ^{0}C (left) and temperature compensated Wavelength shift of the LPG due to temperature varying at 1 % concentration of NaCl (right).