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Fibre Bragg grating encapted with no-core fibre sensors for SRI and temperature monitoring

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ABSTRACT

In this work, a Fibre Bragg grating (FBG) encapted with no-core fibre (NCF) as surrounding refractive index (SRI) and temperature sensors are practically demonstrated. A FBG with 1550 nm wavelength was attached with 5 cm length of no-core fibre (NCF) is used as SRI and temperature sensing probe. The change of temperature and SRI induced the wavelength shift in FBG. The wavelength shift in FBG reacts directly proportional to the temperature with a sensitivity of while the sensitivity of NCF was measured as 13.13 pm °C^{-1}.

Introduction

Optical fibre sensing has attracted great research attention due to the unique properties of the photon that able to remedial the shortcomings of the electron. The effort has been expanding to various sensing elements, including temperature, strain, surrounding refractive index (SRI), curvature, displacement, pressure, and other [1]. Among the sensing elements, SRI and temperature sensing are an important area due to the potential application in biology and chemistry. To date, there are some works have reported in temperature and SRI sensing with the techniques of single sensing element or multiple sensing elements [2]. For instance, IST-MZ interferometer, LPG refractometer, and Michelson interferometer [3] have been utilized as optical based SRI sensor. The proposed system provided a solution for optical based SRI sensing, but not able to perform simultaneous temperature sensing. As have been accepted generally, SRI is temperate dependant parameter, hence, temperature effect should not be neglected in SRI sensing. In optical sensing, the free spectral range (FSR) change or wavelength shift are able to be observed through the variation of both SRI and temperature. As a result, it is favourable to measure SRI and temperature in the same time. In this work, an FBG-NCF based interferometer for simultaneous measurement of SRI and temperature [4]. The wavelength of propagating light in FBG-NCF experienced consistent variation against the changes of SRI and/or temperature of the ambient material vary. The obtained results are well agreed with the theoretical analysis [5,6]. The proposed solution provides a compact, ease of implementation system that able to sense both SRI and temperature. Moreover, the proposed system stands a great feasibility in biology and chemical sensing application.

Theory

A short length of NCF is sandwich between the single-mode fibre (SMF) and an FBG using fusion splice. When the light source is propagating in NCF through the SMF, the mode field mismatch able to induce multimode in the NCF. The multiple modes that exhibited different longitudinal propagation further induced multimode interference (MMI). Eventually, the MMI formed the fourth self-image of input light in NCF. The lasing oscillation wavelength is related to MMI characteristic with equation [7]:

$$\lambda_0 = 4\frac{n_{NCF}\,a_{NCF}^2}{L} \tag{1}$$

where L is the geometry length of the NCF, n_{NCF} is the refractive index of NCF, and a_{NCF} is the diameter of NCF. Between the splicing point of NCF and FBG, a portion of light from NCF is propagated into FBG core, and others may propagated in cladding. Both of different path are experienced reflection at particular wavelength according to the design of FBG. Eventually, this lead to the backward guided mode of the leading SMF. On the other hand, other modes that are not designed as reflective

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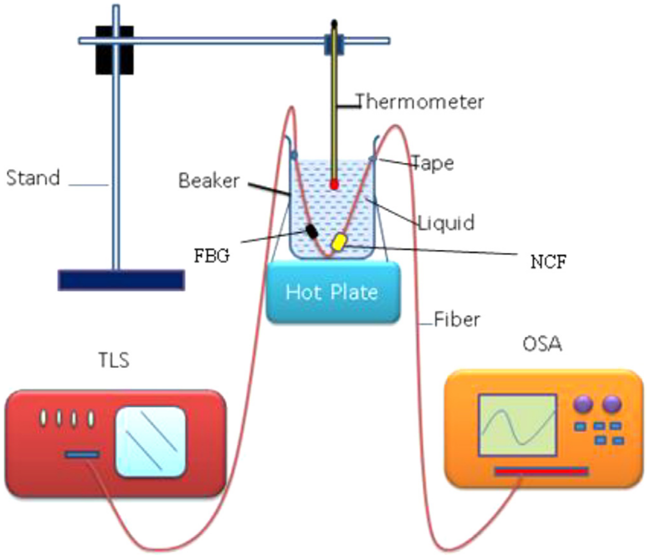
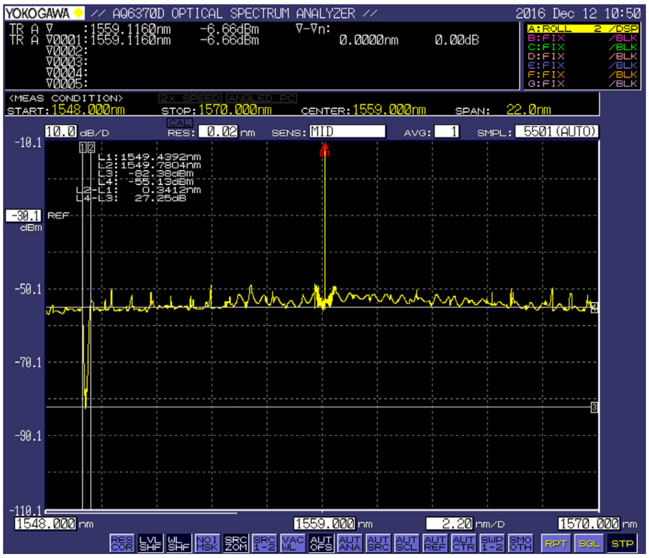


Fig. 1. Experimental set-up.



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TR A ∇     :1559.1160nm    -6.66dBm     ∇-∇n:
TR A ∇0001:1559.1160nm    -6.66dBm          0.0000nm     0.00dB
     ∇0002:
     ∇0003:
     ∇0004:
     ∇0005:
<MEAS CONDITION>
START:1548.000nm     STOP:1570.000nm     CENTER:1559.000nm     SPAN:  22.0nm
10.0 dB/D     RES: 0.02 nm    SENS: MID     AVG: 1     SMPL: 5501 (AUTO)
     L1:1549.4392nm
     L2:1549.7804nm
     L3:  -82.38dBm
     L4:  -55.13dBm
  L2-L1:    0.3412nm
  L4-L3:   27.25dB
1548.000 nm     1559.000 nm     2.20 nm/D     1570.000 nm
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Fig. 2. Initial spectra of FBG and NCF.

wavelength of FBG are propagated as core mode in SMF. These lights are then reflected at the edge of FBG-Air due to the Fresnel reflection [8] and propagated back to SMF through NCF. Due to the short length of FBG, the interference not able to induce large FSR, resulted relatively weak fringe visibility on the reflective spectra [9].

Experimental set-up and discussion

The experimental set-up is presented in Fig. 1, which consists of the proposed FBG-NCF sensor, a tunable laser source (TLS), and optical spectrum analyzer (OSA). In the experiment, the pure silica-based NCF with a core diameter of 50 µm and the refractive index of 1.457 is used as sensing probe. The FBG used in this experiment is an imprinted FBG upon an SMF with the length of 30 mm. The FBG is designed to reflect the center wavelength of 1550 nm, with a reflectivity of 97%. A 3.5 cm of NCF is joined with the FBG with a distance of 5 cm.

This is an experimentally optimized distance to achieved desired sensitivity. In the SRI sensing, the sensing probe is put into a beaker that filled with a different solution with the consistent temperature of 30 °C. For temperature sensing measurement, the sensor probe is put into a temperature-controlled liquid. In this work, 3 different type of solutions is used, which are H_2O, NaCl, and NaOH solutions. These solutions are prepared with a certain concentration that allows the refractive index (RI) of each solution to be calculated. Every time after sensing in a different solution, the sensing probe is cleaned using distilled water. Fig. 2 shows the spectrum of FBG and NCF observed in room temperature. The FBG induced filtering effect is clearly seen at a center wavelength of 1549.560 nm, whereas the wavelength of NCF is located at 1559.116 nm. As can be observed in Fig. 2, the interference between the dominant cladding mode and core mode constructed the main interference pattern. And the interference pattern is slightly modulated by the interferences between the weak cladding modes and the core mode (or other weak cladding modes).

The sensing probe is then tested in H_2O, NaCl, and NaOH solutions. The transmission spectra of the FBG and NCF sensors are recorded as 1550.076 nm and 1560.724 nm in H_2O solution, 1550.356 nm and 1565.808 nm in NaCl solution, and 1550.188 nm and 1566.456 nm in NaOH solution, respectively. Fig. 3 shows the shift of Bragg wavelength and NCF wavelength in NaCl solution at 30, 60, and 90 °C respectively. The experimental results are well agreed with the theory, as the changes of temperature, both FBG, and NCF wavelength experienced redshift.

Fig. 4 illustrates the normalized response of the FBG center

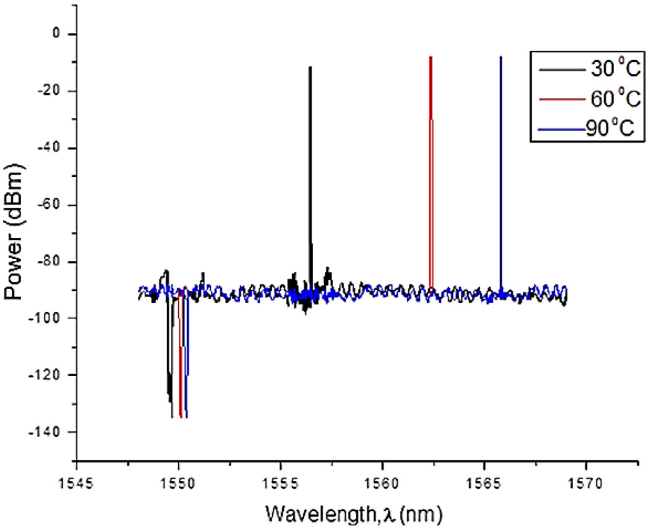

Fig. 3. FBG and NCF spectra with different temperature.

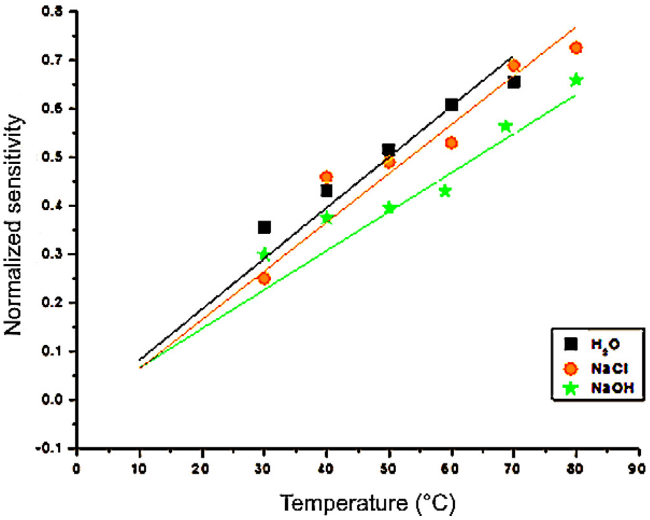

Fig. 4. Normalized response of FBG's center wavelength against temperature.

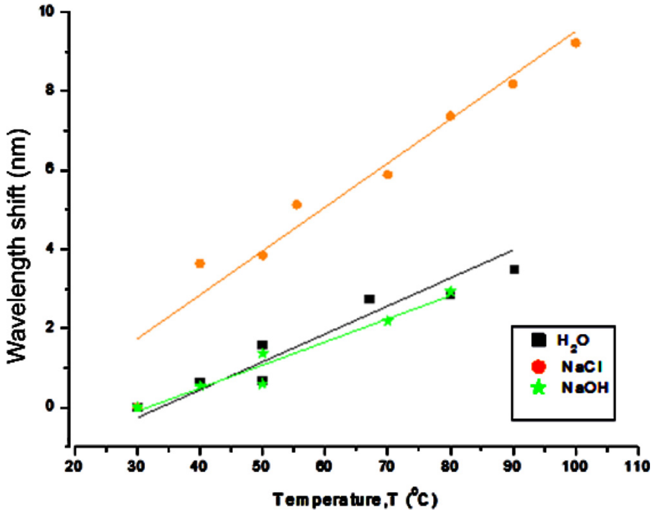

Fig. 5. Wavelength shift of NCF center wavelength against temperature.

wavelength against the change of temperature. From the variation of temperature, the sensitivity of the FBG in H_2O, NaCl, and NaOH is calculated as 10.46 pm/°C, 10.06 pm/°C, and 8.04 pm/°C respectively. On the other hand, Fig. 5 shows the wavelength shift of NCF versus temperature for 3 different types of solutions. The sensitivity of NCF is calculated as 13.13 pm/°C, 11.65 pm/°C, and 7.20 pm/°C for H_2O, NaCl, and NaOH solutions, respectively. From the experimental observation, the peak shift of FBG and NCF center wavelength highly depends upon the peripheral parameter, particularly SRI.

As a result, the different sensitivity in the different liquid is able to use to estimate the SRI. Hence, the proposed design is highly potential to allow simultaneous multi-parameter sensing applications.

Conclusion

In this work, a novel and high feasibility interferometer that combined FBG and NCF are proposed and practically demonstrated for SRI and temperature sensing. The proposed design consists of an FBG and joined with a section of NCF that function as a multimode interferometer. From the experimental observation, the center wavelength of FBG and NCF experienced redshift with the increase of temperature. From the sensitivity of the FBG and NCF against the temperature, SRI is able to be estimated. Furthermore, the proposed sensing probe also carries a great feasibility to perform simultaneous multi-parameter sensing.

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