Optical fibre temperature and humidity sensor

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We have characterised an optical fibre sensor system for humidity and temperature, comprising two Bragg gratings recorded in silica and polymer fibre. The response of this system is very well conditioned (2-norm condition number = 8.8) and consequently uncertainties in wavelength measurement do not lead to large errors in the recovered humidity and temperature.

Introduction: Over the last two decades, fibre Bragg grating (FBG) sensors inscribed in silica optical fibre have become an increasingly mature sensing technology, especially for strain and temperature monitoring [1]. More recently, FBG sensors have been inscribed into polymer optical fibre (POF) in both step-index [2] and microstructured geometries [3]. POF is often based on poly(methyl methacrylate) (PMMA) and one feature of this material is its affinity for water, which leads to a swelling of the fibre and an increase of index, both of which contribute to an increase in the Bragg wavelength of a FBG written in the fibre [4]. This is a potentially very useful property, which has been applied, for example, to quantifying the small amount of water present in aviation fuel [5]. When POF FBGs are applied to humidity sensing, an important issue is the cross-sensitivity to temperature. In this paper we quantify these sensitivities, and describe a dual parameter sensor comprising FBGs inscribed in both silica and polymer fibre which provides a well conditioned response to the two parameters.

Experimental: The dual parameter sensor was fabricated by attaching a 10cm length of POF to a single mode silica fibre down-lead using UV curable glue (Norland 76). The PMMA based POF contained a 5 mm long FBG, fabricated by illuminating from above a phase mask of period 1.057 μm placed on top of the POF using 325nm light from a HeCd laser. The initial Bragg wavelength of 1565 nm was reduced to 1542 nm by annealing the fibre [6]. A second FBG had been inscribed 4 cm from the end of the silica fibre with 244 nm UV light from a frequency doubled CW Argon laser, again using the standard phase mask approach.

Due to the high attenuation of POF at the wavelengths used (around 1dB/cm) the silica FBG was fabricated with a reflectivity of about 4%, which allowed similar levels of signals to be obtained from the two gratings when they were illuminated with light from a broadband light source and observed in reflection using an IBSEN I-MON 400 wavelength interrogation system, see Fig. 1.

The sensor was placed inside an environmental chamber (Sanyo Gallenkamp) for characterisation. Previous research had shown that for this fibre, the diffusion time for water to reach the core was about 30 minutes and so each reading was taken 30 minutes after the humidity was changed by 5%. Fig. 2 shows the response at 25 ℃ of both sensors to humidity in the range 50-95%, where the environmental chamber had greatest stability. The humidity sensitivity of the POF appears to be linear over this range and linear regression (illustrated in the figure) returned a sensitivity of 35.2±0.4 pm/%. It may also be seen that the silica fibre showed some sensitivity to humidity, amounting to just 0.28±0.01 pm/%, probably as a result of the FBG being recoated with polymer following inscription.

The temperature response of the two sensors at a constant 50% humidity is shown in Fig. 3. The sensitivities returned by linear regression are 13.9±0.3 pm/℃ for the silica FBG and -55±3 pm/℃ for that in POF. The negative slope in the case of POF is due to the dominance of the contribution of the thermo-optic effect to the wavelength shift over that due to thermal expansion.

Discussion: The operation of a dual parameter sensing scheme such as that described here is dependent on a transformation $\mathbf{X} = \mathbf{K}^{-1}.\mathbf{L}$, where **L** is a two element column vector of the wavelength shifts measured from the two gratings, **X** is a two element column vector of the humidity and temperature change experienced by the gratings and $\mathbf{K}^{-1}$ is the inverse of **K**: a 2x2 matrix containing the grating sensitivities quoted earlier. Key to the successful operation of the technique is the degree to which **K** is well conditioned [7]. As may be anticipated from the responses shown in Figs. 2 and 3, this is a well conditioned problem with the condition number calculated from the 2-norm of **K** being only 8.8. Such a low value for the condition number is reflected in the way in which errors in the measurements of the Bragg wavelength contribute to the uncertainty in the measurands. As an example, a very modest resolution of 10pm in the measurement of the Bragg wavelength of the silica grating would contribute an error of only 1.1 % relative humidity or 0.7 ℃.

Conclusion: We have demonstrated a compact optical fibre Bragg grating based humidity and temperature sensor element. The use of silica and polymer FBGs leads to a well conditioned response.

References

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Figure captions:

Fig. 1 Spectra returned from sensing gratings. In each case the POF FBG is at the longer wavelength.

Fig. 2 Humidity response of the sensors. Note the very different scales on the ordinate axes.

Fig. 3 Temperature response of the sensors.

Figure 1

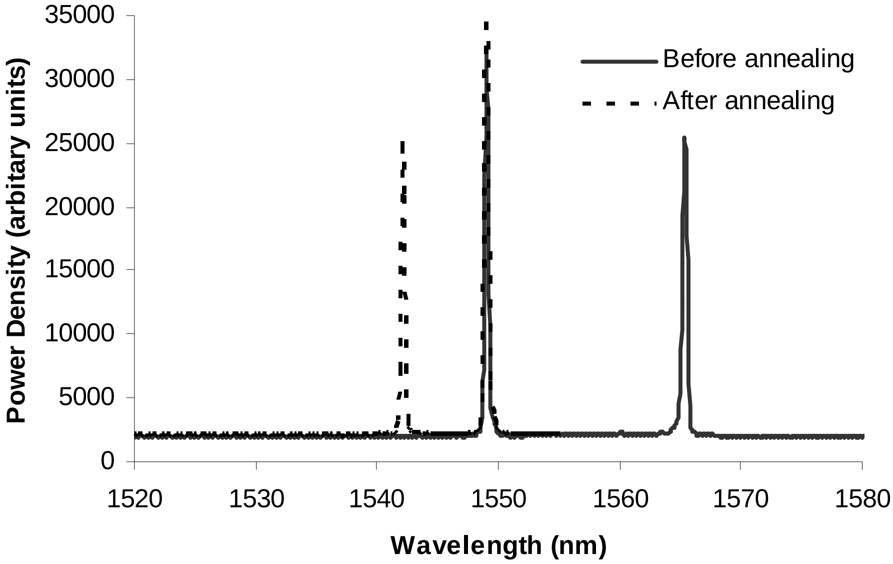
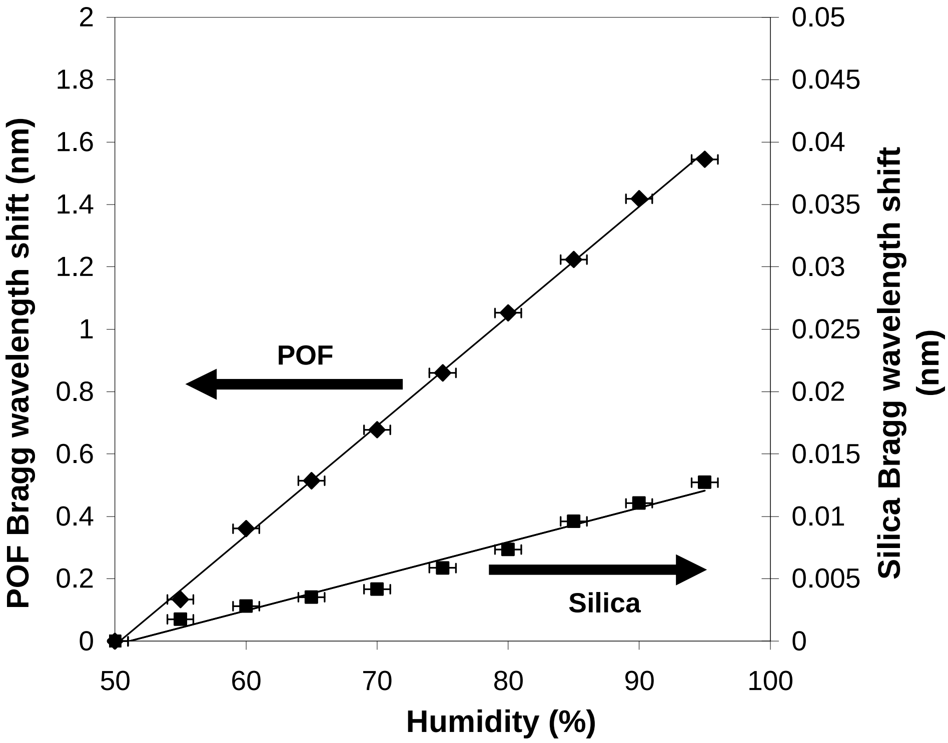
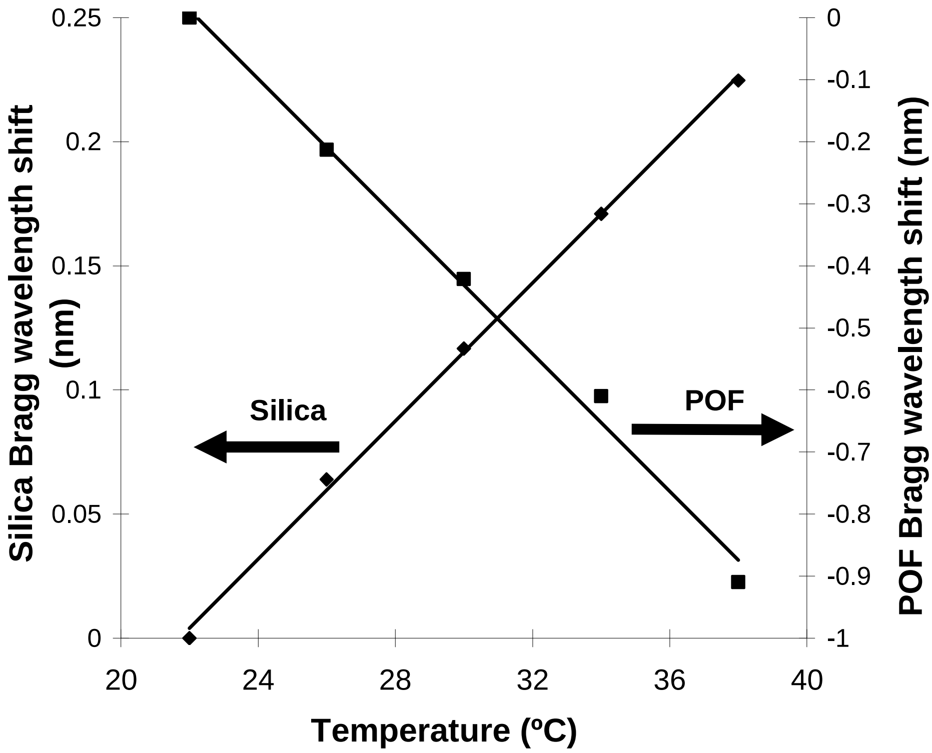

35000
30000
25000
20000
15000
10000
5000
0
Power Density (arbitary units)
1520
1530
1540
1550
1560
1570
1580
Wavelength (nm)
Before annealing
After annealing

Figure 2



2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
POF Bragg wavelength shift (nm)
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Silica Bragg wavelength shift (nm)
POF
Silica
50
60
70
80
90
100
Humidity (%)

Figure 3



Silica Bragg wavelength shift (nm)
POF Bragg wavelength shift (nm)
Temperature (ºC)
Silica
POF
0.25
0.2
0.15
0.1
0.05
0
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
20
24
28
32
36
40