Temperature characterisation of long period gratings for sensor applications

O'FLAHERTY, Fin <http://orcid.org/0000-0003-3121-0492>, GHASSEMLOOY, Z., MANGAT, P. S. <http://orcid.org/0000-0003-1736-8891> and DOWKER, K.

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TEMPERATURE CHARACTERISATION OF LONG PERIOD GRATINGS for SENSOR APPLICATIONS

F.J. O'Flaherty,[1] Z. Ghassemlooy,[2] P.S. Mangat,[1] K.P. Dowker[3]

[1]Centre for Infrastructure Management, Sheffield Hallam University, Sheffield S1 1WB, UK

[2] Optical Communications Research Group, School of Engineering and Technology, The University of Northumbria, Newcastle, NE1 8ST, UK

[3] Health and Safety Executive, Sheffield, S1, UK

ABSTRACT: *Long period grating proposed as a sensor display sensitivity to ambient temperature variations. Therefore full temperature characterisation is essential. In this paper the temperature effects on the spectral profiles of two sets of long period gratings (LPGs) of different periods are investigated. The results obtained show that the shorter period LPGs were found to be less sensitive than the longer period LPGS over identical temperature ranges. The coupling wavelength shifts due to temperature are also seen to be linear and in opposite directions in each set of LPGs.*

Key words: *Long period gratings, sensors, temperature, concrete deterioration*

1. INTRODUCTION

There is widespread use of optical fibre technology in infrastructure monitoring to date, mainly for strain monitoring but more recently, they have been used to monitor corrosion in reinforced concrete structures. For example, fibre optic sensors have been embedded in several newly constructed civil structures, including bridges, buildings and dams yielding information about static and dynamic strain, temperature, wind or water pressure and structural health [1]. A multiplexed Bragg grating optical fibre monitoring system was designed and integrated at the construction stage in an experimental full-scale laboratory bridge. The network of sensors was used to measure the strain throughout the bridge, with sensors bonded to the tension steel in the slab, and attached to the bottom flange of the girders [2].

Long period gratings written in optical fibres are becoming increasingly important in fibre optics communications and optical sensing. LPGs were first presented by Versangkar et al as optical filters in 1995 [3]. LPGs are made by illuminating photosensitive fibres with intense UV light in order to create a periodic increase in the refractive index of the core along the length of the fibres. The fundamental mode travelling in the core is diffracted by the gratings and is excited to cladding modes, which are quickly attenuated. Hence, loss bands or resonance bands are observed in the transmission spectrum. The transmission spectra of LPGs have been shown to be sensitive to changes in index of refraction of the medium surrounding the fibre cladding (ambient refractive index) in the vicinity of the LPG [4-6] and also to changes in the ambient temperature [7]. Changes in the coupling wavelengths from the core modes to the various cladding modes due to changing ambient refractive indices using index-matching gels have been reported in [8]. This investigation examines the effect of the grating period on the temperature profile of an LPG. LPGs with 2 different grating periods (410 μm and 700 μm) written into the cores of identical monomode fibres have been utilised and comparisons between the 2 sets of temperature profiles have been made in order to ascertain the possibility of achieving temperature immunity in a single refractive index sensing LPG.

2 EXPERIMENTAL PROCEDURE

3 different LPGs were tested to establish their temperature characteristics. The LPGs are referred to as fibres A, B and C and the specifications of each are given in Table 1. Fibres A and C each exhibited one loss band at 1551.2 and 1566.6 nm, respectively when tested at 24°C, whereas two loss bands were observed at 1304.0 and 1557.3 nm for Fibre B. The temperature response of the LPGs was determined with either air or water as the ambient

medium. In both cases the wavelength shifts was determined using an optical spectrum analyser that had two built-in LEDs centred at 1310 nm and 1550 nm.

2.1 Temperature Response in Air

To determine the temperature response in air, the set-up shown in Figure 2 was adopted. Fibres A, B and C were each tested in turn. The fibres were held straight between two holders with the gratings passing through an oven in the set-up (Figure 2). Varying the applied voltage using a stabilised power supply controlled the temperature of the oven. The oven temperature was increased to 64°C and the corresponding locations of resonance bands were periodically recorded as the temperature dropped. A decrease in temperature was achieved by reducing the applied voltage. Results are given in Section 3

2.2 Temperature Response in Water

The temperature response of the fibres in water was determined through the use of a water bath as shown in Figure 3. Again, the LPG was kept taut between two clamps with the gratings submerged in the hot water (maximum temperature 40°C). The resonance wavelengths were recorded as the water-cooled to room temperature. Cold water was added to further reduce the temperature to 8°C. The wavelengths of the resonance bands were again periodically recorded using an optical spectrum analyser (OSA) as the temperature decreased and are presented in Section 4.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Temperature Sensitivity in Air and Water

The datum resonance wavelength for Fibre A was 1551.2 nm at 24°C (room temperature). The maximum air temperature employed was 64°C and the minimum was 24°C. The shift in wavelength due to a reduction in air temperature was recorded and is shown in Figure 4 (Graph α). A temperature coefficient of -0.2569 nm/^{o}C was obtained for Fibre A from the best-fit equation of the line. The same fibre (LPG A) was tested for temperature response with water as the ambient medium instead of air. The temperatures ranged between a high of 40°C and a low of 8°C. Graph β (Figure 4) shows the temperature response of the LPG. The temperature coefficient was found to be -0.2429 nm/^{o}C that is similar to the temperature coefficient when tested in air. In practice, the index of refraction of most fluids reduces with an increase in temperature. Since LPGs are sensitive to the external index changes [6], a wavelength shift due to the thermal-induced refractive index will occur and this will add to the temperature sensitivity of the grating. Therefore, a higher temperature coefficient for water would be expected. However, the change in temperature involved in this experiment was too small too cause any significant change in the two temperature coefficients.

3.2 Positive and Negative Temperature Responses

The temperature response, with air as a medium, was repeated using LPG B in the 1550 nm wavelength region to allow comparisons to be made with the test results in air from LPG A. The air temperature ranged between 63.5°C and 24°C as shown in Figure 5 and Table 2. The temperature coefficient obtained from the best-fit line in Figure 5 was +0.0595 nm/^{o}C. This positive temperature coefficient implies that the grating is operating in the normal region. However, the temperature coefficient obtained for LPG A (Figure 4, Graph α) was negative (-0.2429 nm/^{o}C) and this implies that LPG A was operating in the anomalous region at the wavelength considered [7]. Hence, it is shown that the temperature profile of LPGs can be both positive and negative depending upon the characteristics of the gratings at the wavelength considered. The temperature coefficient for LPG B (+0.0595 nm/^{o}C) is one order of magnitude lower that that for LPG A (-0.2569 nm/^{o}C). Hence, LPG B is less affected by temperature variations and can therefore be used for purposes, which require the LPG to remain unaffected by small changes in temperature.

3.3 Temperature Sensitivity of Different Resonance Bands

A major advantage of LPGs is the presence of multiple resonance bands, which can be used for multi-parameter sensing [7]. In the current investigation, LPG B exhibited two resonance bands at 1304.0 and 1557.3 nm and their response to variations in air temperature is presented. The temperature coefficient for LPG B in the 1550 nm band when tested in air is +0.0595 nm/^{o}C (see Figure 5). The shift in the resonance wavelength at 1304 nm for the same fibre (LPG B) when also tested in air is shown in Figure 6. The temperature coefficient obtained was +0.0505 nm/^{o}C (Figure 6), which is very similar to that obtained for 1550 nm resonance band (+0.0595 nm/^{o}C, Figure 6). This shows that lower order bands can be as sensitive to temperature variations as higher order bands. Hence, in multi-parameter sensing, lower order bands can be used to monitor temperature changes while higher order bands can be used to detect external index changes [7].

3.4 Bend-Induced Spectral Changes

LPG C was used in the water bath to determine its response to the temperature variations. The water temperature ranged between 27 ^{o}C and 48 ^{o}C. In this test, the clamps did not tension the LPG. The response to temperature variations shown in Figure 7, display a linear relationship at higher temperatures (between 33 ^{o}C and 48 ^{o}C). However, at lower temperatures (27 ^{o}C to 33 ^{o}C), two dips were observed on the spectrum analyser and the temperature response was no longer linear (Figure 7). This is probably due to bend-induced spectral changes that occurred when testing at lower temperatures. This depicts the importance of keeping the fibre taut when using LPGs.

4. CONCLUSIONS

In this paper it has been shown that LPGs temperature coefficients for water and air are similar, and they exhibit both positive and negative temperature profiles depending on whether they are operating in the normal or anomalous region. The direction of the temperature gradient of an LPG is found to depend on the period of the grating, for fibres with identical optical and physical properties. LPGs can be used for multi-parameter sensing since low order bands are as sensitive to temperature as high order bands

6. ACKNOWLEDGEMENTS

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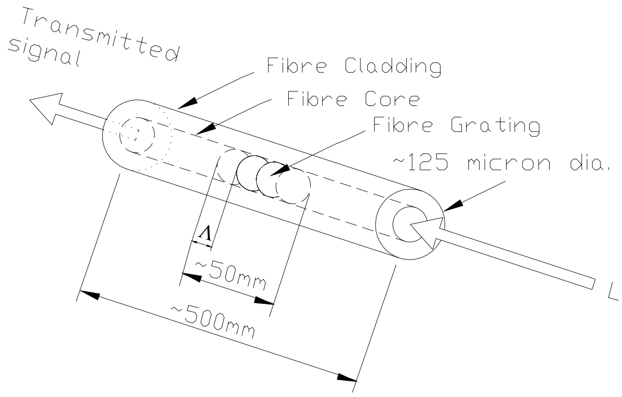

Figure 1 Schematic diagram of the LPG fibre sensor

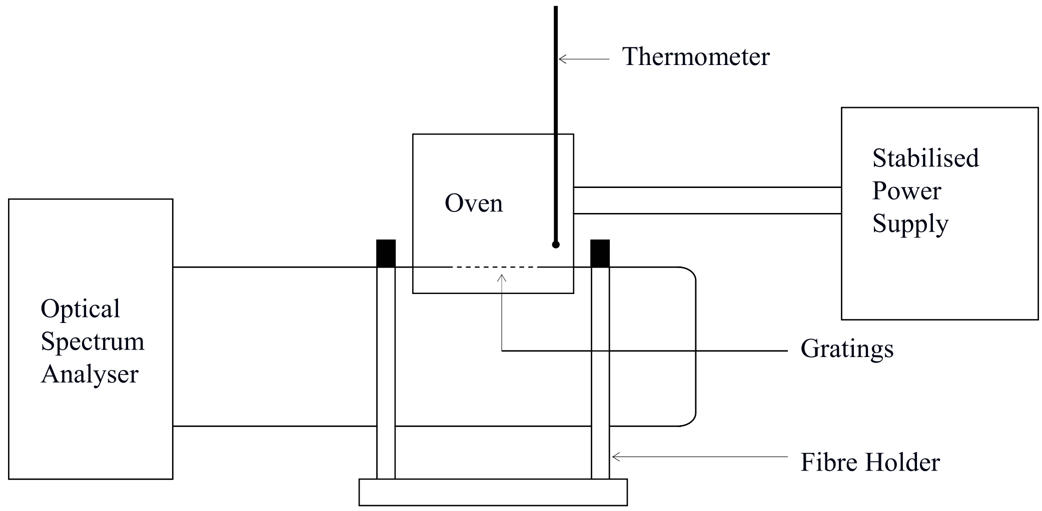

Figure 2 Experimental set-up for temperature response of LPGs in air

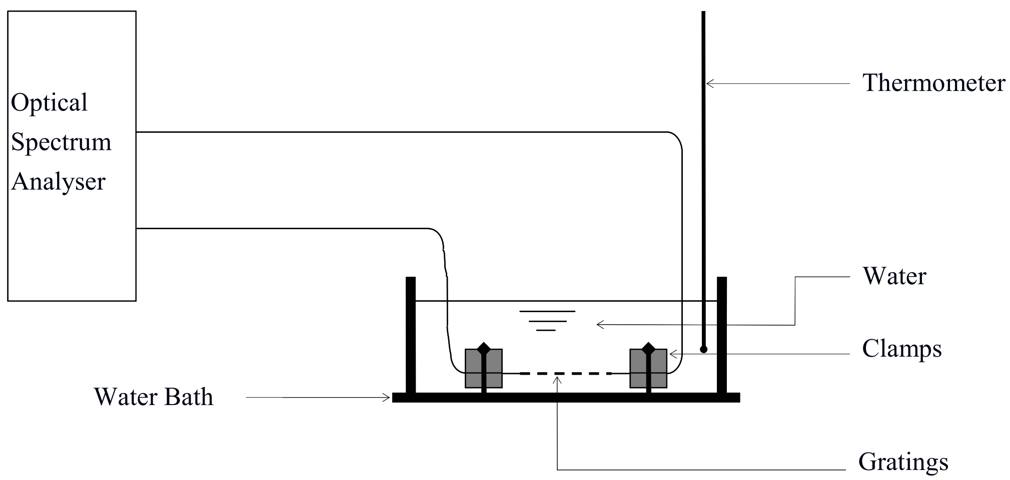

Figure 3 Experimental set-up for temperature response of LPGs in water

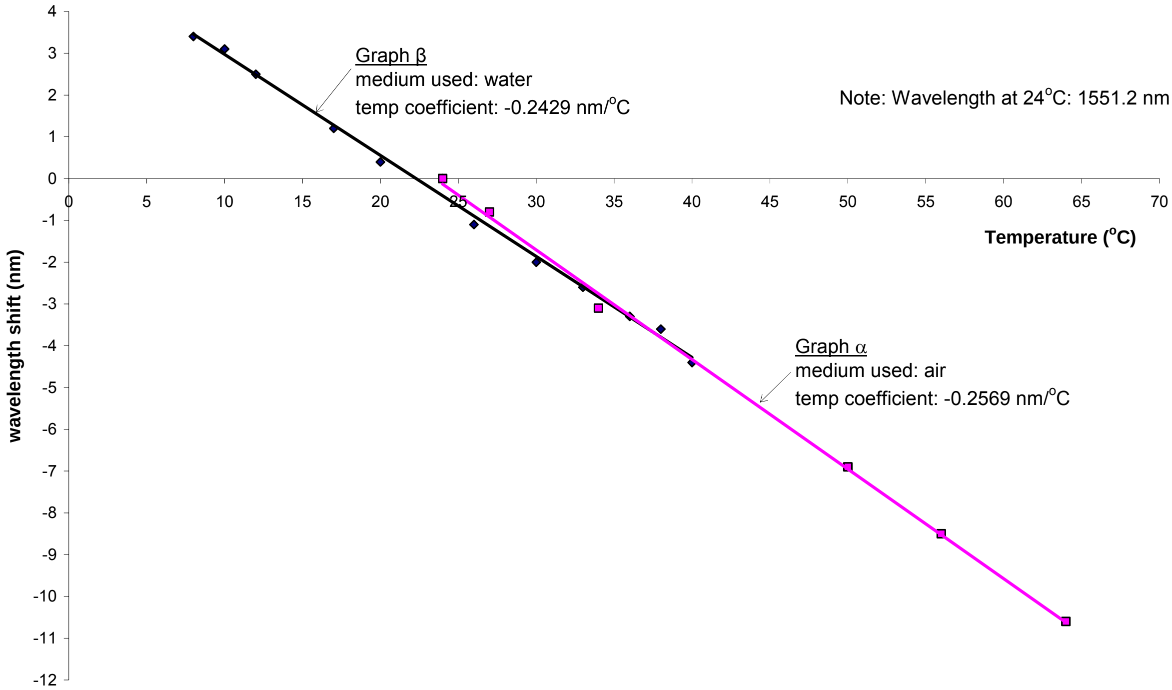

Figure 4 Wavelength shift in Fibre A due to temperature variations

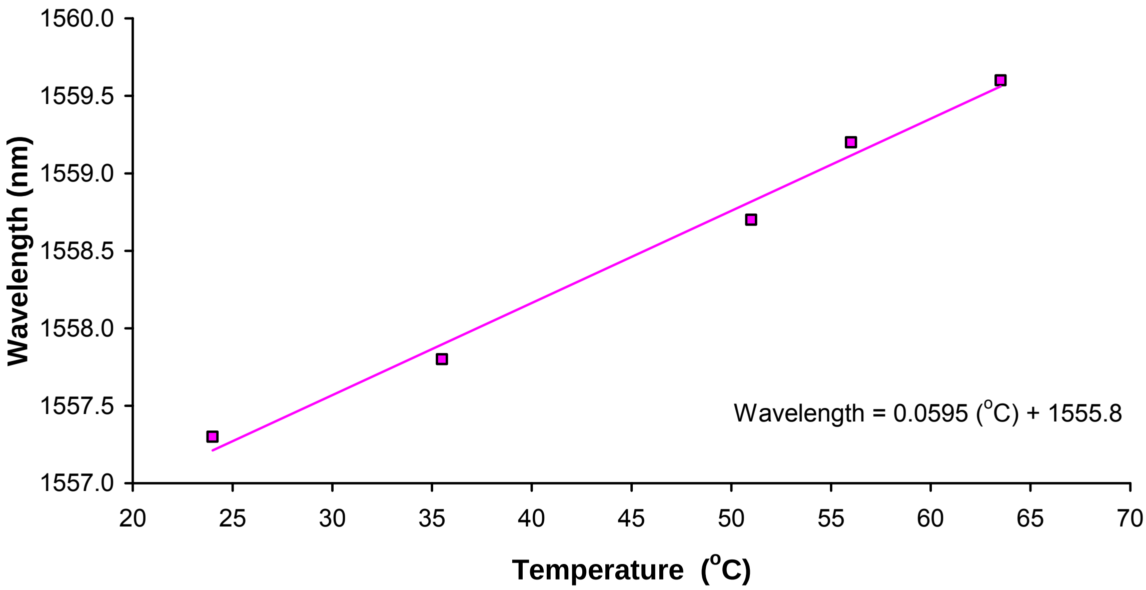

Figure 5 Temperature profile of LPG B in air (1550nm region)

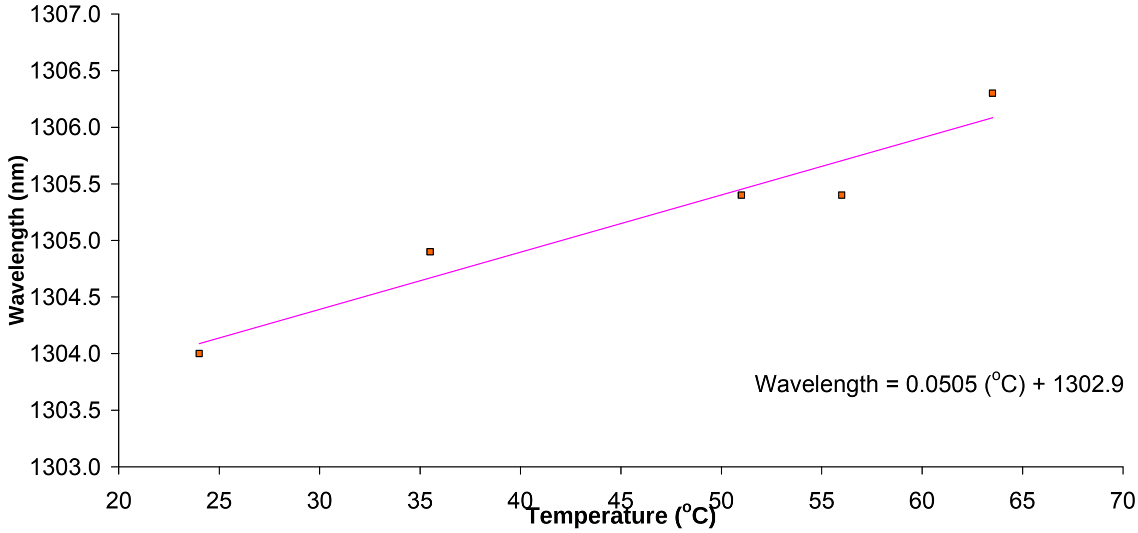

***Figure 6** Temperature profile of coupling wavelength of LPG B in air (1310nm region)*

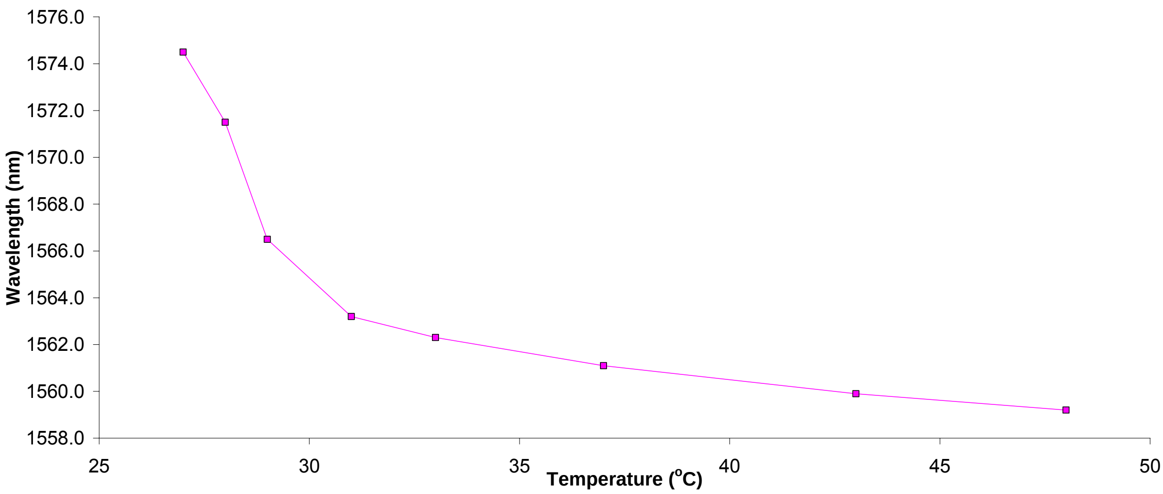

Figure 7 Graph of wavelength against temperature for Fibre C when tested in water

TABLE 1 Specification of LPGs

Fibre	Core Refractive index	Cladding Refractive index	Grating Period, Λ (μm)	Resonance Wavelength in Air 24°C (nm)
A	1.4499	1.4441	700	1551.2
B	"	"	410	1304.0 & 1557.3
C	"	"	700	1566.6

TABLE 2 Temperature results for LPG B in air (1550nm region)

Temperature (°C)	**Resonance wavelength (1550 nm region)**
63.5	1559.6
56	1559.2
51	1558.7
35.5	1557.8
24	1557.2