Period dependent temperature and ambient index effects on long period fibre gratings

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

Published version

DOWKER, P., GHASSEMLOOY, Z, RAY, A.K., O'FLAHERTY, Fin and MANGAT, Pal (2003). Period dependent temperature and ambient index effects on long period fibre gratings. In: PROSSER, S. J. and LEWIS, E., (eds.) Sensors and Their Applications. CRC Press.

Period Dependent Temperature and Ambient Index Effects on Long Period Fibre Gratings.

K.P. Dowker[1], Z.F. Ghassemlooy and A.K. Ray

Electronics Research Group, School of Engineering, Sheffield Hallam University, City Campus, Sheffield S1 1WB, UK.

F.J. O'Flaherty and P.S. Mangat

Centre for Infrastructure Management, Sheffield Hallam University, City Campus, Sheffield S1 1WB, UK.

Abstract. The ambient index and temperature effects on the spectral profiles of two sets of long period gratings (LPGs) of different periods were investigated. The shorter period LPGs were found to be more sensitive than the longer period LPGs over identical ambient index ranges but less sensitive 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 and unlike the ambient index shifts there seems to be no obvious modal dependency with respect to sensitivity in any individual LPG. The conclusion to this investigation is that it may be possible to design an LPG of such a period that parts of the spectral profile are unaffected by temperature whilst maintaining a reasonable ambient index sensitivity.

1. Introduction

In recent years, fibre gratings have been extensively investigated for their applications as a variety of sensors [1,2]. The transmission spectra of long period gratings (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 [3-7] and also to changes in the ambient temperature [8,9]. 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 the subject of many reports [10,11]. This investigation examines the effect of the grating period on the temperature profile of an LPG. LPGs with 2 different grating periods (450μm and 700μm) written into the cores of identical monomode fibres have been utilised and comparisons between the 2 sets of temperature profiles and ambient index profiles have been made in order to ascertain the possibility of achieving temperature immunity in a single refractive index sensing LPG.

---

[1] Present address: Health and Safety Executive, Broad Lane Sheffield S3

2. Experimental Procedure

The six fibre gratings utilised were of the same material and optical and physical parameters before the gratings were written into the respective cores. The grating period of fibres numbered 1 to 4 is 700μm and numbers 5 and 6 is 450μm. All spectral profiles were observed and recorded using a HP 86142A Optical Spectrum Analyser (OSA), the light source used being the 1300nm and 1550nm internal EELED sources of the OSA. The ends of each fibre were connected into the light source and detector inputs of the OSA using bare fibre connectors. The transmission spectra of all of the LPGs were recorded in air at room temperature before any experiments were undertaken. Spectral profiles of each fibre grating were taken using a range of index matching gels. Temperature spectral profiles were taken by placing the grating section under slight tension in a purposely designed heat chamber and recording the spectra at selected temperatures from room temperature to a maximum of around 80°C.

3. Results and Discussion

The transmission spectra at room temperature in air are shown in Figure 1 for gratings with periods of 700μm and 450 μm respectively.

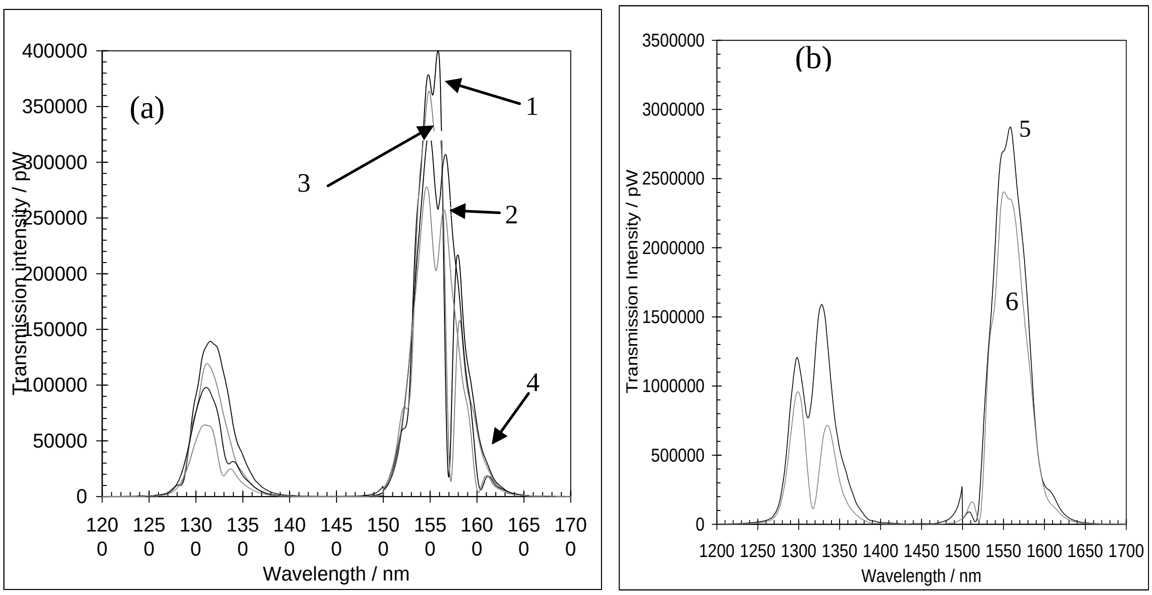

Figure 1: Spectral Profile of (a) 4 LPGs with Periods of 700mm (numbered 1-4) and (b) 2 LPGs with Periods of 450mm (numbered 5-6) at 300K.

The wavelengths at which coupling will occur is written in the form [5]

$$\lambda_{(i)} = \left(\beta_{core}^{(i)} - \beta_{clad}^{(i)}\right)\frac{\Lambda}{k} \qquad (1)$$

where the propagation constants (β) are quoted as functions of the mode number i and coupling wavelength λ, k is the wave number ($2\pi/\lambda$) and Λ is the grating period. Coupling was evident in each fibre at the different wavelengths as summarised in Table I.

Table I: Optical and physical parameters and coupling wavelengths of all six LPGs

core refractive index (n_{core})		cladding refractive index (n_{clad})			core radius (r_{core})		cladding radius (r_{clad})
1.4499		1.4441			3.9μm		62.5μm
LPG No	Λ/ μm	Coupling λs / nm					
1	700				1552.75	1570	
2	700	1285.5		1525.5	1556.5	1572	
3	700		1335		1558.5		1604
4	700		1329.5		1556		1601.5
5	450		1311.5	1516	1550		
6	450		1317.5	1520	1558		

Thus, identical fibres underwent identical writing procedures but the wavelengths at which coupling occurs differs in each grating of the same period. The propagation constants of the cladding modes will change with the ambient refractive index around the cladding, resulting in a shift in coupling wavelengths, the sensitivity increasing with mode number [12]. The ambient refractive index spectral profiles of all 6 fibres shown in Figure 3 showed shifts to shorter wavelengths for each modal coupling as the ambient refractive index was increased. All showed the degree of shift in coupling wavelength to increase as the ambient refractive index approached that of the cladding. The coupling wavelengths showed a positive shift to values greater than in air as an ambient refractive index of 1.452 was exceeded. It has been previously suggested that the process of writing the grating in the core has increased the refractive index of the cladding around the grating from its original value of 1.4441 to at least 1.452 [5]. The core index must also have increased to a value greater than 1.452 for guided modes to exist in the core, which will have a considerable effect on the initial core and cladding modes. The fibres in the period range used in most previously reported experiments of 450μm period, react as predicted by theory. The longer wavelengths coupling to the higher order cladding modes are more sensitive to ambient index changes than the shorter wavelengths. Two of the fibres containing the longer period of 700μm, LPG 1 and LPG2, responded as expected with the longer wavelengths generally showing greater sensitivity to the ambient index changes, however, LPG3 and LPG4 showed the shortest coupling wavelength to be around 6 times more sensitive than the longer ones. The high sensitivity of this wavelength suggests that this may be a higher order of diffraction (-2 order) of the grating period as reported by [9] and is actually coupling to a much higher cladding mode than the wavelengths in the 1500 to 1600nm region.

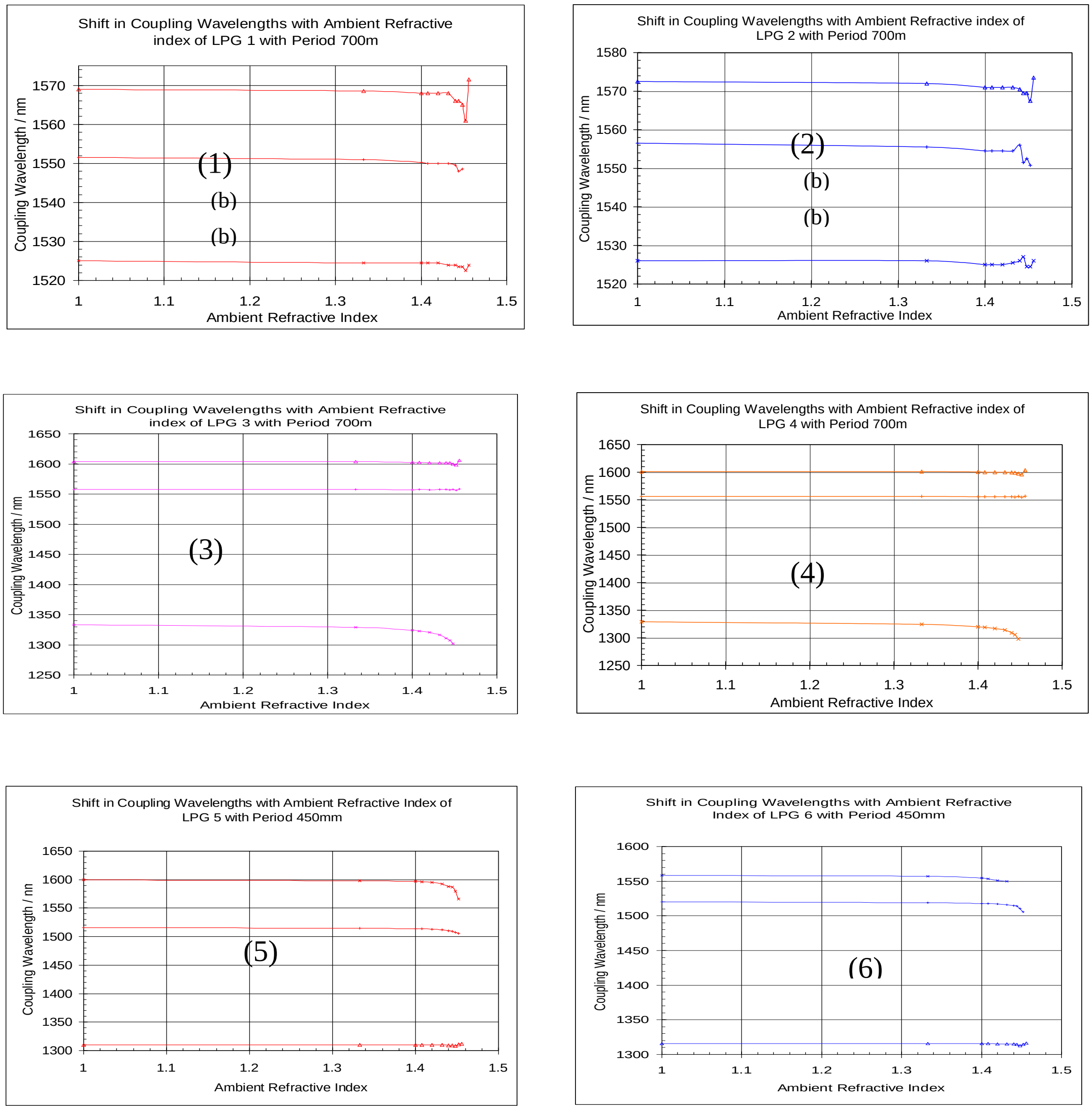

Figure 3: Coupling wavelength shifts of LPGs with Ambient Index

In the gratings with the 450μm period the cladding modes into which the respective wavelengths are coupling will be a higher order than for the gratings with the 700μm period. This would explain the greater sensitivity of the shorter period gratings to the ambient refractive index, as sensitivity is known to increase as the coupling mode increases.

The shifts due to the change in temperature for all 6 fibres are shown in Figure 4. The main feature of this investigation is the fact that all of the LPGs with 700μm periods have a negative temperature profile whilst all of the LPGs with 450 μm periods have a positive temperature profile. Differentiating equation 1 with respect to temperature shows the combined period and refractive index dependency on temperature [8]:

$$\frac{d\lambda}{dT} = \frac{1}{k}\left[\frac{d\lambda}{d(\delta\beta)}\left(\frac{d\beta_{core}}{dT} - \frac{d\beta_{clad}}{dT}\right) + \Lambda\frac{d\lambda}{d\Lambda}\frac{1}{L}\frac{dL}{dT}\right] \qquad (2)$$

where L is the length of the grating. The increase in temperature will cause expansion of the fibre and hence an increase in the grating period. This will result in smaller diffraction angles of all wavelengths and an increase in the wavelength which will match the coupling conditions for the first mode, and thus subsequent modes. It follows therefore that this effect will tend to cause the coupling wavelengths in each cladding mode to undergo a red shift. The directional shift of the coupling wavelength due to the change in refractive indices of the core and the cladding caused by the temperature change is not as obvious from Equation (1). Firstly, the increase in grating period due to the temperature increase would result in coupling to longer wavelengths. As these new wavelengths have their own individual modal core and cladding paths and as the propagation constants are dependent on the modal path this factor will itself cause different propagation constants in both media to be considered.

For the LPGs used in this investigation it is shown that an increase in the ambient index from that of air to values approaching that of the cladding will cause the core to cladding mode coupling wavelengths to undergo a blue shift. The magnitude of these blue shifts increase with cladding mode order and the and the sensitivity increases to an exponential approximation in all modes as the ambient index approaches that of the cladding. Compensating methods have been reported [13,14] including a combination of a number of LPGs or by the combination of LPGs and other sensing mechanisms, each of which has inherent limitations. Compensation systems employing only LPGs include the use of a 2nd fibre with an optically identical grating as a control to reduce the unwanted effect, and fibres containing 2 identical gratings in the same core. However, the production of 2 identical gratings is very difficult, as is shown in this investigation. Other limitations relate to the exact positioning of the 2nd LPG to receive the identical effects of the unwanted measureand in the first system and the fact that the radiation coupled out of the core into the cladding at the first grating may be coupled back into the core at the second grating in the second system. It will therefore have a much reduced intensity loss at the output of the fibre.

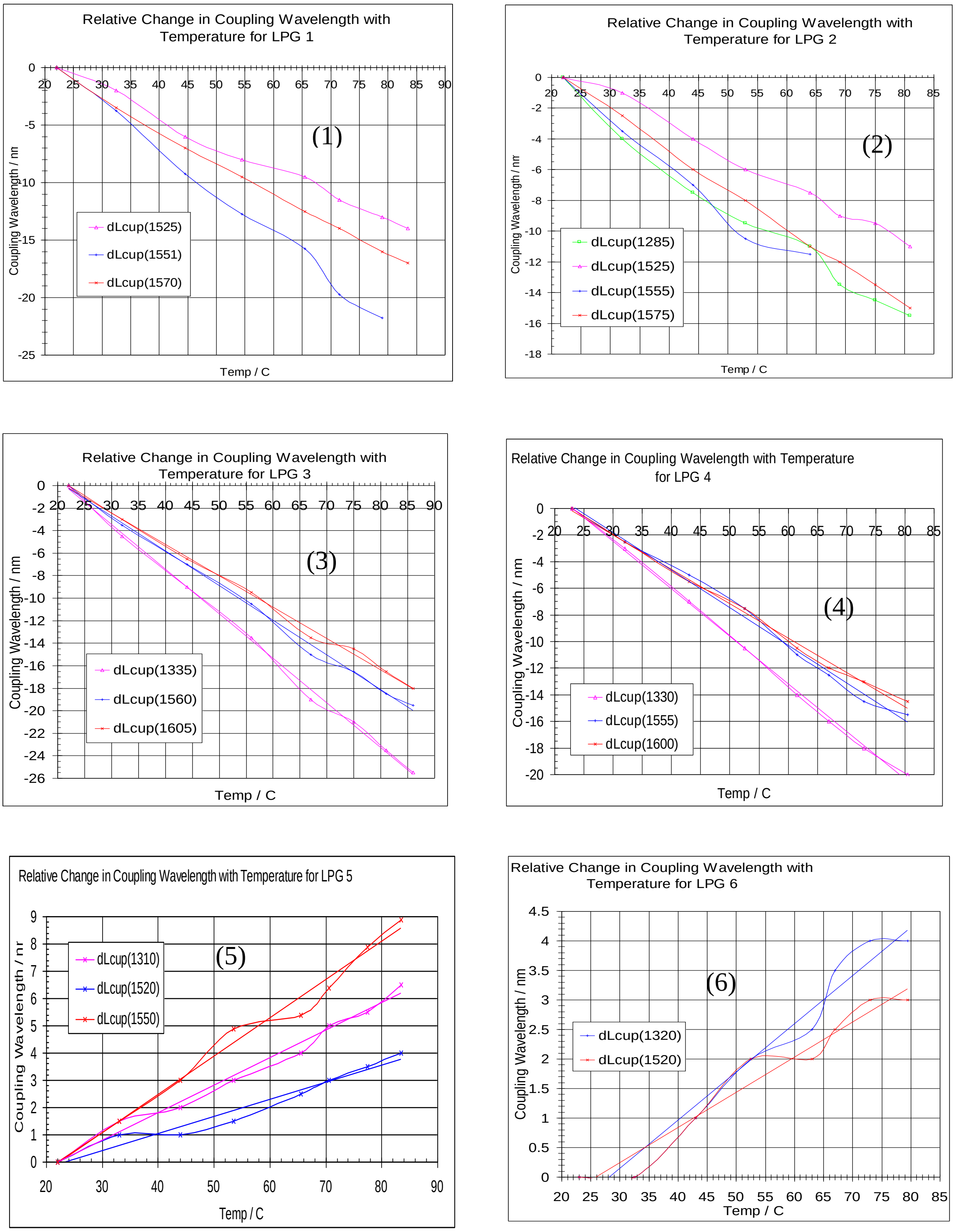

Figure 4: Coupling wavelength shifts of LPGs with Temperature

4. Conclusion

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. If the fractional increase of the period is sufficient the temperature effects on the period become more significant and may overcome the effects of the refractive index changes. The possibility of using a single temperature immune LPG for ambient index sensing has been described. Further work will investigate an optimum period length at which temperature will have negligible affect on the optical profile of one or more of the coupling modes, but is still of a period length which is sensitive enough to detect small changes in ambient indices.

Acknowledgements

The authors are grateful to the Engineering and Physical Science Research Council and TQ Environmental plc, Wakefield for the award of a CASE studentship and to the Engineering and Physical Science Research Council for the award of a grant to develop all optical sensors for use in the construction industry (grant ref: GR/R19151).

References

1. Peng PC, Tseng HY, Chi S 2002*Electronics Letters* **38 (24)** 1510-1512
2. Zhao DH, Shu XW, Zhang L, Bennion I 2002 *Electronics Letters* **38 (7)** 312-313
3. Erdogan, T. 1997*Journal of Lightwave Technology*, **15 (8)** 1277-1294,.
4. Bhatia, V. and Vengsarkar, A.M. 1996 *Optics Letters*, **21(9)** 692-694.
5. Patrick, H.J., Kersey, A.D. and Bucholtz, F. 1998.*Journal of Lightwave Technology,* **16** 1606-1607.
6. Lee, B.H., Liu, Y., Lee, S.B., Choi, S.S., and Jang, N.J 1997 *Optics Letters*, **22(23)** 1769-1771.
7. Bhatia, V., Vengsarkar, A.M. 1996 *Optics Letters*, **21(9)** 692-694.
8. Bhatia, V. 1999 *Optics Express*,.**4(11)** 457-460.
9. Shu, X., Zhang, L., Bennion, I. 2002 *Optics Communications*, **203** 277-281.
10. Shu, X., Huang, D. 1999 *Optics Communications*, **171** 65-69.
11. Shu, X., Zhu, X., Jiang, S., Shi, W., and Huang, D. 1999 *Electronics Letters*, **35(18)** 1580-1581
12. Patrick, H.J., Kersey, A.D., Bucholtz, F., Ewing, K.J., Judkins, J.B., and Vengsarkar, A.M. 1997 “Chemical Sensor Basesd on Long Period Fiber Grating Response to Index of Refraction”, in Proc. Conf. Lasers Electro-Opt., l.11,.420-421.
13. Qin, L., Wei, Z.X., LI, H.P., Zheng, W., Zhang, Y.S., and Gao, D.S. 2000 *Optical Materials,* **14** 239-242.
14. Harumoto, M., Shigehara, M., Kakui, M., Kanamori, H., and Nishimura, M. 2000 *Electronics Letters*, **36(6)** 512-513.