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Experimental study of the thermal properties of Moiré Long Period Gratings

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Abstract

Various Moiré Long Period Gratings are fabricated and their thermal properties are measured. The occurrence of an anomalous switching effect between two thermal response curves is noted to occur at a certain wavelength. A deviation between them by as much as 1nm is observed. As the effect is stable and repeatable it offers the potential for various novel applications in the fields of sensing and optical logic.

Keywords: Long Period Gratings (LPGs), Optical Switching.

1. Introduction

Since their discovery, fibre Bragg gratings (FBGs) [1] and long period gratings (LPGs) [2] have found ready applications in optical communications and sensing. Whatever the application may be a thorough knowledge of their thermal and stress response is essential for their use.

Moiré gratings have been used in the past as a simple method to produce apodised and phase shifted FBGs [3] on fibre grating writing systems which don't have any apodisation or phase control. Only a limited amount of apodisation and phase control can be obtained, but for many applications (in particular most sensing applications) this is sufficient; the spectral improvement obtained from having both full apodisation and phase control over a system not being worth the cost of upgrading the writing system to enable this. However, even though only a limited amount of apodisation and phase control is provided by the moiré structure, such a structure can be useful in its own right.

The operation principle of a moiré grating is based on the trigonometric relations where the sum of two sinusoidal waves is equal to the multiple of another two sine waves with frequencies given by the mean frequency and half the frequency difference of the original two,

$$\sin A + \sin B = 2\sin\left(\frac{A+B}{2}\right)\cos\left(\frac{A-B}{2}\right);$$

the former of the two on the right hand side of the equation being known as the carrier and that of the latter as the modulating wave. Overlaying two Bragg gratings of similar periods will thus give a grating at the mean carrier wavelength that is apodised by the spatial modulating waveform with phase shifts occurring at each point where the modulation envelope pinches off to zero. In this way a limited variety of cosine apodisation profiles can be applied to fibre Bragg gratings.

The moiré grating structure has also been more recently applied to LPGs by fabricating them using the double exposure method with potential correctional exposures [4]. However, the effect it has on the spectrum of LPGs [5] is different from that of FBGs due to the differences between the coupled mode equations which govern each of them [6].

Herein the thermal properties of some of these types of gratings is characterised for the first time and the resultant discovery of an anomalous thermal behaviour is shown and discussed.

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2. Fabrication

For the experiment, three Moiré LPGs (MLPGs) were written into highly photosensitive boron codoped germanosilicate fibre under controlled conditions at the UNSW FBG fabrication facility. These were formed by writing 2 perfectly overlapping LPGs of slightly differing periods using a point by point write approach [7]. All of the MLPGs have a geometric mean of the two periods which composed them of 250 μm and a length of 10mm. Each of the two exposures was incident on the fibre from the same direction.

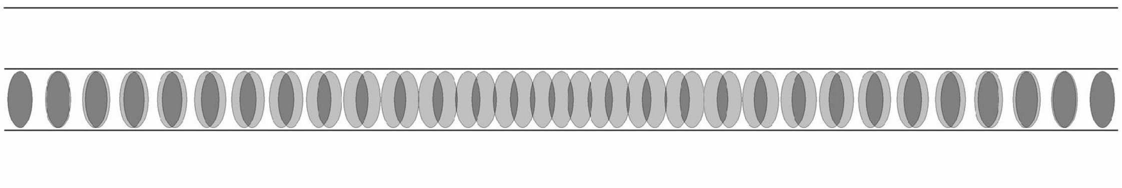

Figure 1. Example of a Moiré LPG with one phase shift in the envelope of the refractive index profile.

MLPG 1 had an envelope with no phase shifts in the AC refractive index profile but pinched off at each end due to the two gratings being out of phase there, MLPG 2 had an envelope with one phase shift and no pinching at the ends (as shown in figure 1) and MLPG 3 had an envelope with two phase shifts and no pinching at the ends. The MLPGs were annealed at 300°C to ensure thermal stability. Figure 2 shows the modulation patterns associated with these various LPGs.

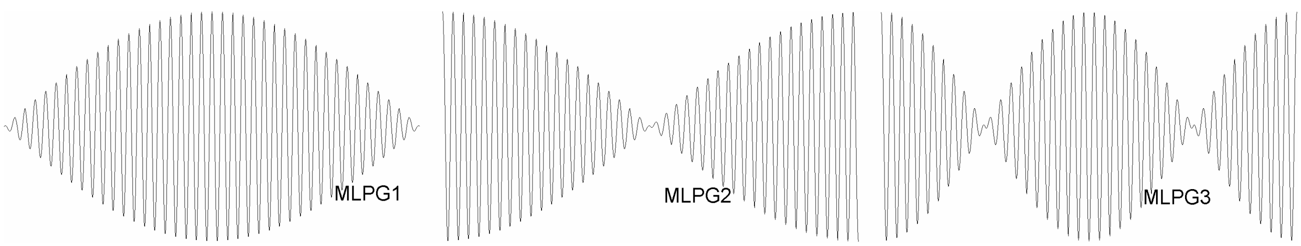

Figure 2. Modulation envelopes of the various Moiré LPGs used for this experiment.

3. Experiment

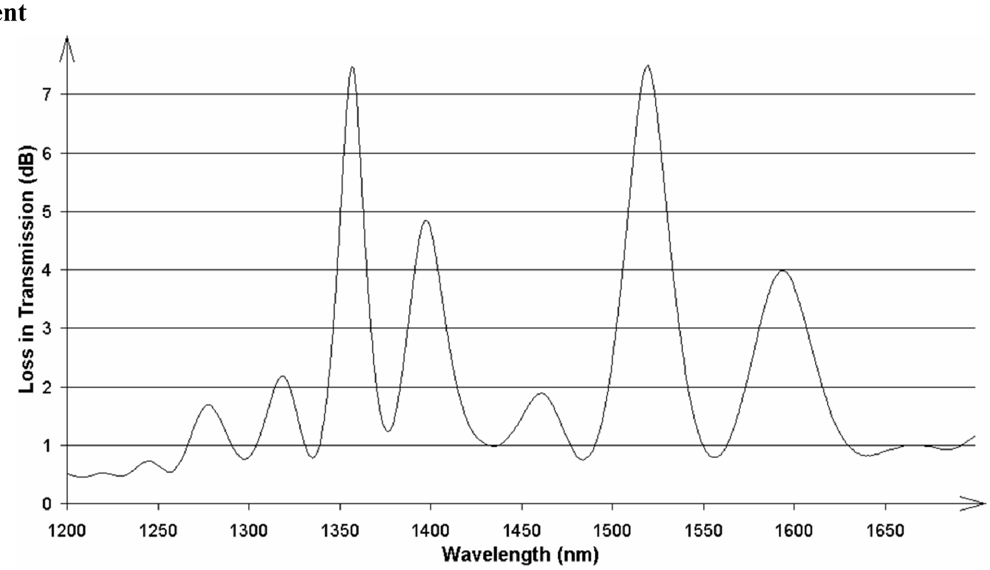

Figure 3. Spectrum of a Moiré LPG with one phase shift in the envelope of the refractive index profile.

All of the MLPGs were packaged in silica capillary tubes and sealed with UV epoxy. Figure 3 shows the spectrum obtained from MLPG 2 where two mode pairs can be seen centred at 1380 and 1560nm. The spectrum obtained from

MLPG 3 was similar but with wider spacing between the mode pairs. The spectrum of MLPG1 was like that of a regular LPG with the exception of a fair amount of sidelobe suppression due to the apodisation of the grating profile. The thermal behaviour of each of the MLPGs was measured by immersing them, along with a thermocouple placed in close proximity to the grating region, in a water or oil bath (depending on the intended temperature range). As they were gradually heated, a white light source and an optical spectrum analyser were used to monitor the spectrum. Wavelength shifts in the profile were determined using a Least Mean Squares fitting algorithm. A mesh resolving down to as fine as 0.01nm was used. The results for MLPGs 1, 2 and 3 are plotted in figure 4, figure 5 and figure 6 respectively. The results from repeating the tests can be seen in the a) and b) graphs for each figure. The two curves are obtained for performing fits for both the lower and higher wavelength mode/mode pairs (labelled 1st and 2nd mode/pair respectively). Thermal hysteresis between tests resulted in an offset of the starting wavelengths between tests.

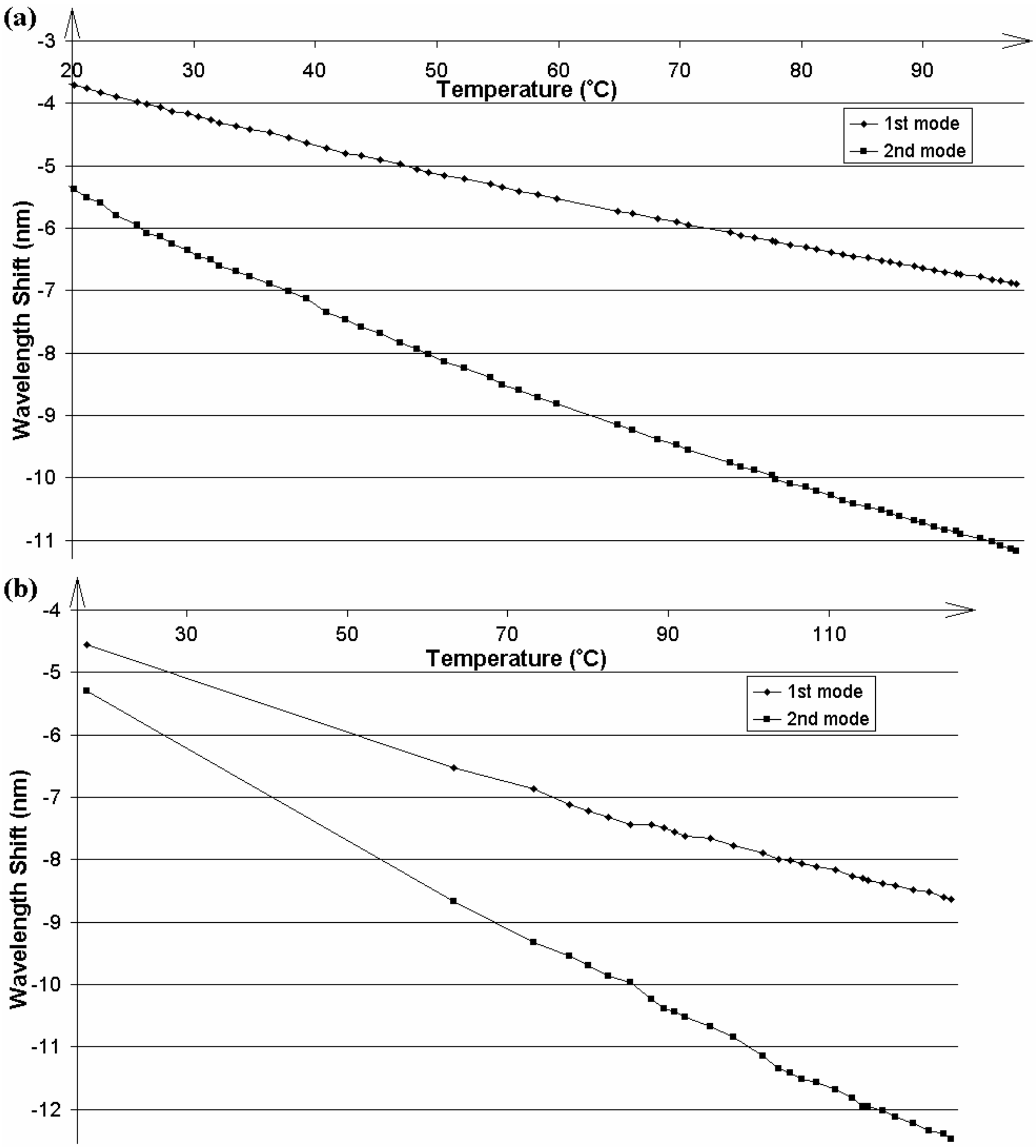

Figure 4. Thermal response of a Moiré LPG with pinched off ends and no phase shifts in the envelope of the refractive index profile (MLPG1).

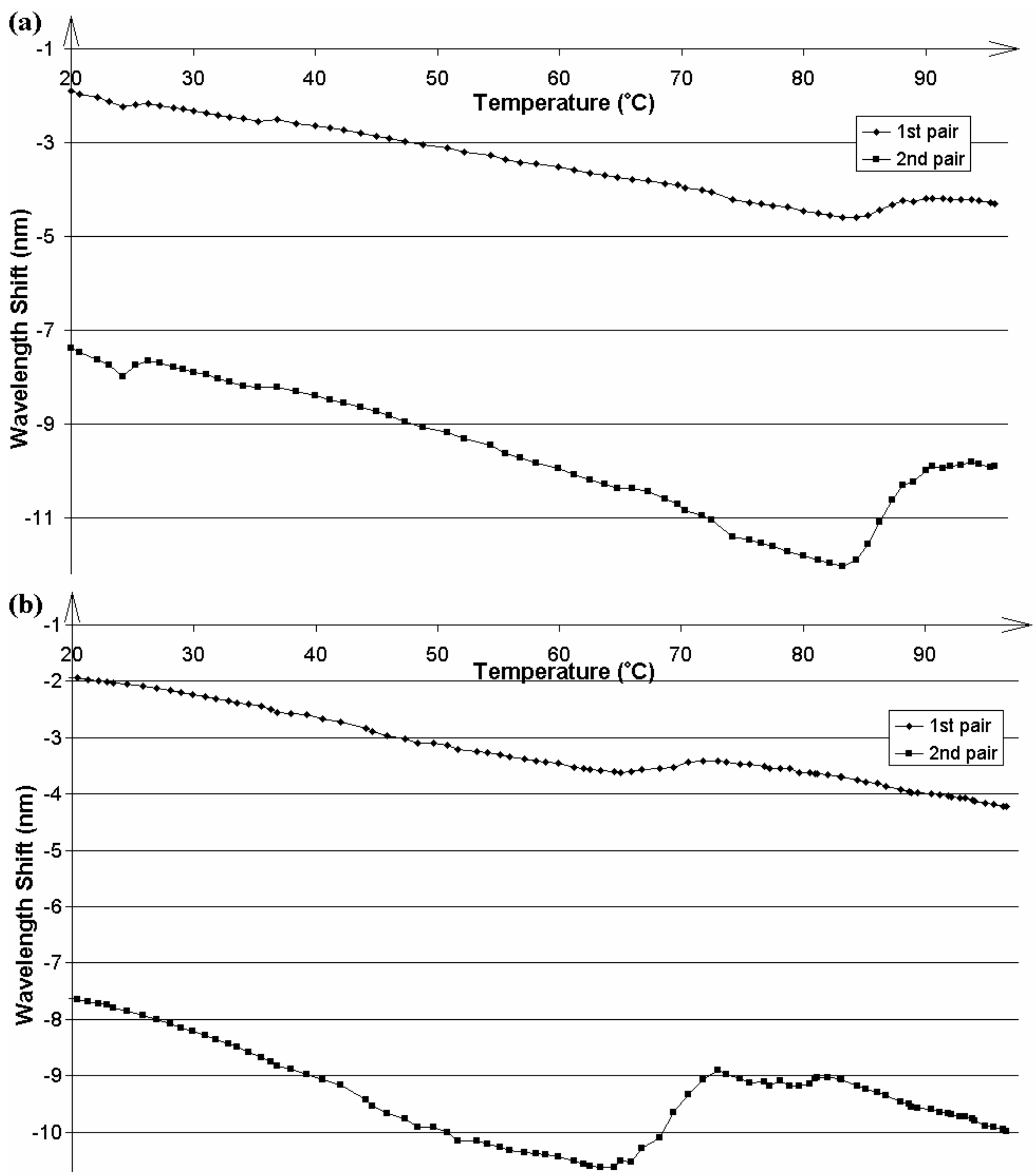

Figure 5. Thermal response of a Moiré LPG with one phase shift and the ends unpinched off in the envelope of the refractive index profile (MLPG2).

It can be seen that MLPGs 2 and 3 exhibit large switching effects (in excess of 1nm) once they reach a certain critical wavelength. Of the two mode pairs of MLPGs 2 and 3, the longer wavelength pair exhibits a much larger degree of switching; this is even in excess of accounting for the differences in the responsivities of the two mode pairs. MLPG 1 however, did not exhibit any switching. It is uncertain at this stage whether this is due to a possible switching effect being outside the temperature range measured or that the switching effect may be restricted to the class of MLPGs to which MLPG 2 and 3 belong, whether that be the class of those with the two constituent gratings in phase at both ends (no pinching at the ends of the envelope) or the class of gratings having at least one phase shift.

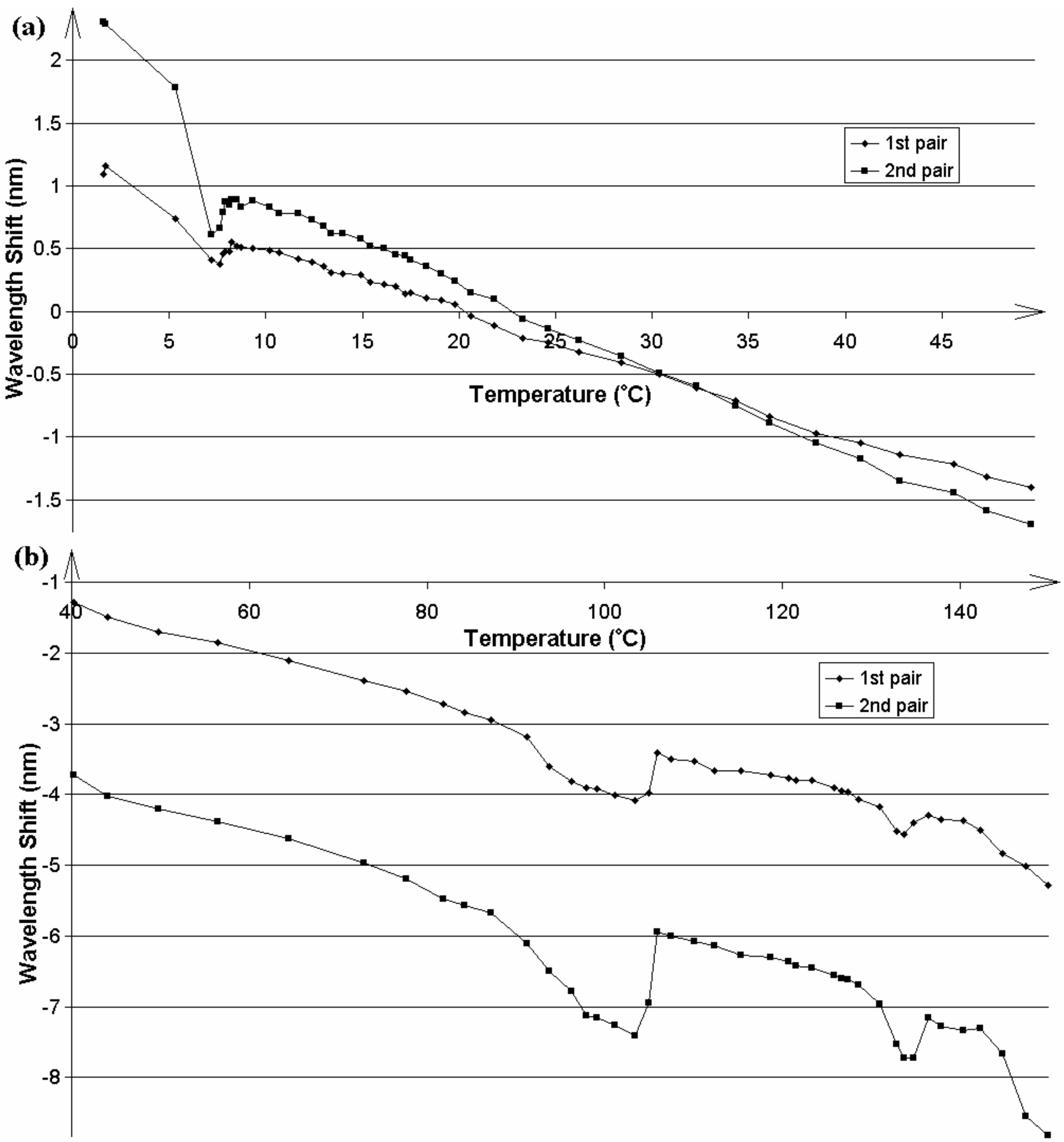

Figure 6. Thermal response of a Moiré LPG with two phase shifts and the ends unpinched off in the envelope of the refractive index profile (MLPG3).

Visual inspection of the spectrum showed that there was indeed a clear switching effect seen at all wavelengths and not some apparent effect due to changes in the spectral shape or of the MLPG spectrum passing through an intrinsic absorption peak or of improper convergence of the Least Mean Squares fit routine. Further tests performed on an unpackaged MLPG of the same design as MLPG 2 confirmed the switching behaviour was still present, ruling out packaging as a possible cause of the effect. The repeatability of the effect ruled out drift of either the scan cycle of the optical spectrum analyser or of the state of polarisation as potential causes. The switching effect is thus an actual effect (rather than an apparent effect); not being able to be accounted for due to system or experimental error.

With careful design of the MLPGs, potential applications of this effect would include optical logic components and critical temperature sensors (where a high sensitivity near a certain temperature is required).

4. Conclusion

The thermal properties of several Moiré LPGs were measured. An anomalous thermal behaviour was discovered in the response of Moiré Long Period Gratings. Controlled testing revealed that the behaviour was inherent to the fibre grating and not the result of an externally induced effect.

5. Acknowledgement

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