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A transverse loading technique to enhance the pressure measurement capability of fibre Bragg gratings

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ABSTRACT

A fibre optic pressure sensor based on the application of a transverse load onto an epoxy-resin material embedded over a sub-section of a fibre Bragg grating (FBG) is presented. When a transverse load is applied to the epoxy material it deforms and transfers the load onto the optical fibre in the form of an axial strain that changes the period of the FBG over the embedded region. This introduces a phase shift between the two resulting identical gratings that lie either side of the loaded section, creating a spectral drop-out within the bandwidth of the FBG. A 2 mm section at the centre of FBGs of length 6 mm, recorded in both single mode and highly linearly birefringent optical fibres, was embedded in resin, and were subsequently subjected to a transverse load. The loading technique, while offering protection to the optical fibre from mechanical damage, enhances transverse load sensitivity, without introducing birefringence.

Keywords: Pore pressure, fibre Bragg grating, spectral drop-out, transverse load.

INTRODUCTION

The transverse loading of fibre Bragg gratings (FBGs) has been used previously to demonstrate their pressure sensing capability. The simplest configuration consists of the direct application of a transverse load the entire length of the FBG that creates a split in the Bragg peak due to the introduction of birefringence[1]. Recently it was shown that by transversely loading a sub-section of an FBG, a spectral drop-out, with central wavelength sensitive to the applied load, appears within the Bragg reflection spectrum[2-4]. The practical application of these techniques is limited by the low sensitivity of bare fibre to transverse load, and by the mechanical damage that can be introduced by direct contact. The transduction of the transverse load into an axial strain allows the enhancement of the transverse load sensitivity, as the sensitivity of an FBG to axial strain is considerably larger than that to hydrostatic loading. Recent studies have shown that, by embedding an FBG within an epoxy resin material, it is possible to transduce transverse load into an axial strain increasing therefore the measurement sensitivity[5-9]. In this paper we studied the effect of transversely loading an epoxy-resin material that embedded a sub-section of an FBG, with the aim of developing a pressure sensor.

1.1 Sensing principle

The principle of operation of the sensor is based on the application of a transverse load onto an epoxy resin material coated over a sub-section in the centre of the FBG (Figure 1).

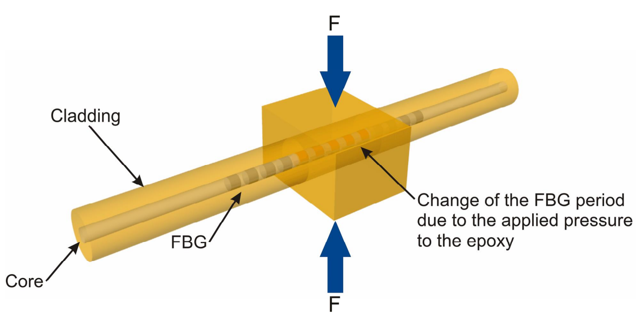

Fig. 1: FBG embedded within epoxy material. F: force.

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When the load is applied, the epoxy resin material deforms and transfers the load onto the fibre as an axial strain that changes the period of the FBG over the embedded region. This leads to the introduction of a phase shift between the two resulting identical gratings that lie either side of the loaded section, creating a spectral drop-out within the bandwidth of the FBG.

EXPERIMENT

Two FBGs, of length 6 mm and central wavelengths 1566.7 nm and 1553 were fabricated in photosensitive single mode (SM) optical fibre (Fibercore PS1250) and in a highly birefringent (HiBi) bow-tie optical fibre (Fibercore HB1500) respectively. The centre of each FBG was identified by coupling the output from a He–Ne laser (632.8 nm) into the fibre, and observing the scatter from the FBG[10]. A 2 mm long section at the centre of each FBG was then embedded in a UV cured epoxy resin (EpoTek OG134). The HiBi fibre was oriented such that the slow and fast axis was aligned with the faces of the resin cube. The experimental arrangement used is shown in Figure 2a.

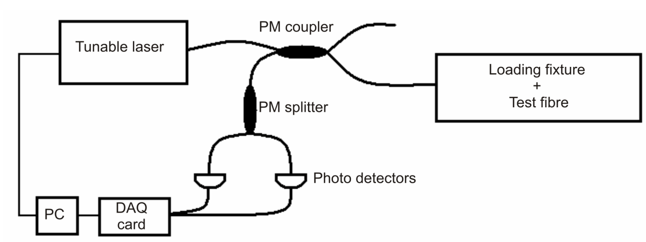

Fig. 2a: Experimental arrangement.

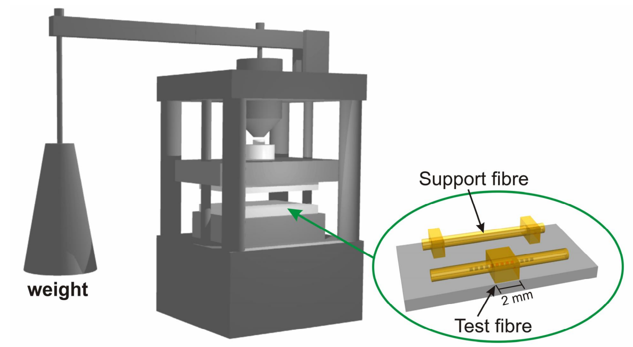

Fig. 2b: Loading fixture and test fibre.

The wavelength range of interest was scanned with a resolution of 1 pm using a tuneable external cavity laser (TUNICS-Plus CL) coupled to a polarisation maintaining (PM) directional coupler. The FBG was attached to one output arm of the PM coupler while the other output was immersed in an index matching gel to prevent unwanted reflections. The light reflected from the FBG was then directed to a PM fibre splitter and the two orthogonal linear polarisation outputs of the splitter were recorded separately by two photo-detectors via a data acquisition (DAQ) card. For the SM FBG characterisation, the same interrogation system was used by substituting the PM coupler and splitter by a SM directional coupler.

A loading fixture, shown in Figure 2b, designed to minimize the fibre twist and used previously to characterise the transverse load response of fibres written in HiBi fibre[11], was employed to apply load to the resin. The test fibre and a support fibre in which two sections were embedded in epoxy cubes of the same dimensions as those use for the test fibre, were placed parallel between the loading fixture plates forming a triangle (Figure 2b). The load was then applied by adding weights to the end of a cantilever arm.

RESULTS AND DISCUSSION

Figure 3 shows the transverse load response of the SM FBG with its central section embedded within an epoxy resin cube. As the load increases, a spectral drop-out track across the FBG spectrum while the main Bragg peak stays fixed. When it reaches the red end of the Bragg spectrum another spectral drop-out appears on the blue side of the Bragg spectrum and a new cycle starts. A measurement sensitivity of 5.7×10^{-3} nm/N and 3.9×10^{-3} nm/N was achieved when monitoring the first and second spectral drop-out cycles respectively. Previously[4], the achieved load sensitivity when directly applying a transverse load onto a sub-section in the centre of the FBG was 1.9×10^{-3} nm/N. This corresponds to an increase of sensitivity of approximately 3.5 times. The different sensitivities obtained for each spectral drop-out cycle is attributed to saturation in the load supported by the resin cube. No peak splitting or birefringence related effects were observed in this experiment.

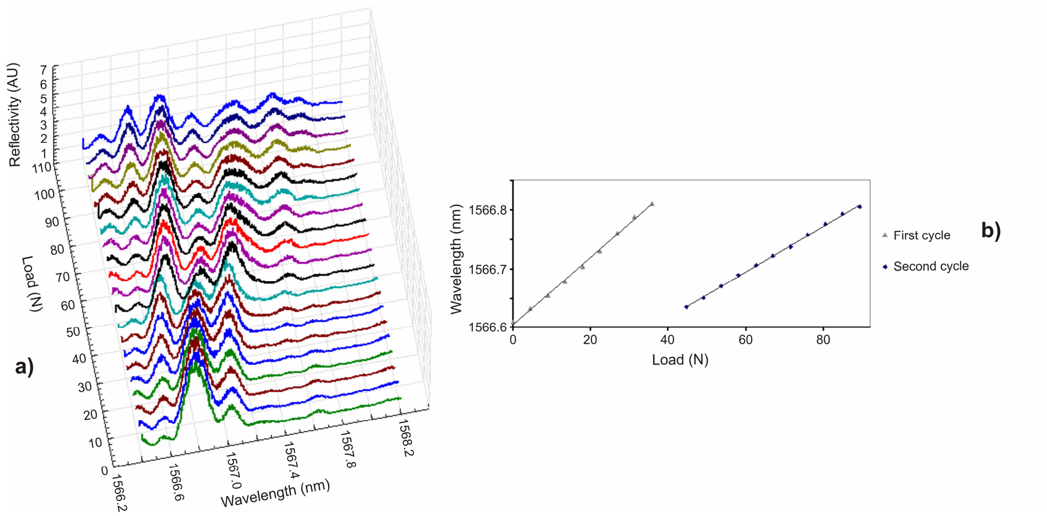

Fig. 3: (a) Experimentally determined evolution of the reflection spectrum from of a 6mm long bow-tie HiBi FBG, embedded with epoxy along 2 mm of its centre, with the applied load; (b) Dependence of the central wavelength of the spectral drop-out on the applied load.

In previous work, the direct application of a transverse load modified the birefringence of the fibre. In [12] it was shown that when a transverse load is applied directly to a sub-section of a HiBi FBG, parallel to one of the eigenaxes, the spectral drop-out appears only in the reflected light polarized along that eigenaxis indicating the local modification of the birefringence of the fibre. However, the experiment described above for the SM FBG indicates that, when a transverse load was applied to the epoxy coated sub-section of the SM fibre, there is no change in the birefringence, and the transverse load is transduced into an axial load. This was investigated further, by the application of the transverse load parallel to the slow axis of the HiBi FBG with its central section embedded within an epoxy resin block. As shown in figure 4, as the load increased a spectral drop-out appeared in *both* the slow and fast axes and tracked across the Bragg spectrum, showing that the birefringence was unchanged in the loaded region.

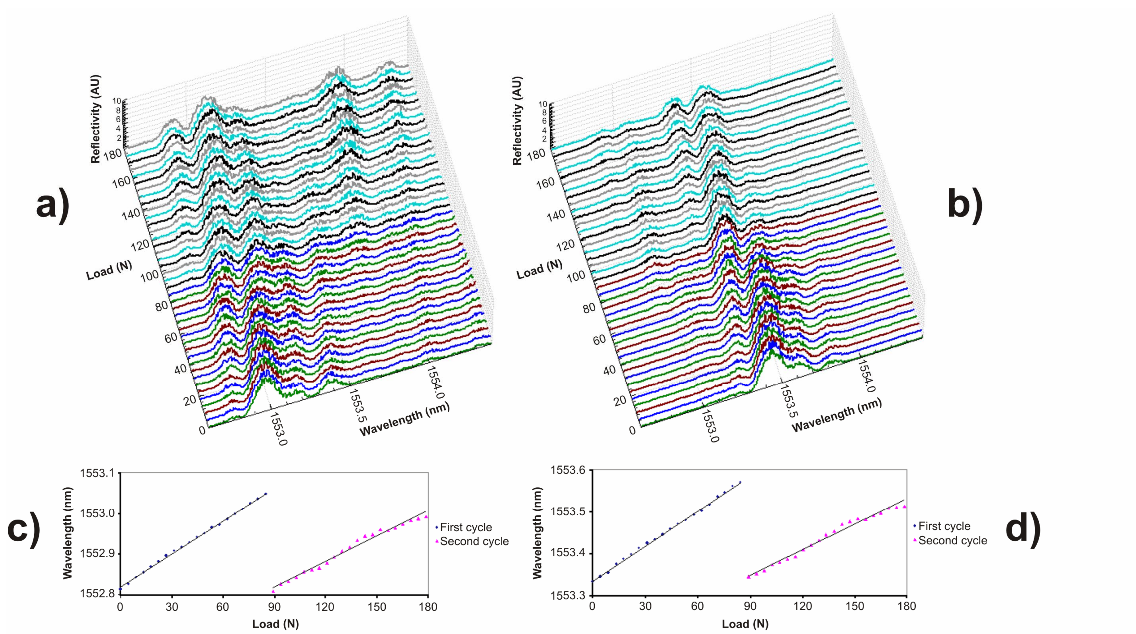

Fig. 4: Experimentally determined evolution of the reflection spectrum from of a 6mm long bow-tie HiBi FBG, embedded with epoxy along 2 mm of its centre, with the applied load (a) fast axis, (b) slow axis; Dependence of the central wavelength of the spectral drop-out on the applied load (c) fast axis; (d) slow axis.

A measurement sensitivity of 2.8×10^{-3} nm/N was achieved when monitoring the first spectral drop-out cycle over the slow axis and 2.0×10^{-3} N/nm for the second cycle. For the fast axis, a measurement sensitivity of 2.7×10^{-3} nm/N was achieved for the first spectral drop-out cycle and 2.1×10^{-3} nm/N for the second cycle. The similar sensitivities obtained for the different axes shows that the applied transverse load was predominantly transduced into an axial strain over the optical fibre.

CONCLUSION

A new transverse loading technique based on transducing transverse load into an axial strain via a block of epoxy resin that embeds a central section of FBG has been presented. The use of the epoxy resin enhanced the transverse load sensitivity resulting in an increase of measurement resolution by a factor of 3.5 and providing mechanical protection for the loaded section of the optical fibre. When transverse load was applied onto a block of resin coated along a sub-section of an FBG fabricated in HiBi fibre, a spectral drop-out was observed in both axes. The similar sensitivities obtained for measurements recorded along the two axes (fast and slow) during the same spectral drop-out cycle shows that the applied transverse load was completely transduced into an axial strain over the central section of the optical fibre. This shows that when using SM fibre no birefringence is introduced by the applied transverse load.

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