827nm Bragg grating sensor in multimode microstructured polymer optical fibre

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We report on the fabrication and characterisation of a Bragg grating in multimode microstructured polymer optical fibre with a Bragg wavelength of 827nm. This is the smallest Bragg wavelength reported to date for a polymer optical fibre grating and the relatively low loss of the fibre at this wavelength considerably enhances the utility of the device compared to gratings at longer wavelengths.

Introduction

Silica fibre Bragg grating (FBG) sensors have become well established as an important sensing technology [1]. However, despite the fact that it is a decade since the first FBG was reported in a polymer optical fibre (POF) [2], applications of the polymer devices away for the optical bench have only just started to be reported [3]. Even though polymer FBGs posses some attractive features (e.g. a lower Young's modulus than silica and a higher failure strain [4]), a considerable barrier to their take-up has been the availability of gratings only at longer wavelengths, mainly around 1550nm [2], [5], though there have been reports of gratings at 980 nm [6]. The problem with these devices is the high attenuation of POF at longer wavelengths, typically around 100dB/m at 1550nm and 10 dB/m at 980nm [7].

FBGs at these wavelengths in POF have only become useful with the development of glued connections to silica fibre down-leads that allow POF sensors just a few centimetres in length to be deployed [3]. However, the presence of the relatively fragile and bulky connection so close to the FBG is a significant limitation on its deployment. Consequently, we have been working towards the inscription of FBGs in the 800nm region where fibre loss is much lower (2dB/m) [7] and broadband semiconductor sources are readily available.

Work from the early 1970s on the photosensitivity of bulk poly(methyl methacrylate) (PMMA) reported a recording resolution of better than 200nm sufficient for the creation of Bragg reflectors for a red dye laser [8] and this suggested that the inscription of FBGs in POF at 820nm should not be problematic. Indeed, in our laboratory, we quickly succeeded in recording gratings with a period of 279 nm in 2mm thick slabs of bulk PMMA using a phase mask illuminated by a HeCd laser. However, numerous attempts to use the same laser to record similar gratings in samples of POF (both doped step-index fibre and pure PMMA microstructured fibre) were completely unsuccessful. These attempts were made using two methods, the conventional phase mask approach [9] and an interferometric technique based on Lloyd's mirror [1].

In this paper we report on our eventual success in producing gratings at 827nm and provide full details of the inscription arrangement that permits exposure times of around 2 hours.

Experimental

Multimode microstructured polymer optical fibre (MMmPOF) was used in this work. The fibre was obtained from Kiriama Pty. Ltd. of Sydney, Australia, and is made purely of PMMA with an outer diameter of 150µm along with a core diameter of 50µm. The photonic crystal fibre (PCF) design consists of three rings of holes providing a lower effective index cladding surrounding a solid higher index core, with the light therefore confined by index guiding.

The grating was inscribed using a HeCd laser with a CW UV output of 30mW at a wavelength of 325nm. The POF was first mounted onto a v-groove plate along the inscription length. Exposures times are very long and hence the POF needs to be immobilised and prevented from sagging during the inscription. The UV beam was focussed to the core vertically using a cylindrical lens of focal length 10cm. The focussed beam passed down through a phase mask of period 557.20nm which was mounted above the fibre at a distance of approximately 200µm from the fibre surface. The length of the grating was governed by the width of the UV beam: 1.8mm. Achieving alignment of the beam to the fibre core was accomplished by monitoring sideways and backward scattering from the fibre; experience has shown that alignment using this method can be highly successful when inscribing gratings with a Bragg response of 1562nm.

The Bragg grating was interrogated both during and after inscription to characterise the grating growth and response. As the fibre used was multimode a broadband light source was first launched into a 20m spool of 50/125µm silica fibre, to approach an equilibrium modal distribution. A

50/125μm 50:50 coupler was used to enable the monitoring of the reflected power from the inscribed Bragg grating using an optical spectrum analyser (OSA) with multimode fibre input capability. The silica arm connected to the POF was equipped with a FC/APC connector and butt-coupled to the POF using a small amount of polymer index matching gel to eradicate any Fresnel reflections from the silica end face. The end face of the POF was cleaved using an 80˚C heated razor blade [10].

The reflected power monitored during the growth phase is shown in Figure 1. There is no sign of the two-phase growth behaviour of POF FBGs reported in [11], though there are some differences between our experiment and theirs. Their work concerned step index fibre with a core containing a co-poymer (benzyl methacrylate), added to raise the refractive index, whereas our fibre is made from pure PMMA. Inscription was carried out at the same wavelength as in our experiment, though in their case a 5ns pulsed laser was used.

Following inscription the grating was glued to a silica fibre pigtail, with the resulting reflection spectrum being shown in Figure 2. From these data, the full-width at half-maximum bandwidth of the grating was found to be 2.45 nm. To characterise the response to strain, the FBG was glued to a translation stage with a gauge length of 39.6 mm. The fibre was gradually stretched to 1% strain while the characteristic wavelength was determined by calculating the average between the rising and falling edge of the reflection spectrum 3dB below the peak value, see Figure 3. The results indicate a sensitivity of 7.1±0.1 nm/% or 0.71±0.01 pm/με.

Discussion

We have reported for the first time the inscription of a polymer optical fibre Bragg grating in the 800nm spectral region. There are several improvements to the inscription arrangement used here that might account for our previous lack of success. The inscription equipment on the optical table was completely enclosed to reduce draughts and a phase mask was obtained that was optimised for use with the HeCd laser (zeroth order beam < 3%). However we feel the main factor was that the height of the mask above the fibre was optimised; previous research has shown the near field pattern beyond the mask varies considerably with distance from the mask when there is only a small amount of zeroth order beam [12].

This development considerably enhances the range of applicability of polymer FBG sensors, permitting their use in a spectral region where fibre losses are acceptably low and where suitable broadband sources are readily available.

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Figure 1. Reflected power from FBG monitored during inscription (resolution bandwidth = 0.5nm). The discontinuities in the growth curve at 30 and 120 minutes appear due to optimisation of the coupling between the polymer and silica fibres at these times.

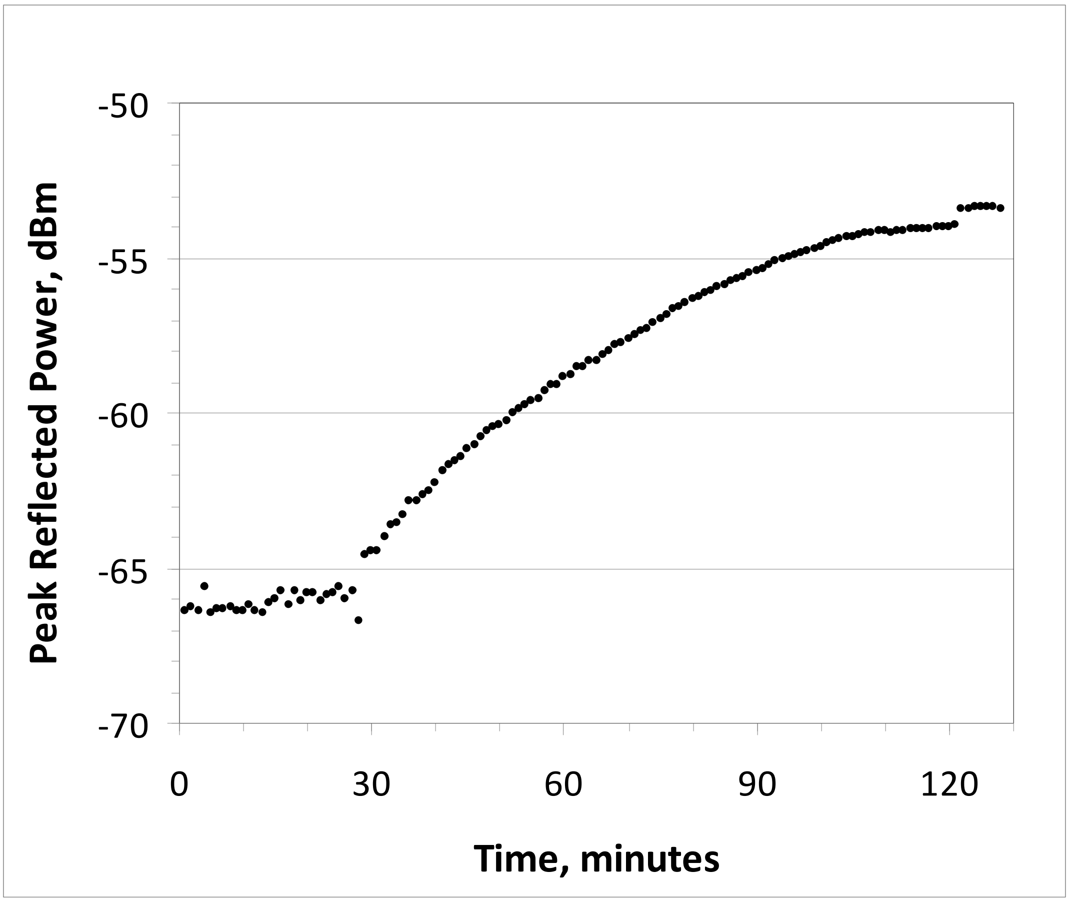


Figure 2. Reflection spectrum of POF FBG after gluing to silica fibre pigtail (resolution bandwidth = 0.5nm).

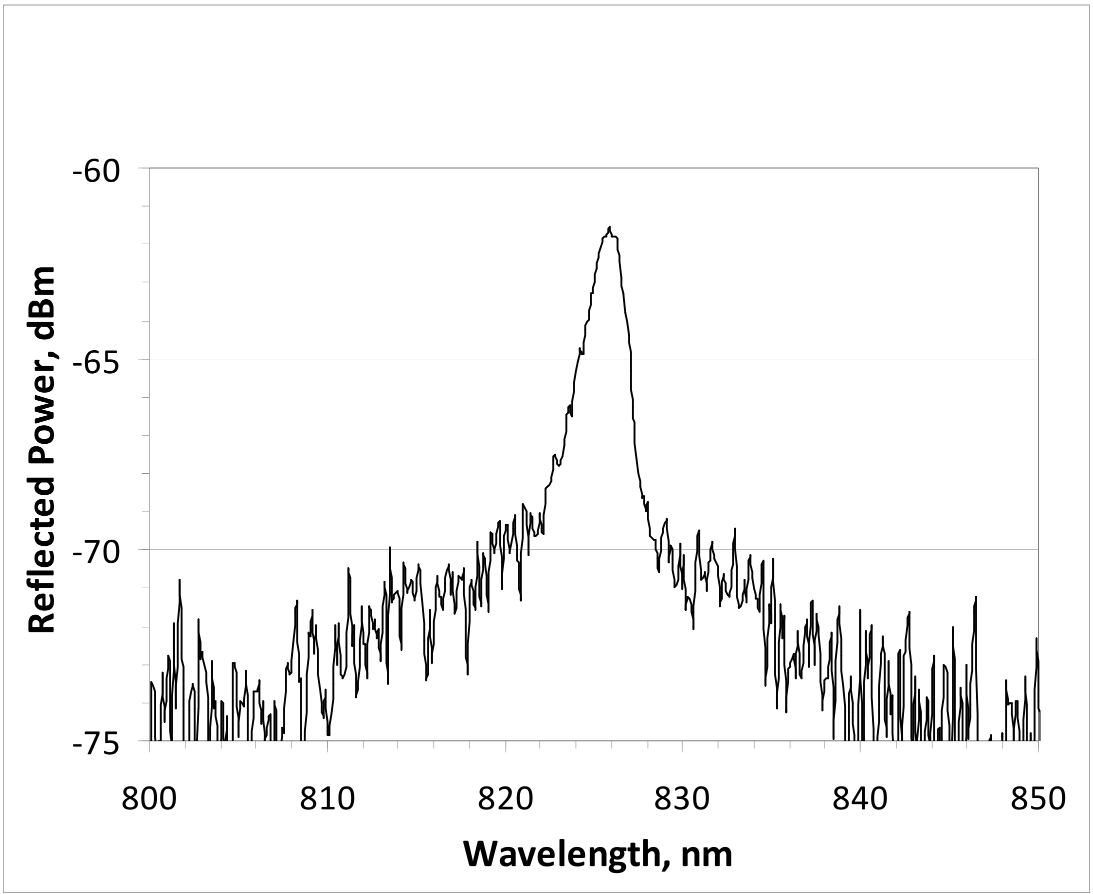
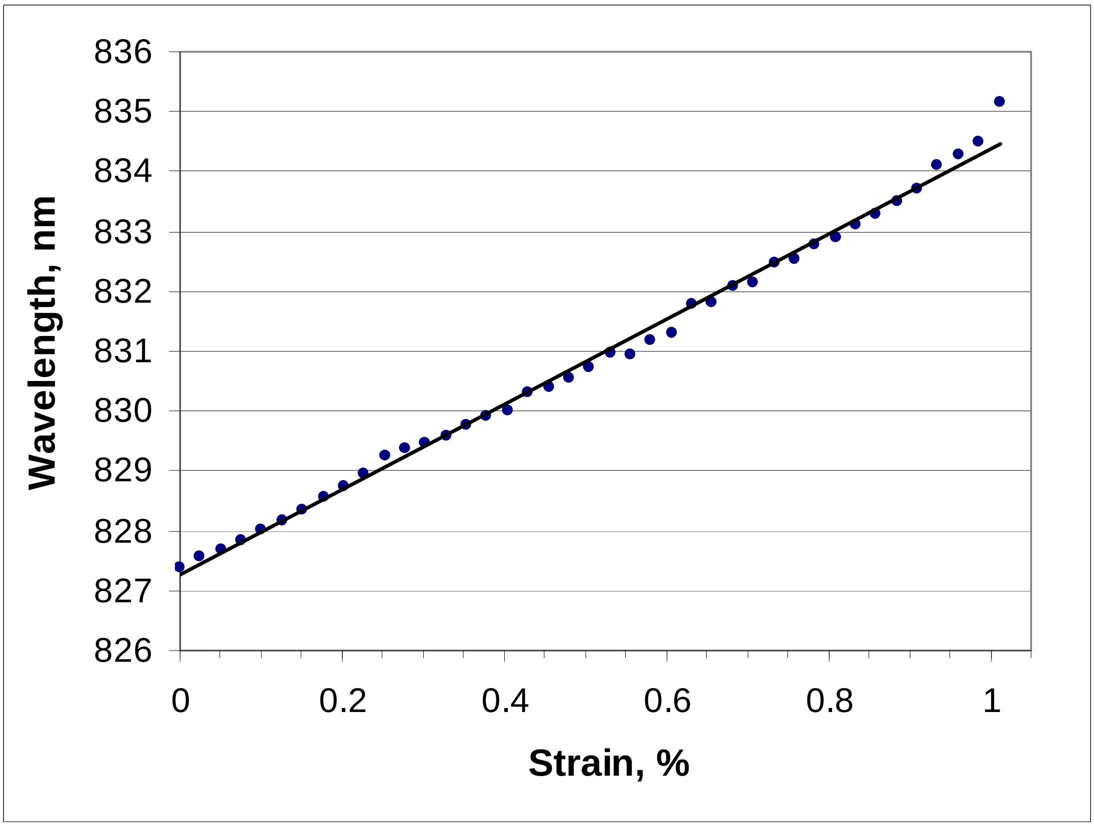


Figure 3. Strain response of POF FBG.



References

1 Othonos, A., and Kalli, K.: 'Fiber Bragg gratings: fundamentals and applications in telecommunications and sensing' (Artech House Publishers, 1996. 1996)

2 Xiong, Z., Peng, G., Wu, B., and Chu, P.: 'Highly tunable Bragg gratings in single-mode polymer optical fibers', IEEE Photonics Technology Letters, 1999, 11, (3), pp. 352-354

3 Ye, C.C., Dulieu-Barton, J.M., Webb, D.J., Zhang, C., Peng, G.D., Chambers, A.R., Lennard, F.J., and Eastop, D.D.: 'Applications of polymer optical fibre grating sensors to condition monitoring of textiles'. 20th International Conference on Optical Fibre Sensors, Edinburgh 2009 pp. 75030M

4 Aressy, M.: 'Manufacturing optimisation and mechanical properties of polymer optical fibre'. MPhil, Birmingham University, 2006

5 Dobb, H., Webb, D.J., Kalli, K., Argyros, A., Large, M.C.J., and van Eijkelenborg, M.A.: 'Continuous wave ultraviolet light-induced fiber Bragg gratings in few- and single-mode microstructured polymer optical fibers', Optics Letters, 2005, 30, (24), pp. 3296-3298

6 Terblanche, J., Schmieder, D., and Meyer, J.: 'Fibre Bragg gratings in polymer optical fibres at 980 nm'. 20th International Conference on Optical Fibre Sensors, Edinburgh 2009, 75037F

7 Boom, H.P.A.v.d., Li, W., Bennekom, P.K.v., Monroy, I.T., and Khoe, a.G.-D.: 'High-Capacity Transmission Over Polymer Optical Fiber', IEEE J. Selected Topics in Quantum Electronics, 2001, 7, (3), pp. 461-470

8 Kaminow, I.P., Weber, H.P., and Chandross, E.A.: ‘Poly(methyl methacrylate) dye laser with internal diffraction grating resonator’, Applied Physics Letters, 1971, 18, (11), pp. 497

9 Hill, K.O., Malo, B., Bilodeau, F., Johnson, D.C., and Albert, J.: ‘Bragg gratings fabricated in monomode photosensitive optical fiber by UV exposure through a phase mask’, Applied Physics Letters, 1993, 62, (10), pp. 1035-1037

10 Law, S.H., Harvey, J.D., Kruhlak, R.J., Song, M., Wu, E., Barton, G.W., van Eijkelenborg, M.A., and Large, M.C.J.: ‘Cleaving of microstructured polymer optical fibres’, Optics Communications, 2006, 258, (2), pp. 193-202

11 Liu, H.B., Liu, H.Y., Peng, G.D., and Chu, P.L.: ‘Novel growth behaviours of fiber Bragg gratings in polymer optical fiber under UV irradiation with low power’, IEEE Photonics Technology Letters, 2004, 1998, pp. 1416-1418

12 Dyer, P.E., Farley, R.J., and Giedl, R. 'Analysis of grating formation with excimer laser irradiated phase masks', Optics Communications, 1995, 115, (3-4), pp. 327-334