CW UV light induced fibre Bragg gratings in few- and single-moded microstructured polymer optical fibres

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Abstract

Reported are observations and measurements of the inscription of fibre Bragg gratings in two different types of microstructured polymer optical fibre: few-moded and endlessly single mode. Contrary to FBG inscription in silica microstructured fibre, where high energy laser pulses are a prerequisite, we have successfully used a low power CW laser source operating at 325nm to produce 1-cm long gratings with a reflection peak at 1570 nm. Peak reflectivities of more than 10% have been observed.

Introduction

Over the last 15 years, fabrication techniques for fibre Bragg grating (FBG) inscription have advanced dramatically, facilitating the development of highly accurate and versatile FBG filter designs in step-index single-mode silica fibre. This has led to a growth in FBG deployment with applications predominantly in telecommunications and optical fibre sensing [1]. In the last few years there has been growing interest in the potential that polymer optical fibre (POF) has within these fields; in the case of telecommunications the driving force is predominantly lower infrastructure cost, while for sensing applications POF may be fabricated from a range of materials with different physical and chemical properties and is inherently biocompatible. The majority of the currently produced POF is based on polymethlymethacrylate (PMMA); a material which has been shown to be photoreactive [2-3]. Only recently has single mode POF become available enabling investigations into the properties of narrow-band FBGs recorded in this material [4]. POF based FBGs offer the prospect of significant advantages over silica based devices for certain applications. For example, POF can withstand and measure much higher strains than is possible with silica fibre and possesses higher temperature sensitivity [5]. Continued optical fibre development has focussed on photonic crystal and microstructured designs, and very recent efforts have resulted in considerable progress in the manufacture of microstructured POF (mPOF) [6]. The geometry of this type of fibre provides it with radically different properties compared to step-index fibre, such as endlessly single-mode and air guiding operation or the ability to expose the electric field of the guided mode to substances contained within the holes; these properties have the potential to open up further significant application areas for POF. It is clearly attractive to be able to combine this new technology with grating based devices, which is the motivation for the work reported here.

The microstructured geometry offers a particular challenge in terms of the grating inscription. For FBG production in step-index fibres it is usual to focus the writing beam down into the fibre core; however, the presence of several rings of holes surrounding the core in the microstructured fibre will tend to scatter the incident beam, which might be expected to lead to a significant reduction in the optical intensity in the core region. Recent success in fabricating FBGs in microstructured silica fibre with a small germanium doped core [7] and in pure silica microstructured fibre [8] using a pulsed 193nm laser, as well as inscription in undoped silica microstructured fibre using a 267nm femtosecond laser [9], have provided confidence that this effect did not necessarily preclude grating inscription, but in the aforementioned cases high energy pulses were always deemed necessary to compensate for the reduction in the optical intensity through hole-induced scattering.

This paper reports for the first time on FBGs inscribed into few-moded and endlessly single mode mPOF, using a low power CW laser source.

Fibre production

The fibre used in this work was made from a PMMA primary preform of 70 mm diameter, into which the desired pattern of holes was drilled; see Fig. 1 [6]. The primary preform was drawn to a diameter of 12 mm to form the secondary preform, and the secondary preform was drawn to fibre directly. In mPOF fabrication the secondary preform is usually sleeved to increase its outer diameter. This step was omitted here to minimise the amount of material surrounding the structure and hence minimise UV absorption outside the core region.

Experimental

The few-moded mPOF had an outside diameter of 160 µm and a core diameter of 13 µm; the core being surrounded by 60 air holes with diameters of 5.5 µm and a separation of 10 µm, giving the ratio of hole diameter to spacing, d/Λ, as 0.55; see Fig 1.

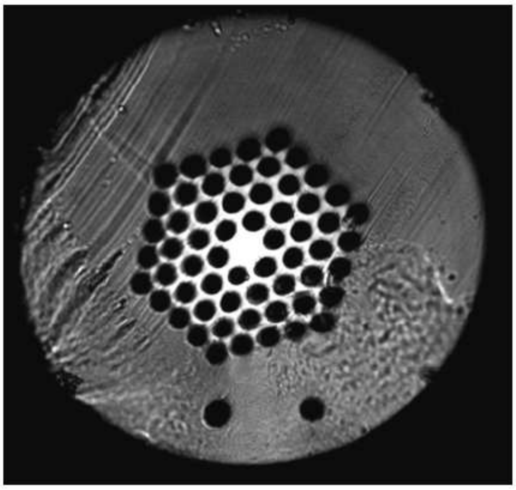

Fig. 1. Optical microscope image of the cross-section of the few moded mPOF.

The ends of both mPOFs were prepared for light transmission by cutting the fibre using a cold sharp razor blade to create a flat end face. POF in general has significantly less mechanical rigidity compared with glass fibre and so a special support was constructed. An 11.4cm length of mPOF was mounted in v-grooves, which were attached to two x,y,z translation stages, allowing for the adjustment of the fibre position. The v-grooves were necessary to provide adequate mechanical support to the mPOF and to minimise the affects of air currents on the position of the fibre relative to the inscription laser beam. FBG inscription was undertaken using the standard phase mask technique utilising a mask with a pitch of 1060.85nm designed to produce a FBG in silica at around 1536nm. A continuous wave helium cadmium (HeCd) laser with an output wavelength of 325nm and a power of 30mW was used to inscribe the FBGs. Two plano-convex cylindrical lenses with 10cm focal lengths were incorporated in the system, one in the usual position before the phase mask, which served to focus the light down towards the core, and the other at a distance of 56.5cm from the mPOF. The second lens was used to expand the 1.8mm diameter laser beam to cover approximately 1cm of the mPOF. See Fig. 2 for the experimental arrangement.

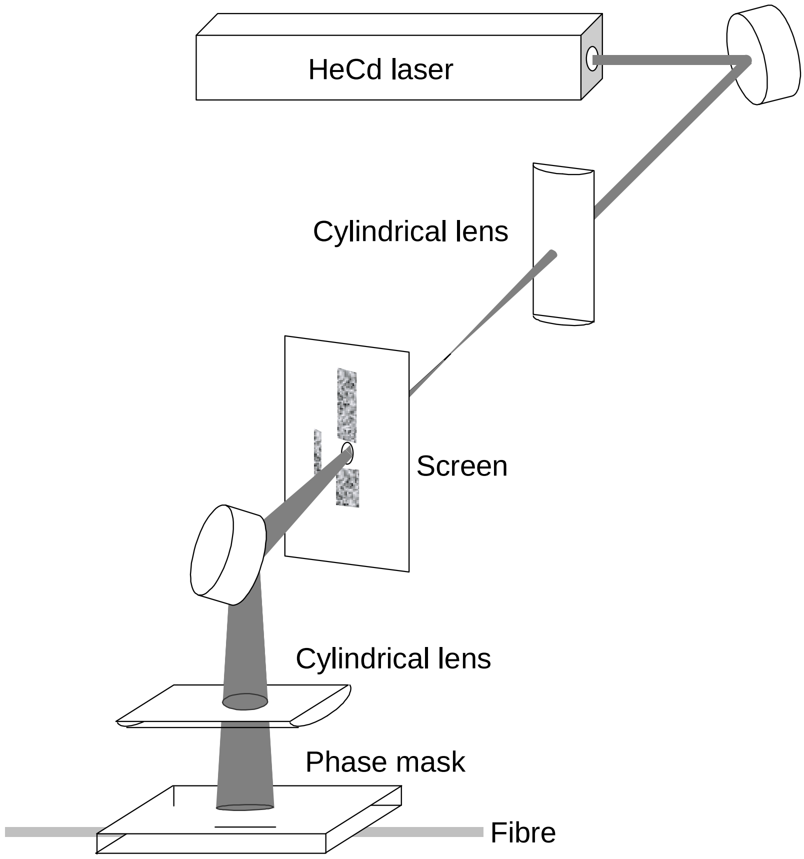

Fig. 2. Experimental arrangement.

We found the orientation of the fibre geometry with respect to the incident laser beam to be critical for FBG fabrication in mPOF. Whereas in step-index fibre the system alignment affects the quality of the grating, incorrect alignment of the mPOF during FBG inscription can completely prevent grating inscription; in particular it is essential that the fibre is correctly oriented rotationally about its axis with respect to the incident beam. Inspection of the back reflections of the HeCd beam from the mPOF revealed two different diffraction patterns as the fibre was rotated; one thin and bright and the other broad and dull. It was found to be essential that the back reflection was thin and bright for inscription. Examples of the two patterns can be seen in Fig. 3. The successful bright diffraction pattern is likely to coincide with the laser beam being incident on the Gamma M (flat side of the hexagon) axis of the photonic crystal structure due to this orientation causing less scattering of the light [10].

Also important for successful inscription was the separation between the phase mask and the fibre. A separation of about 80 microns worked well, whereas reducing this distance by about 20 microns led to fringes being recorded within the holey region of the fibre as well as in the core; in this case the observed reflection profile was irregular and highly dependent on launching conditions.

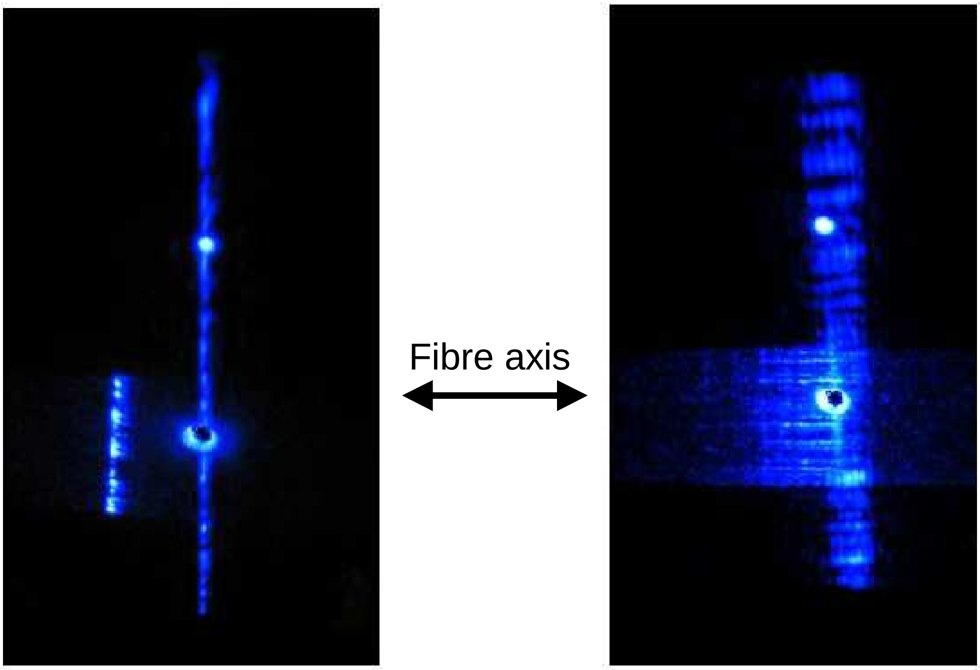

Fig. 3. Backscattered diffraction patterns of the HeCd laser viewed by fluorescence; the pattern on the left was needed for successful inscription. Note that for clarity in the images, the fibre has been twisted slightly in order to shift the backscatter off the core region to the left of the main pattern; for correct alignment these would be superimposed. The orientation of the pattern is indicated on the screen in Fig. 2.

Having aligned the mPOF with the incident beam, light was then coupled into the fibre so that grating growth could be monitored. A SMF 2×2 50:50 coupler designed to operate in the telecommunications C-band was used so that the grating could be monitored in reflection. One of the output arms of the coupler was tied off to eliminate back reflections, whilst the other output arm had an AFC/PC pigtail spliced on to it. The AFC/PC connector was butted up against the launch end of the mPOF with a small amount of index matching gel to reduce the Fresnel reflections from the end and aid coupling into the mPOF. A SMF patchcord was used to monitor the transmission through the mPOF on an optical spectrum analyser (OSA). Alignment was carried out by launching a helium neon (HeNe) laser with an output of 15mW at a wavelength of 633nm into a FC/PC pigtail, which was spliced onto an input arm of the coupler. The translation stage was then adjusted to maximise throughput of the 633nm light in the mPOF. The HeNe laser was then replaced with an ASE light source (Thorlabs ASE-FL7002-C4, 5mW output power) with an operating wavelength range of 1530-1610nm. The launching alignment was altered fractionally to maximise the throughput for these wavelengths. The OSA was then swapped to the second input arm of the coupler to monitor the reflection from the mPOF.

Inscription was initially attempted with the few-moded mPOF due to easier coupling into this fibre. Exposure lasted for 60 minutes at a room temperature of 29 ºC before saturation of the grating occurred. The resulting FBG had a Bragg wavelength of 1570nm, a width (FWHM) of a little under 1 nm, a length of 1cm and a reflective power above the noise level of 7dB. Fig 4. shows the grating profile (OSA bandwidth = 0.2 nm) and the growth characteristics. Evidence for the few-moded structure of the reflectivity profile can be clearly seen.

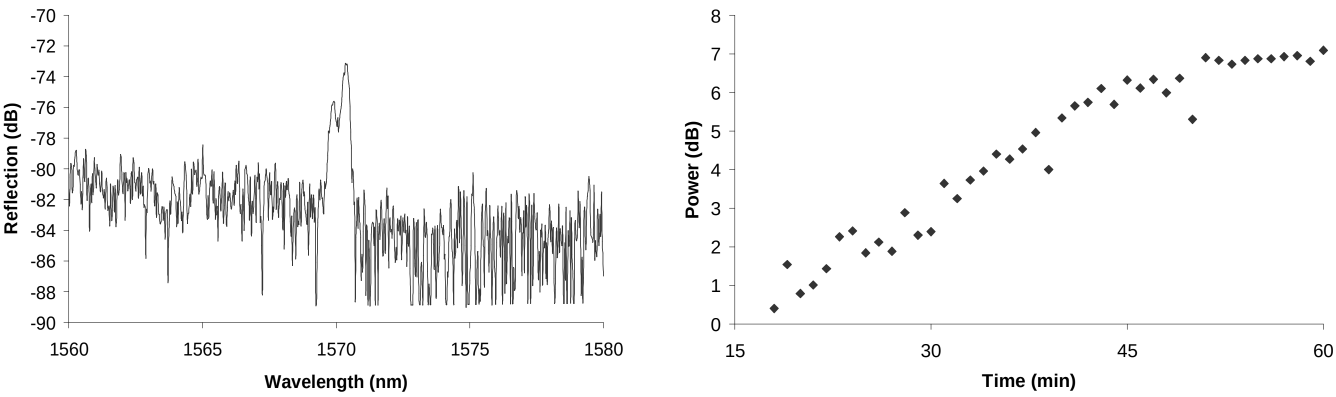

Fig. 4. Left: reflection profile of FBG fabricated in few moded mPOF; Right: growth of signal to noise ratio.

The returned signal was observed to be roughly comparable to the Fresnel reflection from the end of the fibre launching light into the POF in the absence of index matching gel. The attenuation of the POF at the grating wavelength is around 72dB/m; consequently, the 3 cm distance to the grating from the input face of the POF implies that the reflectivity of the grating will be at least 10%. The actual value should be higher since this calculation fails to take into account losses in coupling from the silica fibre to the POF. Possibly due to the high fibre attenuation at these wavelengths, it was not possible to observe the grating in transmission.

The second fibre investigated had single mode operation. The geometry of the holes was maintained but the diameters reduced to 2.7μm with the separation changed to 8.8μm resulting in d/Λ being 0.31, leading to endlessly single mode behaviour. The inscription of the mPOF was then conducted using exactly the same experimental conditions and alignment as previously described. The resulting FBG had a Bragg wavelength of 1569 nm, a width (FWHM) of 0.5nm, a length of 1cm and a reflective power above the noise level 2dB less than that in the few-moded fibre. The slight difference in Bragg wavelengths between the two fibre types is most likely caused by fractionally different strain being applied to the mPOF whilst mounting the fibre for fabrication. The grating profile (OSA bandwidth = 0.2nm) and growth curve can be seen in Fig 5.

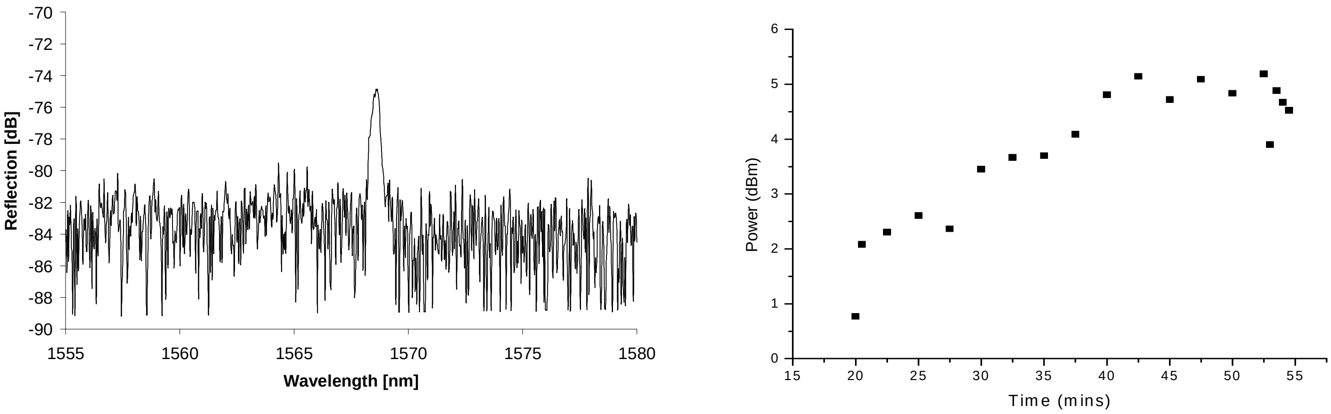

Fig. 5. Left: reflection profile of FBG fabricated in SM mPOF; Right: growth of signal to noise ratio.

Conclusion

We have demonstrated for the first time, to the authors' knowledge, the feasibility of inscribing FBGs in mPOF. We have initiated work to characterise their behaviour, but clearly much still needs to be done. Our primary goals are to increase the grating strength, probably through the addition of dopants to the PMMA, and to characterise the long term properties of the gratings, particularly at elevated temperatures. A move to shorter wavelengths, where the attenuation is much reduced is also desirable.

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