Grating and interferometric devices in POF

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Abstract

To date, much of the development work associated with polymer optical fibre (POF) applications has been aimed at exploiting the potential of the technology to provide low cost solutions. Here we argue that, in the sensing area at least, POF offers a number of other, more relevant advantages. In this paper we describe work on a range of devices based on photoinscribed gratings and on fibre interferometers, which are designed to take advantage of the unique properties of POF.

Introduction

At the time of writing, the polymer optical fibre (POF) community appears to be in fairly buoyant spirits as the prospects for the increasing commercialisation of the technology look promising. The major markets are currently in illumination and short distance communication[1], for example in motor cars, and the major selling feature for POF in these areas is the low cost of the fibre, its associated components and its installation. The low cost advantage has become something of a paradigm for POF research and carries over into sensing, where there is a considerable body of research into potentially cheap intensity based sensors utilising multimode fibre[2].

We feel that there are many potential sensing applications where the low cost of the fibre itself is not particularly significant, for example in small markets, where development costs add significantly to the unit price or in situations where the cost of installation is significant. Here we would suggest that there are other, more relevant features of POF that can make it more attractive than silica fibre in certain situations. We are interested in three such features:

- Physical properties. POF is capable of surviving much higher strains than silica fibre, suggesting its use in situations where this is an issue. Equally, POF based Bragg grating sensors are an order of magnitude more sensitive to temperature than silica fibre[3].
- Chemical properties. POF lends itself potentially to modification by a wide spectrum of organic chemical techniques that cannot be used with silica fibre.
- Biocompatibility. Polymer fibres are far more attractive than silica fibre for in-vivo applications; clinicians are already used to the idea of inserting polymer catheters into the body, where a silica fibre breakage could be serious.

In this paper we describe work towards exploiting these features of POF to realise devices based on interferometric techniques and Bragg and long period gratings.

Interferometry

Interferometry is one of the highest resolution passive optical measurement techniques that can be implemented using optical fibre; for example, in silica fibre, systems capable of measuring fibre length changes of less than 1pm were demonstrated 25 years ago[4]. In collaboration with

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colleagues at Heriot Watt and Birmingham Universities we have begun to investigate the strain and temperature sensitivities of POF and the effect of the fibre drawing conditions on these properties and on the mechanical characteristics of the fibre.

Interferometric measurements were carried out on step-index POF from Paradigm Optics[5], having a 125 micron PMMA cladding and a 6 micron PMMA/PS core. The fibre was designed to have a single mode cut-off wavelength of 750 nm, but at the operating wavelength of 633nm, the fibre was still predominantly single mode. About half a metre of fibre was placed in one arm of a Mach-Zehnder interferometer and approximately 10 cm of this fibre was either stretched or heated in an oven. Interference was observed between light that had travelled down the fibre and light in the second, free space arm of the interferometer and the fringes were counted as the fibre was heated or strained. During the strain measurements, the force on the fibre was monitored to enable the Young's modulus to be computed.

	Measured	**Predicted from bulk PMMA[6,7]**	**Silica[8,9]**
$\frac{d\Phi}{dL}$	$131\pm3\times10^{5}$ rad m^{-1}	132×10^{5} rad m^{-1}	115×10^{5} rad m^{-1}
$\frac{d\Phi}{dT}$	-212 ± 26 rad m^{-1}K^{-1}	-156 rad m^{-1}K^{-1}	99.8 rad m^{-1}K^{-1}
Young's modulus	2.8±0.2 GPa	3.3 GPa	71.70 GPa

Table 1. Comparison between parameters determined from experiments with POF, values calculated from published data and equivalent figures for silica fibre.

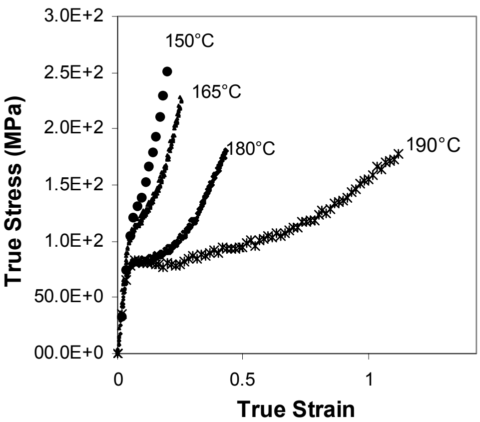

Fig. 1 Room temperature stress-strain characteristics of 200 micron diameter PMMA fibre drawn at various temperatures.

Table 1 summarises the results[10] and reveals surprisingly good agreement between the measured values and those obtained from bulk PMMA, given the sensitivity of fibre properties in general to the drawing conditions[11]. PMMA based POF appears to be better suited to strain measurements than silica fibre as it possesses a higher sensitivity, a lower Young's modulus, thus affecting the structure less for a given strain, and can survive strains as high as 100%, see Fig. 1.

Fibre Bragg gratings

Fibre Bragg gratings in silica fibre have aroused a huge interest within the optical sensing community over the last decade or so. Whilst research in this area is certainly very much alive, aspects of the technology are now sufficiently mature for there to be a number of companies commercialising FBGs, either for telecommunications purposes or, increasingly, for sensing. PMMA has also been known to be photosensitive for some time and indeed Bragg gratings were written in bulk polymer over three decades ago[12], however the potential for applications was significantly increased with the demonstration of gratings in single mode polymer fibre[13]. This research group has now covered a considerable amount of the groundwork needed before POF based FBGs can be applied outside the laboratory.

We have been carrying out research aimed at further increasing the utility of POF grating based sensors, recorded in all cases using a 30 mW HeCd laser, emitting at 325 nm. The first example of this work is the use of FBGs to define interferometric sensing cavities within POF. It is possible to construct fibre interferometers by using directional couplers to carry out amplitude division in a Michelson or Mach-Zehnder configuration, or to use the end reflections from a section of fibre to define a Fabry-Perot or Fizeau cavity; such devices can, however, possess a number of disadvantages, such as their bulk or the difficulty of incorporating them into systems. Fabry-Perot cavities can be much more conveniently produced in silica fibre using FBGs as the mirrors; not only does this allow for a very compact sensor, but it also allows the possibility of wavelength division multiplexing of multiple sensors.

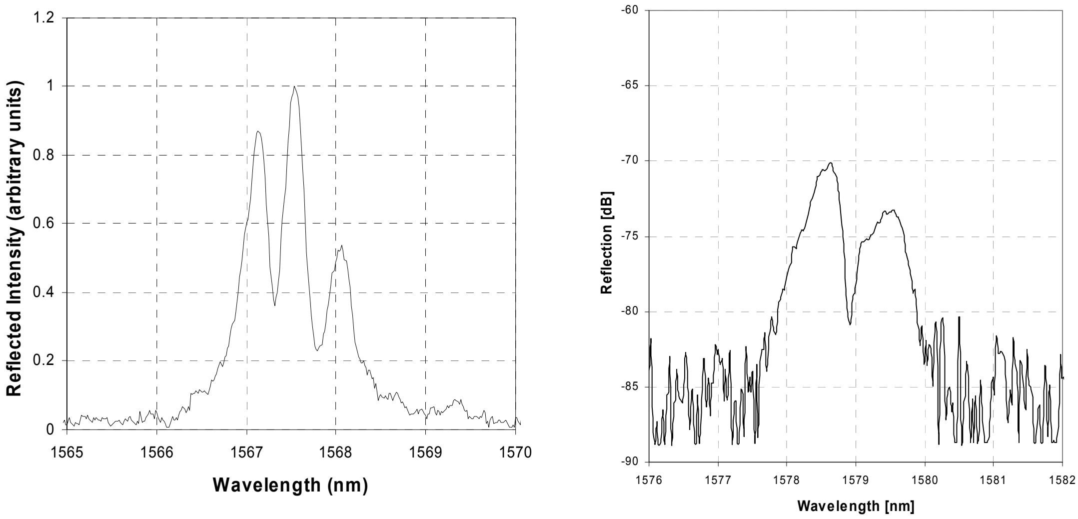

Fig. 2. Reflection spectra from: left – Fabry-Perot cavity; right – π-shifted grating.

Fig. 2 shows reflection spectra from what we believe are the first FBG cavities written in PMMA based step-index POF. The left-hand spectrum is produced by a Fabry-Perot cavity formed from two 1cm long gratings separated by about 3 cm. The approximately sinusoidal nature of the fringes superimposed on the grating reflection profile is indicative of a low finesse cavity, caused partially by the large attenuation in this wavelength range. In fact for many applications, low finesse cavities are preferable. The right hand spectrum is a π-shifted grating produced by uniform exposure to UV of the central 1 mm section of a 1 cm long FBG. The high attenuation is again partially responsible for a lack of sharpness in the central reflection notch; a move to gratings designed for visible wavelengths should result in a much sharper spectral feature, the wavelength of which could be monitored with correspondingly higher precision.

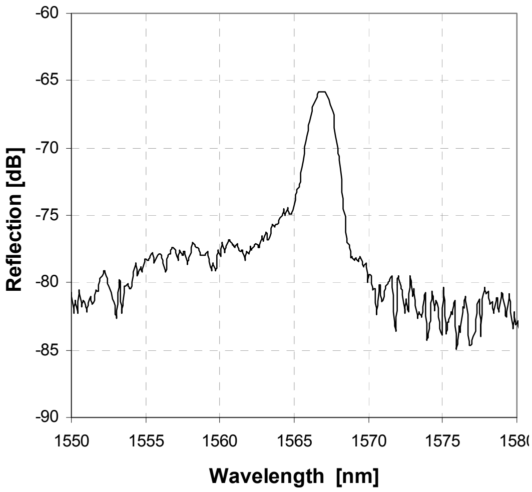

Fig. 3 Reflection spectrum from 1 mm grating recorded in 50 micron core multimode mPOF.

We have also been exploring the inscription of gratings in microstructured POF (mPOF). Getting the UV light into the core through the holey region poses a challenge, but the microstructured geometry offers considerable flexibility for the design of novel fibres. We have succeeded in recording what we believe to be the first FBGs in single mode mPOF[14]. This first grating was 1 cm in length, had a Bragg wavelength of about 1569 nm and a width (FWHM) of 0.5 nm. More recently, we have been exploring the potential of FBGs in multimode mPOF. The motivation behind this is to open up the possibility of using relatively cheap, large area, broad spectrum LEDs as the source, rather than the more expensive single spatial mode emitters needed for use with single mode fibre. Fig. 3 shows the reflection spectrum from a 1mm long grating recorded in a 50 micron core multimode mPOF. These data are rather encouraging as the grating width is still only 2 nm, which is likely to provide sufficient measurement resolution for many applications, particularly where high strains and concomitantly large wavelength shifts are to be expected.

Long period gratings

We believe that mPOF may be particularly useful in the design of fibre long period gratings (LPGs). These have typical periods of 100-1000 microns, as opposed to the 0.5 microns associated with a FBG designed for use in the C band, and act to couple light from the core into forward propagating cladding modes, from which the light is then lost. Thus LPGs are not visible in reflection, but reveal themselves by the presence of a number of attenuation bands in the transmitted spectrum. The attenuation bands of LPGs are in general sensitive to strain, temperature, bending and surrounding index, but unlike with FBGs, the various sensitivities can vary considerably in magnitude and sign, depending on the grating period, the cladding mode order and the type of fibre. As an example of the possibilities this provides, our recent work with microstructured silica fibre has demonstrated a sensor with useful strain and bend sensitivity, but negligible temperature sensitivity[15].

The reason for this behaviour is that the properties of LPGs are strongly dependent on differential effects between the core and the relevant cladding mode, and in particular on the differences between the mode indices and also their group indices[16]. The use of mPOF could offer a convenient means of controlling these parameters through the adjustment of the pattern of holes drilled in the preform. The ability to produce LPGs in mPOF has recently been demonstrated[17], so this would appear to be a fertile area of exploration.

Conclusions

We believe this to be an interesting area of useful research with many potential applications, but before these can be tackled there is still basic work to be done to understand better the inscription process and to enable stable, well characterised and reproducible devices to be constructed.

References

1 http://www.igigroup.com/st/pages/pofmarket.html (12/8/5)
http://www.schleuniger-na.com/Newsandpress/articles/28_POF_Markets.htm (12/8/5)

2 RJ Bartlett, R Philip-Chandy, P Eldridge, DF Merchant, R Morgan and PJ Scully, Transactions of the Institute of Measurement and Control, **22**, 431 (2000)

3 HY Liu, GD Peng and PL Chu, IEEE Photonics Technology Letters, **13**, 824, (2001)

4 DA Jackson, R Priest, A Dandridge and AB Tveten, Applied Optics, **19**, 2926 (1980)

5 http://www.paradigmoptics.com/ (12/8/5)

6 J.M. Cariou, J Dugas, L. Martin and P. Michel, Appl. Opt. **25**, 334 (1986)

7 J. Brandrup, E.H. Immergut, E.A. Grulke, *Polymer Handbook*, V/87, (Wiley, New York 1999)

8 A. Bertholds and R. Dandliker, J. Lightwave Tech. **6**,17 (1988)

9 B.J. White, J.P. Davis, L.C. Bobb, H.D. Krumboltz and D.C. Larson, J. Lightwave Tech. **5**, 1169 (1987)

10 M Silva-Lopez, A Fender, WN MacPherson, JS Barton, JDC Jones, D Zhao, H Dobb, DJ Webb, L Zhang and I Bennion, Optics Letters, (in press).

11 C Jiang, MG Kuzyk, JL Ding, WE Johns and DJ Welker, Journal of Applied Physics, **92**, 4 (2002)

12 IP Kaminow, HP Weber and EA Chandross, Applied Physics Letters, **18**, 497, (1971)

13 Z Xiong, GD Peng, B Wu, and PL Chu, Photonics Technology Letters, **11**, 352 (1999).

14 H Dobb, DJ Webb, K Kalli, A Argyros, MCJ Large and M van Eijkelenborg, Optics Letters (submitted)

15 H Dobb, K Kalli and DJ Webb, Electronics Letters, **40**, 657, (2004)

16 X Shu, L Zhang and I Bennion, Journal of Lightwave Technology, **20**, 255 (2002)

17 MA Eijkelenborg, W Padden, JA Besley, Optics Communications, 236, 75 (2004)