Measurements with an FBG inscribed on a new type of polymer fibre

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Abstract: We present our latest achievements measuring the effects of temperature and pressure on a Bragg grating inscribed on a new type of non-PMMA polymer optical fibre. The fibre is produced using the Light Polymerization Spinning (LPS) process and the Bragg grating is written using a plane-by-plane femto-second laser inscription method. In particular, the 580 micron core fibre was designed to have a very low Young's modulus.

1. Introduction

Polymer optical fibres (POFs) are of interest for a number of applications, from illumination, light harvesting and sensing, to short-range data transmission in automobiles, buildings and industrial automation. A key requirement for the successful development of POFs is a variety of properties (mechanical, optical, etc...) that could be introduced into the POF material and a precisely controlled fibre production process.

Currently, the majority of POFs are made from one polymer - PMMA, and it substantially diminishes the number of possible applications for POFs, especially in the sensor field. Additionally, the POF production is inflexible requiring a number of techniques and manufacturing steps to arrive at the final product, an inflexibility that impacts the fibre’s optical and mechanical properties. Unsurprisingly, the production process is long and complex and it is rarely possible to produce identical properties for two separate batch production runs, particularly when the fibre is produced with the heat-drawing process from a preform.

2. A new type of polymer fibre using Light Polymerization Spinning (LPS) process

The Tecsolut (formerly Intellisiv) company has recently presented [1] a new type of polymer optical fibre that has been developed based on an advanced, single-step, readily customizable and highly scalable Light Polymerization Spinning (LPS) process. In this process there is no polymer at the production starting point, instead formulations of commercially available monomers & other additives are used as required. A liquid formula injection process is followed by a very fast fibre UV polymerization. Thus the fibre formation and polymerization occurs simultaneously (Figure 1).

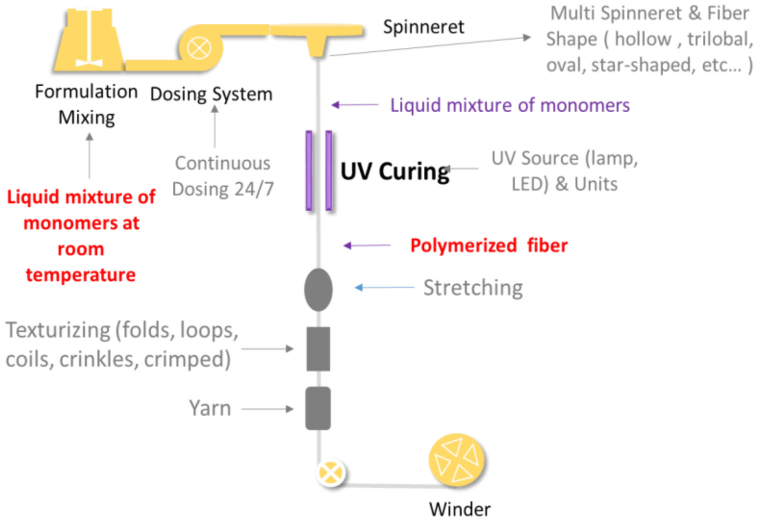

Figure 1. Light Polymerization Spinning process

Proper selection of different monomers and oligomers in the production starting point could produce POFs with vastly different mechanical or other properties (Figure 2).

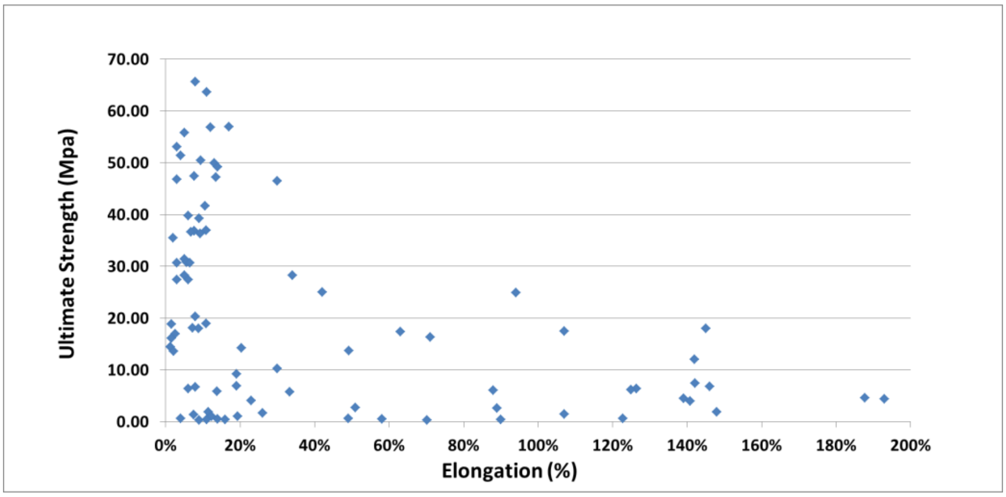

Figure 2. POFs produced by the LPS process. Each dot at this graph represents a POF with different mechanical properties (breakage strength and elongation)

Recently we have published some initial characterization results of some fibres produced by this method [2]. In addition, it was found that modified bisphenol-A fluorene diacrylates with high molecular weight could provide good optical properties and relatively very high elongation and elasticity (low Young Modulus). Here we present additional data, concentrating on one specific, very soft and flexible such fibre (580 µm core, NA=0.47), designated NTO34NTC5. This very low Young's modulus fibre demonstrates the high versatility of the aforementioned fibre production method.

3. Optical transmission of the fibres

Transmission measurements of the POFs were performed by the cut-back method [3] in which light is coupled into a given length of fibre and the transmitted power is measured as the fibre is shortened. To avoid uncertainties regarding coupling efficiency into the fibre, we successively shortened the fibre at its output end, without changing the input coupling conditions, measuring the transmitted power and calculating the loss from the changes in power transmission with fibre length.

The cut-back measurements were performed in two ways: a more accurate way using discrete wavelength (532nm) light, and a second way, more prone to experimental uncertainties, with a broadband visible source and a spectrometer, producing continuous spectral information. When the spectroscopic measurement yielded a result consistent with the laser measurement at 532nm, then the entire spectroscopic measurement was considered verified.

For the discrete measurement, our source was a 5mW 532nm laser (Global Laser Tech) coupled into a 600 µm core NA=0.39 silica fibre patch-cord, with SMA connectors (Thor Labs M21L05). The POF under test was cleaved with a razor blade, inserted into an appropriate SMA connector and butt-coupled to the silica fibre with an SMA fibre adapter. The output end of the POF was also cleaved and the power output was measured with an integrating power meter detector (Newport 818-IS-1). The fibre was cut-back three times to determine the attenuation.

The basis of the spectroscopic cut back measurement was to use as input a broadband 300-1,000 nm light source, coupled into the above mentioned 600 µm core NA=0.39 silica fibre patch-cord. A similar silica fibre patch-cord was permanently attached to the spectrometer SMA fibre input. The POF under test was butt-coupled between the two silica fibre patch-cords for the spectroscopic measurement (see Figure 3). As before, to avoid changes to the input coupling, the POF was successively cut back 3 times at its far end (i.e. the "spectrometer" end).

This set-up leaves as the only uncertainties the quality of the POF cleaves and the butt-coupling to the silica "spectrometer" fibre. As a consequence, we also expect that in this set-up insertion losses will be essentially wavelength independent. As stated above, our validation is the compatibility of the spectroscopic 532nm result with that previously obtained with the 532nm laser.

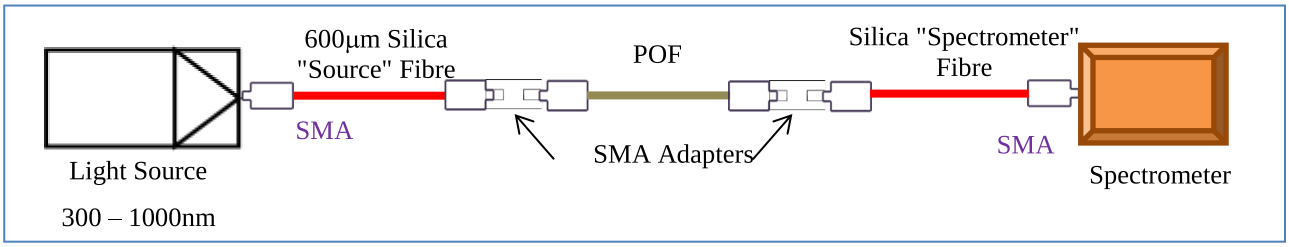

Figure 3: Set-up for spectroscopic cut-back measurements

In Figure 4 we present our results for the above mentioned fibre. The fibre loss is relatively flat over most of the visible range, with a steep increase in attenuation from 850nm.

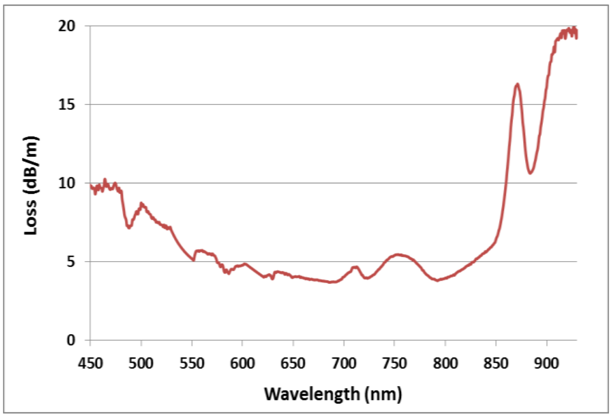

Figure 4: Spectral loss characterization of Tecsolut POF NTO34NTC5

4. Fibre Bragg Grating inscription and Characterization

The fibre sample was mounted on an air-bearing translation stage using a glass slide for a controlled motion during the inscription. The laser beam of a femtosecond laser (HighQ – femtoRegen) operating at 517 nm, with pulse duration of 220 fs and energy of ~40 nJ, was focused from the top of the fibre through a long-working-distance x50 microscope objective (Mitutoyo) mounted on a third stage. Using the Pl-by-Pl inscription method [5], we inscribed a 4th order FBG in the centre of the polymer fibre consisting of 2,000 planes of 50 µm width. The FBG period was calculated to be ~2 µm for a grating with a resonance wavelength at 1,560 nm.

Using the butt coupling method and an SMF-28 fibre circulator, we illuminated the grating with a broadband light source (Thorlabs-ASE730) and the reflection spectrum was measured using a spectrometer (Ibsen IMON) as shown in Fig. 5. After finding good alignment between the SMF and POF the fibres were glued together.

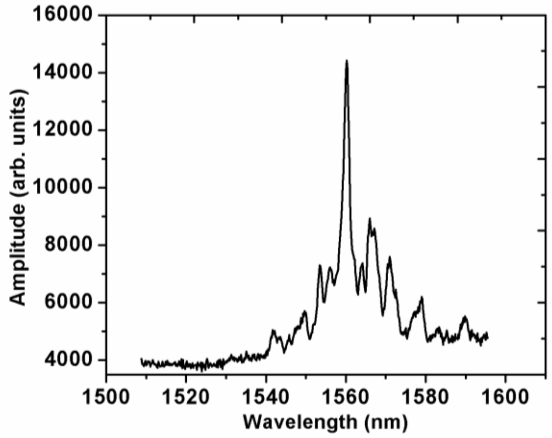

Figure 5: Spectrum of an FBG inscribed using the Pl-by-Pl inscription method on the Tecsolut POF NTO34NTC5

5. Measurements with the Fibre Bragg Grating

The sensing and measuring capabilities of the FBG inscribed with the plane-by-plane method on the Tecsolut POF were demonstrated for temperature and ambient pressure. Figure 6 (left) depicts initial results for the temperature response of the FBG peak wavelength, as measured in a climate chamber. Figure 6 (right) shows a measured response to ambient pressure, when the POF was inserted into a controlled pressure vessel.

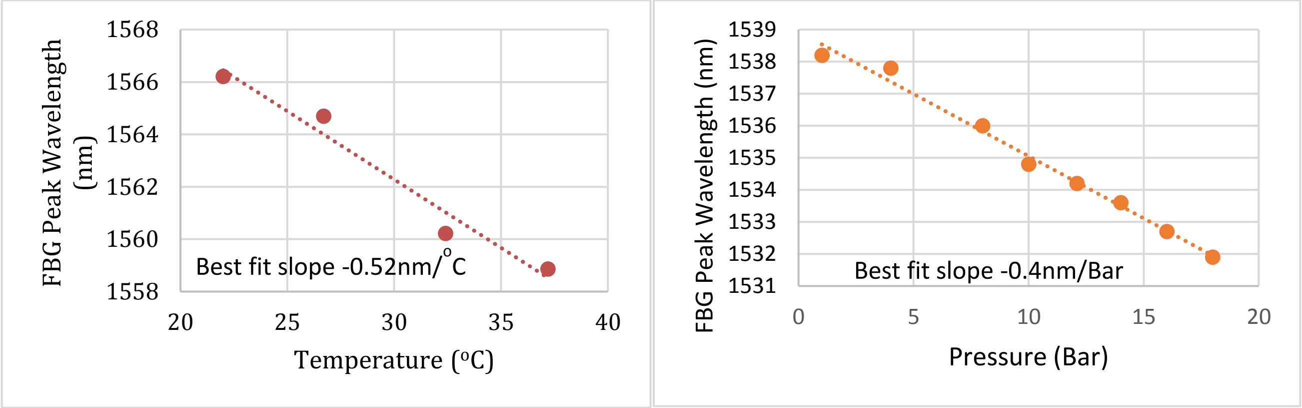

Figure 6: Wavelength response of the POF-FBG to (left) temperature and (right) ambient pressure

We would like to emphasize that the above results were not easily reproducible, and some of the experiments yielded different behaviours. We attribute this fact to hysteresis effects characterizing POFs in general as well as the highly multimode nature of the 580µm step-index POF, making reproducible and constant mode excitation of the POF very difficult. As noted these are preliminary results and additional characterization and preferably smaller core fibres are needed.

6. Conclusions

We have successfully manufactured and characterised a new type of a non-PMMA polymer optical fibre, produced by the Light Polymerization Spinning (LPS) process, which allows manufacturing of fibres with a wide range of mechanical properties. Also, using the plane-by-plane femtosecond laser inscription method, an FBG has been successfully inscribed on such fibres. For the first time, actual measurements have been performed with such a device demonstrating clear sensitivity to changes in temperature and pressure, though more work is needed in order to achieve reproducible, commercial grade results.

7. References

[1] O. Palchik, V. Palchik “Thermoset and thermoplastic fibers and preparation thereof by UV curing” US patent 20140294917.

[2] O. Palchik, N. Tal, E. Shafir, S. Zilberman, A. Theodosiou, K. Kalli “Characteristics of photo polymerized polymer optical fibres, optical properties and femtosecond laser inscription of Bragg gratings”, POF-2016 – 25th International Conference on Plastic Optical Fibres, Conference Proceedings, pp. 78-81 (2017).

[3] See for example: M.G. Kuzyk, Polymer Fiber Optics: Materials, Physics, and Applications (CRC Press Boca Raton, FL.) 2007, p 146.

[5] A. Lacraz, M. Polis, A. Theodosiou, C. Koutsides, K. Kalli, “Femtosecond laser inscribed Bragg grating in low loss CYTOP polymer optical fiber”, IEEE Photonics Technology Letters, 27, 7, 693-696, (2015)