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Humidity insensitive step-index polymer optical fibre Bragg grating sensors

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ABSTRACT

We have fabricated and characterised a humidity insensitive step index(SI) polymer optical fibre(POF) Bragg grating sensors. The fibre was made based on the injection molding technique, which is an efficient method for fast, flexible and cost effective preparation of the fibre preform. The fabricated SIPOF has a core made from TOPAS with a glass transition temperature of 134^{0}C and a cladding from ZEONEX with a glass transition temperature of 138^{0}C. The main advantages of the proposed SIPOF are the low water absorption and good chemical resistance compared to the conventional poly-methyl-methacrylate (PMMA) based SIPOFs. The fibre has a minimum loss of ~6dB/m at 770nm.

Keywords: Injection molding, Fibre fabrication, Polymer optical fibre, Fibre Bragg grating , Fibre optic sensor

1. INTRODUCTION

Interest in polymer optical fibre have increased considerably because of their very low processing temperature, high flexibility in bending, high fracture toughness, ease of handling, and non-brittle than that of glass fibre[1,2]. In addition, POFs are considered ideal candidates for biosensing applications due to their biocompatibility[3, 4]. POFs have also high elastic strain limits and low Young's modulus, these properties giving them great potential for fibre Bragg grating based high strain and acceleration sensing applications [5- 9]. The most common technique that have been used in the past to fabricate SIPOFs is by doping the core of a PMMA fibre with different active materials such as trans-4-stilbenemethanol, Rhodamine B, benzil dimethyl ketal(BDK), etc. for FBG sensors or broad band amplification applications[10-12]. SIPOFs that are made of PMMA have low operating temperature and affinity for water, which make them sensitive to humidity [13]. Thus, the response of FBG sensors based on these fibres presents strong dependence both on temperature and humidity[13-15]. Here we demonstrate for the first time the fabrication of a humidity insensitive SIPOF made of TOPAS grade 5013S-04 with Tg = 135°C as a core and ZEONEX 480R with Tg = 138°C as a cladding. The polymers TOPAS and ZEONEX belongs to the class of cyclic olefin copolymers (COCs)[16] and cyclo-olefin polymer(COP)[17],respectively. These polymers are a class of optical thermoplastics that are chemically inert and have a very low moisture uptake [16-17]. Fiber Bragg grating has been successfully demonstrated in TOPAS fibre[18.] It has been also demonstrated that different TOPAS grades have high operation temperature[19] and are humidity insensitive [20], which make them a potential candidates for humidity insensitive FBG sensors.

2. STEP INDEX PREFORM AND FIBRE FABRICATION

The SIPOF was fabricated in-house at DTU Fotonik. First a SI preform was prepared by injection molding technique. Preparation of SI preform involved casting ZEONEX granulates into solid rod [21]. The particular grade that has been used was ZEONEX® 480R produced by ZEON CORPORATION, which has a glass transition temperature (Tg) of 138 °C [22]. This polymer is suitable for engineering applications requiring mechanical stability at high temperature. After casting, the solid rod was machined to a uniform bulk preform of 60mm diameter and 100mm length. Then a single hole with a diameter of 4 mm is drilled at the center of the preform. The second phases of preparation of SI preform involved injecting TOPAS® 5013S-04 into a 4mm hole of prepared ZEONEX preform. TOPAS® 5013S-04 granulates is obtained

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from TOPAS Advanced Polymers, Inc, and it has a glass transition temperature (Tg) of 134 °C [23]. Engel ES 80/25 HL-Victory injection molding machine has been used for injecting the TOPAS into the host ZEONEX. These two materials have been chosen for several reasons. As TOPAS is cyclic olefin copolymer (COC) and ZEONEX is cyclo-olefin polymer (COP) they have a very close chemical, mechanical and optical properties. In addition, the selected grades of these polymers have almost the same glass transition temperature and very close refractive index with TOPAS 5013S-04 refractive index higher than ZEONEX 480R. Different injection temperatures were preliminarily tested with the aim of optimizing the transparency of TOPAS. Interestingly, a decrease in the injection temperature seemed to lead to increasing its transparency while being injected. Nevertheless, it was not possible to lower temperature too much, since TOPAS would become too stiff to be processed. The optimal injection temperature was found to be around 200 °C. TOPAS was then injection molded into the central hole of the ZEONEX solid rod at an injection pressure slightly lower than the machine limit, which is approximately 2000 bar. Then the SI preform was first drawn to 5mm cane. Then after the 5mm cane is sleeved and drawn to a fibre of a diameter 150μm. The core diameter of the fibre is 15μm. The end facet of the TOPAS-ZEONEX SIPOF is shown in Figure 1.

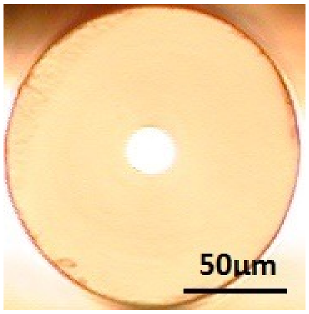

Figure 1. Microscope image of the step index TOPAS-ZEONEX polymer optical fibre

3. FIBRE CHARACTERISATION AND FBG INSCRIPTION

The transmission loss of the SIPOF was measured using the cut-back method. The light from Supercontinuum source (NKT Photonics A/S) was butt-coupled to SIPOF. The other end of the SIPOF coupled to standard single mode fibre, which is connected to Optical Spectrum Analyzer (OSA, Ando AQ6315A) to record the output transmission spectrum of the POF. The end face of the output SIPOF was cleaved with a custom-made cleaver at a temperature of 75°C which it has been shown to be optimum cleaving temperature for both the blade and the fiber [24]. The measured loss profile of the SI TOPAS-ZEONEX POF is shown in Figure 2. The minimum loss was measured to be ~6dB/m at 780nm and 10dB/m at 850nm.

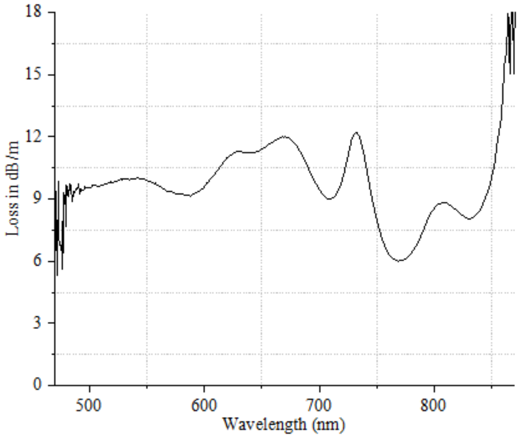

Figure 2. Measured transmission loss of step index TOPAS-ZEONEX polymer optical fibre

Grating has also been inscribed in the fabricated SIPOF using phase mask technique. The technique we use for inscribing FBGs is the phase mask writing technique and it is the same configuration as it was used for fast FBG inscription in PMMA mPOF[25]. The phase mask used for inscribing grating in the SIPOF has 572.4nm uniform period, and it is suitable for writing FBGs at 850nm using a He-Cd 325nm laser. Typical reflection spectrum of a 3mm grating inscribed in the SIPOF is shown in Figure 3.

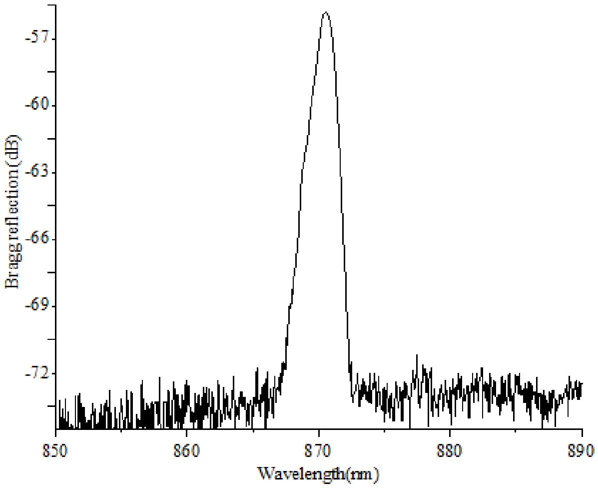

Figure 3. Reflection spectrum of the step index TOPAS ZEONEX polymer optical fibre

4. CONCLUSION

In this work, we have fabricated for the first time a humidity insensitive step index polymer optical fibre using injection molding technique. This technique provided a fast and flexible method of preparing step index preform. The fabricated step index polymer optical fibre has a core made from TOPAS 5013S-04 with a glass transition temperature of 134^{0}C and a cladding from ZEONEX 480R with a glass transition temperature of 138^{0}C. The step index fibre has a minimum transmission loss of 6 dB/m at 770nm and 10 dB/m at 850nm. The loss of the SIPOF can be further reduced by improving the fabrication technology and method. A fibre Bragg grating has also been inscribed in the step index TOPAZ ZEONEX polymer optical fibre. We believe that FBGs inscribed in this step index fibre are particularly suitable for sensing applications that require high operating temperature and very low moisture absorption polymer optical fibre Bragg grating.

5. ACKNOWLEDGMENTS

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