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Strain sensing characterization of polymer optical fibre Bragg gratings

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ABSTRACT

Static tensile strain is applied to polymer optical fibre Bragg gratings for the strain sensing characterization. Experimental results indicate that the strain coefficient of polymer fibre Bragg gratings is larger than that of silica fibre Bragg gratings. It is also demonstrated the large strain sensing range with good reproducibility, reversibility and repeatability is achieved. As a result, the study shows the great potential of polymer fibre Bragg gratings in the fibre strain sensing applications.

Keywords: strain sensing, fibre Bragg gratings, polymer optical fibre, strain sensitivity

I. INTRODUCTION

Silica fibre Bragg gratings have been well developed as important photonic elements. Their features such as wavelength selectivity, wavelength tunability, dispersion characteristics have lead silica fibre Bragg gratings to many important applications in optical communication, sensing and signal processing systems¹. However, silica fibre Bragg grating has limitations in its strain sensing applications. For example, the break-down strain of silica fibre is rather small. Hence, silica fibre Bragg gratings is only stretched to 0.1% without further degradation². Furthermore, due to the poor elasticity of silica material, the sensitivity of the silica fibre Bragg gratings sensors is hard to be further improved. Nevertheless, because of the properties of polymer materials, polymer optical fibre (POF) Bragg gratings based sensors could achieve much better strain sensing characteristics if they are fully developed.

POF Bragg gratings could have remarkable improvements over glass fibre gratings because the bulk thermo-optic, electro-optic and strain sensitivities of polymer are tens of times or more than those of glass. The major advantages of the POF Bragg grating for strain sensing are its low Young's modulus and large break-down strain. Therefore, POF Bragg grating is expected to offer much larger sensing range with higher strain sensitivity. Based on the above consideration, we, Photonics and Optical Communication Group at UNSW, initiated the research and development of Bragg gratings in POFs. We first studied the photosensitivity of PMMA-based optical fibres and reported the first POF grating in the world³. Recently, we have got some significant progresses in this field. First, we have achieved POF Bragg gratings with reflectivity higher than 99.9%⁴. These are the best results ever reported on POF gratings. Further research on grating formation mechanisms and growth dynamics has lead to new insights into this particular topic area⁵.

Because of the promising applications in strain sensing fields, the strain sensing characterization of POF Bragg grating turns out to be very important and attractive. In this paper, the systematic investigation on static tensile strain characterization of POF Bragg gratings will be reported. The research on the strain characterization of POF Bragg grating is very significant for its further applications.

2. EXPERIMENTAL SETUP

The fibre Bragg gratings are made on the PMMA based POF. Details for the fabrication of photosensitive single mode POF can be found in our previous publication⁶. The outer diameter of the fibre is 133 μm with the core diameter of 6 μm . The difference in the refractive index between the core and the cladding is 0.0086. The fibre Bragg grating is prepared using the technique described in our previous publication⁷ which is an adaptation of the transverse method developed by Meltz, Morey and Glenn with the introduction of a static ring interferometer based on the patent invented by Ouellette. The UV writing beam is obtained from a frequency-doubled MOPO pumped by a frequency-tripled Nd:YAG laser. The

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output UV light is in short pulses with the width of 5 ns and the repetition rate of 10 Hz. The wavelength of UV light for polymer fibre gratings fabrication is 325 nm.

The strain characterization of POF Bragg gratings is investigated by the mechanical stretching, whose basic concept is

Figure 1 Scheme of the strain sensing characterization of POF Bragg gratings.

shown in Fig. 1. The two ends of the POF Bragg gratings samples are glued and fixed on two steel blocks, which are connected to two micropositioners. One of the micropositioners is fixed and the other can be moved longitudinally to apply axial tensile strain on the POF Bragg grating sample. The axial strain values are determined by dividing the fibre longitudinal extension displacement, ΔL_z , by the total length of POF, L_z , shown in Fig. 1. The longitudinal displacement accuracy of the moving micropositioner is 0.01 mm. The micropositioner is manually tuned to apply the tensile strain and the loading speed is about 1 mε/min. The reflection spectra of the POF Bragg gratings are recorded as the tensile strain is applied.

3. STRAIN SENSING CHARACTERIZATION OF POF BRAGG GRATINGS

The reflectivity of the POF Bragg gratings used for the strain characterization is about 50% and the reflection output of

Figure 2 Reflection spectra of POF Bragg gratings at different mechanical tensile strain.

the POF Bragg gratings under different tensile strain is shown in Fig. 2. The first spectrum corresponds to the original reflection before any tension is applied, with the Bragg wavelength at about 1536.4 nm. The following ones are the reflection spectra of POF Bragg gratings at different external strain. In Fig. 2 the maximum tensile strain is 3.61% and the corresponding Bragg wavelength is 1589.1 nm. This means the POF Bragg gratings can be easily tuned over 50 nm by the simple tension. It can be also seen from Fig. 2 that there are no obvious changes in the reflection level and spectrum shape when the tensile strain is less than 2.22%. When the strain is greater than 2.22%, the reflection level becomes smaller and the line width of the spectrum also becomes wider.

Fig. 3 displays the Bragg wavelengths of POF Bragg gratings at different tensile strain. The very high linearity of the Bragg wavelength shift over the whole strain tuning range, indicated by the regression R-squared value of 0.9995, has been achieved. The regression line in Fig. 3 is expressed as,

$$\lambda_B = 1535.6 + 1.464 * \varepsilon(\text{milli-strain}), \quad (1)$$

where λ_B is the Bragg wavelength of POF Bragg gratings and ε is the applied tensile strain. Therefore, the Bragg wavelength change ratio is,

$$\Delta\lambda_B / \lambda_B = 0.953 * \varepsilon. \quad (2)$$

Therefore, the strain coefficient of POF Bragg gratings is 0.95, which is larger than that of silica fibre Bragg gratings. With the higher strain sensitivity and the much larger break-down strain, POF Bragg grating could be the better replacement of silica fibre Bragg gratings in the strain sensing applications.

Apart from the sensing range, reproducibility and reversibility are the other two important aspects to examine in the strain characterization of fibre Bragg gratings. Reproducibility is to check the variation of fibre gratings strength at the different applied strain, while the reversibility is to examine the Bragg wavelength variation during the loading-

unloading process. In the loading-unloading experiment, the tensile strain is gradually applied on the POF Bragg gratings up to certain value (loading process) and then gradually released to the zero stress state (unloading process). During the course, the reflection spectra of the POF Bragg gratings at each step are monitored and the Bragg wavelengths and reflection peak level are recorded.

Figure 3 Bragg wavelengths of POF Bragg gratings at different tensile strain.

The variation of the reflection peak for POF Bragg gratings at different tensile strain is recorded and shown in Fig. 4. Below the strain value of 2.22%, the reflection peak level only changes by less than 0.3 dB. With the further increase of tensile strain, the reflection will decrease continuously. At the tuning strain of 3.61%, the reflection level decreases by about 4 dB. Further cyclic loading-unloading test with the maximum strain of 2.22% shows that the reflection peak level variation of POF Bragg gratings is less than 0.5 dB. Therefore, POF Bragg gratings have excellent reproducibility when the tensile strain is less than 2.22%.

Figure 4 Reflection peak of POF Bragg gratings at different tensile strain.

The reversibility of POF Bragg gratings with the maximum strain up to 2.22% has also been examined. The Bragg wavelength variation at both the loading and unloading process is shown in Fig. 5. The circle data in the figure are the Bragg wavelengths obtained during the loading process, while the cross symbols represent the Bragg wavelengths obtained in the unloading process. From the graph, it is obvious that the Bragg wavelength variation curve of the loading process is coincident excellently with that of unloading process, thus indicating the good reversibility. The linear regression is also made according to the data. The regression R-squared value in this case reaches to 1, showing the very high linear relation between the Bragg wavelength and the external strain. From the data in Fig. 5, the strain coefficient is also calculated, which is 0.94. This is about the same as what we've got in Eq. (3).

The repeatability of the POF Bragg gratings with the maximum strain of 2.22% has also been examined. Experiment with twenty cycles of repeatable loading-unloading process on the POF Bragg gratings has been carried out. The strain-Bragg wavelength curves at the different loading-unloading cycles seem to coincide quite well with each other and no obvious decay of the grating strength is observed, indicating an excellent repeatability. As a result, POF Bragg gratings are very promising as strain sensors, offering high sensitivity and large sensing range with excellent reproducibility, reversibility and repeatability.

Figure 5 Bragg wavelengths of POF Bragg gratings under the reversible tensile strain test, where the maximum strain is 2.22%.

4. CONCLUSIONS

The tensile strain characterization of POF Bragg gratings is examined. It is found out that the strain coefficient of POF Bragg gratings is about 0.95, which is higher than that of silica fibre Bragg gratings. This reveals the higher strain sensitivity of POF Bragg gratings. In addition, the relation between the tensile strain and Bragg wavelength shift is highly linear. Further investigation indicates that the large strain sensing range with excellent reproducibility, reversibility and repeatability is also achieved. Consequently, POF Bragg gratings could be very capable sensors in the fibre strain sensing systems.

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