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Polymer Fiber Bragg Gratings With 28-dB Transmission Rejection

H. Y. Liu, G. D. Peng, and P. L. Chu

Abstract—**Polymer fiber Bragg gratings (FBGs) with 28-dB transmission rejection and a line width less than 0.5 nm has been achieved for the first time. This result is achieved based on the systematic investigation of growth dynamics of polymer FBGs. We have observed that the growth of polymer FBGs bears some similarities to that of silica FBGs. This work links the mechanism of polymer fiber gratings formation to silica fiber grating and helps to gain better understanding of polymer fiber grating formation process.**

Index Terms—**Fiber Bragg gratings (FBGs), poly-methyl methacrylate (PMMA), polymer optical fiber (POF), refractive modulation index.**

I. INTRODUCTION

PHOTOSENSITIVITY in silica fiber was first revealed by Hill *et al.* in 1978 [1], then fiber Bragg gratings (FBGs) have been developed for many important applications in optical communication systems such as dispersion compensation, ADD–DROP wavelength-division multiplexing (WDM), and optical sensing, etc. [2]–[5]. However, the tunability of silica fiber gratings is not particularly large. Typically, silica fiber gratings can only be tuned within 6 nm by temperature and mechanical stress [6]. Though a broader range ($>$36 nm) can be achieved by compression tuning [7], [8], its reproducibility and reversibility is low [9]. Furthermore, complicated and bulky components are required for the performance.

Tunability for polymer fiber gratings is expected to be much better because of its much higher elasticity, or much smaller Young's modulus. In recent years, some significant work on planar polymer technologies for telecom and datacom has been carried out and high quality Bragg gratings have been produced in the polymer waveguides [10], [11]. We have succeeded in developing Bragg gratings in poly-methyl methacrylate (PMMA) based polymer optical fibers [12]. Furthermore, it is demonstrated that polymer fiber gratings have very high tunability in comparison with silica fiber gratings [13]. A tuning range of 73 nm by tensile strain variation [14] and 18 nm by temperature change from 20 °C to 80 °C [15] have been achieved in PMMA-based polymer fiber.

However, in those previous research on PMMA-based polymer FBGs, the maximum rejection in transmission is only about 6 dB. In our present work, we thoroughly investigate the growth dynamics of POF Bragg gratings. Based on the research, by optimizing the UV illumination conditions we are able to fabricate grating with 28-dB transmission rejection, which is so far the largest value for POF Bragg gratings to the author's knowledge. A line width of less than 0.5 nm for the rejection band is also achieved. In addition, the growth dynamics study helps to understand the mechanism of POF Bragg gratings formation as well.

II. POF BRAGG GRATING FABRICATION

Details for the fabrication of the photosensitive single-mode POF were described in our previous publications [14]. The diameter of the fiber is 133 μm with a core diameter is 6 μm. The difference in the refractive index between the core and the cladding is 0.0086, which was measured using the transverse interference method with a microscope after the fiber was drawn. Thus, the fiber is single moded in the 1550-nm window. The FBG was prepared using the technique described in our previous publication [13] 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 Ouellettee. The period of the phase mask is 1.06 μm, which was designed for use at 248 nm. The UV writing beam was obtained from a frequency-doubled MOPO pumped by a frequency-tripled Nd:YAG laser. The UV laser beam was not focused and has an effective spot size of 3 mm. The wavelength of UV light for POF gratings fabrication in our case is 325 nm. In the course of gratings inscription, we use Advantest Q8384 optical spectrum analyzer to monitor its transmission spectra.

III. GROWTH DYNAMICS OF POF BRAGG GRATINGS

The transmission spectra of POF gratings at different UV exposure time are shown in Fig. 1. An obvious change in transmission at around 1574 nm can be observed after 12-min exposure. Then the maximum rejection level increases slowly until 62 min of exposure. After that, the rejection level increases significantly with further exposure. At 67th min, the rejection level is even doubled of that at 62nd min. At the exposure time of 85 min, the transmission at the Bragg wavelength even goes down to the noise level.

Fig. 2 displays the transmission spectra of the POF gratings when the UV radiation goes on after 85th min. It is shown that the transmission level for the rejection band stays unchanged

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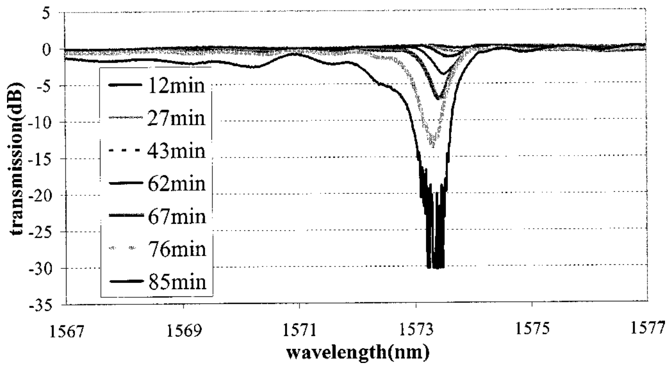

Fig. 1. The transmission spectra of POF gratings at different UV exposure time.

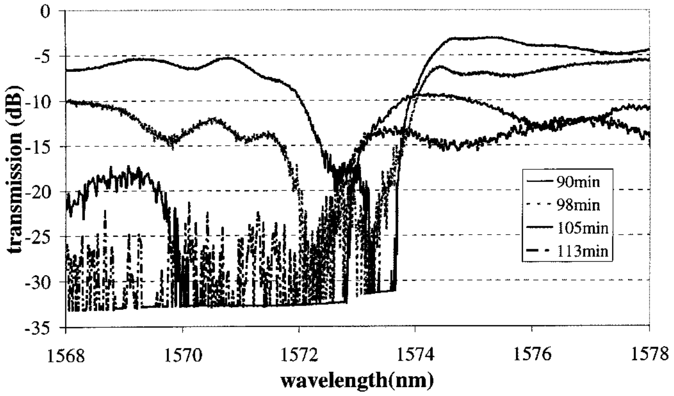

Fig. 2. Transmission spectra of POF gratings over-exposed after 85th min.

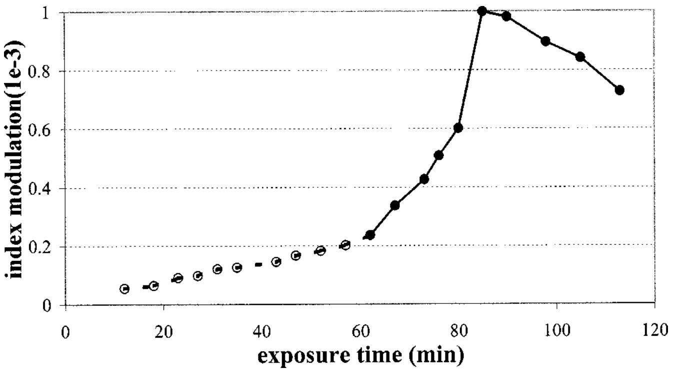

Fig. 3. Refractive index modulation of POF Bragg gratings at different UV radiation time.

while the line width of band becomes larger with further exposure. At the same time, the loss to the shorter wavelength increases as well.

The refractive index modulation Δn of the gratings were estimated from the spectra using the results of coupled mode theory. Δn values corresponding for the gratings at different inscription time are assembled in Fig. 3. It is apparent that a sharp threshold occurs at the time around 62nd min. Before that, Δn increases almost linearly, which is shown by the dotted line. Whereas after that Δn increases dramatically to the maximum value at 85th min. At 85th min, Δn gets to the value even four times greater than that at 62nd min and an index modulation high up to 10^{-3} is achieved. When the POF is over-exposed after 85th min, the index modulation gradually goes down.

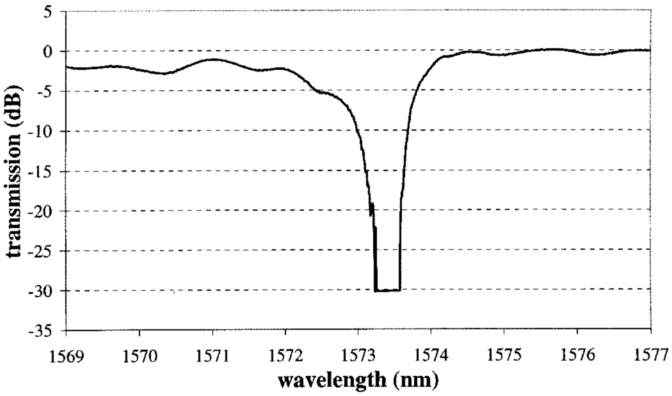

Fig. 4. Transmission spectrum of POF Bragg gratings at the optimized exposure time, with 28-dB transmission rejection and a line width less than 0.5 nm.

From the results above, we can find that there is an optimized UV exposure energy level for the POF fiber gratings to achieve the maximum modulation index and small line width. Under our experimental conditions, the optimal level is at an exposure of 85 min. The transmission spectrum with higher accuracy measurement for the POF gratings fabricated by 85-min exposure is displayed in Fig. 4. The spectrum indicates at least 28 dB (limited by measurement system) extinction at the Bragg wavelength, which means that only less than 0.2% of the light is transmitted. The line width of less than 0.5 nm is also achieved. The unidentified ripples in transmission spectra might be due to the coupling to cladding modes and can be eliminated by printing the gratings with uniform strength across cladding/core/ cladding [11].

Compared with the growth dynamics of Ge-doped silica fiber grating, the behavior of the Δn versus UV exposure energy of polymer fiber grating (Fig. 3) is quite similar. In the process of silica fiber grating fabrication, there is also a threshold of exposure energy, below which the index modulation grows linearly. When above the threshold point, the induced index modulation increases dramatically and becomes saturated [17]. Consequently, we can also categorize the POF gratings formed in low (the dotted line areas) and high (the solid line areas) index modulation regimes as type I and type II, respectively, as they did in Ge-doped silica fiber [17]. For type II POF gratings, the line width of the gratings becomes large and the loss to short wavelength is also high, which is exactly the same as type II silica fiber gratings. The mechanism for type II silica fiber Bragg grating is that the damages on the boundary of core and cladding caused by UV exposure strongly couples the transmission light into cladding modes [17]. Though we have not carried out any work to prove it, we can deduce the same mechanics for POF Bragg gratings from the similar spectra.

Another note worthy feature of the POF Bragg grating growth dynamics is that the Bragg wavelength of type I gratings shifts to the blue part of the spectrum in the process of grating fabrication, which means the average refractive index is decreased and Δn is negative. Type I gratings is supposed be due to the refractive index change in the core induced by UV exposure. There are several researches on the mechanism of formation of periodic structures in polymer. They can be classified into photolysis, oxidation, and laser ablation for the surface relief gratings, while chain scission and photopolymerization are considered to be responsible for bulk or volume gratings and the infiber gratings. Further work on the mechanism of POF gratings formation still needs to be completed, but our present work clearly indicates that the reactions to decrease the refractive index are responsible for the type I POF gratings.

IV. CONCLUSION

By investigating the growth dynamics and optimizing the UV exposure conditions, we have fabricated polymer FBGs with much better performance—28-dB transmission rejection and the line width less than 0.5 nm under the optimal UV exposure conditions. Our experimental observation revealed, for the first time, the growth characteristics of polymer fiber grating similar to that of silica FBGs. We found the existence of a threshold of UV exposure energy with regard to grating index modulation. Below the threshold, the induced index modulation grows linearly. While above it, the index modulation increases dramatically to maximum. This is clear evidence that the POF Bragg grating experiences the type I and type II of index modulation regimes, respectively, similar to the cases in silica fiber. Furthermore, optical spectra for type II POF gratings are found in resemblance to that of silica fiber gratings, suggesting that the optically induced damage may also be the cause of type II polymer fiber grating formation. Another feature worth noting is that the Bragg wavelength of type I POF gratings shifts to the blue part of the spectrum in the course of the grating inscription, which indicates that the type I POF gratings is due to the refractive index decrease induced by UV exposure.

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