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Author/Contributor:
Liu, Hongbo; Peng, Gang-Ding; Chu, Pak; Liu, Huiyong

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Novel Growth Behaviors of Fiber Bragg Gratings in Polymer Optical Fiber Under UV Irradiation With Low Power

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

***Abstract*—Some novel behaviors in fiber Bragg gratings (FBGs) growth have been observed when the polymer optical fiber are exposed to low-power level of ultraviolet (UV) irradiation. For the first time, we observed the growing and erasing of polymer FBGs under UV exposure, and regrowing after the UV exposure is OFF. The growth behaviors are quite different in contrast with the previously reported Type I and Type II polymer optical FBGs behaviors. This discloses that polymer FBG growth is a writing-power-dependent process.**

***Index Terms*—Polymer fiber Bragg grating (FBG), polymer optical fiber (POF), thermal stress, Type I and Type II fiber Bragg gratings (FBGs).**

I. Introduction

THE RESEARCH regarding polymer optical fiber in the past decades has shown its potential applications in telecommunications. Furthermore, it can also be the backbone of many optical devices. For example, its photosensitivity is essential to produce fiber Bragg grating (FBG), a very important and potential optical device in optical telecommunication and sensing fields. Due to the smaller Young's modulus and larger thermooptic coefficient than silica, polymer FBGs might be advantageous over silica FBGs in some applications. Useful photosensitivity has been found in polymethyl methacrylate (PMMA)-based polymer optical fiber; moreover, a grating with 28-dB transmission rejection has also been achieved [1]. The further strain and thermal characterization of polymer FBGs demonstrate a tuning range of 73 nm in Bragg wavelength shift by tensile strain variation [2], and more than ten times of thermal sensitivity than silica FBGs [3].

Although some significant work has been achieved in polymer FBG research, a lot of questions regarding the formation mechanism and the growth behavior still remain unanswered. In our previous work, we reported the distinctive Type I and Type II polymer FBG growth behavior when the gratings were fabricated under the ultraviolet (UV) pulse irradiation with the power level of 6 mJ. During the grating inscription process, the polymer FBG grew slowly with the increase of UV exposure, whereas, it grew extraordinarily when the UV fluence exceeded the threshold. This observed growth behaviors were similar to that for silica FBGs [4]. Nevertheless, we do not think it is the comprehensive picture for the growth dynamics of polymer FBG. Recently, we investigated the grating growth behavior when the polymer optical fiber is exposed to UV pulses with lower power level. A totally different growth behavior from the Type I and Type II growth behaviors previously reported has been found. For the first time, we have observed the growing and erasing of polymer FBG under UV exposure, and regrowing of the grating after the UV irradiation is OFF. This interesting observation will give us insights into the formation mechanism of polymer FBGs.

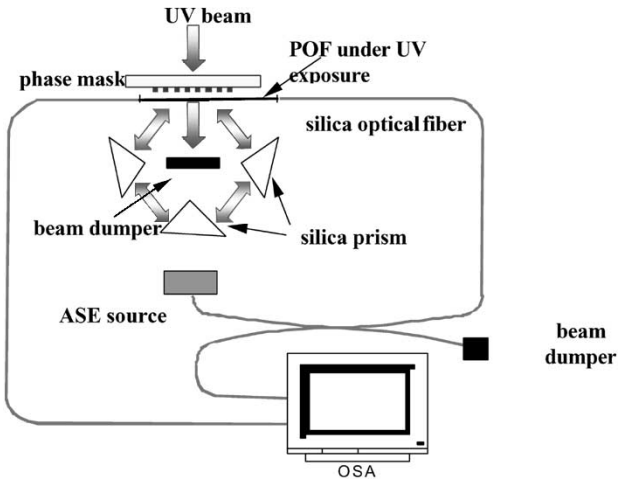

Fig. 1. Polymer FBG fabrication and measurement systems.

II. Experiment Setting

The polymer fiber used for grating fabrication is PMMA based polymer optical fiber (POF), which is the same as that in our previous report [4]. The details of the polymer fiber fabrication can be referenced in our earlier publications [5], [6]. The outer diameter of the polymer fiber is 125 μm with a core diameter of 6 μm. The difference in the refractive index between the core and the cladding is 0.0086. The fiber is single-mode in the 1550-nm window. The polymer FBG is prepared using the setup with the introduction of a static ring interferometer based on the patent invented by Cortes *et al.* [8]. The fabrication and measurement setup is shown in Fig. 1. The UV writing beam is obtained from a frequency doubled master oscillator power oscillator (MOPO) laser system pumped by a frequency tripled Nd : YAG laser. The output UV light is in short pulses with the width of 5 ns and the repetition rate of

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H. B. Liu, H. Y. Liu, and G. D. Peng are with the Photonics and Optical Communications Group, University of New South Wales, Sydney 2052, Australia (e-mail: hongbo.liu@student.unsw.edu.au).

P. L. Chu is with the Optoelectronics Research Centre, City University of Hong Kong, Kowloon, Hong Kong (e-mail: eepchu@cityu.edu.hk).

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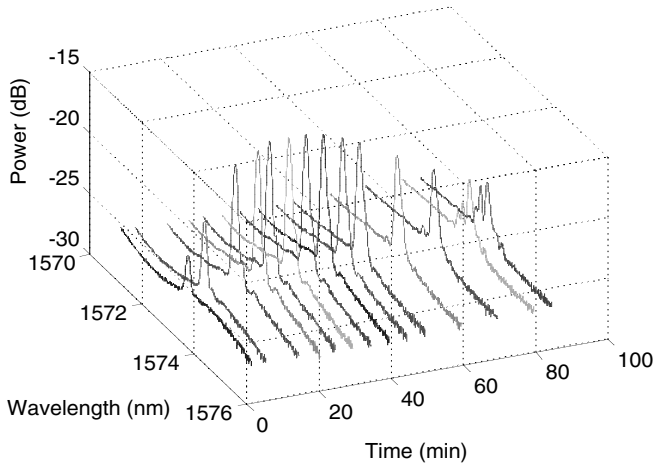

Fig. 2. FBG growth versus time (with UV exposure at power 4.5 mJ).

10 Hz. The wavelength of UV light for polymer FBG fabrication is 325 nm. The polymer optical fiber has been butt joint with single-mode silica fiber for the convenience of grating measurement. In the course of the grating inscription, the transmission and reflection spectra of the grating are monitored by an optical spectrum analyzer. An amplified spontaneous emission source is used as an optical source for polymer FBG measurement. The energy of the UV beam is measured by a Newport power meter. The UV beam energy for this experiment is 4.5 mJ, which is lower than that in our previous work [4].

III. Experiment Results

Fig. 2 shows the dynamic growth process of the polymer FBG under UV exposure with power level of 4.5 mJ, where its reflection spectra at different UV exposure time are demonstrated. A noticeable reflection peak can be observed after 5-min exposure; then the grating continues to grow stronger with further exposure. With proactive irradiation after 28 min, there are no dramatic changes in the reflection peak until the grating reflection peak starts to decrease after 48 min, indicating an onset of the grating erasing process. At 88 min, the peak level becomes negligibly small. Then, the UV irradiation is OFF. The transmission rejection level of the above polymer FBGs is very small, demonstrating rather small index changes in the polymer FBGs. The reflection peak of the polymer FBG becomes less defined at the very long UV exposure time, say later than 70 min.

After we stop the UV illumination, we keep on monitoring the reflection and transmission spectra of the polymer FBG fabricated above. Amazingly, we find out that the polymer FBG begins to regenerate only a couple of minutes after the UV is OFF. Furthermore, the polymer FBG becomes stronger with time passing. Fig. 3 displays the reflection and transmission spectra of the polymer FBG after the UV irradiation are OFF. The reflection peak begins to reappear and the transmission rejection dip becomes noticeable in 10 min after the UV pulse is OFF. Then, the polymer FBG keeps growing stronger. After about 8 h, there are no noticeable changes in the reflection peak level (we continued to observe up to 24 h).

Fig. 4 shows the reflectivity of the polymer FBGs versus time after the UV irradiation is OFF. It is clearly shown that the regrowing of the polymer FBG happens faster at the first hour then slows down. At about 8 h, no more regrowing occurs and the polymer FBG becomes stable afterwards. The reflectivity of the polymer FBG formed at last is 61.7%, which corresponds to the refractive index change of 2.6×10^{-4}. The refractive index change value falls in the regime of Type I polymer FBG categorized in our previous work [4]. Moreover, we had a close check on the reflection and transmission spectra of the polymer FBG formed and found out that they are complementary. These evidences indicate that the polymer FBG formed above might be Type I polymer FBG. Further study on the thermal and strain characterization of the polymer FBG needs investigation. This will help us identify the polymer FBG formed above.

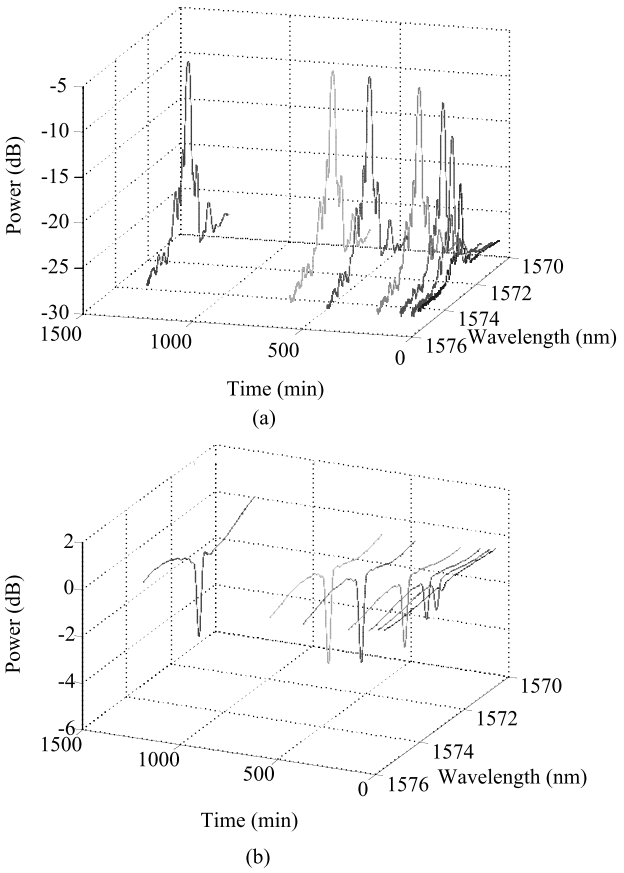

Fig. 3. Polymer FBG reflection and transmission spectra after UV irradiation are OFF.

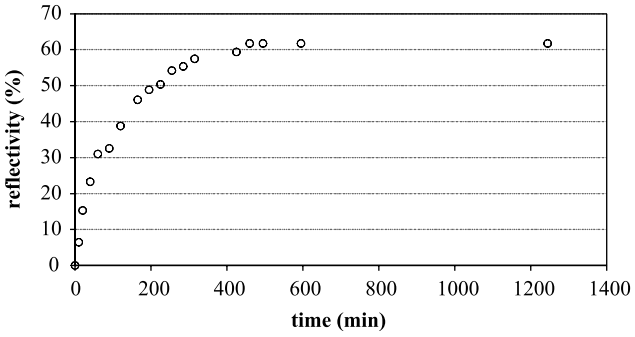

Fig. 4. Reflectivity of polymer FBG versus time after UV irradiation is OFF.

So far it is still not clear about the mechanism of this novel polymer FBG growth behavior. But we do believe that the thermal stress induced by UV irradiation in polymer optical fiber plays an important role. The thermal stress might induce the refractive index change with an opposite sign of that induced by UV photoreactions to the polymer fiber. With UV irradiation ON, the polymer FBG measured is the compromise of two effects: refractive index change induced by thermal stress and UV photoreaction. After the UV exposure is OFF, the thermal stress will be relaxed with time and its induced refractive index change will be eliminated gradually. The refractive index change by the UV photoreaction is permanent and will not change with time; therefore, the regrowing phenomena of the polymer FBG will occur. The polymer FBG becomes stable when the thermal stress is completely relaxed.

Apparently, with the above observation, it clearly demonstrates a novel polymer FBG growth behavior, which is quite different from the Type I and Type II polymer FBG behaviors previously reported [4]. The reason for this novel grating behavior from the previous observation is the low UV irradiation power. Under the low UV irradiation power, we observed the growing and erasing of polymer FBG during UV exposure, and the regrowing of the grating after UV irradiation is OFF. Therefore, the growth behavior of polymer FBG is a UV power-dependent process.

IV. Conclusion

A novel grating growth behavior for polymer FBG is observed to when it is exposed to low-power UV pulses. This growth behavior is quite different from the Type I and Type II polymer FBG growth behavior previously reported. In this novel behavior, the growing and erasing of polymer FBG happens when the UV irradiation is ON; and regrowing of the polymer FBG occurs after the UV exposure is OFF. The polymer FBG formed under low-power UV irradiation has a small refractive index change, which falls in the regime of Type I polymer FBG categorized in our previous study. The study on the novel growth behavior of polymer FBG will give significant insight on the formation mechanism of polymer FBGs.

References

[1] H. Y. Liu, G. D. Peng, and P. L. Chu, "Polymer fiber Bragg gratings with 28 dB transmission rejection," *IEEE Photon. Technol. Lett.*, vol. 14, pp. 935–937, July 2002.

[2] Z. Xiong, G. D. Peng, B. Wu, and P. L. Chu, "73 nm wavelength tuning in polymer optical fiber Bragg gratings," in *Proc. 24th Australian Conf. Optical Fiber Technology (ACOFT'99)*, Sydney, NSW, Australia, July 1999, pp. 135–138.

[3] H. B. Liu, H. Y. Liu, G. D. Peng, and P. L. Chu, "Strain and temperature sensor using a combination of polymer and silica fiber Bragg gratings," *Opt. Commun.*, vol. 219, pp. 139–142, 2003.

[4] H. Y. Liu, H. B. Liu, G. D. Peng, and P. L. Chu, "Observation of Type I and Type II gratings behavior in polymer optical fiber," *Opt. Commun.*, vol. 220, pp. 337–343, 2003.

[5] G. D. Peng, Z. Xiong, and P. L. Chu, "Photosensitivity and gratings in dye-doped polymer optical fibers," *Opt. Fiber Technol.*, vol. 5, pp. 242–251, 1999.

[6] Z. Xiong, G. D. Peng, B. Wu, and P. L. Chu, "Highly tunable Bragg gratings in single-mode polymer optical fibers," *IEEE Photon. Technol. Lett.*, vol. 11, pp. 352–354, Mar. 1999.

[7] H. B. Liu, H. Y. Liu, and G. D. Peng, "Different types of polymer fiber Bragg gratings (FBGs) and their strain/thermal properties," *Proc. Optical Memory and Neural Networks (Information Optics)*, vol. 12, pp. 147–155, 2003.

[8] P.-Y. Cortes, F. Ouellette, and S. LaRochelle, "Intrinsic apodization of Bragg gratings written using UV-pulse interferometry," *Electron. Lett.*, vol. 34, pp. 396–397, 1998.