Fabrication of long-period gratings in poly(methyl methacrylate-co-methyl vinyl ketone-co-benzyl methacrylate)-core polymer optical fiber by use of a mercury lamp

Zengchang Li

Structure Research Laboratory, Department of Polymer Science and Engineering, University of Science and Technology of China, Hefei 230026, China, and Photonics Research Centre, Department of Electrical Engineering, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

H. Y. Tam

Photonics Research Centre, Department of Electrical Engineering, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

Lixin Xu

Department of Physics, University of Science and Technology of China, Hefei 230026, China

Qijin Zhang

Department of Polymer Science and Engineering, University of Science and Technology of China, Hefei 230026, China

Received November 29, 2004

Polymer optical fiber (POF) with a highly photosensitive poly(methyl methacrylate-co-methyl vinyl ketone-co-benzyl methacrylate) core is fabricated. Gratings can be fabricated in the core of a POF with a low-cost mercury lamp. The part of the emission spectrum of the mercury lamp in which the cladding material exhibits photosensitivity is effectively filtered by a 1.5-mm-thick Pyrex glass to ensure that a long-period grating is formed only in the core of a POF. A long-period grating with a 3-dB resonant peak at 1568 nm is fabricated with 0.3 mW/cm^2 of UV irradiation over a period of 200 s. © 2005 Optical Society of America

OCIS codes: 060.2280, 060.2290, 160.5470, 050.2270.

Fiber gratings written in silica glass have attracted much interest since the work of Hill *et al.* in 1978[1] because they offer many advantages, such as compatibility with single-mode fibers, small size, ease of fabrication, and low cost. In communications, fiber grating devices are employed as wavelength lockers, gain equalizers to flatten the gain spectrum of erbium-doped fiber amplifiers, tunable bandpass filters, and wavelength-division multiplexers. Silica fiber Bragg gratings are also used as sensing elements for measuring temperature and strain. However, in applications in which a large Bragg wavelength shift is required or sensing elements are needed for use inside the human body, polymer fiber Bragg gratings are highly desirable because polymers such as poly(methyl methacrylate) (PMMA) are not brittle, are biocompatible,[2,3] have a Young's modulus of only 1/70th that of silica, have a thermo-optic coefficient of approximately 12 times that of silica, and have a thermal expansion coefficient of approximately 100 times that of silica.

With the development of polymer optical fiber (POF) an increasing number of research activities have been carried out in the field of POF gratings. In 1999 Xiong *et al.*[4] reported a method of fabricating Bragg gratings in a PMMA-based POF. To increase the photosensitivity, they used a minute amount of initiator to reserve a small amount of monomer in the core of the fiber. However, the photosensitivity of the fiber decreased gradually over time because the monomers migrated to the cladding and eventually diffused out of the core. Therefore it is important to explore new material to improve the photosensitivity of POF so that stable gratings can be fabricated. Doped polymer as a core material was also reported in the fabrication of gratings.[5] Besides Bragg gratings, long-period gratings (LPGs) also find many uses in communications, as well as in sensor applications. Examples include gain flattening filters,[6] chemical

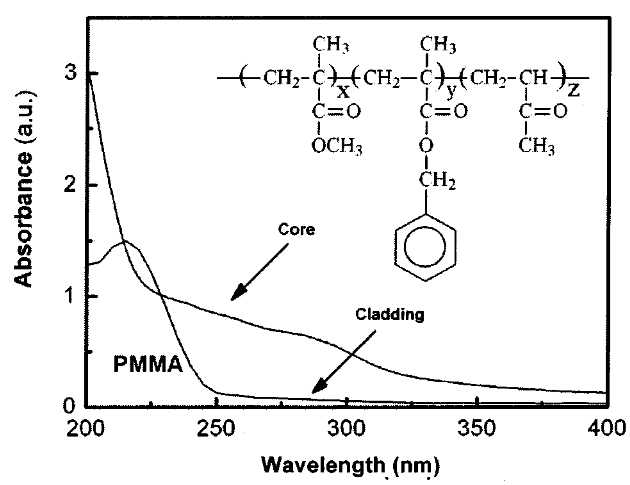

Fig. 1. Absorbance spectra of P(MMA-co-MVK-co-BzMA) (core material) and PMMA (cladding material).

0146-9592/05/101117-3/$15.00

sensors,[7] and temperature sensors.[8] LPGs can be fabricated inexpensively because neither costly phase masks nor excimer lasers are needed. To our knowledge, no LPGs written in POF have yet been reported. In this Letter we present a cost-effective method of fabricating LPGs in a photosensitive POF. We use poly(methyl methacrylate-co-butyl acrylate) as the cladding material and poly(methyl methacrylate-co-methyl vinyl ketone-co-benzyl methacrylate) P(MMA-co-MVK-co-BzMA) as the core material to fabricate the POF. In this work traditional photoetching technology is used to write a LPG in POF with a low-cost high-pressure mercury lamp as the light source.

To write stable gratings in POF, the fiber materials should satisfy the following criteria: (1) the core material must have a higher refractive index than the cladding, (2) the core material should be highly photosensitive at the writing UV wavelengths at which the cladding material exhibits negligible photosensitivity, (3) the material should be stable under storage conditions, and (4) the photosensitive units should connect with the polymer main chain by chemical bonds so that a stable refractive-index modulation can be obtained during the writing process. We propose to use a copolymer of methyl methacrylate and methyl vinyl ketone (MVK) as the core material for PMMA-based fiber because it satisfies all four aforementioned criteria. It can be expected that the intrinsic loss of this kind of copolymer would not be higher than that of pure PMMA since there is no new kind of chemical bond in the copolymer.

Several polymer films are prepared with spin-coating technology to study the photosensitivity of the material. Figure 1 shows the absorbance spectrum of the cladding and core material. The chemical structure of the core material is shown in the inset of Fig. 1. The cladding material has negligible absorption beyond 250 nm, and the core material exhibits fairly strong absorption in the wavelength band of 250–300 nm. The absorption spectrum shows that UV light around 300 nm will transmit through the cladding material with negligible loss.

To study the photosensitivity of these films, change in refractive index Δn is measured with a prism coupler against UV exposure time. Figure 2 shows the measured Δn as a function of the UV exposure time. Δn for both a copolymer of poly(methyl methacrylate-co-benzyl methacrylate) [P(MMA-co-BzMA)] and pure poly(methyl vinyl ketone) (PMVK) increase steadily with UV exposure time. However, when the UV light in the wavelength region of 200–300 nm is filtered with a 1.5-mm Pyrex glass, the result obtained is different. Figure 3 shows the dependence of Δn on UV exposure time for P(MMA-co-BzMA), pure PMVK, and core copolymer material. For P(MMA-co-BzMA) no detectable Δn is observed even after a 200-s period of UV irradiation. On the other hand, Δn of PMVK increases by as much as 6×10^{-3} over the same period of irradiation. MVK with a concentration of 10% in weight is added to the core material, and a 10% increase in Δn above that of pure PMVK is observed under the same irradiation conditions. The increase in Δn is mainly attributed to the composite of the MVK unit because the other two composites are virtually inert under the given irradiation conditions. The transmission spectra of the Pyrex filter and the cladding material are shown in Fig. 4, and the spectrum of the high-pressure mercury lamp is shown in the Fig. 4 inset. From the transmission spectra it is observed that UV light in the wavelength range of 200–300 nm is effectively blocked by the Pyrex glass. Therefore the UV light that induces an increase in refractive index in the core has a negligible effect on the cladding of the POF.

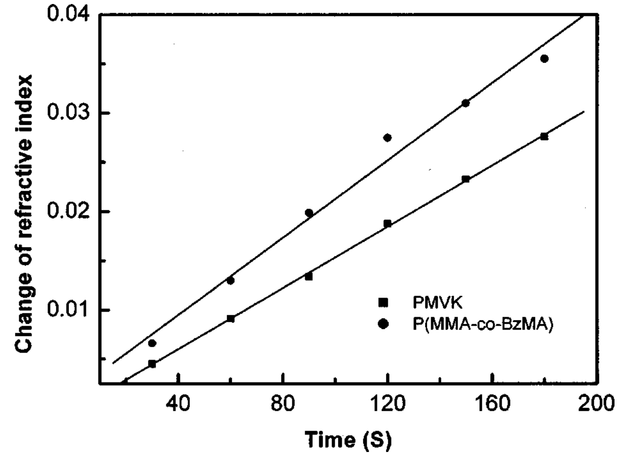

Fig. 2. Dependence of Δn on exposure time to UV light. The power of the high-pressure mercury lamp is 500 W, and the distance between the films and the lamp is 30 cm.

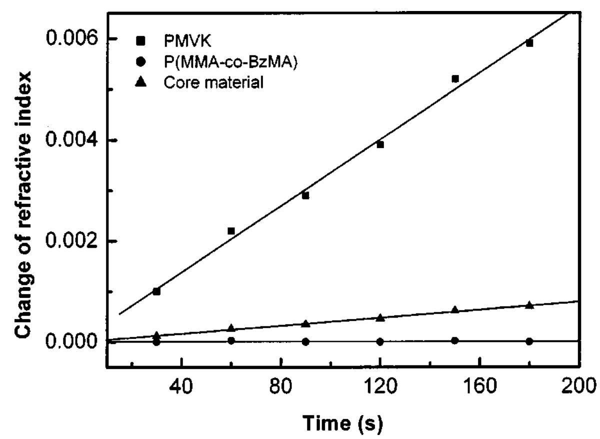

Fig. 3. Dependence of Δn on UV exposure time when a Pyrex glass is used as the filter. The power of the high-pressure mercury lamp is 500 W, and the distance between the films and the lamp is 30 cm.

The POF is fabricated with a preform fabrication technique. First a rod made from a copolymer of poly-(methyl methacrylate-co-butyl acrylate) with a small hole in the center is produced, similar to the procedure reported in Ref. 9. Then the core materials made from 10 ml of methyl methacrylate, 0.8 ml of benzyl methacrylate, 30 mg of benzyl peroxide, 4 μl of n-butyl mercaptan, and 1 ml of MVK are mixed in a vessel. The solution is prepolymerized and poured into a hollow rod. The thermal polymerization of the filled rod is carried out in an oven filled with N_2 at 5 atm of pressure. The temperature of the oven is increased gradually from 40°C to 120°C during a 7-day period until solidification is complete. The preform is then heat drawn into an optical fiber at 110°C by a takeup spool. The diameter of the POF is 176 μm, and the diameter of the core is 10 μm. The refractive index of the core is 1.4778, and the relative index difference (Δn) between the core and the cladding is 0.0077.

Figure 5 shows the experimental setup used to write a LPG in POF. The UV light emitted from the lamp irradiates the POF through the amplitude mask and a 1.5-mm Pyrex glass that serves as a filter (the length of the amplitude mask is 3 cm, the pitch of the amplitude mask is 275 μm with a 50% duty cycle, and the distance between the lamp and the fiber is 300 mm). The radiation flux density of the UV light is approximately 0.3 mW/cm^2. In the writing process the POF undergoes several UV exposures of 30-s duration. This is to prevent excessive heating of the POF by the heat produced by the mercury lamp. The POF is irradiated for a total of approximately 200 s. The transmission spectrum of the LPG is measured by butt joining the two ends of the 25-cm POF containing the LPG to silica fibers to permit light to be launched into the grating, and the transmitted light from the grating is directed to a powermeter. A tunable laser with an output power of 10 dBm is injected into the polymer LPG, and a powermeter is used to measure the output power from the polymer LPG. The wavelength of the laser is tuned from 1530 to 1580 nm with a wavelength step of 0.1 nm. Figure 6 shows the transmission spectrum of the LPG. The maximum loss is 3 dB at a peak wavelength of 1568 nm, and the FWHM of the peak is 3 nm.

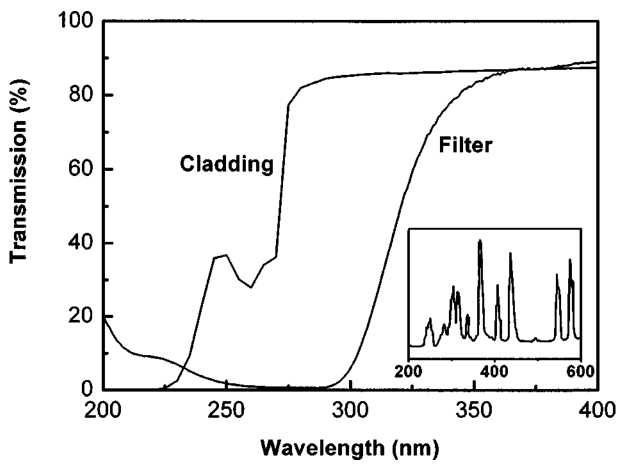

Fig. 4. Measured transmission spectrum of the Pyrex filter and cladding material. Inset, spectrum of the high-pressure mercury lamp.

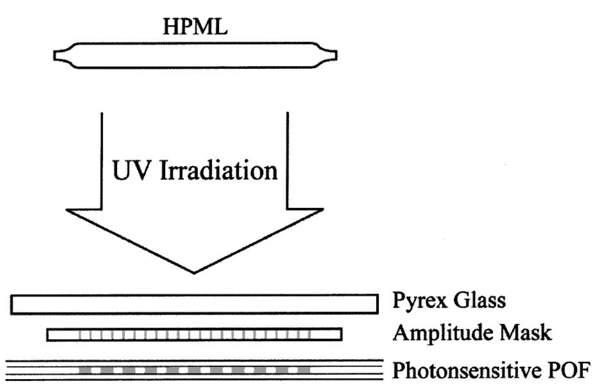

Fig. 5. Experimental setup for writing a LPG in photosensitive POF with a high-pressure mercury lamp (HPML).

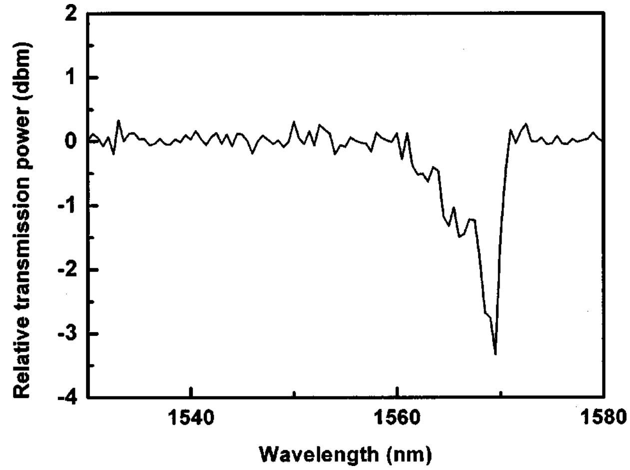

Fig. 6. Measured transmission spectrum of the LPG fabricated in POF.

In conclusion, photosensitive POF with a P(MMA-co-MVK-co-BzMA) core has been prepared, and a 275-μm-pitch LPG has been fabricated in the core of a POF by use of a low-cost mercury lamp. The part of the emission spectrum of the mercury lamp in which the cladding material exhibits photosensitivity was effectively filtered by a 1.5-mm-thick Pyrex glass to ensure that the LPG was formed only in the core of the POF. This fabrication method is suitable for the mass production of LPGs. Experimental results show that PMVK is much more photosensitive than P(MMA-co-BzMA) to UV light at wavelengths beyond 300 nm. A LPG that exhibits a 50% resonance peak was successfully fabricated in the photosensitive polymer fiber.

Q. Zhang (zqjm@ustc.edu.cn) and Z. C. Li acknowledge funding support from the National Natural Science Foundation of China (grants 50025309 and 90201016).

References

1. K. O. Hill, Y. Fujii, D. C. Johnson, and B. S. Kawasaki, Appl. Phys. Lett. **32**, (1978).
2. X. M. Li, W. M. Shen, C. J. Liu, S. Nishimoto, and T. Kagiya, Radiat. Phys. Chem. **38**, 377 (1991).
3. M. Jager and A. Wilke, J. Biomater. Sci. Polym. Ed. **14**, 1283 (2003).
4. Z. Xiong, G. D. Peng, B. Wu, and P. L. Chu, IEEE Photonics Technol. Lett. **11**, 352 (1999).
5. J. M. Yu, X. M. Tao, and H. Y. Tam, Opt. Lett. **29**, 156 (2004).
6. C. E. Chou, N. H. Sun, and W. F. Liu, Opt. Eng. **43**, 342 (2004).
7. S. T. Lee, R. D. Kumar, P. S. Kumar, P. Radhakrishnan, C. P. G. Vallabhan, and V. P. N. Nampoori, Opt. Commun. **224**, 237 (2003).
8. T. Mizunami, T. Fukuda, and A. Hayashi, Meas. Sci. Technol. **15**, 1467 (2004).
9. G. D. Peng, P. L. Chu, X. Lou, and R. A. Chaplin, J. Electr. Electron. Eng. Aust. **14**, 289 (1995).