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Polymeric Waveguides with Bragg Gratings in the Middle of the Core Layer

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In this paper we proposed a new Bragg grating waveguide in order to improve reflectivity and to achieve compactness. Bragg gratings with various thicknesses were engraved in the middle of the core layer with a length of 3 mm. For the sake of cost-effectiveness, the 3rd order Bragg grating waveguides were fabricated via conventional photolithography. The maximum reflectivities for the fixed width waveguide of 6 μm with the 0.1 and 0.3 μm-thick Bragg gratings were, -13.14 and -6.25 dB, respectively, and the Bragg wavelengths were 1562.28, 1564.10 nm, respectively. A slight increase in the Bragg grating thickness can result in a remarkable reduction in the length of the Bragg grating waveguide with a fixed reflectivity.

Keywords : Waveguide Bragg grating, Conventional photo-lithography, Higher-order-grating, Higher-index-polymer

OCIS codes : (350.2770) Gratings; (230.1480) Bragg reflector; (250.5460) Polymer waveguides-fibers

I. INTRODUCTION

Diffraction gratings are devices that reflect or refract light to varying degrees according to the wavelength. Of these, Bragg gratings are widely used in a range of applications, such as filters, couplers, resonators, polarizers, sensors, multiplexer, and dispersion compensators [1-2]. In an optical communication system, fiber Bragg gratings (FBGs) have attracted much attention because they can cost-effectively provide advanced features for such devices, owing to their characteristic spectral responses [3-6]. Though FBGs are simply fabricated with unique spectral responses, they are too lengthy to integrate with other components. Such problems can easily be eliminated with Bragg grating waveguides [7]. The Bragg grating waveguides achieved compactness, high performance, and cost-effectiveness, as well as integration with an optical add/drop multiplexer [8-9], an external cavity laser [10-11], an optical triplexer transceiver[12], and a dispersion compensator[13] in a wavelength division multiplexing (WDM) optical communication system.

Instead of using e-beam lithography, we introduced a 3rd order grating pattern rather than a 1st order grating pattern, using conventional photolithography to cost-effectively make the Bragg grating waveguides. To achieve compactness and to compensate for the lower reflectivity of the 3rd order gratings, we used a polymer for the Bragg gratings that had a higher refractive index than that of the core material, and we placed the Bragg grating layer in the middle of the core layer.

In this paper, we simulated and fabricated waveguides with 3rd order Bragg gratings with various thicknesses of from 0.1 and 0.3 μm located in the middle of the core layer. We found the optical spectra of our waveguides and discussed their practical applications.

II. GRATING DESIGN AND FABRICATION

Schematic views of the proposed polymeric waveguides with Bragg gratings in the middle of the core layer (MBG) are shown in Fig. 1(a) and (b). The total length of the MBG waveguide is 10 mm, and the length of the Bragg grating located in the center of the MBG waveguide is 3 mm. Without the Bragg grating in the MBG waveguide, the length is 7 mm with the 3.5 mm-long front and rear waveguides. The thickness of the

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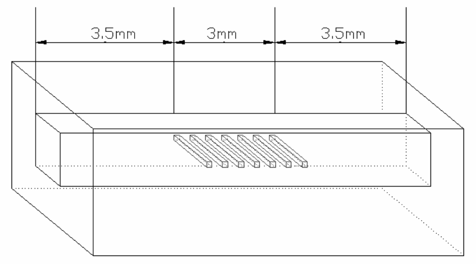
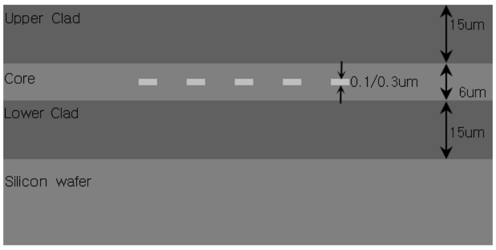


(a) Schematic view of the MBG Waveguide.



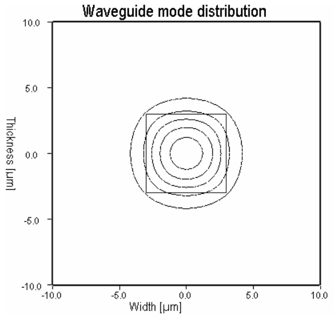
(b) Cross-sectional view of the MBG Waveguide.

FIG. 1. Schematic views of the MBG Waveguide.

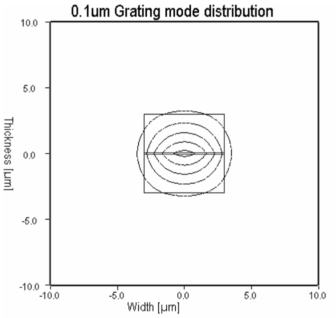
core waveguides is 6 μm and the widths of the core waveguides are 6, 7 and 8 μm. The thicknesses of the Bragg grating layer are 0.1 and 0.3 μm, and the grating period is 1680 nm for 3^{rd} order Bragg grating.

Based on the measured refractive indices (1.390, 1.395 and 1.457) of the used clad, core and the Bragg grating materials with the dimensions of the proposed MBG waveguide, we calculated the effective refractive index (n_{eff}), refractive index modulation (Δn_{eff}) and the mode field distributions via a finite element method. The neffs of the waveguide without the Bragg gratings and the waveguides with the 0.1 and 0.3 μm-thick Bragg gratings are 1.3921, 1.3929 and 1.3963, respectively. The Δn_{eff}s of the waveguides with the 0.1 and 0.3 μm-thick Bragg gratings are 0.0008 and 0.0042, respectively. The mode field distributions in the waveguide without the Bragg gratings, and in the MBG waveguides with the 0.1 and 0.3 μm-thick Bragg gratings, are shown in Fig. 2 (a), (b) and (c), respectively. Based on Fig. 2, the mode field distribution for the MBG waveguide with the 0.3 μm-thick Bragg grating is denser than that of the waveguide without the Bragg gratings or the MBG waveguide with the 0.1 μm-thick Bragg grating. In other words, the mode fields become increasingly confined as the thickness of the Bragg grating increases. This is due to the increase of the n_{eff} value obtained by increasing the thickness of the Bragg grating in the MBG waveguides.

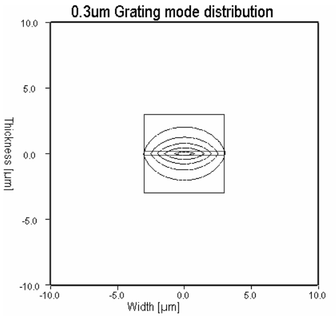
The Bragg wavelength (λ_B) and maximum reflectivity (R_{max}) are given by Eq. (1) and (2) [14], where Λ_g is the Bragg grating period, m is the order of the Bragg grating, κ is a coupling coefficient, and L is the length of the Bragg grating.



(a) TE Mode field distribution in the core waveguide without the Bragg grating.



(b) TE Mode field distribution in the MBG waveguide with the 0.1 μm-thick Bragg grating.



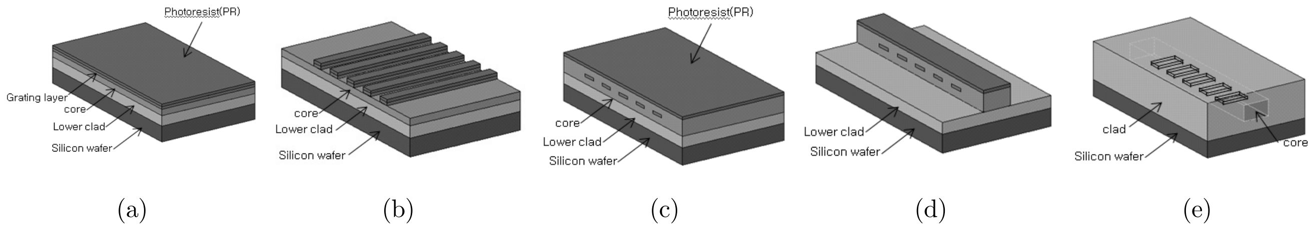
(c) TE Mode field distribution in the MBG waveguide with the 0.3μm-thick Bragg grating.

FIG. 2. TE Mode field distributions in the MBG waveguides.

$$\lambda_B = 2\,\frac{\Lambda_g}{m}\,n_{eff} \tag{1}$$

$$R_{\max} = \tanh^2(\kappa L) = \tanh^2\left(\frac{\pi \Delta n_{eff}}{\lambda_B m} L\right) \tag{2}$$

In order to obtain the λ_B value close to 1560 nm, we set the Λ_g value to 560 nm, and m = 1 for the 1^{st} order Bragg grating in Eq. (1), for the sake of easy calculation. [14] The theoretical R_{max} value is obtained via Eq. (2) and it is in hyperbolic-tangent squared proportion to the Δn_{eff} value of the Bragg grating waveguide. [14]



(a) (b) (c) (d) (e)

FIG. 3. Fabrication procedure for the waveguide-engraved Bragg gratings in the middle of the core layer.

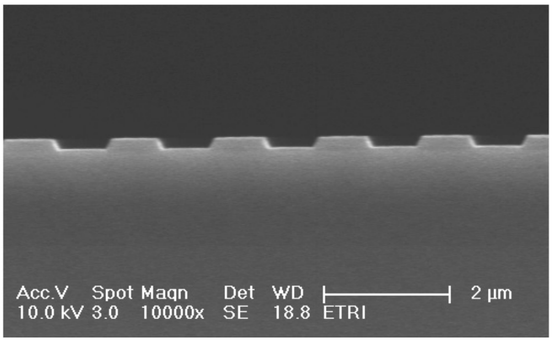


FIG. 4. SEM picture of the fabricated Bragg grating.

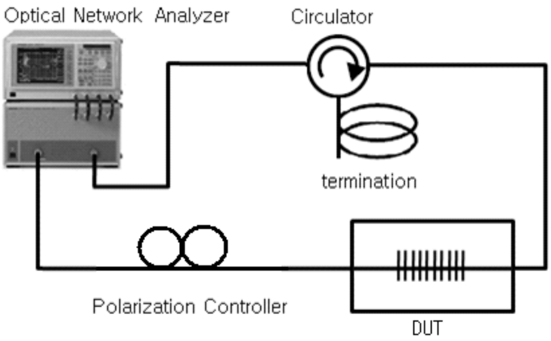


FIG. 5. Experimental setup for measuring optical spectra.

In our calculation, the Bragg wavelengths with the 0.1 and 0.3 μm-thick Bragg gratings are 1560.05 and 1563.82, respectively. The Δn_{eff} of the MBG waveguide with the 0.3 μm-thick grating is 5 times higher than that of the MBG waveguide with the 0.1 μm-thick grating. Based on the calculated results, we designed and fabricated a photomask for the MBG waveguides. For the conventional photolithography method, rather than using the Λ_g value of 560nm of the 1st order grating we used the 1680 nm of the 3rd order Bragg gratings. [15] Because of the resolution limitation (~ 1 μm) of photolithography, which is much more cost-effective than e-beam lithography, we chose the 3rd order Bragg gratings rather than the 1st order Bragg gratings, which are usually engraved by an e-beam lithography method. [16]

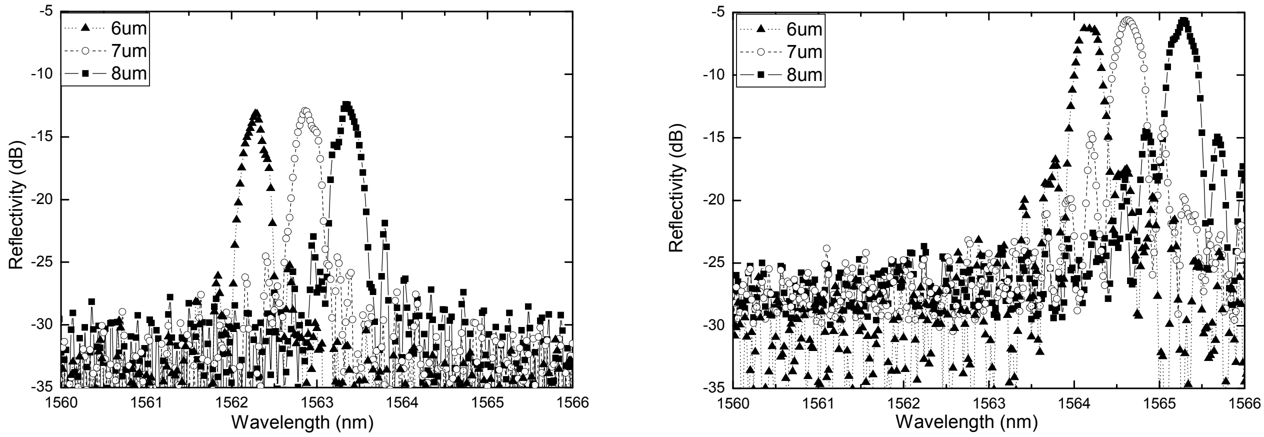
The fabrication process is shown in Fig. 3. First, the lower clad, half-core, Bragg grating and the photoresist layers are subsequently coated and cured on a Si wafer via a spin-coater, as shown in Fig. 3(a). We used the polymeric clad, core, and grating materials comprising a LFR series (Chemoptics Inc). The tailored refractive indices of the clad, core and Bragg grating materials are 1.390, 1.395 and 1.457, respectively. We also used the adhesion promoter ZAP1020 (Chemoptics Inc) in order to enhance the adhesion between the layers. The lower clad layer was coated with 15 μm-thickness. The half-core layer was coated with 3 μm-thickness. The Bragg grating layer was coated on top of this and its respective thickness was 0.1 and 0.3 μm.

In Fig. 3(b), after coating the photoresist (AZ50214E), we developed and etched the grating patterns via a conventional photolithography technique and a dry etching technique of an inductively coupled plasma (ICP). The well-formed grating pattern is shown in Fig. 4. Subsequently, we coated the upper core layer with a fixed thickness of 3 μm, as shown in Fig. 3 (c). The AZ5214E photoresist was again spin-coated on top of this. Then, we developed and fabricated the waveguide via the conventional photolithography technique and the dry etching technique, as shown in Fig. 3 (d). Subsequently, the upper clad layer was coated with the same material and thickness as the lower clad layer. Fig. 3 (e) shows a diced chip. After 8° polishing of the diced chip, it was pig-tailed with single mode fibers via epoxy welding.

III. RESULTS AND DISCUSSION

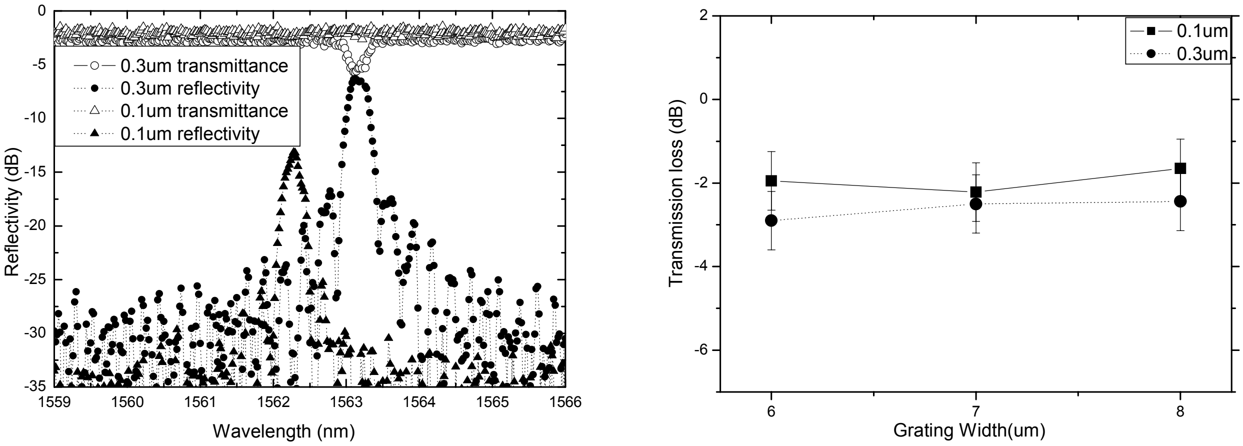
We measured the optical characteristics of the pig-tailed MBG waveguides over a wavelength range of 1550~1570 nm. The measuring apparatus was an Optical Network Analyzer (ONA, Advantest Q7760). A polarization controller was used in order to distinguish between the TE- and TM-modes. A circulator was located between the ONA and DUT (Device Under Test), in order to terminate the reflected light from the ONA. This measurement system setup is shown in Fig. 5.

The measured reflectivities and Bragg wavelengths are shown in Fig. 6 (a), and (b). The Bragg wavelengths for the 6, 7 and 8 μm-wide waveguides with the 0.1 μm-thick Bragg grating were 1562.28, 1562.86 and 1563.34 nm, and the maximum reflectivities were -13.14, -12.93 and -12.41 dB, respectively, as shown in Fig. 6 (a). The



(a) Reflectivities for the 6, 7 and 8μm-wide MBG waveguides with the 0.1 μm-thick Bragg grating.

(b) Reflectivities for the 6, 7 and 8 μm-wide MBG waveguides with the 0.3 μm-thick Bragg grating.



(c) Compared reflectivity and transmittance for the fixed 6 μm-wide MBG waveguide with the 0.1 and 0.3 μm-thick Bragg gratings.

(d) Transmission losses for the 6, 7 and 8μm-wide MBG waveguides with the 0.1 and 0.3 μm-thick Bragg gratings.

FIG. 6. Measured optical spectra of the MBG waveguides with the 0.1 and 0.3μm-thick Bragg gratings.

Bragg wavelengths for the 6, 7 and 8 μm-wide waveguides with the 0.3 μm-thick Bragg grating were 1564.10, 1564.64 and 1565.26 nm, and the maximum reflectivities were -6.25, -5.93 and -5.64 dB, respectively as shown in Fig. 6 (b). The Bragg wavelength is shifted to a longer wavelength with increasing width of the MBG waveguide. The Bragg wavelength is also shifted to a longer wavelength with increasing thickness of the Bragg grating. These results are apparently due to the increase of the n_{eff} value obtained by increasing the width and thickness. The Bragg wavelength is infinitesimally adjustable by varying the width of the waveguides and/or the thickness of the Bragg grating.

Fig. 6(c) shows that the Bragg wavelengths for the 6 μm-wide MBG waveguide with the 0.1 and 0.3 μm-thick Bragg gratings were 1562.28, 1564.10 nm, respectively, and the maximum reflectivities were -13.14 and -6.25 dB respectively. Based on the measured results of the 3rd order Bragg gratings, the reflectivity was improved by ~7 dB due to the introduction of a thicker Bragg grating layer from 0.1-0.3 μm.

Fig. 6(d) shows that the transmission losses for the 6, 7 and 8 μm-wide MBG waveguides with the 0.1 μm-thick grating were -1.95, -2.22 and -1.65 dB, respectively, and those for the 6, 7 and 8μm-wide MBG waveguides with the 0.3 μm-thick grating were -2.90 dB, -2.50 and -2.44, respectively. The wavelength for the measured transmission loss was 1561 nm. The transmission losses for the waveguides with the 0.3 μm-thick grating were slightly larger than those for the waveguides with the 0.1 μm-thick grating. This larger loss is mainly due to the increased scattering loss, which originates from the larger thickness of the Bragg gratings. In the waveguides with the 0.3 μm-thick Bragg grating, the slightly larger transmission losses were negligible by comparison to the greatly enhanced maximum reflectivities. A slight increase in the Bragg grating thickness can result in a remarkable reduction (-2.4 times) in the length of the MBG waveguide with a fixed reflectivity.

IV. CONCLUSION

In this paper we proposed MBG waveguides with various thicknesses of the Bragg grating. Via the conventional photolithography method, we fabricated MBG waveguides with 3rd order Bragg gratings. The maximum reflectivities for the fixed width waveguide of 6 μm with the 0.1 and 0.3 μm-thick Bragg gratings were, -13.14 and -6.25 dB, respectively, and the Bragg wavelengths were 1562.28, 1564.10 nm, respectively. The transmission losses for the waveguides with the 0.1 and 0.3 μm Bragg grating thicknesses and a fixed width of 6 μm were -1.95, and -2.90 dB, respectively. The maximum reflectivity of the waveguides with the 0.1-0.3 μm-thick Bragg gratings increased by ~7 dB, but the transmission loss increased by ~1 dB. A slight increase in the Bragg grating thickness can result in a remarkable reduction (-2.4 times) in the length of the MBG waveguide with a fixed reflectivity.

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REFERENCES

1. M. C. Oh, M. H. Lee, J. H. Ahn, H. J. Lee, and S. G. Han, "Polymeric wavelength filters with polymer gratings," Appl. Phys. Lett. **72**, 1559–1561 (1998).
2. L. Eldada, R. Blomquist, M. Maxfield, D. Pant, G. Boudoughian, C. Poga, and R. A. Norwood, "Thermo-optic planar polymer Bragg grating OADM's with broad tuning range," IEEE Photon. Technol. Lett. **11**, 448–450 (1999).
3. Z. Pan, Y. W. Song, C. Yu, Y. Wang, Q. Yu, J. Popelek, H. Li, Y. Li, and A. E. Willner, "Tunable chromatic dispersion compensation in 40-Gb/s systems using nonlinearly chirped fiber Bragg gratings," J. Lightwave Tech. **20**, 2239–2245 (2002).
4. C. H. Kim, J. K. Bae, K. I. Lee, and S. B. Lee, "Performance evaluation of a tunable dispersion compensator based on strain-chirped fiber Bragg grating in a 40 Gb/s transmission," J. Opt. Soc. Korea **12**, 244-248 (2008).
5. S. S. Lee and H. D. Chae, "Continuous photonic microwave true-time delay using tapered chirped fiber Bragg grating," Electron. Lett. **41**, 690–691 (2005).
6. S. C. Kim, "Performance analysis of chromatic dispersion compensation of a chirped fiber grating on a differential phase-shift-keyed transmission," J. Opt. Soc. Korea **13**, 107-111 (2009).
7. C. Greiner, T. W. Mossberg, and D. Iazikov, "Bandpass engineering of lithographically scribed channel-waveguide Bragg gratings," Opt. Lett. **29**, 806–808 (2004).
8. S. Sato, Y. Ishigami, S. Takasugi, H. Arai, and H. Ohkubo, "Fiber/PLC Bragg grating devices for WDM transmission systems," Hitachi Cable Review **20**, 11-14 (2001).
9. H. Lee, G. W. Kim, J. O. Park, S. H. Kim, and Y. C. Chung, "Widely tunable wavelength-selective reflector using polymer waveguide double-ring-resonator add/drop filter and loop-back mirror," J. Opt. Soc. Korea **12**, 157-161 (2008).
10. J. H. Lee, M. Y. Park, C. Y. Kim, S. H. Cho, W. L. Lee, G. Jeong, and B. W. Kim, "Tunable external cavity laser based on polymer waveguide platform for WDM access network," IEEE Photon. Technol. Lett. **17**, 1956-1958 (2005).
11. G. Jeong, J. H. Lee, M. Y. Park, C. Y. Kim, S. H. Cho, W. R. Lee, and B. W. Kim, "Over 26-nm wavelength tunable external cavity laser based on polymer waveguide platforms for WDM access networks," IEEE Photon. Technol. Lett. **18**, 2102-2104 (2006).
12. J. H. Song, J. H. Lim, R. K. Kim, K. S. Lee, K. Y. Kim, J. Cho, D. K. Han, S. T. Jung, Y. K. Oh, and D. H. Jang, "Bragg grating-assisted WDM filter for integrated optical triplexer transceivers," IEEE Photon. Technol. Lett. **17**, 2067-2068 (2005).
13. M. S. Kim, J. J. Ju, S. K. Park, M. H Lee, S. H. Kim, and K. D. Lee, "Tailoring chirp characteristics of waveguide Bragg gratings using tapered core profiles," IEEE Photon. Technol. Lett. **18**, 2413-2415 (2006).
14. A. Yariv, *Optical Electronics in Modern Communications* (Oxford University Press, Oxford, UK, 1997), Chapter 13.
15. J. U. Shin, S. H. Oh, Y. J. Park, S. H. Park, Y. T. Han, H. K. Sung, and K. R. Oh, "External cavity lasers composed of higher order gratings and SLDs integrated on PLC platform," ETRI Journal **29**, 452-456 (2007).
16. W. H. Wong and E. Y. B. Pun, "Polymeric waveguide wavelength filters using electron-beam direct writing," Appl. Phys. Lett. **79**, 3576–3578 (2001).