Athermalized Polymeric Arrayed-Waveguide Grating by Partial Detachment from a Si Substrate

Jong-Moo Lee, Joon Tae Ahn, Suntak Park, and Myung-Hyun Lee

ABSTRACT—We demonstrate a new fabrication method for adjusting the temperature dependence of a polymeric arrayed-waveguide grating (AWG) on a Si substrate. A temperature-dependent wavelength shift of –0.1 nm/°C in a polymeric AWG on a Si substrate is reduced to +0.01 nm/°C by detaching part of the polymer film, including the grating channel region of the AWG, from the Si substrate while the other parts remain fixed on the substrate.

Keywords—Waveguide, polymer, AWG

I. Introduction

Polymeric waveguide devices have been actively studied and developed for commercial products such as thermo-optic switches and variable optical attenuators due to their extremely high thermo-optic property and, on an economic merit, their simple fabrication process [1]-[6]. Their high thermo-optic property, however, can be a critical problem in other applications such as the athermal arrayed-waveguide grating (AWG), which is necessary for the emerging passive-optical network application based on wavelength division multiplexing [7].

There have been many efforts to reduce the temperature-dependent wavelength shift (TDW) of a polymeric AWG. N. Keil and others showed that the temperature dependence of polymeric devices can be compensated by using a substrate with an appropriate coefficient of thermal expansion (CTE), which was around 80 ppm/°C in their experiment [8]. R. Gao and others showed the temperature dependence can be reduced further using a proper superstrate together with a polymeric substrate [9]. There had been another trial of an all-polymeric AWG by J. Kobayashi and others [10] even before N. Keil. They provided an all-polymeric AWG just by detaching the whole polymeric film from the Si substrate in order to decrease the birefringence of the polymeric AWG, which is induced by thermal stress. However, there were no efforts to reduce the temperature dependence in that case, and the AWG film was hard to use since the flexible thin film was mechanically unstable and very difficult for handling in packaging processes, such as in the aligning and bonding to fiber-array blocks.

The method using a thick polymeric substrate, as described in [8] and [9], is a nice solution in solving the thermal problem of AWGs, but it involves some disadvantages for mechanical flexibility and a poor thermal conductivity of the polymer substrates. The poor thermal conductivity, in particular, can be a problem in integration of the all-polymeric AWG with other functional devices such as thermo-optic switches and laser diodes requiring a thermally conductive substrate, while there have been many demands for polymer devices to be integrated with functional devices such as dynamic optical add-drop multiplexers [11], hybrid integrated transceivers with planar light circuit platforms, and so on [12].

In this regard, we have attempted a method for compensating the temperature dependence of a polymeric AWG on a Si substrate. This method is based on partially detaching the polymer film including the grating channel region of the AWG, from the Si substrate while the input and output parts are kept fixed on the substrate after the fabrication and bonding to the fiber array blocks is completed. The main concept of this method is using the advantage of an all-polymeric AWG in the grating channel region while taking advantage of the silicon substrate in the other region.

Manuscript received Sept.15, 2003; revised Jan. 5, 2004.

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II. Experiment and Results

The experiment was performed to improve the temperature dependence of a 16×16 channel AWG. We used thermally curable fluorinated polyethers, supplied by Zen Photonics, for the core (ZP1010) and cladding (ZP2145) of the AWG. The refractive indices of the materials for transverse electric (TE) polarization were 1.501 for the core material and 1.484 for the cladding material at a wavelength of around 1550 nm. The birefringence or the refractive index difference between the TE mode and transverse magnetic (TM) mode of the slab waveguide made of the core material on a Si wafer was measured as about 0.004. The main fabrication process of the polymeric AWG started from the spin coating of the cladding material on a Si substrate whose surface was treated with an adhesion promoter (ZAP1010 from Zen Photonics). Then, we coated and thermally cured the core material after an initial thermal curing of the lower cladding; each curing was at 250 °C. We formed 6×6 μm waveguide patterns using a photo lithography process and a following dry etching process.

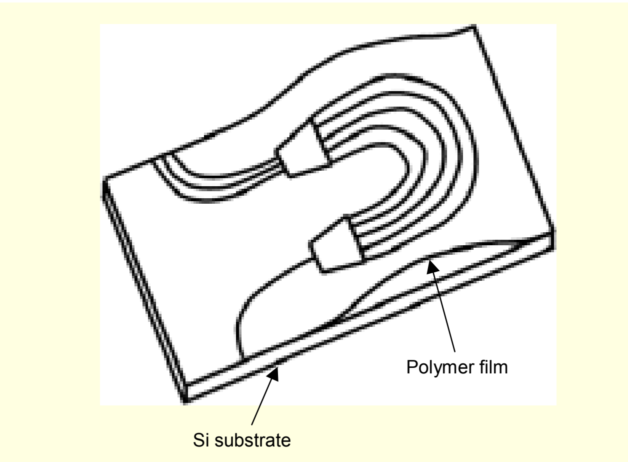

Fig. 1. Schematic diagram of a polymeric AWG with a polymer film partially detached from a Si substrate

Finally, we finished the waveguide by covering the upper cladding layer. To compensate for the mismatched CTE, we added a CTE-compensating over-layer on the surface of the AWG. We used the core material, ZP1010, as the CTE-compensating material. After connecting an input and an output fiber-array block, we immersed part of the AWG chip into a solvent, AZ 340. Since the solvent deteriorates the adhesion property of the promoter between the polymer film and the Si substrate, the immersed part of the polymer film was detached from the substrate after about a day of immersion. Figure 1 shows the schematic diagram of the AWG, while Fig. 2 shows the AWG connected with the input and output fiber

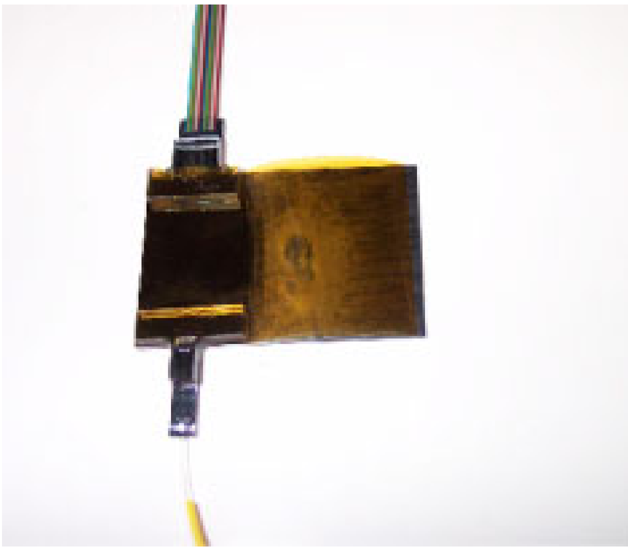

Fig. 2. A photo of the partially-detached polymeric AWG connected with input and output fiber arrays.

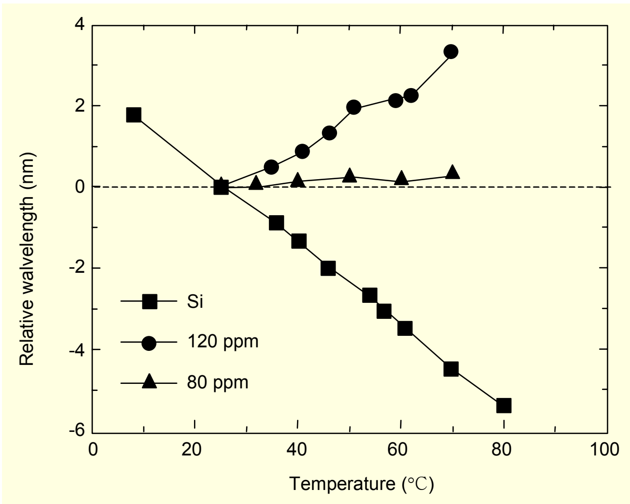

Fig. 3. Variation of the central wavelength for TE mode through a channel of polymeric AWG: fabricated fully on a Si substrate (Si), having a partially detached region (120 ppm), and having a partially detached region with a CTE compensating over-layer of 80 ppm/°C (80 ppm).

arrays. As shown in the figure, we detached a partial region of the polymeric film, including the grating channels, from the substrate and, for mechanical stability, fixed the end part of the separated polymer film with an epoxy.

Figure 3 shows the measured temperature-dependent properties of the polymeric AWGs from this experiment. The TDW changed from –0.1 nm/°C found in an original polymeric AWG fully fixed on a Si substrate to +0.08 nm/°C for our partially detached AWG without a CTE-compensating over-layer. A TDW of +0.08 nm/°C is due to the CTE value of 120 ppm/°C for the cladding material while an optimal CTE value is calculated as 70 ppm/°C in our case. A TDW of +0.01 nm/°C was achieved by adding an over-layer with a CTE value of around 80 ppm/°C. We could not test with an over-layer of 70 ppm/°C in this experiment, but we believe the TWD will be reduced further using the proper over-layer material.

Figure 4 shows the transmission spectra for TE mode through the AWG with the CTE-compensating over-layer. The central wavelength shifts about 0.45 nm as the temperature changes from 25 to 70 °C, resulting in a TDW of +0.01 nm/°C. As the figure shows, there is no critical change with the variation in temperature. The loss of about 8 dB and the crosstalk of about 25 dB remain without significant variation. The losses of the AWGs are mainly due to the propagation loss of 0.5 dB/cm, resulting in about a 3 dB loss, and a mode-mismatched coupling loss of 1 dB/facet by calculation, which results in about another 2 dB loss by the end facets. An extra loss should come partially from the roughness of the side wall of the waveguides and mainly from the slight deformation of the surface of the polymer film after the detachment, while the deformation is believed to be fixed by optimizing the detaching process. The cross-talk of about 25 dB should come mainly from the poor resolution of 100 nm for the mask used in this experiment—the resolution of 10 nm is normally used in an AWG mask these days. We expect that the loss and the cross-talk can be enhanced by a further optimization of the design and fabrication process, and the temperature dependence can be further decreased by using a material with the proper CTE value.

Figure 5 shows the relative variation of the central wavelength for each TE and TM mode through a channel of a polymeric AWG on a Si substrate, and Fig. 6 shows the variations of a polymeric AWG with the CTE compensating over-layer after the partial detachment of the film. As shown in these figures, there was a big difference in the TE-TM shift as

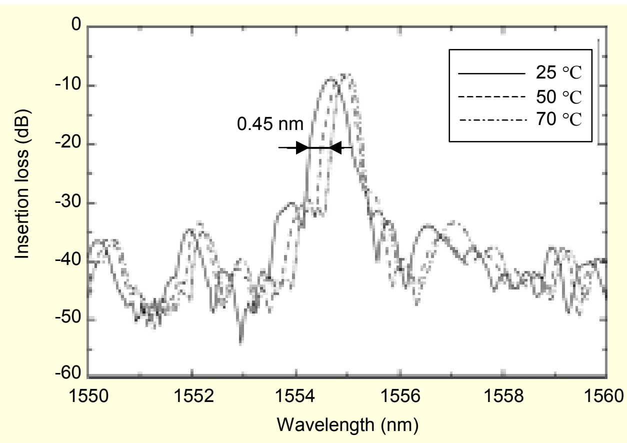

Fig. 4. Transmission spectra for TE mode through a AWG with a CTE-compensating over-layer of 80 ppm/°C at the temperatures of 25, 50, and 70 °C.

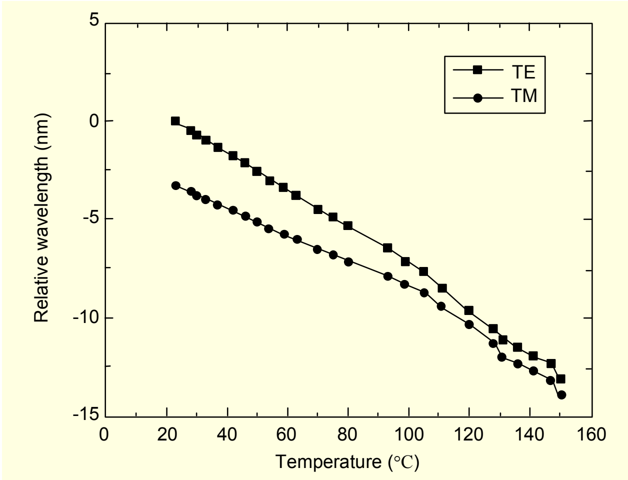

Fig. 5. A relative variation of the central wavelength for the TE and TM modes through a channel of a polymeric AWG on a Si substrate.

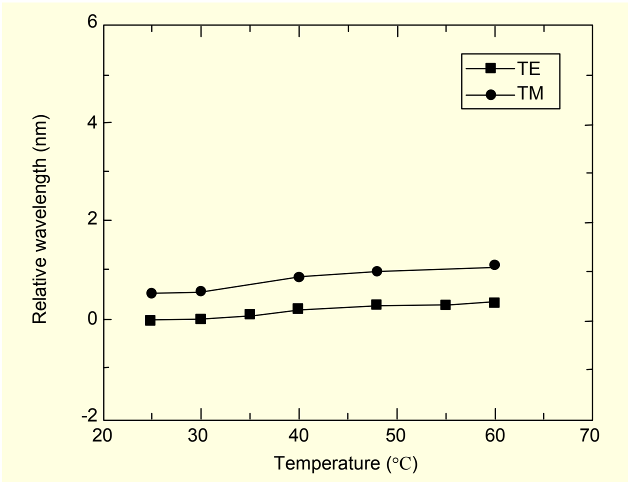

Fig. 6. A relative variation of the central wavelength for both TE and TM modes through a channel of polymeric AWG with a CTE compensating over-layer of 80 ppm/°C after partial detachment of the film.

the film detached. The TE-TM shift in Fig. 6 is almost constant—around 0.6 nm—while it varies from around 4 nm to 1 nm in Fig. 5. The TE-TM shift in Fig. 6 can be reduced further by adjusting the thickness and number of overcladding sub-layers, as demonstrated in [5] and [6].

III. Conclusion

In summary, we demonstrated a new fabrication method to adjust the temperature dependence of a polymeric AWG fabricated on a Si substrate. This method is based on partially detaching the polymeric film from the substrate to utilize the advantage of the all-polymeric athermal property in the grating-channel region and to utilize the advantage of the Si substrate in the other regions. We demonstrated that the TDW was reduced from –0.1 nm/°C for an original polymeric AWG fully fixed on a Si substrate to +0.01 nm/°C for a partially detached polymeric AWG. We expect further improvement of the temperature-dependent property of the polymer AWG to be achieved easily by sophisticated optimization processes, and these methods to be applicable for various other commercial polymeric devices utilizing the silicon substrate.

References

[1] M.-H. Lee, J.J. Ju, S. Park, J.Y. Do, and S.K. Park, "Polymer-Based Devices for Optical Communications," *ETRI J.*, vol. 24, no. 4, Aug. 2002, pp. 259-269.

[2] N. Keil, H.H. Yao, C. Zawadzki, K. Lösch, K. Satzke, W. Wischmann, J.V. Wirth, J. Schneider, J. Bauer, and M. Bauer, "Hybrid Polymer/Silica Thermo-Optic Vertical Coupler Switches," *Appl. Phys. B.*, vol. 73, 2001, pp. 469-473.

[3] J.-M. Lee, J.T. Ahn, D.H. Cho, J.J. Ju, M.-H. Lee, and K.H. Kim, "Vertical Coupling of Polymer Double-Layered Waveguides Using a Stepped MMI Coupler," *ETRI J.*, vol. 25, no. 2, Apr. 2003, pp. 81-88.

[4] L. Eldada and L.W. Shacklette, "Advances in Polymer Integrated Optics," *IEEE Select. Topics Quantum Electron.*, vol. 6, 2000, pp. 54-68.

[5] J.-M. Lee, S. Park, M.-H. Lee, J.T. Ahn, J.J. Ju, and K.H. Kim, "Simple Method to Adjust Polarization Dependence in Polymeric Arrayed Waveguide Gratings," *IEEE Photon. Technol. Lett.*, vol. 15, 2003, pp. 927-929.

[6] J.-M. Lee, S. Park, M.-S. Kim, J.T. Ahn, and M.-H. Lee, "Birefringence as a Function of Upper-Cladding Layers in Polymeric Arrayed Waveguide Gratings," *Optics Communications*, vol. 232, 2004, pp. 139-144.

[7] H.D. Kim, S.-G. Kang, and C.-H. Lee, "A Low-Cost WDM Source with an ASE Injected Fabry-Parot Semiconductor Laser, " *IEEE Photon. Technol. Lett.*, vol. 12, 2000, pp. 1067-1069.

[8] N. Keil, H.H. Yao, C. Zawadzki, J. Bauer, M. Bauer, C. Dreyer, and J. Schneider, "Athermal Polarization-Independent All-Polymer Arrayed Waveguide Grating (AWG) Multi/Demultiplexer," *OFC 2001*, Anaheim, post-deadline paper, PD7.

[9] Renyuan Gao, Renfeng Gao, K. Takayama, A. Yeniay, and A.F. Garito, "Low-Insertion Loss Athermal AWG Multi/Demultiplexer Based on Perfluorinated Polymers," *ECOC 2002*, Copenhagen, Denmark, paper 6.2.2.

[10] J. Kobayashi, Y. Inoue, T. Matsuura, and T. Maruno, "Tunable and Polarization-Insensitive Arrayed-Waveguide Grating Multiplexer Fabricated from fluorinated Polyimides," *IEICE Trans. Electron.*, vol. E81-C, 1998, pp. 1020-1026.

[11] T. Saida, A. Kaneko, T. Goh, M. Okuno, A. Himeno, K. Takiguchi and K. Okamoto, "Athermal Silica-Based Optical Add/Drop Multiplexer Consisting of Arrayed Waveguide Gratings and Double Gate Thermo-Optical Switches," *Electron. Lett.*, vol. 36, 2000, pp. 528-529.

[12] T. Ido, A. Kuwahara, T. Nagara, H. Ichikawa, T. Kinoshita, M. Tokuda, S. Tsuji, and H. Ichikawa, "A Simple Low-Cost Polymer PLC Platform for Hybrid Integrated Transceiver Modules," *OFC 1999*, post-deadline paper, PD41.