Polarization Mode Converter With Polyimide Half Waveplate in Silica-Based Planar Lightwave Circuits

Y. Inoue, *Member, IEEE*, Y. Ohmori, *Member, IEEE*, M. Kawachi, *Member, IEEE*, S. Ando, T. Sawada, and H. Takahashi, *Member, IEEE*

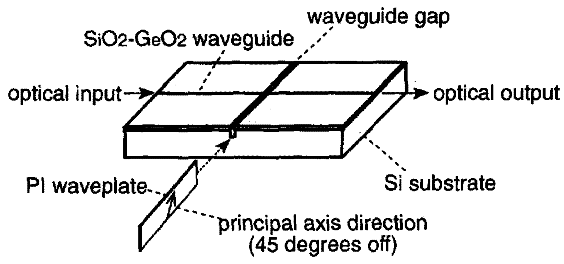
***Abstract*— A TE/TM polarization mode converter, with an excess loss of 0.26 dB, is constructed by inserting a polyimide half waveplate into a groove formed in a silica-based single mode waveguide. The polarization dependence of an arrayed-waveguide grating multiplexer is completely eliminated with this mode converter.**

I. Introduction

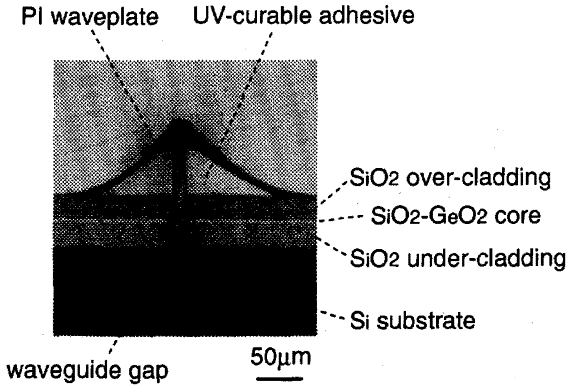
THE arrayed-waveguide grating (AWG) wavelength multiplexer with silica-based planar lightwave circuits (PLCs) is a key component for optical communication networks. They are, however, polarization dependent due to stress-induced waveguide birefringence. Several approaches have already been reported which achieve polarization insensitive multiplexer operation [1]–[3]. Of these approaches, the most practical appears to be the TE/TM mode conversion method, in which a half waveplate is inserted in the center of the multiplexer, since this technique is applicable to any waveguide, irrespective of its birefringence value. One problem with this method, however, is the large excess radiation loss resulting from waveplate insertion; a loss as large as 5 dB was reported with a 92 μm-thick quartz half waveplate in a silica-based arrayed-waveguide multiplexer. [1] There are two ways to reduce the excess loss; one is to enlarge the mode field diameter in the waveguide and the other is to narrow the waveguide gap for the waveplate. The first approach includes the thermally expanded core technique [4]. The latter approach is reported here.

This letter describes a very low-loss polarization mode converter with a 14.5 μm thick polyimide (PI) half waveplate specially designed for PLCs [5]. The polarization insensitive operation of an AWG multiplexer incorporating with this mode converter is also demonstrated [6].

Figs. 1(a) and 1(b) show a schematic configuration and a cross sectional photograph, respectively, of a polarization mode converter. The waveguide was fabricated on a silicon substrate by using silica-based PLC technologies [7]. The refractive index of the 7×7 μm germanium doped core is 0.75% higher than that of the cladding glass. The mode field diameter is 8 μm. The PI half waveplate used in this work was prepared by spin-coating a poly(amic acid) solution onto a dummy Si wafer. The solvent was dried and the poly(amic acid) film was peeled from the wafer. The two sides of the film were fixed in a metal frame and the film was then heated to 350°C to induce uniaxial tensile stress and to convert the poly(amic acid) film into polyimide film. By controlling the spinning speed and the heating conditions, the PI film thickness and in-plane birefringence value were adjusted to produce a half wavelength optical retardation at 1.55 μm between the two in-plane-axes. In this way we obtained a 14.5 μm thick PI film with a birefringence of 0.053 which are used in our experiments. The in-plane refractive indices of the film were 1.638 in parallel and 1.585 in perpendicular to the drawing direction at 1.52 μm. It was sufficiently strong and also easy to handle. The thickness of the half waveplate was less than 1/6 of that when quartz is used. The retardation in the PI waveplate still remained after annealing it at 350°C for 1 hour, which



(a)



(b)

Fig. 1. TE/TM polarization mode converter with polyimide half waveplate (a) schematic configuration, (b) cross sectional photograph.

Manuscript received January 3, 1994.

Y. Inoue, Y. Ohmori, and M. Kawachi are with NTT Opto-electronics Laboratories, Tokai, Ibaraki-ken, 319-11 Japan.

S. Ando and T. Sawada are with NTT Interdisciplinary Research Laboratories.

H. Takahashi is with NTT Transmission System Laboratories.

IEEE Log Number 9401090.

1041-1135/94$04.00

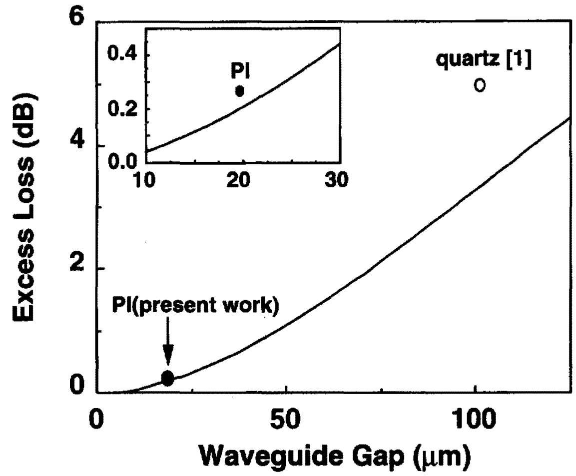


Fig. 2. Excess loss in waveguide gap. The line, open circle and filled circle show calculated results and the results in [1] and in the present work, respectively.

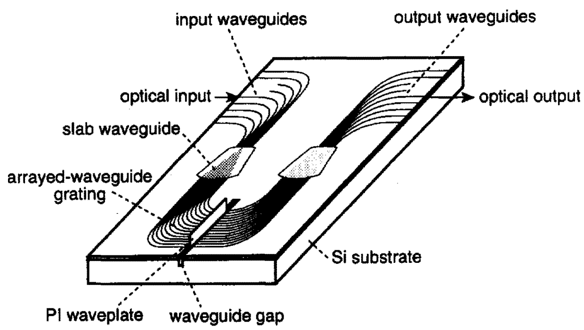


Fig. 3. Configuration of polarization-insensitive arrayed-waveguide grating multiplexer.

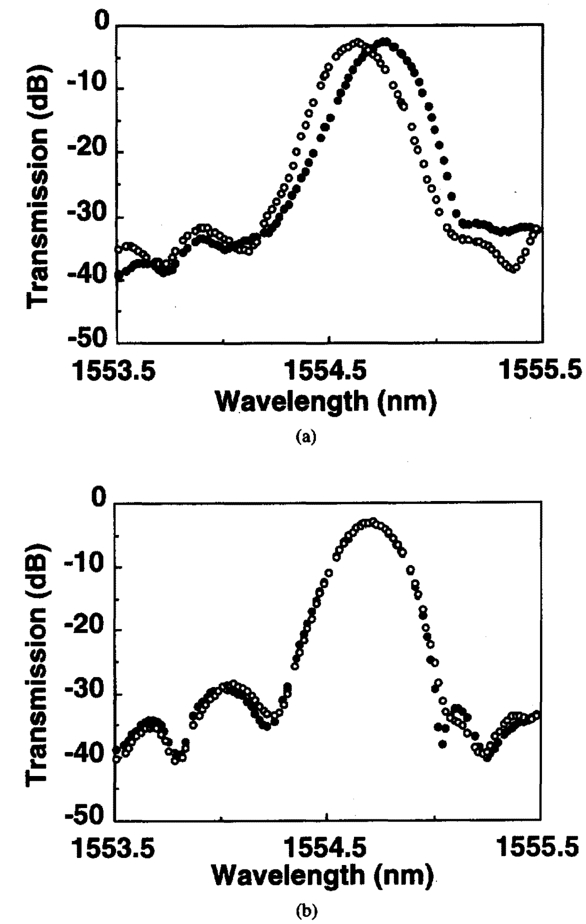


Fig. 4. Transmission spectra of the multiplexer with the mode converter. The open and filled circles indicate TE and TM mode, respectively. (a): without polarization mode converter. (b): with polarization mode converter.

indicates that it has sufficient thermal stability [5]. This PI half waveplate was inserted in the waveguide gap. The gap was 18 μm wide and 120 μm deep, and was formed with a diamond dicing saw. The principal axis of the waveplate was tilted by 45 degrees from the substrate. It was then fixed in the groove with a UV-curable adhesive.

The excess loss of the mode converter was precisely measured and found to be 0.26 dB. The measurement was made by forming 10 grooves with the waveplates in a straight single mode waveguide. The loss didn't change after pulling out the PI films from the grooves. This indicates that the loss was dominantly due to a radiation in the grooves. The loss is less than 1/10 of that with a quartz half waveplate. Fig. 2 shows the relation between the excess loss and the waveguide gap. The excess loss was in good agreement with the calculated radiation loss. The excess loss which results when the quartz half waveplate is inserted is also shown. It can be seen in Fig. 2 that the loss was successfully reduced by reducing the waveplate thickness and the groove width. The back reflection at the PI waveplate was measured and found to be less than −30 dB. The polarization mode conversion ratio was 99%.

The polarization mode converter was used to eliminate the polarization dependence in an AWG multiplexer. Fig. 3 is a schematic configuration of the fabricated 16 channel, 0.8 nm-spaced multiplexer. The multiplexer parameters are listed in Table I. Fig. 4(a) shows the a transmission spectra without the mode converter and polarization sensitivity is clearly observed.

TABLE I
DESIGN PARAMETERS OF THE WAVELENGTH MULTIPLEXER.

Operating wavelength	1.555 μm
Number of wavelength channels	16
Wavelength channel spacing	0.8 nm (100 GHz)
Focal length of concave slab	9381 μm
Path difference of arrayed-waveguide	ΔL=126.4 μm
Number of arrayed waveguides	101
Diffraction order	m=118
Free spectrum range	12.8 nm

It corresponds to a birefringence of 1.3×10^{-4}. The insertion loss of the multiplexer from the center input port to the center output port was 2.7 dB including the coupling losses with dispersion-shifted fibers. Fig. 4(b) shows the transmission spectra with the polarization mode converter. The spectrum for the TE input mode exactly coincides with that for the TM input mode, confirming the polarization-insensitive operation of the multiplexer. The insertion loss was 3.1 dB. The excess loss due to PI waveplate insertion was, therefore, estimated to be 0.4 dB. This value is nearly the same as that measured precisely in a straight waveguide. This polarization insensitive AWG multiplexer was packaged and used as an add/drop MUX [8] and a ring laser filter [9].

In conclusion, a TE/TM polarization mode converter with a PI half waveplate was demonstrated. The excess loss, back reflection, and mode conversion ratio were 0.26 dB, −30 dB and 99%, respectively. As a result, the mode converter was capable of completely eliminating the polarization dependence in an AWG multiplexer. This polarization mode converter can be also applied to other PLCs (such as Mach-Zehnder multiplexers and directional couplers) and further to other material waveguides (such as Ion-exchanged waveguides and $LiNbO_3$ waveguides).

Acknowledgment

The authors wish to thank T. Oguchi and F. Yamamoto for useful discussions, and K. Onose, H. Okazaki and M. Yasu for waveguide fabrication.

References

[1] H. Takahashi, Y. Hibino and I. Nishi, *Optics Lett.*, Vol. 17, pp. 499–501, 1992.
[2] M. Zirngibl, C. H. Joyner, L. W. Stulz, Th. Gaiffe and C. Dragone, *IPR Technical Digest*, vol. 10, pp. 147–150, 1993.
[3] H. Takahashi, Y. Hibino, Y. Ohmori and M. Kawachi, *IEEE Photon. Technol. Lett.*, vol. 5, pp. 707–709, 1993.
[4] M. Yanagisawa and Y. Yamada, to be presented at *IPR'94*, ThF14, San Francisco.
[5] S. Ando, T. Sawada and Y. Inoue, *Electron. Lett.* (to be published).
[6] Y. Inoue, Y. Ohmori, M. Kawachi, S. Ando, T. Sawada and H. Takahashi, to be presented at *IPR'94*, ThE3, San Francisco.
[7] M. Kawachi, *Opt. Quantum Electron*, vol. 22, pp. 391–416, 1990.
[8] Y. Tachikawa, Y. Inoue, M. Kawachi, H. Takahashi and K. Inoue, *Electron. Lett.*, (to be published).
[9] H. Takahashi, H. Toba and Y. Inoue, *Electron. Lett.*, (to be published).