IEICE Electronics Express, Vol.3, No.23, 499–503

Compact silica arrayed-waveguide grating with small bend radius utilizing trenches filled with low-refractive index material

Jiro Ito[a)], **Tom Yen-Ting Fan, Takanori Suzuki, and Hiroyuki Tsuda**
Graduate School of Science and Technology, Keio University
3–14–1 Hiyoshi, Kouhoku-ku, Yokohama-shi, Kanagawa, 223–8522, Japan
a) *jiro-i.23@tsud.elec.keio.ac.jp*

Abstract: We present details of a local high-index contrast silica waveguide that uses trenches filled with a low-refractive index material enabling bends with small radius to be used. The lateral relative refractive index difference was 8.34% and the minimum bend radius was 300 μm. An 8-channel, 100 GHz spacing compact arrayed-waveguide grating using waveguides with small bend radius was successfully fabricated.

Keywords: planar lightwave circuit, integrated optics, waveguide
Classification: Photonics devices, circuits, and systems

References

[1] T. Miya, "Silica-based plannar lightwave circuits: Passive and thermally active devices," *IEEE J. Select. Topics Quantum Electron.*, vol. 6, pp. 38–45, Jan. 2000.
[2] B. Schauwecker, G. Przyrembel, B. Kuhlow, and C. Radehaus, "Small-size silicon-oxynitride AWG demultiplexer operating around 725 nm," *IEEE Photon. Technol. Lett.*, vol. 12, pp. 1645–1646, Dec. 2000.
[3] M. Popovic, K. Wada, S. Akiyama, H. A. Haus, and J. Michel, "Air Trenches for sharp silica waveguide bends," *J. Lightwave Technol.*, vol. 20, no. 9, pp. 1762–1771, Sept. 2002.
[4] S. Akiyama, M. Popovic, P. T. Rakich, K. Wada, J. Michel, H. A. Haus, E. P. Ippen, and L. C. Kimerling, "Air Trenches bends and splitters for dense optical integration in low index contrast," *J. Lightwave Technol.*, vol. 23, no. 7, pp. 2271–2277, July 2005.
[5] K. Kohtoku, "Low-loss compact silica-based AWG using deep ridge waveguide," *Integrated Photonics Research and Applications 2005*, San Diego, U.S.A., ITuF1, April 2005.
[6] Tom Y. Fan, J. Ito, T. Suzuki, and H. Tsuda, "Compact arrayed-waveguide grating using air trench and high mesa structure," *Integrated Photonics Research and Applications 2006*, Connecticut, U.S.A., IMB3, April 2006.
[7] J. Ito, T. Suzuki, T. Y. Fan, A. Tate, and H. Tsuda, "Proposal of silica waveguide buried with a low-refractive index material for compact pla-

DOI: 10.1587/elex.3.499
Received November 06, 2006
Accepted November 09, 2006
Published December 10, 2006

IEICE Electronics Express, Vol.3, No.23, 499–503

nar lightwave circuits," *Contemporary Photonics Technology 2006*, Tokyo, Japan, Last-Minute3, Jan. 2006.
[8] J. Ito, T. Y. Fan, T. Suzuki, A. Tate, and H. Tsuda, "Compact arrayed-waveguide grating using low-refractive index material filled trenches," *OptoElectronics Communication Conference 2006*, 5B2-2, Kaohsiung, Taiwan, July 2006.

1 Introduction

Planar lightwave circuits (PLCs) incorporating fiber-matched silica-based waveguides have become very popular in the field of passive integrated optical components. Silica waveguides with low index contrast have small fiber-to-chip coupling loss and small propagation loss. However, low refractive index contrast silica waveguide circuits require a large bend radius, usually ranging from millimeters to one centimeter [1]. The ability to shrink large-sized waveguide circuits to a smaller size while maintaining low bend-loss would overcome the major obstacle currently facing silica technology [2]. However, high refractive index contrast waveguide circuits have large coupling losses with single mode fibers. Therefore, a scheme in which a pair of air trenches is integrated along the waveguide bend to form a high refractive index contrast region has been proposed [3, 4]. By using air trench bends, the bend radius can be shrunk while maintaining low coupling losses. A semiconductor arrayed-waveguide grating (AWG) featuring a high aspect-ratio mesa has been reported by K. Kohtoku [5]. Moreover, a silica AWG that includes air trenches and high aspect-ratio mesa structures has also been reported [6]. In order to approximate the single mode condition, however, the mesa width should be narrow, which makes the waveguide fragile. Additionally, the side walls can become contaminated with dust and impure substances leading to degradation of the characteristics.

In this paper, we propose a solution to these problems by filling the trenches with a material with a lower refractive index relative to the refractive index of silica. Using this structure we designed and fabricated a compact AWG with bends of small radius.

2 Waveguide design

In order to fabricate an AWG with small radius bends using trenches filled with low-refractive index material, we optimized the insertion angle of the trenches, the bend radius and the mesa width using the 2-D Beam Propagation Method (BPM). Firstly, we conducted simulations of the insertion angle. To eliminate the junction loss between conventional waveguides and our proposed waveguides, the trenches are inserted gradually at the input and output junctions. This reduces Fresnel reflections and the radiation losses that normally occur at the junction.

We simulated the excess loss in a straight waveguide consisting of conventional input and output waveguides, and a low-refractive index material

DOI: 10.1587/elex.3.499
Received November 06, 2006
Accepted November 09, 2006
Published December 10, 2006

ELectronics EXpress
IEICE Electronics Express, Vol.3, No.23, 499–503

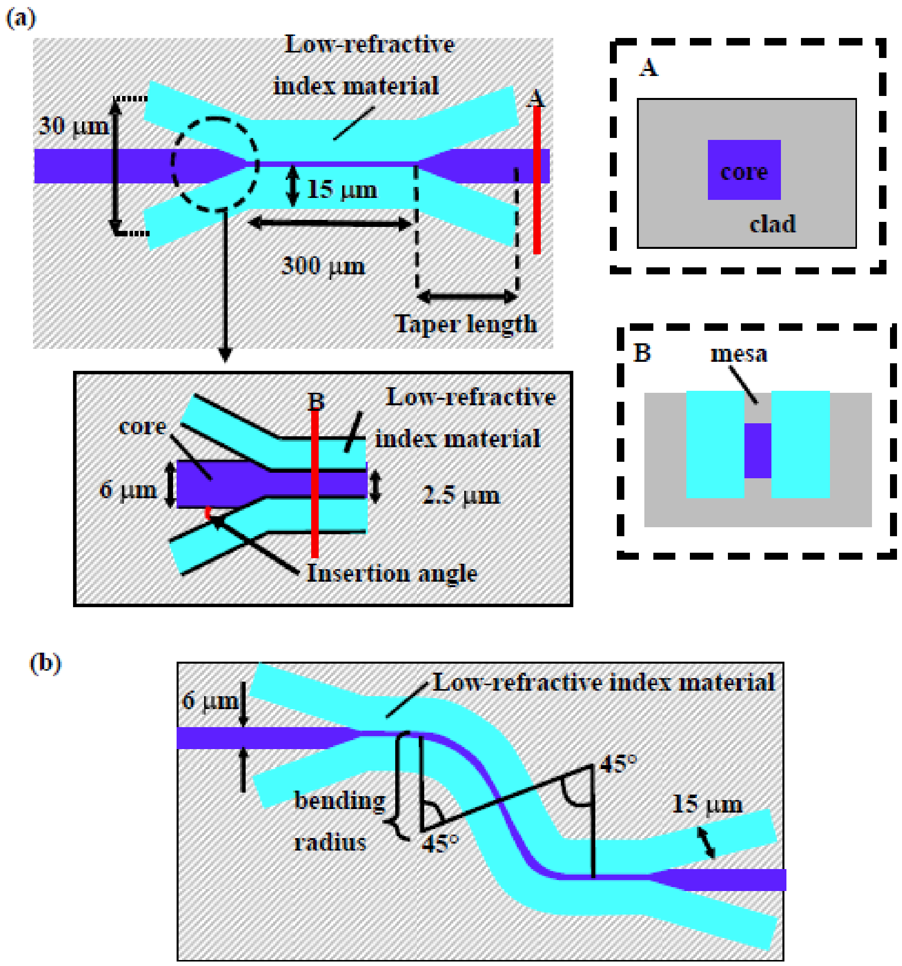

Fig. 1. (a) Schematic diagrams and cross sections of a straight waveguide consisting of conventional input and output waveguides and a low-refractive index material buried waveguide. (b) Schematic of S-shaped waveguide for calculating bend loss.

buried waveguide as shown in Fig. 1 (a). The core width of the conventional waveguide was 6 μm. The refractive indices of the core and the cladding were 1.45225 and 1.44402, respectively, and the refractive index of the resin was 1.3335. In this research we used Cytop^{TM} as a low-refractive index material. Cytop^{TM} is an amorphous fluoropolymer having high transparency. By incorporating Cytop^{TM} filled trenches, the relative refractive index difference changed from 0.75 to 8.34%. The widths of the mesa and trench were 2.5 μm and 12 μm, respectively. These are the minimum widths we can fabricate. The result is shown in Fig. 2 (a). The larger taper angle provides a shorter taper length; however, it leads to higher junction loss because the relative refractive index difference changes abruptly. We determined the optimum insertion angle to be 1 degree. In addition, we confirmed that the polarization dependent loss (PDL) was less than 0.015 dB.

We calculated the bending losses for various bend radii and mesa widths for waveguide circuits based on an S-shaped configuration. The S-shaped waveguide consists of two 45 degree bends with the same radii, as shown in

DOI: 10.1587/elex.3.499
Received November 06, 2006
Accepted November 09, 2006
Published December 10, 2006

ELectronics EXpress

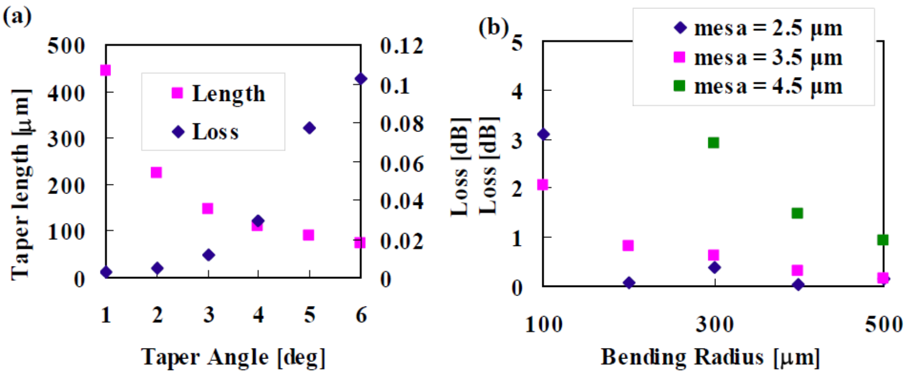

Fig. 2. (a) Excess loss and taper length of the straight waveguide as functions of the insertion angle of the trench. (b) Excess loss as a function of mesa width and bend radius.

Fig. 1 (b). We assumed the insertion angle of the trenches to be 1 degree. The result is shown in Fig. 2 (b). It is well known that a smaller mesa-width provides a lower loss; however, mesas with widths of less than 3.0 μm are particularly difficult to apply to AWGs because the waveguides are very fragile. This being the case, a mesa width of 3.5 μm is more suitable. On the other hand, the loss for a bend radius of 300 μm is about 0.1 dB when the mesa width is 3.5 μm. Therefore, the parameters chosen for our design were 3.5 μm for the mesa width and 300 μm for the bend radius. Under these conditions the PDL is about 0.34 dB.

3 AWG with small bend waveguides

Based on the results of the simulations, we determined the insertion angle to be 1 degree, the mesa width to be 3.5 μm, and the bend radius to be 300 μm. The core width and core height of the conventional waveguide were 6 μm. The refractive indices of the core and the cladding were 1.45485 and 1.44402, respectively, and the refractive index of the resin was 1.3335. A schematic of the AWG with enlarged pictures of the bend regions is shown in Fig. 3 (a). The AWG consists of an array of 22 waveguides and 8 input and output waveguides. The channel spacing is 100 GHz. The length of the slab is 2988.34 μm and the center wavelength is 1555.11 nm. We designed the length of the Cytop$^{\mathrm{TM}}$-buried waveguides to be identical in order to reduce the polarization dependent peak wavelength difference (PD$\Delta\lambda$), because the difference in equivalent refractive index for the TE and TM modes is quite large (6.6×10^{-4}) when the mesa width is 3.5 μm. Moreover, by using the same bending waveguide structure, propagation loss fluctuations can be reduced. The measured loss characteristics are shown in Fig. 3 (b). These include a coupling loss of 1 dB between the single mode fiber and the waveguide. The minimum loss at the center wavelength was 7.33 dB and the PDL was 0.18 dB. Crosstalk between adjacent channels was −18.8 dB and PD$\Delta\lambda$ was not observed. The size of the AWG was $3.7 \times 8.9\,\mathrm{mm}^2$, which is about 1/4 of the size of a conventional AWG ($\Delta = 0.75\%$) with the same channel

DOI: 10.1587/elex.3.499
Received November 06, 2006
Accepted November 09, 2006
Published December 10, 2006

ELectronics EXpress
IEICE Electronics Express, Vol.3, No.23, 499–503

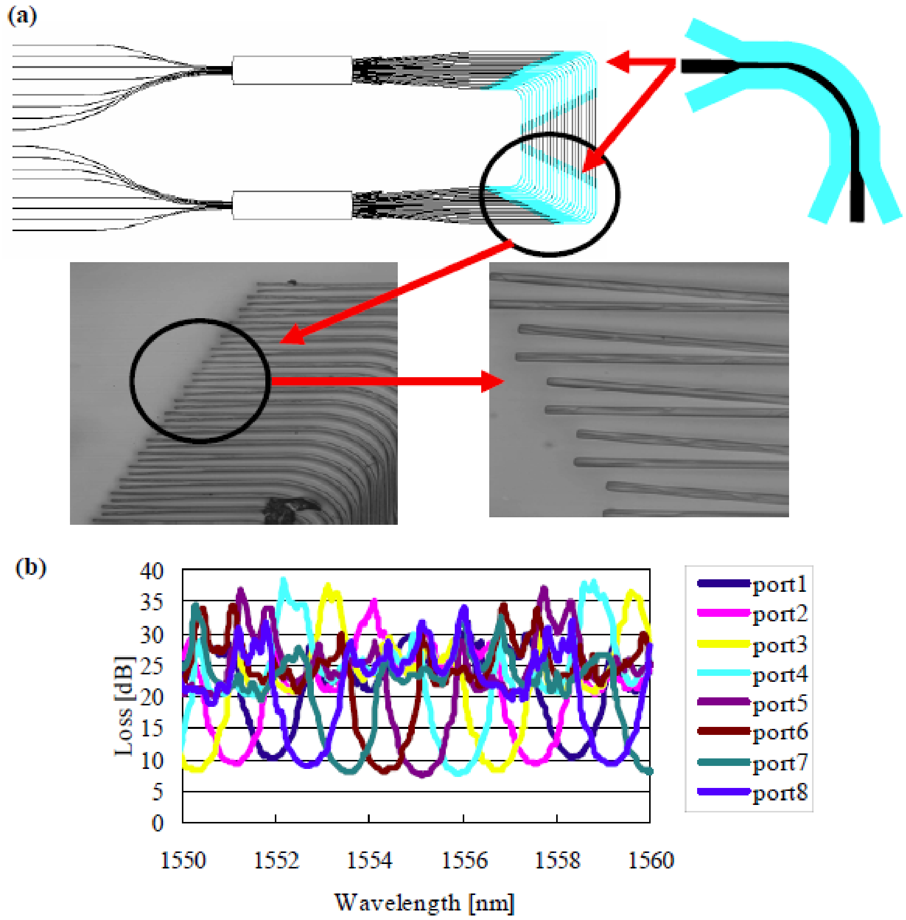

Fig. 3. (a) Schematic of our AWG design and an enlarged pictures of the 90 degree bend and taper regions. The slab waveguides and arrayed waveguides occupying and area of $3.7 \times 8.9\,\mathrm{mm}^2$. (b) Transmission characteristics of the AWG.

number, diffraction order and free spectral range.

4 Conclusion

We proposed a compact PLC utilizing trenches filled with a low-refractive index material in order to enhance the lateral confinement and enable a reduction in bend radius while maintaining low loss. We successfully fabricated an AWG with a chip size of $3.7 \times 8.9\,\mathrm{mm}^2$, a loss at the center wavelength of 7.33 dB, a polarization dependent loss of 0.18 dB, and crosstalk between adjacent waveguides of -18.8 dB. The size is about 1/4 of that of a conventional AWG with the same number of channels, diffraction order and free spectral range.

Acknowledgments

We are grateful to Hitachi Cable, Ltd. for supporting the fabrication of the devices.

DOI: 10.1587/elex.3.499
Received November 06, 2006
Accepted November 09, 2006
Published December 10, 2006