A compact arrayed-waveguide grating with a locally enhanced optical confinement structure using trenches filled with low-refractive index materials

Jiro Ito (1) and Hiroyuki Tsuda (2)
1) *Department of Electronics and Electrical Engineering, KEIO University.* jiro-i.23@tsud.elec.keio.ac.jp
2) *Department of Electronics and Electrical Engineering, KEIO University.* tsuda@elec.keio.ac.jp

Abstract: We have reduced the minimum bending radius of a silica waveguide from 2 mm to 200 μm by burying low-refractive index material along both sides of the core. The local lateral relative refractive index difference (Δ) was increased to 9.05%. Moreover, we fabricated both an 8-channel, 100-GHz channel-spacing arrayed-waveguide grating (AWG) and an 8-channel, 12.5-GHz channel-spacing AWG using variations of these new compact bend structures. Compared with conventional AWGs, the relative chip-sizes of these devices were reduced to about 1/2 and 1/4, respectively.

Introduction

Planar lightwave circuits (PLC) are useful devices for realizing large capacity and high-speed photonic networks. In particular, arrayed-waveguide gratings (AWGs) are key devices that can multi/demultiplex a number of wavelength channels with low loss. Optical communication requires multifunctional small-sized PLCs.

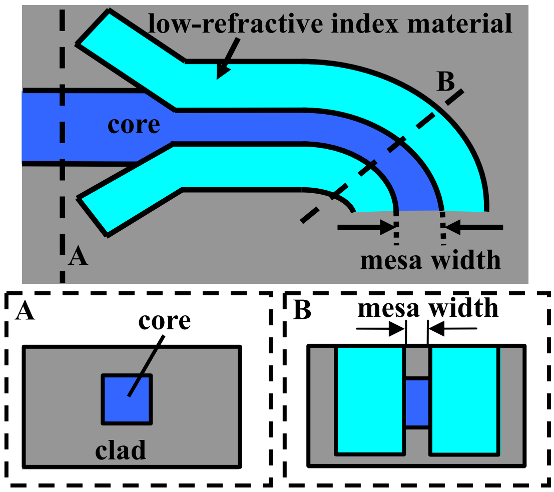

Fig. 1: Schematic of a silica bend waveguide with trenches filled with a low-refractive index material.

However, dense integration is difficult because the minimum bend radii of conventional silica waveguides with high (H)-relative refractive index differences (Δ) of 0.75 % and with super-high (SH)-Δ values of 1.5% are 5 mm and 2 mm, respectively. Semiconductor AWGs [1] and Si photonic wire AWGs [2] with large Δ have been reported. However, the coupling losses of these devices with single mode fibers are large without the use of mode-conversion interfaces. Air trench bend (ATB) technology, which consists of a "cladding taper" and a pair of air trenches along the waveguide bend, can reduce the bend radius, maintaining low loss [3], [4]. We have previously fabricated air-trenched AWGs by this method [5]. However, such trenches can be contaminated by dust and by impurities, and therefore they do not have stable characteristics. On the other hand, we have proposed a locally-enhanced optical confinement structure using trenches filled with low-refractive index resin along the both sides of the core, and we applied this structure to AWGs with H-Δ [6], [7].

In this paper, we have fabricated both a 90-degree bend-type AWG and a triple-arrowhead-type AWG using locally-enhanced optical confinement structures with SH-Δ waveguides. The sizes of these AWGs were reduced to about 1/2 and 1/4 of those of conventional devices, respectively.

Waveguide Design

We used a two-dimensional beam propagation method (2DBPM) to optimize the taper angle of the transition region between a conventional single mode straight waveguide and a narrow-width core sandwiched between low-refractive index material, as shown in Fig. 2.

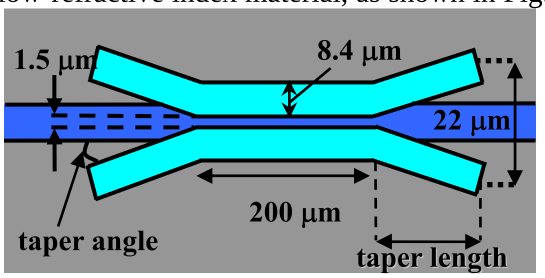

Fig. 2: Straight waveguide for simulations.

The widths of the core, the mesa and the trench were assumed to be 4.3 µm, 2.5 µm and 8.4 µm, respectively. The refractive indices of the core, the cladding and the low-refractive index material were 1.4611, 1.4440 and 1.3335, respectively. The lateral Δ was 9.05%. The simulation results are shown in Fig. 3.

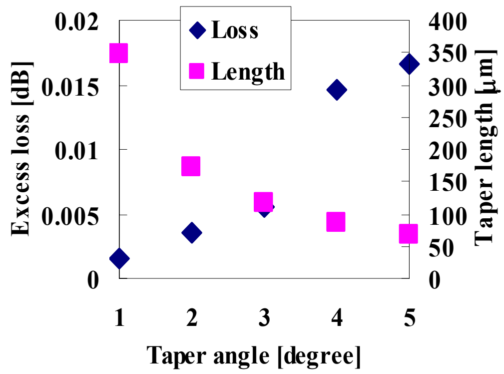

Fig. 3: Excess loss and taper length as a function of taper angle.

The larger taper-angle provides a shorter taper length. However, this leads to higher junction losses because the lateral Δ changes abruptly. Therefore, we determined that the optimum taper angle was 3 degrees, which allows a shorter taper length to minimize losses. The bend radius and the mesa width were optimized by 3D BPM simulation. We used a 90-degree bend to calculate the bend loss, as illustrated in Fig. 4.

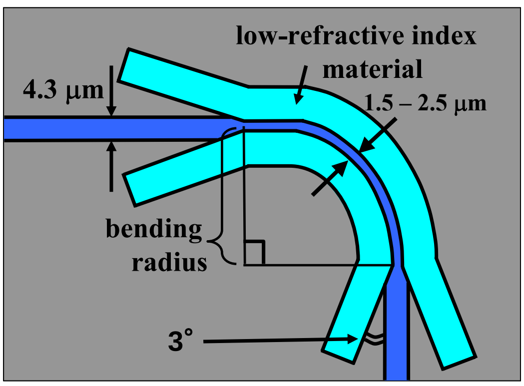

Fig. 4: Schematic of a 90-degree bend waveguide for calculating bending loss.

The taper angle was 3 degrees. The bending radius was changed from 100 to 500 µm. The mesa width was changed from 1.5 to 2.5 µm. The result of the simulation is shown in Fig. 5. For a bending radius of 200 µm, the loss was about 0.1 dB. In addition, the bend loss increased rapidly when the bending radius was less than 100 µm. Hence, we determined that the minimum bending radius for practical applications was 200 µm. The polarization-dependent loss (PDL) was 0.02 dB. Smaller mesa widths provide lower losses, as shown in Fig. 5.

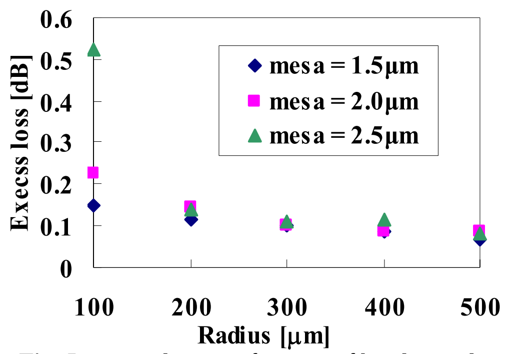

Fig. 5: Excess loss as a function of bending radius.

90-degree Bend-Type AWG

We then applied these small-radius bend structures to an 8-channel, 100-GHz channel spacing, 90-degree bend-type AWG, as shown in Fig. 6. The specifications for this type of AWG are shown in Table I.

Table I: Specifications of a 90-degree bend-type AWG.

Parameter	Value [unit]
number of channels	8
channel spacing	100 [GHz]
FSR	800 [GHz]
number of arrayed waveguides	30
path length difference	252.7 [µm]
diffraction order	237
center wavelength	1552.45 [nm]
taper angle	3 [degree]
minimum bending radius	200 [µm]

We fabricated three kinds of AWGs by changing the mesa width from 1.5 to 2.5 µm. We used Cytop™, which has a refractive index of 1.3335, as the low-refractive index material. The transmission characteristics from the center ports for the three different mesa widths are shown in Fig. 7. The transmission loss includes a coupling loss of 0.9 dB/facet between the single mode fiber and the waveguide, a

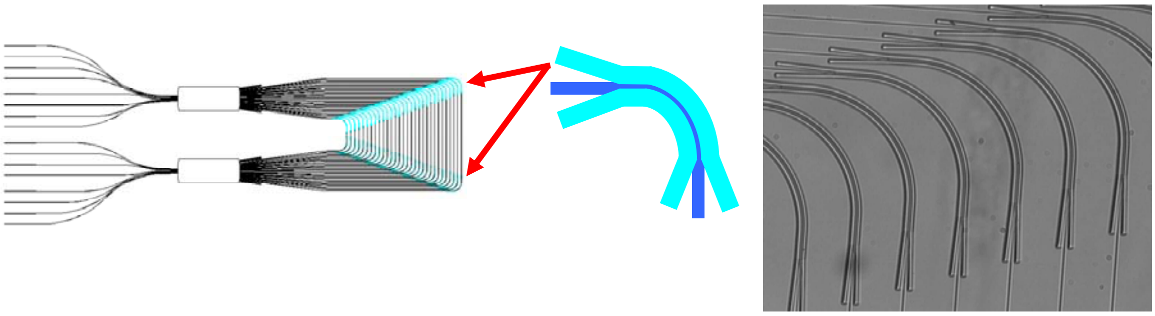

Fig. 6: Schematic of a 90 degree AWG using trenches filled with low-refractive index material.

transition loss of 0.75 dB/slab between the slab waveguide and the array waveguide, and an excess loss due to the bend of 0.1 dB × 2. Contrary to the simulation, the AWG with the mesa width of 2.5 μm had the best characteristics in terms of both loss and crosstalk. These results are attributed to sidewall roughness. Therefore, we determined that the optimum mesa width was 2.5 μm.

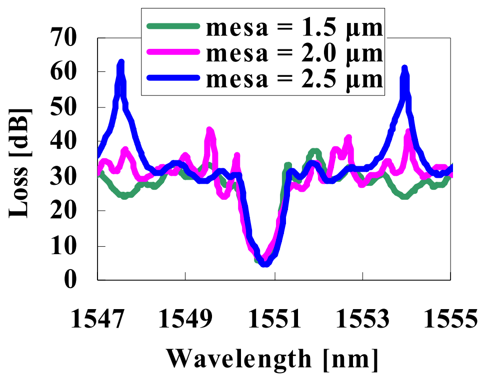

Fig. 7: Transmission characteristics from the center port of a 90 degree bend AWG.

Arrowhead Type AWG

Arrowhead-shaped AWGs using elliptic Ag mirrors have been reported [8]. The size of the chips can be reduced by using multiple arrowhead structures [9]. However, the propagation losses of v-bend waveguides using elliptic Ag mirrors were very large, and the degradation of their characteristics due to fabrication errors was also significant. Therefore, we have fabricated an 8-channel, 12.5-GHz channel spacing, triple-arrowhead AWG using trenches filled with low-refractive index material instead of the elliptic Ag mirrors. The specifications of the fabricated AWG are shown in Table II.

Table II: Specifications of the triple Arrowhead AWG.

Parameter	Value [unit]
number of channels	8
channel spacing	12.5 [GHz]
FSR	100 [GHz]
number of arrayed waveguides	30
path length difference	2021.56 [μm]
diffraction order	1899
center wavelength	1550 [nm]
taper angle	3 [degree]
minimum bending radius	200 [μm]
mesa width	2.5 [μm]

The triple arrowhead AWG configuration is shown schematically in Fig. 8. The bending angle of the small-bend waveguides was 150 degrees. The chip area, including the arrayed-waveguides and the slab waveguides, was 4.33 × 23.43 mm^2. This is about 1/4 of the size of a conventional AWG with a Δ value of 1.5% with the same number of channels, the same diffraction order, the same array number, and the same channel spacing. The transmission characteristics are shown in Fig. 9. The losses included a coupling loss of 1.8 dB between the single mode fibers and the waveguides. The minimum loss at the center wavelength was 8.25 dB. The PDL was 0.27 dB, and the adjacent channel crosstalk was -15.7 dB. The polarization-dependent peak wavelength difference (PDΔλ) was 3.1 GHz.

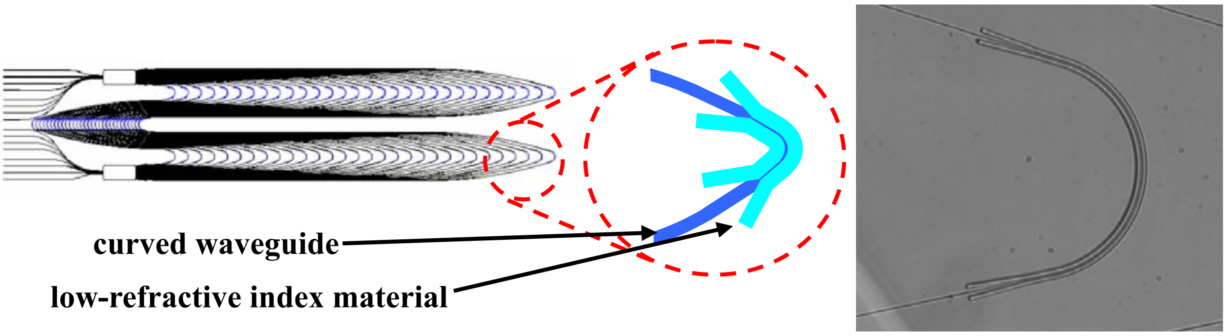

Fig. 8: Schematic of the triple arrowhead type AWG using trenches filled with low-refractive index material.

Conclusion

We proposed two types of AWGs into which we introducing small-bend structures using trenches filled with low-refractive index material. The 90-degree bend-type AWG had 8 channels with a spacing of 100 GHz and the triple-arrowhead AWG had 8 channels with a spacing of 12.5 GHz, respectively. The sizes of the 90-degree bend-type and the triple-arrowhead-type AWGs were about 1/2 and 1/4 of those of conventional AWGs with a Δ of 1.5 % respectively. They exhibited minimum losses of 4.47 dB and 8.25 dB, PDL values of 0.25 dB and 0.27 dB, and adjacent-channel crosstalk of -26.3 dB and -15.7 dB, respectively.

Acknowledgments

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

References

1. K. Kohtoku, IPRA, Paper ITuF1, 2005.
2. T. Fukazawa, F. Ohno and T. Baba, Jpn. J. Appl. Phys., vol. 43, no. 5B, pp. L673-L675, 2004.
3. M. Popovic, K. Wada, S. Akiyama, H. A. Haus, and J. Michel, J. Lightwave Technol., vol. 20, no. 9, pp. 1762-1771, 2002.
4. S. Akiyama, M. Popovic, P. T. Rakich, K. Wada, J. Michel, H. A. Haus, E. P. Ippen, and L. C. Kimerling, J. Lightwave Technol., vol. 23, no. 7, pp. 2271-2277, 2005.
5. T. Y. Fan, J. Ito, T. Suzuki and H. Tsuda, IPRA, Paper IMB3, 2006.
6. J. Ito, T. Y. Fan, T. Suzuki, A. Tate and H. Tsuda, OECC, Paper 5B2-2, 2006.
7. J. Ito, T. Y. Fan, T. Suzuki and H. Tsuda, IEICE Electron. Express, vol. 3, no. 23, pp. 499-503, 2006.
8. T. Suzuki and H. Tsuda, IEEE Photon Technol. Lett., no. 4, pp. 810 - 812, 2005.
9. T. Suzuki and H. Tsuda, Jpn. J. Appl. Phys., vol. 45, no. 7, pp. 5575-5581, 2006.