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Fabrication of Silicon Reflection-Type AWGs with Distributed Bragg Reflectors

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Abstract

Silicon reflection-type arrayed waveguide gratings (AWGs) with -20dB crosstalk are experimentally demonstrated for the first time to our knowledge. The AWG has 14 output channels with 400GHz channel spacing and a footprint of 230x530 μm^2. The minimum on-chip loss of 3.0 dB is achieved by using a second-order distributed Bragg reflector (DBR) facet.

I. INTRODUCTION

Silicon photonics is a promising technology to meet the requirements of rapid bandwidth growth and energy-efficient communications, while reducing cost per bit. Silicon AWG is expected to play an important role in wavelength division multiplexing (WDM) systems in the same way as silica AWG functions in commercial multi/demultiplexing and signal routing applications. An ultra-compactness of silicon photonics device is one of the greatest advantages not only for on-chip CMOS applications but for data communications beyond 100G [1]. Reflection-type AWG (R-AWG) was proposed in silica AWG [2] and fabricated in InP AWG [3]. However, high insertion loss (13 dB) and poor crosstalk (~ -13 dB) have been obtained probably due to the high absorption loss by Au-metal at the reflection facet and imperfection in the facet verticality.

In this presentation, we report the successful fabrication of silicon R-AWG, which enables us to achieve the smallest possible footprint when compared with the conventional transmission-type AWG having the same AWG parameters (Fig. 1(a) and (b)). Straight array waveguides and the length reduction of them both contribute to minimize the total accumulated phase error and lead to lower the crosstalk of AWGs [4].

II. DESIGN and FABRICATION

R-AWGs were fabricated on 200 mm silicon-on-insulator SOI wafers having a 220 nm thick silicon core layer on a 2 μm buried oxide layer. Figure 1(a) shows the schematic configuration of the silicon R-AWG which consists of input/output (I/O) Si-wire waveguides, slab region with arc length of 91.7 μm, and 40 Si-rib straight array waveguides with successive $\Delta L/2$ (ΔL = 13.2 μm) geometrical path-length difference. Width of the Si-wire waveguide is 480 nm and that of the Si-rib waveguide is 650 nm with 150 nm peripheral heights, respectively. The super-linear adiabatic taper was used at the interface between the Si-wire I/O waveguides and slab region to reduce reflections. Array waveguide spacing at the slab interface is 1.55 μm and I/O waveguide spacing is 2.2 μm, respectively. We used a deeply etched (220 nm) second-order DBR as a reflection facet which was

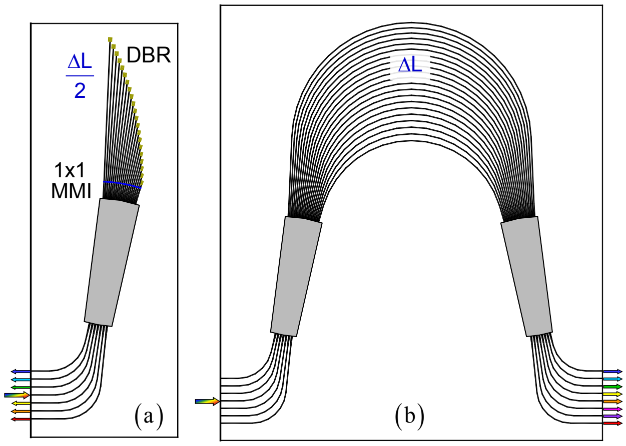

Fig. 1. (a) Reflection-type and (b) transmission-type AWGs.

demonstrated in planar concave grating [5]. The period is 620 nm, the gap width is 130 nm and number of period is N_{DBR} = 10, respectively. Different from the surface relief grating, mode-coupling coefficient of the deeply etched grating does not depend on the diffraction order and more than 90 % (< 0.5 dB loss) power reflectivity can be obtained for $N_{DBR} > 8$ [6]. On the other hand, reflection bandwidth of the second-order DBR is 160 nm which is almost the half of that of the first-order DBR.

1x1 multimode interference (MMI) mode filter was added to every array waveguide to suppress the higher-order mode because the Si-rib waveguide with 650-nm width is slightly multi-moded [7]. The MMI mode filter was 1.3 μm in width and 3.0 μm in length. Simulated insertion loss of the mode filter for the fundamental mode is ~0.04 dB, while loss for the higher-order mode is larger than 50 dB.

Array waveguides in the R-AWG can be entirely weakly-guiding waveguides such as Si-rib waveguides because bent-waveguides are not required. Effective-index fluctuation (δn_c) of the Si-rib waveguide with respect to the core-width fluctuation (δW) is ~2 times smaller than that of the Si-wire waveguide [4]. In addition to that, the average array waveguide length (L_c) of the R-AWG can be 3~4 times shorter than that of the transmission-type AWG as shown in Figs. 1(a) and (b). Smaller δn_c and shorter L_c in the R-AWG both contribute to reduce crosstalk (XT) of AWG because it is empirically expressed by [4]

$$XT \sim 10\,\mathrm{Log}\left(\frac{\delta n_c L_c}{\lambda}\right)^2, \qquad (1)$$

where λ denotes the center wavelength.

Measurement result of 14ch-400GHz Si-RAWG is

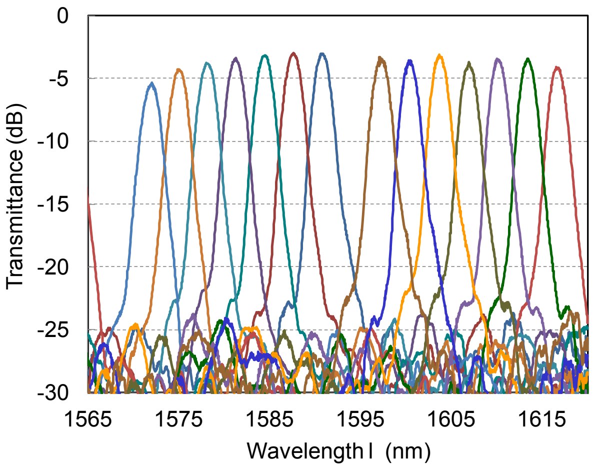

Fig. 2. Measurement result of 14ch-400GHz Si reflection-type AWG.

shown in Fig. 2. On-chip loss of 3.0 dB and crosstalk of -20 dB have been obtained. Fiber coupling loss was about 3.0 dB by using a spot-size converter. Central channel at λ~1594 nm is not available because it comes back to the input port. In order to investigate the functionality of MMI mode filter, we coupled light into the (original) output port and measured at the (original) input port. Measurement was repeated by shifting the coupling position through the entire positions. In this off-center light coupling, farfield radiation field is expected to excite higher-order mode in the array waveguide and degrade the crosstalk characteristics. However, almost no substantial crosstalk degradation has been observed as shown in Fig. 3. Slight deviations in the insertion losses may be due to the coupling loss variations from port to port because fixed coupling loss value was used. It is confirmed that the MMI mode filter can sufficiently suppress the higher-order modes.

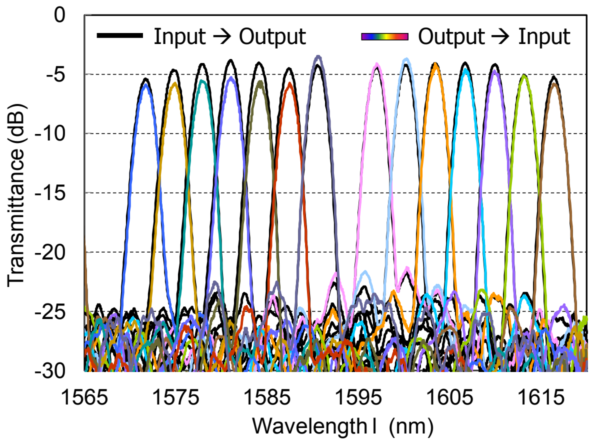

Fig. 3. Transmission spectra for the center input (black lines) and off-centered (colored lines) light coupling.

MMI mode filter allows us to implement a standard layout of I/O waveguides as shown in Fig. 4.

Fig. 5 shows a transmission spectrum of one of the 14 channels of 8 AWGs on the same die. Center wavelength fluctuation is measured to be ~0.6 nm, which is about 3 times smaller than the previously reported value [8]. It suggests that the effective-index fluctuation δn_c is also 3 times smaller because δn_c is proportional to $\delta\lambda$ and the crosstalk of less than -20 dB should have been obtained.

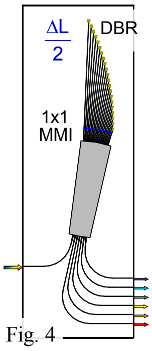

Fig. 4

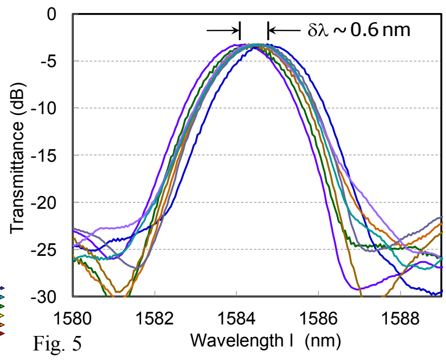

Fig. 5

Fig. 4. Standard layout of I/O waveguides which is made possible by use of the MMI mode filter.

Fig. 5. Transmission of one of the 14 channels of 8 AWGs.

Several factors are considered to be the origin by which crosstalk is limited to around -20 dB; they are, irregularities in DBR periodicity, size fluctuations in MMI mode filters, and SOI thickness fluctuations (δT). The former two factors can be reduced by the improvement of the fabrication process. Crosstalk degradation by the SOI thickness fluctuations can be reduced by using thicker core layer, for example, with 0.5 μm [4]. $\delta n_c/\delta T$ for both of the Si-rib waveguide and slab region with 0.5-μm-thick cores are calculated to be ~5 times smaller than those of 0.22-μm-thick cores.

Although R-AWG resembles planar concave grating, the major difference is that the delay arms (array waveguides) and the light interference region (slab region) are clearly separated in the R-AWG. Then, athermal R-AWG can be fabricated by using two different kinds of SOI-based cores, such as Si-rib and Si-slot waveguides, in array waveguide region [9].

III. Conclusions

Compact SOI-based reflection-type 1x14 AWGs with 400-GHz channel spacing have been demonstrated for the first time. Good crosstalk value of -20 dB was achieved with the on-chip loss of 3 dB. R-AWG configuration allows us to achieve the smallest possible footprint when compared with the conventional AWG having the same parameters. Fabrication of the athermal R-AWG is ongoing and the results will be reported in the near future.

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