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A High-Crosstalk Silicon Photonic Arrayed Waveguide Grating

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***Abstract*—**In this paper, we demonstrated a 1 × 4 silicon photonic cascaded arrayed waveguide grating, which is fabricated on a SOI wafer with a 220 nm top Si layer and a 2μm buried oxide layer. The measured on-chip transmission loss of this cascaded arrayed waveguide grating is ~ 5.6 dB, including the fiber-to-waveguide coupling loss. The adjacent crosstalk is 33.2 dB. Compared to the normal single silicon photonic arrayed waveguide grating with a crosstalk of ~ 12.5 dB, the crosstalk of this device has been dramatically increased.

***Keywords*—**Silicon photonic, arrayed waveguide grating, high-crosstalk, cascaded structure.

I. Introduction

ARRAYED WAVEGUIDE GRATING (AWG) is a very critical component in our modern optics communication system. In the wavelength division multiplexing (WDM) networks, AWG is usually used as a multiplexer or a de-multiplexer, which can remarkably improve the transmission capability of the optics networks [1], [2]. Although AWG is based on silica in the current optics networks, silicon-based AWG has a more attractive application prospect because of low price, high-speed performances and compatible process with CMOS circuits. Ten year ago, the silicon AWG was fabricated on a SOI wafer with a thick top Si, however the foot print size is big because of big bend radius of the silicon waveguide [3]. Recently, the silicon photonics devices have been dramatically developed and excellent performances have been achieved in many silicon photonics devices. These silicon photonics devices include high-speed modulators [4], [5], high-speed Ge-on-Si photodetectors [6], [7], low coupling loss converters [8], low power consumption switches [9], which are developed on a SOI wafer with a thin top Si layer, such as 220nm-thick top Si. A thin top Si can contribute to the high speed of modulator and photodetector and the low power consumption of switch. However, the design/fabrication tolerance on the thin top silicon layer is very small, especially for AWG. It is why the reported AWG on SOI wafer with 220nm-thick top Si layer has not a good cross-talk [10], [11].

In this paper, we designed and fabricated a 1 × 4 silicon photonic arrayed waveguide grating, which is based on a SOI wafer with a 220 nm top Si layer and a 2μm buried oxide layer. The cascaded AWG include 5 single AWGs with the same design. The optical signals can further be filtered for two times. The noise can be reduced further. The cascaded structure with arrayed waveguide gratings can dramatically increase the performance of crosstalk. The cascaded AWG has a perfect crosstalk performance of 33.2 dB by characterization.

II. Design and Fabrication

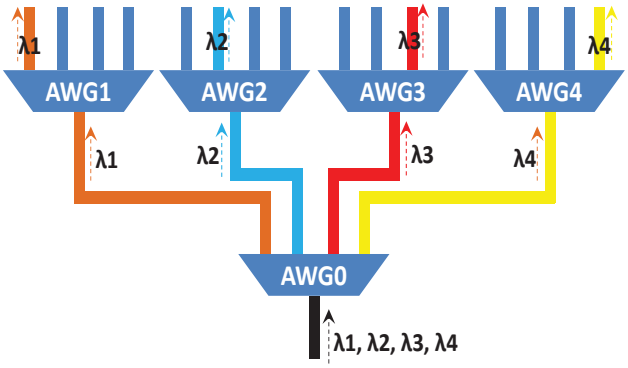

Fig. 1 Schematic of 1 × 4 cascaded silicon photonic AWG

TABLE I
Design Parameters of Single AWG

Silicon channel waveguide height	220 nm
Silicon rib waveguide height	120 nm
Min. pitch of input/output waveguides	2.5 μm
Min. pitch of arrayed waveguides	2.5 μm
Width of arrayed waveguides	600 nm
Channel spacing	6.4 nm
grating order	28
FPR	82.9 μm
FSR	44.1 nm
Min. radius of arrayed waveguides	30 μm
Length difference of arrayed waveguides	13.95 μm
Operation wavelength	1.55 μm

The schematic of the cascaded silicon photonic AWG is shown in Fig. 1. The five AWGs (from AWG0 to AWG4) have the same design. Table I shows the main design parameters of single AWG. The arrayed waveguide grating is designed for a channel spacing of 6.4 nm at 1550 nm. In order to reduce the coupling loss between the nano-taper and the optical lensed

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fiber at the input while ensure mode confinement at the output, the ridge waveguides are gradually transited into channel waveguides at the input/output of the AWG. The channel waveguides are 600 nm wide and 220 nm tall while the ridge waveguides are similarly wide, with a slab thickness of 120 nm. The device is designed to operate at the grating order of 28, with a path length difference of 13.95 μm for the transverse-electric mode. And the free propagation region (FPR) focal lenth is 82.9 μm. The minimum pitch between the neighboring waveguides is 2.5 μm at the fan-out section. The minimum radius of arrayed waveguide is 30 μm. The number of arrayed waveguides is 20. The free spectrum range is 44.1 nm. The operation is shown in the below. Four wavelength signals, λ1~λ2, are launched into the input waveguide of the first AWG (AWG0). The four signals are separately coupled into the four output channels of AWG0, shown in Fig. 1. After demutiplxed by AWG0, the four signals, λ1 ~ λ4, are separately coupled into AWG1 ~ AWG4. After further filtered, λ1 ~ λ4 come out separately from the 1st output waveguide of AWG1, the 2nd output waveguide of AWG2, the 3rd output waveguide of AWG3 and the 4th output waveguide of AWG4. In principle, no signal will come out from other output waveguide of AWG1 ~ AWG4. However, some weak signals will come out from the other output waveguides, due to the crosstalk. In order to compare the crosstalk improvement of the cascaded AWGs, we also design one single same AWG on the layout.

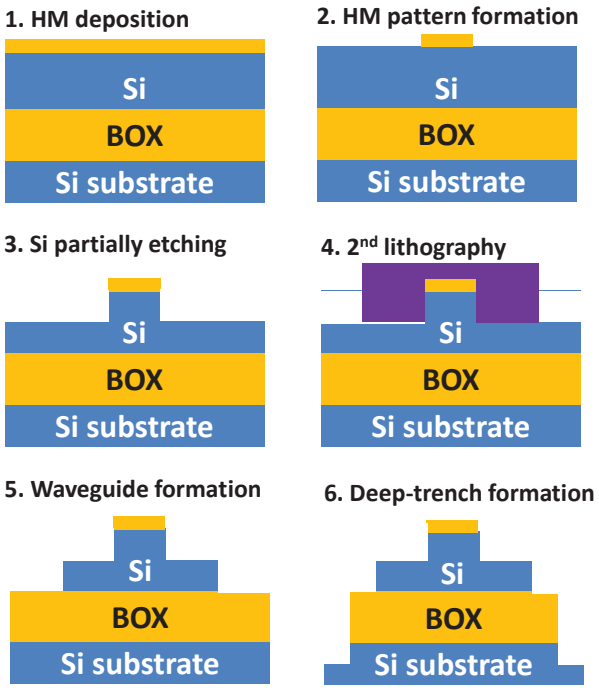

Fig. 2 Process flow of 1 × 4 cascaded silicon photonic AWG

The device was fabricated on an 8-inch SOI wafer with a 220 nm-thick top Si layer and a 2 um-thick buried oxide layer using 248-nm deep UV lithography. The process flow is shown in Fig. 2. A 600Å-thick SiO_2 layer was first deposited as a hard-mask (HM) layer for silicon etching process. After the first lithography for waveguide, the hard-mask oxide was etched by reactive ion etching (RIE) to form the waveguide pattern on oxide layer. Then, the photoresist was stripped and the wafer was clean using HF and SPM solution. After clean, the top silicon layer was partially etched using Applied Materials Precision 5000 Etcher and the remained silicon height is 110 nm. The 2nd lithography was processed for the waveguide formation and the remained Si was fully etched to BOX to form the waveguide. Finally, more than 100 um-deep deep-trench was etched for fiber coupling. This deep-trench is very useful to reduce the coupling loss with input/output fibers, instead of the polish of the device. The SEM images are shown in Fig. 3 the TEM result of one of arrayed waveguides is shown in Fig. 4. The left-top image of Fig. 3 is the fan-out range of the AWG. The right-top image of Fig. 3 is the deep-trench of more than 100 μm deep. The left-bottom image is the nano-tip of 200 nm wide. The nano-tip is located near the deep trench and 1μm-wide gap between the nano-tip and the deep trench is design for avoiding the misalignment of deep-trench lithography. The right-bottom image of Fig. 3 is the transition area from rib waveguide to channel waveguide. This transition structure is usually used to reduce the optical transition loss between channel waveguides and rib waveguides. The measured slab thickness of arrayed waveguide is 115 nm, close to the design value of 120 nm high. The measured total Si thickness is around 216 nm, also close the design value of 220 nm thick. After fabrication, the optical microscope image of the device is shown in Fig. 5. The size of the 1×4 silicon cascaded arrayed waveguide grating is 1.0 × 1.4 mm^2. The core size of single AWG is 275 × 320 μm^2.

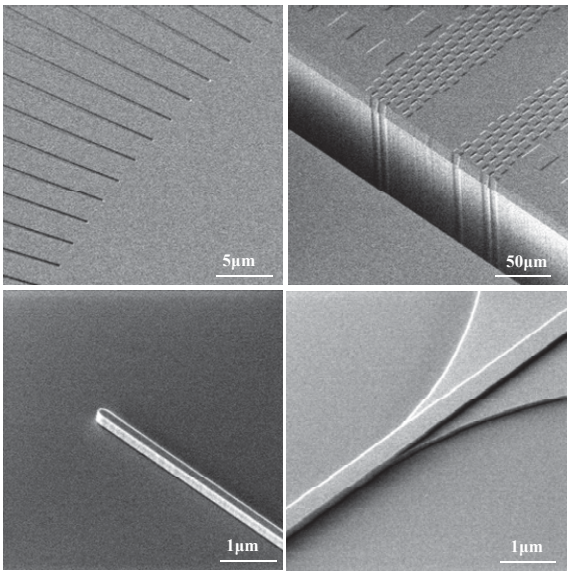

Fig. 3 SEM images of 1 × 4 cascaded silicon photonic AWG

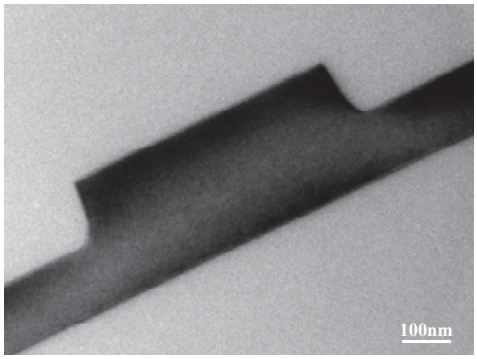

Fig. 4 TEM images of one of arrayed waveguides

III. Measurement Results

After dicing, the chip was measured using a high performance ASE light source with broad band wavelengths, a polarization controller, an optical polarizer, a high sensitivity optical power meter and a high precision optical spectrum analyzer. The Transverse electric (TE) mode of the input light was operated by a polarizer. Then, we measured the optical spectrum of input polarization maintaining (PM) lensed fiber to output PM lensed fiber. Later, the TE spectra of 1×4 silicon cascaded AWG and the reference single AWG were achieved using the same characterization. The spectra are shown in Figs. 6, 7. The main results are shown in Table II.

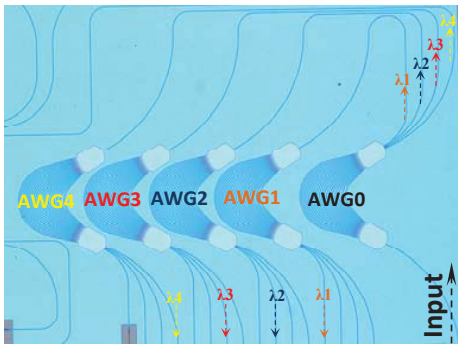

Fig. 5 OM images of 1 × 4 cascaded arrayed waveguides

TABLE II
Results of Single AWG and 1×4 Cascaded AWGs

	Single AWG	Cascaded AWG
Insertion loss (including coupling loss)	5.6 dB	8.2 dB
Loss non-uniformity	0.2 dB	0.4 dB
Crosstalk	12.5 dB	33.2 dB
1st channel wavelength (λ1)	1569.2 nm	1570.2 nm
2nd channel wavelength (λ2)	1575.6 nm	1576.6 nm
3rd channel wavelength (λ3)	1581.9 nm	1582.9 nm
4th channel wavelength (λ4)	1588.2 nm	1589.3 nm
Channel spacing	6.4±0.1 nm	6.4±0.1 nm
FSR	44.5 nm	44.5 nm
Average 3-dB bandwidth	3.0 nm	1.9 nm

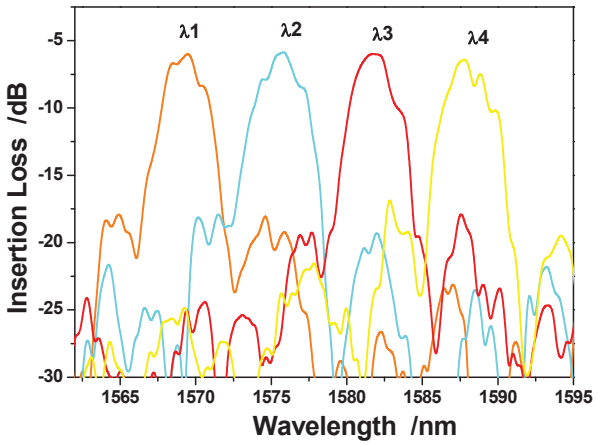

Fig. 6 Spectrum of the single AWG (TE)

Based on the insertion loss of single AWG and cascaded AWGs, we estimate the coupling loss of fiber-to-waveguide of 1.5 dB/facet and the on-chip transmission loss of single AWG of 2.6 dB. The on-chip transmission loss of cascaded AWGs is 5.2 dB. And the loss non-uniformity is 0.4 dB which is twice as large as the single AWG. The crosstalk has been dramatically improved. The cascaded AWGs has the crosstalk of 33.2 dB. Compared to the single AWG, the crosstalk of more than 20 dB is enhanced. Channel spacing for both AWGs are close to design value of 6.4 nm.

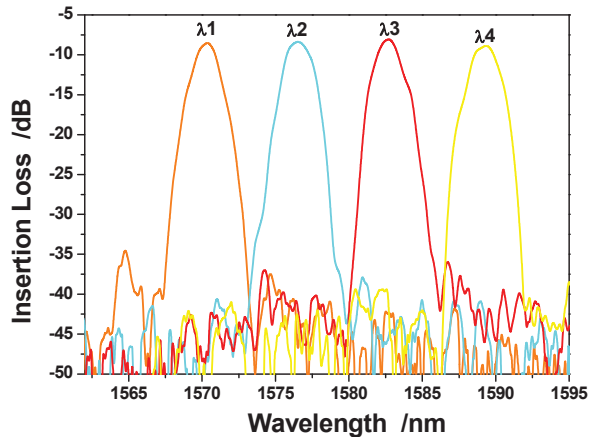

Fig. 7 Spectrum of 1 × 4 cascaded arrayed waveguides (TE)

Due to the fabrication deviation and testing environment difference, the central wavelength shifts more than 20 nm to the long wavelength direction, compared to the design. The wavelength of each channel of both AWGs shows the difference of related channel is only 1 nm. The both AWGs are fabricated on the same die of the same wafer. So, the result also proves that the fabrication uniformity is good in IME. Due to filter two times, the 3dB-bandwidth of the cascaded AWGs become smaller and is 60% of that of the single AWG.

IV. Conclusion

A 4-channel cascaded silicon-photonics arrayed waveguide grating was fabricated on SOI platform. The silicon thickness of the SOI wafer is 220 nm. The on-chip transmission loss of single AWG is 2.6 dB and the coupling loss of fiber-to-waveguide is 1.5 dB/facet. The on-chip transmission loss of cascaded AWG is around 5.2 dB. The measured channel spacing is 6.4 ± 0.1 dB, close to the design value. The cascaded AWG has a good crosstalk of 33.2 dB, compared to the single AWG, the design of cascaded structure improves the crosstalk, more than 20 dB. Due to filter for two times, the cascaded AWG has little small 3-dB bandwidth and little high loss non-uniformity. This solution is a good choice to reduce the issue of crosstalk of arrayed waveguide grating fabricated on SOI wafers with a thin top Si layer, although the on-chip transmission loss will increase. However, once the waveguide propagation loss can be further improved, the on-chip loss of the cascaded AWG will be reduced.

Acknowledgments

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