High-suppression-ratio silicon bandpass filter using apodized subwavelength grating coupler

Boyu Liu, Yong Zhang, Yu He, Xinhong Jiang, Ciyuan Qiu, and Yikai Su

State Key Lab of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering
Shanghai Jiao Tong University
Shanghai 200240, China
Email: yongzhang@sjtu.edu.cn

Abstract— **We experimentally demonstrate a compact silicon contradirectional coupler with high sidelobe suppression by using apodized subwavelength grating waveguide. A suppression ratio of higher than 20 dB is achieved with a ~100-µm coupling length.**

Keywords- Silicon photonics; Sidelobes suppression; Subwavelength grating waveguides; Apodization.

I. Introduction

Integrated optical add-drop filters are key components for next-generation wavelength division multiplexing (WDM) networks [1-7]. Due to the advantages of single passband operation and great design flexibility, grating-assisted contra-directional couplers (contra-DCs) enable flexible add-drop operation [1, 3, 5]. Subwavelength grating (SWG)-based contra-DC is a promising candidate among contra-DCs since it offers the benefits of short coupling length, high fabrication tolerance, and no significant ripples in the passband [1]. However, the SWG-based contra-DC suffers strong sidelobes, which introduce high crosstalk between adjacent channels in coarse wavelength division multiplexed (CWDM) demultiplexers [1, 6]. Apodization is a widely used technique in tailoring the spectra of gratings and suppressing sidelobes [2-5, 8, 9]. Recently, an apodized Bragg grating-assisted contra-DC was proposed to realize high sidelobe suppression ratio, with a long coupling length of 829.4 µm [3]. To date, no silicon contra-DCs with apodized SWG has been demonstrated.

In this paper, we propose and experimentally demonstrate the first silicon contra-DC with high sidelobe suppression based on an apodized SWG waveguide, to the best of our knowledge. It consists of two asymmetric waveguides where a SWG waveguide is placed next to a strip waveguide. Due to the large phase mismatch between the SWG and the strip waveguide, undesired codirectional coupling can be suppressed. The coupling length can therefore be reduced to ~100 µm, which is much shorter than that of the apodized Bragg grating-assisted contra-DCs. Meanwhile, the high sidelobes can be effectively reduced by tapering the coupling strength to implement apodization in the contra-DC. By using a Gaussian profile to taper the gaps between SWG and the strip waveguide, a high sidelobe suppression ratio of ~20.1 dB at the drop port can be achieved, with a ~1.4-dB insertion loss.

II. Device Design

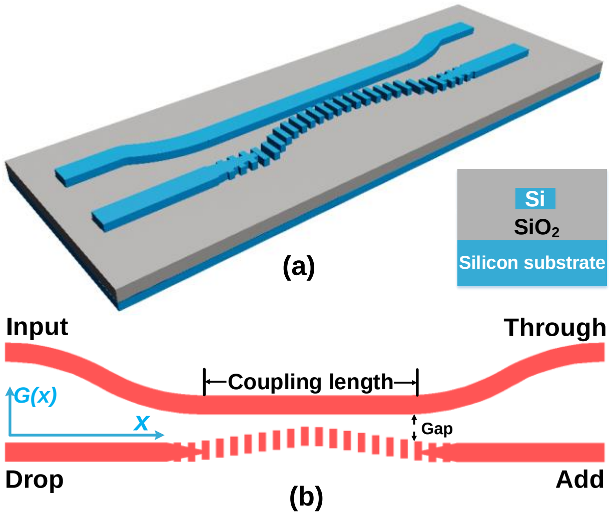

Fig. 1. Schematic configuration of the proposed silicon apodized SWG-based contra-DC, (a) the 3D view, (b) the top view.

Figures 1(a) and (b) depict the 3D and top views of the proposed silicon contra-DC using an apodized SWG, respectively. The device consists of two waveguides, the upper waveguide is a strip waveguide and the bottom waveguide is a coupler-apodized SWG waveguide. The coupler gap $G(x)$ is designed as a Gaussian function of the relative longitudinal position x, which is given by [3]:

$$G(x) = G_{\min} + R[1 - e^{\frac{-a(x-0.5L)^2}{L^2}}]$$

where $G_{\min}$ is the minimum gap at the center of the coupling area, in this design $G_{\min}$ is 200 nm. The constant R is chosen to be 1 µm. The apodized index a determines the curvature of the SWG waveguide, *i.e.*, the coupling strength of the two waveguides. The simulations show that, there is a tradeoff between the apodized index a and the sidelobe suppression ratio. A larger a leads to a higher suppression ratio, however, results in a larger insertion loss. In the contra-DC structure, the thickness of the silicon waveguide is 220 nm. The widths of the upper strip waveguide and bottom SWG waveguide are both 500 nm. The coupling length between the two waveguides is 100.3 µm. The period and the duty cycle of the SWG are Λ = 378 nm and 50%, respectively.

III. EXPERIMENTAL RESULTS

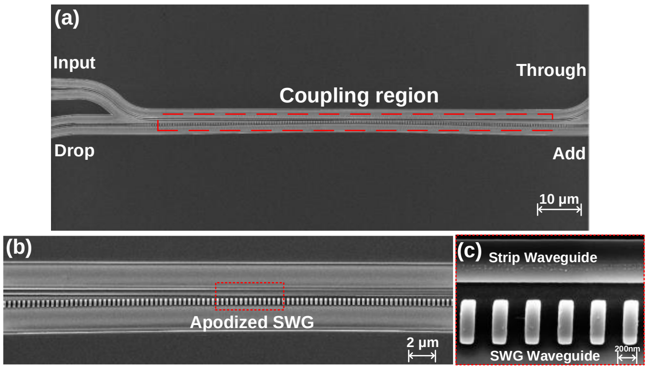

Fig. 2. (a) Scanning electron microscope (SEM) photo of a fabricated contra-DC based on apodized SWG. (b) Zoom-in SEM graph of the coupling region. (c) Magnified micrograph of the strip and SWG waveguide.

The scanning electron microscope (SEM) photos of a fabricated contra-DC based on the apodized SWG are shown in Fig. 2. The proposed apodized SWG-based structure was fabricated on a silicon-on-insulator (SOI) wafer with a 220-nm-thick top silicon layer and a 3000-nm-thick buried dioxide layer. E-beam lithography (Vistec EBPG 5200) was used to define the device structures on the ZEP520A resist. Then the patterns were transferred to the top silicon layer by an inductively coupled plasma (ICP) etching process. A 1-μm-thick silica layer was deposited over the whole device as the upper cladding by plasma-enhanced chemical vapor deposition (PECVD).

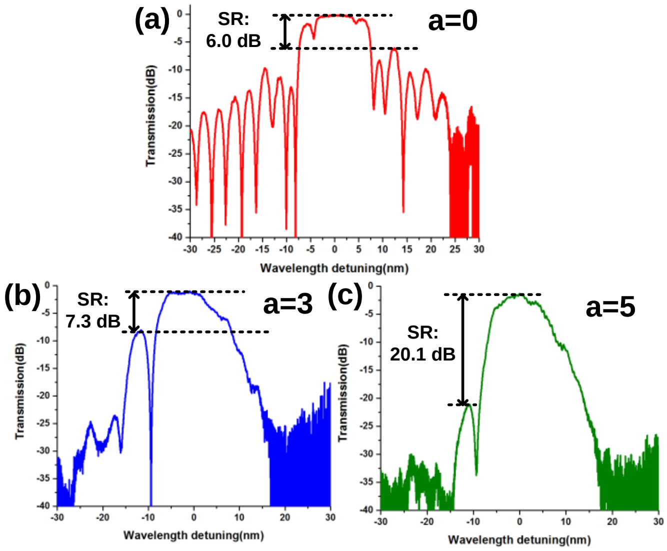

Fig. 3. Measured transmission responses and sidelobe suppression ratio (SR) at the drop port for different apodized indices a (a) a = 0, (b) a = 3, (c) a = 5, respectively.

Figure 3 plots the measured transmission responses of the drop port of contra-DCs using uniform and apodized SWG with different apodized indices a. As depicted in Fig. 3(a), when a = 0, the uniform SWG-based device with a constant gap has strong sidelobes that are higher than –6 dB at an off-center wavelength of 12 nm, and are as high as –10 dB with a 15-nm detuning. Fig. 3(b) shows that by replacing the uniform SWG with the apodized SWG, the sidelobes of the contra-DC are clearly suppressed in the case of apodized index a = 3. The suppression ratio of the highest sidelobe has been improved by ~1.3 dB, and the rest sidelobes are ~10 dB lower than those in the uniform SWG-based device. Furthermore, as shown in Fig. 3(c), the apodized SWG-based device with a = 5 shows strong sidelobe suppression ratio of ~ 20 dB near the –10 nm detuning, which is ~14 dB better than the uniform SWG coupler case. Other sidelobes are all suppressed below –27.5 dB, indicating that the apodization of the gap distance over the coupling length is an effective technique to suppress the sidelobes. Compared with the uniform design, the bandwidth of the apodized design is slightly expanded which can be optimized by adjusting G_{min} [1, 3].

IV. SUMMARY

We have experimentally demonstrated a silicon SWG-based contra-DCs with strong sidelobes suppression by tailoring the coupling strength between the strip and SWG waveguides. A high sidelobe suppression ratio of 20-dB has been obtained. The coupling length is 100.3 μm, which is much shorter than that of the apodized Bragg grating contra-DCs.

REFERENCES

[1] B. Naghdi, and L. R. Chen. “Silicon photonic contradirectional couplers using subwavelength grating waveguides.” Optics Express 24, 23429-23438 (2016).

[2] R Kashyap. “Fiber bragg gratings,” Academic Press, (1999).

[3] W. Shi, *et al.*, “Coupler-apodized Bragg-grating add–drop filter,” Optics Letters 38, 3068-3070 (2013).

[4] T. Erdogan. “Fiber grating spectra,” Journal of lightwave technology 15, 1277-1294 (1997).

[5] A. D. Simard, *et al.*, “Apodized silicon-on-insulator Bragg gratings,” IEEE Photonics Technology Letters 24, 1033-1035 (2012).

[6] W. Shi, *et al.*, “Silicon photonic grating-assisted, contra-directional couplers,” Optics express 21, 3633-3650 (2013).

[7] M. T. Boroojerdi, *et al.*, “Wavelength tunable integrated add-drop filter with 10.6 nm bandwidth adjustability, ” Optics Express 24, 22043-22050 (2016).

[8] G. Huang, *et al.*, “Surface relief apodized grating tunable filters produced by using a shadow mask,” Optics Express 23, 21090-21096 (2015).

[9] J. St-Yves, *et al.*, “O-band silicon photonic bragg-grating multiplexers using UV lithography,” Optical Fiber Communication Conference, Tu2F.7, 2016.