Four-channel, Silicon Photonic, Wavelength Multiplexer-Demultiplexer With High Channel Isolations

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Abstract: We present a four-channel, silicon-photonic, wavelength multiplexer-demultiplexer made using cascaded contra-directional couplers with adjacent and non-adjacent channel isolations of at least 37 dB and 45 dB, respectively. The device's maximum insertion-loss is 0.72 dB.

OCIS codes: 060.1810 Buffers, couplers, routers, switches, and multiplexers; 130.7408 Wavelength filtering devices; 250.5300 Photonic integrated circuits.

1. Introduction

Wavelength-division multiplexing (WDM) is an attractive technology for increasing the aggregate bandwidth of optical interconnects. Optical multiplexers and demultiplexers are key devices that enable this technology. Realizing such multiplexers and demultiplexers on photonic integrated circuits, such as can be done using the silicon-on-insulator (SOI) platform, will allow for low cost, high-performance, optical interconnects. In this work, we demonstrate a four-channel, silicon photonic, wavelength multiplexer-demultiplexer, on the SOI platform, made using contra-directional couplers. As a demultiplexer, our device is fully-passive (i.e., other than temperature stabilization, it requires no electronic control) demultiplexer with flat-top channel responses, high channel isolations, low channel insertion-losses, and a compact footprint.

Table 1. Performance comparison of recent work on SOI multiplexers-demultiplexers

Ref.	Channel Isolation	Channel Insertion-loss	Channel Bandwidth	Number of Channels	Number of Control Signals*
[1]	16 dB	1 dB	0.4 nm	4	4
[2]	73 dB	7.15 dB	<1 nm	1	14
[3]	23 dB	2.7 dB	13 nm	4	21
[4]	24 dB	1.5 dB	1.32 nm	4	Not discussed
This work	37/45 dB**	0.72 dB	7 nm	4	0

* In addition to temperature stabilization.
** Adjactent/non-adjacent channel isolations.

Filtering for WDM applications is a well-studied field within silicon photonics. However, increased adoption of silicon photonics, for the numerous applications, is driving the need for the design of filters with increasingly stringent specifications. Many devices have been used to realize high-performance, silicon photonic, optical add-drop filters, some of which include micro-ring resonators (MRRs) [1,2], Mach-Zehnder interferometers (MZIs) lattice filters [3], arrayed waveguide gratings (AWGs), Echelle gratings [4], and integrated Bragg grating waveguides (IBGs). MRRs have narrow-band filter spectra and are not suitable for designing wide-band filters; they additionally require active thermal tuning and stabilization. MZIs lattice filters require thermal tuning and stabilization since they are sensitive to fabrication variations, which may cause phase errors in the waveguides and affect the coupling coefficients. AWGs and Echelle gratings have a very large footprints and have overall poor performance as regards their insertion losses, isolations, and bandwidths [5]. Table 1 presents a summary of recent work on filters used for WDM applications.

Contra-directional couplers (contra-DCs), shown in Fig. 1, are wavelength-selective, grating-based couplers, in which two or more, grating-perturbed, asymmetric waveguides are brought into close proximity to each other [6].

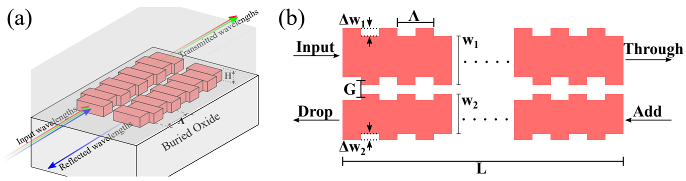

Fig. 1. (a) A perspective-view of the typical structure of an SOI-based contra-directional coupler made using sidewall corrugations. (b) Top-view schematic of the contra-directional coupler operating as an optical add-drop multiplexer with some of the design parameters highlighted.

In such devices, the grating is used to contra-directionally couple specific wavelengths between two otherwise dissimilar, uncoupled waveguides by coupling the forward mode of one waveguide into the backward mode of the other [7]. The contra-DCs allow one to selectively add and drop wavelengths, making them a suitable candidates for realizing add-drop filters on the SOI platform [8,9]. Contra-DC-based filters can be made to have high channel isolations by cascading the drop-port responses of multiple, identical contra-DCs [10,11].

2. Design and Experiment

A schematic (top-view) of our four-channel, wavelength multiplexer-demultiplexer is shown in Fig. 2(a). We designed our device to have four, 12 nm-spaced channels, each with a 3 dB bandwidth of 7 nm. The device used four sets of cascaded contra-DCs in which each set was designed to filter a specific channel centered at λ_M, where λ_M is determined by the phase-match condition:

$$\lambda_M = (n_{eff1} + n_{eff2})\Lambda_M$$

in which n_{eff1} and n_{eff2} are the effective refractive indicies of the first and second waveguide, respectively. Λ_M is the period of the perturbations for the Mth channel, as illustrated in Fig. 2(b).

The contra-DCs in the device were each made of two asymmetric waveguides with widths of W_1 =560 nm and W_2 =440 nm, separated by a gap of G =110 nm. The waveguide perturbations were chosen to be ΔW_1 =60 nm and ΔW_2 =35 nm for the first and second waveguide, respectively. The waveguide perturbations were apodized with a gaussian apodization function [10]. Each set had a perturbation period of 312 nm, 316 nm, 320 nm, and 324 nm designed to filter wavelength ranges around 1533 nm, 1544 nm, 1556 nm, and 1568 nm, respectively, as illustrated in the dispersion plot in Fig. 2(b). Each channel was designed to have a bandwidth of 7 nm, determined by the perturbations and the gap.

Our devices were designed for an SOI platform with a 220 nm-thick silicon layer, a 2.2 μm-thick upper-cladding oxide layer, and a 2 μm-thick buried oxide layer. The devices were patterned using electron-beam lithography at The University of British Columbia through Applied Nanotools Inc. An anisotropic ICP-RIE etching process was used to fully etch the 220 nm-thick silicon layer to form the devices. Sub-wavelength fiber grating couplers were used for the optical input and output ports. We used a tunable laser source, Agilent 81600B, and two optical power sensors, on an Agilent 81635A module, to measure the channels' spectra. A scanning-electron microscope image of a fabricated device is shown in Fig. 3(a).

Using our device as a demultiplexer, we measured the response of each of its channels and overlayed them in Fig. 3(b). We measured a minimum adjacent channel isolation of 37 dB and a minimum non-adjacent channel isolation of 45 dB. The maximum, measured insertion-loss was 0.72 dB, which was seen on channel 4 centered at

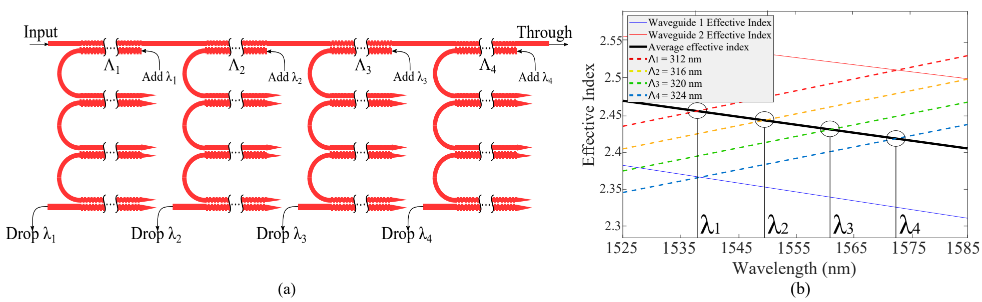

Fig. 2. (a) Schematic (top-view) of our design, four-channel multiplexer-demultiplexer. (b) Dispersion plot illustrating the four phase-match conditions in the device.

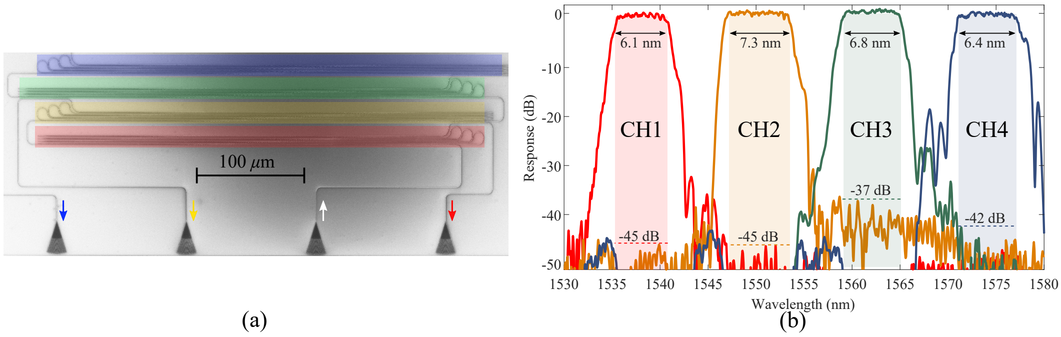

Fig. 3. (a) Scanning electron microscope image of our four-channel multiplexer and demultiplexer, with each channel filter highlighted. (b) Measured, calibrated spectra of the drop port response for each channel in the demultiplexer. Highlighted are the minimum adjacent channel isolations and the 3 dB bandwidths of each channel.

1568 nm. The measured 3 dB bandwidths were 6.1 nm, 7.3 nm, 6.8 nm, and 6.4 nm for the channels at 1533 nm, 1544 nm, 1556 nm, and 1568 nm, respectively. The overall footprint of the device was 571 μm by 158 μm.

3. Conclusion

In conclusion, we have demonstrated a compact, high-performance, fully-passive, wavelength multiplexer-demultiplexer with high channel isolations and low insertion-losses on the SOI platform. Owing to the contra-DC's design versatility, such a cascaded configuration can be used to design high-performance multiplexers-demultiplexers for various WDM standard grids such as LAN-WDM and CWDM as well as for future standard grids [11].

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