Microring-Based Si/SiN Dual-Layer Switch Fabric

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***Abstract*—The first microring-based Si/SiN dual-layer switch fabric is fabricated, packaged and characterized. The 4×4 thermally-actuated switch fabric implements the switch-and-select architecture in an ultra-compact footprint. It leverages the Si/SiN dual-layer structure achieving a crossing-free design, showing great potential for ultra-low loss and crosstalk switching applications.**

I. Introduction

The ever-growing interconnect demand of datacenters motivates the deployment of new technologies. Optical switching has received much attention to potentially address the challenges in regards to the bandwidth, cost and power consumption in datacetners. Silicon photonic integration platform holds a great promise due to its high energy efficiency, large index contrast, and most importantly, its CMOS compatibility. Silicon microring resonators have been extensively studied as modulators, filters, (de-)multiplexers, and switches owing to the small footprint and low power consumption. We have proposed a novel modular switch implementation by using microrings as add-drop multiplexers in the switch-and-select topology [1] and performed further study revealing that for monolithic integration, the scalability is ultimately limited by the performance of passive shuffles [2]. The multi-layer SiN-on-Si platform that leverages the ultra-low loss SiN waveguide has been introduced [3] and very recently, a two-layered 4×4 MZI-based multi-stage switch was demonstrated [4]. In this work, we present the first microring-based Si/SiN dual-layer switch fabric and discuss the device design, fabrication, packaging and control. Initial testing results show crosstalk ratios of <-30 dB, extinction ratios of >30 dB, and on-chip loss of as low as 1.8 dB. The device shows a great potential for ultra-low loss and ultra-low crosstalk switching applications.

II. Device Design, Fabrication and Packaging

The topology of our microring-based switch-and-select spatial switch is depicted in Fig. 1a. The n input spatial $1\times n$ de-multiplexers are shuffling to n output $n\times 1$ multiplexers. Each $1\times n/n\times 1$ de/multiplexing element consists of n cascaded add-drop microring resonators coupled to a common bus waveguide to drop or add the optical signal. This configuration maintains the number of drop (i.e. resonating) microrings in any path at two, while scaling n only adds bypassing rings through the bus. The central passive shuffle connects the i^{th} ring in the j^{th} $1\times n$ input element (A) to the j^{th} ring in the i^{th} $n\times 1$ output element (B). Therefore, the mapping of input i to output j occurs only when both A and B rings are in the drop state (on resonance) and the rest of the rings on the input and output elements are adequately detuned from the drop state to ensure the maximum crosstalk suppression. This topology only allows for the second-order crosstalk. For instance, the optical path from input 1 to output n is highlighted in Fig. 1a by red line and all the rings except the n^{th} one in the 1st $1\times n$ element are detuned from the drop state. The first order crosstalk leakage to the detuned rings, e.g. outlined in green at the 1st and 2nd microrings, will get dropped by another detuned ring at the output stage before adding to the signal, hence experiencing two degrees of attenuation.

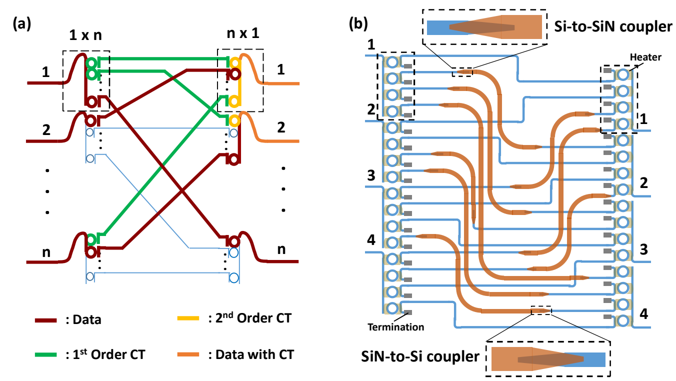

Fig. 1. (a) Schematic of switch-and-select configuration. (b) Schematic of the 4x4 Si/SiN dual-layer switch with enlarged Si-to-SiN and SiN-to-Si couplers.

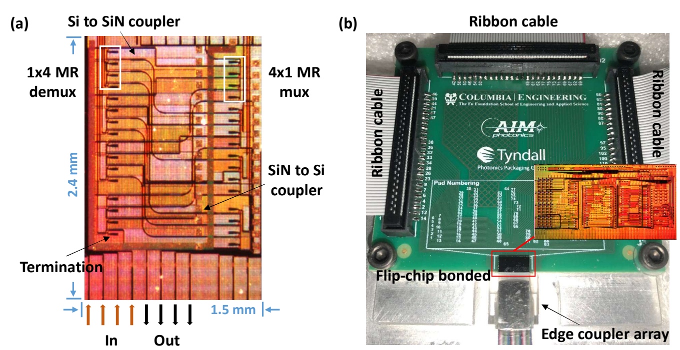

Fig. 2. (a) Microscope photo of the device. (b) The breakout PCB board with ribbon cables and the flip-chip bonded silicon die. Inset photo shows the entire chip of allocated 3.3×6 mm^2 space.

Each add-drop microring is designed to operate close to its critical coupling to maximize the extinction of resonance and minimize the drop loss. The add-drop micro-rings used in our design feature an FSR of ~25 nm, an optical 3 dB bandwidth of ~0.65 nm, and larger than 20 dB of extinction. The tuning of microrings is accomplished through an integrated microheater and the measured shift of resonance indicated a thermal efficiency of 1 nm/mW [5].

Figure 1b schematically shows the layout design of the 4×4 thermo-optic switch-and-select device. The silicon microrings are juxtaposed with a separation distance of 100 µm for thermal isolation. The central passive shuffle is designed in a Si/SiN dual-layer structure with interlayer couplers. Shuffling intersections are realized by making SiN waveguide over pass Si waveguide to achieve a crossing-free design. Key parameters for such a dual-layer device are the width of SiN waveguide and the separation between the two layers, determining the mode interaction and thus the loss and interlayer crosstalk. The device was designed using standard AIM Photonics PDK elements and fabricated through the AIM Photonics' 2nd MPW run [6], as shown by the microscope image in Fig. 2a. It has a footprint of 1.5×2.4 mm^2 and was placed with other designs and test structures with a sector size of 3.3×6 mm^2 (inset photo in Fig. 2b). The bare die was then flip-chip bonded onto a PCB breakout board at Tyndall (Fig. 2b). The size of the electrical trace and gap on the PCB only allowed electrical fan-out on 28 microrings (controlling 12 optical connections out of the total 16). A 48-channel single-mode cleaved fiber array was attached by UV-cured glue to couple light into and out of the whole chip. A pair of looped-back edge couplers was introduced to facilitate the coupling process and determine the coupling loss, at 5.3 dB per facet, as a reference.

III. TEST RESULTS

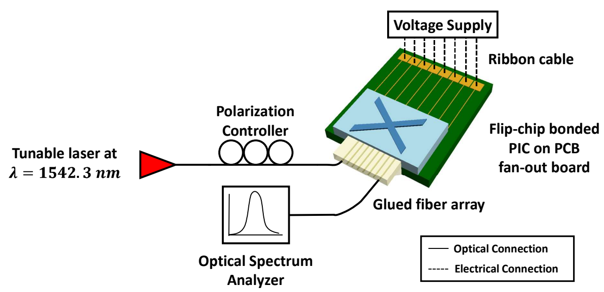

Fig. 3. Experimental setup detailing the electrical and optical connections.

The schematic of our experiment test-bed is shown in Fig. 3. All established optical paths show excellent crosstalk ratios of lower than -30 dB and extinction ratios of higher than 30 dB benefitting from the switch-and-select topology, though a few microrings lost the electrical connection during testing. The switch fabric currently has a large path dependent loss which can be attributed to the high excess loss of interlayer couplers. Optical paths routed only in the Si layer exhibit on-chip losses in the range of 1.8-3 dB; however, the numbers increase to higher than 11 dB for paths go through both Si and SiN layers. Figure 4a and 4b present two routing cases of path 4-4 and 2-3. Referring back to Fig. 1b, optical signal in path 4-4 passes through three off-resonance microrings and two on-resonance ones with no interaction on SiN layer resulting in the optimal case. The 1.8 dB on-chip loss with -48.8 dB crosstalk ratio and 46.6 dB extinction ratio, shown in Fig 4a, indicate the outstanding performance of the microrings. The optical path 2-3 as the worst-case scenario encounters an additional pair of interlayer couplers and a few crossover intersections giving rise to an extra ~19 dB loss. It is suspected that the SiN waveguide and bend bring about excess loss but it requires further investigation. The high insertion loss also attributes to the degraded crosstalk and extinction ratios. Detailed examination will be performed on the test structures of the interlayer couplers and intersections. This however can be largely improved by optimizing the component design.

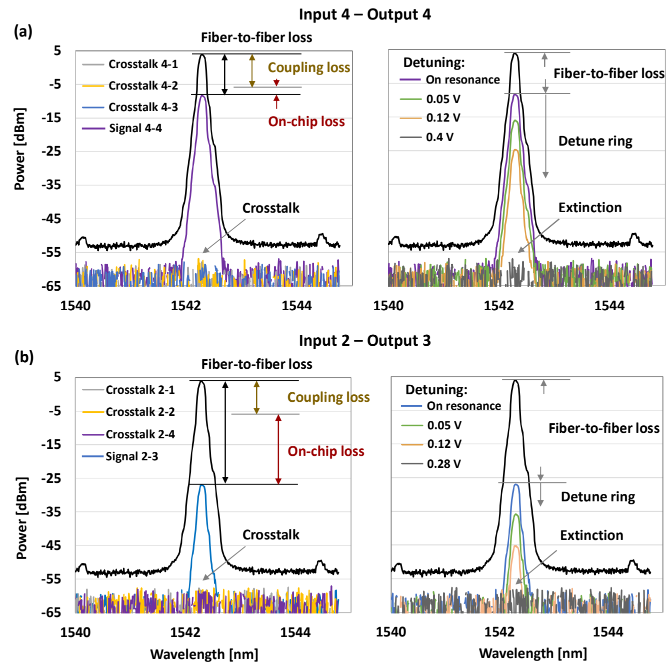

Fig. 4. Representative paths of (a) 4-4 with measurement on crosstalk ratio (left) and extinction ratio (right) (b) 2-3 with measurement on crosstalk ratio (left) and extinction ratio (right).

IV. CONCLUSION

This paper presents the first microring-based Si/SiN dual-layer switch fabric with 4×4 port count. The thermo-optic device was implemented in the switch-and-select topology and fully packaged via flip-chip bonding to a PCB breakout board. The switching circuit shows excellent crosstalk ratios of lower than -30 dB, extinction ratios of higher than 30 dB, and on-chip loss of as low as 1.8 dB.

Acknowledgement

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REFERENCES

[1] D. Nikolova *et al.,* "Modular architecture for fully non-blocking silicon photonic switch fabric," Microsystems & Nanoengineering, (2017) 3, 16071.
[2] Q. Cheng *et al.,* "Highly-scalable, low-crosstalk architecture for ring-based optical space switch fabrics," 2017 IEEE Optical Interconnects Conference (OI), Santa Fe, NM, 2017, pp. 41-42.
[3] W. D. Sacher *et al.*, "Multilayer Silicon Nitride-on-Silicon Integrated Photonic Platforms and Devices," in Journal of Lightwave Technology, vol. 33, no. 4, pp. 901-910, Feb.15, 15 2015.
[4] K. Suzuki *et al.*, "Ultralow-crosstalk and broadband multi-port optical switch using SiN/Si double-layer platform," 2017 Opto-Electronics and Communications Conference (OECC) and Photonics Global Conference (PGC), Singapore, 2017, pp. 1-2.
[5] M. Bahadori *et al.*, "Thermal Rectification of Integrated Microheaters for Microring Resonators in Silicon Photonics Platform," in Journal of Lightwave Technology, vol. 36, no. 3, pp. 773-788, Feb, 1, 2018.
[6] http://aimphotonics.com