Si-SiN-SiN Tri-Layer Strictly Non-blocking 8×8 Microring-Based Optical Switch

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Abstract: We report a Si-SiN-SiN tri-layer switch-and-select 8×8 optical switch with 128 thermally-driven microring-resonators. Crosstalk ratio and on-chip loss are measured in the range of -33.2 to -50.8dB and 2.1 to 10.5dB, respectively, with >70GHz passband. © 2024 The Author(s)

1. Introduction

As cloud computing technology continues to evolve, the demand for switching capacity remains on a continuous upward trajectory. Concurrently, the data traffic within data centres is experiencing substantial annual growth, increasing by 25%. To efficiently handle this surge in information processing requirements, electrical switches have been doubling their bandwidth every two years, but this poses challenges on power consumption [1]. Optical switches offer a promising alternative with distinct advantages, including high power efficiency, low latency, data modulation agnosticism [2]. Integrated optical switches are built from numerous elementary switching cells, which are interconnected in a logical topology. One of the critical metrics of optical switches is crosstalk, which arises when a fraction of input light is inadvertently directed to incorrect output ports. The switch-and-select (S&S) architecture is fully immune to first-order crosstalk and provides strictly non-blocking connectivity. It can be well tailored for microring resonators (MRR) but the management of waveguide crossings in the central shuffle network could pose a limitation to its scalability [3]. Studies have looked into interlayer shuffling structure leveraging low-loss SiN waveguides to break the 2D in-plane propagation and instead, creating crossing-free 3D interconnects [3-6].

This paper for the first time introduces a Si-SiN-SiN tri-layer 8×8 S&S optical switch with thermo-optic MRRs. The fabricated optical switch exhibits low crosstalk ratio of -33.2 to -50.8 dB while has insertion loss in the range of 2.1 to 10.5 dB. In the meantime, an excellent channel passband of over 70 GHz is achieved.

2. Optical switch design

Figure. 1(a) and (b) show the microscope photo of the switch chip and schematic of the 8×8 tri-layer of the S&S topology, featuring strictly non-blocking connectivity and is full immunity to first-order crosstalk [3]. The device

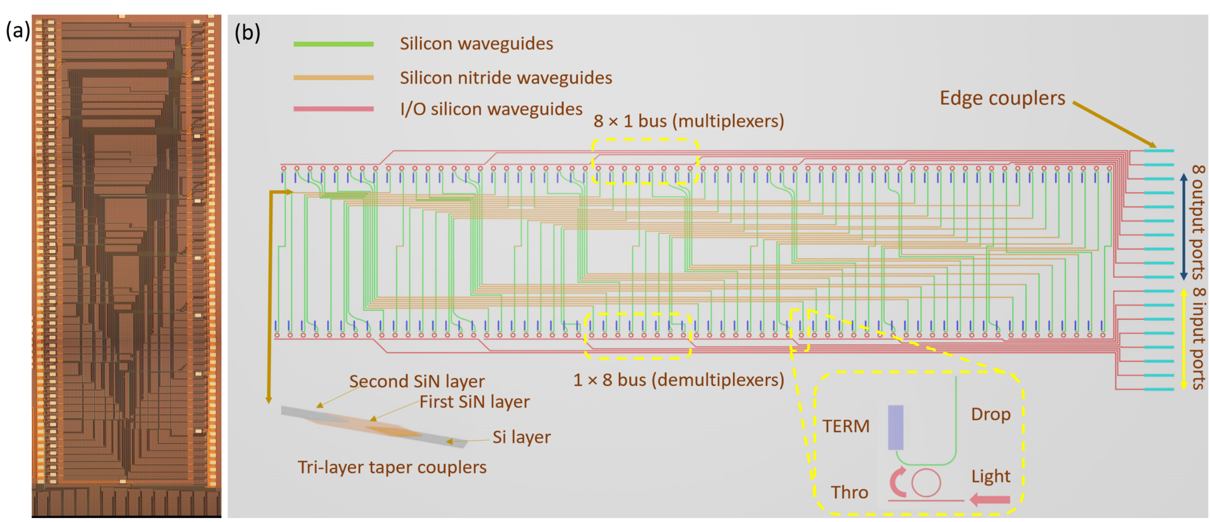

Fig. 1. (a) Microscope photo of the switch chip. (b) Schematic layout of the 8 × 8 MRR-based S&S switching fabric with the Si-SiN-SiN layer coupler structure.

integrates eight 1×8/8×1 MRR bus banks, and each assembled with eight add-drop MRR filters, serving as spatial (de)multiplexing units. A central shuffle network is built upon a Si-SiN-SiN tri-layer platform to connect the MRRs from each input demultiplexer block to each output multiplexer block. Hence, the establishment of each optical path only necessitates the tuning to resonance of two MRRs, while the other MRRs in the relevant input and output units are detuned from resonance to minimize crosstalk. All the add-drop MRRs are equipped with microheaters for thermo-optic (TO) phase tuning.

S&S switches often have a challenge to manage the exponentially increasing number of waveguide crossings in the central shuffle, which makes the path-dependent loss as well as the crosstalk deteriorate [4]. Si-SiN dual-layer shuffles often need to trade off the interlayer separation against coupling efficiency in the vertical coupler designs that inevitably compromises interlayer crosstalk, coupling loss, and footprint. In this work, a Si-SiN-SiN tri-layer structure is used to break this trade-off. The inset in Fig. 1(b) depicts the schematic of the tri-layer vertical coupler structure utilizing adiabatic tapers. The first SiN layer serves as an intermediate layer to facilitate efficient light transition from the base Si layer to the upper SiN layer, which also ensures a substantial vertical separation distance to enable ultra-low interlayer crosstalk for the 3D waveguide crossings.

3. Results and analysis

The switch is taped out via AIM photonics, with a total footprint of 8.7×1.9 mm^2. We employ an ultra-high numerical aperture (UHNA) fiber array to couple light into and out of the chip, with a coupling loss of about 4.9 dB per facet. This can be improved by the use of optical fibers with a better matched core diameter. The chip is wire-bonded to custom PCB boards for electrical fan-out. An electrical control plane is developed to automatically drive the switch. Specifically, the control signals from a PC are sent to a 16-bit digital-to-analog convertor (DAC) via the serial peripheral interface (SPI) to the generate desired voltages, which are then amplified by a driving circuit and loaded on the heaters. Accordingly, we calibrate all the add-drop MRRs by adjusting their bias voltages to maximize or minimize the corresponding output power, thereby determining the voltage transfer functions for on and off states.

A laser signal at 1561 nm is used as the input source. As shown by Fig. 2(a), the measured on-chip losses for different optical paths range from 2.1 to 10.5 dB, which can be mainly attributed to the interlayer couplers and the MRR filters. The crosstalk leakage to other ports varies from -33.2 to -50.8 dB. Note that the measurement of three input channels is absent in Fig. 2(a) due to the physical damage in their optical paths. The crosstalk ratio of a few paths gets compromised by the path excess insertion loss. In addition, we evaluate the switch passband by launching an ASE signal from a semiconductor amplifier (SOA) and measuring the output spectra with an optical spectrum analyzer. The normalized transmissions of representative optical paths are depicted in Fig. 2(b), showing a 3-dB passband of around 72 GHz.

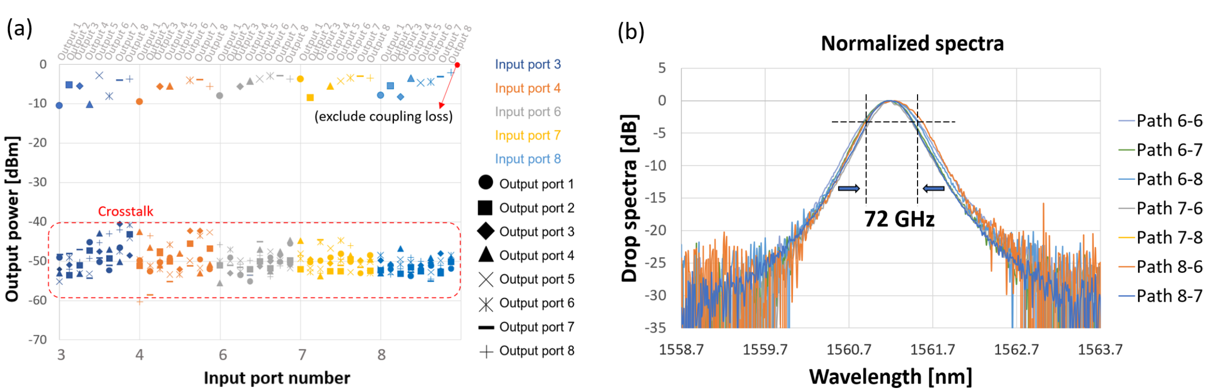

Fig. 2. (a) Measured optical power map of 8 × 8 switch. (b) Normalized transmission spectra for few representative optical paths

Fig. 3(a) shows the microscope image of part of the fabricated switch, highlighting the optical IO channels 6, 7, and 8. To evaluate the crosstalk suppression by each MRR, we take path 6-6 with the crosstalk leakage to outport 8 as an example. The measurement results are shown in Fig. 3(b): the yellow curve denotes the signal transmission of path 6-6, while the orange and grey curves represent the channel response when the 6th MRR at the output channel 8 is biased on and off, respectively. The contrast signifies both the first- and second-order crosstalk ratio at 24.6 dB and 26.2 dB, respectively, which culminates in a total crosstalk ratio at 50.8 dB between the output ports 6 and 8.

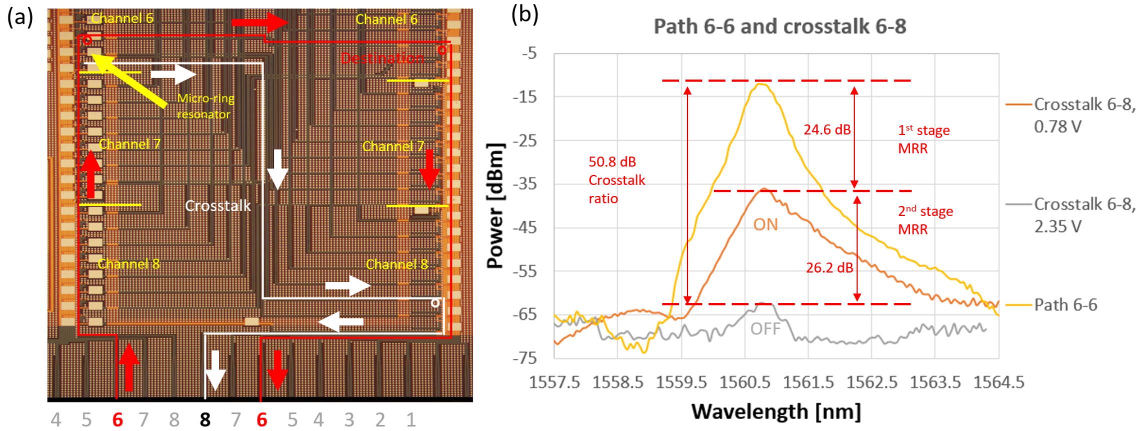

Fig. 4. Crosstalk ratio measurement. (a) Optical paths labeled on real chip photo: signal routed in path 6-6 and the crosstalk at output port 8. (b) Signal power at output port 6 and crosstalk at output port 8 with two MRR states.

The transient behavior of the switch is characterized by measuring its optical time-domain response. We employ a function generator to produce a 15 kHz square wave signal with a 50% duty cycle, modulating the MRR on a specific optical path for on/off switching. The time trace of the output signal is then recorded on an oscilloscope. As shown by Fig. 4(a-b), the switching rise and fall time (10%-90%) are 17.6 μs and 0.42 μs, respectively.

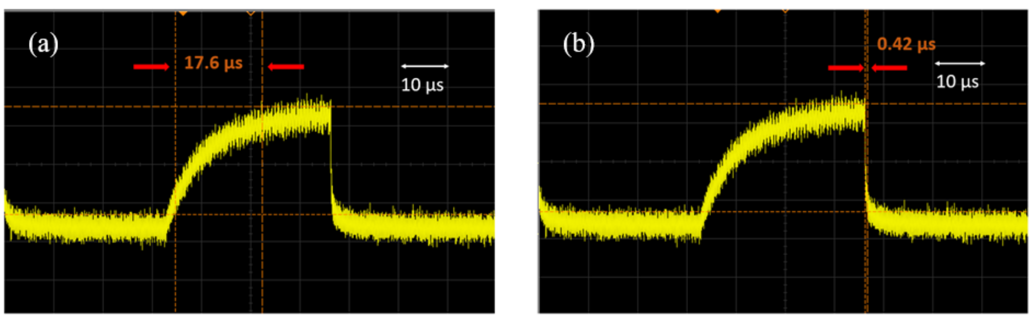

Fig. 3. Optical time-domain response of T-O switch (a) Switching rise time. (b) Switching fall time

4. Conclusion

This paper presents an 8×8 tri-layer optical switch in the switch-and-select topology, comprising of 128 thermally actuated MRR-based switch cells, each featuring an on-off extinction ratio exceeding 25 dB. Experimentally, the fabricated switch demonstrates crosstalk ratio ranging from -33.2 dB to -50.8 dB and on-chip loss in between 2.1 dB and 10.5 dB across different paths. The switch exhibits an impressive 3 dB bandwidth of 72 GHz, holding great promise for future datacentre agile network application.

5. Acknowledgment

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