Silicon 16x16 switch matrix based on dual-ring assisted MZI structures with fast and energy efficient switching

Linjie Zhou*, Liangjun Lu, Zhanzhi Guo, and Jianping Chen
State Key Laboratory of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering, Shanghai Jiao Tong University, Shanghai 200240, P.R. China
**ljzhou@sjtu.edu.cn*

Abstract: We review our recent progress on silicon photonic switches based on electro-optic dual-ring assisted MZI switch elements. The ring resonances are aligned using thermal tuning to set the initial switching state. Nano-second switching is realized upon free-carrier injection with PIN diodes in the ring resonators.

Silicon ring resonator-based switches have attracted a lot of research interest in recent years due to their compactness, low power consumption and wavelength selectivity [1, 2]. They can be employed for spatial and wavelength flexible superchannel switching. The switches can be implemented based on both passive and active ring resonators. The passive ring switch relies on the wavelength tuning of the source light to establish an optical path through the ring resonators. The active ring switch, on the other hand, uses resonance-tunable ring resonators to reconfigure the connection topology of the switch network while the light wavelength is kept fixed. Active electrical or thermal tuning needs to be performed to the ring resonators with control electronics. The active ring switch is more flexible and can alleviate the requirement for tunable lasers in source data transmission. In our previous work, we have proposed and demonstrated several ring resonator-based silicon switches, including arbitration-free passive optical crossbar ring switch [3], dual-ring switch with inter-ring coupling enabled by a three-waveguide directional coupler [4], and dual-ring assisted Mach-Zehnder interferometer (DR-MZI) [5, 6]. The interference provide by the MZI structure in the DR-MZI ensures a high on-off switching extinction ratio with low tuning power.

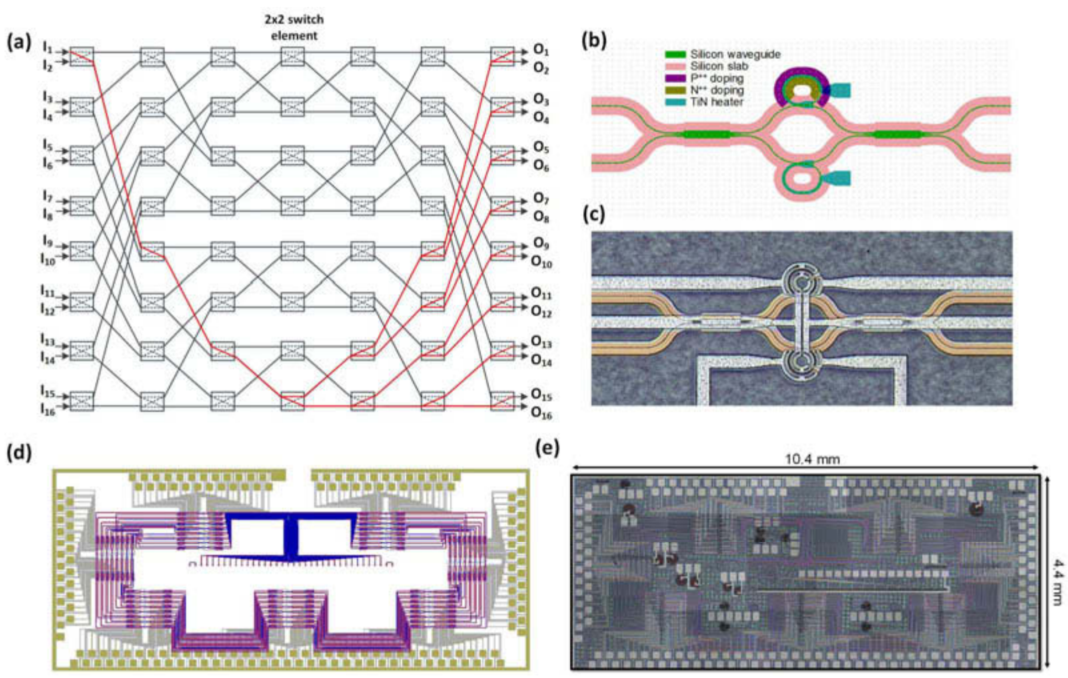

Fig. 1. (a) Benes switch architecture for the 16×16 optical switch. (b) Mask layout of the 2×2 switch element. The trench and metal layers are not shown for clarity. (c) Photograph of the 2×2 switch element. (d) Full layout of the 16×16 optical switch. (e) Photograph of the entire chip. Test devices are placed in the spare area of the switch chip.

Figure 1(a) presents the structure of the 16×16 silicon photonic switch with the DR-MZI as the basic building block. We choose to use the Benes architecture, as it uses the minimum number of switching elements for reconfigurable non-blocking switching. The chip is more compact and control electronics is easier to realize with the reduced number of switching elements. Two types of active tuners are integrated in the ring resonators based on the thermo-optic (TO) effect and the electro-optic (EO) effect, respectively. The TiN heater-based TO tuner is used to compensate the resonance deviation caused by imperfect fabrication and the PIN diode-based EO tuner for fast switching upon free-carrier injection. The chips were fabricated using the CMOS-compatible processes. A fiber array was attached to the chip surface to couple light into and out of the chip via grating couplers. In total, there are 56 PIN diodes and 112 TiN heaters that need to be driven through a printed circuit board.

In the experiment, we first calibrated each DR-MZI switch element and the resonance random shift was corrected by TO tuners so that each element was set to the initial "cross" state. In this state, the input I_1 is connected to output O_9. Then we turned on the PIN diodes in certain switch elements to switch the routing path to other output ports as indicated by the red lines in Fig. 1(a). The full sets of output spectra for the 16 optical paths ($I_1 \rightarrow O_1$, $I_1 \rightarrow O_2$, …, $I_1 \rightarrow O_{16}$) are shown in Fig. 2. The switch operates around 1552.2 nm with average on-chip insertion loss of 17 dB and extinction ratio of 15 dB. In principle, the operation wavelength can be set to other wavelengths by thermally shifting all ring resonators. The EO driving voltage is around 1V and the power consumption is less than 1mW for each switch element. The response time of the PIN diodes is in the order of ns, facilitating fast exchange of small-size data between nodes in big-data applications.

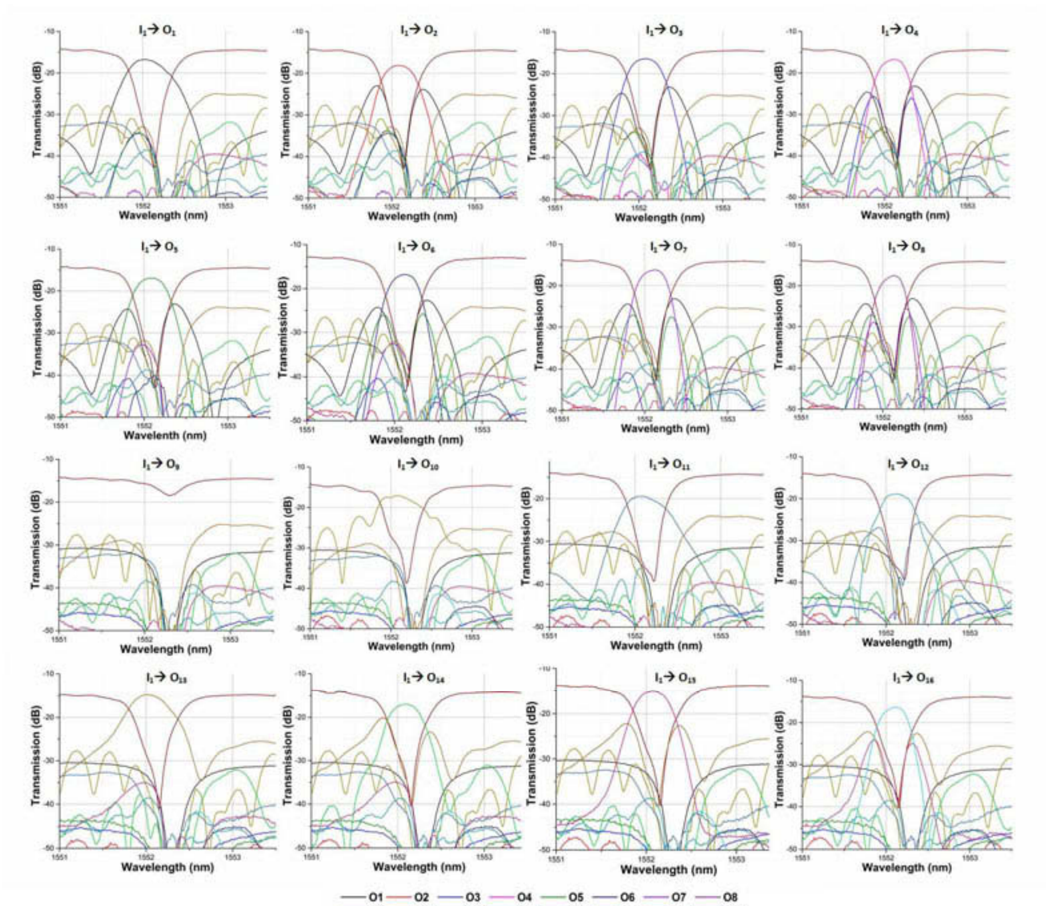

Fig. 2. Measured output transmission spectra of 16 optical paths when input is from I_1.

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