A compact programmable silicon photonic circuit

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***Abstract*—We experimentally demonstrate a programmable photonic circuit based on a 7-cell hexagonal waveguide mesh of coupled 2x2 Mach-Zehnder interferometer gates. The use of undercut heaters results in a compact circuit with a large free spectral range for interferometers and ring resonator filters.**

***Index Terms*—programmable photonic integrated circuit, wavelength filters, silicon photonics**

I. Introduction

Benefiting from the maturity of industrial CMOS technology, silicon photonic integrated circuits (PICs) are widely used in many applications such as data communication and computing, steadily growing in the number of building blocks and the functional complexity. As their performance is very sensitive to the fabrication tolerances, so active tuners and controllers are commonly used to compensate the imperfection of the PICs.

Similar as field-programmable gate arrays (FPGAs) in programmable electronic hardware, programmable PICs take this one step further and using the active tuners to fully configure the functionality of the circuit. In this way, a variety of functions can be programmed and performed on the same generic photonic circuit. Like with FPGAs, this can be extremely beneficial for accelerating the development and prototyping of new PICs [1].

In this paper, we describe a programmable PIC using a recirculating waveguide mesh, in which we experimentally demonstrate different optical functions, such as a two-ring resonator coupled circuit as a band-pass filter.

II. Hardware

Shown in Fig. 1(a), the programmable PIC is constructed in a hexagonal mesh structure with seven cells, consisting of 42 optical gates, where each optical gate is implemented as a balanced arm Mach-Zehnder interferometer (MZI) with a thermo-optic phase shifter in each arm, bringing the total to 84 actuation tuners. The chip is fabricated in IMEC's iSiPP200 process, using local undercut for the heaters. By delivering electrical power to the phase shifters (P_π=7.8 mW) in each gate, the power coupling ratio of the gate can be fully altered between 0 (bar state) and 1 (cross state) while the common phase response of the gate is tunable too. The phase shifters are wire-bonded to a printed circuit board (PCB) and connected to a multi-channel current driver. The circuit has 24 optical input/output ports which are accessible via a fiber array

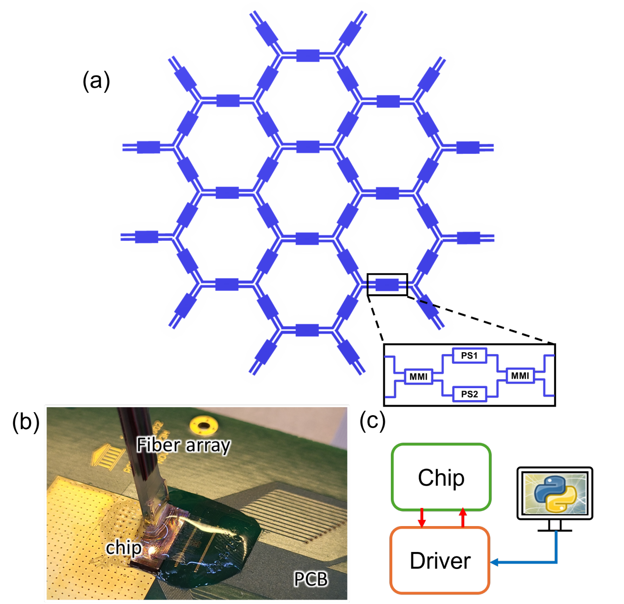

Fig. 1. (a) The schematic of our programmable PIC. MMI: multi-mode interferometer; PS: thermal-optic phase shifter. (b) An image of a packaged programmable PIC chip on a printed circuit board. (c) The hardware connection schematic for the control.

connected through grating coupler, as shown in Fig. 1(b). In order to configure the functionality of the circuit, the multi-channel current driver are controlled by a Python software library to deliver the desired electrical power to the targeted optical gates on chip, as shown in Fig. 1(c).

III. Optical gate

The insertion loss and the group delay of a single optical gate are measured by configuring various delay lines with different delay lengths. By tuning the gates to bar or cross state, the delay lines are configured between the same optical input and output ports, which is intended to eliminate the measurement variation between different optical ports.

Shown in Fig. 2, the insertion loss and the group delay of the delay lines show an ideally linear relationship with the optical gate numbers configured into the delay lines. The insertion loss of a single gate is 0.28 dB, and the group delay of it is 5.5 ps at 1550 nm wavelength.

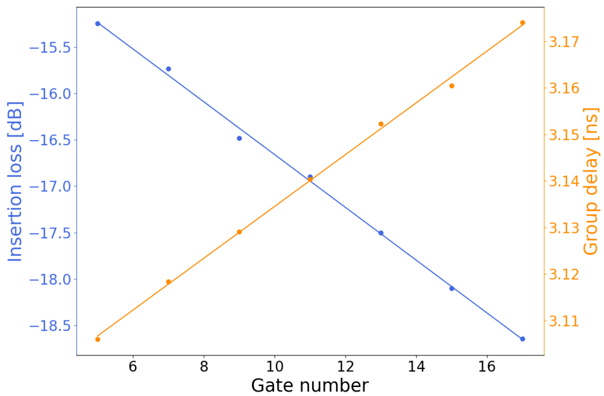

Fig. 2. The measurement results of the insertion loss (blue line) and the group delay (orange line) of the configured delay lines with different gate number in path.

IV. Hexagon Unit Cell

As the smallest unit for a ring configuration, the performance of a hexagonal cell plays an important role in many applications such as filter synthesis. A ring resonator is constructed by six gates in the cell, where we configure five of them to be in bar state, while tuning the coupling ratio of the sixth gate to set the ring in critical coupling state. The transmission response of this ring configuration is shown in Fig. 3. The free spectrum range (FSR) is $0.25\,\mathrm{nm}$ which corresponds to a $31\,\mathrm{GHz}$ frequency range. At the critical coupling state, the Q factor of the ring is around 51666. This corresponds to a loss per gate of $0.28\,\mathrm{dB}$, which matches well to the delay line measurement mentioned above.

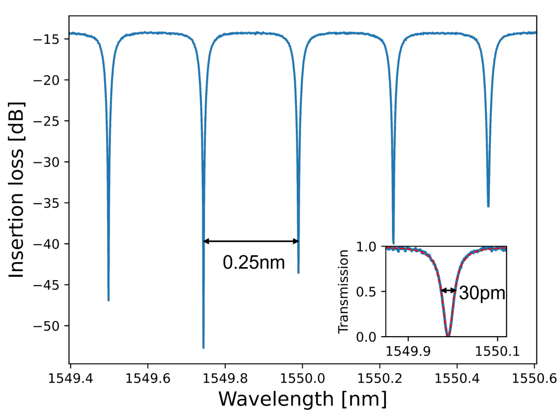

Fig. 3. The measurement results of the transmission spectrum of a single ring configuration.

V. Two-ring filter

As a second example, a filter circuit constructed by two coupled rings is configured. By precisely tuning the coupling ratios of the gates and the phase relationship between these two rings, a type-I Chebyshev band-pass filter is implemented with tunable passband width [2]. The transmission spectrum measured between the input port 2 and the drop port 13 is shown in Fig. 4. When the passband width is $0.1\,\mathrm{FSR}$, an extinction ratio of more than $20\,\mathrm{dB}$ between passband and stopband is achieved.

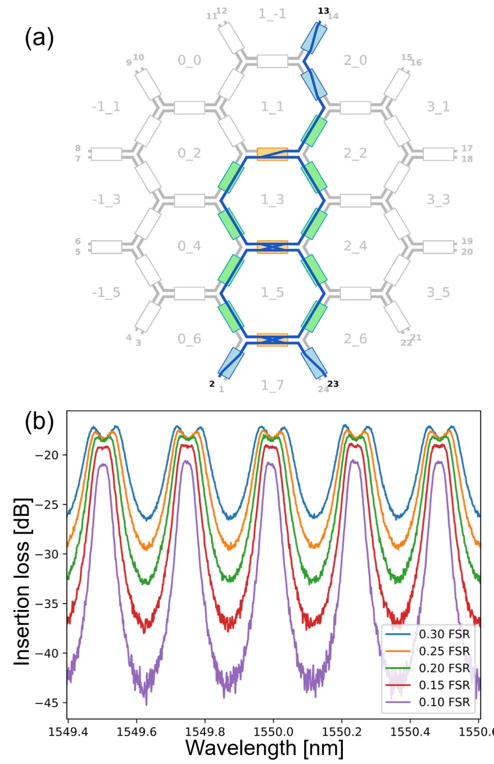

Fig. 4. (a) The schematic of the coupled two-ring filter configuration. (b) The measurement results of the configured two-ring circuit as a band-pass filter with tunable passband width.

VI. Summary

We show the first results of our newly realized compact programmable recirculating waveguide mesh in IMEC's silicon photonics platform, and demonstrate low loss and rings with a large FSR. Further demonstrations include MZI lattice filters, multi-port switching and power distribution networks.

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References

[1] W. Bogaerts, D. Pérez, J. Capmany, D. A. Miller, J. Poon, D. Englund, F. Morichetti, and A. Melloni, "Programmable photonic circuits," *Nature*, vol. 586, no. 7828, pp. 207–216, 2020.

[2] C. K. Madsen and J. H. Zhao, "Optical filter design and analysis: a signal processing approach," 1999.