Silicon Photonics for Matrix Switching Applications: Ingredients and Recipes

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Abstract: We present an overview of the key aspects for the design of scalable silicon photonic switch matrices. We first discuss different possible configurations, and then we present the proposed architecture for a multiport transponder aggregator within the European project IRIS. We also analyze all the necessary photonic building blocks for this application; we will show design considerations as well as experimental demonstrations of many of them, discussing all the possible issues that must be considered for the system to work within specifications.

OCIS codes: (130.4815) Optical switching devices; (130.3120) Integrated optics devices; (200.4650) Optical interconnects; (200.6715) Switching.

1. Introduction

Next generation multiport optical switches will require low-power, highly scalable devices capable of handling and routing many wavelength division multiplexed (WDM) channels simultaneously. Silicon photonics, thanks to its CMOS compatibility and its strong light confinement, is well suited for this particular application [1, 2]. The last decade has seen a remarkable development and optimization of silicon photonic devices, which now facilitates the implementation of more complex photonic systems that are required to generate the products needed by the telecom and datacom markets.

The most efficient switch topology and architecture depends on the specific application. In the European project IRIS [3], we aim to fabricate a transponder-aggregator device for a telecom application, capable of rerouting channels coming from four different directions, each carrying 12 WDM, 200GHz-spaced channels in the C-band, towards 8 different output ports [4]. For this kind of device, we propose a cross-bar switch fabric which involves 384 switch elements each one needing independent control. In addition, wavelength demultiplexers, interleavers and monitors are needed too. Controlling such number of elements requires bonding an electronic integrated circuit (EIC) on top of the photonic integrated circuit (PIC), and communicating through more than one thousand copper pillars. Many aspects need to be considered, not only the specifications of each building block, but also how channel cross-talk issues can affect the system, and possible thermal cross-talk issues.

2. System architecture

Multiport switches can be implemented with several different topologies, such as the Beneš, cross-bar, switch-and-select, etc [1]. Although the Beneš topology minimizes the number of switches, it is not necessarily the best suited fabric for all applications. If the switch element is a ring resonator, the transmission loss can be very different whether the switch is on the *on* or *off* state. In the *off* state, the signal is not tuned to the resonance, therefore the loss is typically very small. However, when it is on the *on* state, the signal resonates in the ring and is sent to the drop port, which is typically much more sensitive to fabrication imperfections. In this situation, a cross-bar topology is more indicated, because even though the signal encounters more switches, all except one are ensured to be in the *off* state. Therefore, for this reason, and also because of its simplicity, the cross-bar topology is typically preferred.

When the switching needs to be wavelength dependent, wavelength demultiplexing is necessary. Integrated optics can offer several possibilities for this functionality, like arrayed waveguide gratings (AWGs), echelle gratings, cascaded interleavers, cascaded ring resonators, *etc*. We have opted for a combination of an AWG preceded by an interleaver, which relaxes the specifications of the AWG from 200GHz to 400GHz channel separation. The overall architecture proposed for the IRIS project is shown in Fig. 1. The device is reversible, which means that it can work in *drop* configuration (as shown in Fig. 1) or reversing the ports, in *add* configuration.

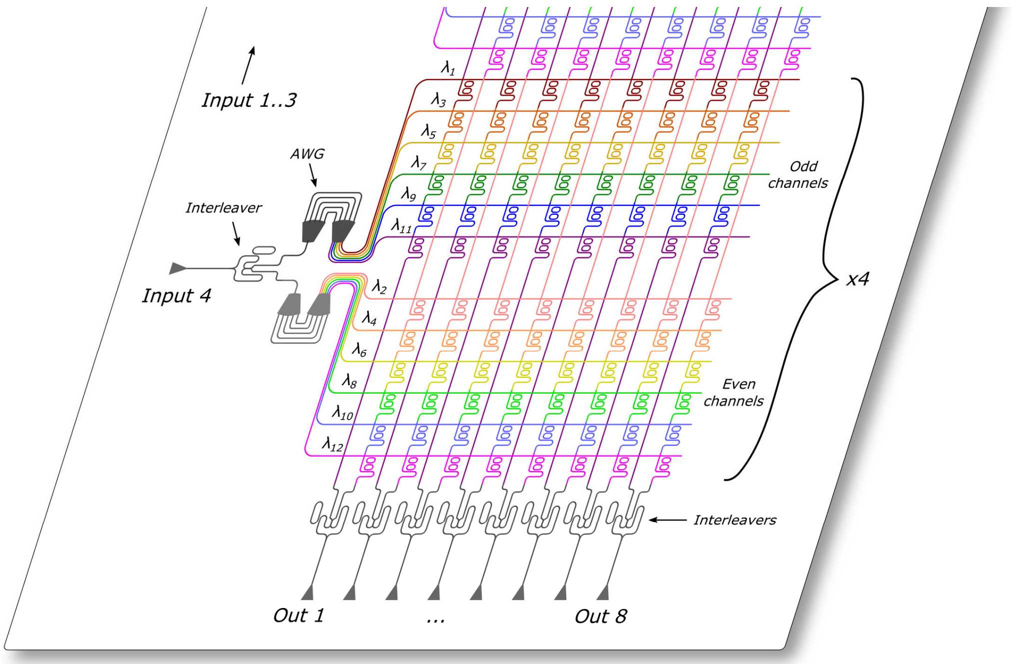

Fig. 1: System architecture for the transponder-aggregator proposed in IRIS project. The figure corresponds to the system with double-ring switching in *drop* configuration. The *add* functionality can be implemented by inverting the direction of the ports.

3. Photonic building blocks

The architecture shown in Fig. 1 requires the following building blocks:

- *Switch element:* This is the key element of the device. We investigated two alternatives, a single and a double ring resonator. Single ring resonators are simpler to tune and consume less power although the channel isolation and channel flatness are both low. In particular, it is impossible to reach the required 35dB isolation with a single ring if the channel width is 50 GHz. On the other hand, double rings can simultaneously improve channel flatness and isolation, because they are second-order filters. However, when thermal tuning is needed, two resonators have to be heated instead of one, which consumes more power. In addition, the optical paths have to be identical, which may lead to problems if the heating efficiency is not identical, as in that case the control signal would need to be different. We demonstrate the fabrication of double-ring filters with ultra-high free spectral range (FSR) of 2.4THz (19 nm) by using modified racetrack resonators with adiabatic Bezier bends. We also investigated how these filters are tuned, and how the effects of non-identical conditions impact on the performance of the filter. Finally, we studied three different ring heating schemes: (i) Ti/TiN metallic heaters situated above the ring; (ii) integrated heaters in the internal area of the ring using doped silicon; (iii) integrated heaters using silicide as heating material. These three heating mechanisms are experimentally evaluated and compared, and inter-ring thermal crosstalk issues are studied too.
- *Crossings:* The cross-bar topology implies a large number of waveguide crossings. However, silicon photonics technology has demonstrated very compact and low loss crossings based on tapered 1x1 multimode interference couplers [5].

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- *AWG:* The AWG is used for fanning out the channels in rows to be able to switch specific wavelengths. It is designed to have low cross-talk and to be robust to fabrication inaccuracies through a phase-noise reduction strategy based on waveguide width modification. Some designs also include thermal tuning of the channels by gradually heating the interferometer paths. The star couplers have also been improved by introducing “whiskers” to reduce back-reflection effects.
- *Interleavers:* Interleavers are used before the AWG in order to relax the demultiplexer specifications by separating even from odd channels. They are also used for the recombination of the signals from the even and odd columns of the cross-bar (Fig. 1). They are designed as Infinite Impulse Response (IIR) filters which consist of an asymmetric Mach-Zehnder interferometer (MZI) with a racetrack resonator on the short path [6]. The phase noise and fabrication error sensitivity can be greatly improved by introducing waveguide width variations along the propagation paths.
- *Optical monitors:* These are simply Ge photodiodes connected through tap couplers, and are used to monitor the signals in different positions along the system. If the device is reversible, these need to work in both directions, therefore a ring configuration is proposed with two input ports coming from opposite sides of the photodiode.

4. Conclusions

In this paper we discuss why silicon photonics is well suited for switching applications, and the most typical architectures for scalable multiport switches. We also show a variety of building blocks that are necessary to fabricate this device. We will show optical designs and experimental demonstrations of these devices, and possible difficulties that one can encounter are discussed.

5. Acknowledgments

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