Integrated SiPh Flex-LIONS Module for All-to-All Optical Interconnects with Bandwidth Steering

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Abstract: We experimentally demonstrate the first all-to-all optical interconnects with bandwidth steering using an integrated 8×8 SiPh Flex-LIONS module. Experimental results show a 5-dB worst-case crosstalk penalty and 25 Gb/s to 100 Gb/s bandwidth steering. © 2020 The Author(s)

1. Introduction

Heterogeneous processor and memory nodes are applied in today's high performance computing (HPC) and datacenter system for better resource utilization (Fig. 1(a)). The communication patterns in such a system tend to be spatial and temporally non-uniform which means the hotspots and coldspots simultaneously created in different locations of the network can result in heavy congestions in some data links [1]. However, today’s interconnection networks based on electronic switches and optical fibers are with fixed topology and fixed connectivity which is incapable of dynamically adapt the bandwidth between certain node pairs to the workloads. On the other hand, the capability of all-to-all interconnects is also necessary for many applications such as deep neural network (DNN), map-reduce, and parallel sorting applications. Then it would be desirable to design an all-to-all interconnection network with bandwidth steering so that the network topology can be dynamically reconfigured to match with communication patterns. Indeed, wavelength-and-space selective optical switching fabric that can reconfigure the bandwidth between selected pair of nodes has been demonstrated on various platforms including InGaAsP/InP arrayed waveguide grating routers (AWGR) + semiconductor optical amplifiers (SOAs) [2], silicon photonic (SiPh) echelle gratings + microelectromechanical systems (MEMS) arrays [3], and SiPh multi-wavelength selective microring resonator (MRR) crossbar [4]. In our previous work [5,6], bandwidth-reconfigurable one-to-all multicast has been experimentally demonstrated with SiPh Flex-LIONS with multi-wavelength MRR spatial switch. However, all-to-all interconnects with bandwidth steering are yet to be demonstrated with a fully integrated module and the power penalty induced by AWGR crosstalk need be verified.

In this paper, we experimentally demonstrate the first all-to-all optical interconnects with bandwidth steering using a fully integrated 200-GHz-spacing 8×8 SiPh Flex-LIONS module. By using wide-band Beneš MZS networks as the spatial switch, this architecture exhibits lower complexity and higher bandwidth of the reconfigured channel compared with our previous work [5,6]. System testing show error-free all-to-all interconnection with 5-dB power penalty induced by AWGR intra-band crosstalk under worst-case polarization scenario. Bandwidth steering from 25 Gb/s to 100 Gb/s has also been demonstrated between selected pairs of nodes.

2. Principle, Design, Fabrication, and Single Components Measurements

Figure 1(b) shows the architecture of the NxN Flex-LIONS which contains an NxN cyclic AWGR at the core, b MRR add/drop filters at the input/output ports of the AWGR (b<N), and a wide-band NxN Beneš Mach-Zehnder...
switch (MZS) network (rearrangeable non-blocking) at the bottom. For uniform-random traffic, all the input and output ports can be all-to-all interconnected with $N$ wavelength division multiplexing (WDM) signals based on the wavelength routing function of the AWGR. For resolving hotspots, up to $b$ of the $N$ wavelengths from each input port can be dropped by the MRR drop filters and spatially switched to a selected output port by the Beneš MZS network so that the bandwidth between them can be increased by a factor of $b$. Compared with our previous work [5,6], the number of cascaded MRRs on the path of the reconfigured channels is reduced from three to two so that the MRR filtering effect is reduced. Besides, the architectural complexity of this work is lower since the number of switching elements of the spatial switch is reduced from $N^2$ to $\log_2 N \cdot N^2$.

The SiPh Flex-LIONS device is designed on a multi-layer platform. The bottom layer is the 220-nm Si layer which contains MRR add-drop filters and Beneš MZS network. Above the Si layer is the 200-nm SiN layer which contains the 8x8 AWGR. An oxide cladding window is etched on top of the Si area for higher thermos-optical (TO) tuning efficiency. On top of the oxide cladding are the 400-nm-thick Ti heater layer and 800-nm-thick Au contact metal layer. The SiN layer vertically interfaces with the Si layer through inverse-tapered evanescent couplers with a 600-nm gap. The Flex-LIONS chip was fabricated on 220-nm silicon on insulator (SOI) wafer as shown in Fig. 2(a).

3. Experimental Demonstration of Bandwidth-Reconfigurable All-to-All Optical Interconnects

The fabricated chip with 176 electrical pads on the edge was wire-bonded to a co-designed printed circuit board (PCB) for electrical fan-out, as shown in Fig. 3(a). Two lid-less 16-channel 127-μm-pitch polarization-maintaining (PM) fiber arrays were attached to the input and output of the chip using index-matching UV epoxy. Figure 3(b)
shows the experimental setup. Eight small form pluggable (SFP) lasers provide the light source of the 200-GHz-spacing WDM signals which match with the AWGR channels. All the WDM signals are multiplexed and modulated by an MZ modulator at 25 Gb/s. The driven signals are $2^{11}$-1 PRBS signals generated by a high-speed digital to analog converter (DAC). Eight polarization controllers (PCs) before the multiplexer (MUX) and a polarizer before the MZ modulator are used for polarization alignment. The modulated signal is boosted by an erbium-doped fiber amplifier (EDFA) and split by a 1x8 splitter. Then the eight signals are decorrelated by single-mode fiber catch cables with different lengths and aligned to the polarization of the PM fiber by a PC before input into the packaged Flex-LIONS chip. The output signal from the chip is then received by an optically pre-amplified receiver (RX). A real-time error analyzer (EA) performs BER measurements as a function of the RX input power, which is measured by the optical power monitor of the variable optical attenuator (VOA).

Before reconfiguration, the device provides all-to-all connectivity. Figure 3(c) shows the transmission spectrum from input port 4 to output port 8 with AWGR channel $\lambda_s$. The power penalty from center and side input ports is measured under the worst-case crosstalk scenario (all the input signals aligned in polarization). Figure 3(d) shows the BER curves for selected input and output port combinations which show error-free all-to-all interconnects. The measured power penalty at BER=10^{-12} is in the range of 3.9 dB to 5 dB compared with back-to-back (no crosstalk signal added). Figure 3(e) shows the transmission spectrum from input port 4 to output port 8 after reconfiguration. $\lambda_s$ channel is from the passband of AWGR while the other three channels ($\lambda_1, \lambda_2, \lambda_3$) are from the path through cascaded MRR add-drop filters and Beneš MZS network. Error-free operation of all the four channels demonstrates 4x bandwidth steering (25 Gb/s to 100 Gb/s) between input port 4 and output port 8 as shown in Fig. 3(f).

4. Conclusion

This paper demonstrates the first all-to-all optical interconnects with the ability of bandwidth steering using a fully integrated Flex-LIONS module. The worst-case crosstalk power penalty is measured as below 5 dB. Error-free operation of bandwidth steering shows 4x bandwidth enhancement between selected node pairs.

5. References


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