8 x 40 Gb/s WDM photonic integrated wavelength switch module for optical data center networks

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ABSTRACT

We characterize the performance of a photonic integrated 1x8 WDM (8 channels Wavelength-Division Multiplexing) wavelength selective switch (WSS) module to realize a modular 8x8x8λ cross-connect switch. The module is based on SOA (Semiconductor Optical Amplifier) optical gates for nanoseconds wavelength and time switching operation. This technology enables the realization of low latency optical data center networks. Experimental measurements demonstrate a cross-talk lower than -35 dB, 11 dB/channel on chip gain and error-free operation at 40 Gb/s with limited penalty. The on chip gain and low cross-talk results presented in this study and the device proposed, being a scaled up version with double the channels of a previously demonstrated 4 x 4 modular architecture, validate the potentialities of this approach to scale up to an even larger channel number and hence port count.

Keywords: SOA (Semiconductor Optical Amplifier), PIC (Photonic Integrated Chip), DCN (Data Center Network), WSS (Wavelength Selective Switch).

1. INTRODUCTION

Due to emerging cloud computing, IoT, e-commerce and upcoming 5G applications more stringent requirements in terms of high bandwidth, low latency and large interconnectivity are imposed on the communication network inside the data centers [1]. In order to enable the scalable growth both of communication nodes and exchanged data traffic new architectural and technological solutions are needed. Optical switching is an attractive technology in this respect, providing data-rate and data-format transparency operation, and also avoiding the need for power hungry O/E/O conversions as well as format-dependent interfaces. Nanoseconds reconfiguration time optical cross-connect (OXC) switches have been previously considered and proposed for realizing flat optical DCNs [2-5].

The novelty of this study rests in the attempt to fulfil the scalability requirement through the performance assessment of a photonic integrated 1x8λ WDM WSS module, significantly reducing the required foot-print, hence the power consumption. Static characterization of the elements (SOAs, AWGs, etc.) and 10, 20 Gb/s NRZ-OOK single channel measurements has been performed in a recent study [6].

In this work, we experimentally assess the switching performance of a photonic integrated WDM WSS module with 40 Gb/s NRZ-OOK WDM input traffic. Results show 11 dB/channel on chip gain and error-free operation with less than 2.5 dB power penalty for WDM input operation with a cross-talk lower than -35 dB.

2. SYSTEM OPERATION

WDM OXC switches can be employed to build a novel distributed flat DCN architecture as illustrated in Fig. 1(a). The schematic of the WDM OXC switch allowing for nanoseconds wavelength, space, and time switching operation is depicted in Fig. 1(b). The non-blocking switch has N inputs each carrying M different wavelengths generated by the top-of-rack (ToR) switches. The modular structure enables the parallel processing of the N WDM inputs by the respective optical modules. Each WSS (Wavelength Selective Switch) module can select one or more wavelength channels and forward the channels to the output ports according to the switching control signals [5]. The WSS consists of two AWGs (Arrayed Waveguide Gratings) and M SOA-based optical gates. The first 1×M AWG operates as wavelength de-multiplexer. Turning on/off the M SOAs determines which wavelength channel is forwarded to the output or is blocked. The second M×1 AWG operates as wavelength multiplexer. It should be noted that the amount of SOAs is N×N×M which is only partially (< N×M) turned on simultaneously.

In this work the tested non-blocking optical switch has 1 input and 8 outputs. The input carries 8 different wavelengths generated by the ToRs. Each optical module consists of a Pre-amplifier SOA (2 mm long) at the input, a 1:2 MMI (Multimode Interferometer) power splitter that broadcasts the WDM channels to both the WSS that process the WDM inputs in parallel. The WSS consists of, two AWGs, 8 quantum well active InGaAsP/InP SOA based optical gates (950 μm), and the SOA as booster at the output (1 mm). The 1x8 AWG operates as wavelength de-multiplexer. Turning individually on or off the 8 SOA optical gates determines which wavelength channel is forwarded or blocked to the respective output. Multicast operation is also possible by turning more than one SOA. The AWGs are designed with a free spectral range (FSR) of 2 nm.

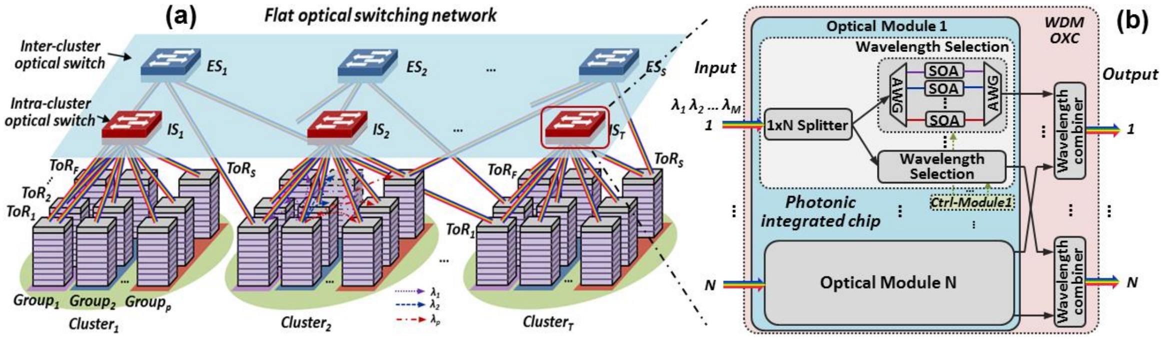

Fig. 1: (a) DCN architecture employing the distributed WDM switches. (b) Schematic of the WDM optical switch.

The broadband operation of the SOAs enables the selection of any wavelength in the C band with an On/Off response time in the order of nanoseconds. Moreover, the amplification provided by the SOAs not only compensates the losses introduced by the splitters and the two AWGs but provides on chip gain of 11 dB. The chip has been realized in a multi-project wafer (MPW) with limited space of the cell (4.6 mm x 4 mm). An image of the photonic integrated switch is shown in Fig. 2 (upper left) with colored boxes around the main components and one of the WSS module contained in the photonic chip. The light shaded electrodes are routed through on-chip metal tracks and then wire bonded to a neighbouring PCB (Printed Circuit Board) which provides a control interface for the SOA gates. Lensed fibers have been employed to couple the light in and out of the chip.

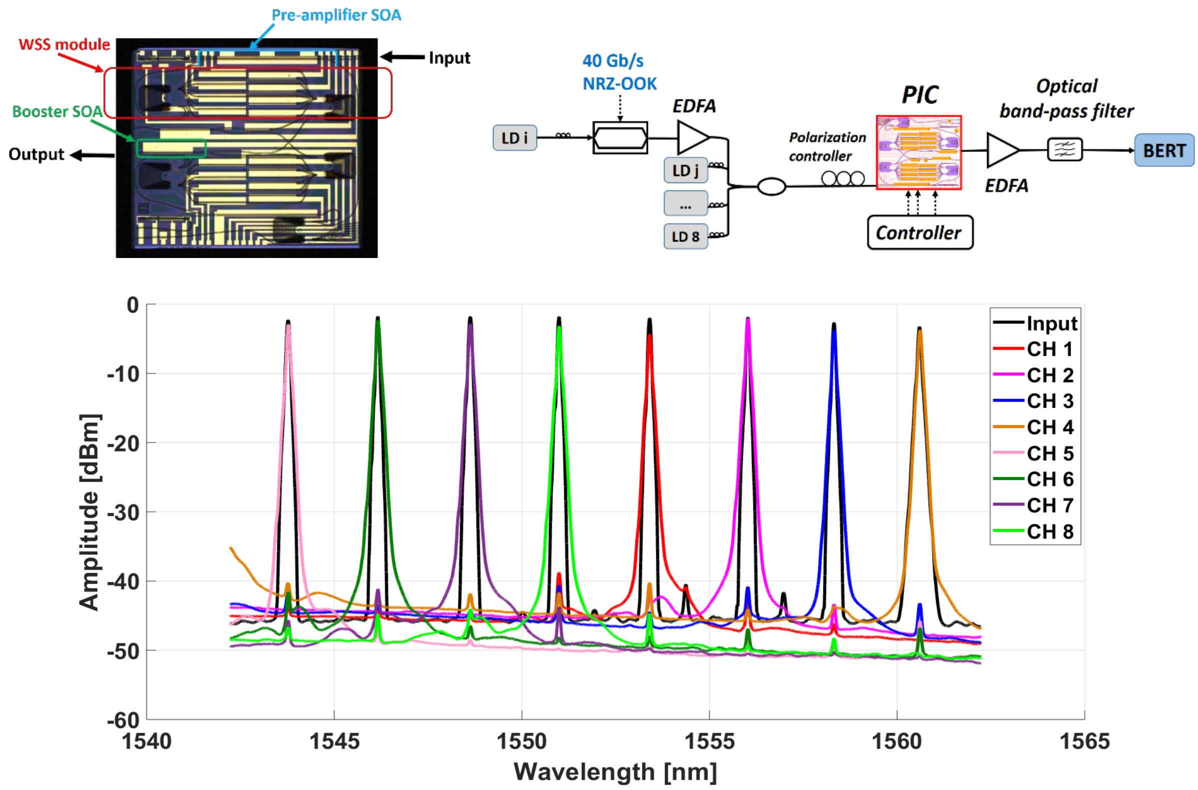

Fig. 2: Microscope image of the modular WDM photonic switch (upper left). Experimental set-up employed to assess the performance of the WDM photonic integrated optical cross-connect (upper right). The eight switched channels by the PIC (Photonic Integrated Chip), LD: Laser Diode, BERT: BER tester (bottom).

3. EXPERIMENTAL RESULTS

The experimental set-up employed to assess the 1x8λ WDM WSS photonic switch module is shown in Fig. 2 (upper right). Eight optical wavelengths spaced by 2 nm, from λ1 = 1544 nm to λ4 = 1560 nm, are generated. The WDM signal consists of only one modulated channel at a time using an NRZ OOK amplitude modulator driven by a 40 Gb/s pattern generator with 2^{15}-1 PRBS, and seven carriers. Since the availability for multiple modulators that could generate this significantly high bit rate (40 Gb/s) was limited to one instrument, this setup choice is intended to avoid the need for an additional inter-channel de-correlation stage, necessary if all channels were modulated by the same instrument, that brings more losses to the setup [6] with additional EDFA stages that deteriorate the input OSNR. The optical power of the WDM input channels was -2 dBm/channel (Fig. 2 bottom -

lossless operation). The input and output booster SOAs were biased with currents 90 mA and 60 mA, respectively. The temperature of the chip was maintained at 20°C through a water cooler. Polarization controllers were employed at the input of the chip as well as after each channel source (LD 1 to LD 8).

First, we assess the static operation of the WSS. One WDM channel at the time is statically switched at the WSS output by enabling one of the eight SOA gates at the time. The current applied at gate SOAs in On-state was 70 mA. The spectra of the switched channels are depicted in Fig.2 demonstrating on chip gain of 11 dB if considering the coupling 6 dB/facet coupling losses and a cross-talk lower than -35 dB.

To investigate the data integrity of the chip operation, BER curves, including the back-to-back as reference, are recorded and shown along with eye diagrams in Fig. 3. Clear open eye diagrams of the switched channels testify for a high quality signal. Error-free operation with a penalty less than 2.5 dB for the worst channel was measured at BER=1e-09. The main source of this penalty is considered to be the added noise by the SOAs and the limited crosstalk.

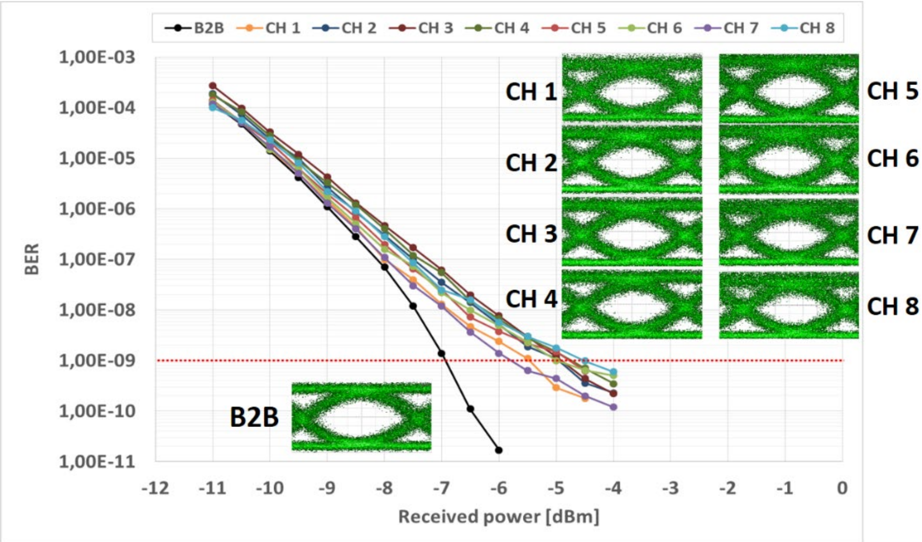

Fig. 3: BER (logarithmic scale) vs Received Optical Power curves and eye diagrams of switched channels at the output port for WDM 40 Gb/s NRZ-OOK input signal.

4. CONCLUSIONS

We have presented a modular 1x8 photonic integrated WDM optical switch including SOA based wavelength selective switches for nanoseconds wavelength and time switching operation. The system performance assessment confirmed the capability of the chip to switch a WDM signal in the wavelength domain. Experimental results show lossless and error-free operation with less than 2.5 dB penalty for data rate up to 40 Gb/s NRZ-OOK 2^{15}-1 PRBS traffic. These results together with the doubling of the channel number compared to the 1x4 switch in [7] are persuasive indications that the modular architecture could scale to a larger number of ports.

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