Performance assessment of a nanoseconds and modular Photonic Integrated Wavelength Selective Switch for Optical Data Centre Networks

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***Abstract*—We assess the performance of a photonic integrated 1x8 WDM (8 channel) wavelength selective switch module to realize a modular 8x8x8λ WDM cross-connect switch. The 1x8 wavelength switch module exploits SOA technology for nanoseconds wavelength and time switching operation to enable the implementation of a low latency optical data center network. Experimental results confirm a cross-talk lower than -30 dB, loss less and error-free operation at 10 Gb/s and 20 Gb/s. The results shown in this study and the fact that the device proposed is an evolved version of a similar modular architecture with double the channels are clearly the proof of the potentialities of this approach to scale up to an even larger port count.**

Keywords—SOA (semiconductor optical amplifier), PIC (photonic integrated chip), Data center network (DCN) optical switch.

I. INTRODUCTION

Driven by the cloud computing paradigm and Internet applications, data centers experience a steady annual increase of over 70% in the amount of traffic. Emerging data centre applications and workloads are creating new communication patterns where up to 75% of the total data center traffic is within data centres [1] (server to server and rack to rack). This huge increase of intra data center traffic requires architectural and technological changes to the underlying interconnect in order to enable scalable growth both in communicating endpoints and traffic volume, while decreasing the costs and the energy consumption. Optical switching could be an attractive technology featuring data rate and data format agnostic operation, and fast (nanoseconds) switching speed. Recently the advantages of using fast (nanoseconds) optical cross-connect switches to realize novel and efficient flat DCN providing low latency and high capacity have been investigated in several projects [2-4]. For high performance operation of the DCNs, a fast (nanoseconds) optical wavelength, space and time cross-connect switch were employed to efficiently handle short lived flows exploiting statistical multiplexing. Optical cross-connect architecture based on SOA technology have been investigated to achieve nanoseconds switching, and lossless and broadband operation. To validate the DCN architectures [5], the optical cross-connects were realized with off the shelf optical components (SOAs, AWGs, optical couplers, etc..). However, practical implementation requires the integration of 100's of those optical components, resulting in power and cost inefficient large and bulky systems. System performance of a photonic integrated 4x4 WDM cross-connect switch for optical DCN has demonstrated dynamic switching within few nanoseconds of WDM data packets in space and wavelength with large contrast ratio (> 28 dB). Error-free operation with < 2 dB penalty has been measured for 10, 20 and 40 Gb/s multiple WDM channels [6]. Aiming to prove the scalability of such architectural approach, in this work we design, fabricate, and characterize a photonic integrated 1x8 WDM switch module as the main module to realize a 8x8x8λ WDM cross-connect switch. The 1x8 module is an SOA based wavelength selective switch module that implements nanoseconds wavelength and time switching operation. We experimentally assess the scalability of the modular architecture to implement a larger port number. In order to simulate a higher output port number a 12 dB attenuation was applied at the input of the chip corresponding to a virtual 1:16 splitting ratio for multicasting. The physical 1:2 splitting ratio on-chip permits to speculate an overall 1:32 splitting ratio which would mean a possible scaling to 32 ports. Experimental results indicate loss-less and broadband operation of the photonic chip, and error-free operation at 10 Gb/s and < 2.5 dB penalty at 20 Gb/s, respectively, for a splitting ratio up to 1x32.

II. SYSTEM OPERATION

The schematic of such modular optical wavelength and time switching modules inside a DCN context is illustrated in Fig. 1 (left side). In the schematic shown each module processes a WDM signal arriving from a

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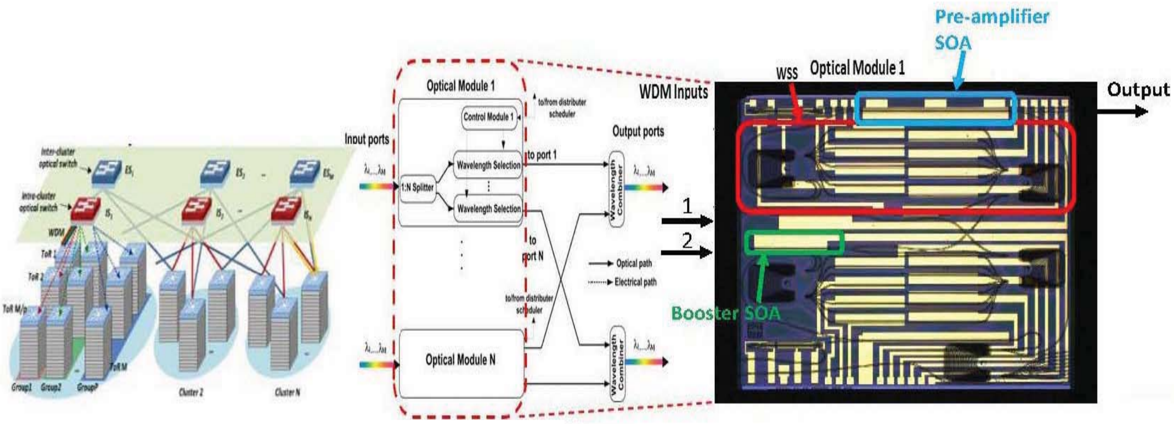

Fig. 1: Schematic of the optical cross-connect. N = 2 optical modules, M = 8 channel wavelengths for the proposed device.

TORs cluster. In this work the proposed non-blocking optical switch has 2 inputs, and each input carries 8 different wavelengths generated by the TORs. The modular switch processes the WDM inputs in parallel by the respective optical modules, and forwards the individual wavelength channels to the output ports according to the switching control signals. More information about the controlling of the switch is reported in [5]. Each optical module consists of a 1:2 splitter to broadcast the WDM channels to the 2 wavelength selective switches (WSS). Each WSS can select one or more wavelength channels and ports according to the control signals. The WSS consists of an SOA (booster) at input, two AWGs and 8 SOA based optical gates, and the SOA as pre-amplifier at the output. The first 1x8 AWG operates as wavelength de-multiplexer. Turning on or off the 8 SOA optical gates determines which wavelength channel is forwarded to the output or is blocked. The second 8x1 AWG operates as wavelength multiplexer. Multicast operation is also possible with this architecture. The broadband operation of the SOA enables the selection of any wavelength in the C band. Moreover, the amplification provided by the SOA compensates the losses introduced by the two AWGs. The chip has been realized in a multi-project wafer (MPW) with limited space of the cell (4.6 mm x 4 mm).

III. PHOTONIC CHIP FABRICATION

The microscope image of the modular WDM 1x8 photonic switch is shown in Fig. 1 (right side). The chip is realized employing the MPW in the Jeppix platform. Each of the two modules processes one of the WDM inputs. At the input and output of the module, a 1 mm SOA and 2 mm SOA is employed to compensate the 3 dB losses of the 1:2 splitter and partially the AWGs losses of the WSS. The passive 1:2 splitters were realized by 1x2 multimode interferometer (MMI). The two outputs of the 1:2 splitters are connected to both of the WSSs, respectively. The WSS consists of two AWGs and 8 SOA based optical gates placed in between the two AWGs. The AWGs are designed with a free spectral range (FSR) of 2 nm. The FSR has been tailored to fit the limited cell size (4.6 mm x 4 mm) offered in the MWP. The quantum well active InGaAsP/InP SOA gates have a length of 950 µm. The SOA electrodes are routed through on-chip metal tracks and then wire bonded to a neighboring PCBs to enable the SOA gates. Lensed fibers have been employed to couple the light in and out of the chip. Spectral tuning of the AWGs is in principle possible by using heaters on top of the AWG waveguides (not implemented in this design).

IV. EXPERIMENTAL RESULTS

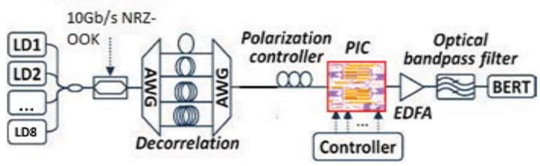

Fig. 2: Experimental set-up employed to assess the performance of the WDM photonic cross-connect.

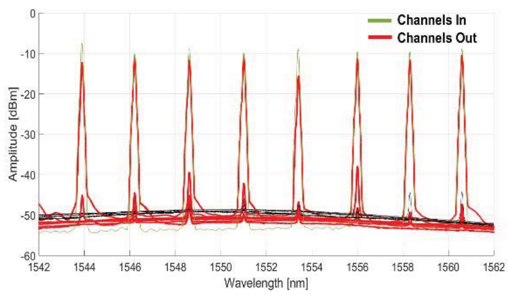

Fig. 3: Optical spectra of the WDM channels switched by the WSS.

The experimental set-up employed to assess the WDM 1x8 photonic switch is shown in Fig. 2. Eight optical input channels spaced by 250 GHz, from λ1=1544 nm to λ4=1560 nm, are generated by using an amplitude modulator driven by 10 Gb/s (or 20 Gb/s) pattern generator with 2^{31}-1 PRBS. Since a single modulator has been used for all the 8 channels, a decorrelator consisting of two AWGs and delay lines has been used to decorrelate the channels. The eight WDM channels are de-correlated and launched into the input port 2 of the photonic chip. As the optical modules are identical, we have assessed the operation of one optical module to characterize the switching operation, the upper one. The optical power of the WDM input channels was -10 dBm/channel (see also

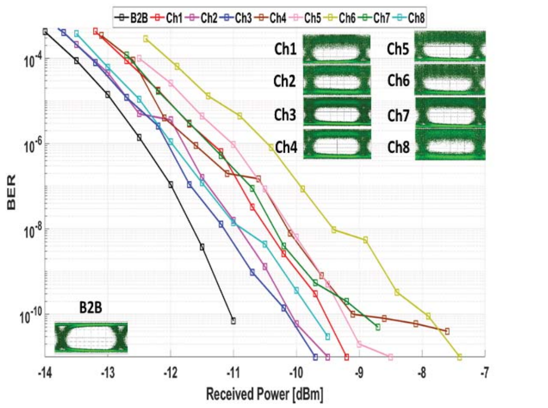

Fig. 4: Eye diagrams and BER curves of the switched WDM signals to the output ports of the photonic chip.

Fig. 3). The input and output booster SOAs were biased with 100 mA and 60 mA of current, respectively. The temperature of the chip was maintained at 20°C. Polarization controller was employed at the input of the chip. First, we assess the static operation of the single 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 each of the SOA gates was 70 mA. The eight measured spectra at the WSS output (output 1 of the chip) are shown in Fig 3. An on/off switch ratio higher than 30 dB was measured. The optical power at the chip output for channel was around -12 dBm. Considering 6 dB/facet coupling loss, 10 dB on chip gain is estimated. However, the power varies slightly from channel to channel. To investigate data integrity of the chip operation, BER curves and eye diagrams are recorded and shown in Fig. 4. For the the channels with extra losses, an optical amplifier was necessary at the chip output. Fig. 4 shows clear open eye diagrams of the switched channels. The BER curves, including the back-to-back as reference, are also shown in Fig. 4. Error-free operation with a penalty less than 2 dB for the channels 1, 2, 3, 4, 5, 7 and 8 was measured. The penalty for channel 6 was slightly higher due to the higher accumulated noise. Additionally, in order to stress further the performance of the switch in terms of data rate measurements of penalty have also been conducted for 20 Gb/s. As can be seen from the Fig. 5 below the power penalty for an error free signal is under 2.5 dB for all channels.

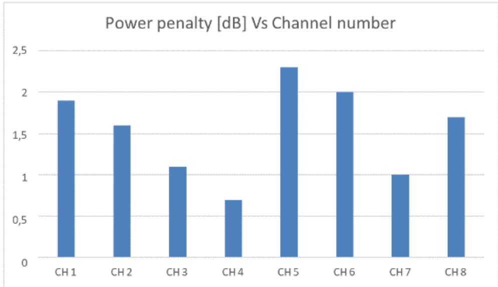

Fig. 5: Power penalty for an error-free signal (BER = 10e-09) at 20Gb/s bitrate.

V. CONCLUSIONS

We have presented a monolithically integrated 1x8 WDM modular optical switch including SOA based wavelength selective switches for nanoseconds wavelength and time switching operation. The experimental assessment confirmed the capability of the cross-connect chip to switch WDM signal in the wavelength domain. Experimental results show lossless operation, cross-talk < -30 dB, and error-free operation with less than 2.5 dB penalty for data rate up to 20 Gb/s. Compensation of the losses is a good indication that the modular architecture could scale to a larger number of ports.

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