Characterization of Photonic Integrated WDM Switch Module for Optical Data Centre Networks for DMT Modulation Format

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In this paper we characterize a photonic integrated 1x8 (8 channels) WDM wavelength selective switch as a building module for the possible future realization of a modular 8x8x8λ WDM cross-connect optical switch. The modulation format of the data used to characterize the module is discrete multi-tone (DMT). The experimental measurements reveal a capability of transmitting at bit rate as high as 12 Gb/s with a power penalty of 1 dB for the best performing channel.

Introduction

Driven by the emerging of new data hungry services such as: Cloud computing, IoT, 5G, e-commerce etc., data centers experience a steady annual increase of over 70% in the amount of traffic. Emerging data center applications and workloads are creating new communication patterns where up to 75% of the total data center traffic is within data centers [1] (server-to-server and rack-to-rack). This huge increase of intra- data center traffic requires new solutions to the underlying interconnect in order to enable scalable growth both in terms of bandwidth and connectivity, while decreasing the latency, costs and energy consumption.

Optical switching could be an attractive technology featuring data rate and data format agnostic operation, and fast switching speed (down to nanoseconds switching times). Recently the advantages of using fast optical cross-connect switches to realize novel and efficient flat DCNs (Data Center Networks) providing low latency and high capacity have been investigated in several projects [2-4]. For high performance operation of the DCNs, a fast optical wavelength, space and time cross-connect switch was employed to efficiently handle short lived flows by exploiting statistical multiplexing.

Optical cross-connect architectures based on semiconductor optical amplifier (SOA) technology have been investigated to achieve nanoseconds switching, lossless and broadband operation. To validate the DCN architectures, the optical cross-connects were realized with off the shelf optical components (SOAs, AWGs, optical couplers, etc.) [5].

Moreover, the advantages of photonic integration enable the reduction of footprint, cost, power consumption and latency. In a previous work, 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 an 8x8x8λ WDM cross-connect switch. The 1x8 module is an SOA based wavelength selective switch (WSS) module that implements nanoseconds wavelength and time switching operation. We experimentally assess the capability of the module to transmit data rate adaptive traffic, optimized to the transmission channel conditions, with limited power penalty. The modulation format of the data used for characterizing the module was discrete multitoned (DMT). The experimental measurements reveal a capability of transmitting at a bit rate as high as 12 Gb/s with a power penalty of 1 dB for the best performing channel.

System operation

The schematic of such modular optical wavelength and time switching modules inside a DCN context is illustrated in Fig. 1.

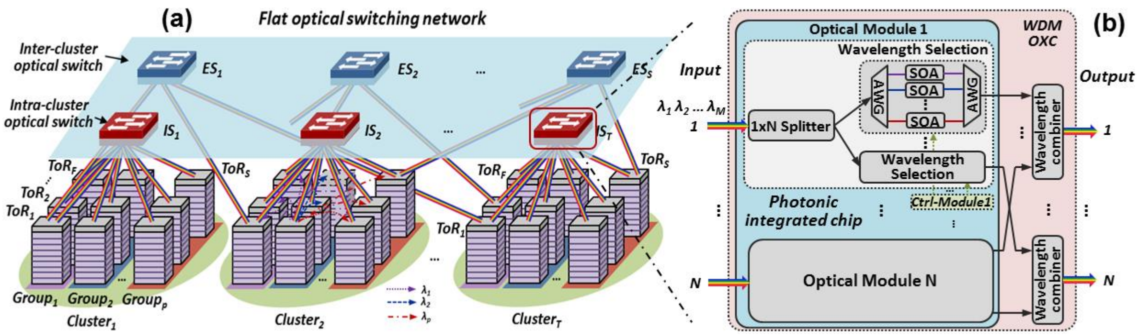

Fig. 1: (a) Schematic of a flat DCN topology. (b) Schematic of the WDM optical cross-connect. TOR: Top Of the Rack (switch), refers to the servers organized in racks and cluster of racks.

In the schematic shown in Fig. 1 (b) each optical module processes a WDM signal arriving from a local TOR electrical switch. 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]. In our photonic integrated switch each of two optical modules consists of a 1:2 splitter to broadcast the WDM channels to two WSS modules. Each WSS can select one or more wavelength channels according to the control signals. The WSS consists of a SOA (booster) at the input, two AWGs and 8 SOA based optical gates. Another SOA as a pre-amplifier is near the output. The first 1x8 AWG operates as a 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 a 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).

Photonic Integrated Chip (PIC)

The microscope image of the modular WDM photonic switch is shown in Fig. 2. Each of the two WSS modules processes one of the WDM inputs. At the input and output of the single module, a 1 mm Booster SOA and 2 mm Pre-amp SOA are employed, respectively, to compensate the 3 dB losses of the on-chip 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 2.4 nm. The FSR has been tailored to fit the limited standard cell size (4.6 mm x 4 mm) of the MPW approach. 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 PCB that feeds current to 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).

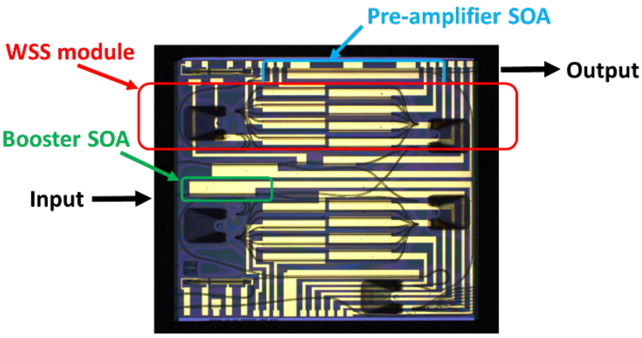

Fig. 2: Microscope image of the modular WDM photonic switch.

Experimental results

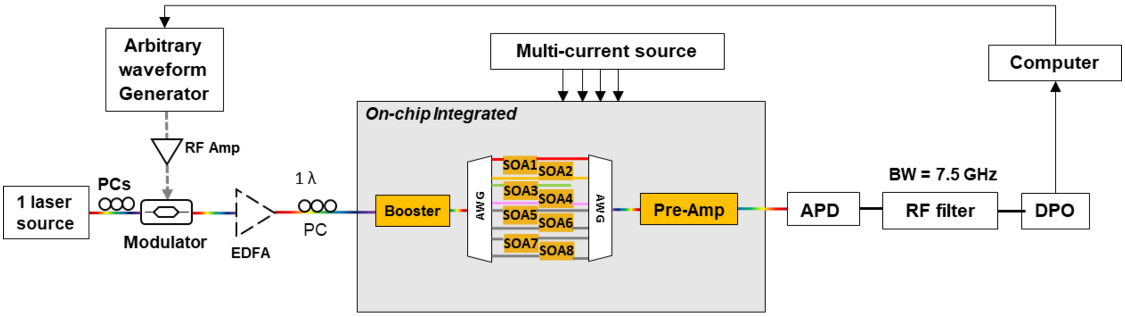

Fig. 3: Experimental set-up employed to assess the performance of the WDM photonic switch for DMT modulation format. EDFA: Erbium Doped Fiber Amplifier, APD: Avalanche Photo Diode, DPO: Digital Phosphor Oscilloscope.

The experimental set-up employed to assess the single WDM 1x8 photonic switch module is shown in Fig. 3. Eight optical input channels spaced by 2.4 nm, from λ1=1544 nm to λ4=1560 nm, are generated one at a time by using an MZM amplitude modulator driven by an arbitrary waveform generator (AWG). The AWG is configured through a Matlab code running in a computer. The eight optical channels are launched into the input port 1 of the photonic chip one at a time. 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 -2 dBm/channel.

The input and output booster SOAs were biased with 85 mA and 120 mA of current, respectively. The temperature of the chip was maintained at 20°C. Polarization control was employed at the input of the chip. One WDM channel at a 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 80 mA. The eight measured spectra at the WSS output

(output 1 of the chip) are shown in Fig. 4 (left). An on/off switch ratio higher than 30 dB was measured.

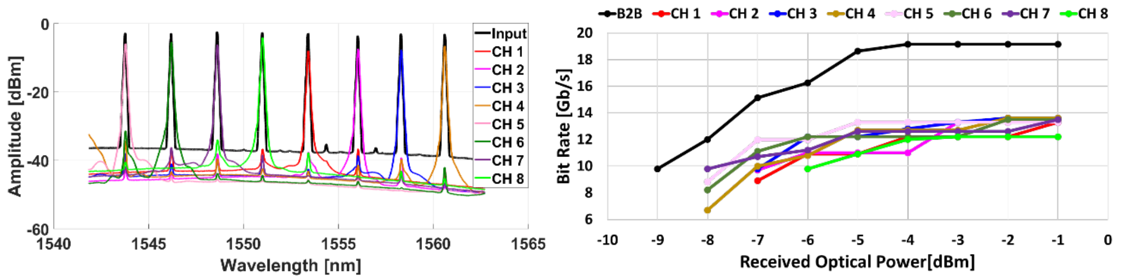

Fig. 4: Optical spectra of the WDM channels switched by the WSS (left). Highest bit rate achievable as a function of received optical power for each channel for DMT modulated traffic (right).

The optical power at the chip output per channel was around -6 dBm. Considering 6 dB/facet coupling losses, 8 dB on chip gain is estimated. In Fig. 4 (right) are reported the curves of the highest bit rate achievable as a function of the received optical power for each channel for DMT modulated traffic. The curve for the back-to-back is also reported as reference. For each received power value the algorithm that generates the DMT traffic firstly estimates the transmitting conditions of the physical channel in terms of signal-to-noise ratio (SNR). After determining the SNR the algorithm loads the bit stream at the highest bit rate that would guarantee a certain target value for the bit error rate (BER) of the received bit sequence. The target value for the BER chosen in order to consider the received signal error-free was 3.4 x 10^{-3}. These curves show that for the best performing channel, CH 5, is possible to achieve a bit rate as high as 12 Gb/s with a limited power penalty of 1 dB with respect to the back-to-back case. Within a 3 dB power penalty interval the bit rate can increase to 13 Gb/s for channel 5. As for the rest of the channels, the poor performance could be attributed to the noise accumulated on chip as a result of having multiple SOAs in cascade. This noise deteriorates the OSNR of the optical carrier and hence the performance of the switching module for higher bit rates.

Conclusions

In this work we characterized a photonic integrated 1x8 (8 channels) WDM wavelength selective switch module using a bit rate adaptive modulation format of the such as DMT. The experimental assessment showed the potential of the photonic chip to switch WDM signals in the wavelength domain with less than 1 dB penalty for data rate up to 12 Gb/s at BER = 3.4 x 10^{-3}. These results confirm the transparency of the SOA-based optical switching towards adaptive modulation formats optimized for different transmission channel conditions.

References

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