Experimental Assessment of C- and L-band Photonic Integrated SOA-based-1x8 Wavelength Selective Switch

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Abstract *We experimentally assess C-and L-band photonic integrated 1x8 Wavelength Selective Switch (WSS) based on SOA switches/amplifiers. The C-and L-band channels exhibits crosstalk of -22dB and -20dB, on-chip amplification of 26dB and 23.5dB, and 10Gbps NRZ-OOK error-free operation with 1.5dB and 2.5dB power penalty, respectively.*

Introduction

The growth of IP traffic in metro and data centre interconnect scenarios has led to the development of new optical systems covering multiband transmission (MBT) operation beyond C-band to support this demand [8]. To manage optical network traffic, a wideband reconfigurable optical add-drop multiplexer (ROADM) is required [1], which relies on a wavelength selective switch (WSS) to function. Consequently, the development of WSSs operating in the C+L band is crucial. Photonic Integrated WSSs offer a promising low-cost alternative for edge access or networks located closer to the end consumer, where multi-degree optical mesh connectivity is less critical [1,2]. WSS based on microring resonators with tuneable capabilities to operate in the C- or L-band have also been reported [3], but active monitoring and tuning is necessary.

The initial iteration of our developed chip exhibited WDM functionality only in the C-band [4]. In this manuscript, we introduce an enhanced version of the chip, referred to as the second generation. We report a photonic integrated SOA based 1X8 WSS for fast switching and amplification, operating on the C- and L-Band. Experimental results show that the 400 GHz channel spacing WSS has an average extinction ratio of 40 dB, on chip gain of 26dB and 23.5dB for C- and L-band respectively, and BER below 1×10^{-9} at both bands at bit rate of 10 Gbps.

Photonic WSS Architecture and Fabrication

The PIC WSS architecture is shown in Fig 1a. The chip architecture features a single input port that branches into eight WDM modules or WSS, each of which has eight output ports. Each WDM module processes eight channels spaced 400 GHz apart. As all the module are the same copy, for our discussion, we will focus on the 6th WDM PIC switch module located at the 6th output port from the top. The module includes an SOA booster amplifier, followed by an AWG demultiplexer that separates the WDM channels, and an array of SOAs. A second AWG serves as a multiplexer. In total, the module includes three cascaded multimode interference (MMI) splitters that split the input signal to feed other WSS modules on the chip, and one MMI on the input port and one MMI on the output port for alternative routing. Therefore, each channel of every WDM module contains one booster SOA, one gate SOA, five MMIs, and 2 AWGs, from input to output.

This photonic technology is based on SOAs to provide nanosecond switching for statistical multiplexing, loss-less operation, high contrast ratio and low channel cross-talk. The PIC can select one or multiple wavelength channels and forward the channels to the output ports according to the switching control signals. Turning ON/OFF the SOAs determines which wavelength channel is forwarded to the output or is blocked. The broadband operation of the SOAs enables the operation with any wavelength, whereas the cyclic AWGs allow the PIC to work in dual band. Moreover, the amplification provided by the SOA compensates the loss introduced by the two AWGs and five MMIs.

The designed chip is InP material-based wafer and all 8 WSS together occupies the space

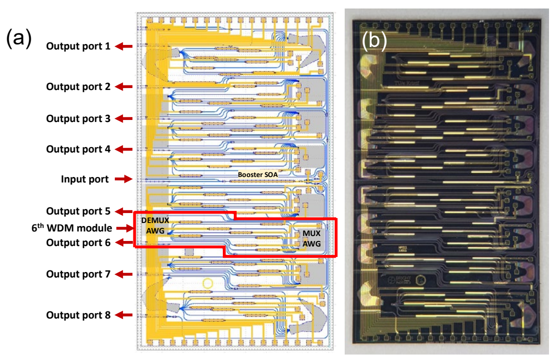

Fig. 1: (a) WSS chip layout, (b) fabricated WSS chip

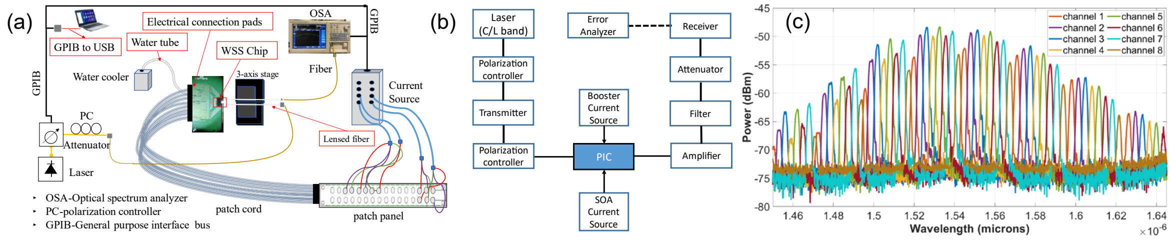

Fig. 2: (a) Experimental setup for the WSS chip characterization, (b) Bit-Error-Rate measurement setup, (c) Multiplexer AWG channels through SOA-gate-ASE

of two generic InP cells, with each cell measuring 4.6×4 mm². This means that each WSS module occupies one-fourth of a single cell. The chip was fabricated by the SMART Photonics foundry. Fig.1b shows the fabricated chip.

Experimental setup

A testbed has been set-up as shown in Fig. 2a for experimental assessment of the switch. The switch is mounted on a water-cooled heat sink and operated at 20°C to stabilize the chip temperature. Fiber to chip coupling was performed using lensed fibers. The alignment was performed via two three-axis stages with two lensed fibers used to couple the light from the laser to the chip or from it to the optical spectrum analyser. A polarization controller was used before the chip input to tune the polarization. PCB which is connected to a multichannel current controller to switch on/off the SOAs. The characterization was performed using a tuneable laser at wavelengths ranging from C to L band with 0 dBm optical power.

Circuit level characterization

The 8 channels of the AWG at port 6 were measured individually and the combined representation is showed in Fig 2b. The AWG provides channel separation of 3.2 nm, with a 3 dB bandwidth of 1.9 nm and 2 nm for the C- and L-bands, respectively. The crosstalk for the two bands is -22 dB and -20 dB.

Next, we have investigated the switching performance of the WSS output port 6. Figure 3 shows the switching states of all 8 channels of the WSS both in C and L band. It is visible that both C and L band provides an average extinction ratio of 40 dB. In terms of optical signal to noise ratio, C-band provides an average of 30 dB and L-band provides an average of 35 dB OSNR. Similar performance have been measured for the other AWGs of the other output ports as well.

The WSS channel peak powers in the C-band range from -15 dBm to -6 dBm. In each optical path, the five 1X2 MMIs result in a loss of 17.5dB, while 2 AWGs cause a loss of 6dB, and the link

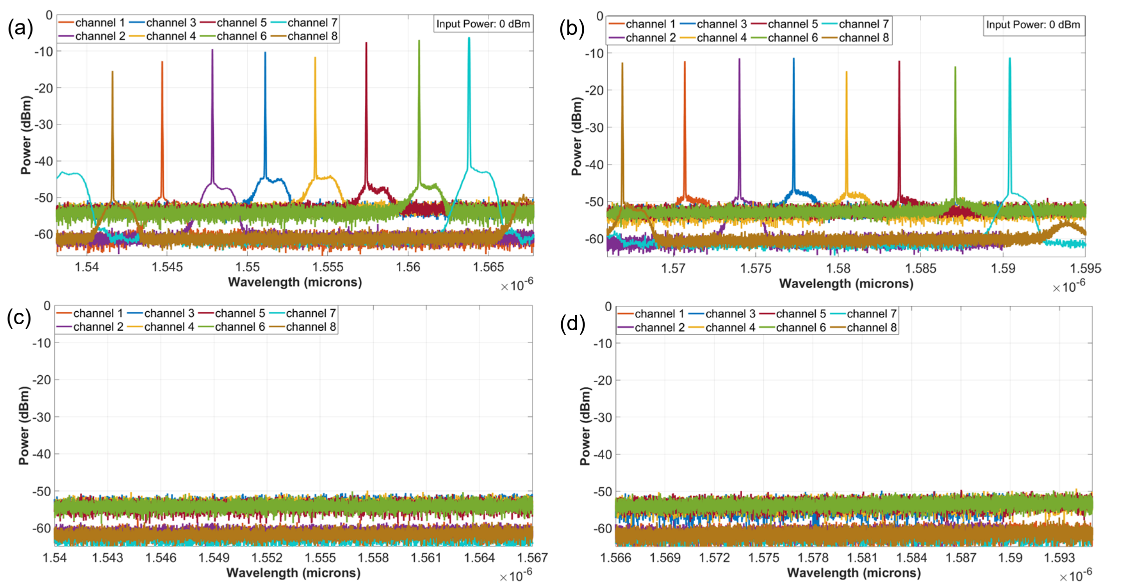

Fig. 3: Switching operation of the WSS (a) C-band channels switched ON, (b) L-band channels switched ON, (c) C-band channels switched OFF, (d) L-band channels switched OFF

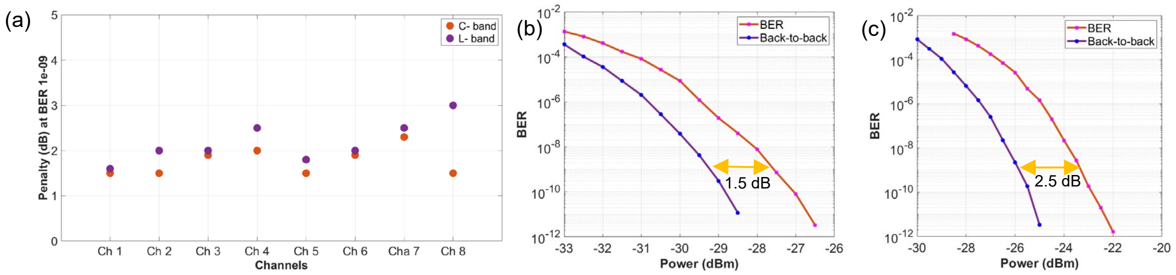

Fig. 4: Bit-Error-Rate measurements at 10Gbps NRZ-OOK: (a) power penalty at BER 1e-09 (b) C-Band BER Performance for Representative Channel and (c) L-Band BER Performance for Representative Channel

and bends contribute 1dB of loss, totalling 24.5dB of on-chip loss. Additionally, input and output coupling losses account for approximately 12dB loss. Therefore, the total loss per channel due to all these factors is around 36.5dB. The SOAs (booster and gate) provide approximately 21.5 to 30.5 dB of gain, which compensates for the on-chip losses when the input power is 0 dBm. Similarly, in the L-band, the peak power ranges from -15 dBm to -11 dBm, and the SOAs provide around 21.5 to 25.5 dB of gain to compensate for the on-chip losses.

System level characterization

For system level characterization, a measurement setup was built to transfer data through the WSS PIC and analyse the transmission. The experimental setup depicted on Fig. 5(a) was aimed to assess the bit-error-rate (BER) for the C and L-band channels. In this setup a continuous wave (CW) source was followed by a PC used to control the SOP to the input of the electro-optic-modulator (EOM), which by in turn was driver a pattern generator with a $2^{31} - 1$ pseudo-random binary sequence (PRBS). Fig. 4 shows the BER measurement results for C- and L-band channels where the power penalties are 1.5 dB and 2.5 dB, respectively. The power penalties are mainly caused by the ASE of cascaded SOAs which degrades the OSNR.

Fig. 5 depicts the WDM switching operation of all eight channels together, with random channels turned on and off simultaneously to demonstrate the switching behaviour. On average, the WDM channels exhibit an ON/OFF ratio of approximately 40 dB, and there is an average crosstalk of 36 dB between the channels.

Conclusions

We developed and demonstrated a photonic integrated 1x8 WSS with 8 channels operating on the C- and L-bands. The WSS achieved an average extinction ratio of 40 dB, 30 dB OSNR, 400 GHz channel spacing, and error-free transmission at 10 Gbps on both bands.

Acknowledgements

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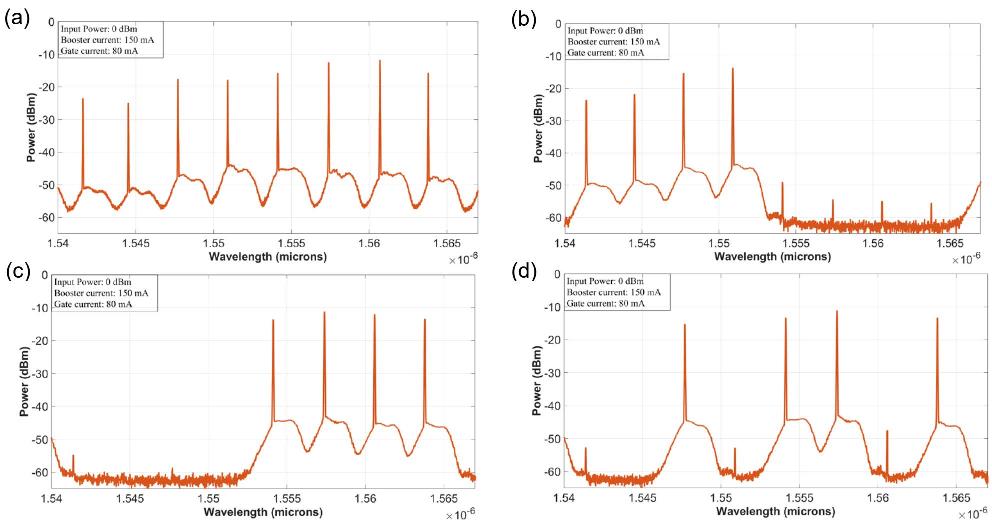

Fig. 5: Simultaneous switching operation of the WSS in C band: (a) all the channels are in ON state, (b) channel 2,3,4 and 5 are in ON state, (c) channel 6,7,8 and 1 are in ON state, (d) channel 2,4,5 and 7 are in ON state

References

[1] B. C. Collings and P. Roorda, “ROADM-based networks,” in Optically Amplified WDM Networks, Elsevier, 2011, pp. 23–45.

[2] Y. Ikuma, T. Mizuno, H. Takahashi, T. Ikeda, and H. Tsuda, “Low-loss integrated 1×2 gridless wavelength selective switch with a small number of waveguide crossings,” in Proc. ECOC 2012, p. Tu.3.E.5.

[3] P. Prabhathan et al., “Discrete and Fine wavelength tunable thermo-optic WSS for low power consumption C+ L band tunability,” IEEE Photonics Technol. Lett., vol. 24, 152–154, 2012.

[4] K. Prifti, A. Gasser, N. Tessema, X. Xue, R. Stabile and N. Calabretta, "System Performance Evaluation of a Nanoseconds Modular Photonic Integrated WDM WSS for Optical Data Center Networks," 2019 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 2019, pp. 1-3.

[5] N. Calabretta et al, “System Performance Assessment of a Monolithically Integrated WDM Cross-Connect Switch for Optical Data Centre Networks,” Paper W.2.F.3, ECOC 2016.

[6] Y. Ohsita et al., “Optical Data Center Networks: Architecture, Performance, and Energy Efficiency”, Springer (2015).

[7] W. Miao et al., “Towards Petabit/s All-Optical Flat Data Center Networks Based on WDM Optical Cross-Connect Switches with Flow Control,” J. Lightw. Technol., vol. 34, no. 17, pp. 4066-4075 (2016).

[8] N. Sambo et al., “Provisioning in multi-band optical networks: A C+L+S-band use case,” J. Light. Technol., p. 4, 2020.

[9] A. Ferrari et al., “Assessment on the achievable throughput of multi-band ITU-T G.652.D fiber transmission systems,” J. Light. Technol., p. 14, 2020.

[10] K. Seno, K. Yamaguchi, K. Suzuki, and T. Hashimoto, “Wide-passband C+L-band wavelength selective switch by alternating wave-band arrangement on LCOS,” p. 3.