26th Optoelectronics and Communications Conference (OECC)
2021 © OSA 2021

Broadband Polarization Insensitive 1x8 WDM Multi-Cast Switch and Amplifier for Optical Networks

Aref Rasoulzadeh Zali[1], Netsanet M. Tessema[1], Kristif Prifti[1], Steven Kleijn[2], Luc Augustin[2], Ripalta Stabile[1], Nicola Calabretta[1]

[1]IPI-ECO research institute, Eindhoven University of Technology, Eindhoven, the Netherlands
[2]Smart Photonics, High Tech Campus, Eindhoven, the Netherlands
E-mail: a.rasoulzadehzali@tue.nl

Abstract: We have experimentally demonstrated a 1x8 WDM polarization-insensitive multicast switch based on bulk SOAs. Results show net gain of 11dB, broadband and error-free operation with 0.55dB power penalty at 10GBps NRZ-OOK, and crosstalk <-39dB. © 2021 The Author(s)

1. Introduction

Boosted by 5G, IoT, and Big Data applications, data traffic and scale out of data center are steadily increasing. With the aim to satisfy the scalable growth in both network traffic volume and connected endpoints while decreasing the cost and the energy consumption, transparent optical DC networks (DCNs) based on fast optical switches have been investigated which could provide high bandwidth and agile (nanosecond) reconfigurability [1-3]. Several optical switch architectures have been presented. An example of a modular N×N optical switch [2] is shown in Fig. 1(a). The switch consists of N 1xN multicast and select switches (MCSS) modules, which broadcast the signal to the N possible outputs and use N optical gates to select at which of the N outputs the signal will be forwarded, and N 1xN power combiners. Practical implementation would require the photonic integration of hundreds or even more of optical passive-active components, such as splitters, optical gates, and optical amplifiers to compensate the broadcast losses. Compact, broadband, polarization-insensitive WDM MCSS and amplification based on SOAs can be realized on the InP platform owing to the passive-active co-integration process. It involves the co-integration of active SOAs with several passive elements such as straight/bend waveguides and multimode interferometers (MMIs) which functions as power splitter/couplers. Polarization-insensitive (PI) operation of MCSS is an important feature as the incoming signals to the different ports of the optical switch have no predefined polarization state, as well as the switch can support dual-polarization modulation formats to increase the capacity of the network. Up to now, few MCSSs based on SOAs have been reported in both monolithic and hybrid platforms [3-4], but no polarization-independent operation of the MCSS based on bulk SOAs has been demonstrated. Fabrication of MCSS based on bulk SOA is robust and easier, also the designed bulk SOAs are polarization insensitive in wide range of current and wavelength which makes them superior to their counterparts such as MQW and QD SOAs [5-7].

In this paper, we have designed, fabricated, and characterized a monolithically integrated broadband and polarization-insensitive 1×8 WDM multicast and select switch with net gain based on bulk SOAs which is suitable for optical packet switching systems. Results show that the MCSS has a net gain of 11dB with very low PDG (<0.5dB) and cross talk (<-39dB). Besides data transmission analysis shows an error free operation with power penalty of 0.55dB at 10Gbps NRX-OOK data.

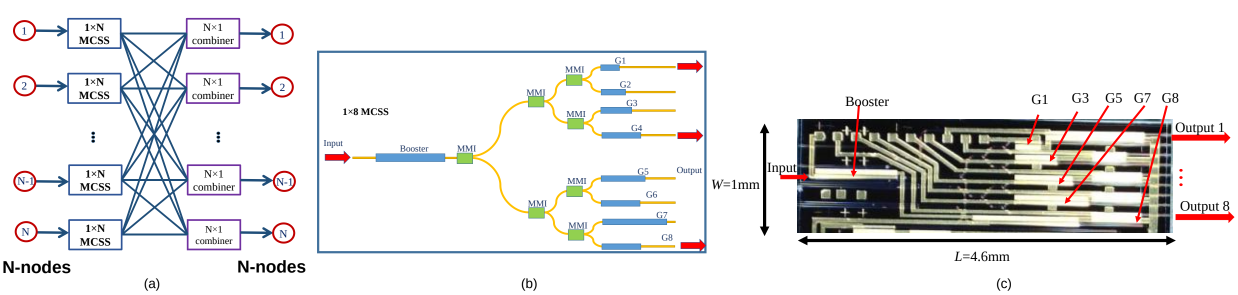

Fig.1. (a) Broadcast and select N×N photonic switch architecture. (b) Schematic of the 1×8 MCSS, (b) Fabricated sample of MCSS.

2. Broadcast and select switch design and fabrication

The schematic of the 1x8 WDM MCSS is shown in Fig. 1(b). It consists of nine active SOAs which one performs as booster and the other eight SOAs act as optical gates. MMIs functions as power splitter/combiner and connects the booster to the gates with passive straight and bended waveguides. The input signal gets amplified in the booster, then the power of the amplified signal is splitted and fed into the eight SOA gates through three stages of cascaded 1×2 MMIs. At each of the eight SOA based gate, the optical signal can pass or is blocked based on the ON/OFF applied current. We have fabricated the 1×8 MCSS in InP platform based on different building blocks including passive shallow/deep waveguides, shallow/deep multimode interferometers, bulk semiconductor optical amplifiers, and shallow to deep transition (or deep to shallow) tapered waveguide. To fabricate low PDG SOA, the layer stack consists of an unstrained InGaAsP surrounded by symmetric cladding layers of Q1.25. The passive waveguides connected to the SOAs and MMIs are deep-etched waveguides with 1.5μm width. S-bends with radii larger than 100um connects the cascaded MMIs. The shallow to deep tapered waveguide is used to connect active SOA element to passive waveguides. The detail of the fabrication process is given in Ref [6]. The fabricated MCSS with size of 1mm×4.6mm is shown in Fig. 1(c). The length of the SOA gates varies between 300um and 900um to investigate the performance of the MCSS with different SOA lengths in terms of output optical power, broadband and polarization insensitive operation. The light-yellow electrodes are routed by gold metal tracks and then wire bonded to mounted PCBs. The chip facets are antireflection coated to avoid reflections which deteriorate the SOAs performance. Tapered lensed fibers are used to couple the light into and out of the chip.

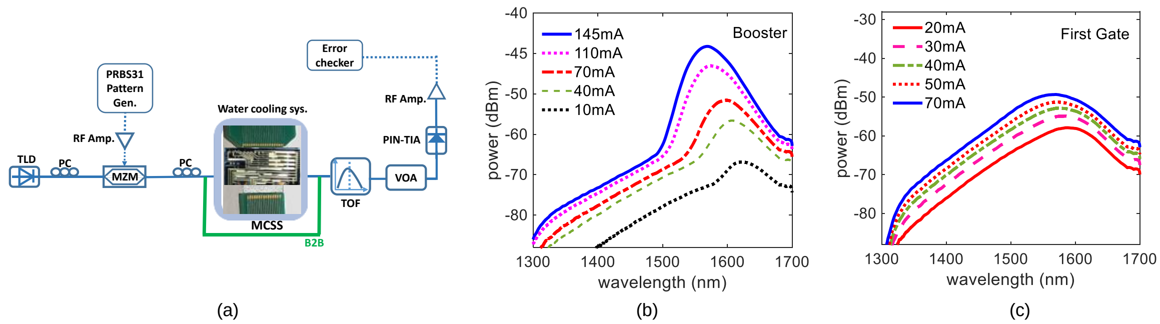

Fig. 2. (a) Experimental setup. TLD: tunable laser diode; PC: polarization controller; MCSS chip, TOF: tunable optical filter, VOA: variable optical attenuator. (b) ASE spectrum of the booster, and (c) first gate with a length of 300 μm.

3. Characterization results and discussion

The experimental setup to characterize the MCSS is shown in Fig. 2(a). It consist of a tunable laser modulated by a Mach–Zehnder modulator (MZM) to generate a non-return-to-zero (NRZ) on–off keying (OOK) optical data signal at 10 Gbps with $2^{31}-1$ pseudo-random bit sequence (PRBS31). A polarization controller before the MCSS chip is used to change the polarization state of the light and test the polarization insensitive operation. The optical power of the modulated signal that enters the MCSS is 0 dBm. Watercooling system is used to control and stabilize the chip temperature at 20°C. Fig. 2(b) and (c) shows the amplified spontaneous emission (ASE) spectra for the booster and one of gate SOAs, respectively, with a blue shift of the peak wavelength when the bias current increases due to the band-filling effect. Based on ASE profile the spectral profile of the first gate is around 70 nm which shows that the switch efficiently covers almost the C- and L-band and could be used in both communication bands. Similar performance have been measured for the other SOA gates.

Fig. 3(a) shows the total gain of the MCSS through first gate (output 1) biased with 70mA of current. By increasing the booster current from 40mA to 120mA, the MCSS net gain increases from -8dB (loss) to 11 dB. Beyond 100mA, the gain saturates at around 11dB. Fig. 3(b) shows the polarization-dependent gain (PDG: defined as the difference between TE- and TM-mode net gain) versus booster current (current of the gate is set to 70 mA). The PDG level is less than 0.5 dB for a broad range of booster currents. This is very promising to realize transparent and polarization-insensitive optical switches based on cascaded of MCSSs as the one shown in Fig 1(a). Similar gain performance and PDG is reported for the other gates (outputs). These results confirm the good performance of the polarization insensitive MCSS with amplification indicating the potential to further scaling out the MCSS port numbers and the operation at higher data rates and different modulation formats.

The contrast ratio, defined as difference between ON and OFF state of the optical gates, is measured for each output port. Under static measurements, Fig. 3(c) shows the contrast ratio and optical signal to noise ratio (OSNR) for each output port when the SOA booster is biased with 95mA of current. The average contrast ratio is around 44dB which depends on the SOAs length and bias current that impact on the absorption (OFF-state) and amplification (ON-state) of the input signal. Specifically, the output 8 has the highest contrast ratio of 51dB (bias current of the gate 8 was 100 mA) and output 2 has the minimum contrast ratio of 39 dB (bias current of gate 2 was 100 mA). The corresponding (OSNR) values for each output varies between 53dB (for output 1) to 46dB (for output 5).

To quantify the performance of the MCSS, the BER curve at the output port 8 of the MCSS was measured and reported in Fig. 3(d). The back-to-back (B2B) BER curve is also reported as reference. Error-free operation with power penalty at 1E-9 BER less than 0.55 dB for both gate currents of 120mA and 100mA. Finally, Fig. 3(e) shows the power penalty at 1E-9 BER for wavelengths in the range of 1560nm to 1600nm by applied bias current of 100mA and 90mA for the optical gate 8 and the booster, respectively. The power penalty for wavelength shorter than 1580nm is less than 1dB. Beyond 1580nm the penalty increases, and at 1600nm the power penalty is 2.45dB.

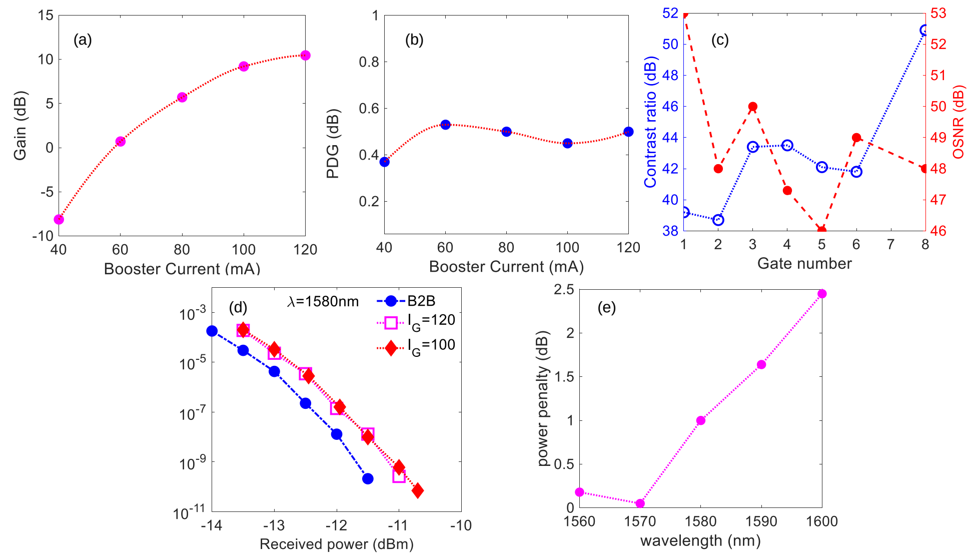

Fig.3. (a) The net gain of MCS chip versus booster current for output 1; (b) The PDG of MCS chip versus booster current; (c) Contrast ratio between ON and OFF states (left axis) and OSNR (right axis) for each gate by assuming booster current is around 95mA; (d) BER curves for two current of 120mA and 100mA at 1580nm and input power to the chip is 0dBm; (e) power penalty @ 1E-9 BER (by applying 10Gbps NRZ-OOK bitrates modulation) versus wavelength and the input power is -5dBm.

4. Conclusions

We have designed, fabricated, and characterized a broadband polarization insensitive 1x8 photonic integrated MCS switch with net gain on the InP platform based on bulk SOAs. Experimental results confirm that the MCSS shows very low polarization sensitivity less than 0.5dB and suitable gain of 11dB at booster current of 120mA. The contrast ratio at the different output ports varies between 39dB and 51dB. Besides, high OSNR values, recorded at the output ports, are in the range from 46dB to 53dB. BER test measurements at 10GBps confirm error-free operation with power penalty at 1E-9 BER varying from of 0.55dB (at 1560 nm) to around 2.5dB at 1600nm. Those results are promising to scale the MCS to a larger port count and to operate at higher data rates to realize high capacity datacom and telecom optical switches.

This work has been supported by the European ICT project QAMeleon, contract No. 780354, an initiative of the Photonics Public-Private Partnership (PPP), funded under Horizon 2020.

5. References

[1] Tessema, N. et al. "Compact InP Wavelength Blocker based on a Single AWG and SOA gates for Metro Networks" 22nd International Conference on transparent optical networks (ICTON), Italy 2020.
[2] Ramaswami, R. et al. "Optical networks: a practical perspective." Morgan Kaufmann, third edition 2009.
[3] Tanaka, Sh., et al. "Monolithically integrated 8: 1 SOA gate switch with large extinction ratio and wide input power dynamic range." IEEE journal of quantum electronics 45.9 pp-1155-1162, 2009.
[4] Gustavsson, M. et al. "Monolithically integrated 4* 4 InGaAsP/InP laser amplifier gate switch arrays." Electronics Letters 28.24, pp-2223-2225, 1992.
[5] Morito, K. et al. "High-output-power polarization-insensitive semiconductor optical amplifier." Journal of Lightwave Technology IEEE, 21.1 pp-176-181, 2003.
[6] Zali, A. et al. "Low polarization-sensitive semiconductor optical amplifier co-integrated with passive waveguides for optical datacom and telecom networks", Proc. 22nd European Conference on Integrated Optics, 2020.
[7] Zali, A. et al. "Low Polarization Dependent MQW Semiconductor Optical Amplifier with Tensile-Strained-Barrier Design for Optical Datacom and Telecom Networks", 22nd International Conference on transparent optical networks (ICTON), Italy 2020.