Polarization Insensitive Photonic Integrated 1x4 WDM Wavelength Selective Switch for Optical Networks

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Abstract: We experimentally demonstrate a 1x4 WDM polarization-insensitive wavelength selective switch based on bulk SOAs co-integrated with AWGs. Results show a net gain, broadband, and error-free operation with 0.6 dB power penalty up to 25Gbps NRZ-OOK. © 2022 The Author(s)

1. Introduction

Nowadays, the demand for high bandwidth optical networks and the growth of the data center industry are boosting the dramatic expansion of world connectivity via exchanging data. Providing high bandwidth and agile reconfigurability, optical switching systems, as a main dynamic optical connection element, have a crucial role in high-performance network applications. Inside metro-access networks, electronic switch technology executes the data packet aggregation and switching function but at the cost of latency and jitter, protocol-dependent operation, and high power consumption required for O/E/O conversion. Therefore, all-optical switching technology emerged, proposing low latency and jitter, low power consumption, high bandwidth, and data rate and data format-independent functionality. To improve the transparency and performance of the optical networks, wavelength selective switches (WSS) based on LCOS (liquid crystal on SI) and MEMS (Micro-ElectroMechanical Systems) are considered [1-3]. However, they are bulky and costly, and the reconfiguration time is in the order of milliseconds. Photonic integration can help to reduce the reconfiguration time to the order of nanoseconds by using SOAs as an active switching element [3-5]. Several works on PIC WSS have been proposed [3-4]. The main challenge is that these switches are polarization sensitive and do not have the same gain/loss for TE- and TM- modes; mainly, they work only for one polarization [3-4]. In this work, we designed, fabricated, and characterized a novel polarization-insensitive (PI) lossless photonic integrated 1x4 wavelength selective switch with 200GHz channel spacing as the main building block to realize a reconfigurable optical add-drop node. The main building blocks of the switch are the PI bulk semiconductor optical amplifier (SOA) co-integrated with PI AWGs to transparently forward and/or drop (with nanosecond reconfiguration time) the modulated data on multiple WDM channels over a broad wavelength band. Due to SOA's optical gain, SOA compensates for the in-line fiber losses and on-chip losses and can equalize the channels' optical power. Experimental results show a net gain, broadband operation, and error-free operation with 0.7dB power penalty up to 25Gbps NRZ-OOK. The architecture of the photonic integrated 1x4 WSS is illustrated in Fig 1. It includes a set of multimode interferometers (MMIs) that broadcast the signal to four wavelength blockers (WBLs). Each WBL consists of two AWGs acting as multiplexers, demultiplexers, and SOAs as active and switching elements between two AWGs. The first 1x8 AWG operates as a wavelength demultiplexer. Eight SOAs act as switching elements, and turning on and off each of them, determines which channel can pass (SOA ON) the WBL or be blocked (SOA OFF). Moreover, the SOA's gain compensates for the insertion loss of two AWGs. The outputs of the WBLs can pass through or be dropped inside the add-drop node.

2. Wavelength Selective Switch Design, Fabrication, and characterization

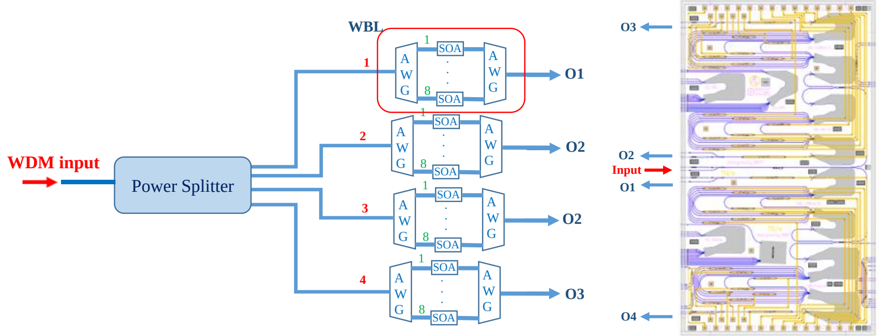

Fig.1. (a) The schematic view of the PIC 1x4 WSS (left). GDS of the PIC (right). The input and outputs are depicted in the figure.

The architecture of the photonic integrated 1x4 WSS is illustrated in Fig 1. We have fabricated a 1 x 4 wavelength selective switch that can be realized on the InP platform owing to the passive-active co-integration process and based on different building blocks. It involves the co-integration of active SOAs with passive elements such as waveguides (straight/bend), polarization insensitive arrayed waveguide gratings (AWGs) which function as a multiplexer and demultiplexer, and MMI power splitters/couplers. The GDS of the fabricated chip is also shown in Fig. 1. It is important to note that to fabricate low PDG SOA, a layer stack consisting of an unstrained InGaAsP surrounded by symmetric cladding layers of Q1.25 is designed. This design can provide polarization-insensitive gain in broadband covering C- and L-band [6-8]. The passive waveguides connected to the SOAs and MMIs are deep-etched waveguides with 1.5 µm width. The tapered (shallow to deep) waveguide connects active SOA elements to passive waveguides. The fabricated PIC WSS has a size of 8 mm×4.6 mm. The booster and gate SOAs have lengths of 1000 µm and 500 µm, respectively. The light-yellow gold metal electrodes are routed by metal line tracks wire bonded to mounted PCBs. To avoid any unwanted reflection, the chip facets are antireflection coated. To couple, the light into and out of the chip tapered lensed fibers are used.

The experimental setup to characterize the WSS is illustrated in Fig. 2(a). It consists of a tunable laser that provides a coherent optical field and a polarization controller to change the polarization state of the light entering the chip. The lensed fiber directs and couples the optical signal to the chip. With a current source, the booster and gate SOAs are DC-biased. First, the static characterization of the chip is performed. Fig. 2(b) shows the amplified spontaneous emission (ASE) spectra for the booster SOA. Due to the band-filling effect blue shift of the peak wavelength occurs when increasing the bias current. Based on the ASE profile, the spectral net gain profile of the booster is around 60 nm which shows the switch efficiently covers almost the C- and L-band and could be used in both communication bands.

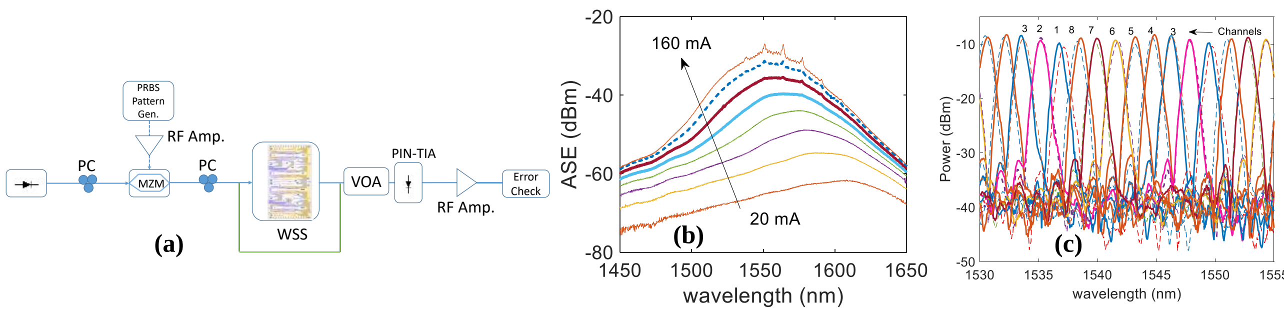

Fig. 2. (a)The characterization setup. TLD, tunable laser diode; PC, polarization controller; VOA, variable optical attenuator. The B2B is shown with a green line in the setup. (b) ASE spectrum of the booster SOA and (c) Transmission power spectrum through eight channels of AWG.

In Fig. 2(c), the spectrum of one of the AWGs with 200 GHz channel spacing (and a free spectral range of eight times the channel spacing) is shown for both TE- and TM-mode. Based on this figure, AWG shows a low polarization-dependent operation for all eight channels. The maximum polarization dispersion is around 0.4 nm. The insertion loss of the AWG is 3-4 dB.

To characterize SOAs, Fig. 3(a) shows the ON state (when both booster and gate SOAs are on and biased at 100 mA) and OFF state (when the gate SOA is OFF) for TE- and TM-mode for channel 2 from output 1 (O1). It shows the polarization-dependent gain (PDG) is less than 0.5 dB. This low PDG is promising for designing transparent and polarization-insensitive optical switches based on cascaded polarization-independent AWGs and SOAs. The average extinction ratio is around 50 dB which depends on the SOAs quality in absorbing (OFF-state) and amplifying (ON-state) the input signal. For the sake of space limitations, we only report the results of one gate; a similar operation was measured for the other channels. To quantify the performance of the WSS, the BER curves at the output of the first port of the WSS have been measured and reported in Fig. 3. The experimental setup is shown in Fig. 2(a). The pattern generator generates a non-return-to-zero (NRZ) on-off keying (OOK) electrical signal at 10 Gbps and 25 Gbps using a $2^{31}-1$ pseudo-random bit sequence. The Mach–Zehnder modulator (MZM) modulates the optical carrier signal at 1548.5 nm, and the output signal enters the WSS input waveguide. The BER curve in the back-to-back (B2B) case is reported as a reference. Figure 3(b) shows that the BER curve for both TE and TM-mode matches, confirming the polarization-insensitive operation of the WSS switch. For bitrates up to 25 Gbps, error-free operation with a power penalty of less than 0.6 dB is achieved when both gate and booster SOAs are biased at 100mA, c.f. Fig. 3(b) and (c).

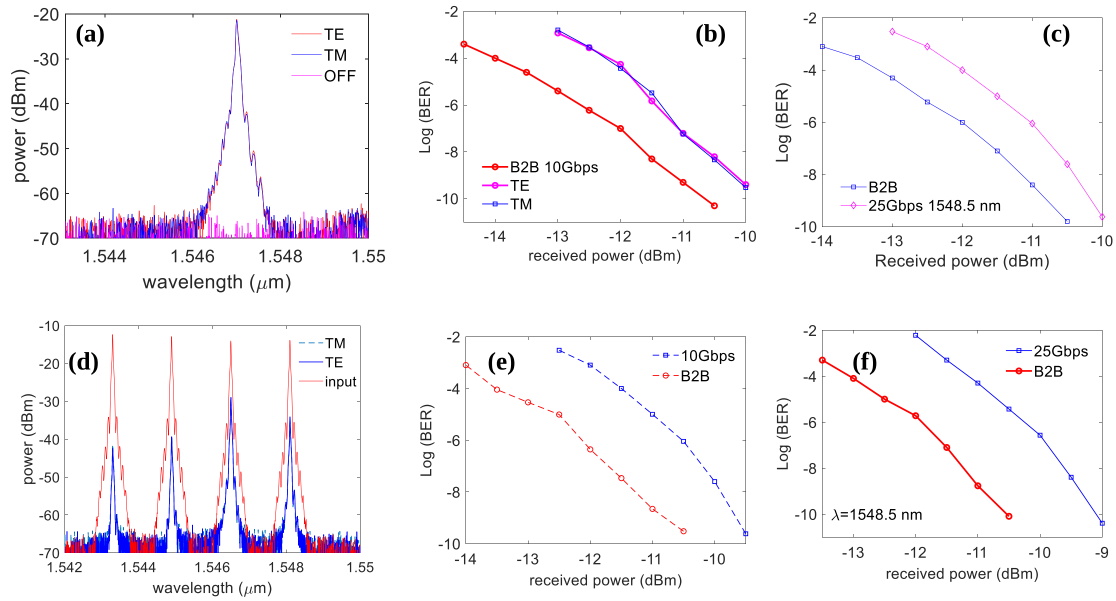

Fig.3. (a) The power spectrum for channel 2 of O_1 for TE- and TM-mode. The OFF state is also shown in this figure. (b) The BER curves for TE- and TM-mode at 10 Gbps for the corresponding channel (for gate and booster current of 100 mA). (c) The BER curves for TE-mode at 25 Gbps for the corresponding channel. (d) Four wavelength input to the chip and corresponding output from O_1 when only channel 2 is ON. (e) and (f) correspond to 10 Gbps and 25 Gbps BER curves, assuming four wavelengths coupled to the chip.

Moreover, to investigate the switch response to the WDM signal, we consider four optical wavelengths spaced 1.6 nm, from λ1 = 1545.3 nm to λ4 = 1550.1 nm, coupled to the chip. Using the amplitude modulator, the WDM input signal is modulated up to 25 Gbps with NRZ OOK pattern. The data transmission bit error rate test for 10 Gbps and 25 Gbps show error-free operation with a power penalty of less than 1 dB and 1.5 dB, respectively (at a carrier optical wavelength of 1548.5 nm). The measured power penalty can be attributed to the in-band spontaneous emission noise produced by both SOAs and mismatches in the transmission spectrum of AWGs. These data transmission results demonstrate the excellent performance of the polarization-insensitive WSS and pave the way for further investigation and scaling up WSS port numbers.

Conclusions

We have designed, fabricated, and characterized a broadband polarization-insensitive 1x4 photonic integrated WSS on the InP platform based on polarization-insensitive AWGs and bulk SOAs. Experimental results confirm that the WSS shows low polarization sensitivity of less than 0.5dB. BER test measurements at 10GBps and 25 GBps confirm error-free operation with a power penalty of 0.6 dB at 1E-9 BER. Furthermore, the modular architecture of the WSS allows port and wavelength scalable growth and hence node degree.

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5. References

[1] G. S. Zervas et al., “Multi-granular optical cross-connect: Design, analysis, and demonstration,” J. Opt. Commun. Netw., 1.1, pp. 69–84, 2009.
[2] S. Han, et al., “Large-scale silicon photonic switches with movable directional couplers,” Optica, 2.4, pp. 370–375, 2015.
[3] Prifti, Kristif, et al. "Lossless photonic integrated add-drop switch node for metro-access networks." IEEE Photonics Technology Letters 32.7 pp. 387-390, 2020.
[4] N. Tessema et al., “Modularly and hybrid integrated SiPh/InP wavelength blocker switch for metro networks,” in Proc. Eur. Conf. Opt. Commun., pp. 1–4, 2020
[5]Zali, Aref Rasoulzadeh, et al. "InP monolithically integrated 1× 8 broadcast and select polarization insensitive switch for optical switching systems." CLEO: Science and Innovations. Optica Publishing Group, 2021.
[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), 2020.
[8] Zali, Aref Rasoulzadeh, et al. “Design and Fabrication of Low Polarization Dependent Bulk SOA Co-Integrated With Passive Waveguides for Optical Network Systems.” Journal of Lightwave Technology 40.4, pp. 1083-1091. 2021.