Analysis of the 1×8 Monolithically Integrated InP Based Wavelength Selective Switch

Aref Rasoulzadeh Zali, Netsanet Merawi Tessema, Kristif Prifti, Ripalta Stabile, Nicola Calabretta

[1] IPI-ECO Research Institute, Eindhoven University of Technology, Eindhoven, the Netherlands

To cope with the exponential growth of the communication network traffic demand, programmable optical wavelength selective switches (WSS) with large bandwidth, speed, and flexibility have become key elements in optical Datacom and Telecom networks. The proposed WSS structure involves the co-integration of active and passive components on-chip. The optical signal power is distributed to multiple wavelength blockers (WBL) via an optical power splitter. WBLs consist of a Mach-Zehnder interferometer-based interleaver to separate the input WDM channels and an array of semiconductor optical amplifiers (SOA) which act as both optical gates and gain elements in order to achieve lossless operation. The arrayed waveguide gratings (AWG) function as multiplexers and de-multiplexers in the WBL structure. In this work, the system performance of the 1×8 WSS architectures has been numerically investigated. To this end, we have assumed 64-λ WDM input signal with 12.5 GHz spectral spacing and analyzed the WSS performance by studying the steady-state impulse response of hybrid time and frequency domain simulation.

Introduction

Large heterogeneous data traffics should be efficiently handled by next generation metro networks. To this end, technological and architectural innovations are required in the data center network in order to enable the exchange of traffic and scalable growth. In this respect optical switches are an essential technology due to their data-format transparency and data rate operation [1,2]. Optical switches provide an opportunity to avoid the need for high power consumption due to O/E/O conversions as well as format-dependent interfaces. Among the optical switches, the wavelength selective switches (WSS) are the main building blocks of reconfigurable optical add/drop multiplexers (ROADMs) [3-5]. The miniaturized WSS, which is monolithically integrated on chip, allows for a fast and compact switch at the same time. In recent years, a WSS with 4 wavelengths and a large channel spacing of 500 GHz has been experimentally demonstrated [3,4]. Nevertheless, in practical communication systems the system requires a large number of channels with a narrower channel spacing. To analyze and investigate the performance of the scaled dense WSS, one needs to carefully consider all optical and electrical aspects of the WSS components.

Our aim is to analyze and simulate the performance of integrated 1×8 WDM WSS (shown in Fig. 1(a)) which enables the control of 64 wavelengths with 12.5 GHz frequency slices (channel spacing). The WSS works in the C-band around 1550 nm and is designed based on the eight wavelength blockers (WBLs). Fig. 1 (b) shows that each of the wavelength blockers includes an interleaver stage and a circuitry for wavelength selection, as will be explained later. As depicted in Fig. 1(c), WBL includes a 1-to-8 wavelength (de-)multiplexer (de-interleaver) based on cascaded Mach-Zehnder interferometer (MZI) filters. The design of the MZI filter is based on a four-port filter building block which includes directional couplers [6]. Through cascading 3 stages of these filters, each of the 8 wavelengths can be routed to each output. The proposed MZI filter takes advantage of three stage filters which are designed to have a channel spacing of 12.5 GHz, 25 GHz, and 50 GHz, respectively. The first and second stages of the MZI filter make use of 3 and 2 directional coupler units. By proper design and control of the coupling coefficients of the directional couplers as well as the delay lines of MZI, one could realize 1 to 8 (de-)multiplexer to (de-)interleave the WDM signal [6]. The design details of the MZI filter (de-) multiplexer are extensively investigated in [6]. It is worth mentioning that while one may think of an AWG with 12.5 GHz channel spacing rather than MZI filter as a de-multiplexer in the WBL, an AWG with 12.5 GHz channel spacing occupies a large wafer space which is not a reasonable choice.

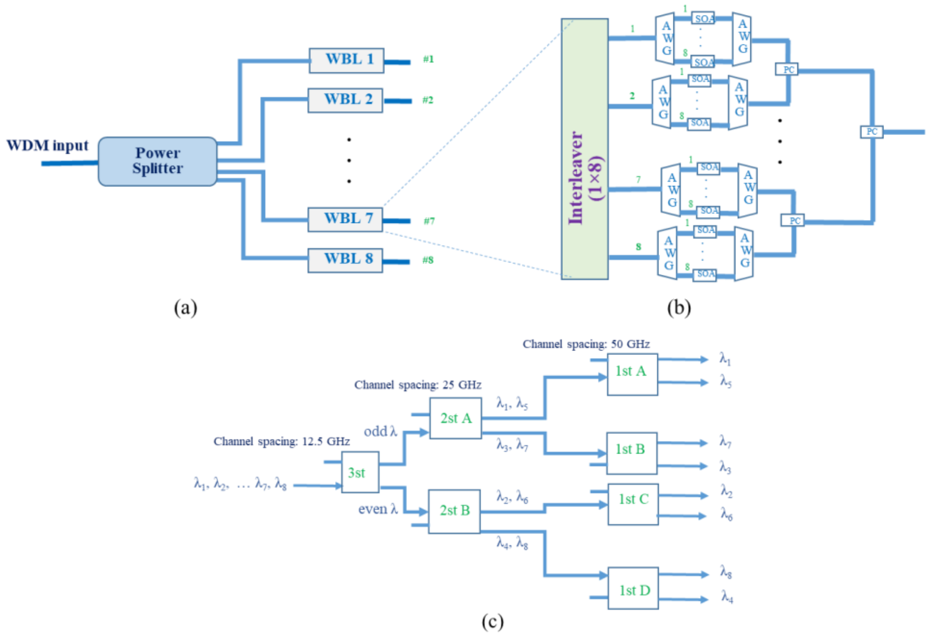
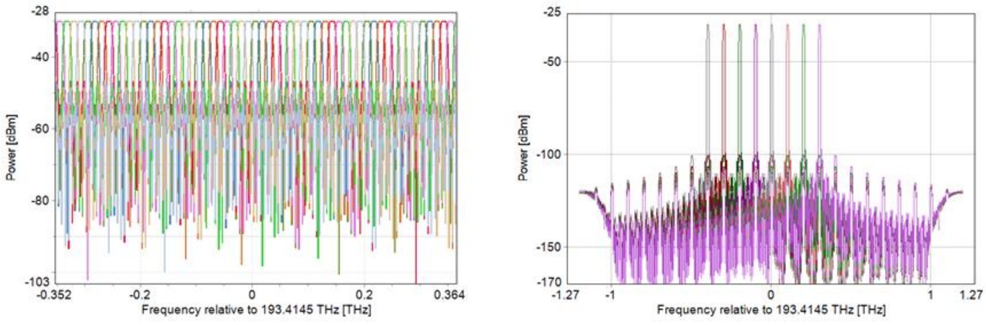


Fig. 1. (a) The structure of the wavelength selective switch (WSS), (b) internal structure of the 64-λ wavelength blocker (WBL), and (c) structure of the MZI interleaver which acts as a (de-)multiplexer and consists of three stages with different channel spacings written above the blocks in each column.

After interleaving the input optical signal to 8 outputs, we need two AWGs, c.f. Fig. 1(b); the first AWG acts as de-multiplexer (DeMUX) element to de-multiplex the input to 8 different wavelengths. Each of these wavelengths connects to current-driven SOA gates. Theses SOA gates will allow passage to the desired wavelength or block the undesired one. Moreover, the SOAs provide the opportunity to achieve switching times in the order of tens of nanoseconds which in turn allows for independent control of each spectral channel. After the array of SOAs, the second AWG acts as a multiplexer (MUX) for the wavelengths that have passed through. Subsequently, power combiners (PC) combine the power of the corresponding wavelengths. The channel spacing of the WBL is assumed to be 100 GHz and the free spectral range (FSR) of the interleaver should be the same.

Results and discussion

Each WBL includes one interleaver and a DeMUX/MUX stage. The interleaver section is composed of 11 directional couplers. The DeMUX/MUX section includes 16 AWGs with 64 SOAs (acting as gate switches) as well as power combiners. The large number of components in the WSS structure makes it difficult to simulate the function of the WSS efficiently in terms of time and reliability. Furthermore, composition of different active and passive elements such as like SOA, AWG, MZI filters, power combiners and power splitters makes the simulation more complex.



(a) (b)

Fig. 2. (a) The output power spectrum (all 8 outputs) of the interleaver (MZI filter). (b) The power spectrum of one output of the AWG in the WBL structure.

The active devices require sample by sample simulation in time domain so as to account for their nonlinear dynamics, whereas the passive devices should be simulated and described in frequency domain. Thus in this paper, the WSS performance is analyzed with the help of VPIphotonics simulator using the hybrid time and frequency domain approach.

Here we investigate one of the 8 WBL units which are indicated in Fig. 1(a). Following the splitter (splitting the power among 8 WBLs), the input power to each WBL is assumed to be -30 dBm. This is the input power at the MZI filter interleaver. Fig. 2(a) shows the output of the MZI filter interleaver. This stage de-interleaves the dense 12.5GHz spectral grid to 8 outputs with 100 GHz spectral spaces. Each of these outputs (from MZI filter) connects to one AWG and each AWG de-multiplexes each channel to 8 wavelengths with 100 GHz spacing. Fig. 2(b) shows the output of the AWG for the assumed WBL.

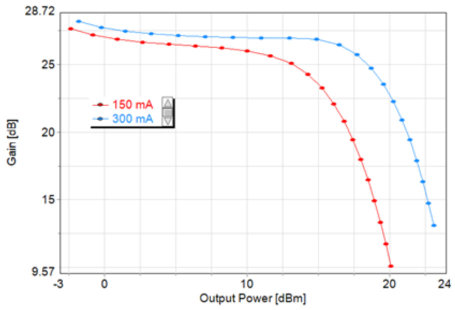


Fig. 3. Gain of 1mm length SOA vs. output power for two different bias currents.

The SOAs used in the WBL structure are 1mm long and driven with a pump current density of 6.25 kA/cm^2 (150mA) for the ON-state. Fig. 3 illustrates the gain characteristics of the SOA versus the output power for two different bias currents of 150 and 300 mA. It is clear that for the assumed bias current of 150 mA, the gain of the SOA remains constant (27 dB) in the linear regime of operation (before saturation). However for higher output powers it starts saturating. Based on this simulation, the saturation power of SOA is about 14 dBm. It is important to note that the switching is controlled electrically by applying an electrical current source to each SOA gate which enables the SOA to amplify the desired wavelength power. This amplification could compensate the losses originating from passive elements such as AWGs and star couplers, MZI filters and directional couplers, as that the coupling process is inherently lossy.

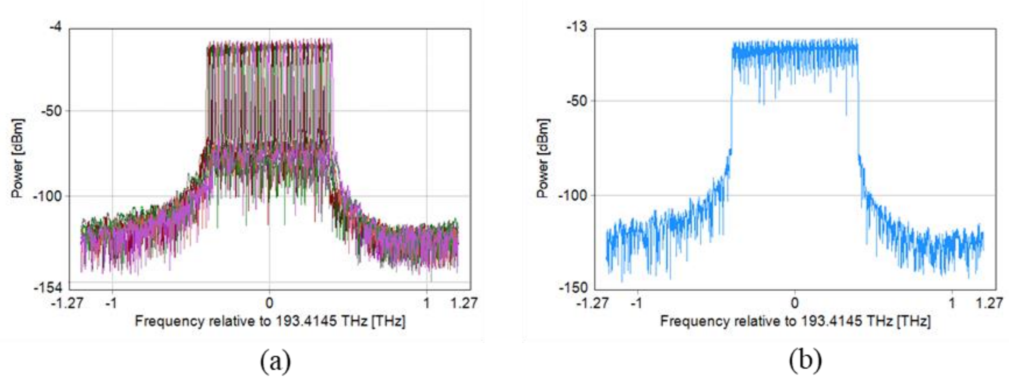


Fig. 4(a) Power spectrum of the signal after passing through 64 SOAs in WBL prior to combining, (b) the power spectrum of the combined power emerging from the WBL output.

By controlling the bias currents of the SOA, WSS could arbitrarily choose and allow passage to certain wavelengths. In the combined output power, certain notches are observed which may be the result of a mismatch between the Interleaver and the MUX-DEMUX AWGs free spectral range. However, this could be avoided by increasing the bandwidth of one of the AWGs and the interleaver. Simulation demonstrates that the WSS has low cross talk of -40 dB.

In conclusion, we have presented the numerical analysis of 64-λ monolithic integrated 1×8 WSS which consists of 8 WBLs. Each WBL is composed of 16 AWGs, 64 SOAs and 11 directional couplers. MZI filter functions as an interleaver block which could divide the dense channels through to eight outputs. Subsequently, AWGs with 100 GHz free spectral range act as DEMUX/MUX elements to route each wavelength to the corresponding SOA. The SOAs enable us to achieve fast and compact switches as well as a compensation element which compensate the loss through the entire WSS. Hybrid time and frequency domain simulation is employed in order to investigate the performance of the WSS. Via the steady-state response of the WSS, the switching capability of the WSS has been verified.

Acknowledgment

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.

References

[1] Aimone, A., et al., “Monolithically Integrated Wavelength-Selective Switch on InP: a Circuit Simulation-Based Design Study”, ECIO conference, 2019.

[2] Prifti, K., et al., “System Performance Evaluation of a Nanoseconds Modular Photonic Integrated WDM WSS for Optical Data Center Networks”, Optical Fiber Communications Conference and Exhibition (OFC) IEEE, 2019.

[3] Calabretta, N., et al., “Monolithically integrated WDM cross-connect switch for nanoseconds wavelength, space, and time switching,” In European Conference on Optical Communication (ECOC), 2015.

[4] Calabretta, N., et al., “System performance assessment of a monolithically integrated WDM cross-connect switch for optical data center networks,” In European Conference on Optical Communication (ECOC) 2016.

[5] Miao, W. 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, pp. 4066-4075, 2016.

[6] Horst, F., et al. “Cascaded Mach-Zehnder wavelength filters in silicon photonics for low loss and flat pass-band WDM (de-) multiplexing” Optics express vol. 21, 11652-11658, (2013).