Draft version of the published paper in Proceedings SPIE Vol. 12424, Integrated Optics: Devices, Materials, and Technologies XXVII; 1242407 (2023) https://doi.org/10.1117/12.2649958

Cascaded directional coupler-based polarization splitter/combiner on commercial silicon photonics integration platform

Kalliopi Spanidou[a], Luis Orbe[b], Luis Gonzalez-Guerrero[a], Dan Herrmann[b], Guillermo Carpintero[a]
[a]University Carlos III of Madrid, Av. de la Universidad, 30, Leganés, 28911, Spain; [b]Synopsys Photonic Solutions, Ottawa, Canada

ABSTRACT

Silicon photonic (SiPho) platforms hold vast potential for providing multi-functional processing capabilities, such as filtering, mode-handling, modulation, etc. Structures for polarization manipulation have become essential elements to enhance channel capacity and to facilitate polarization multiplexing functions. Therefore, 1x2 polarization beam splitters (PBS) are introduced as polarization-division key building blocks based on a silicon-on-insulator (SOI) platform for separating/combining the fundamental modes. By cascading three bent directional couplers (DC), high-performance coupling characteristics can be obtained similar to those of asymmetric ones. A first-ever integration of this kind of PBS has been achieved utilizing Tower Semiconductor's PH18MA silicon photonics platform, which offers 180 nm SOI process technology. In this work, both output ports of the proposed PBS are being tested for polarization filtering across a polarization sweep. The advanced features of this integration process pave the way for next-generation coherent transceivers and aim to meet future optical interconnecting requirements. Furthermore, Synopsys OptoCompiler and the Photonic IC Design Flow, featured in Tower's process design kit (PDK), were used to design the devices.

Keywords: polarization beam splitter, silicon photonics, polarization-handling, cascaded directional couplers, photonic integration

1. INTRODUCTION

On-chip polarization manipulation has played a pivotal role in revolutionizing and enhancing the versatility of the photonic integrated systems for communication and sensing applications. As a complementary technique to other optical processing techniques such as amplification, filtering, (de)multiplexing and modulation, polarization handling can significantly improve communication channel capacity and bandwidth. [1]. For on-chip polarization (de)multiplexing, cascaded bent directional couplers (DC) have the advantage of ease of fabrication and short device lengths, among multimode and directional couplers with metal or grating [2, 3]. Silicon photonics (SiPho) platform has significant potential to host these devices thanks to high-index-contrast and low loss silicon waveguides to perform modal birefringence for polarization splitting. Thus, cascaded DC configurations in silicon have already demonstrated high extinction ratios (ER) (>20 dB) [4, 5], wide operating wavelength ranges by covering S, C, and L bands [4, 5, 6] and fabrication tolerance up to 50 nm [6].

A 1x2 polarization beam splitter/combiner (PBS/C) is presented via a 180-nm-thick silicon-on-insulator (SOI) process technology, utilizing Tower's PH18MA silicon photonics platform. It is a commercial open-access foundry that offers photonic integration of optical components combined with advanced SiGe BiCMOS processes for complete system solutions, especially for data communication. So far, first- and second-order ring filters with efficient heater elements and Mach-Zehnder modulators have been successfully tested [7]. In addition, Synopsys's OptoCompiler platform owing an optimized process development kit (PDK) for Tower's processes is used to design the photonic integrated components. In this way, fast and accurate electronic and photonic design control over complex designs can be handled.

2. STRUCTURE DESIGN AND OPERATING PRINCIPLE

2.1 Structure Design

The proposed PBS is based on a cascaded configuration of three bent directional couplers with a total length of 20 µm. Grating couplers (GC) of 18 µm diameter provide access to input and output ports, while at the output, they feature polarization dependence for mode filtering. Fig. 1 depicts the layout of the PBS/C configuration consisting of one decoupling section between DC#1 and DC#2 and two individual sections to filter the residual power and outcouple only the desired mode (DC#2, DC#3, and WG#1). The proposed structure characteristics are similar to those of the prototype structure in [4]. At the input and output, tapered sections are employed to guide and couple out the isolated fundamental modes. In this way, undesired higher mode components are adapted to the fundamental mode ensuring an ultra-loss and smooth transition.

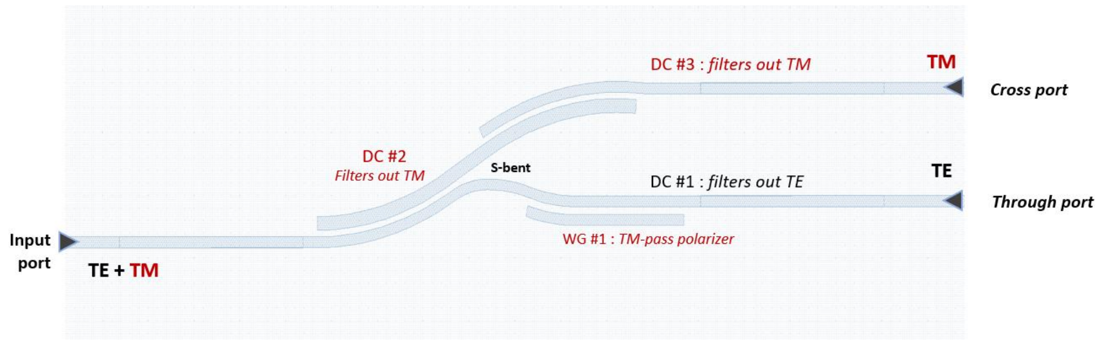

Fig. 1. Schematic of the compact PBS/C in SOI technology platform owing a cascaded-bent DC configuration.

2.2 Operating Principle

Next, the working principle of the proposed PBS is described. First, as the two orthogonal polarization modes propagate through the input waveguide DC#1, they interact with the first-cascaded DC#2 of width w_2 = 550 µm that is optimized along the phase matching conditions for TM polarization. DC#2, thanks to its s-bent shape, filters TM-polarized light and guides it to DC#3. Additionally, DC#3 is designed to guide only TM polarization to couple it out from the cross port. The distance d_1 between the two DCs and curvature of the arc-bent section ensures accurate cross-coupling and mode filtering, respectively. Following by the arc-bent section, the input waveguide is evolving to a high TE-pass selector providing TE mode isolation from DC#2. As the final stage of mode-handling, the cascaded WG#1 is used to filter any residual TM polarization power from the TE mode transmission waveguide, resulting in higher extinction ratios.

Bent directional couplers-based configurations have already been reported as potential design solutions to achieve low-loss mode (de)multiplexing capabilities for polarization diversified photonic integrated circuits (PIC). In the following section, the performance of a three-stage cascade configuration in a compact design with footprint of 5.7 x 20 µm is reported for mode demultiplexing.

3. EXPERIMENTAL RESULTS

According to the proposed PBS/C design, grating couplers (GC) are used to couple in and out light have a diameter of 18 um and a diffraction angle at 8°. A single wavelength laser source is utilized as the input light of optical power of 10 dBm at λ= 1550 nm, using single-mode lensed fibers to couple in and out the light. Polarization adjustments are needed at the input to maximize coupling into the structure. Fig. 2 (a) depicts the experimental setup including the optical source, followed by a polarization controller (PC), a rotating linear polarizer (LP) and a power splitter with ratio 50:50. The PC is utilized to adjust the polarization of the laser to that of the LP. While the combination of the PC and LP assists as a new polarization controller of the input laser to perform the polarization sweep.

Below, the filtering performance by this PBS is tested over a 180-degree sweep with a step of 10° of the LP's transmission axis in Fig. 2 (b). The transmission at the cross (TM) and through (TE) ports along the polarization sweep is normalized according to the maximum output power.

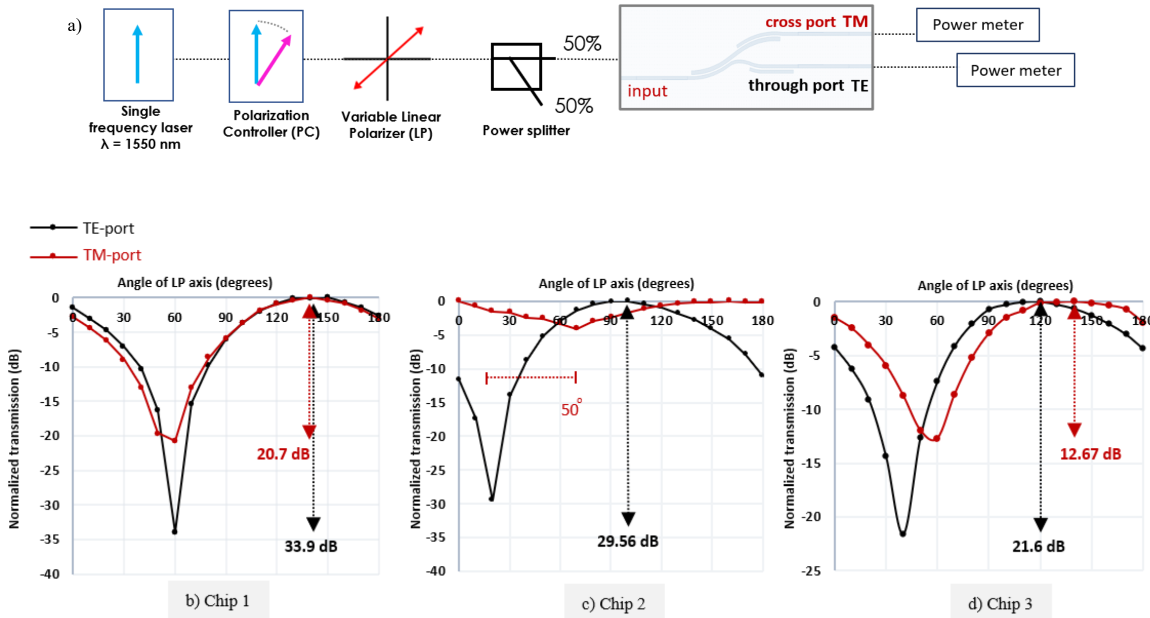

Fig. 2. a) Experimental setup including an optical source, a polarization controller, a rotating linear polarizer and a power splitter. b) PBS transmission spectra measurements for the 180-angle sweep with input wavelength of λ=1550 nm at the TE-type (through) port and at the TM-type (cross) port for chip 1, (c) chip 2 and (d) chip 3.

Fig. 2 (b)-(d) display the filtering responses of the two ports for the three different splitters. Every splitter is in a different chip. The extinction ratios for each TE- and TM-port are highlighted in the graphs. It can be seen that in chip 1 and 3, TE-port filters out with good ER ranging from 21-34 dB. Thanks to the arc-bent for TE-polarized light guidance and the WG#1 for the additional filtering of the TM remained power, TE mode isolation of 34 dB is achieved. Similar extinction ratios have been reported, confirming the capabilities of the cascaded bent waveguide configurations [3-5]. In contrast with the TM-port of the same chips that doesn't filter since there is lack of orthogonality. Since single-mode fibers are used, only the relative shifts between the two responses are taking into account and not the absolute ones. Furthermore, on chip 2, the TM-port exhibits filtering in a 50o shift but insufficient ER. A study of the non-orthogonality between the two modes is in progress, for which possible reasons may be related to the photonic design or the experimental setup.

4. CONCLUSION

To conclude, polarization demultiplexing is investigated in the Tower Semiconductor's SiPho platform. This silicon platform has been affirmed to be a beneficial commercial platform with the capability to integrate optical components of low loss and high performance. The PBS that is demonstrated here, behaves as a partial mode filter. The reasons for the non-orthogonality between the ports as well as the operating wavelength range are still being investigated. However, this silicon splitter shows potential on filtering revealing a good TE-pass polarizer with ER of 34 dB, adding it as an optical component to complex transceiver modules.

ACKNOWLEDGEMENTS

Authors acknowledge TOWER Semiconductor for the fabrication of the chips and Synopsys Photonic Solutions support through the University Program. We acknowledge financial support by the TERAOPTICS project and TERAWAY project funded from the European Union's research and innovation programs under grant agreements No. 956857 and No 871668, respectively and the CONEX-Plus project funded by UC3M and the European Union under grant agreement No. 801538.

REFERENCES

[1] Willner, A. E., Khaleghi, S., Chitgarha, M. R. and Yilmaz, O. F., "All-Optical Signal Processing," Journal of Lightwave Technology, 32(4), pp. 660-680 (2014).

[2] Augustin, L. M. [Polarization handling in photonic integrated circuits] Technische Universiteit Eindhoven, pp. 55-17 (2018).

[3] Chen, S., Wu, H. and Dai, D., "High extinction-ratio compact polarization beam splitter on silicon" Electron. Lett., 52(12), 1043-1045 (2016).

[4] Wu, H., Tan, Y., and Dai, D., "Ultra-broadband high-performance polarizing beam splitter on silicon," Opt. Express 25, 6069-6075 (2017).

[5] Chen, L., Doerr, C. R., and Chen, Y. K., "Compact polarization rotator on silicon for polarization-diversified circuits," Opt. Lett. 36, 469-471 (2011).

[6] Wu, H. and Dai, D., "High-Performance Polarizing Beam Splitters Based on Cascaded Bent Directional Couplers," IEEE Photonics Technology Letters, 29(5), pp. 474-477 (2017).

[7] Spanidou, K., Orbe, L., Guzman, R., Guerrero, L. G., and Carpintero, G., “Experimental Characterization of sub-THz Wireless Communications Building Blocks on a Silicon Platform,” in ECIO’22, pp. 113–115 (2022).