Flat-band 8-Channel Optical MUX/DeMUX for Long Reach 400GbE Applications

Seok-Hwan Jeong
Dept. of Electronic Materials Engineering, The University of Suwon
17 Wauan-gil, Bongdam-eup, Hwaseong, Gyeonggi-do, 18323, South Korea
Corresponding Author: jeong@suwon.ac.kr

Abstract- We propose novel optical demultiplexer scheme for LR-8 applications, and theoretically verify flatband spectral response with the discrete 8-channel wavelengths. By the additional band rejection filter, non-continuous wavelength filtering response was achieved with spectral flatness and low crosstalk of < -15dB within an entire LR-8 targeted spectral range.

I. Introduction

Global traffics have been continuing to rapidly increase in mega datacenters. As one of the standardization technologies for 10km reach utilizing single-mode fiber, 400GBASE-LR8 has been actively investigated [1-4].

In the case of the wavelength division multiplexing (WDM) scheme based on the LR-8, each operating grid for eight-channels is discretely determined within O-band spectral regime [1,2]. In WDM systems, the optical multiplexers (MUXs) and demultiplexers (DeMUXs) [5,6] are needed for transmitting and receiving optical signals. As the optical MUX/DeMUX for the LR-8 applications, silica-based flatband arrayed wavelength grating (AWG) type filter has been reported [1]. In this case, the discrete LR-8 channel grid was obtained by asymmetrically locating the output channel arrays at the output slab waveguide region. However, there remained several technical problems. The AWG usually has relatively large footprint and inherent loss. Moreover, since the flatbabd was achieved by using multimode waveguides at the slab region, this device can only be applied to the receiver side. Meanwhile, silica-based device is not suitable for monolithic integration with active optical functional devices (i.e. modulators or photodetectors).

Recently, to overcome those drawbacks, Si based optical MUX/DeMUX based on cascade connected delayed interferometers (DIs) was reported [4]. Usually, the DI-DeMUX device is promising for low loss, compactness and efficient monolithic integrability. The discrete LR-8 spectral response was achieved by adjusting the specific optical path difference (OPD) at the third-stage DI. However, the suppression ratio for unnecessary spectral bands were <4dB, and the filter spectra were Gaussian-shape rather than box-like one, which are insufficient for practical applications.

In this work, in an effort to overcome aforementioned technical shortcomings, we propose and theoretically verify novel flat-topped spectral shape 8-channel optical MUX/DeMUX scheme for use in LR-8 400GbE datacenter applications.

II. Theoretical Demo

A. Proposed Optical DeMUX for LR-8

Figure 1 shows the schematics of LR-8 targeted optical DeMUX with the LR-8 grid relation. The device is configured with four-stage cascade-connected DIs. In principle, eight wavelength components can be differentiated by using three-stage DIs [5]. However, in Ref. 5, the operating wavelength grid was not fit into the LR-8 grid due to the cyclic filter response nature of the multi-stage DIs. Meanwhile, in Ref. 4, to break the cyclic filter response in the wavelength domain, thus enabling to match with each LR-8 grid, one of the OPD at the third-stage DI was adjusted to one half compared with other OPDs. As a result, in spite of clear spectral difference at around λ=1291nm, the crosstalk was too high. This is the reason why we used the fourth-stage DI in the proposed device scheme.

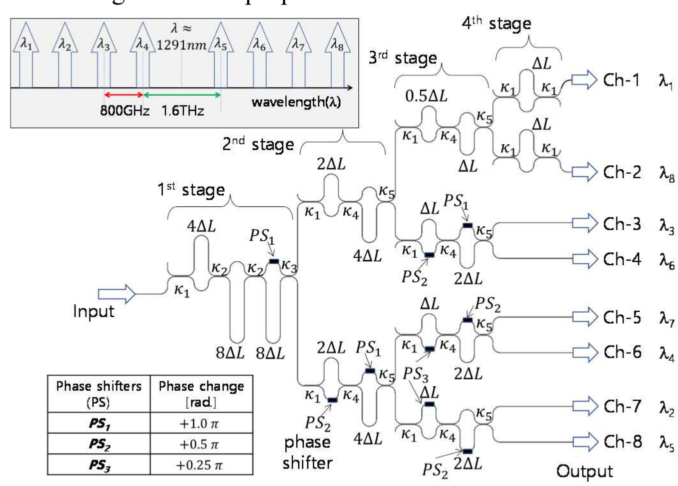

Fig. 1. Proposed multi-stage DI based optical DeMUX for LR-8 400GbE applications together with LR-8 channel grid relations.

The fourth-stage DI works to filter the above-mentioned needless spectral band (λ=1291nm) out, thus enabling to suppress the crosstalk to be <-20dB. To make such a filtering operation happen, the OPD for third and fourth DIs for Ch-1,2 was properly adjusted to make the relative phase relation at λ=1291 nm completely canceled out.

On the other hand, other parameters in the proposed scheme were optimized in terms of spectral flatness as described in previous works [5,6]. The first delayed interferometers with integer multiple values (= 4ΔL, 2ΔL, ΔL) at each DI stage determines each filtering grid. Additionally connected multiple interferometric schemes at each DI stage make the filter response flat-topped and box-like, which is accompanied by optimizing optical splitting ratios at each DI stage (κ_1=0.5, κ_2=0.2, κ_3=0.04, κ_4=0.33, κ_5=0.08) and each OPD as shown in Fig. 1. If the proposed scheme is configured with Si-wire waveguides [7], the total footprint can be estimated to 350-µm-long and 340-µm-wide.

B. Analytic Calculation Results

The spectral response of the proposed scheme was implemented by transfer matrix method based on coupled mode theory [5-7]. In the simulation, wavelength sensitive response of Si-wire-type directional couplers (DCs) used as an optical power divider was analytically formulated, and its spectral validity was confirmed by experimental results. As the waveguide structure, we assumed 350-nm-wide and 220-nm-thick Si-wire channel waveguides operating at O-band regime. The gap for each DC was commonly set to 0.2 µm, which is a standard condition in currently available foundry process. Based on these design guidelines, several kinds of DC splitting ratios were numerically simulated by a 3-dimensional beam propagation method. Then, their numerical results were applied to the main loop of the transfer matrix for the multiple DI-type optical DeMUX [7].

Figure 2 shows the calculated 8-channnel spectral characteristics for (a)conventional flatband DeMUX based on multiple DIs [5], (b)Gaussian-shaped DI-DEMUX using the local OPD optimization at 3rd-stage DI [4], (c)the technical combination in Refs. 4 & 5, and (d)proposed flatband DI-DeMUX using additional band rejection filters. The OPDs for each DeMUX scheme were commonly controlled to have the channel spacing of 800GHz within O-band spectral range.

In Fig. 2(a), flatband is attained by connecting excessive DIs. It is note that the operating window tends to be equally spaced by 800GHz, which means the inability to process the LR-8 modulated signals. In Fig. 2(b), the unwanted band at around λ=1291nm can be slightly suppressed by the OPD control at the 3rd-stage DI [4]. However, its extinction ratio (ER) is too small to keep the WDM system penalty sufficiently low. As seen in Fig. 2(c), if the design strategies shown in Fig.2(a) and (b) are combined, spectral distinction over (a) is available with flat-topped filter response. However, there still remains insufficient ER of <4dB. As can be clearly seen in Fig. 2(d), the drawback on ER is drastically relaxed (>20dB) by the proposed scheme without degrading flatband spectral quality. Further reduction of the λ-sensitivity on DC splitting ratio or the introduction of MMI couplers [7] could make the proposed scheme more practical.

III. Summary

We proposed novel LR-8 targeted 8-channel flatband optical DI-DeMUX, and theoretically validated dramatic spectral reduction (ER >20dB) at around λ=1291nm by making intentional phase mismatching at specific output channels. The proposed scheme can be realized with Si-wire waveguides through standard CMOS process without increasing any fabrication or design complexity.

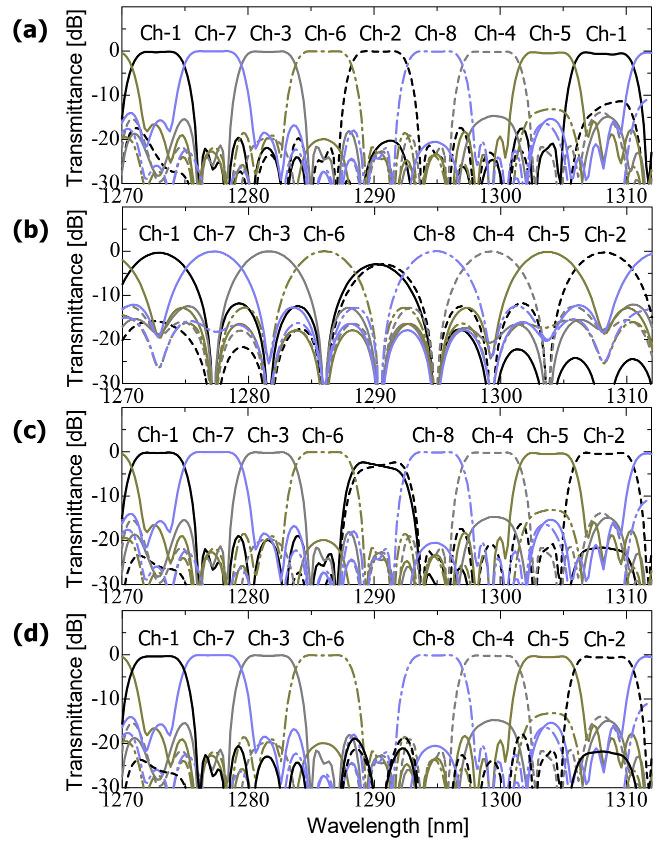

Fig. 2. Calculated 8-channel optical filter response for (a)conventional flatband DI-DEMUX [5], (b)Gaussian-shaped DI-DEMUX using the local OPD optimization at the 3rd-stage DI [4], (c) the technical combination in Refs.4 & 5, and (d)proposed flatband DI-DEMUX.

References

[1] Y. Doi et al, “Compact 8-wavelength receiver optical sub-assembly with a low-loss AWG demultiplexer for 400-gigabit datacom,” Proc. ECOC 2015, DOI: 10.1109/ECOC.2015.7341911.

[2] Y. R. Zhou et al, “Field and laboratory trials of 400GBASE-LR8over fibre distances up to 35 km,” IET Electron., Lett., **54,** 1288-1290 (2018).

[3] Y. Yue et al, “400GbE technology demonstration using CFP8 pluggable modules,” Appl. Sci., **8,** 2055 (2018).

[4] Z. Zhao et al, “Eight-channel LAN WDM (De)Multiplexer based on cascaded Mach-Zehnder interferometer on SOI for 400GbE,” Photonics, **9,** 252 (2022).

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

[6] S. -H. Jeong et al, “Si-nanowire-based multistage delayed Mach–Zehnder interferometer optical MUX/DeMUX fabricated by an ArF-immersion lithography process on a 300 mm SOI wafer,” Opt. Lett., **39,** 3702-3705 (2014).

[7] S. -H. Jeong et al, “Theoretical verification of a silicon-wire flat-spectral-band wavelength filter based on multimode interference couplers with symmetric and asymmetric splitting ratios for the broadband operating range,” Appl. Opt., **60,** 9411-9418 (2021).