On-Chip Switching of Mode- and Polarization-Multiplexed Signals with a 748-Gb/s/λ (8 × 93.5-Gb/s) Capacity

Qingming Zhu, Yong Zhang, Yu He, Shaohua An, Ciyuan Qiu, Xuhan Guo, and Yikai Su*
State Key Laboratory of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
**Corresponding author: yikaisu@sjtu.edu.cn*

Abstract: We experimentally demonstrate an on-chip optical switching scheme for mode- and polarization-multiplexed signals. A quadrupled switching capacity of 748 Gb/s/λ is achieved by routing eight 93.5-Gb/s data channels on two modes and two polarizations.
OCIS codes: (130.4815) Optical switching devices; (060.4230) Multiplexing; (230.3120) Integrated optics devices

1. Introduction

Ever-increasing global data traffic is driving the demand for high network capacity [1]. In the past few decades, multiple dimensions of an optical signal, including polarization, space, amplitude, phase, wavelength/frequency, and time, have been explored to increase the transmission capacity. Among them, polarization and space dimensions are desired to multiplex data channels with one laser source and limited electrical bandwidth. Switching of polarization- and space-multiplexed signals is one basic requirement in such optical networks and has attracted much attention [2, 3]. Recently, we presented an on-chip 1 × 2 mode- and polarization-selective switch (MPSS) [4] and a 2 × 2 MPSS device [5]. In analogy to a wavelength-selective switch (WSS), the MPSS can route any polarization/mode channel from one input port to any output port. However, no switching of high-speed data was demonstrated in [5].

In this paper, a proof-of-concept switching experiment is carried out using our previously fabricated 2 × 2 MPSS device [5] to verify the feasibility of mode and polarization switching. Two modes and two polarizations are employed to quadruple the capacity on one wavelength. An intensity modulation-direct detection orthogonal frequency division multiplexed (IM-DD OFDM) signal is routed in the 2 × 2 MPSS. By using multiple digital signal processing (DSP) techniques, a 93.5-Gb/s net data rate is achieved. Therefore, the total switching capacity is 2 × 4 × 93.5 = 748 Gb/s/λ, which is the highest capacity of on-chip polarization-division multiplexing (PDM) and mode-division multiplexing (MDM) devices [4,6], to the best of our knowledge.

2. MPSS structure

Figure 1(a) shows an on-chip *N* × *N* optical switching network architecture for mode- and polarization-multiplexed signals. The *N* 2-PDM and *M*-MDM signals are injected into the photonic chip. The signals are then de-multiplexed into 2*M* fundamental mode signals by mode and polarization de-multiplexers, and each of them is routed to designated output port by a conventional 1 × *N* switch and a subsequent multiplexer.

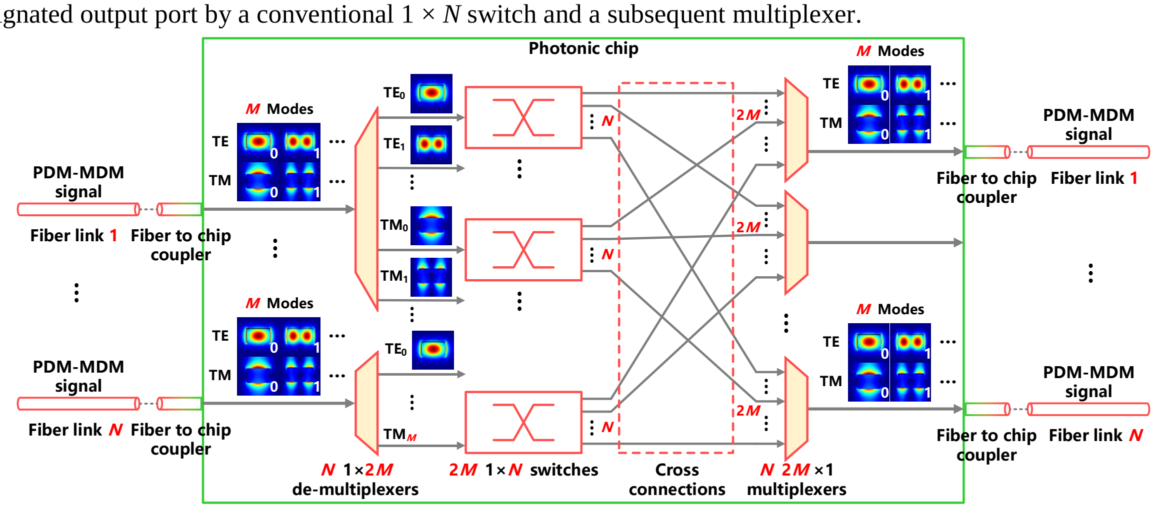

Fig. 1. On-chip optical switching network architecture for mode- and polarization-multiplexed signals.

3. Switching experiment

We perform a proof-of-concept switching experiment using a silicon 2 × 2 MPSS chip [5]. In the MPSS, the (de)multiplexers are realized as mode (de)multiplexers and polarization beam splitters (PBSs). Eight 1 × 2 TE_0 or TM_0 Mach–Zehnder interferometer (MZI)-based thermal-optic switches are used to route the corresponding de-multiplexed data channels. Due to the lack of few-mode fibers (FMFs), additional mode multiplexers and de-multiplexers are placed before and after the MPSS on the same chip, thus enabling the switching experiment with single-mode fibers (SMFs). The inter- and intra-modal crosstalk values are below −22.8 dB at 1550 nm, and the overall insertion losses of the chip are <8.6 dB [5].

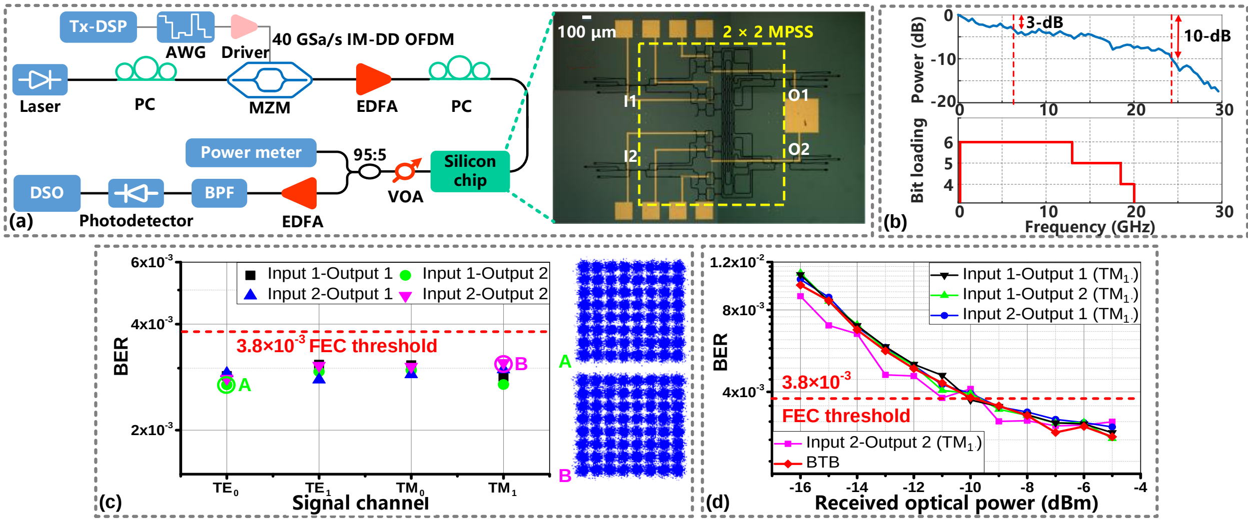

Fig. 2: (a) Experimental setup. PC: polarization controller. MZM: Mach-Zehnder modulator. Tx-DSP: transmitter-digital signal processor. AWG: arbitrary waveform generator. EDFA: erbium-doped fiber amplifier. VOA: variable optical attenuator. BPF: bandpass filter. DSO: digital storage oscilloscope. (b) Frequency response and bit loading. (c) BERs of 16 switching configurations. (c) BER versus received optical power.

The experimental setup is illustrated in Fig. 2(a). At the transmitter, a continuous wave light at 1550 nm is launched into a 25-GHz Mach-Zehnder modulator (MZM) (FTM7939EK), which is driven by a 40-GSa/s electrical IM-DD OFDM signal. An arbitrary waveform generator (AWG) (Keysight M8195A) generates the OFDM signal with a resampling rate of 60 GSa/s, which is amplified by a linear driver. The modulated optical signal is amplified by an erbium doped fiber amplifier (EDFA) and injected into the MPSS by grating couplers. Due to the lack of a fiber array, we tested one input and one output port at a time. For practical MPSS chip with inter- and intra-modal crosstalks, multiple-input multiple-output (MIMO) equalization [7] can be used to mitigate the crosstalk effects. The signal is coupled out, amplified, filtered, detected by a 40-GHz photodetector (XPDV2120R), and sampled by an 80-GSa/s digital storage oscilloscope (LeCroy 10-36Zi-A). The frequency response of the transmission system is shown in Fig. 2(b). For the digital processing of the signal, overheads of 0.1%, 3.7%, 1.9%, 1.5%, 2.9% are included by synchronization, equalization, cycle prefix, guard band and optimization, respectively. Symbol scaling [8] and peak-to-average power ratio (PAPR) reduction [9] techniques are implemented to improve the receiver sensitivity. Bit loading is also realized with 64-, 32- and 16- quadrature amplitude modulation (QAM) mapping, and 64% subcarriers are allocated for 64-QAM data. A raw data rate of 100.0 Gb/s is therefore achieved. The BERs of all the 16 possible switching configurations are measured with a same −5-dBm received optical power. As shown in Fig. 2(c), similar performances are achieved, and the BERs are below the 7% forward error correction (FEC) threshold [10]. Therefore, the net data rate and the switching capacity of the MPSS are 93.5 Gb/s and 2 × 4 × 93.5 = 748 Gb/s/λ, respectively. Compared to the back-to-back (BTB) case, negligible power penalties are observed for the worst TM_1 channels in Fig. 2(d).

4. Conclusion

In summary, optical switching of mode- and polarization-multiplexed signals is demonstrated on a 2 × 2 MPSS chip. By routing eight data channels on two modes and two polarizations, a quadrupled switching capacity of 748 Gb/s (2 × 4 × 93.5 Gb/s) is achieved on one wavelength.

5. References

[1] Cisco, "VNI forecast and methodology, 2015-2020," white paper (2016).
[2] B. Stern, et al., Optica, Vol. **2**, no. 6, pp. 530-535 (2015).
[3] X. Wu, et al., in OECC/PS, 2016, Paper ThE2-4.
[4] Y. Zhang, et al., in OFC, 2017, Paper W4E.2.
[5] Y. Zhang, et al., Photon. Res., Vol. **5**, no. 5, pp. 521-526 (2017).
[6] X. Wu, et al., J. Lightwave Technol., Accepted (2017).
[7] T. Sakamoto, et al., J. Lightwave Technol., Vol. **31**, no. 13, pp. 2192-2199 (2013).
[8] J. Peng, et al., in CLEO, 2017, Paper STh1O.3.
[9] S. H. Han, et al., IEEE Signal Processing Letters, Vol. **11**, no. 11, pp. 887-890 (2004).
[10] ITU-T Recommendation G.975.1, Appendix I.9, (2004).