Silicon Photonic Integration of DWDM and Mode-Division Multiplexing for Advancing Multi-Dimensional Data Transmission

Robert Parsons,[1,*] Xiang Meng,[1] James Robinson,[1] Maarten Hattink,[1,2] Asher Novick,[1,2] Anthony Rizzo,[1,3] Utsav D. Dave,[1] Michal Lipson,[1] and Keren Bergman[1]

[1] *Department of Electrical Engineering, Columbia University, New York, NY, 10027, USA*
[2] *Now with Xscape Photonics, New York, NY 10027, USA*
[3] *Now with Air Force Research Laboratory, Rome, NY 13441, USA*

[*] *rp3020@columbia.edu*

Abstract: We demonstrate an innovative integration of DWDM and Mode-Division Multiplexing, enabling multi-dimensional transmission with 8 wavelengths and 4 modes. The packaged photonic chip demonstrates a remarkable 512 Gbps aggregate bandwidth with a BER < 1e-9.

1. Introduction

In the rapidly evolving landscape of data centers and high-performance computing driven by AI/ML tasks, the demand for cutting-edge optical solutions has surged. Our innovative fusion of Dense Wavelength Division Multiplexing (DWDM) and Mode-Division Multiplexing (MDM) achieves unparalleled performance, extending extreme parallelism across wavelengths and modes. In this work, we leverage our DWDM devices that not only provide exceptional total bandwidth but also set new benchmarks for energy efficiency [1]. Additionally, we seamlessly integrate MDM, at the forefront of advancements in foundry-based silicon photonic integrated circuits, providing a new dimension in overall transmission capacity by multiplexing encoded light onto orthogonal modes of a waveguide [2, 3]. Our demonstration of this cutting-edge technology is embodied in our packaged photonic chip, showcasing a remarkable 512 Gbps aggregate bandwidth with a BER < 1e-9.

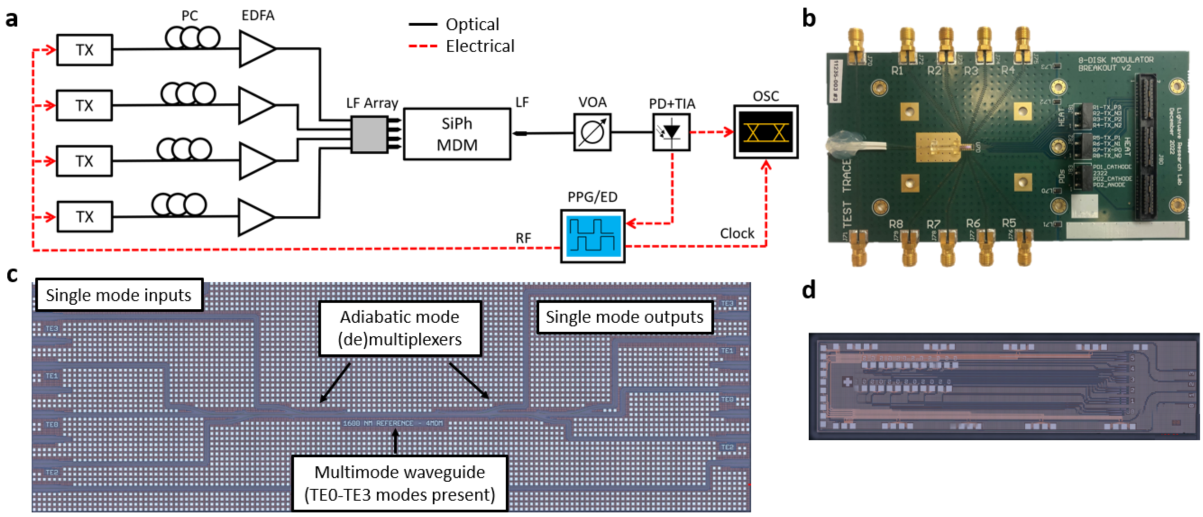

Fig. 1. **(a)** Experimental setup for DWDM/MDM demonstration.TX, Transmitter; PC, Polarization Control; EDFA, Erbium-Doped Fiber Amplifier; LF, Lensed Fiber; VOA, Variable Optical Attenuator; PD, Photodiode; TIA, Transimpedance Amplifier; OSC, Oscilloscope; PPG, Pulse Pattern Generator; ED, Error Detector. **(b)** Packaged custom microdisk modulators. RF wirebonds and traces allow high-speed testing and DC wirebonds allow thermal control. **(c)** Micrograph of SiPh mode-division multiplexer and demultiplexer. Adiabatic couplers and multimode waveguide at center, edge couplers located on left and right sides of PIC. **(d)** Micrograph of modulator PIC packaged in (b).

2. Experimental Setup & Results

We designed a Photonic Integrated Circuit (PIC) incorporating 8 custom microdisk modulators. This PIC was fabricated through a custom full-reticle wafer run, conducted in collaboration with AIM Photonics, as shown in Fig. 1d. In conjunction with Optelligent, we utilized an advanced packaging process for the PIC, involving RF wire-bonding and fiber-attach on a purpose-designed PCB, showcased in Fig. 1b. This packaged PIC served as the linchpin of our experimental setup, functioning as the DWDM transmitter. As illustrated in Fig. 1a, our transmission methodology involved the use of a lensed fiber array, enabling the sequential launch of one modulated wavelength at a time into four inputs of the MDM chip simultaneously. These four inputs were multiplexed onto four distinct modes (TE0, TE1, TE2, and TE3) within a single multimode waveguide characterized by a width of 1600 nm. To facilitate this multiplexing, we exploited ultra-broadband, low-loss adiabatic couplers (shown in Fig. 1c), achieving an extraordinary bandwidth exceeding 100 nm and an impressive 20 dB crosstalk suppression [4]. Subsequently, the four multiplexed modes underwent a demultiplexing process using a mirror structure identical to the mode multiplexer, resulting in four individual single-mode outputs.

The analysis of the received signal involved capturing the eye diagram from each output using an oscilloscope, with the Bit Error Rate (BER) recorded through the error detector. We modulated each wavelength channel at a speed of 16 Gbps, attaining a BER of $<$ 1e-9 at a received power of 0 dBm, with open eye diagrams observed for all 32 channels, as depicted in Fig. 2. Our innovative device and design not only demonstrate groundbreaking capabilities but also hold the promise of easily expanding capacity. By seamlessly integrating with a comb laser source, our approach can achieve a remarkable aggregate bandwidth in excess of 2 Tbps, marking a significant leap forward in the realm of high-performance data transmission and meeting the evolving demands of advanced communication systems [5].

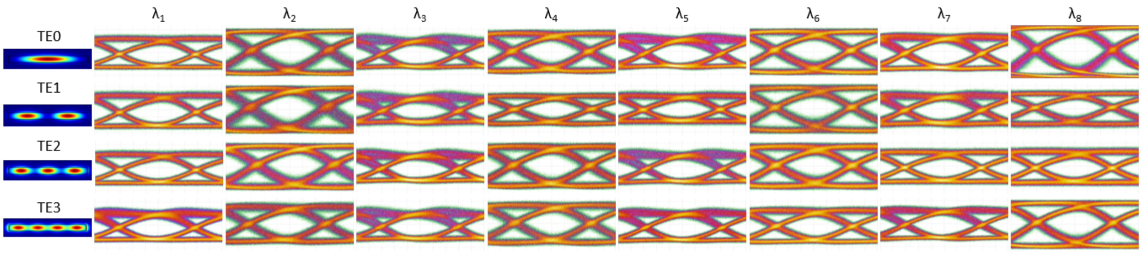

Fig. 2. Eye diagrams captured at 8 wavelengths at 150 GHz channel spacing across C-band and 4 modes TE0-TE3 at 16 Gbps per channel. Bit error rate of all channels less than 1e-9.

3. Conclusion

Our research integrates DWDM and MDM, yielding an innovative PIC with 512 Gbps aggregate bandwidth and a BER <1e-9. This design, featuring 8 custom microdisk modulators, demonstrates exceptional performance and scalability, offering a seamless path to 2 Tbps by integrating with a comb laser source. Our work anticipates meeting the escalating demands of AI/ML-driven data centers and high-performance computing, showcasing the adaptability and transformative potential of integrated DWDM and MDM interconnects.

References

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