Simultaneous Error-Free Data Modulation with Silicon Microdisks in the Multi-FSR Regime for Scalable DWDM Links

Vignesh Gopal[1,*], Anthony Rizzo[1], Maarten Hattink[1], Asher Novick[1], James Robinson[1], Kaveh Hosseini[2], Tim Tri Hoang[2], and Keren Bergman,[1]

[1] *Department of Electrical Engineering, Columbia University, New York, NY, 10027, USA*
[2] *Intel Corporation, CA, USA*

[*] *vvg2113@columbia.edu*

Abstract: We demonstrate simultaneous error-free modulation of wavelength channels with spectral separation exceeding the individual microdisk FSR. The channels, re-interleaved onto a single optical output, are demultiplexed using ring filters validating the scalable transceiver architecture. © 2023 The Author(s)

1. Introduction

Microring and microdisk modulators are widely used as tools to support dense wavelength division multiplexing (DWDM) for co-packaged optics due to their inherent wavelength selectivity, small footprint, and compatibility with CMOS drive voltages [1,2]. Previous works have demonstrated error-free transmission of cascaded resonant modulators on a single bus using multi-wavelength frequency comb sources, showing a path to extreme scaling in the wavelength domain [3]. However, in such cases, the number of wavelengths is limited to the free spectral range (FSR) of the modulator divided by the channel spacing of the laser source due to aliased resonances corrupting otherwise orthogonal signals. Here, we experimentally demonstrate the first validation of even-odd interleaved arrays of resonant modulators as a method to overcome this single-FSR limit. This work validates the use of broadband frequency comb sources to achieve unprecedented channel counts in future high-capacity DWDM silicon photonic links.

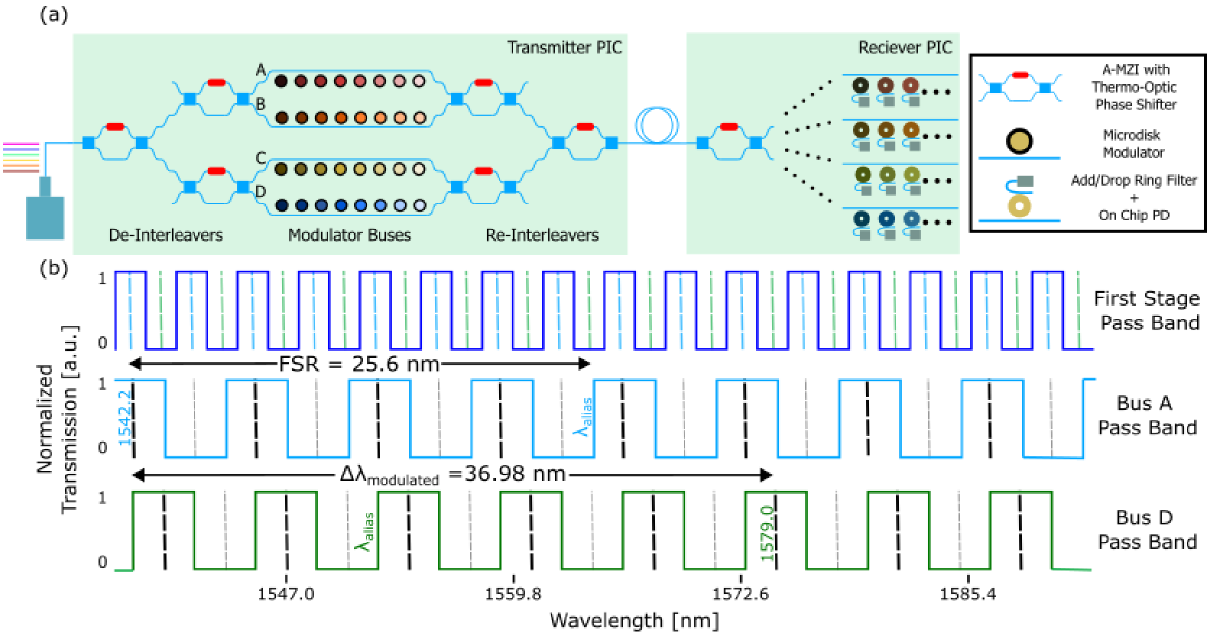

Fig. 1. (a) Schematic of transceiver architecture for the case of a 32 channel transmitter with corresponding receiver. (b) Example transmission spectrum of a 2-stage interleaver onto the top and bottom buses of a scalable transmitter. As seen, the transmitter can modulate beyond the single FSR limit while maintaining a single optical input and output.

2. Operating Principle and Experimental Results

To operate in the multi-FSR regime, the proposed architecture splits the multichannel laser source into different subgroups through the use of broadband interleavers. In this Vernier-like scheme, unwanted resonances of a given resonator are placed in the expanded inter-channel guard-bands, thus avoiding interference with the other wavelength channels beyond a single FSR from an evenly spaced, multi-wavelength source [4]. Each successive interleaver stage doubles in FSR, following $FSR_i = 2^i \times \Delta\lambda_{source}$. This splits every other wavelength channel onto a different arm of the interleaver, which in turn increases the effective channel spacing. Fig. 1 illustrates the architecture and operating principle for the case of a 32 channel transmitter with two interleaver stages (4 buses of 8 modulators). Though the multi-wavelength source provides channels corresponding to multiple disk modulators, Fig. 1 (b) demonstrates how the aliased resonances are avoided via even-odd interleaving. This architecture can be scaled by increasing the number of interleaving stages, allowing for a greater number of modulators on each bus, thus widening the overall optical bandwidth.

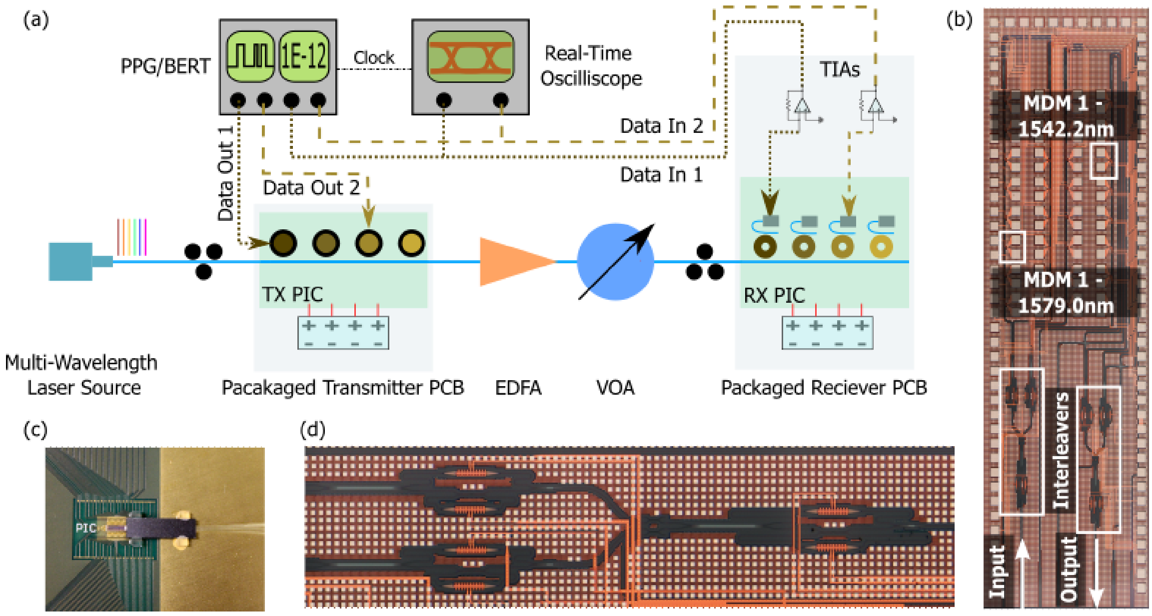

Fig. 2. (a) Full experimental setup for the multi-channel demonstration. (b) Microscope image of full silicon photonic chip with even-odd interleavers and cascaded modulators. (c) Packaged board with 96 DC wirebonds and fiber-attached eight channel v-groove array. (d) Microscope image of the on-chip 2 stage interleaver.

Fig. 2 shows a high level schematic of the setup we use in this experiment. Both the transmitter and receiver photonic integrated circuits (PICs) are fabricated from the AIM Photonics multi-project wafer (MPW) service. They are both fully packaged onto printed circuit boards (PCBs), which include die attach, wirebonding, and fiber-attach. The transmitter PIC consists of 4 interleaved arrays, containing 8 disk modulators each, which are then re-interleaved through a symmetric set of two cascaded interleaver stages before coupling out to a single mode fiber (SMF). The modulators are vertical junction silicon microdisks with FSRs of 25.6 nm. Once the interleavers and disks are appropriately aligned, the output is amplified and sent to the receiver PIC. The packaged receiver PIC demultiplexes the two channels via cascaded add/drop ring resonator filters. The signals from the filters are sent to high speed germanium photodiodes (PDs) wirebonded to transimpedance amplifiers (TIAs) on a separate electronic IC chip packaged on the same PCB.

The microdisks are driven with high speed RF 50 Ω G-S probes that are connected to an Anritsu MP1900a pulse pattern generator (PPG), which sends a PRBS31 non return to zero (NRZ) signal to the modulators with a V_{pp} of 0.9 V and a DC reverse bias of -1.5 V. The outputs of the TIAs are connected to a real-time oscilloscope and bit error rate tester (BERT) via high-speed RF cables. The received power is then programatically varied using a Keysight N7764a variable optical attenuator (VOA). Fig. 3 (a) shows the transmission spectra following the 2-stage interleaver and array of microdisks. Using the thermo-optic phase shifters, the pass bands of both stages are actively aligned with the respective carrier wavelengths. Fig. 3 (b) shows an example spectrum of a ring filter tuned to the channel wavelength ($\lambda_c = 1542.2$ nm). As seen in Fig. 3 (c) and (d), we successfully modulate the two channels simultaneously with open eye diagrams measured at up to 20 Gbps. Data collected from the BERT shows that the signals for both wavelengths are error-free. The selected channels, set to 1542.2 nm and 1579.0 nm ($\Delta\lambda_{modulated} = 36.8$ nm), correspond to a channel spacing beyond a single FSR (25.6 nm) of the disks.

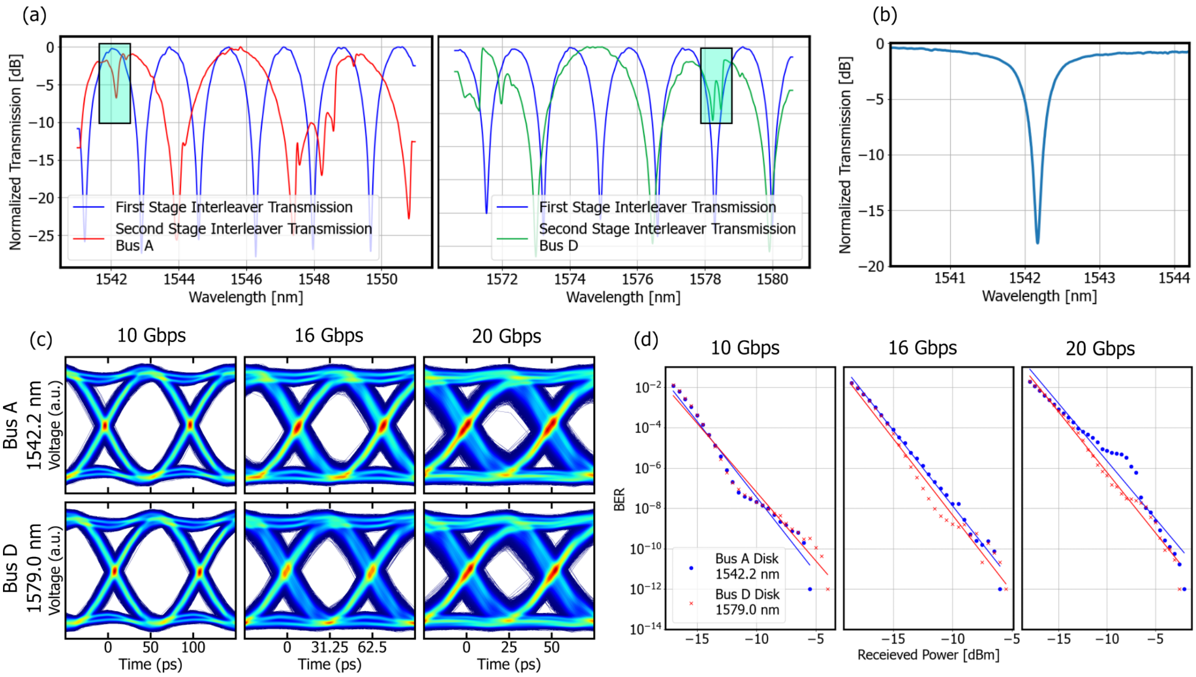

Fig. 3. (a) Transmission spectra after both stages of interleavers and buses. Boxed areas show resonance dip following the modulators. (b) Example transmission spectrum from add/drop ring filter. (c) Eye diagrams measured using a real-time oscilloscope at speeds up to 20 Gbps. (d) BER measurements collected simultaneously on both wavelength channels.

3. Conclusion

To the best of our knowledge, this work is the first demonstration of simultaneous error-free modulation of cascaded resonant modulators beyond the single-FSR limit. These experiments validate the previously proposed highly scalable transceiver architecture for DWDM interconnects [4], supporting a significantly increased number of wavelength channels. Additionally, we demonstrate the architecture using a completely chip-based silicon photonic link, from a scalable transmitter PIC to a fully integrated receiver PIC. Error-free measurements are confirmed for modulation speeds as high as 20 Gbps on both channels concurrently. The demonstrated link architecture can scale to support multi-Tbps links in future data center interconnects, showing a clear path to achieving energy-efficient terabit-scale communication on a single fiber with low latency.

References

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