Towards 3.2 Tb/s Direct Detection Polarization-Multiplexed Transceivers using on-chip Microring assisted Coherent Network

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Abstract *We propose and demonstrate 400 Gb/s per wavelength per single mode fiber silicon photonics dual-polarization transceiver using hardware-based polarization unscrambling. By using the reconfigurable microring based coherent network solution, we minimize inter-channel crosstalk and achieve high baud rate transmission on a single carrier. ©2023 The Author(s)*

Introduction

Direct detection transceivers in data centers include single wavelength spatially division multiplexed modules using 8 parallel data lanes with 16 simplex single mode fibers plugged into Octal Small Form-factor Pluggable extra density (OSFP-XD) or Quad-Small form factor Pluggable- double density (QSFP-DD) Multi-source Agreements (MSA) transceivers for 400Gb/s, 800Gb/s and even 1.6Tb/s data rates. With the commercial availability 5nm optical digital signal processing (oDSP) chipsets supporting 100Gbaud transmission, we have witnessed early demonstrations at OFC 2023 of pluggable transceivers supporting aggregate data rates of 1.6Tb/s using 8 channels of 100Gbaud PAM-4 transmission [1-2].

With the impetus for new 3.2 Tb/s and faster transceivers in the next few years. One possible option is to further increase baud rate or use PAM-8 and implement single lane data rates >300Gb/s [3-6]. Another option is to employ the advanced coherent modulation techniques developed for long-haul links, but the cost of deploying coherent transceivers in data centers remains uncompetitive. There is also a short-term low-cost option to further increase the data transmission capacity using polarization multiplexing, like used in coherent systems [7-13], but without coherent detection and the complex DSP, to double transceiver capacity from 1.6 Tb/s to 3.2 Tb/s. This option has the advantage of being able to use the same electronics and oDSP chips as are currently becoming available [1-2].

In this paper, we demonstrate an intensity modulation-direct detection (IM-DD) polarization-multiplexed optical fiber communications solution using an integrated silicon photonics (SiPh) transmitter and receiver to unscramble the two polarization data lanes. The data is unscrambled using a reconfigurable integrated network of microring resonators (MRR) [14]. The implementation of the integrated coherent network using MRR has the advantage of better thermal tuning efficiency and smaller footprint when compared with conventional Mach-

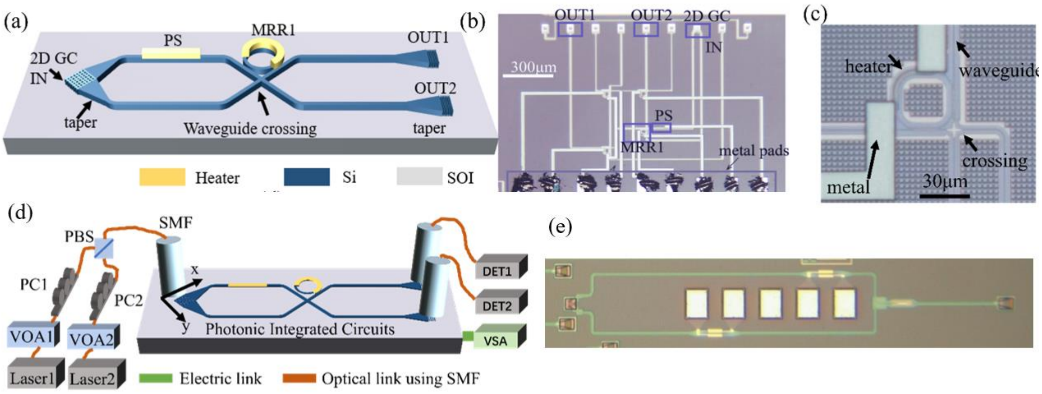

Fig. 1: (a) Schematic of the proposed network for polarization modes unscrambling. (b) Micrograph image of the fabricated MRR-based coherent network. (c) Micrograph image of the fabricated MRR with radius of 10μm. (d) Experimental setup of the proposed system for device characterization. (e) Dual-polarization transmitter. PC, VOA, PBS, DUT, and VSA represent polarization controller, variable optical attenuator, polarization beam splitter, the device under test, and voltage source array.

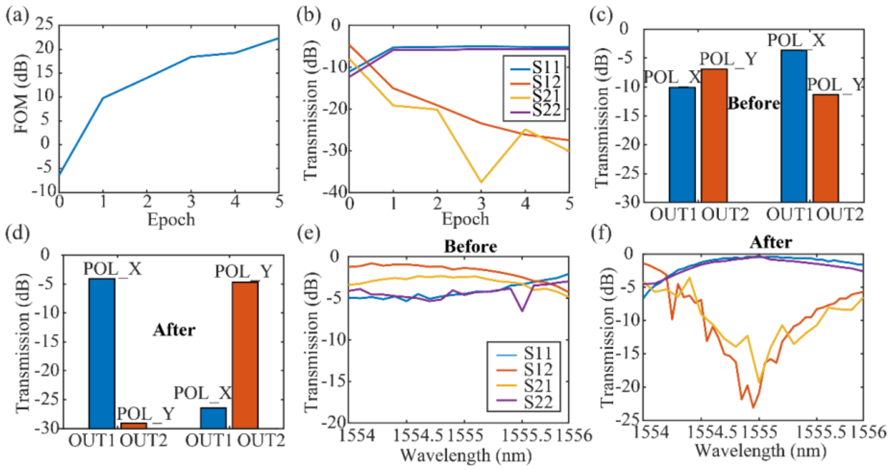

Fig. 2: (a) FOM value evolved with epoch number. (b) Scattering matrix evolved with epoch number. Scattering matrix (c) before unscrambling and (d) after unscrambling. Normalized transmission spectra of Sij (e) before and (f) after being unscrambled by the coherent network.

Zehnder Interferometer coherent networks for unitary matrix operations [15]. The pol-muxed data was produced using two silicon-germanium electro-absorption modulators (EAM), using PAM-4 modulation up to 100 Gbaud (200 Gb/s) per polarization channel on the transmitter side. The receiver photonic integrated circuit implemented a novel MRR based coherent network for the optical signal processing to unscramble the two polarization channels. In our proof-of-concept experimental demonstration, we observed negligible impairment on the two data lanes despite the bandwidth limit of the MRR network and demonstrate 400 Gb/s aggregate data rate in the two polarization channels.

Microring Resonator Coherent Network

Schematic overview of the integrated MRR coherent network receiver is shown in Fig. 1(a). The 2DGC couples light from fiber with orthogonal polarizations to the TE0 mode of two output waveguides. The orthogonal polarizations in the single mode fiber (denoted as x and y polarizations) are both launched intoTE0 mode of the orthogonally orientated output waveguides from the 2-dimensional grating coupler (2DGC). The two waveguides from the 2DGC then enters the two-input bus waveguide of the four port MRR. Fig. 1(a) and 1(c) shows the 4-port MRR, which is formed by a dual-bus crossbar tunable MRR. The two phase shifters (PS) in the four port MRR can be used to realize arbitrary 2 by 2 unitary matrix operation, and therefore it can compensate for crosstalk introduced by random mixing of the two polarization channels, which are caused by: (1) mutual coupling of polarizations, or (2) fiber rotations. The optical tuning of the PS in the four port MRR was implemented using integrated metal heater embedded in the top oxide cladding above the waveguide. We carefully design the power coupling ratio of the bus waveguide into the MRR to be between 0.3 to 0.4. We fabricated the chip in a multi-project wafer (MPW) silicon-on-insulator (SOI) shuttle run provided by a commercial foundry. The MPW offers 220nm thick top silicon in a silicon-on-insulator (SOI) wafer with a buried oxide (BOX) of 2 μm. Micrograph image of the whole chip was illustrated in Fig. 1(b).

We first characterized the static performance of MRR based system. The pol-demux test setup is shown in Fig. 1 (d). The two data lanes (Laser1 and Laser2) were combined by a fiber-optic packaged polarization beam splitter (PBS) with a polarization controller (PC) on each path to ensure maximum coupling. In this way, we coupled two independent data channels to the orthogonal polarization modes in one single mode fiber. To measure the scattering matrix of the system, we used a variable optical attenuator (VOA) to switch the light in each path 'ON' and 'OFF'. The two input polarizations go through unknow mix and random perturbation which results in random orientations before coupling into the device under test (DUT) as shown in Fig. 1(b) and illustrated in Fig. 1(d). And we used the genetic algorithm to optimize the optical integrated network to realize polarization modes unscrambling. The crosstalk level between the two data lanes can be suppressed to lower than -20dB as indicated in Fig. 2(b) despite arbitrary rotation of the input fiber orientation. Fig. 2(c) shows the scattering matrix before unscrambling circuit, with crosstalk level initially at -4dB. Fig. 2(d) shows the scattering matrix after unscrambling with crosstalk level lower than -20dB at the wavelength of 1.555μm. The transmission spectra before and after unscrambling by the MRR-based coherent network were shown in Fig. 2(e) and Fig. 2(f).

Dual-Polarization Transmitter

A SiPh dual-polarization transmitter was used to generate the dual-polarization PAM-4 signal as shown in Fig. 1(e). Using two germanium-silicon electro-absorption modulators (EAM), the transmitter has a single TE input from a grating coupler, the light then enters a 1 by 2 multimode interferometer (MMI), generating two TE polarized optical signal which are modulated by the two EAMs. Through the 2DGC, the two TE0 signal is launched into single mode fiber with orthogonal polarizations. The EAM has a wide electro-optic (EO) bandwidth of over 60 GHz and features a very small device size 0.24cm^2, which allows for the compact dual-polarization transmitter.

High-Speed Data Transmission Experiment

At the transmitter side, the electrical signal is generated using a 120 GSa/s arbitrary waveform generator (Keysight M8194A), amplified using RF amplifiers and the two uncorrelated PAM-4 signal are fed into the modulators with the light source set at 1555 nm. At the receiver side, two polarization demultiplexing techniques are used for comparison between a reference system and our proposed system. The reference polarization demultiplexer uses a discrete PBS with a PC to demultiplex the signal. For the integrated polarization demultiplexer, by controlling the on-chip phase shifter and the MRR heater, the system unscrambles the pol-muxed signal and generates two outputs which correspond to the two data streams. Due to the insertion loss (IL) (11 dB) introduced from fiber-chip coupling and device IL, and our lack of a transimpedance amplifiers for the high-speed photodiode, an optical amplifier was used before coupling to the receiver chip. The demultiplexed signal was received using a 70 GHz photodetector and digitized using a real-time oscilloscope with 256 GSa/s sampling rate (Keysight UXR0592). The captured data was processed using linear digital signal processing (DSP), including the standard feed-forward equalizer (FFE) and decision-feedback equalizer (DFE). The bit-error-rate is calculated and analyzed.

Results and discussion

Fig. 3 show the B2B results for the two demuxed channels using both the reference system and the on-chip demux system. The results show the proposed system achieves a very similar performance compared with the reference bulk optics solution. Under the general 7% hard-decision forward error correction (HD-FEC) threshold of 3.8e-3, both systems can operate at single lane data rates up to 160 Gb/s, which corresponds to an aggregated data rate of 320 Gb/s. Under the general 20% soft-decision forward error correction (SD-FEC) threshold of 2.4e-2, up to 200 Gb/s are achieved for both systems, corresponding to an aggregated data rate of 400 Gb/s.

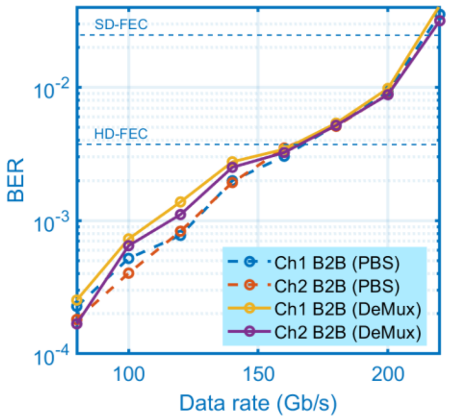

Fig. 3: Reference (PBS) and DeMux system results.

The proposed system can serve as a dynamic polarization controller and can operate at conditions which the polarization state entering the chip is not at optimal, the system can unscramble the crosstalk between the two polarizations and generate clean outputs as shown in our static testing. The proposed system can achieve good performance under a worse signal quality (extra IL and EDFA ASE noise) compared to the reference system, this is because the proposed system can unscramble crosstalk, and this is not possible when using the PBS based solution.

The 2D and 1D grating couplers in the proposed system induced IL of 6 dB and 3 dB, respectively. Total IL of the transceiver is more than 23 dB and was compensated using EDFA in this proof-of-concept demonstration. We expect improvements in the grating couplers and the availability of high speed transimpedance amplifiers for the receiver would remove the need for EDFA.

We believe with an improved chip design and reducing the IL, our proposed system can outperform the reference system.

Conclusion

We proposed and demonstrated an integrated solution for polarization demultiplexing, the on-chip MRR based demultiplexer can effectively separate and unscramble polarization multiplexed signal, up to 400 Gb/s aggregated data rate is achieved and can be used for future 400 Gb/s × 8 = 3.2 Tb/s transceivers.

Acknowledgements

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