Integrated Silicon Photonics Transmitter and Receiver Array Modules Enabling 1 Tb/s Interboard Optical Interconnect over 8-channel Polymer Optical Waveguide

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Abstract: 1-Tb/s PS-PAM-4 interboard optical interconnect using integrated SiPh transmitter and receiver array modules over an 8-channel polymer optical waveguide is proposed and experimentally demonstrated, achieving a low-cost and high-speed solution for short-range optical interconnects. © 2024 The Author(s)

1. Introduction

With the rapid development of technology, artificial intelligence (AI) is gradually penetrating into our lives, bringing us unprecedented changes and convenience. The widespread application of AI technology has shown enormous potential in various fields, and it is becoming an indispensable part of our daily lives. These AI deep learning models, such as ChatGPT, undoubtedly require large capacity and low latency transmission networks to support the effective collaboration between thousands of high computing power chips [1,2]. Therefore, high-performance transmission network is essential. However, the conventional electronic interconnection has limited bandwidth and high-power consumption. Optical interconnection technology provides an effective solution [3-4].

Compared to electrical interconnection, optical interconnection has many advantages such as low latency, large bandwidth, and low power consumption. From the perspective of connection structure, optical interconnection can be divided into chip-to-chip optical interconnects, board to board optical interconnects, and device to device optical interconnects. We have achieved 230-Gb/s on-chip optical interconnection based on GeSi transceiver [5], and 4.8 Tb/s PS-PAM-8 bidirectional optical interconnection over 10-km 24-core fiber between devices [6]. Usually, interboard optical interconnect requires multiple channels to be interconnected between the transmitter and receiver board. Therefore, adopting a low-cost solution to achieve high-speed interboard optical interconnection is a huge technical challenge and highly demanded.

In this paper, we experimentally demonstrate an interboard optical interconnection of 1.024-Tb/s (128-Gb/s×8) probabilistic shaping pulse amplitude modulation-4 (PS-PAM-4) over 8-channel polymer optical waveguide based on integrated SiPh transmitter and receiver array. The integrated SiPh transmitter and receiver array chips are produced by China Information Communication Technologies Group (CICT), which include 8 independent transmitters and receivers, respectively. Besides, the arrayed polymer optical waveguides with 8-cm length and 7-dB loss at the O-band are used to connect optical signal transmission and reception boards. Finally, an interboard optical interconnection of 1.024-Tb/s PS-PAM-4 signals is successfully achieved using the integrated SiPh transmitter and receiver array with the bit error rate (BER) below the 20% overhead soft-decision forward error correction (SD-FEC) limit of 2.4×10^{-2}.

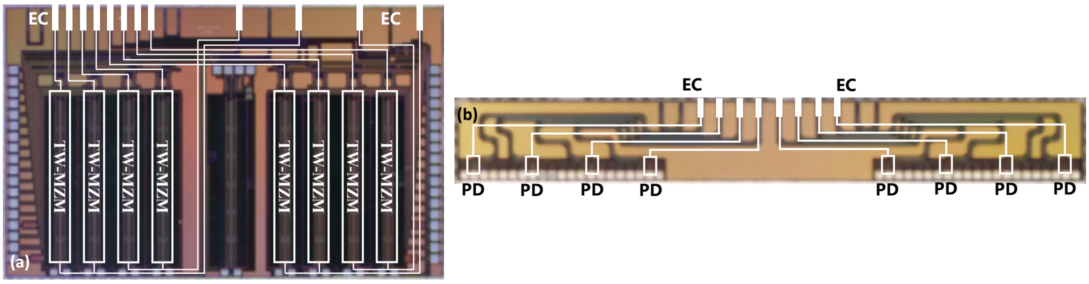

Fig.1 Optical micrograph of the 1×8 all-silicon transmitter (a) and receiver (b) array chip; EC, edge coupler; TW-MZM, traveling wave Mach-Zehnder modulator; PD, photodetector.

2. Configuration of transmitter and receiver array chips

Figure 1(a) shows an eight-channel silicon-based transmitter chip. There are a total of 12 edge couplers (ECs) equipped, of which 4 ECs are used for the input of the lasers and 8 ECs are used for the output of the modulated signals. The modulation part is composed of eight Mach-Zehnder modulators, which are connected to the optical port through optical passive structures such as straight waveguides, beam splitters, curved waveguides, etc. Each modulator is designed with a corresponding on-chip germanium silicon detector and a corresponding thermal phase shifter. Based on monitoring photodetector (MPD), the working status of each modulator can be monitored. The receiver chip is equipped with a total of 8 edge couplers for input of 8-channel transmitted optical signals. The detection part is composed of eight vertical germanium silicon detectors.

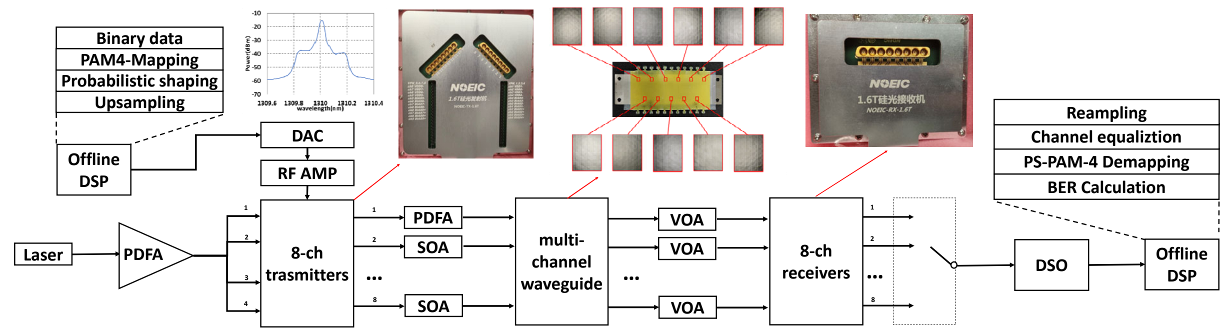

Fig. 2. Experimental setup for the interboard optical interconnection of 1.024-Tb/s PS-PAM-4 signals based on SiPh integrated transmitter and receiver array modules at O-band;

3. Experimental Setup and Results

Figure 2 shows the experimental setup for interboard optical interconnection of 1.024-Tb/s PS-PAM-4 signals based on SiPh integrated transmitter and receiver array modules at O-band. At the transmitter side, signal coding and probabilistic shaping methods are shown in Fig. 2. The original binary data is firstly mapped into PS-PAM-4 symbols. signal probabilistic shaping method is used to map original binary data into PS-PAM-4 symbols. The probability distribution PS-PAM-4 signal conforms to the Maxwell-Boltzmann distribution with net entropy of 1.97, while the transmitted baud rate is 65-GBaud with bit rate of 128-Gbit/s. Then, signals are up-sampled to 256-GSa/s, which is send to the Keysight arbitrary waveform generator (AWG) M8199A, running at 256-GSa/s. The four output signals of two AWGs are all used to drive the 8-ch transmitter to work. The driver with bandwidth of 40-GHz is employed to amplify the signal before injecting into the transmitter. The optical source is amplified using praseodymium doped fiber amplifier (PDFA) and then divided among all channels of the 8-ch transmitter by a 1 × 4 coupler, with the operation wavelength 1310-nm in the experiment. Due to limitations in the number of PDFAs, the modulated optical signal to be tested is amplified using PDFA, and other signals are amplified by semiconductor optical amplifier (SOA).

The optical interconnection link is composed of a multi-channel polymer optical waveguide. The used polymer optical waveguide with core size of 10μm×10μm and total length of 8-cm is made up of hybrid organic and inorganic materials, fabricated by a 365-nm wavelength UV lithography, and placed on a FR-4 substrate. The MT connectors are used to package the inputs and outputs of optical waveguide, which are fixed to the waveguide by UV curing. With MT package, both inputs and outputs are connected with single mode fiber via APC connectors.

At the receiver, a variable optical attenuator (VOA) is placed in front of the multi-channel receiver, which is used to measure the receiver sensitivity. The output electrical signal of the chip is injected into a digital sampling oscilloscope (DSO) operating at 256-GSa/s with a cutoff frequency of 59-GHz, and the signals are then processed offline. For digital signal processing (DSP), resampling is first used, which makes the sampling rate to be twice the baud rate of the transmitted signal. Then, only linear equalization is employed for signal equalization. Finally, PS-PAM-4 are input into the decoder to recover the original binary stream, and BER calculation is performed.

4. Results and Discussions

We first investigate the influence of different wavelengths on the performance of optical interconnection. Fig. 3 (a) shows the performance of the PS-PAM-4 signals and the insertion loss of the polymer optical waveguide under the condition of different wavelengths. It is observed that when the insertion loss of the optical waveguide is minimized, the transmission performance of the system is optimal. The optimal wavelength in the proposed method is about 1310-nm. Fig. 3 (b) shows the spectrum of the unmodulated light signals of the tested channel with and without other channel RF input signals. We can see that even if all other RF signals are loaded onto the chip, there will be no interference with the tested signal.

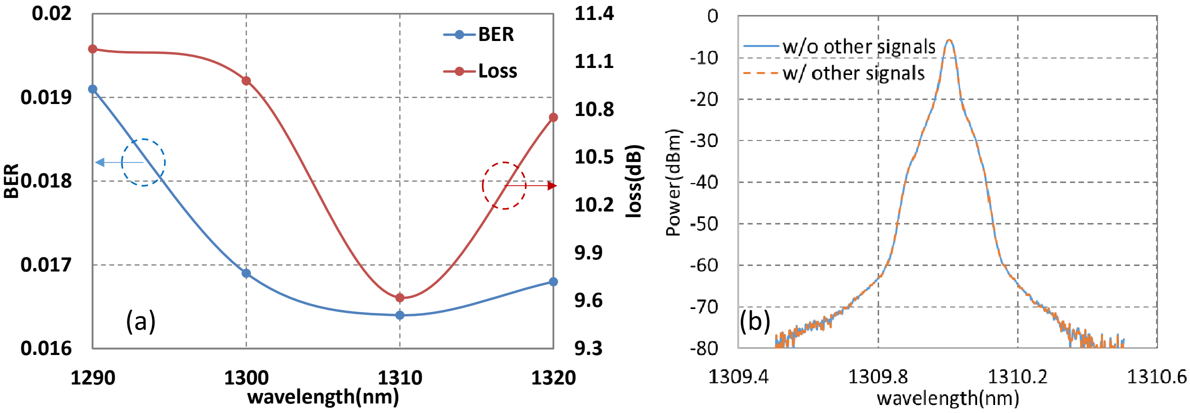

Fig. 3 (a) Measured curve of BER versus wavelength and Loss versus wavelength; (b) Signal spectrum with and without other channel signals

We also study the interconnection performance of PS-PAM-4 in multi-channel polymer optical waveguide. Figure 4 (a) shows the measured curve of BER versus receiver power of the 8-ch 128-Gbit/s PS-PAM-4 signals in the optical back-to-back (OBTB) case. It is observed that the performances of 8-ch signals are at the same level, and the best and worst receiver sensitivity at the 20% FEC limit are -15.4-dBm and -14.8-dBm, respectively. The performances of the signals transmitted through the optical waveguide are shown in Figure 4 (b). Due to the attenuation introduced through the optical waveguide, the overall performances of the 8-channel signal have decreased. Results show that the best and worst receiver sensitivity at the 20% FEC limit are -14.8-dBm and -14.3-dBm, respectively, and the average transmission cost is about 0.5-dBm.

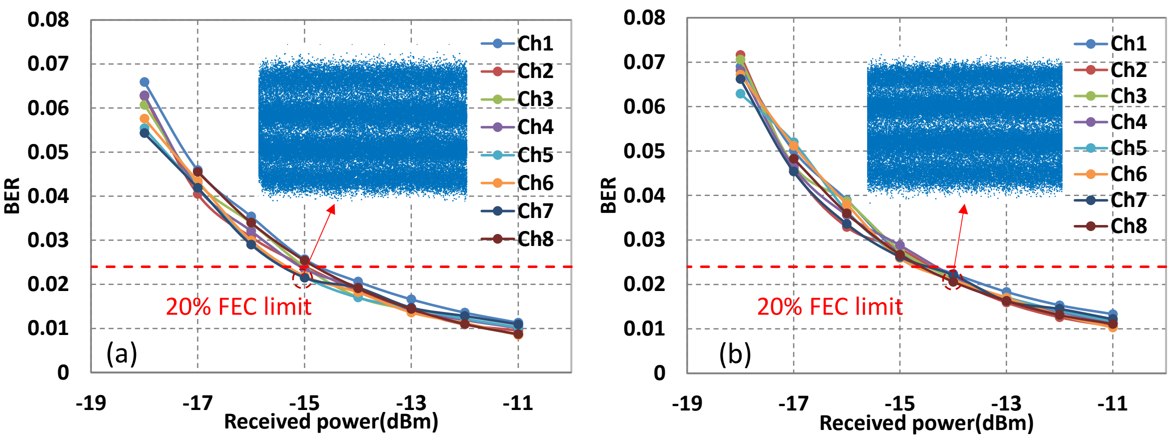

Fig. 4 Receiver sensitivity measured for the 8-ch PS-PAM-4 signals (a) BTB; (b) Connected via optical waveguide

5. Conclusion

Based on the available 90-nm silicon photonics foundry, 8-ch SiPh integrated transmitter and receiver array modules are designed and fabricated, which successfully experimentally enable the interboard optical interconnection of 1.024-Tb/s PS-PAM-4 signals using a multi-channel polymer optical waveguide at the O-band. We believe that the proposed scheme has great potential to achieve low-cost, low-complexity, and high-speed interboard optical links, which can offer a promising upgrade path from electrical interconnection to optical interconnection.

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6. References

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