# 8×250 Gbit/s PAM4 transmission over 1 km single mode fiber with an all-silicon LAN WDM transmitter

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**Abstract:** We demonstrate 2 Tbit/s (8×250 Gbit/s) and 1.6 Tbit/s (8×200 Gbit/s) 4-level pulse amplitude modulation (PAM4) transmissions over 1 km and 10 km single mode fibers (SMF) with an all-silicon wavelength division multiplexing transmitter chip. 

## 1. Introduction

Driven by emerging applications in cloud computing, big data, artificial intelligence, internet of things, industrial internet, etc., the global data traffic is expected to reach 175 ZB by 2025 [1]. To meet the ever-growing demand for data traffic, the next generation optical transceivers in data center are expected to offer the capacities of 800G and beyond [2]. Depending on the specific application scenarios, the transceivers are broadly classified into the parallel single-mode (PSM) fiber transmission and the wavelength division multiplexing (WDM) transmission schemes. In the SR/DR/FR (100 m/500 m/2 km) scenarios, PSM transmissions such as PSM4 and PSM8 [2, 3] serve as the current mainstream solution. In the FR/LR (2 km/10 km) scenarios, coarse wavelength division multiplexing (CWDM) or local area network wavelength division multiplexing (LAN WDM) schemes are the potential candidates for 400G and 800G data rates [4, 5].

In this work, we demonstrate an O band 1×8 LAN WDM PAM4 all-silicon transmitter chip. The bit error rates (BERs) of 170 Gbit/s PAM2, 250 Gbit/s PAM4, and 225 Gbit/s PAM8 for back-to-back (B2B) transmissions are measured to be lower than the 20% soft-decision forward error correction (SD-FEC) threshold (e.g., 2E-2). Furthermore, aggregated 8×200 Gbit/s PAM4 transmission over 10 km SMF and 8×250 Gbit/s PAM4 transmission over 1 km SMF are demonstrated. To the best of our knowledge, it is the first demonstration of the all-silicon LAN WDM PAM4 transmitter chip with capacities of 1.6 Tbit/s and beyond.

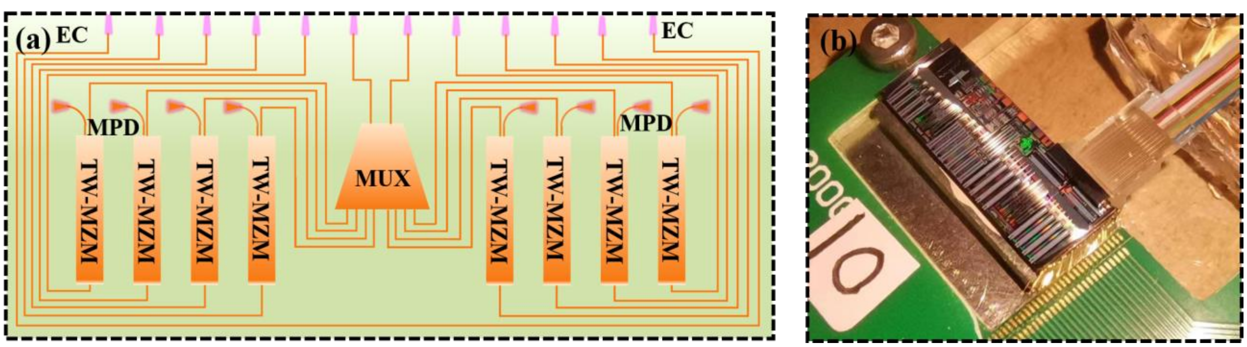


Fig. 1. (a) A floorplan of the 1×8 all-silicon LAN WDM transmitter. EC, edge coupler; MPD, monitoring photodetector; TW-MZM, traveling wave Mach-Zehnder modulator; MUX, multiplexer. (b) Micrograph of the all-silicon transmitter chip packaged on the evaluation printed circuit board (PCB).

## 2. Configuration of the transmitter

A floorplan of the 8-lane all-silicon LAN WDM transmitter chip is shown in Fig. 1. In this chip, 8 traveling wave Mach-Zehnder modulators (TW-MZM) with a 3 dB electro-optical (EO) bandwidth of 60 GHz, 8 monitoring photodetectors (MPD) with a responsivity > 0.9A/W, a flat-passband 8×1 multiplexer (MUX) with a channel spacing of 4.4 nm, and multiple edge couplers (EC) with an insertion loss of 2 dB/facet are integrated monolithically. The total footprint is 7.3 mm×5.7 mm. The spacing between ECs is 250 μm. The 2 outmost ECs are connected by a U-shaped routing waveguide to enable the alignment with the fiber array. In order to avoid the EO crosstalk, the spacing between adjacent TW-MZMs is 625 μm. At the output port of each TW-MZM, 10% of the light is tapped into a MPD to probe the operating point of TW-MZM. Figure 1(b) shows a micrograph of the all-silicon transmitter chip packaged on the evaluation printed circuit board (PCB).

### 3. Performance of the transmitter

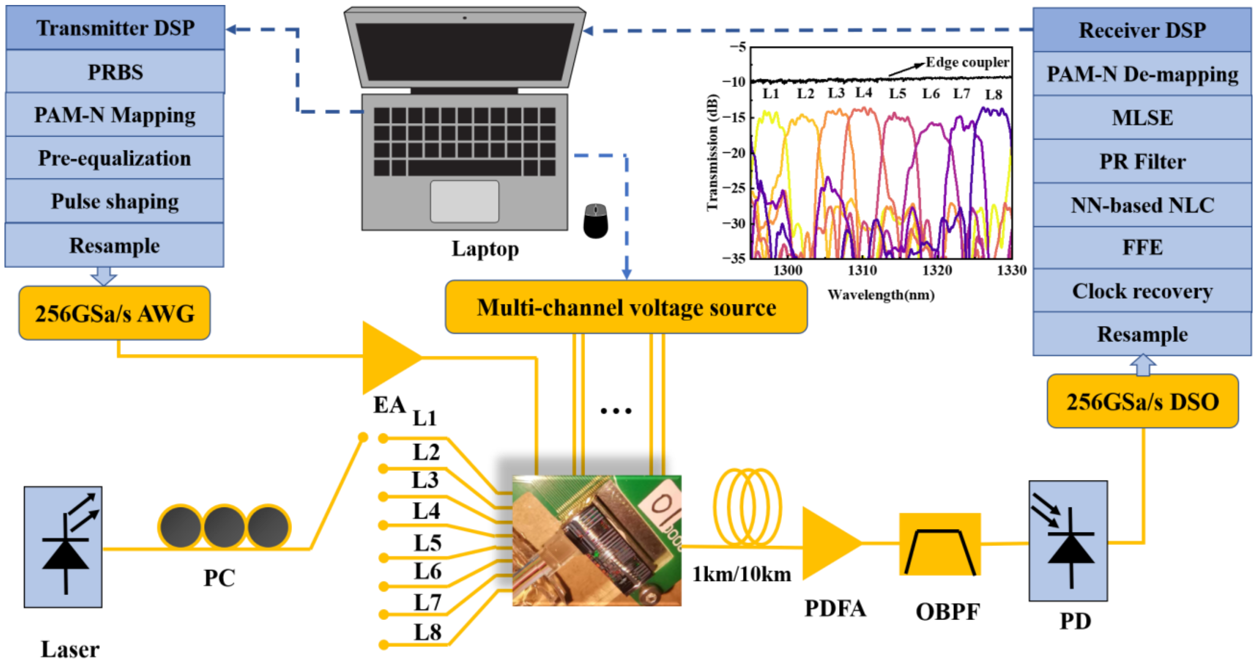


Fig. 2. Testing setup of the PAM4 modulation and transmission measurement. The inset shows the measured transmission spectra of the transmitter. AWG, arbitrary waveform generator; EA, electrical amplifier; PC, polarization controller; PDFA, praseodymium-doped fiber amplifier; OBPF, optical bandpass filter; PD, photodiode; DSO, digital storage oscilloscope; SMF: single mode fiber; PRBS, pseudo-random binary sequences; FFE, feedforward equalization; NN-based NLC, neural network-based nonlinear compensation; PR Filter, partial response filter; MLSE, maximum likelihood sequence estimation.

The testing setup of the all-silicon transmitter chip is shown in Fig. 2. Inset of Fig. 2 shows the measured transmission spectra of the transmitter. The channel spacing of lane 1-lane 8 (L1-L8) is 4.4 nm. The overall loss of the transmitter is about 14-16 dB. It is noted that the insertion loss of referenced optical I/O ports are ~10 dB which can be attributed to the losses on a 2.5 cm-long routing single mode channel waveguide as well as the misalignment between fiber array and chip. Therefore, in the following iterations, the 410-nm-wide single mode channel waveguide with a propagation loss of 2 dB/cm should be replaced by a 3-um-wide muti-mode rib waveguide with a propagation loss of 0.1 dB/cm to reduce the overall loss. Since 8-channel lasers are not accessible at this time, an O band tunable laser is used to test 8 channels one by one. The electrical baseband data is generated and encoded by a transmitter digital signal processing (DSP) block which consists of pseudo-random binary sequences (PRBS) generation, PAM-*N* mapping, bandwidth pre-compensation, pulse shaping, and resampling procedures. The generated waveform is downloaded into a 60 GHz arbitrary waveform generator (AWG, Keysight M8199A) with a sampling rate of 256 GSa/s, and then is launched into a 55 GHz linear electrical amplifier to boost the driving swing to 2.5 Vpp. To compensate optical coupling and transmission losses, the output fiber is connected to a praseodymium-doped fiber amplifier (PDFA, AMP-FL8611-OB-13) with noise figure of 7 to boost the power to +9 dBm. After the PDFA, an optical bandpass filter (OBPF, EXFO XTM-50) with an insertion loss of 5 dB and a bandwidth of 1 nm suppresses the out-band noise. Finally, the modulated optical signal with a power level of 4 dBm is detected by a 60 GHz PD (Keysight N7005A). The recovered electrical signal without any transimpedance amplifying is captured by a 59 GHz digital storage oscilloscope (DSO, Keysight UXR 0592A) for the subsequent off-line DSP. The receiver DSP block is composed of resampling, clock recovery, feedforward equalization (FFE), neural network (NN)-based nonlinear compensation (NLC), partial response (PR) filter, maximum-likelihood sequence estimation (MLSE), PAM-N de-mapping, and BER counting procedures [8].

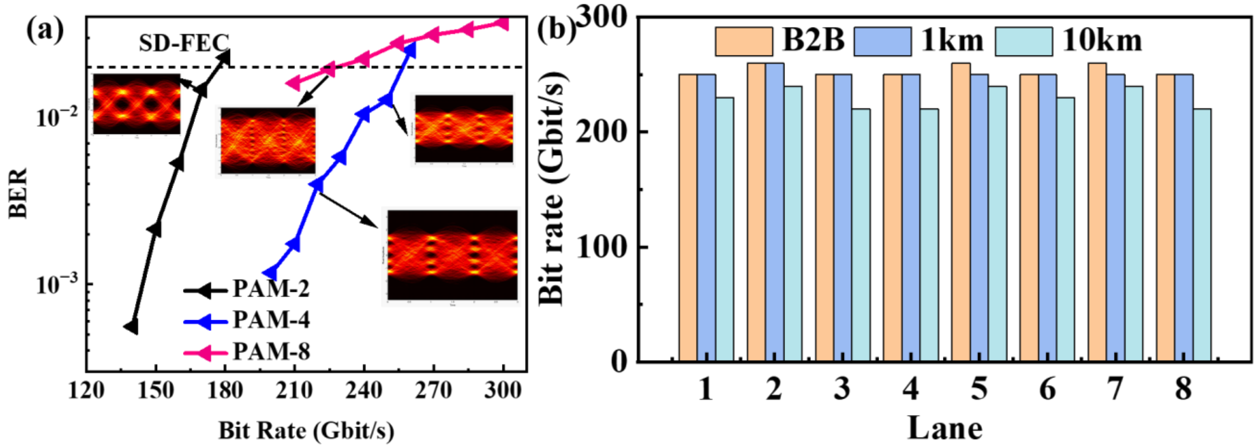


Fig. 3. (a) B2B BERs with respect to different data rates for PAM2, PAM4 and PAM8 signals of a single lane. (c) The highest PAM4 bit rates of 8 lanes with BERs below the SD-FEC threshold for B2B, 1 km and 10 km SMF transmissions.

We firstly explore the optimal order of PAM-*N* modulation to achieve the highest bit rate. In this experiment, we set *N*=2/4/8 to satisfy the Gray coding. To count the BER, we transmit 65536 symbols at the transmitter DSP and capture 51.2k data points at the receiver DSP. In the intensity modulation and direct detection (IM-DD) system, the main impairments are linear impairments, i.e., bandwidth-constrained link, chromatic dispersion (CD) and nonlinear impairments, i.e., intensity modulation and square-law detection, etc. [7, 8]. These impairments can be well overcome by our advanced DSP algorithms [8]. In Fig. 3(a), we plot the B2B BERs as a function of bit rate for PAM2, PAM4 and PAM8 modulations of L4. The measured BERs of 170 Gbit/s PAM2, 250 Gbit/s PAM4, and 225 Gbit/s PAM8 signals are 1.5E-2, 1.3E-2 and 2E-2. They are all below the SD-FEC threshold. Insets of Fig. 3(a) show the eye diagrams at different bit rates and modulation order. According to the result in Fig. 3(a), we select PAM4 format for 1 km and 10 km SMF transmissions. Figure 3(b) shows the highest PAM4 bit rates achieved by all 8 lanes with BERs below the SD-FEC threshold. The results demonstrate the 8×250 Gbit/s PAM4 over 1 km SMF transmission and 8×200 Gbit/s PAM4 over 10 km SMF transmission, respectively.

## 4. Conclusion

We present an O band LAN WDM all-silicon transmitter which is composed of 8 TW-MZMs, 8 MPDs and an 8×1 MUX. An 8×250 Gbit/s PAM4 transmission over 1km SMF is also demonstrated with this chip.

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