850 nm VCSELs Exceeding 40 GHz Bandwidth Enable 200 Gbps Transmission over 100 m Multimode Fiber Link

Zhiteng Luo(1) (3) (4), Hao Qin(2) (4), Tianxiang Lan(2), Huawen Hu(1), Tingyu Cheng(1), Connie J Chang-Hasnain(1) (3), Chuanchuan Yang(2)*, Jiaxing Wang(1)*

(1) Berxel Photonics Co. Ltd, 518071, Shenzhen, China, jiaxing.wang@berxel.com
(2) State Key Laboratory of Photonics and Communications, Peking University, Beijing 100871, China, yangchuanchuan@pku.edu.cn
(3) Key Laboratory of EMW Information (MoE), Fudan University, Shanghai 200433, China
(4) These authors contributed equally

Abstract *We report integrated 850 nm VCSEL-based transceivers achieving 200 Gbps PAM4 and 240 Gbps PAM8 over multimode fiber link, enabled by high-performance VCSEL and low-complexity architecture with integrated VCSEL drivers, demonstrating low-power potential toward 200 Gbps/lane short-reach optical interconnects target. ©2025 The Author(s)*

Introduction

In recent years, the rapid development of technologies such as artificial intelligence (AI), the Internet of Things (IoT), and 5G mobile networks has significantly increased data traffic in data center [1]. Vertical cavity surface emitting lasers (VCSELs), with their advantages of low power consumption and low cost, have become the primary choice for short-reach interconnects in data centers [2]. Current research on 850 nm multimode VCSELs is advancing toward the goal of achieving ultra-high-speed rates of 200 Gbps per channel to address the demands and challenges of next-generation 1.6T/3.2T data transmission in data centers [3]. To the best of our knowledge, Broadcom Inc. has reported 850 nm VCSELs capable of 100 GBd PAM4 optical interconnects [4]. Huawei Inc. has achieved 200 Gbps/lane transmission over multimode links using VCSELs combined with duobinary PAM4 precoding [5]. These encouraging results demonstrate that 850 nm multimode VCSELs are promising candidates for supporting next-generation 200 Gbps/lane optical interconnects.

In this work, we constructed an integrated optical transceiver system based on Berxel 850 nm multimode VCSELs. Leveraging the VCSELs' modulation bandwidth exceeding 40 GHz, we successfully realized 200 Gbps/lane PAM4 and 240 Gbps/lane PAM8 back-to-back data transmission, as well as high-speed transmission of 180 Gbps PAM4 and 225 Gbps PAM8 over 100-meter multimode fiber under the 20% soft-decision forward error correction (SD-FEC) threshold. This work is expected to provide a systematic solution for 1.6T/3.2T optical interconnects based on 850 nm VCSELs.

VCSEL and integrated optics transceiver characterization

The integrated optical transceiver consists of a transmitter and a receiver. The transmitter integrates Berxel VCSELs and a VCSEL driver, supporting up to four differential input channels to achieve 1.6 Tbps data rate in total. Differential signals are input to the driver via board-level electrical connectors. The VCSEL driver incorporates automatic gain control (AGC) and feed forward equalizer (FFE) signal processing functionalities.

The optoelectronic properties of Berxel 850 nm multimode VCSELs shows in Fig. 1. The relative intensity noise (RIN) spectrum is illustrated in the accompanying Fig. 1 (a). Under room temperature (RT) conditions, the measured average RIN of the VCSEL within a 40 GHz bandwidth is approximately -152.58 dB/Hz. Current technical limitations in VCSEL-based short-reach optical

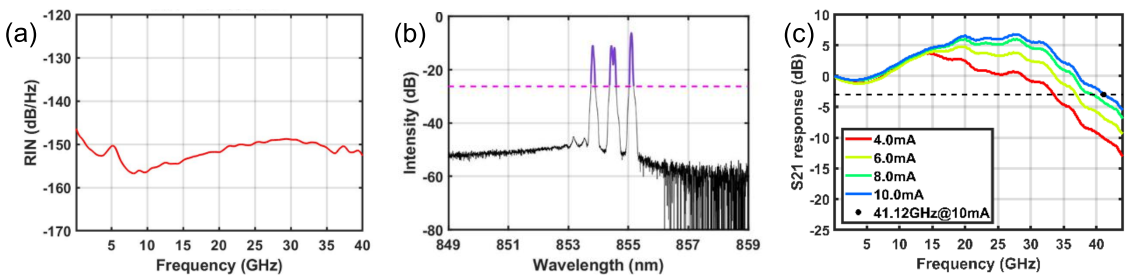

Fig. 1: The optoelectronic properties of Berxel 850 nm multimode VCSELs. (a) The RIN spectrum of the VCSEL. (b) The optical spectrum of the VCSEL. (c) The S21 of directly-modulated VCSEL.

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interconnects lie in the VCSEL bandwidth. To reliably achieve over 200 Gbps/lane, VCSELs typically require bandwidth exceeding 35 GHz and lower noise levels [5]. Notably, Berxel 850 nm multimode VCSEL demonstrates a measured modulation bandwidth of ~40 GHz under a 10 mA bias current in Fig. 1 (c).

The VCSEL array and driver are packaged with wafer bonding, and electrical interconnects between the VCSEL and driver achieved via wire bonding. The receiver comprises a high-speed photodetector (PD) and a transimpedance amplifier (TIA) integrated chip. Unfortunately, the current bandwidth of PD and TIA is only 35GHz, and there is still a problem of bandwidth limitation for the 850nm multimode link communication system, which leads to the limitation of channel capacity.

Experimental setup

The experimental setup is depicted in the Fig. 2. We employed an arbitrary waveform generator (AWG, Keysight, M8199A) as the signal source. PRBS15 pattern is utilized to simulate the data stream in data center. The binary data stream is modulated with Gray encoded PAM4 or PAM8 format, and further compressed in spectrum by the pulse shaping filter to reduce the impact of the bandwidth-limited. We adjusted the bias current of the VCSEL to approximately 10 mA and employed FFE inside the VCSEL driver to compensate for high-frequency signal attenuation. While this method partially mitigates the effects of frequency-dependent attenuation, it concurrently amplifies high-frequency noise, thereby imposing challenges on the signal-to-noise ratio (SNR) margin in the high-frequency regime. The differential electrical signal generated by the AWG is fed into the transmitter through an RF interface, with setting the peak-to-peak voltage of the AWG output amplitude to 450mV. Under the condition, the received optical power at the receiver is approximately 3.1 dBm.

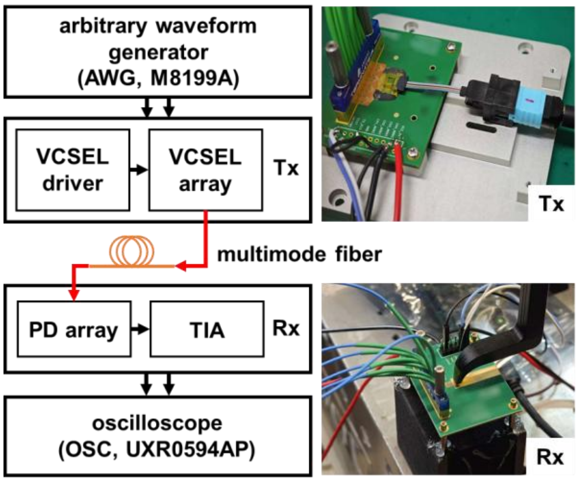

Fig. 2: Experimental setup.

The VCSEL coupled the output light into a multi-mode optical fiber through a micro-lens, and the optical signal is transmitted through a 3 m multimode fiber and converted into an electrical signal by the PD on the receiver. After transimpedance amplification by the TIA, the signal is converted from a single ended to a differential signal output to the oscilloscope (OSC, Keysight, UXR0594AP). Using compensation provided by the equalization function integrated in the TIA and Volterra equalizer digital signal processing (DSP). The receive signal from the oscilloscope after synchronization and demodulation, compares with the transmitted binary data stream to obtain the bit error rate (BER). Furthermore, by calculating the noise power introduced by the system through the transmitted and received signals, we compute the system's SNR.

Experimental result

We conducted signal transmission experiments using PAM4 and PAM8 modulation formats over optical links based on an 850nm VCSEL, including back-to-back (BTB) and 100m

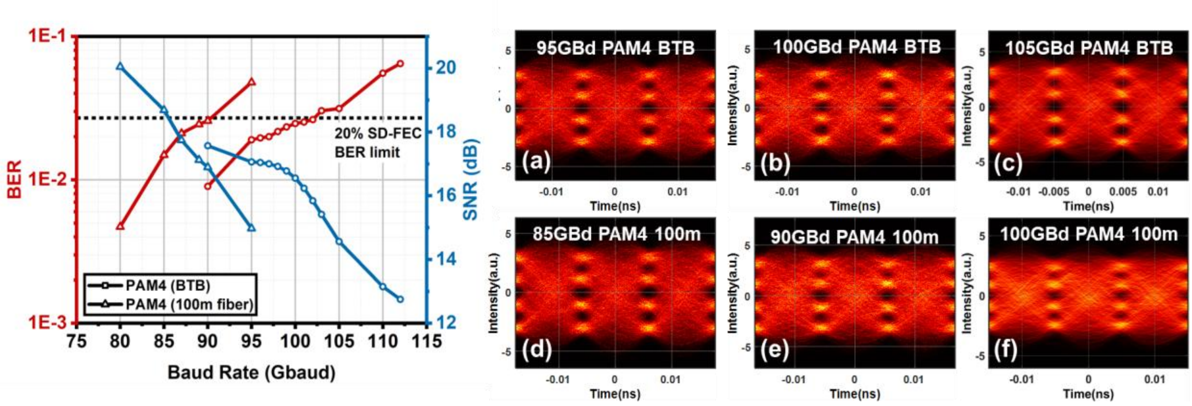

Fig. 3: PAM4 signals transmit BER and SNR in back-to-back and 100m MMF links. (a)-(f): eye diagrams of 95 GBd BTB, 100 GBd BTB, 105 GBd BTB, 85 GBd 100m, 90 GBd 100m, 100 GBd 100m

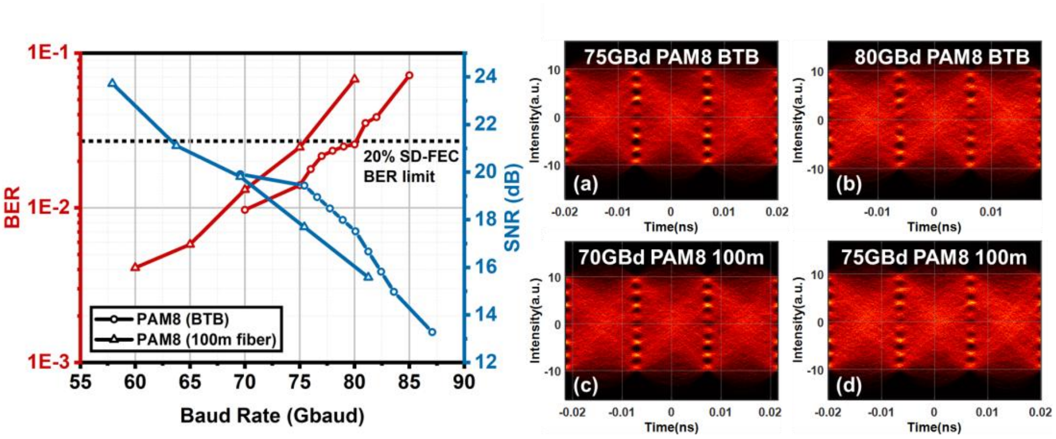

Fig. 4: PAM8 signals transmit BER and SNR in back-to-back and 100m MMF links. (a)-(d): eye diagrams of 75GBd BTB, 80GBd BTB, 70GBd 100m, 75GBd 100m

OM4 multimode fiber scenarios. The evolution of BER under varying signal transmission rates is analyzed, along with the SNR redundancy conditions required for error-free transmission. Additionally, we present the received eye diagrams for PAM4 and PAM8 signals under the critical error-free threshold, as shown in Fig. 3 and Fig. 4.

As shown in Fig. 3, the BER increases with the baud rate for both BTB and 100m MMF transmissions. This phenomenon is primarily attributed to the intensified inter-symbol interference (ISI) and accumulated noise at higher baud rates. In the BTB scenario, the BER remains below the 20% SD-FEC threshold at a baud rate of 100 GBd, indicating high reliability for short-distance transmissions. At this point, digital signal processing at the receiver is essential, and the received signal exhibits an SNR of 16.55 dB. For a 100-meter multimode fiber transmission, the maximum achievable PAM4 signal baud rate is 90 GBd, with the corresponding received signal SNR reaching 16.89 dB. Compared with the BTB transmission link, dispersion in 100m MMF transmission seriously affects the bandwidth of signal transmission, while PAM4 signals require a higher transmission bandwidth and therefore are more severely affected. It is worth noting that we simultaneously conducted eye diagram tests for 200 Gbps signals in 100 m multimode fiber transmission. At the receiver side, we were able to observe discernible eye openings, indicating that the communication system retains a certain SNR margin. However, owing to bandwidth limitations inherent in the transmission medium, the BER performance still exhibits room for further optimization through systematic improvements. This observation suggests that while the current implementation demonstrates basic functionality, there remains potential for enhancing transmission quality by addressing bandwidth constraints and optimizing system parameters.

The experimental results for PAM8 signal transmission are presented in Fig. 4. PAM8 signals are successfully transmitted at 240 Gbps over the BTB link and at 225 Gbps over the 100 m MMF link. Under the error-free threshold, the SNR of the received signal is approximately 17.6 dB for both the MMF and BTB links, with the transmission rate reduced by 10 Gbps. Notably, the transmission rate is less affected by the signal link in the case of PAM8 format compared to PAM4 format. This is mainly because PAM8 has lower bandwidth requirements than PAM4, making it less susceptible to nonlinearity in bandwidth constrained systems.

Conclusions

We present experimental demonstrations of PAM4 and PAM8 modulated signal transmission using Berxel 850nm VCSELs in both BTB and 100-meter multimode fiber links. Leveraging the superior performance of Berxel VCSELs with over 40 GHz modulation bandwidth, we achieved error-free transmission of 200 Gbps PAM4 in BTB configuration and 225 Gbps PAM8 over 100m MMF under the 20% SD-FEC threshold. In our ongoing research on 850nm multimode VCSELs targeting next-generation 1.6T/3.2T short reach interconnect applications, enhancing modulation bandwidth and reducing RIN remain primary objectives. Furthermore, we aim to optimize packaging designs to minimize parasitic parameters and improve system performance.

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