56G VCSEL Transmission at 980 nm across 500 m Multimode Fiber

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Abstract: Transmission of 56-Gbps signals across a 500-meter 980 nm optimized multimode fiber with 14.2 GHz·km bandwidth using 980 nm multimode VCSEL is demonstrated. The results show promising performance within IEEE standards for short reach applications. © 2024 The Author(s)

1. Introduction

The exponential growth of data traffic, driven by applications such as cloud computing, high-definition video streaming, 5G connectivity, and AI computing requires innovations that can accommodate the increasing data volumes while maintaining low latency and high reliability. Vertical-cavity surface-emitting laser (VCSEL) based transceivers working with multimode fibers (MMFs) is the preferred solution for short reach transmission due to its low cost and low power consumption [1].

Current MMF systems use 850 nm VCSELs and 850 nm optimized MMFs. As the data rate increases beyond 100G, the chromatic dispersion of MMFs at 850 nm, which is around -95 ps/(nm·km) could become a limiting factor. One solution is to use VCSELs and MMF optimized for high bandwidth at a longer wavelength, for example 980 nm [2]. The long wavelength MMF system retains the advantage of low loss coupling and passive alignment of conventional 850 nm MMF systems. At the same time, the chromatic dispersion and attenuation of the fiber are significantly lower at a longer wavelength. 980 nm VCSELs provide several advantages such as large gain, temperature stability over a wide range, and high wear out robustness [3]. Longer wavelength VCSELs such as 980 nm attract much attention in the industry due to their inherent advantages such as possibility of incorporating binary GaAs layers in DBRs, backside emission through transparent GaAs substrates, and superior reliability due to pinning of dislocation growth in high In-content QWs with sufficient compressive strain [4]. Nevertheless, to our best knowledge, 980 nm transmission has so far only been published for MMF fiber distances of 100 m or below. The best result is data transmission at 55 Gbps over 100 meters of MMF [5].

In this paper, we report a 56 Gbps transmission experiment using a 980 nm VCSEL over 500 m of MMF optimized for 980 nm, thus significantly increasing the distance of high data rate MMF transmission at 980 nm.

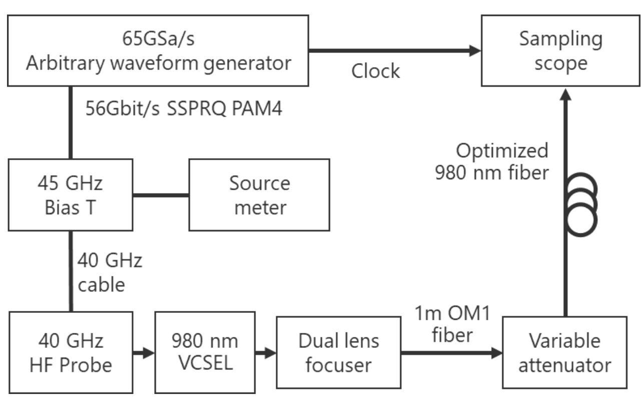

Fig. 1 56 Gbit/s PAM4 transmission test setup for 980 nm VCSEL and 100 m to 500 m of optimized MMF.

2. Experiment

The influence of different optical fiber distances in our 980 nm link is studied in a performance assessment setup shown in Fig. 1. The electrical signal is produced by a Keysight M8195A arbitrary waveform generator (AWG), connected to the 980 nm VCSEL, which is operated at 7.5 mA, via a 45 GHz bias T and a 40 GHz probe. The AWG modulation is set to ensure a 4 dB extinction ratio for the received signal. The VCSEL output is coupled into a 1 m long OM1 MMF via a dual lens focuser. The OM1 fiber is linked to a variable attenuator to adjust the signal level. In our experiment, the attenuation is set to 3 dB. After the attenuator, the optical signal is coupled to a series of 980 nm optimized MMFs under test with lengths from 100 m to a total maximum length of 500 m with 100 m increment. After transmitting through the MMFs, the output signal is sent to the sampling scope for transmission performance analysis.

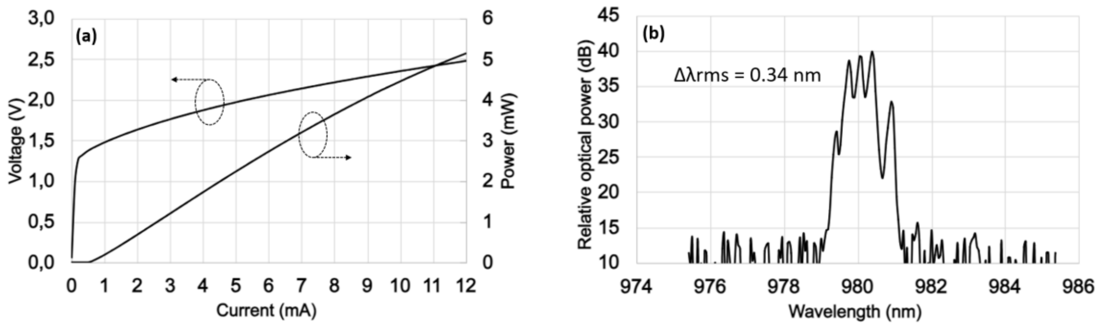

Fig. 2 (a) Measured LIV curves. (b) Measured optical spectrum at 7.5 mA.

A 26.5625 GBaud SSPRQ test pattern is generated via the AWG, set to a rate of 65 GS/s, in accordance with the IEEE 802.3cd standard [6]. The sampling scope is used to quantify the optical output power, equalize the signal with a 5-taps equalizer, generate the eye-diagram of the received signal, and compute the TDECQ (Transmitter and Dispersion Eye Closure Quaternary) [5]. The TDECQ parameter serves as a crucial quality metric for PAM4 signals, assessing the penalty relative to an ideal transmitter. A TDECQ value of 1 dB is equivalent to the performance of an ideal transmitter. Higher values signify inferior performance, whereas values below 4.4 dB are deemed acceptable.

The VCSEL used in the experiment is grown by metalorganic vapor phase epitaxy (MOVPE) and consists of InGaAs quantum wells, AlGaAs p- and n-DBRs, and a high Al-content AlGaAs layer in the p-DBR to form an oxidation layer for current and optical confinement. The VCSEL design and growth are optimized to satisfy requirements on manufacturability, performance, and reliability. The VCSEL shows a superior electro-optical performance enabling 56 Gbps data transmission at 980 nm. Measured room temperature LIV curves and optical spectrum at 7.5 mA are plotted in Fig. 2. The measured VCSEL has a threshold current of 0.6 mA and shows a voltage drop of 2.2 V and an optical output power of 3.4 mW at 7.5 mA bias current. The VCSEL operates in multiple transverse modes at 7.5 mA bias current with an RMS spectral width of around 0.34 nm. Such low values for spectral width can reduce the effects of fiber dispersion and increase the transmission distance.

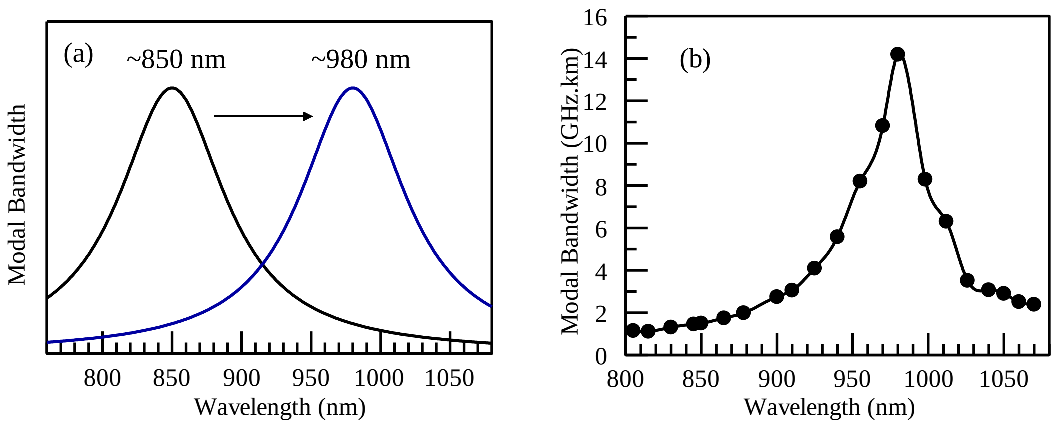

Fig. 3 (a) Schematic showing wavelength dependence of 850 nm and 980 nm optimized MMFs. (b) Measured modal bandwidth of the experimental MMF over a range of wavelength 805-1070 nm.

The fiber used in the experiment is an MMF optimized for 980 nm wavelength. Currently, the most common MMFs used are OM3 and OM4 specified to have 2000 MHz·km and 4700 MHz·km effective modal bandwidth (EMB) at 850 nm. They are largely optimized for operation around 850 nm as shown in the 850 nm modal bandwidth curve in Fig. 3(a). Although IEC 60793-2-10 has specified the EMB over wavelength, the wavelength range is from 840 nm to

953 nm. At 980 nm, the modal bandwidths of OM3 and OM4 are only 0.91 GHz·km and 1.28 GHz·km, respectively, which would limit the transmission reach at 980 nm. To enable longer transmission reach, we optimize MMF by shifting the peak wavelength bandwidth near 980 nm as illustrated in Fig. 3(a) [1]. An experimental MMF with 50 μm core diameter is fabricated according to the design. The modal bandwidth is measured over the wavelength range of 805 nm to 1070 nm. The launch condition is an encircled flux launch condition (set by ModCon mode controller from Ardent Photonics), a typical launch condition used for VCSEL transmission. Fig. 3(b) shows the measured bandwidth. The MMF has a modal bandwidth of 1.5 GHz·km at 850 nm. By shifting the peak wavelength to around 980 nm, we successfully increase the modal bandwidth to 14.2 GHz·km, thus providing the opportunity for excellent transmission performance at 980 nm. The fiber samples are prepared for the transmission experiment with lengths of 100 m, 200 m and 200 m in three samples with FC/PC connectors in the fiber ends, which allow us to construct different fiber lengths from 100 m to 500 m for system testing.

3. Results and discussions

The influence of the optical fiber length on the optical link quality is shown in Fig. 4 (a). We observe an optical power penalty of 2.62 dB/km. The TDECQ increases from 1.1 dB at the minimum fiber length of 2 m to 2.85 dB at the maximum length of 500 m. In this distance range the TDECQ shows a linear relation to the distance. Even at longest fiber length of 500 m, the value is staying far below the acceptance criteria for the IEEE 56G standard providing room for other link deteriorating factors such as clock-recovery, temperature etc. The good link performance is shown in the optical eye-diagrams in Fig. 4 (b). Open eyes are achieved up to the longest MMF fiber distance of 500 m.

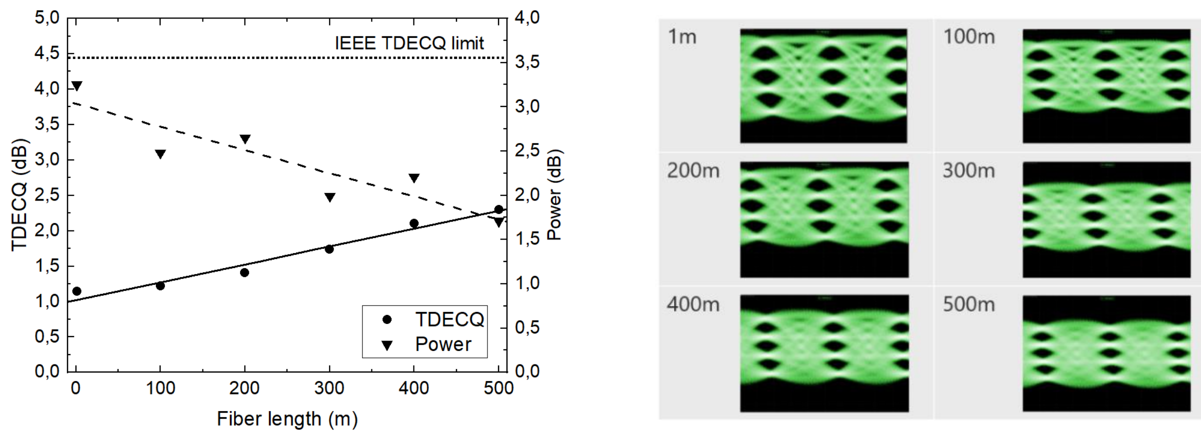

Fig. 4 (a) 56 Gbit/s PAM4 TDECQ and optical power as function of fiber length. (b) Eye-diagrams of 5-taps equalized signal.

4. Summary and Conclusion

We have demonstrated 56G PAM4 transmission using a 980 nm multimode VCSEL across 500 m of optimized MMF. Via the optimized MMF with a measured modal bandwidth of 14.2 GHz·km we increase the maximum transmission reach at 980 nm to 500 m while fulfilling the IEEE standards. Low TDECQ values provide margin for further link optimization and demonstrate the potential for use in IEEE standard short reach applications. Our experimental results demonstrate that 980 nm VCSEL systems are attractive for high data rate optical interconnect applications in data centers.

5. References

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[6] IEEE Standard for Ethernet - Amendment 3, IEEE Standard 802.3cd, 2028