225-Gb/s PAM4 Operation Using Lumped-Electrode-Type EA-DFB Laser for 5- and 10-km Transmission with Low TDECQ

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Abstract: Both 5-km and 10-km transmission was demonstrated under 225-Gb/s PAM4 operation using EA-DFB lasers. We confirmed low TDECQ values of 2.0~3.2 dB for 5 km in the CWDM range and 10 km at 1293.5 nm. © 2023 The Author(s)

1. Introduction

Intra-data center communication traffic is increasing sharply. Thus, installing 400-Gbit Ethernet (400GbE) transceivers has become standard. For next-generation Ethernet, further improvement of Ethernet capacity is required. 800-Gbit Ethernet (800GbE) and 1.6-Tbit Ethernet (1.6TbE) [1] are under active discussion and standardization to meet demands. 112.5-Gbaud 4-pulse amplitude modulation (PAM4) has been proposed for 800G-FR4 [2] since PAM4 is technology used in 400GbE. The CWDM4 band is assigned for the wavelength of light sources for 800G-FR4, and a transmission distance of 2 km is regulated for it. In a previous report of 2021, our group reported 224-Gb/s uncooled operation of a lumped electrode (LE)-type electro-absorption modulator-integrated distributed feedback (EA-DFB) laser [3]. In a recent report, 2-km transmission of 200 Gb/s PAM4 using a semi-cooled LE-type EA-DFB laser with L0 and L3 wavelengths in the CWDM4 band was demonstrated [4]. To address an even further long reach such as 10-km transmission of 200 Gb/s PAM4, 800G-LR4 [1] standardization is under discussion. One candidate is to use the LAN-WDM wavelength range from 1294.53 nm to 1310.19 nm, for which chromatic dispersion is lower than that of the CWDM wavelength range.

In this report, we demonstrate 5-km transmission of 225-Gb/s PAM4 using the LE-type EA-DFB laser with the CWDM4 band under semi-cooled operation for a longer transmission distance than 800G-FR4. This results in the longest ever 200-Gb/s class PAM4 transmission distance using a LE-type EA-DFB laser with the CWDM4 band, to the best of our knowledge. TDECQ after 5-km transmission was confirmed to be less than 3.2 dB in all lanes with an outer-extinction ratio (OuterER) of 4.5 dB. In addition, the deterioration in TDECQ through 5-km transmission was less than 1 dB in all lanes. We also evaluated 10-km transmission of 225-Gb/s PAM4 using LE-type EA-DFB laser lasing at 1293.5 nm, which is almost the same as the shortest wavelength of LAN-WDM. A clear eye opening was obtained after 10-km transmission with a low TDECQ of 2.2 dB.

2. Device structure and static characteristics

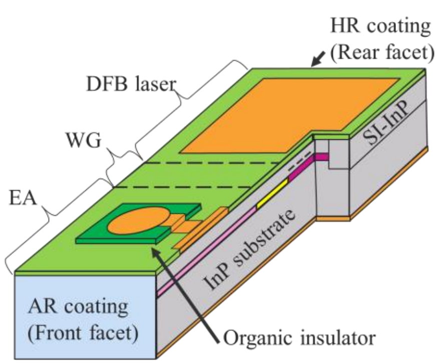


Figure 1: Schematic view of LE-type EA-DFB laser.

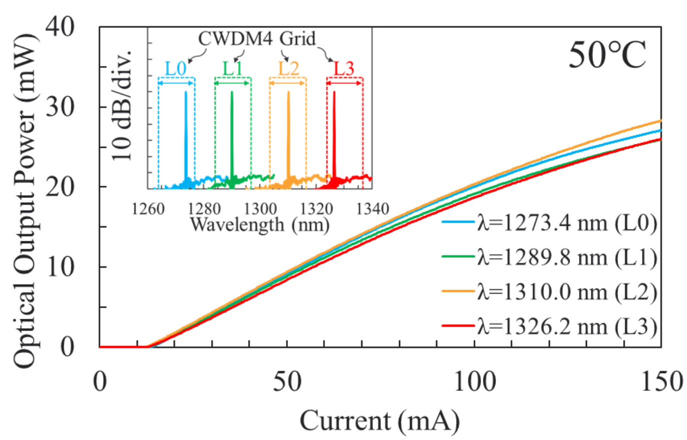


Figure 2: I-L characteristics and lasing spectra (50°C).

Figure 1 shows a schematic view of the LE-type EA-DFB laser. We designed the device in reference to the technology reported in [3]. The detuning between the lasing wavelength of the DFB laser and the edge of the absorption spectrum at the EA modulator was optimized for each lane to adjust the balance between the extinction ratio and output optical power. This EA-DFB laser is for operating optimally at around 50°C since semi-cooled operation can reduce the power consumption of the thermoelectric cooler (TEC). Figure 2 shows I-L characteristics and the lasing spectra of the developed EA-DFB laser at 50°C. Each spectrum represents lasing in the area enclosed by a dashed line, which indicates the CWDM4 band. The lasing wavelength was 1273.4 nm for L0, 1289.8 nm for L1, 1310.0 nm for L2, and 1326.2 nm for L3, and a stable single mode was obtained with a side-mode suppression ratio of over 40 dB. The optical output power was over 18 mW at 100 mA in all lanes.

3. Evaluation of 225-Gb/s PAM4 transmission

Figure 3 shows the experimental setup for 225-Gb/s PAM4 transmission. An electrical signal was generated by an arbitrary waveform generator (AWG, Keysight M8199A) with 256 GSa/s. The test pattern was SSPRQ (Short Stress Pattern Random Quaternary). The signal from the AWG was amplified by the RF amplifier with a 67-GHz bandwidth. The voltage swing of the electrical signal was set to 1.0 Vpp with 5-tap pre-emphasis. The electrical signal and DC bias voltage were applied to the EA modulator via a bias tee, ground-signal-ground (GSG) probe, and RF line of the chip carrier. The temperature of the EA-DFB laser bonded on the chip carrier was set to 50°C by using a TEC. The operating current of the DFB laser was set to 100 mA. The optical output of the EA-DFB laser was coupled to a lensed single-mode fiber (SMF) and transmitted through 5-km or 10-km SMF. The transmitted signal was detected by a digital communication analyzer (DCA, Keysight N1030A). The detected optical signal was equalized by a TDECQ filter and fourth-order Bessel-Thomson filter. The calculation of TDECQ was compliant with 800G-FR4 [2].

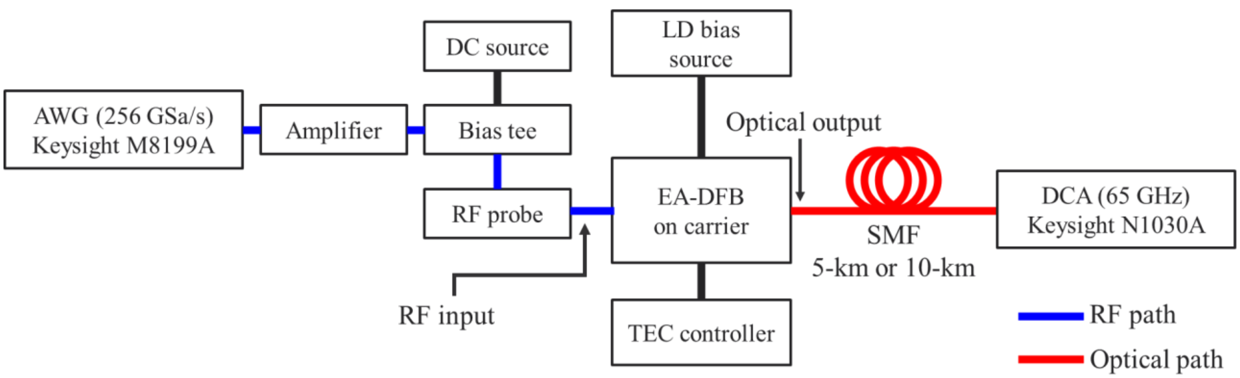


Figure 3: Experimental setup for 225-Gb/s PAM4 transmission.

Figure 4 shows the detected optical PAM4 waveforms of EA-DFB lasers for back-to-back (BTB) and after 5-km transmission. The zero-dispersion wavelength of the 5-km SMF was 1307.2 nm, and the dispersion values of each EA-DFB laser were -13.99 ps/nm for L0, -7.2 ps/nm for L1, 1.17 ps/nm for L2, and 7.88 ps/nm for L3. The EA bias voltage of each lane was set for OuterER to be about 4.5 dB. As a result, clear eye openings were obtained for BTB and after 5-km transmission for each wavelength. The average output power (Pave) was over 9 dB at the chip facet. If we refer to the specifications for 800G-FR4, our devices have a sufficient optical output power assuming 3-dB fiber coupling loss. TDECQ after 5-km transmission was confirmed to be less than 3.2 dB in all lanes. These TDECQ values met a specification of 800G-FR4, that is, TDECQ < 3.9 dB. In particular, for L1 and L2, TDECQ was almost the same between BTB and after 5-km transmission. This is because L1 and L2 are close to the zero-dispersion wavelength of the fiber. Though L0 and L3 have more of a dispersion effect than L1 and L2, a low TDECQ was observed. In addition, TDECQ deteriorated less than 1 dB in all lanes. This superior transmission performance was due to the appropriate chirp design for the EA modulator. Such low TDECQ and its small deterioration suggest that our LE-type EA-DFB laser could be applicable to 225-Gb/s 5-km transmission in the CWDM4 band.

In addition, we evaluated 10-km transmission of 225-Gb/s PAM4 using the LE-type EA-DFB laser, with lasing performed at 1293.5 nm. This wavelength is almost the same as the shortest wavelength for LAN-WDM. We performed the evaluation with the same setup as shown in Figure 3. The zero-dispersion wavelength of the 10-km fiber used was 1306.4 nm, and the dispersion value of the measured EA-DFB laser was -11.2 ps/nm. Figure 5 shows the waveform after 10-km transmission. A clear eye opening was obtained after 10-km transmission without an optical amplifier. TDECQ after 10-km transmission was 2.2 dB, and this value was almost the same as the TDECQ of BTB. This means that our EA-DFB laser also has the potential to be used for 800G-LR4 applications.

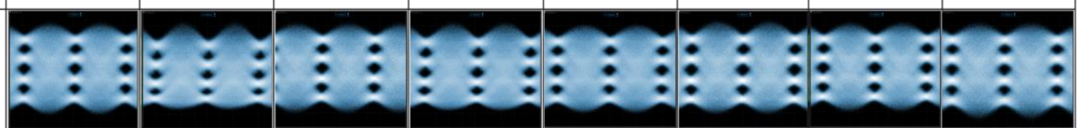
	225-Gb/s PAM4 in CWDM4, 50°C							
Lane	L0		L1		L2		L3	
Transmission Distance	BTB	5-km	BTB	5-km	BTB	5-km	BTB	5-km
Waveform OuterER = 4.5 dB								
λ (nm)	1273.4		1289.8		1310.0		1326.2	
Pave (dBm)	9.3		9.3		9.2		9.0	
TDECQ (dB)	2.2	3.2	2.2	2.0	2.2	2.1	2.2	2.8

Figure 4: Optical waveforms of 225-Gb/s PAM4 in CWDM4, at BTB, and after 5-km transmission with TDECQ filter.

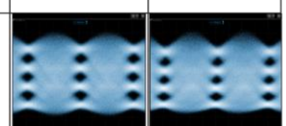
	225-Gb/s PAM4, 50°C	
Transmission Distance	BTB	10-km
Waveform OuterER = 4.5 dB		
λ (nm)	1293.5	
Pave (dBm)	9.0	
TDECQ (dB)	2.3	2.2

Figure 5: Optical waveforms of 225-Gb/s PAM4 at 1293.5 nm for BTB and after 10-km transmission.

4. Conclusion

We developed a LE-type EA-DFB laser and demonstrated 5-km transmission of 225-Gb/s PAM4 using the laser with the CWDM4 band under 50°C operation. In an evaluation of this 5-km transmission, the electrical signal was set to a 1.0-Vpp swing with 5-tap pre-emphasis, and the EA bias voltage was set for OuterER to be about 4.5 dB. As a result, TDECQ after 5-km transmission was confirmed to be less than 3.2 dB in all lanes. This indicates that our EA-DFB laser is a promising light source for 800G-FR4 and could be available even for longer reach applications for 5 km in CWDM4. We also evaluated 10-km transmission of 225-Gb/s PAM4 with the EA-DFB laser with a 1293.5 nm wavelength and obtained a clear eye opening without an optical amplifier. TDECQ after 10-km transmission was 2.2 dB, and this value was almost the same as the TDECQ of BTB. Our EA-DFB is also an attractive candidate as a light source for 10-km applications such as 800G-LR4.

5. References

[1] IEEE P802.3df 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force, https://www.ieee802.org/3/df/index.html, accessed on 30 September 2022.

[2] 800G Pluggable MSA, https://www.800gmsa.com/, accessed on 21 April 2022.

[3] S. Yamauchi, K. Adachi, H. Asakura, H. Takita, Y. Nakai, Y. Yamaguchi, M. Mitaki, R. Nakajima, S. Tanaka, and K. Naoe, “224-Gb/s PAM4 Uncooled Operation of Lumped-electrode EA-DFB Lasers with 2-km Transmission for 800GbE Application,” in Proc. OFC, Tu1D.1., 2021.

[4] X. Chen, R. Cronin, H. Wang, M. Pate, P. Liao, K. Bian, J. Zhao, L. He, J. Liu, E. Repiso, D. Rogers, C. Wang, G. Berry, X. Liu, and B. Zhou, “A Low Chirp Electroabsorption Modulated Laser Suitable for 200Gb/s PAM4 CWDM Transmission over 2km,” in Proc. ECOC, Th1E.4. 2022.