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420 Gbps PAM8 Operation Using 93 GHz Bandwidth Lumped-Electrode Type EA-DFB Laser at 50°C beyond 400 Gbps/lane

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Abstract *420 Gbps (140 Gbaud) PAM8 operation using a lumped-electrode EA-DFB laser was demonstrated with clear eye-openings over 500 m and 2 km transmissions. The output power and the extinction ratio were 9.1 dBm and 3.7 dB, respectively, with 0.9 Vpp swing at 50°C. ©2022 The Author(s)*

Introduction

800 Gigabit Ethernet (800GbE) and 1.6 Terabit Ethernet (1.6TbE) [1] are under active discussion and standardization to meet the demand of increased data center traffic. On short reach communication, 112.5 Gbaud 4 pulse amplitude modulation (PAM4) has been proposed for 800G-FR4 [2] due to the simple intensity modulation and direct detection (IM/DD) scheme and its twice bitrate per symbol rate.

Recently, 3.2 Tbps transceivers have appeared on the agenda of an international conference [3], with the form-factor and the optical channel format being under discussion. On the optical channel format, digital coherent communication is being discussed due to its advantages in high bitrate per lane, high receiver sensitivity, and electrical compensation of chromatic dispersion. On the other hand, the format of IM/DD and PAM has advantages of low cost and low power consumption due to its simple configuration. However, to realize 3.2 Tbps using IM/DD and PAM4, 16 channels will be required if conventional 200 Gbps/lane [2] technology is to be used.

Under these circumstances, beyond 200 Gbps operations have been studied actively, and the electro-absorption modulator-integrated distributed feedback (EA-DFB) laser is a promising light source for beyond 200 Gbps/lane because of its high bandwidth, high extinction ratio (ER) with low voltage driving and compactness. Furthermore, it has also been proven by studies for beyond 200 Gbps/lane PAM operation as follows: A traveling-wave electrode C-band EA-DFB laser with 300 Gbps PAM8 for 400 m transmission using a 15-tap feed-forward equalizer (FFE) and a 15-tap feedback equalizer [4] and a commercially available O-band EA-DFB laser with 402 Gbps PAM8 for 5 km transmission using over a 51-tap feed-forward equalizer or Volterra nonlinear equalizer [5]. In addition, 384 Gbps PAM8 operation and 76 GHz bandwidth at 50°C using a lumped-electrode type EA-DFB laser have been reported by our group [6].

In this paper, we report 420 Gbps PAM8 operation using a lumped-electrode type O-band EA-DFB laser with the highest recorded bandwidth of 93 GHz at 50°C. Clear eye-openings of 420 Gbps (140 Gbaud) PAM8 over 500 m and 2 km transmissions were demonstrated with only a 5-tap FFE. In addition, the average output power at the chip facet of 9.1 dBm and the outer extinction ratio of 3.7 dB were obtained with 0.9 Vpp swing at 50°C.

Device structure and static characteristics

Figure 1 shows a schematic view of a lumped-electrode type EA-DFB laser. The DFB laser and the EA modulator have a high-mesa semi-insulating buried heterostructure (SI-BH) consisting of InGaAsP-based multiple quantum wells (MQWs). Each MQWs is optimized individually for high output optical power and high bandwidth. The DFB laser section and the EA modulator section are connected using the waveguide section (WG) to reduce optical coupling loss. A low permittivity organic material is applied under the bonding pad of the EA modulator. The chip facets are coated with anti-reflection (AR) and high-reflection (HR) films. The AR on the front facet is for low reflection, and the HR on the rear facet is for high optical output power. In this study, the EA-DFB laser is optimized for high bandwidth by tuning the EA modulator and low inductance assembly [7].

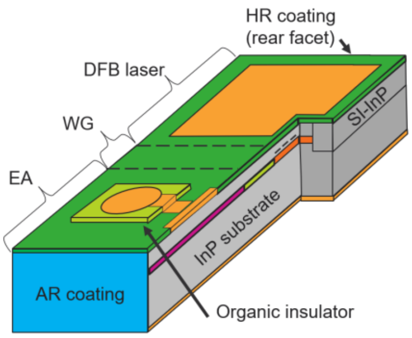


Fig. 1: A lumped-electrode type EA-DFB laser.

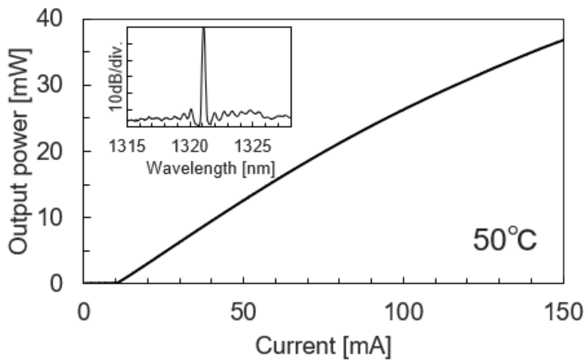


Fig. 2: I-L curve and lasing spectrum at 50°C.

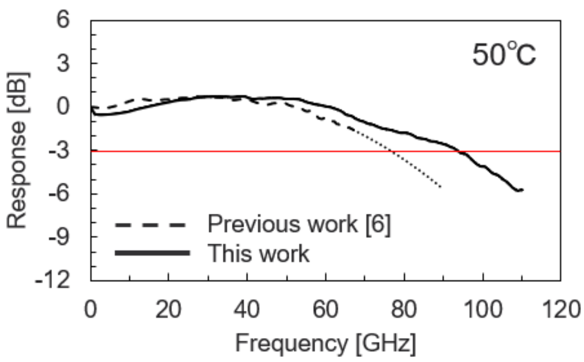


Fig. 3: EO-response at 50°C.

Moreover, we design the EA-DFB laser to operate optimally at around 50°C because semi-cooled operation can minimize the power consumption of the thermoelectric cooler (TEC). As a result, the optical output power was 26.3 mW at 100 mA, 50°C and stable single mode was obtained with a side-mode suppression ratio of over 40 dB, as shown in Fig. 2. The lasing wavelength was 1321.5 nm. Figure 3 shows the EO-response at 50°C measured by the Keysight N4372E 110 GHz lightwave component analyzer. The 3-dB down frequency (f3dB) bandwidth was 93 GHz which was improved from the 76 GHz obtained in previous work [6]. The bandwidth was measured under the condition of 100 mA of laser current and −1.4 V of EA bias voltage, which was almost equal to the condition of PAM8 waveform evaluations in the next section.

PAM8 waveform evaluations

Figure 4 shows the setup of the transmission experiments. An electrical signal was generated using a 256 GSa/s arbitrary waveform generator (AWG, Keysight M8199A), and the signal was amplified by an RF amplifier. The bias voltage of the electrical signal was controlled with a bias tee and a DC source. The frequency response of the above electrical setup was calibrated up to 75 GHz except for the RF probe. Then, a 140 Gbaud PAM8 signal of 0.9 Vpp swing was obtained with a raised-cosine pulse shaping filter. In this experiment setup, the voltage amplitude was only 0.9 Vpp limited by the AWG output voltage, the amplifier gain, and the loss of electrical frequency response. The temperature of the EA-DFB laser on a carrier was adjusted to 50°C by the TEC. The electrical signal drove the EA modulator via a ground-signal-ground (GSG) probe contact to the carrier. The optical output of the EA-DFB laser was transmitted using a standard single mode fiber (SMF) of 500 m and 2 km. The fiber dispersions at the lasing wavelength of 1321.5 nm were +0.7 ps/nm of 500 m fiber and +1.9 ps/nm of 2 km fiber, respectively. The transmitted signal was received by a digital communication analyzer (DCA, Keysight N1030A) without an optical amplifier. The optical waveforms were equalized by a T-spaced, 5-tap FFE to enhance the eye-opening under the constraint that the number of precursors was no more than 2, which is the same as that of 100G-PAM4.

Figure 5 shows the electrical and optical eye-diagrams of 420 Gbps (140 Gbaud) PAM8 with Back-to-Back (BTB), 500 m, and 2 km transmissions. We tuned the EA bias voltage and each level of the electrical PAM8 waveform to obtain clear eye-openings with > 3.5 dB extinction ratio, which adjustments are in a similar

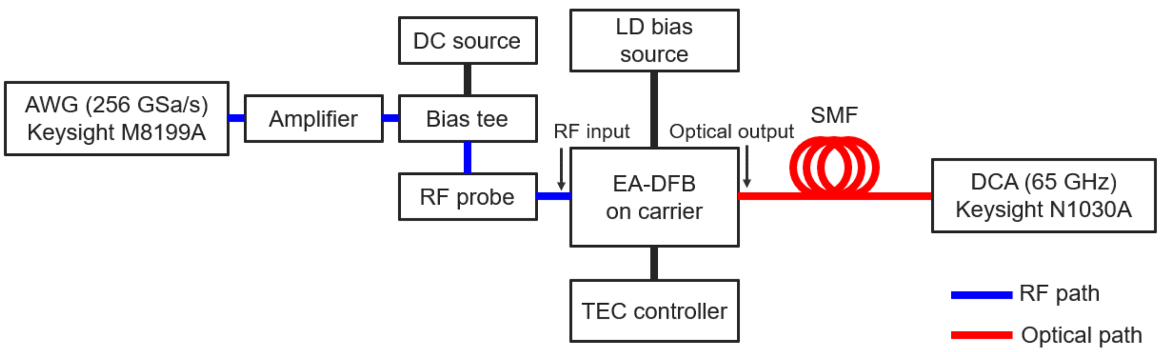


Fig. 4: Experimental setup of 420 Gbps (140 Gbaud) PAM8 waveform evaluation.

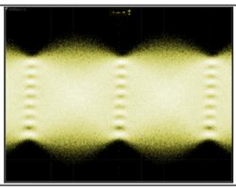
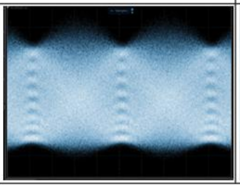
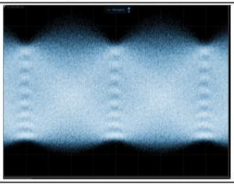
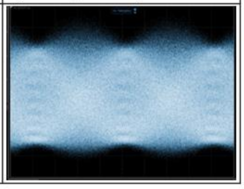
	Electrical waveform (0.9 Vpp)	Optical waveform with 5-tap FFE, 50°C		
		Back-to-Back	After 500 m (+0.7 ps/nm)	After 2 km (+1.9 ps/nm)
420 Gbps PAM8 ER = 3.7 dB Pave = 9.1 dBm				

Fig. 5: Electrical and optical waveform of 420 Gbps (140 Gbaud) PAM8 at Back-to-Back, 500 m and 2 km transmissions.

way reported on PAM4 [8]. The BTB waveform showed that the extinction ratio was 3.7 dB and clear eye-opening almost equivalent to the electrical waveform. The average output power (Pave) was 9.1 dBm at the chip facet, which is enough optical output power if we refer the outer optical modulation amplitude specification of 800G-FR4 [2] assuming 3.0 dB coupling loss and 3.5 dB extinction ratio. After 500 m (+0.7 ps/nm) transmission, the waveform showed clear eye-openings as same as that of BTB with only a 5-tap FFE. In case of 2 km transmission (+1.9 ps/nm), the eye-openings were slightly degraded due to fiber dispersion, however the eye-openings were still recognizable.

Conclusions

We demonstrated 420 Gbps PAM8 operation using a lumped-electrode O-band EA-DFB laser with clear eye opening adopting a 5-tap FFE. The EA-DFB laser showed the optical output power of 26.3 mW and 93 GHz bandwidth at 50°C. In addition, the extinction ratio and the average chip facet power were 3.7 dB and 9.1 dBm, respectively, at 50°C. Clear eye-openings of 500 m and 2 km transmissions were experimentally demonstrated without an optical amplifier. Therefore, these results show our EA-DFB lasers are promising optical light sources for beyond 400 Gbps/lane IM/DD applications with low cost and low power consumption.

Acknowledgements

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