Uncooled Operation of 53-Gbaud PAM4 EA-DFB Lasers in the Wavelength Range of 1510-1570 nm for 800-GbE Applications

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Abstract: 53-Gbaud EA-DFB lasers—with four wavelengths in the 1500-nm region—for 800-GbE applications were developed. They demonstrated uncooled 53-Gbaud PAM4 operation with a TDECQ of lower than 2.5 dB over a wide temperature from 20 to 85°C.

OCIS codes: (140.0140) Lasers and laser optics, (320.7080) Ultrafast devices.

1. Introduction

With growth of social-network services, cloud services, and so on, data traffic is rapidly increasing. For large-capacity data transmission, the IEEE has standardized the specifications of 400-GbE optical interface for next-generation transceivers. In response to that standardization, we have already developed electro-absorption modulator-integrated distributed-feedback (EA-DFB) lasers that are applicable to four lane×50-Gbaud (100-Gb/s) four-level pulse amplitude modulation (PAM4) for 400-GbE transceivers [1]. Moreover, standardization of transceivers beyond 400-GbE ones, namely, 800-GbE transceivers, has started to be discussed. It is therefore necessary to develop a new light source for those 800-GbE transceivers. They are two main approaches to achieve transmission speed of 800-Gb/s: one is to use four-wavelengths (4λ)×100-Gbaud (200-Gb/s) PAM4 as the optical interface, and the other is to use eight-wavelengths (8λ)×50-Gbaud (100-Gb/s) PAM4 as the optical interface. If the first approach, 4λ×100-Gbaud (200-Gb/s) PAM4, is chosen as the optical interface, an EA-DFB laser with extremely broad bandwidth is necessary to drive the optical interface at 100-Gbaud. Over-100-Gbaud PAM4 operation using a high-bandwidth EA-DFB laser has been reported [2,3]. On the other hand, the approach using the 8λ×50-Gbaud optical interface has the advantage that its electronic components such as a digital signal processor are currently available. However, four additional light sources with different wavelengths are required for the 8λ×50-Gbaud optical interface in addition to the existing four wavelengths of light sources for CWDM in the O-band, which is defined as 1270 to 1330 nm [1,4]. The most-attractive wavelength range for these additional four wavelengths is the 1500-nm range, which overlaps with the C-band range defined as 1530 to 1565 nm, and EA-DFB lasers using the C-band range have been widely applied in telecom optical networks with high transmission speed up to 40-Gb/s [5,6]. Therefore, the four wavelengths, which can be selected from 1510 to 1570 nm with 20-nm intervals, in addition to the existing four wavelengths of the O-band, are promising candidates for realize an eight-wavelength multiplexing optical interface. However, due to the larger fiber dispersion for the C-band compared to the O-band, fiber transmission distance is a concern in regard to the 1500-nm range.

In this paper, high-bandwidth 1500-nm uncooled EA-DFB lasers were demonstrated, and a 53-Gbaud PAM4 (106-Gb/s) operation over a wide temperature range from 20 to 85°C with four different wavelengths from 1510 to 1570 nm for 800-GbE was demonstrated for the first time. The developed EA-DFB lasers showed a clear 53-Gbaud PAM4 eye diagram with a small transmission-dispersion eye-closure quaternary (TDECQ) of less than 2.5 dB from 20 to 85°C. And clear eye openings after 500-m fiber transmission were confirmed for in the data center applications.

2. Device structure and design

The developed 1500-nm EA-DFB laser chip is shown schematically in Fig. 1. It consists of an InGaAsP-MQW EA modulator and DFB laser. The EA-DFB laser has four different wavelengths, i.e., 1510, 1530, 1550 and 1570 nm, which are separated at 20-nm intervals because 20-nm separation of four wavelengths is necessary in the same manner as in the case of CWDM under assumed uncooled operation. The detail of the fabrication process is similar to our O-band uncooled 53-Gbaud EA-DFB lasers described in a previous work [1]. For low-reflection and high-optical output, an anti-reflection (AR) film with a reflectivity of lower than 0.1% and a high-reflection (HR) film were coated on the front and rear facets at the 1500-nm range, respectively. The structure of LD active layer is designed to provide larger gain to compensate the influence of Auger recombination and increase in intervalenceband absorption in 1500-nm range. Moreover, to increase the bandwidth of the EA modulator, a SCH structure was carefully designed because the band offset between MQW and InP in the 1500-nm range is larger than that in the O-band region. Fiber dispersion at 1500-nm is larger than that in the O-band in the case of a normal single-mode fiber (SMF). We set the transmission distance target at 500 m with SMF, which is an appropriate distance in the data center. The design of the EA-MQW was therefore optimized for lower chirp to allow 500-m transmission by SMF in the 1500-nm range.

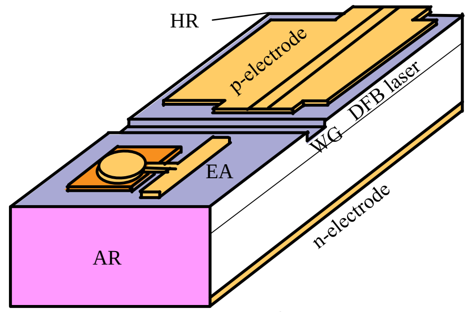

Fig. 1: Schematic view of EA-DFB laser

3. Static characteristics

The developed 1500-nm EA-DFB laser chip was die-bonded on a carrier with termination resistor, and controlled the temperature by thermo-electric cooler (TEC). Output power of the laser is about 15 mW at 50°C. The measured output power included absorption loss of the EA modulator with non-bias. Optimizing the design of MQW and modulator length made it possible to obtain high extinction ratio of about 10 dB even at 20°C and EA bias of -2.5 V while maintaining high linearity. Thus, the possibility of achieving high extinction ratio with low-voltage drive at low temperature was demonstrated. The measured optical spectra of the 1500-nm four-wavelength range are shown in Fig. 2 together with the spectra in the O-band [1]. The spectra confirm stable single-mode operation with high side-mode suppression ratio (SMSR) of more than 40 dB in the wavelength of 1510, 1530, 1550, and 1570 nm. E/O response (S21) at 50°C at EA bias of -1.0 V under operating current of 100 mA is shown in Fig. 3. Measured 3-dB down-frequency bandwidth is 47 GHz, which is sufficient bandwidth for 53-Gbaud modulation. This high bandwidth performance is due to the optimized design of the EA modulator containing the SCH structure. The LD and EA portions show almost the same characteristics for the four different wavelengths.

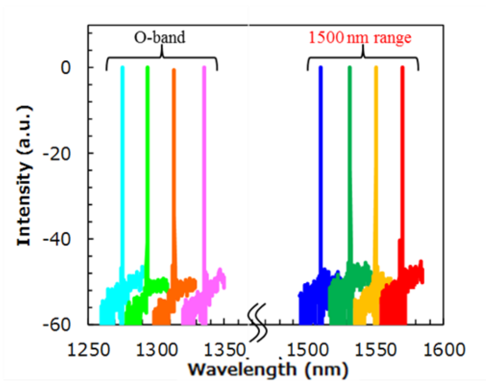

Fig. 2: Lasing spectra in O-band and 1500-nm range of newly developed EA-DFB laser.

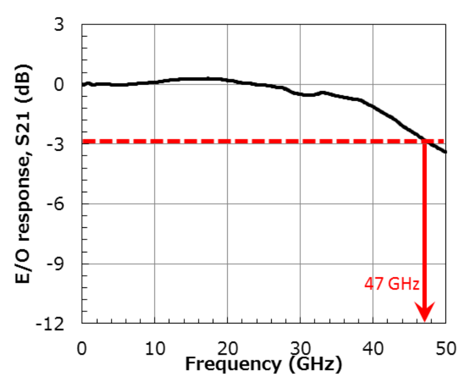

Fig. 3: E/O response (S21) at 50°C and EA bias of -1.0 V.

4. Experimental setup and results

A pattern generator (PG, M8045A) was used to generate the 53-Gbaud PAM4 driving signal, and it was set to a 53-Gb/s short-stress-pattern random-quaternary (SSPRQ) pattern. The electrical signal from the PG was amplified by using a linear driver with bandwidth of >67 GHz to obtain sufficient driving voltage. Then, DC bias voltage was applied to the EA modulator through a bias tee. Driving voltage of the EA modulator was set to 1.2 Vpp at all temperatures. Driving voltage at each level of PAM4 was set to the same voltage in spite of the nonlinear extinction performance of the EA modulator. Temperature of the EA-DFB laser bonded to the carrier was changed from 20 to

85°C using TEC. Optical output of the EA-DFB laser was detected by a digital communication analyzer (DCA, N1092C). The conditions for obtaining the TDECQ are compliant with those defined in the IEEE standard [7].

PAM4 optical eye diagrams of uncooled 53-Gbaud operation of the 1500-nm EA-DFB lasers with equalizing of 5 tap are shown in Fig. 4. 53-Gbaud PAM4 operation of four EA-DFB lasers was evaluated. The results for wavelengths of 1510 and 1570 nm are shown in the figure as examples. Extinction ratio at each temperature was set to around 5 dB by adjusting bias voltage. As shown in the figure, excellent eye openings with TDECQ of less than 2.5 dB were obtained from 20 to 85°C before transmission. In the case of the measurement at 20°C, de-emphasis was not applied because TDECQ was low enough. If the de-emphasis was applied or the adjusted extinction ratio was lower than 5 dB, lower TDECQ could be achieved. Average output power was more than 5 dBm, which is sufficient for the practical use. Clear eye openings after 500-m SMF transmission for each 1500-nm-ragne EA-DFB laser were confirmed. Even in the case of the longest wavelength of 1570 nm, at which fiber dispersion has the most effect, the TDECQ was lower than 3.4 dB which is the IEEE criterion. These results suggest that uncooled 53-Gbaud PAM4 operation with four different wavelengths in the 1500-nm range enables data rate to be increased by 400-Gb/s.

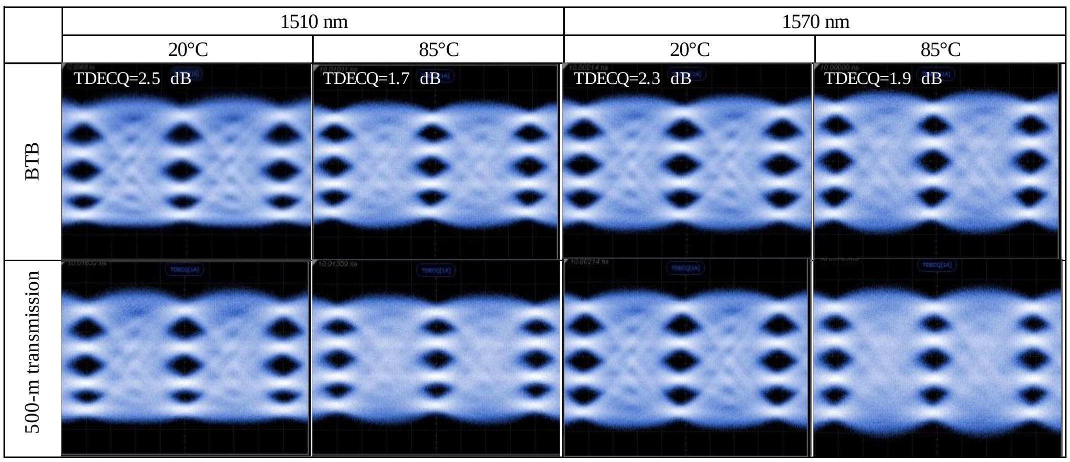

Fig. 4: Optical eye diagrams of 53-Gbaud operation of 1500-nm EA-DFB lasers with equalizer (5 tap). Measurement temperatures are 20 and 85°C. Extinction ratio was adjusted to 5 dB.

5. Conclusion

High-bandwidth 1500-nm uncooled EA-DFB lasers were developed, and they demonstrated uncooled 53-Gbaud PAM4 operation from 20 to 85°C for the first time. The EA-DFB lasers with four wavelengths of 1510, 1530, 1550, and 1570 nm achieved a TDECQ of lower than 2.5 dB under operation from 20 to 85°C without transmission and extinction ratio of 5 dB. And the lasers demonstrated excellent eye openings after 500-nm-fiber transmission at all four wavelengths. Therefore, 800-Gb/s application with 8λ x 53-Gbaud PAM4 will be achieved by using the 4λ O-band EA-DFB laser [1] and 4λ-1500 nm EA-DFB laser as reported above. These results suggest that a 1500-nm EA-DFB laser is a promising devices for 800-GbE application.

6. References

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