Wide-temperature-range 100-Gbaud Operation of a Lumped-electrode-type EA-DFB for an 800-Gb/s Optical Transceiver

K. Adachi, S. Yamauchi, H. Asakura, A. Nakamura, K. Naoe, and S. Tanaka

Lumentum, 4-1-55 Oyama, Chuo-ku, Sagamihara, Kanagawa, 252-5250, Japan
koichiro.adachi@lumentum.com

Abstract *A lumped-electrode-type EA-DFB with a short-length modulator packaged by using an ultra-short wiring technique achieved bandwidth over 60-GHz in a wide-temperature range, and 100-Gbaud NRZ eye opening up to 80ºC was demonstrated for the first time.*

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Introduction

Driven by recent advances in using cloud computing as the technological backbone of modern internet services, the amount of data traffic in data centres (DCs) continues to grow. Toward next-generation network in DCs, 25.6-Tb/s-class Ethernet switches are being commercialized[1]. To be equipped in such switches, 800-Gb/s optical transceivers (TRVs) have been actively discussed in regard to specifications[2]. One of the controversial points of these discussions is the optical-signal specification for single-mode fibre (SMF) application. There are mainly two approaches; one is 8 x 50-Gbaud four-level pulse amplitude modulation (PAM4), and the other is 4 x 100-Gbaud PAM4.

The latter allows the same optical configuration as the standardized 400-Gbps TRV with 4 x 50-Gbaud PAM4 (i.e., four optical lanes)[3]. It thus leads to cost advantage in terms of sharing the same optical components and/or well-established manufacturing process as the 400-Gbps TRV. However, the baud rate per optical lane is doubled from 50 to 100 Gbaud. The optical device with further high-speed characteristic is therefore being required.

An electro-absorption modulator integrated DFB laser (EA-DFB) is one of the leading light sources used in a 400-Gbps TRV thanks to its superior high-speed characteristic for 50-Gbaud operation[4][5]. Moreover, there have been several pioneering studies on developing an EA-DFB for over 100-Gbaud operation. For example, 160-Gbaud PAM4 operation was demonstrated by using a standard lumped-electrode-type EA-DFB (LE-type EA-DFB) with a flip-chip interconnection technique[6]. Alternatively, to overcome a bandwidth limitation of the LE-type EA-DFB, a novel travelling-wave-type EA-DFB (TW-type EA-DFB) integrated with a distributed transmission-line electrode is being developed, and 204-Gbaud non-return-to-zero (NRZ) operation was demonstrated successfully[7]. However, 100-Gbaud operation of an EA-DFB in wide-temperature range has not been reported as far as we know. Wide-temperature operation without a thermo-electric cooler (TEC) is clearly advantageous in terms of reducing cost and power-consumption of a practical TRV.

In this study, we demonstrated wide-temperature-range 100-Gbaud operation of an EA-DFB for the first time to the best of our knowledge. By using a newly developed LE-type EA-DFB with a short-length (less than 100 μm) modulator and ultra-short wiring technique with a step-like carrier, large 3-dB-down bandwidths of over 67, 63.6, and 61.9 GHz at 20ºC, 50ºC, and 70ºC were obtained, respectively. We then demonstrated 100-Gbaud NRZ operation with the modulation voltage of 1.2 V_{pp}, and confirmed clear optical eye waveforms at 20ºC, 50ºC, 70ºC, and up to 80ºC with extinction ratio of over 4.0 dB in all cases. We also evaluated 100-Gbaud PAM4 operation at 50ºC with modulation amplitude of 1.2 V_{pp}, and confirmed a good optical eye waveform by using a feed-forward equalizer (FFE) with 5 taps.

Design and DC characteristics

Although a TW-type EA-DFB enables extremely-large bandwidth, it needs extra impedance-control passive waveguides[8]. As well as fabrication complexity, its chip size is therefore inevitably bigger than that of the LE-type EA-DFB. Taking into account the balance between required chip characteristics and mass productivity, we adopted an LE-type EA-DFB in this study.

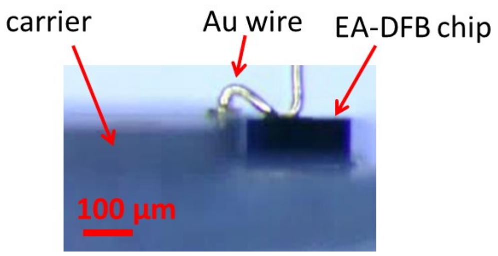
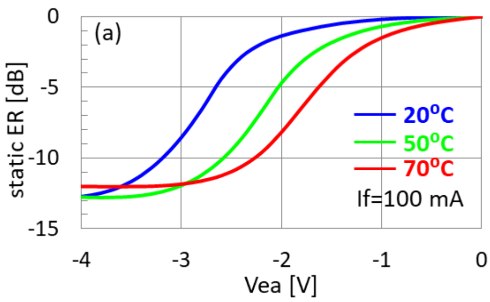


Fig. 1: Photograph of fabricated LE-type EA-DFB chip on carrier.

A photograph of the fabricated LE-type EA-DFB chip on a carrier (COC) is shown in Fig. 1. It is well known that shortening the modulator length is effective to enlarge the bandwidth of the LE-type EA-DFB[9][10]. The modulator length of the LE-type EA-DFB was optimized to less than 100 μm in this study. Reducing parasitic inductance of the bonding wire is also important to attain superior bandwidth taking into account the total packaging[5]. We developed a step-like carrier for ultra-short wiring to attain sufficiently low inductance that would not degrade intrinsic chip bandwidth as shown in Fig. 1 (i.e., wire length is around 100 μm, and its corresponding inductance is around 0.04 nH).

Measured static extinction ratios (ERs) of the fabricated LE-type EA-DFB with respect to DC bias voltage applied to the modulator (V_{ea}) at 20ºC, 50ºC, and 70ºC under forward DC current supplied to the DFB laser (If) of 100 mA are plotted in Fig. 2(a). By optimizing the modulator design, a steep ER characteristic was obtained from 20ºC to 70ºC. The measured spectra with V_{ea} of 0 V under the same temperature and If as the static ER evaluation are shown in Fig. 2(b). Lasing wavelengths are in 1310-nm range as designed, and stable single-mode operation with side-mode suppression ratio of over 50 dB was confirmed under each condition.



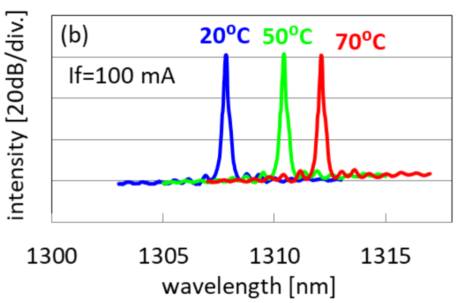


Fig. 2: Static extinction ratio and spectrum at 20, 50, and 70ºC under DFB applied bias of 100 mA.

Results and discussions

Measured frequency responses of the COC with V_{ea} of -2.4 V, -2.2 V, and -1.4 V at 20ºC, 50ºC, and 70ºC, respectively, under If of 60 mA are shown in Fig. 3. Smooth profiles to the measurement limit (67 GHz) are confirmed at all temperatures thanks to the carefully optimized high-frequency design of the COC. The 3-dB down bandwidth at 20ºC is over 67 GHz (i.e., S21 of -1.4 dB at 67 GHz.), and the corresponding values at 50ºC and 70ºC are 63.6 GHz and 61.9 GHz, respectively.

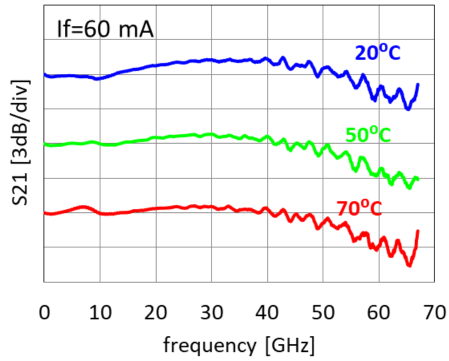


Fig. 3: S21 characteristics at 20, 50, and 70ºC under DFB applied bias of 60 mA.

The experimental setup for measuring a 100-Gbaud eye waveform is shown in Fig. 4. A 100-Gbaud electrical signal is generated from an arbitrary waveform generator (AWG) with sampling rate of 120 Gsa/s (Keysight M8094A). The signal is amplified by a driver amplifier (M827A), and applied to the COC via a bias tee (SHF BT65) combined with V_{ea} from a DC source. The optical signal from the LE-type EA-DFB is coupled to a lensed SMF, and detected by a digital communication analyzer (DCA) with 60-GHz optical bandwidth (Keysight N1030A).
A 100-Gbaud NRZ electrical eye waveform after passing through bias tee with modulation voltage of 1.2 V_{pp} is shown in Fig. 5(a). A pseudo-random binary sequence (PRBS) of 2^{15}-1 was used.

Measured optical eye waveforms with V_{ea} of -3.3 V, -2.4 V, and -1.9 V at 20ºC, 50ºC, and 70ºC, respectively, under If of 100 mA in back-to-back (BTB) configuration are shown in Fig. 5(b). As shown in the figures, clear eye openings with dynamic ER of over 4.0 dB under each condition are confirmed, reflecting the superior bandwidths of the fabricated COC. Moreover, we evaluated 100-Gbaud eye waveforms under higher-temperature condition. 100-Gbaud NRZ optical eye waveforms at 80ºC for BTB configuration and after 1-km transmission using SMF with zero-chromatic dispersion wavelength of 1305 nm are shown in Fig. 5(c). Even after 1-km transmission at 80ºC, a clear eye opening with dynamic ER of 4.4 dB is confirmed.

Finally, we evaluated the feasibility of 100-Gbaud PAM4 operation. An electrical PAM4 eye waveform of a PRBS of 2^{15}-1 with the modulation voltage of 1.2 V_{pp} is shown in Fig.

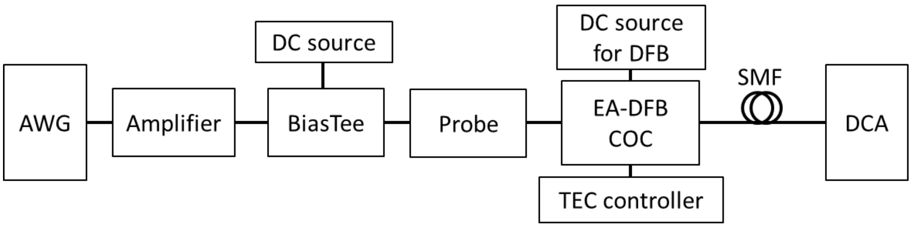


Fig. 4: Experimental setup for eye measurement

6(a). Measured optical eye waveforms of raw data and after FFE (5-taps) with 4th-order Bessel-Thomson filter (57.9 GHz) at 50ºC are shown in Figs. 6(b) and (c), respectively. Although the raw data is noisy, a good eye opening is confirmed by using FFE with 5 taps.

These results experimentally demonstrate that that under the design concept of using a short-length modulator and ultra-short wiring, 100-Gbaud PAM4 operation is feasible with our LE-type EA-DFB

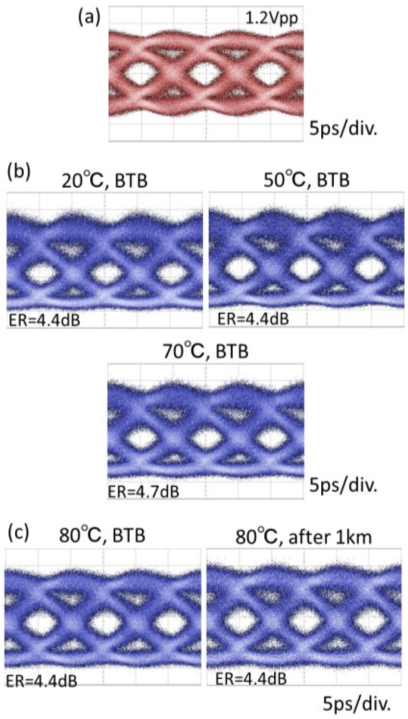


Fig. 5: 100-Gbaud NRZ eye waveforms: (a) input electrical signal, (b) measured optical signal at 20, 50, and 70ºC, and (c) measured optical signals of BTB and after 1km at 80ºC.

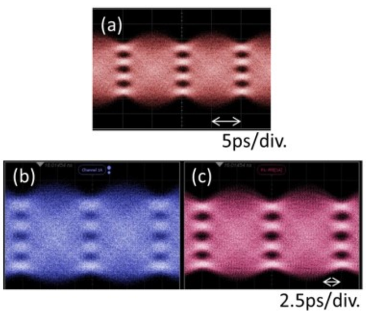


Fig. 6: 100-Gbaud PAM4 eye waveforms: (a) input electrical signal, (b) raw data of measured optical eye, and (c) optical eye with 5-taps FFE.

Conclusions

Wide-temperature-range 100-Gbaud operation of the EA-DFB was demonstrated for the first time. By using a newly developed LE-type EA-DFB adopting a short-length (less than 100 µm) modulator and ultra-short wiring technique, superior 3-dB down bandwidths of over 67, 63.6, and 61.9 GHz at 20ºC, 50ºC, and 70ºC were obtained, respectively. Clear 100-Gbaud NRZ eye openings at 20ºC, 50ºC, 70ºC, and 80ºC with dynamic ER over 4.0 dB under all conditions were confirmed. As a preliminary study, a 100-Gbaud PAM4 eye opening after FFE with 5 taps at 50ºC was also demonstrated. These results indicate the developed EA-DFB is a promising light source for an 800-Gbps TRV with 4 x 100-Gaud PAM4.

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