2-ch EML Array and Assembling Technique Operating at 224 Gbps PAM4

Mizuki Shirao(1), Shinya Okuda(2), Asami Uchiyama(2),Takuma Fujita(1), Nobuo Ohata(1)

(1) Information Technology R & D Center, Mitsubishi Electric Corporation, 5-1-1, Ofuna, Kamakura, Japan, shirao.mizuki@db.mitsubishielectric.co.jp
(2) High Frequency and Optical Devices Works, 4-1-1, Mizuhara, Itami, Hyogo, Japan

Abstract *We reported a high-performance 2ch EML array on a wide bandwidth sub-mount: Capable of dual high-speed modulation, demonstrating 3 dB bandwidths of > 67 GHz and low TDECQ values of ≤1.75 dB for 112 GBaud PAM4.*

Introduction

The EML is widely used in optical transceivers with a CWDM grid for 2 km data centre links, thanks to their high bandwidth and power-efficient modulation. The data transmission capacity per wavelength has reached 224 Gbps and beyond [1-3]. However, adopting multiple technologies has been considered along with EMLs, such as silicon photonics modulators for ≤ 500 m and digital coherent for ≤ 40 km [4-7]. For short-distance links, an optical fibre array is employed to eliminate WDM couplers for lower-cost transceivers, and silicon photonics matches it well despite its relatively narrower modulation bandwidth. For longer distances of ≤ 40 km, multiplexing wavelength (i.e., CWDM) causes serious chromatic dispersion, so the adoption of the coherent technique.

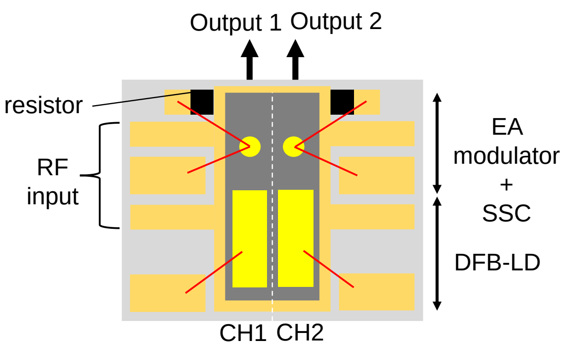


Fig. 1: 2ch EML on high-speed sub-mount.

Arraying Electro-Absorption (EA) modulator in a single chip could provide advantages in addition to the EML's superior modulation bandwidth. One is an easier optical coupling to the optical fibre array. Also, using high-speed EML array provides a higher data rate per lane, resulting in a smaller fibre count. Another is that it facilitates the new application as Intensity Modulation-Direct Detection (IM-DD) Polarization Division Multiplexing (PDM) using a single chip for long-distance links [8-10]. Using few-mode fibre with PDM is also expected to increase data transmission capacity without expanding wavelength bandwidth [11].

Arrayed EMLs have been proposed for 100 GbE TOSA [12] and PSM4 links [13, 14]. However, arrayed EML with a high-mesa EA modulator, known as a high-speed and low Vpp device [1], has not been demonstrated yet. In addition to this, the difficulty of the RF signal connection to arrayed EA modulator requires a unique assembling technique to access middle lanes [13, 15], which impedes the implementation of arrayed EMLs. In this report, we demonstrate a 2ch EML array with a high-mesa EA modulator on a wideband sub-mount using a conventional wire bonding technique. The combination of 2ch EML array and lateral input sub-mount [16] realizes significant high bandwidth multi-lane driving. We believe this configuration contributes

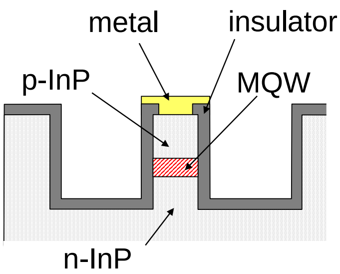


Fig. 2: Cross-sectional view of EA modulator [1]

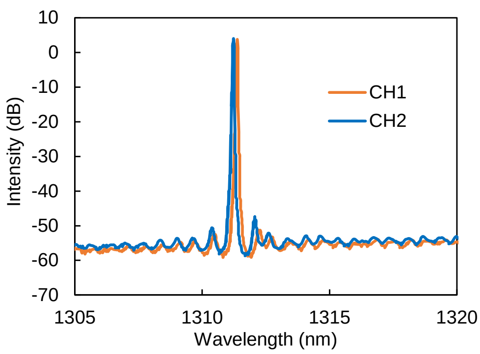
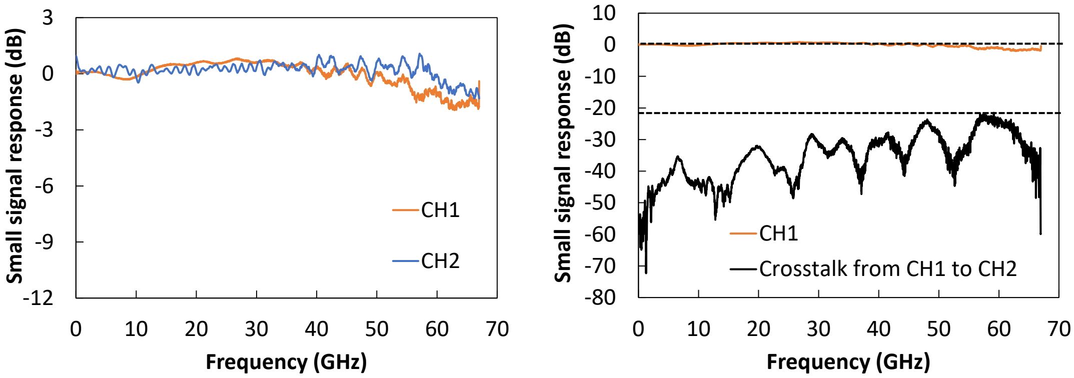
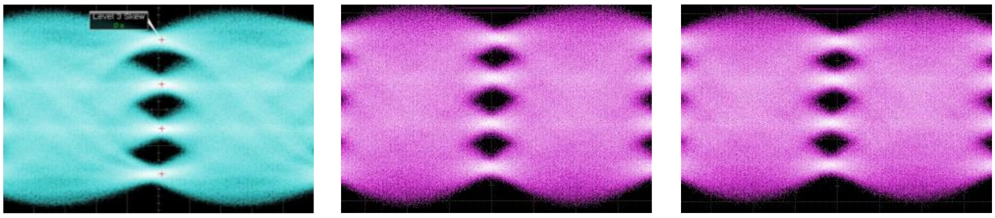


Fig. 3: Spectrum characteristics of 2ch EML array.



(a) Small signal response (b) Cross-talk from CH1 to CH2

Fig. 4: Frequency characteristics of 2ch EML array



(a) Electric eye (b) optical eye CH1 (c) optical eye CH2

Fig. 5: Eye diagrams at 112 GBaud PAM4

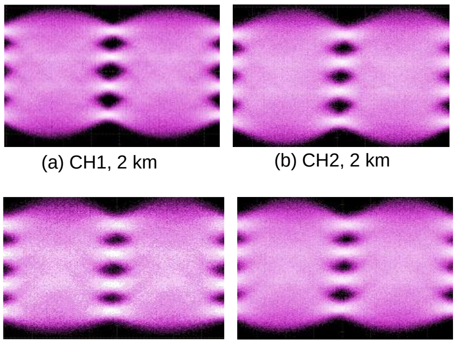
to the penetration of EMLs into more comprehensive applications.

Device Configuration

As the DFB-LD locates on the rear side of the EML chip, RF input to the EA modulator needs to route to the side of the EML chip as long as the wire bonding technique is used. It leads to difficulty accessing the EA modulator in the middle of the chip for three or more channel EMLs. To avoid this problem, we introduced a 2ch EML configuration with high bandwidth AlN sub-mount concept proposed in the previous report, as shown in Figs. 1 and 2. The mounted 2ch EML array consists of Buried-Heterostructure (BH) DFB-LDs operating at 1310-nm wavelength, high-mesa EA modulators, and Spot Size Converter (SSC). Anodes (top side of EML) of two EA modulators are electrically separated within the chip, allowing independent drive of modulators. If necessary, two DFB-LDs could be replaced with a DFB-LD and a 1:2 Multi-Mode Interferometer (MMI). For example, a PDM scheme prefers well-matched wavelengths for each polarization to separate the transmitted signal at the receiver [10].

Evaluation Result

Then, a 2ch EML array on the sub-mount was evaluated. A 256 GSa/s Arbitrary Waveform Generator (AWG) generated an SSPRQ 112 Gbaud PAM4 signal. The generated signal was amplified using a 67 GHz bandwidth linear amplifier, so an output voltage swing of 1.0 Vpp was obtained. The DFB-LD current was 80 mA. EML temperature was fixed at 55 °C. Fig. 3 shows the spectrum characteristics. The lasing wavelengths were 1311.48 nm for CH1 and 1311.32 nm for CH2, respectively. Changes in the output power and lasing wavelength between single and dual laser operation were negligibly low values of 0.2 dB and 0.02 nm, respectively. Fig. 4 (a) shows the small-signal responses. Both channels have a bandwidth of 67 GHz or higher (equipment limitation), indicating that the 2ch EML array on the designed sub-mount has sufficient bandwidth for 112 GBaud PAM4 modulation. The crosstalk from CH1 to CH2 is shown in Fig. 4 (b). Here, DFB-LD currents of 80 mA were applied, and the optimum bias voltages for PAM4 modulation were also applied to the EA modulators. Then, an electrical input signal was input to CH1, and the optical output of CH2 was evaluated. The amount of crosstalk was better than 20 dB up to 67 GHz. Fig. 5 shows optical eye diagrams for the 112 GBaud PAM4. The EMLs were not driven simultaneously because multiple electrical input signals were not available due to the convenience of the measurement equipment. The output signal was processed by a 56 GHz 4th order Bessel-Thomson filter followed by a 5-tap FFE to calculate the TDECQ. The target SER of 4.85E-3 was used. Estimated



(a) CH1, 2 km (b) CH2, 2 km

(c) CH1, 10 km (d) CH2, 10 km

Fig 6. Optical eye of 112 GBaud PAM4 after transmission.

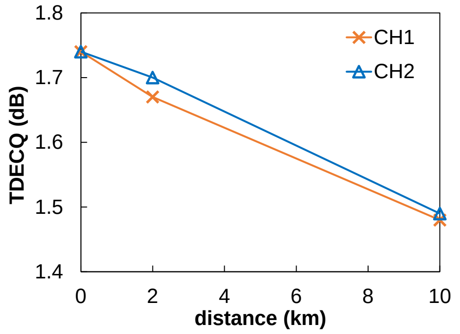


Fig. 7: Transmission distance dependence of Estimated TDECQ

TDECQ values of CH1 and CH2 were 1.74 dB and 1.75 dB, respectively. The extinction ratio was higher than 4.5 dB.

Transmission Test

Next, a transmission test was conducted. The fibres used were 2 km and 10 km standard SMF. No major degradation of the optical eyes was observed after 2 km and 10 km as shown in Fig. 6. TDECQ values were slightly lower than back-to-back after transmission, as shown in Fig. 7, which is attributed to a positive alpha parameter of the EA modulator and negative dispersion by the optical fibre. The increase of noise for 10 km in Fig. 6 (b) and (d) is due to fibre transmission loss, e.g., insufficient input power for the sampling oscilloscope.

Discussion

The evaluated 2ch EML array on the designed sub-mount showed superior performance for 112 GBaud PAM4. A pair of these devices realize a four-lane transmitter supporting PSM4, though we need an active alignment for optical coupling. However, the assembling process is much simpler than four 1ch EML configurations. The superiority of the 2ch EML array would be significant for future applications. We believe EMLs could operate at a higher Baud-rate (i.e., > 200 Gbaud PAM4) and transmit more data per lane, thus reducing fibre counts. For example, 1.6 Tbps could be achieved with a pair of 2ch EML arrays with four fibre, although it has not been confirmed yet due to measurement equipment inconvenience. Regarding transmission test results, it is natural that the chromatic dispersion penalty of single-wavelength transmission is low near 1310 nm wavelength. The non-WDM IM-DD system demonstration, suitable for > 2 km links [8-11], requires multiple transmitters at the same wavelength; a 2ch EML array is promising for such a system. In that case, two EA modulators could share a single DFB-LD by adding a 1:2 MMI as a power splitter.

Conclusion

We report a high-performance 2ch EML array with high-mesa EA modulator and its assembling technique. A 2ch EML was assembled on a sub-mount using a wire bonding technique. A 3 dB bandwidth of > 67 GHz and low crosstalk lower than 20 dB were achieved. The TDECQ values at 112 GBaud PAM4 signals were 1.74 dB and 1.75 dB, respectively. The extinction ratio was > 4.5 dB. No clear degradation of the optical eye was obtained after 2 km and 10 km transmission.

Acknowledgments

This paper is based on results obtained from “Research and Development Project of the Enhanced Infrastructures for Post-5G Information and Communication Systems” (JPNP20017), commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

References

[1] A. Uchiyama, S. Okud1, Y. Hokam1, M. Shirao, K. Abe, T. Yamatoya, "225 Gb/s PAM4 2 km and 10 km Transmission of EMLs With Hybrid Waveguide Structure for 800GbE and 1.6TbE Transceivers," 2023 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, M2D.2

[2] P. Bhasker, S. Arora, A. Robertson, T, McCaully, A. Ni, J. Johnson, "200G per Lane Uncooled CWDM Hybrid CMBH-Ridge Electroabsorption Modulated Lasers for 2-km Transmission," 2023 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, M2D.3

[3] K. Nishimura, H. Asakura, S. Yamauchi, T. Suzuki, Y. Nakai, Y. Yamaguchi, T. Kageyama, M. Mitaki, Y. Endo, K. Naoe, "225-Gb/s PAM4 Operation Using Lumped-Electrode-Type EA-DFB Laser for 5- and 10-km Transmission With Low TDECQ," 2023 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, M2D.4

[4] S. Tanaka, T. Shimoyama, T. Aoki, T. Mori S. Sekiguchi, S. H. Jeong, T. Usuki, Y. tanaka, K. Morito, "Ultralow-Power (1.59 mW/Gbps), 56-Gbps PAM4 Operation of Si Photonic Transmitter Integrating Segmented PIN Mach–Zehnder Modulator and 28-nm CMOS Driver," in Journal

of Lightwave Technology, vol. 36, no. 5, pp. 1275-1280, 1 MarCH1, 2018, doi: 10.1109/JLT.2018.2799965.

[5] M. Sakib, R. Kumar, C. Ma, D. Huang, X, Wu, G. L. Su, H. Rong, "A 240 Gb/s PAM4 Silicon Micro-Ring Optical Modulator," 2022 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 2022, pp. 01-03.

[6] H. Sepehrian, J. Lin, L. A. Rusch and W. Shi, "Silicon Photonic IQ Modulators for 400 Gb/s and Beyond," in Journal of Lightwave Technology, vol. 37, no. 13, pp. 3078-3086, 1 July1, 2019, doi: 10.1109/JLT.2019.2910491.

[7] A. Maharry, S. Misak, H. Andrade, J. Liu, G. Gilardi, S. Liao, A. Liu, Y. A. Akulova, L. Coldren, J. Buckwalter, C. Schow, "A 224 Gbps/λ O-Band Coherent Link for Intra-Data Center Applications," 2023 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, M1E.5

[8] M. Morsy-Osman, M. Chagnon, M. Poulin, S. Lessard and D. V. Plant, "224-Gb/s 10-km Transmission of PDM PAM-4 at 1.3 μm Using a Single Intensity-Modulated Laser and a Direct-Detection MIMO DSP-Based Receiver," in Journal of Lightwave Technology, vol. 33, no. 7, pp. 1417-1424, 1 April1, 2015, doi: 10.1109/JLT.2015.2390650.

[9] M. Baier, F.M. Soares, Z. Zheng, C. Schmidt-Langhorst, R. Elschner, F. Frey, M. Gruner, J. K. Fischer, C. Schubert, M. Moehrle, N. Grote, M. Schell, "112 Gb/s PDM-PAM4 Generation and 80 km Transmission Using a Novel Monolithically Integrated Dual-Polarization Electro-Absorption Modulator InP PIC," 2017 European Conference on Optical Communication (ECOC), Gothenburg, Sweden, 2017, pp. 1-3, doi: 10.1109/ECOC.2017.8346039.

[10] X. Wu, D. Huang, T. Kim, R. Kumar, G. L. Su, C. Ma, S. Liu, G. Balamurugan, H. Rong, "Fully Integrated Dual-Polarization Silicon Photonic Transceiver With Automated Polarization Control," 2023 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, Tu2E.3

[11] R. Tanomura, R. Tang, G. Soma, S. Ishimura, T. Tanemura and Y. Nakano, "All-Optical Dual-Polarization MIMO Processor based on Integrated Optical Unitary Converter," 2022 European Conference on Optical Communication (ECOC), Basel, Switzerland, 2022, pp. 1-4.

[12] T. Ohyama, Y. Doi, W. Kobayashi, S. Kanazawa, T. Tanaka, K. Takahata, A. Kanda, T. Kurosaki, T.Ohno. H. Sanjoh, T. Hashimoto, "Compact Hybrid-Integrated 100-Gb/s TOSA Using EADFB Laser Array and AWG Multiplexer," in IEEE Photonics Technology Letters, vol. 28, no. 7, pp. 802-805, 1 April1, 2016, doi: 10.1109/LPT.2015.2514108.

[13] D. Kawamura, S. Makino, K. Kogo, Y. Matsuoka, Y. Lee, T. Sugawara, S. Tanaka, "A 1.3-μm 4-channel × 40-Gb/s lens-integrated EA/DFB laser array for optical interconnects," 2012 38th European Conference and Exhibition on Optical Communications, Amsterdam, Netherlands, 2012, pp. 1-3.

[14] M. A. Theurer, C. Kottke, R. Freund, F. Ganzer, P. Runge, M. Moehrle, U. Troppenz, A. Sigmund, M. Schell, "4 x 200 Gb/s EML-Array With a Single MQW Layer Stack," 2023 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, M2D.5

[15] S. Kanazawa, T. Fujisawa, K. Takahata, Y. Ueda, H. Ishii, R. Iga, W. Kobayashi, H. Sanjoh, "Flip-Chip Interconnection Technique for Beyond 100-Gb/s (4 × 25.8-Gb/s) EADFB Laser Array Transmitter," in Journal of Lightwave Technology, vol. 34, no. 2, pp. 296-302, 15 Jan.15, 2016, doi: 10.1109/JLT.2015.2462728.

[16] M. Shirao, T. Fujita, A. Uchiyama, H. Miura, S. Okuda and N. Ohata, "A High-Speed EML on Sub-mount for 200G PAM4," 2022 IEEE Photonics Conference (IPC), Vancouver, BC, Canada, 2022, pp. 1-2, doi: 10.1109/IPC53466.2022.9975611.