225 Gb/s PAM4 2 km and 10 km Transmission of EMLs with Hybrid Waveguide Structure for 800GbE and 1.6TbE Transceivers

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Abstract: We experimentally demonstrated 10 km transmission of 225 Gb/s PAM4 modulation signal using our developed high-speed EMLs with a hybrid waveguide structure. Clear eye patterns were observed with 5 taps of TDECQ reference equalizer. © 2022 The Authors
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1. Introduction

The expansion of cloud service is leading to deployments of higher data rate transmission in data centers. Recently 200 and 400 Gigabit Ethernet (200GbE and 400GbE) transceivers came to be installed for intra-data center communication. In 400GbE optical transmitters, modulation formats of 26 Gbaud pulse amplitude modulation 4 (PAM4) and 53 Gbaud PAM4 are applied. To keep up with the strong demand for higher-speed communication, the next generation of 800GbE and 1.6TbE standardizations is intently discussed [1]. Intensity modulation and direct detection (IM-DD) is widely implemented for shorter reach communication because of low cost, low power consumption, and backward compatibility. One of the candidates for 800GbE transmission is 100 Gb/s x 8 wavelengths applying 53 Gbaud PAM4 modulations. This is a comparably mature technology, and some reports of electro-absorption modulator integrated lasers (EMLs) confirm clear eye diagrams [2, 3].

Another solution is 200 Gb/s x 4 wavelengths applying 100 Gbaud PAM4 modulation. When we consider the transceiver's size, cost, power consumption, and evolution to the next-generation 1.6TbE, 200 Gb/s modulations shall be a key technology for the next-generation intra-data center communication. Some reports on 200 Gb/s EMLs have been published, confirming that transmission of 100Gbaud PAM4 signal is feasible [4, 5]. As chromatic dispersion tolerance is indirectly proportional to a squared modulation rate, a transmission distance is limited in 100 Gbaud PAM4 modulation compared to 53 Gbaud PAM4 modulation. However, there are few articles to experimentally investigate relatively long-distance transmission, such as 10 km for 100 Gbaud PAM4 transmission.

In this work, we developed high-speed EMLs with a hybrid waveguide structure and experimentally demonstrated back-to-back (BTB), 2 km, and 10 km transmission of 225 Gb/s PAM4 modulation signal over wavelengths from 1271 nm to 1331 nm, which covers a CWDM4 wavelength range. The design of our EML chip was optimized for high-speed modulation. An extinction ratio of over 3.5 dB and facet output power of over 7 dBm were obtained with these EMLs. Clear eye diagrams were obtained after 10 km transmission for EMLs with wavelengths from 1294.5 nm to 1315.8nm. Therefore, we demonstrated 225 Gb/s PAM4 10 km transmission using EMLs for a wide wavelength range.

2. EML design

A schematic structure of our developed EML is shown in Figure 1. This EML has a unique hybrid waveguide structure, which combines a buried heterostructure distributed feedback laser diode (DFB-LD) for high optical output power and a high-mesa electro absorption modulator (EAM) waveguide for a high extinction ratio and high-speed operation [2, 6]. To achieve 225Gb/s modulation, the design of the EML chip was optimized. A spot-size converter (SSC) contributes to a good fiber coupling coefficient. EML chip was assembled on a wide bandwidth sub-mount designed for 200 Gb/s modulation.

Figure 2 shows the output optical spectra of the EML chips. We manufactured eight EML chips with wavelengths from 1271nm to 1331nm covering a range of CWDM4. These were measured at 50°C with a DC current of 100 mA applied to the LD part and without a bias voltage to the EAM part. Enough side-mode suppression ratios were obtained for all EML chips.

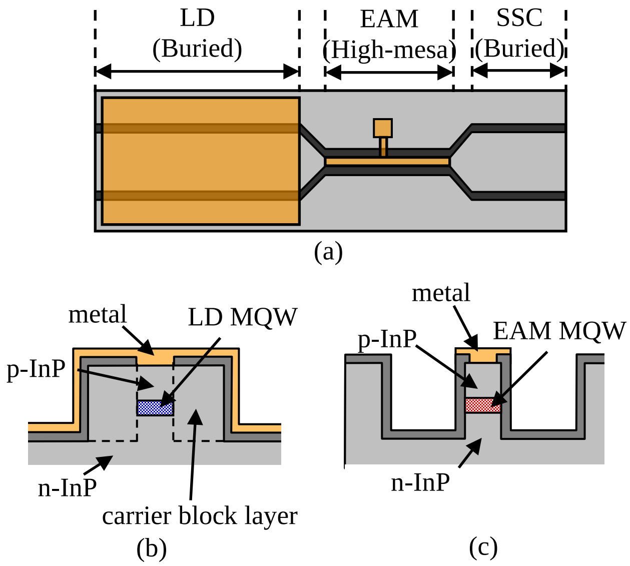


Fig. 1. Schematic structure of hybrid-waveguide EML for 225Gb/s PAM4 modulation
(a) Top view of entire chip
(b) Cross-sectional view of buried LD
(c) Cross-sectional view of high-mesa EAM

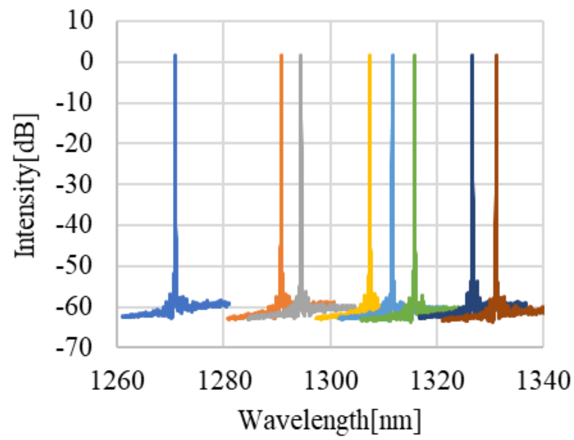


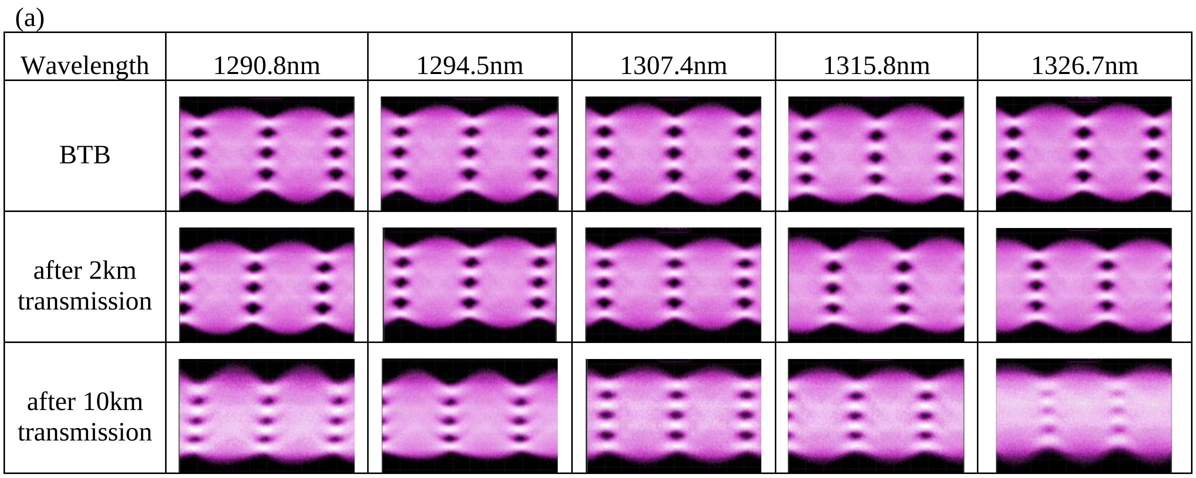
Fig. 2. Output optical spectra of EML chips with If=100mA at 50 °C

3. Experimental result

We experimentally evaluated 225 Gb/s (112.5 Gbaud) PAM4 optical eye diagrams. Measurements were conducted by contacting a probe directly to a sub-mount. An electrical signal was generated by an arbitrary waveform generator (AWG, Keysight M8199) and amplified by a linear amplifier, including a bias tee (SHF, M827). An output electrical signal had a peak-to-peak modulation amplitude of about 1.2 Vpp, and approximately equal separations between all four levels. Optical eye diagrams were captured by a sampling oscilloscope (Keysight, N1030A) applying a half-baud-rate 4^{th} order Bessel-Tomson filter followed by a 5tap T-spaced transmitter and dispersion eye closure quaternary (TDECQ) reference equalizer. Standard single mode fibers with a zero-dispersion wavelength of around 1310nm were used for 2 km and 10 km transmission tests.

The EML chips were measured at 50°C controlled by a thermo-electric controller (TEC). DC bias voltage which makes a linear optical eye diagram was applied to the EAM part through a bias tee, and a DC operation current of 100 mA was applied to the LD part. At this condition, an extinction ratio of over 3.5 dB and facet output power of over 7 dBm were obtained without a TDECQ reference equalizer.

Figure 3 (a) shows measured eye diagrams of five EML chips with wavelengths of 1290.8 nm through 1326.7 nm after a TDECQ reference equalizer. The upper, middle, and lower rows show eye diagrams of BTB, after 2 km transmission and after 10km transmission, respectively. Clear eye diagrams were observed at BTB and after 2 km transmission for all EML chips. In addition, clear eye diagrams were obtained after 10km transmission for EML chips with wavelengths from 1294.5 nm to 1315.8 nm. Though distortion of eye diagrams was observed for wavelengths of 1290.8 nm and 1326.7 nm caused by chromatic dispersion after the 10km transmission, eye openings were also recognized for these two chips. Figure 3 (b) shows measured TDECQ values for eight EML chips with different wavelengths using a target symbol error rate (SER) of 4.85E-3 after 2 km and 10 km transmission. We confirmed that TDECQ after 2km were less than 2dB for all EML chips with wavelengths from 1271 nm to 1331 nm. After 10 km transmission, we obtained TDECQ less than 2.5 dB for chips with wavelengths from 1294.5 nm to 1315.8 nm. TDECQ was not obtained for chips with wavelengths shorter than 1290.8 nm and longer than 1326.7 nm because the actual SER was higher than the target SER. These results agree with the principle of optical transmission characteristic dependence on chromatic dispersion.



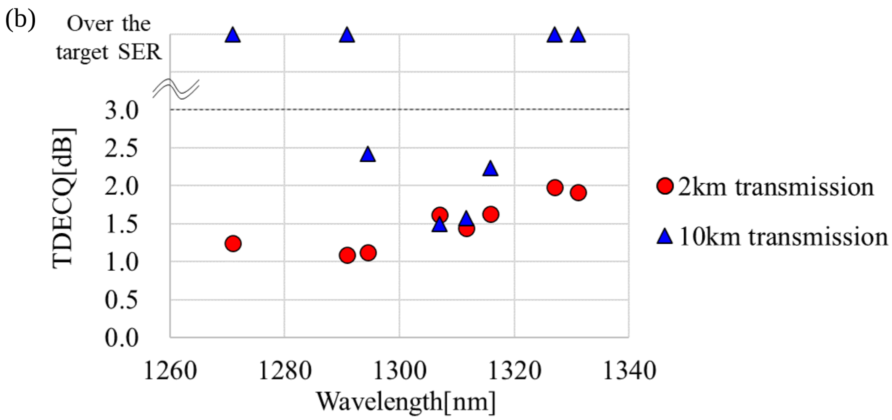


Fig. 3. (a) Eye diagrams of BTB, after 2 km transmission and after 10 km transmission with TDECQ reference equalizer. (b) Measured TDECQ values of all eight EML chips with different wavelengths at SER=4.85E-3 after 2 km and 10 km transmission.

4. Conclusions

We developed high-speed EMLs with a hybrid waveguide structure and experimentally demonstrated BTB, 2 km and 10 km transmission of 225 Gb/s/lane PAM4 modulation signal. An extinction ratio of over 3.5 dB and facet output power of over 7 dBm were obtained. Clear eye diagrams after 2 km were obtained for EML chips with wavelengths from 1271 nm to 1331 nm, which covers the CWDM4 range. After 10 km transmission, we observed clear eye diagrams for EML chips with wavelengths from 1294.5 nm to 1315.8nm. Therefore, we demonstrated 225 Gb/s PAM4 10 km transmission using EMLs for a wide wavelength range.

5. Acknowledgement

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