

Integrated TOSA with High-Speed EML Chips for up to 400 Gbit/s Communication

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Optical transceivers for high-speed transmission at more than 100Gbit/s have been downsized and implemented at increasingly high density. We have developed a new compact optical transmitter that consists of a low-coupling-loss optical multiplexer and four distributed feedback lasers with integrated electro-absorption modulators. This transmitter can be installed into QSFP28 to enable transmission at 100 Gbit/s up to 40 km and also used for 200 and 400 Gbit/s systems. This paper presents the design and performance of the transmitter.

Keywords: over 100 Gbit/s, transmitter, high integration, modulation type LD

1. Introduction

Data communication services, such as social networking services and video streaming, have been continuously growing in line with the spread of highly functional mobile devices. As the communication traffic volume has increased, efforts have been made to expand the capacity of communication networks.

The capacity of optical transport systems used in communication networks increases by reducing the size of optical transceivers implemented in the converters and achieving high-density implementation of multiple optical transceivers.

Specifically, 100G form-factor pluggable (CFP) was the mainstream form factor of 100 Gbit/s optical transceivers.⁽¹⁾ Recently, there has been a shift to a smaller form factor CFP2, CFP4,^{*1} and Quad small form-factor pluggable (QSFP) 28.

Regarding optical transmitters and receivers (TOSA, ROSA)^{*2} that are mounted in these small optical transceivers, the development of devices incorporating the wavelength multiplexing function is underway.

The new transmitter that we have developed is equipped with four electro-absorption modulator integrated laser (EML) chips that are suitable for medium- and long-distance transmission. Integration has been achieved by an optical multiplexing system of our proprietary design.

The new transmitter is designed to be applied to the four-level pulse amplitude modulation (PAM4)^{*3} systems (the next-generation modulation) toward 200 and 400 Gbit/s. This paper reports the structure and characteristics of the new device.

2. Development Policy and Specifications

The dimensions of the CFP2 and QSFP28 are shown in Fig. 1. The new transmitter is designed to be mounted in the QSFP28.

The QSFP28 (width: 18.4 mm) is equipped with an optical transmitter and receiver. The target width of the new transmitter is 7 mm or less (less than half the width of

the QSFP28).

100 Gbit/s system generally transmits and receives four wavelengths of LAN wavelength division multiplexing (WDM)^{*4} at 25 Gbit/s each. In the conventional CFP optical transceiver, four transmitters (one transmitter per wavelength) were mounted.⁽²⁾

To cope with the dimensional restrictions of the QSFP28 discussed above, the size of the new transmitter has been reduced by integrating the four transmitters for each wavelength into a single device.

The target specification of the transmitter is shown in Table 1. The new transmitter is designed for medium- and long-distance applications. Thus, it's aimed to meet the optical output and extinction ratio characteristics in compli-

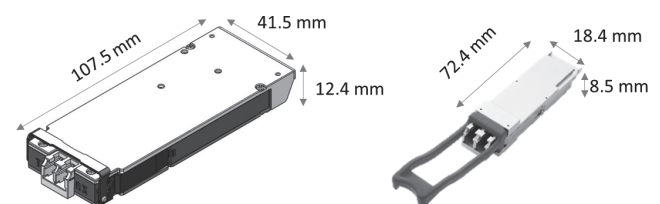


Fig. 1. Optical transceivers (CFP2/QSFP28)

Table 1. Target specification of the transmitter

	Min.	Max.	Unit
Bit rate	25.78 - 27.95		Gbit/s
Transmission distance	0 ~ 40		km
Operating case temperature	-5	75	°C
Optical output power	-2.9	-	dBm
RF extinction ratio	8.0	-	dB
Optical wavelength	Lane 0	1294.53 to 1296.59	nm
	Lane 1	1299.02 to 1301.09	nm
	Lane 2	1303.54 to 1305.63	nm
	Lane 3	1308.09 to 1310.19	nm
TEC power consumption	-	1.5	W

ance with 100 G BASE-LR4 (transmission distance: 10 km) and 100 G BASE-ER4 (transmission distance: 40 km) of IEEE 802.3ba.⁽³⁾

The device also aimed to achieve operation at high speeds in compliance with ITU-T G.959.1 (27.95 Gbit/s).⁽⁴⁾

3. Structure of the Device

The structure of the transmitter is shown in Fig. 2. Four EMLs of different wavelengths are mounted in the package. Thermo-electric cooler (TEC)*⁵ and thermistor are incorporated to keep the laser temperature constant.

For optical multiplexing, the spatial multiplexing method characterized by low optical loss is used. Two flexible printed circuits (FPCs) are used for electrical connection with the circuit board of the optical transceiver. The high-frequency signals are separated from the low-frequency signals. An LC receptacle incorporating a single mode fiber (SMF) is used for the optical output port.

This configuration achieved the device dimensions of 26.8 mm in total length, 6.7 mm in width, and 5.3 mm in height. (The total length is the span between the tip of the LC receptacle and the end of the package.)

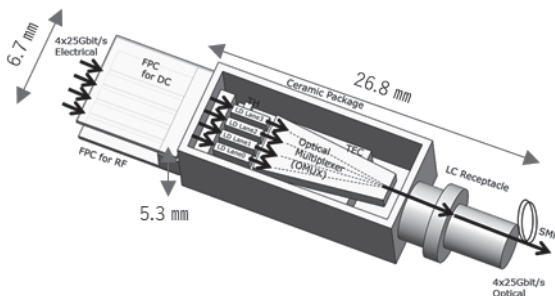


Fig. 2. Structure of the device

4. Design of the Optical Multiplexer

Regarding the optical multiplexing method, the spatial multiplexing method of our proprietary design is used to take full advantage of the laser polarization characteristics. The multiplexing loss is lower than the optical waveguide method such as the arrayed waveguide grating (AWG) method.⁽⁵⁾

Figure 3 shows the schematic diagram of the optical multiplexer. The optical beam from each laser is converted into collimated beam by an optical lens. The P-polarization parallel beams of Lane 0 and Lane 2 are multiplexed by WDM filter #2. The parallel beams of Lane 1 and Lane 3 are converted from P-polarization to S-polarization by a half-wave plate and multiplexed by WDM filter #1. The two pairs of parallel beams are eventually multiplexed into a single beam by a polarization beam combiner, and multiplexed to a fiber by a condenser.

In this optical multiplexing method, the wavelength can be changed by replacing the WDM filter, facilitating application to other wavelength bands.

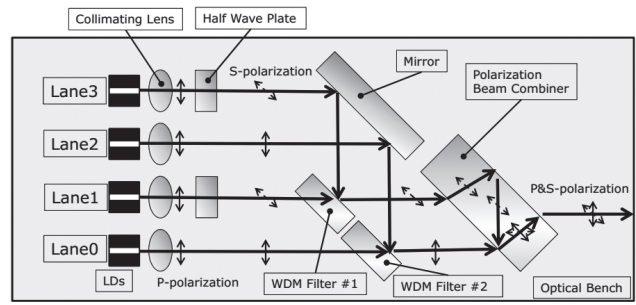


Fig. 3. Schematic diagram of optical multiplexing components

5. Electro-Absorption Modulator Integrated Laser

There are two candidates for the high-speed light source: direct modulation lasers (DMLs) and EMLs. It is difficult for DMLs to achieve a high extinction ratio, and they are characterized by significant distortion of the optical waveform due to relaxation oscillation. Thus, DMLs are unsuitable for medium- and long-distance transmission. Therefore, the new transmitter uses EML chips for these targets.

The schematic diagram of the cross section of EML is shown in Fig. 4. EML has an optical modulator integrated in front of a distributed feedback (DFB) laser. To increase the extinction ratio of EML, the modulator length needs to be increased.

Meanwhile, to ensure band characteristics sufficient for high-speed operation, the modulator length needs to be reduced from the viewpoint of reducing the capacitance. Thus, the modulator length was optimized to achieve RF extinction ratio 8 dB and operation at 27.95 Gbit/s.

An anti-reflection (AR) coat is formed on the front emission end face. If the reflectance of this part is high, the light reflected by the emission end face returns to the laser part adversely affects the device characteristics.

AR coat with an extremely low reflectance is used in this EML chip to achieve excellent characteristics.

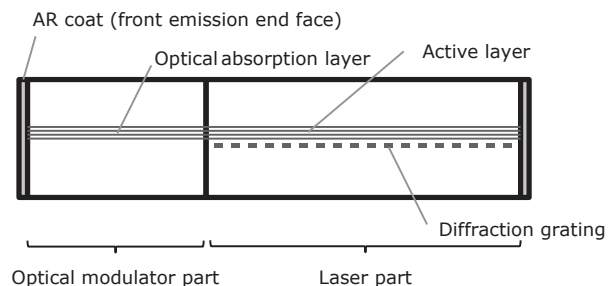


Fig. 4. Schematic diagram of an EML

6. DC Characteristics

Figure 5 shows the laser forward current versus optical output power (I-L characteristic). When the laser

current is 80 mA, an optical output of 3.2 mW (about 5 dBm) is achieved.

Figure 6 shows the DC extinction ratio characteristics when reverse voltage is applied to the modulator. The extinction ratio between -1 V and -3 V is 10 dB or more.

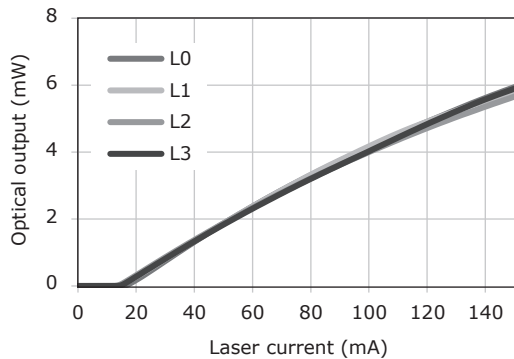


Fig. 5. Laser current-optical output characteristics (I-L characteristics)

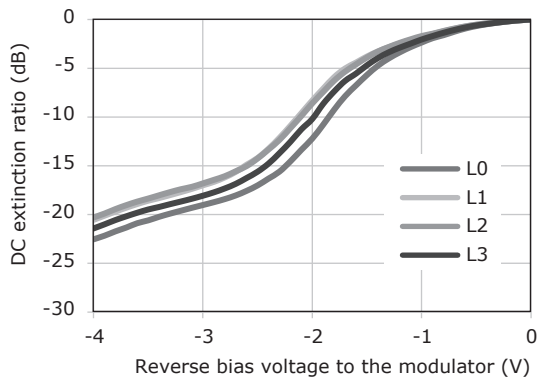


Fig. 6. DC extinction characteristics

7. Power Consumption

When the temperature of the case increases or decreases, the TEC incorporated in the transmitter functions as a cooling/heating element to keep the laser temperature constant.

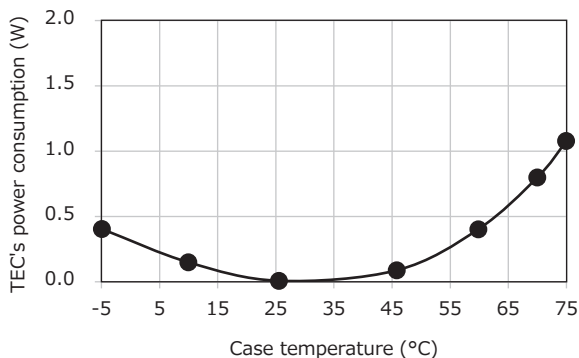


Fig. 7. Power consumption characteristics

Figure 7 shows the power consumption of the TEC at laser current of 80 mA. The power consumption tends to increase when the temperature is high. When the case temperature is 75°C, TEC's power consumption is below the target (1.5 W).

8. RF Characteristics

This section shows the evaluation results of the RF characteristics. The electro-optical conversion frequency characteristics are shown in Fig. 8. The frequency of the 3 dB bandwidth is over 20 GHz, showing that the characteristics are sufficient for 27.95 Gbit/s operation⁽⁵⁾ (ITU-T standard).

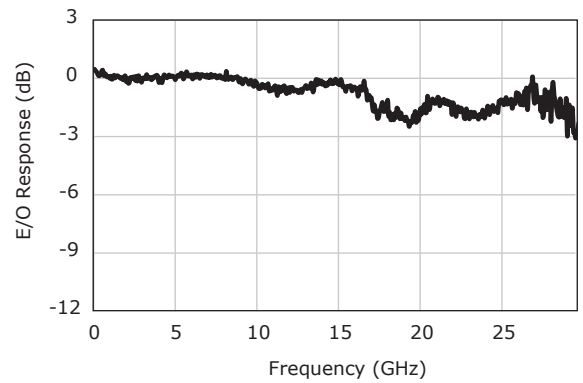


Fig. 8. Frequency characteristics

Figure 9 shows the optical output waveform of 27.95 Gbit/s when a Bessel-Thomson filter is used. The evaluation results are shown in Table 2. The pulse pattern generator (PPG) was used as the signal source, and the electric signal of PRBS $2^{31}-1$ was input to the transmitter at the transmission speed of 27.95 Gbit/s to observe the optical output waveform.

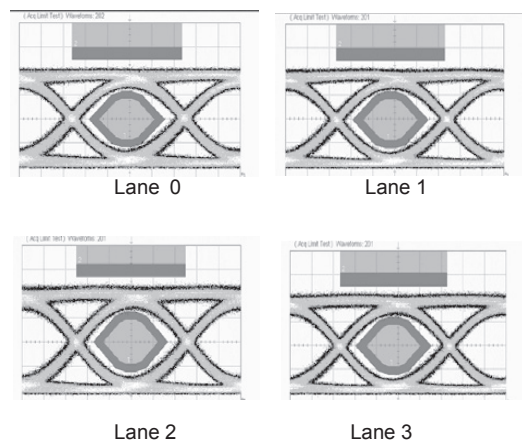


Fig. 9. Optical output waveform

Table 2. Evaluation results of the optical output waveform

	Lane 0	Lane 1	Lane 2	Lane 3
Optical output (dBm)	2.3	1.8	1.5	1.5
Extinction ratio (dB)	8.1	8.5	8.7	8.3
Mask margin (%)	39	41	38	42

Favorable results were obtained for all four lanes (RF extinction ratio: 8 dB or more, optical output power during modulation: 1.5 dBm or more), meeting the target specifications. Regarding eye mask margin as specified in IEEE and ITU-T, the characteristics were also favorable for all four lanes (35% or more).

9. 200 and 400 Gbit/s support

The next-generation 200 and 400 Gbit/s systems increase communication speed by using the PAM4 modulation instead of the non-return-to-zero (NRZ) modulation. While the 200 Gbit/s system uses the four-wavelength multiplexing method, the 400 Gbit/s system uses the eight-wavelength multiplexing method (double that of the 200 Gbit/s system) for the signal transmission of 400 Gbit/s in total.

We have fabricated eight types of laser chips with different wavelengths for the 400 Gbit/s system. Four laser chips are mounted in two transmitters to enable optical signal output of eight wavelengths in total.

The optical spectrum of eight signals is shown in Fig. 10, and the emission wavelength is shown in Table 3. The obtained optical spectrum meets the IEEE P802.3bs standard (400GBASE-LR8).⁽⁶⁾

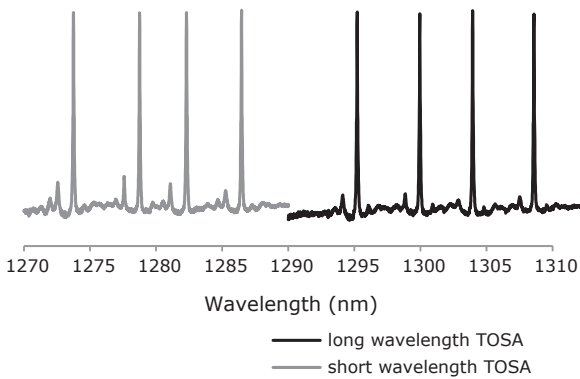


Fig. 10. Spectrum of eight signals

Table 3. Eight-wavelength emission wavelength

TOSA short wavelength (nm)	Lane 0	Lane 1	Lane 2	Lane 3
	1273.7	1278.8	1282.3	1286.5
TOSA long wavelength (nm)	Lane 4	Lane 5	Lane 6	Lane 7
	1295.2	1300.0	1304.0	1308.6

The evaluation results using PAM4 modulation signals are shown in Fig. 11. The signal source IC and linear laser driver IC were used to input PAM4 modulation signals (symbol rate: 25.6 Gbaud, signal pattern: PRBS $2^{13}-1$) to observe the optical waveform of the transmitter. The equalizer specified by the Transmitter and Dispersion Eye Closure Quaternary (TDECQ) was used to achieve this optical waveform.

The evaluation results show the extinction ratio of 5.1 dB and TDECQ of 1.8 dB. These results confirmed that the characteristics required of the IEEE P802.3bs standard, which is currently being standardized, (extinction ratio: 3.5 dB or more, TDECQ: 3.3 dB or less) are met.

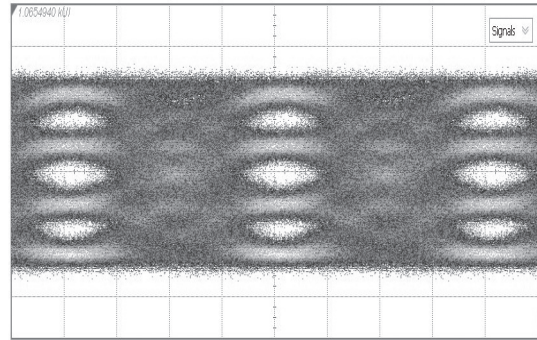


Fig. 11. Optical output waveform of PAM4 signals

10. Conclusion

We have developed 4-ch integrated transmitter with an LD chip (incorporating an external modulator) that can be mounted in the QSFP28 small 100 Gbit/s optical transceiver.

The size has been reduced by taking full advantage of (1) our proprietary optical multiplexer design that uses laser polarization characteristics and (2) high-precision and high-density implementation technology.

We verified favorable operating characteristics at the transmission speed of 27.95 Gbit/s by using EMLs manufactured in-house. We also verified the characteristics of the PAM4 modulation to be used in the 200 and 400 Gbit/s systems. The device has been confirmed to be usable in next-generation communication applications.

Technical Terms

- *1 CFP2, QSFP28: Industry standard optical transceivers for 100 Gbit/s.
- *2 Transmitter Optical Sub-Assembly (TOSA): Small optical devices for transmission.
Receiver Optical Sub-Assembly (ROSA): Small optical devices for reception.
- *3 PAM4 modulation: Four-level pulse amplitude modulation. The amount of information handled is double that of the conventional two-level NRZ modulation.
- *4 LAN wavelength division multiplexing (WDM): A method to transmit the signals of four wavelengths (between 1294.53 nm and 1310.19 nm) using a single fiber.
- *5 Thermo-electric cooler (TEC): Peltier module. One of the electrothermal elements. The heating/cooling element utilizes the Peltier effect.

References

- (1) EIJI TSUMURA at al., "Development of 43/112 Gbit/s Optical Transceiver Modules," SEI Technical Review No75 (OCT 2012)
- (2) HISASHI FUJITA at al., "25 Gbit/s Optical Transmitter Modules for Optical Transceiver," SEI Technical Review No80(April 2015)
- (3) "IEEE 802.3ba Media Access Control Parameters," Physical Layers and Management Parameters for 40 Gb/s and 100Gb/s Operation
- (4) "ITU-T G.959.1 SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS" (04/2016)
- (5) TOMOYA SAEKI et al., "Compact Optical Transmitter Module with Integrated Optical Multiplexer for 100 Gbit/s," SEI Technical Review No82 (April 2016)
- (6) "IEEE 802.3bs/D3.4 Draft Standard for Ethernet Amendment 10:Media Access Control Parameters," Physical Layers and Management Parameters for 200 Gb/s and 400 Gb/s Operation

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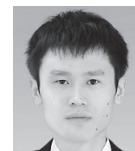
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