High Output Power and Compact LAN-WDM EADFB Laser TOSA for 4 × 100-Gbit/s/λ 40-km Fiber-Amplifier-Less Transmission

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Abstract: We achieved the world's first demonstration of 4 × 100-Gbit/s/λ 4-PAM signals 40-km fiber-amplifier-less transmission featuring a power budget over 18 dB using a 4-channel high output power LAN-WDM EADFB laser TOSA and APD ROSA.
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1. Introduction

Internet traffic continues to increase explosively due to the rapid growth of smart computing and mobile devices, causing the Ethernet data rate to continue to grow rapidly also. To cope with this trend, 400-gigabit Ethernet (400GbE) was standardized for under 10-km single-mode fiber (SMF) transmission [1]. One 400GbE system uses 4-channel (4-ch) × 100-Gbit/s/λ net data rate signals. For 40-km single-mode fiber (SMF) transmission, 100GBASE-ER4 was standardized in 2010 [2]. It uses 4-ch × 25-Gbit/s non-return-to-zero (NRZ) signals. Therefore, a 4-ch × 100-Gbit/s/λ scheme is a promising candidate for 400-Gbit/s beyond the 10-km transmission optical system.

As a 100-Gbit/s operation optical transmitter, an electroabsorption modulator integrated with distributed feedback lasers (EADFB laser) [3, 4] is a promising candidate. The 2-km SMF transmission of 4-ch × 100-Gbit/s/λ net data rate signals has also been reported [5]. However, 40-km SMF transmission of 400-Gbit/s signals without an optical fiber amplifier has never been reported, chiefly due to the lack of power budget. An avalanche photo-diode (APD) can improve receiver sensitivities compared with the p-i-n photo-diode (PD). A single-wavelength 100-Gbit/s net data rate signal 40-km SMF transmission using an EADFB laser and APD has already been reported [6]. In this context, construction of a high output power 4-ch transmitter optical sub-assembly (TOSA) for 40-km transmission application is strongly desired. A compact TOSA, which is suitable for the QSFP-DD transceiver form factor [7], is also needed. The QSFP-DD is a promising candidate for the 400-Gbit/s transceiver.

In this paper, we fabricate a compact 4-ch TOSA using an SOA assisted extended reach EADFB laser (AXEL). An AXEL can increase the optical output power thanks to the integrated SOA [8]. To fabricate this compact QSFP-DD supported TOSA, we designed and fabricated compact AXEL sub-assemblies with a 3-dB bandwidth of more than 40 GHz and a width of just 0.65 mm. Using the 4-ch LAN-WDM AXEL TOSA and the 4-ch APD receiver optical sub-assembly (ROSA), we achieved the world's first demonstration of 4-ch × 100-Gbit/s/λ net data rate signals 40-km SMF transmission without an optical fiber amplifier.

2. Design and performance of 4-ch AXEL TOSA

Figure 1(a) shows the schematic structure of AXEL. The lengths of the DFB laser, EAM, and SOA are 300, 125, and 85 μm, respectively. The SOA length was decided by considering its pattern effect and the modulated optical output power requirement. The SOA works as a modulated optical signal amplifier, so it can obtain higher modulation optical output power than a conventional EADFB laser. Figure 1(b) shows the schematic structure of the AXEL sub-assembly. After passing through the 50-ohm resistance, the electrical signal is transmitted from the RF circuit board to the capacitor through wire (b). If the parasitic inductance of wire (b) increases, the peak level of the E/O response increases. However, the wire (b) length increase prevents downsizing the AXEL sub-assembly. Therefore, we designed the arrangement of all components in the subcarrier with a width of only 0.65 mm to achieve a high modulation bandwidth of over 40 GHz, which is sufficient for 100-Gbit/s/λ operation. The length of wire (b) was set to 0.5 mm. Figure 1(c) shows the simulated and measured E/O responses. The simulated result fits the measured one. We obtained the 3-dB bandwidth of more than 40 GHz.

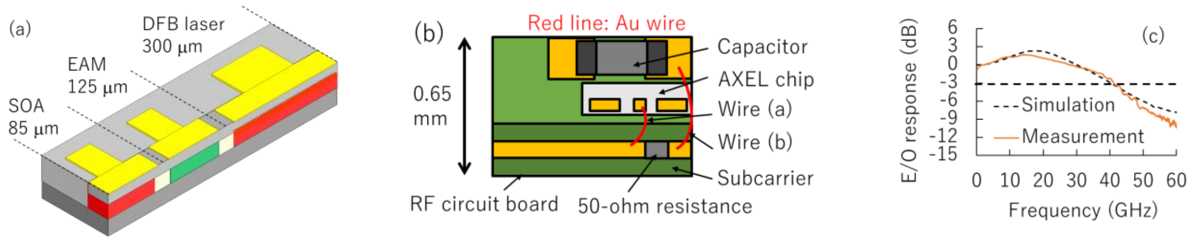


Fig. 1 (a) Schematic structure of AXEL chip. (b) Schematic structure of AXEL sub-assembly. (c) Simulated and measured E/O responses of sub-assembly.

Figure 2(a) shows the schematic structure of the 4-ch AXEL TOSA. Four discrete previously designed AXEL sub-assemblies, a 4-ch optical MUX consisting of thin film filters (TFFs) and a mirror, four 1st lenses, and an isolator were mounted on an optical base, and the base was mounted on a thermo-electric cooler (TEC). After passing through the optical MUX, the four optical signals were multiplexed as shown in the figure. The multiplexed optical signals were coupled to an LC receptacle through a 2nd lens. The measured coupling losses of all lanes were less than 3 dB. A photograph of the fabricated 4-ch AXEL TOSA is shown in Fig. 2(b). Thanks to the compact AXEL sub-assembly, we were able to achieve a compact TOSA sized just 6.2 × 18.2 × 5.4 mm, which is suitable for the QSFP-DD transceiver. Figure 3 shows the lasing spectrum of the 4-ch AXEL TOSA. For all the measurements, the chip temperature was set to 50°C, and the LD and SOA currents were 80 and 40 mA, respectively, for all lanes. The EA bias voltages of lanes 0, 1, 2, and 3 were set to –1.27, –1.52, –1.56, and –1.37, respectively. The four peak wavelengths were 1295.35, 1300.25, 1304.45, and 1309.35 nm. These peaks coincide with the LAN-WDM grid.

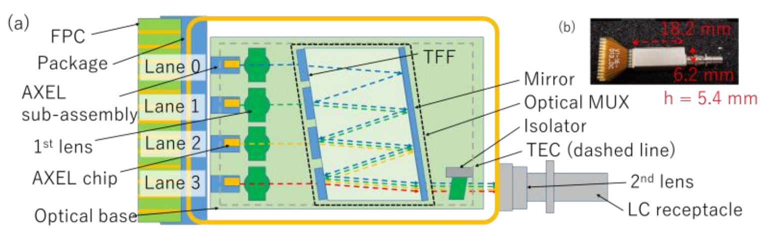


Fig. 2 (a) Schematic structure of 4-ch AXEL TOSA. (b) Photograph of 4-ch AXEL TOSA.

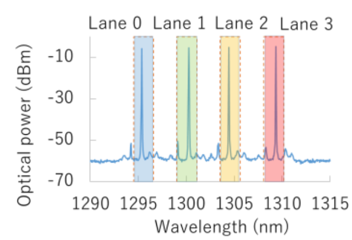


Fig. 3 Lasing spectrum of AXEL TOSA (colored areas indicate LAN-WDM grid).

3. Experimental results

We measured the eye diagrams and the bit-error-rate (BER) characteristics for all four lanes. Figure 4 shows the experimental setup of the 4-ch × 100-Gbit/s/λ net data rate signal 40-km SMF transmission. A commercially available digital signal processor (DSP) was used to generate the four 53.125-Gbaud 4-PAM electrical signals which includes KP4 forward error correction (FEC) overhead of 5.8% [9]. The amplified electrical signals were converted into optical signals by the 4-ch AXEL TOSA. For the eye diagram measurement, the optical signal was measured using a sampling oscilloscope (sampling OSC). For the BER measurement, a 4-ch APD ROSA converted optical signals into electrical signals. The received electrical signals were demodulated and equalized by the DSP. We performed a 4-ch × 53.125-Gbaud/λ 4-PAM signal transmission experiment using the fabricated 4-ch AXEL TOSA and APD ROSA. Figure 5 shows the 53.125-Gbaud/λ 4-PAM eye diagrams of four optical signals under single-channel operation and the BER characteristics for 4-ch simultaneous operation. For the eye diagram measurement, we used a 4th-order Bessel-Thomson filter and a transmitter dispersion eye closure quaternary (TDECQ) filter (1UI-5taps) based on IEEE 802.3cd [10]. The applied swing voltage was about 0.75 Vpp. The TDECQs were less than 2.4 dB for all the lanes for a back-to-back (BtoB) configuration. The optical modulation amplitudes (OMA) were more than +4.7 dBm for all lanes thanks to the AXEL. As for BER measurement, the solid and dashed lines indicate the BER characteristics for BtoB configuration and 40-km SMF transmission, respectively. The red line indicates the BER of 2.4×10^{-4}, which is an error-free condition using KP4 FEC. For the 40-km SMF transmission, we achieved error-free transmission using KP4-FEC for all the lanes, and the minimum receiver sensitivities of lanes 0, 1, 2, and

3 were –13.4, –12.3, –13.4, and –14.1 dBm, respectively. For 40-km transmission against the BtoB configuration, the power penalties of 0, 1, 2, and 3 were 0.6, 1.2, 0.3, and –0.3 dB, respectively. These power penalties were caused by the chromatic dispersion of the SMF, the positive chirp parameters of the AXEL, and the electrical crosstalk of the TOSA. For all lanes, the power budgets exceeded 18 dB thanks to the high output power of the AXEL chips and the high sensitivity of the APD chips.

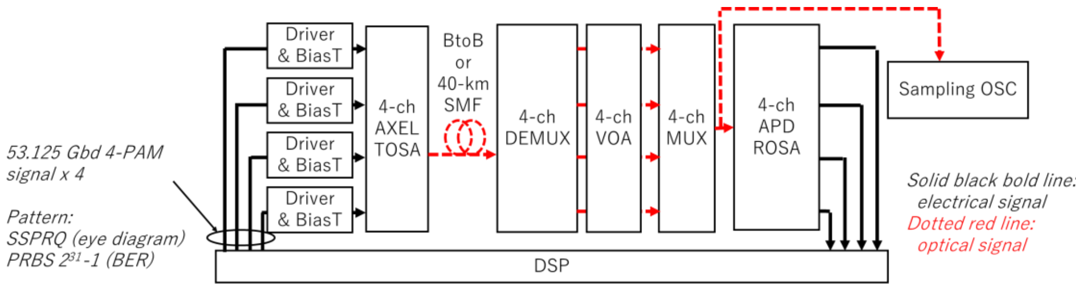


Fig. 4 Experimental setup for 4-ch × 100-Gbit/s/λ net data rate signals 40-km SMF transmission.

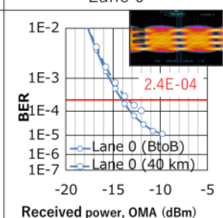
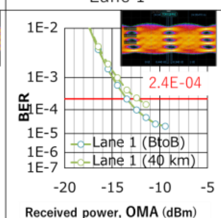
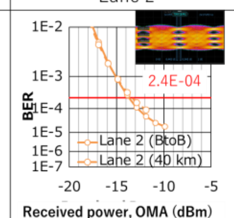
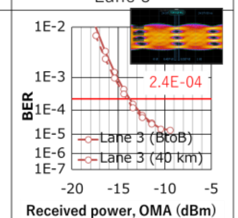
		Lane 0	Lane 1	Lane 2	Lane 3
BER					
TDECQ (dB)		1.8	2.4	1.2	1.8
ER (dB)		3.9	4.2	3.8	4.3
OMA (dBm)		4.7	5.8	5.8	6.3
Receiver sensitivity (dBm)	BtoB	-14.0	-13.5	-13.7	-13.8
	40 km	-13.4	-12.3	-13.4	-14.1
Loss budget (dB)		18.1	18.1	19.2	20.4

Fig. 5 53.125-Gbaud/λ 4-PAM eye diagrams after TDECQ filter and BER characteristics under 4-ch ×53.125-Gbaud/λ 4-PAM operation for BtoB and 40-km SMF transmission.

4. Conclusion

We fabricated a high output power 4-ch AXEL TOSA feauturing a compact AXEL sub-assembly with a 3-dB bandwidth of more than 40 GHz. OMAs of more than +4.7 dBm were observed for all four lanes. We successfully demonstrated 4-ch × 100-Gbit/s/λ net data rate 4-PAM signal 40-km SMF transmission and achieved a high loss budget of more than 18 dB by using the 4-ch AXEL TOSA and the 4-ch APD ROSA. These results demonstrate that the 4-ch AXEL TOSA is the most promising candidate for a 400-Gbit/s light source beyond 10-km configuration.

5. References

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