A Hybrid-Integrated 400G TROSA Module Using Chip-to-Chip Optical Butt-Coupling

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Abstract: Using an optical butt-coupling method, we have developed a low-cost hybrid-integrated 4×100G TROSA module, showing clear Tx optical eye patterns and Rx sensitivities within -7.0 ~ -6.4 dBm at 106-Gbps PAM4 signals for all channels.

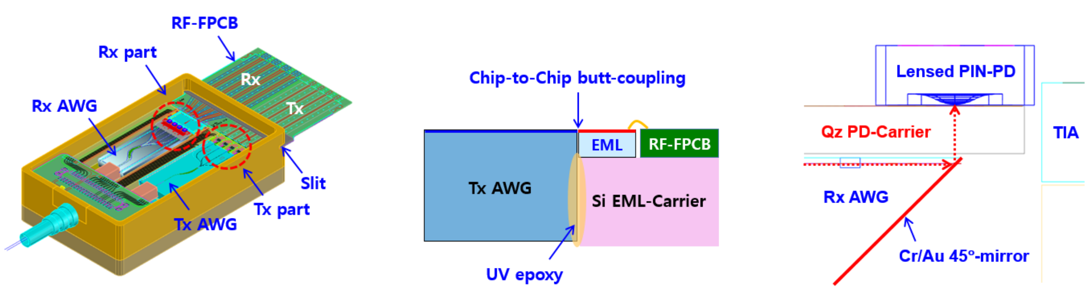
1. Introduction

Due to the explosive growth of data traffic for cloud computing, search engines, and social network services in the datacenter optical interconnects, the demands for cost-effective and high-speed optical transceivers or transmitter-receiver optical subassemblies (TROSAs) operating at 400 Gbps have been incessantly increasing. According to the 400G-FR4 multiple source agreement (MSA), 400-Gbps operation is based on 4 channels comprising the coarse wavelength division multiplexing (CWDM) optical filters, each channel operating at 100-Gbps PAM4 signals [1].

Recently, 4×100G TOSA and ROSA modules have been demonstrated mainly by using the optical multiplexer and demultiplexer based on the bulk-optic components such as thin film filters and multiple lenses [2, 3]. Meanwhile, in the hybrid integration using a silica-based arrayed waveguide grating planar lightwave circuit (AWG PLC), direct chip-to-chip alignment and butt-coupling of the AWG and light source/detector chips is more advantageous than alignment and coupling using individual lenses in terms of packaging yields and cost reduction for the module fabrication [4]. Moreover, to further lower the packaging cost of the TOSA and ROSA modules, Tx and Rx functions need to be integrated into one package case.

In this paper, we present a cost-effective silica PLC hybrid-integrated 400G (4×100G) TROSA module with Tx and Rx functioning simultaneously, which is realized by using the chip-to-chip optical butt-coupling between a vertically polished Tx AWG and electro-absorption modulated laser (EML) chips, and between a 45°-polished Rx AWG and lensed PIN-PD chips. The Tx and Rx AWGs are based on the CWDM wavelength grids and silica waveguides with an index contrast of 2%-Δ for a compact chip size, and Tx and Rx submodules are integrated into a single package case. By using an evaluation board, we demonstrate that both Tx and Rx sides of our fabricated TROSA well operate at 106-Gbps (53-Gbaud) PAM4 signals, especially after offline-digital signal processing (DSP) of electrical Rx signals for transimpedance amplifier (TIA) outputs.

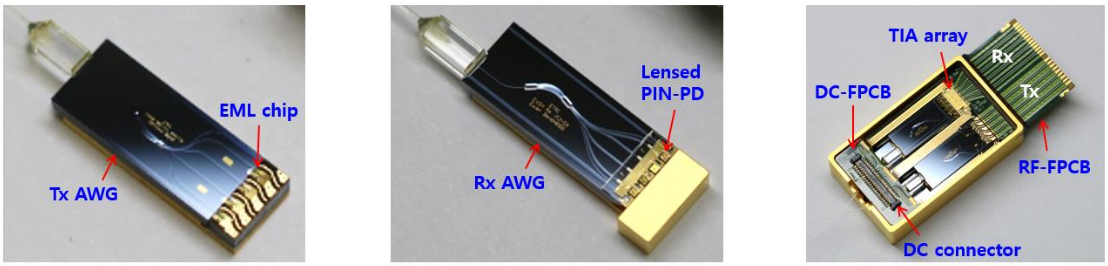
2. Design and fabrication of a hybrid integrated 400G TROSA module



(a) (b) (c)

Fig. 1. (a) Schematic diagram of our hybrid-integrated 400G TROSA module, (b) cross-sectional view of the EML-based Tx submodule, and (c) that of the Rx submodule with lensed PIN-PDs on the Qz flat PD-carrier.

Figure 1(a) shows a schematic diagram of our hybrid-integrated 4×100G TROSA, in which an EML-based Tx submodule and a Rx submodule are integrated into one package case. For a compact-sized TROSA, a very small Tx and Rx AWGs with a footprint of 10 mm × 4.4 mm or less were designed and fabricated by using the silica waveguides having an index contrast of 2%-Δ and a core size of 3.5 μm × 2.5 μm, operating at the CWDM wavelength grids. In the EML-based Tx submodule, four commercial EML chips precisely die-bonded on a silicon carrier are actively aligned with the vertically polished Tx AWG chip, and the waveguides between the EML and Tx AWG chips are butt-coupled each other in a straight form without tilting in vertical and lateral directions, as shown in Fig. 1(b). For the Rx submodule, a quartz (Qz) flat PD carrier (PDC) holding four commercial lensed PIN-PDs is passively aligned and then epoxy-bonded on the 45°-polished output waveguides of the Rx AWG as shown in Fig. 1(c), using the metal alignment patterns formed on surfaces of both the PDC and Rx AWG. The Cr/Au metal was deposited on the 45°-polished surface to form a low loss reflecting mirror. All-in-one RF-flexible printed circuit board (FPCB) with Tx GSG and Rx GSSG transmission lines are inserted through the slit of a metal package case, as depicted in Fig. 1(a).



(a) (b) (c)

Fig. 2. Photographs of (a) the EML-based Tx submodule, (b) the Rx submodule, and (c) the fully packaged 400G TROSA module.

A fabricated EML-based Tx submodule and a Rx submodule are shown in Figs. 2(a) and 2(b), and those Tx and Rx submodules were integrated into one metal case. For easy replacement of the TROSA module, a clamping contactable RF-FPCB as well as a small FPCB-stacked DC connector are used on a top side of the TROSA case, as shown in Fig. 2(c). Our fabricated Tx and Rx submodules can be fitted in a board-mount assembled optical transceiver, and the fully packaged TROSA itself can be used as an on-board optical module as well. For the Tx submodule, optical output powers were measured to be 2.5 ~ 4.4 dBm at bias currents of 100 mA for DFB-LD sections of the EMLs for all channels. Side mode suppression ratio values and 3-dB bandwidths were achieved to be over 50 dB at a DFB-LD bias current of 100 mA and about 38 ~ 42 GHz at EAM bias voltages of -1.5 ~ -1 V for the EMLs, respectively, even in the case of straightly coupled waveguides between the EMLs and Tx AWG. This means that the optical characteristics were insensitive to the influence of feedback light which might be reflected from a vertically polished facet of the Tx AWG chip. For the Rx submodule, a 53-Gbaud TIA array was die-bonded near the lensed PIN-PDs, and wedge-bonding was applied for high-speed operation. The submodule exhibited good responsivity values of 0.515 ~ 0.55 A/W.

3. Experimental results

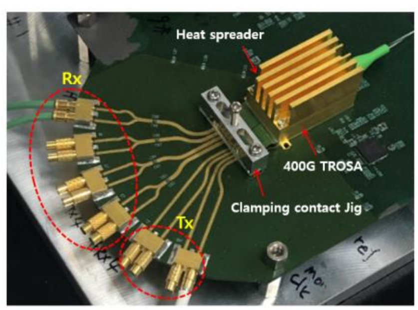
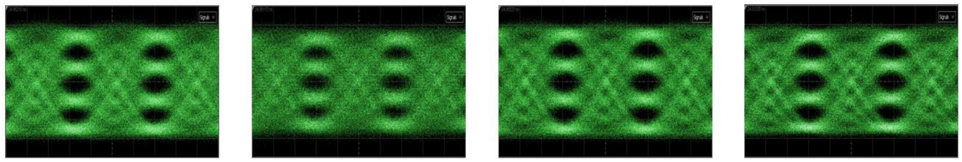


Fig. 3. A photograph of our fabricated 400G TROSA module mounted on a RF evaluation board.

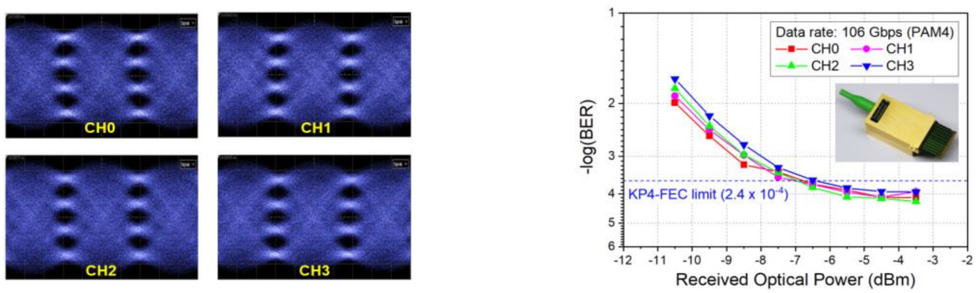
To examine high-speed characteristics in large signal modulation, the fabricated 400G TROSA module was mounted on our RF evaluation board (EVBD) without a clock and data recovery (CDR) chip, in which dual SMPM (or GPPO) connectors were soldered on the EVBD. The TROSA module is first put on the EVBD in an upside-down way, and then the RF-FPCB of the TROSA is connected using the clamping contact jig as shown in Fig. 3. Next, the DC-connector of the TROSA is fitted on the EVBD, resulting in easy replacement of the TROSA module. For efficient heat dissipation, a heat spreader was tightly bolted on the bottom surface of the TROSA. 106-Gbps PAM4 signals were generated by using a 92-GSa/s arbitrary waveform generator and amplified by a 55-GHz linear amplifier to make output voltage swings of 2 ~ 2.5 V_{pp}, and reverse bias voltages were applied to the EML chips through a bias-tee module. Also, 106-Gbps PAM4 optical and electrical eye patterns were obtained after transmitter dispersion eye closure quality (TDECQ) equalizer processing using a broadband sampling oscilloscope.



(a) (b) (c) (d)

Fig. 4. Measured Tx PAM4 optical eye patterns for 106-Gbps (53-Gbaud) signals on each channel from CH0 to CH3 in back-to-back transmission: (a) CH0 (1271 nm), (b) CH1 (1291 nm), (c) CH2 (1311 nm), (d) CH3 (1331 nm).

As shown in Fig. 4, the fabricated TROSA shows very clear Tx PAM4 optical eye patterns for 106-Gbps (53-Gbaud) signals on each channel from CH0 to CH3 in back-to-back transmission. Outer extinction ratios of each channel were measured to be as high as 6.7 dB, 6.8 dB, 6.9 dB, and 6.8 dB, respectively. TDECQs were less than 1.8 dB, fully satisfying a value of 3.4 dB specified in the 400G-FR4 MSA [1].



(a) (b)

Fig. 5. (a) Measured Rx PAM4 electrical eye patterns after TDECQ equalizer processing and (b) offline-DSP processed BER curves for 106-Gbps signals on each channel from CH0 to CH3 with Tx and Rx of the TROSA optically loopbacked.

Fairly clear eye openings of Rx PAM4 electrical patterns for 106-Gbps signals are revealed after the TDECQ equalizer processing for electrical outputs of the TIA, as shown in Fig. 5(a). Back-to-back bit error rate (BER) curves of the fabricated 400G TROSA in the inset of Fig. 5(b) were obtained through offline-digital signal processing (DSP) of TIA's electrical outputs with Tx and Rx optically loopbacked. Measured Rx sensitivities are within -7.0 ~ -6.4 dBm at a BER of 2.4×10^{-4} (KP4-FEC limit) for all channels as shown in Fig. 5(b), which are slightly below a value of -7.3 dBm specified in the 400G-FR4 MSA. It is expected that the sensitivity can be further improved by optimizing the EVBD through impedance matching or by placing a 400G CDR chip closest to the RF-FPCB for the TROSA module.

4. Conclusion

We have developed a low-cost hybrid-integrated 400G TROSA module with both Tx and Rx functions, operating at 106-Gbps PAM4 signals and the CWDM wavelength ranges. To reduce packaging cost, EML and lensed PIN-PD chips were chip-to-chip butt-coupled with 2%-Δ silica-based Tx AWG and Rx AWG chips, respectively, and Tx and Rx submodules were housed into one metal case. In the fabricated 400G TROSA, clearly opened Tx optical eye patterns were obtained under 106-Gbps PAM4 operations, and Rx sensitivities within -7.0 ~ -6.4 dBm at the KP4-FEC threshold (BER = 2.4×10^{-4}) were achieved at 106-Gbps receiving signals for all channels. From these results, our newly developed 400G TROSA is applicable to datacenter network systems.

5. Acknowledgments

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6. References

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